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Residential Losses from Urban Water Shortages in California

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Residential Losses from Urban Water Shortages in California

Executive Summary

California's water system is susceptible to periodic and potentially prolonged periods of water supply disruption due to natural variations in precipitation and runoff. Recent environmental protections in the Delta and the possibility that climate change may alter future precipitation levels both over regions and over time increase the risk that California water providers are at times unable to meet their target levels of water delivery. Combined with projections for continued population growth in the State, this confluence of forces makes it increasingly important to model the economic implications of periodic disruptions in water supply.

This report measures the economic losses to residential customers of California Urban Water Agencies (CUWA) that arise from different magnitude reductions in annual water deliveries. The analysis considers consumer willingness to pay to avoid a water supply disruption of a given size based on regional estimates of residential demand conditions facing water purveyors within CUWA member agencies. Economic losses are calculated and presented as a range between a lower bound value of consumer surplus loss, which is the additional premium consumers are willing to pay above the prevailing water rate for water units displaced during a shortage, and an upper bound value of total consumer willingness to pay, which includes the water rate that would actually be paid for the displaced water units absent a shortage. Actual economic losses in each region, which would fall somewhere between these extremes, can be calculated as consumer willingness to pay to avoid a water supply interruption (the upper bound value) net of any cost savings incurred at the agency level from reduced delivery levels during the period of interruption.

The foundation for calculating consumer willingness to pay to avoid a supply disruption is based on regional estimates of the price elasticity of demand facing water retailers within each CUWA member agency. The estimated residential demand model controls for several pertinent factors apart from water rates that affect water consumption levels. These factors include average household income, average lot size, average daily summer temperature, average annual precipitation level, and the current extent to which best-management practices (BMPs) are employed for water conservation in each region, as well as time trends. Controlling for these factors is essential, as the empirical results indicate that: (*i*) households with higher income levels are willing to pay a greater amount to avoid a supply disruption than households with lower income levels; (*ii*) households with larger lot sizes have a lower willingness to pay than households with smaller lot sizes due to a greater share of water allocated to lower-valued uses in outdoor irrigation; and (*iii*) households in regions that extensively employ BMPs are willing to pay a greater amount to avoid a water supply disruption. This last result is important because it provides empirical evidence of demand hardening: Given previous

conservation gains from adopting BMPs in a region, achieving further reductions in water use through conservation efforts becomes more difficult.

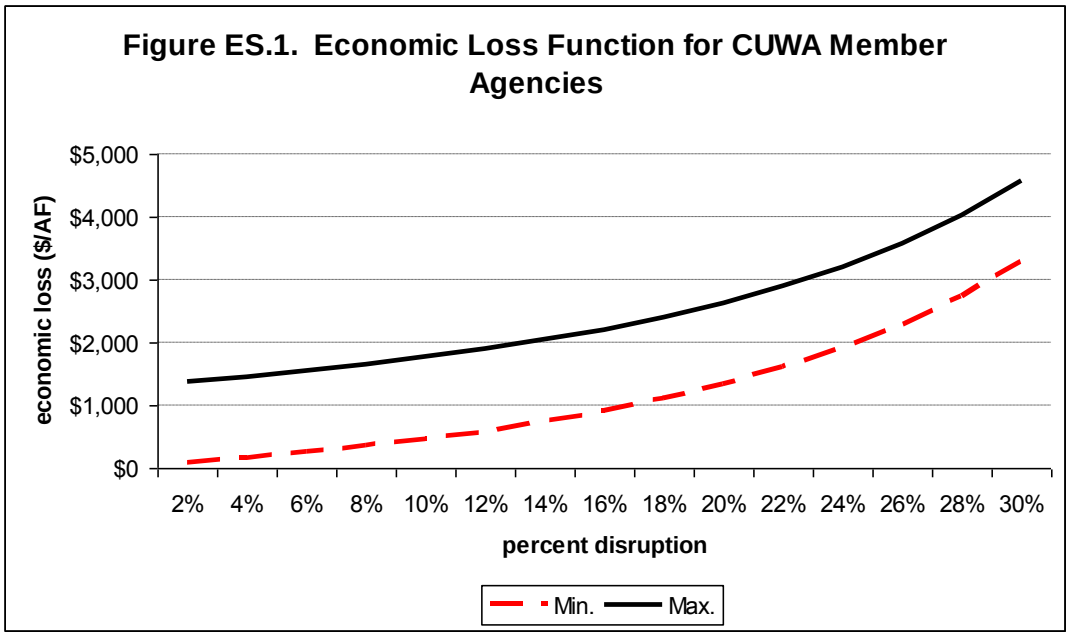
The combined economic loss across CUWA member agencies is summarized in Table ES.1 for an annual supply disruption of 10%, 20%, and 30%. For the total loss calculation, annual losses are expressed for the case in which the decline in municipal and industrial deliveries is mediated through the residential sector of each region. For a 10% annual reduction in water deliveries among CUWA member agencies, the total economic loss is in the range between $222 million ($458/AF) and $858 million ($1,765/AF); for a 20% annual reduction in water deliveries, the total economic loss is in the range between $1.3 billion ($1,324/AF) and $2.6 billion ($2,632/AF); and for a 30% annual reduction in water deliveries, the total economic loss is in the range between $4.8 billion ($3,267/AF) and $6.7 billion ($4,574/AF).

Table ES.1. Economic Losses from a Cumulative 10%, 20%, and 30% Supply Disruption for CUWA Member Agencies

Scenario	10% disruption	20% disruption	30% disruption
Lower Bound			
Total Loss (million $s)	$222.33	$1,287.19	$4,763.84
Average Loss ($/AF)	$458	$1,324	$3,267
Upper Bound			
Total Loss (million $s)	$857.68	$2,557.88	$6,668.89
Average Loss ($/AF)	$1,765	$2,632	$4,574

Economic losses on a per unit basis ($/AF) increase considerably for larger magnitudes of supply disruption. The reason is that less costly methods of water conservation are adopted by households before turning to more costly methods of water conservation. Thus, consumer willingness to pay to avoid a supply disruption rises at an increasing rate with the magnitude of the water shortage as more valuable end-uses of water are displaced at larger disruption levels than at smaller disruption levels.

Figure ES.1 shows the trend in economic losses ($/AF) across CUWA members for increasing magnitudes of the water shortage. The dashed line represents the lower bound of losses represented by the loss of consumer surplus and the solid line represents the upper bound of losses represented by total consumer willingness to pay to avoid a water service disruption.



There is considerable variation in economic losses across individual CUWA member agencies. CUWA member agencies differ widely in socioeconomic factors such as average household income levels, adoption of conservation BMPs, and prevailing water rates, each of which has an important bearing on the willingness to pay of consumers to avoid a water shortage. For a 10% supply disruption, the standard deviation of economic losses across members is $406/AF at the lower boundary and $807/AF at the upper boundary of losses. For a 20% supply disruption, the standard deviation of economic losses across members is $1,353/AF at the lower boundary and $1,710/AF at the upper boundary of losses. For a 30% supply disruption, the standard deviation of economic losses across members is $3,895/AF at the lower boundary and $4,216/AF at the upper boundary of losses.

Variability in economic losses across members in response to a water supply disruption is driven by two features: (i) differences in water rates; and (ii) differences in the elasticity of residential water demand. Average economic losses from a water shortage rise at a faster pace with the magnitude of the disruption in regions in which residential demand conditions are less elastic, for instance in regions that have extensively adopted best-management practices for conservation prior to undergoing a water shortage. Agencies that have intensively implemented BMPs are less able to facilitate further water conservation relative to agencies that have not as actively exploited the conservation potential of households, and accordingly, consumer willingness to pay to avoid a supply disruption rises more rapidly in the magnitude of the water supply disruption in these regions.

1. Introduction

California's water system is vulnerable to supply fluctuations. Natural variations in precipitation and runoff, which are likely to be exacerbated with climate change, make it difficult to meet target levels of demand in all circumstances. Recently, environmental protections in the Delta have eroded the ability of state and federal project operators to provide reliable supplies on these two crucial systems. Despite these challenges, urban water demand in California continues to grow, and is projected to do so for decades to come.

Taken together, variations in supply coupled with unabated growth in water demand highlight the importance of water shortage as a public policy issue. This report considers the economic dimensions of urban water shortage by considering water supply disruptions of various levels that are mediated through the residential segment of the market. The report contains estimates of the loss resulting from requiring residential water customers to reduce their water consumption in a range of 10-30 percent below baseline levels of water use.

The approach taken in this report is based on principles of modern welfare economics. We emphasize estimates of losses that are based on actual valuations of water units by residential consumers as opposed to stated preferences or the results of hypothetical optimization scenarios. The goal of the research is to measure the losses that will actually occur in California under various levels of shortage, given existing institutions and rules for allocating water.

This research has been conducted for the California Urban Water Agencies (CUWA). In presenting our findings, we show aggregated results for CUWA agencies in terms of both total economic losses among CUWA members and average economic losses ($/AF), as well as report distributional information on average economic losses for individual CUWA member agencies. The California water system is highly fragmented, with water provided to customers by over 400 major urban utilities. Partly as a result of this fragmentation, there is no single number for the economic loss resulting from a water shortage that can be applied to all regions of California. Rather, losses are different for each agency, depending on various factors including the nature of water demand in the area, the rate structure currently being implemented, the conveyance and delivery cost of water, and other idiosyncratic factors. Regional losses are calculated at the level of individual water purveyors and then aggregated into measures of total economic loss and average loss per unit of supply disruption ($/AF) across CUWA members. The distribution of losses across individual members is then characterized.

The report is structured as follows. Section 2 lays out the conceptual model underlying the analysis. Section 3 describes the empirical analysis of urban water demand that is used to make the loss calculations. Section 4 describes the construction of price indices for each CUWA member that take into account the prices set by a potentially large number of retail water purveyors in the service territory of each member. Section 5

presents annualized economic losses and average losses ($/AF) across CUWA members for a water supply disruption of various levels.

2. Loss Framework

The loss framework considered in this report considers the economic impacts specifically related to water supply interruption. The loss framework in this report addresses damages from a water supply disruption in a setting that applies a uniform percentage reduction in water supplies simultaneously across all CUWA members (10%, 20% and 30% levels, respectively).

Water shortages following a supply disruption have the potential to adversely affect economic outcomes among several types of water users, including agricultural, residential, industrial, commercial, and government water users. The model considers a drought response framework in which water supply reductions of a given magnitude are mediated through the residential segment of the market.

Residential losses are measured by computing consumer willingness to pay to avoid water service interruptions.[1] For a given household, willingness to pay to avoid an interruption in water service of a given magnitude is the total amount of money the household would pay to restore water deliveries to the baseline level of use.

Residential water use can be classified into several broad categories, each with a different priority of use, and the willingness to pay for water by residential customer depends on the intended use of each unit of water. The willingness to pay for water used for drinking and basic sanitation is larger than the willingness to pay for water used for bathing and laundry, which in turn is larger than the willingness to pay for water used for washing cars, for filling swimming pools, and for outdoor irrigation. When faced with a water service disruption of a given magnitude, residential consumers have the choice of which types of water uses to curtail, and the framework for measuring residential losses incorporates the idea that residents respond to a water service disruption by eliminating less valuable water units before eliminating more valuable water units, for instance by reducing water used for landscaping irrigation prior to reducing drinking water consumption.

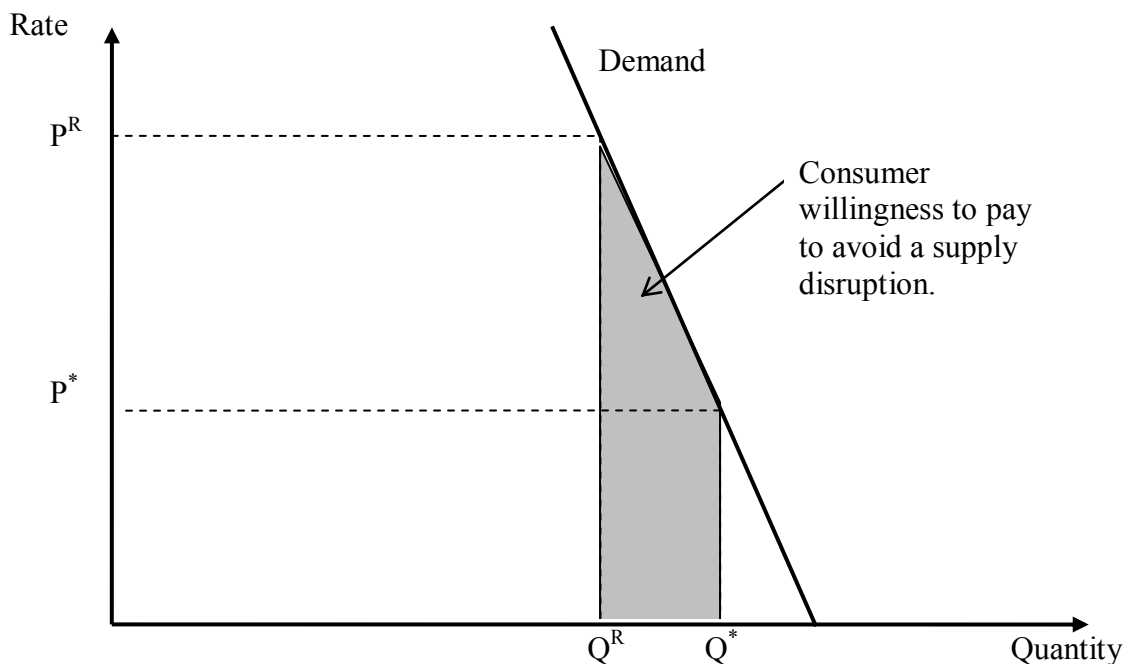
Figure 2.1 depicts a schedule of consumer willingness to pay for different units of water as a household demand curve for water that orders values from highest valued uses to lowest valued uses. Consumer willingness to pay for water, which sums the willingness to pay of households for individual water units, is the area under the household demand curve. Prior to a water supply disruption, a household facing a volumetric water rate of P^* consumes all units of water for which consumer willingness to pay for the unit

[1] This approach follows Jenkins, M.W., J.R. Lund, and R.E. Howitt, "Using Economic Loss Functions to Value Urban Water Scarcity in California," *Journal of the American Water Works Association* 95(2003), pp. 58-70, and Brozovic, N., D. Sunding and D. Zilberman, "Estimating Business and Residential Water Supply Interruption Losses from Catastrophic Events," *Water Resources Research* (2007).

exceeds the price households must pay for the water unit, which leads to a level of household consumption of Q^* units. Additional units of water consumption beyond this level have value for the household, but the value of each unit to the household in these relatively low valued uses beyond the quantity Q^* is not high enough to justify paying the volumetric rate to acquire these units.

In the event of a service disruption, consumer willingness to pay to avoid a water service interruption is rising in the magnitude of the supply shortage, as consumers are forced to cut more deeply into priority uses of water when faced with larger shortage levels. Consumer willingness to pay to avoid a water shortage sums the willingness to pay for each unit of water from the baseline level (Q^*) to the disrupted level (Q^R), which is depicted as the shaded region in Figure 2.1. The value of the last unit of water used under rationing, which is consumer willingness to pay for the individual unit Q^R, rises from P^* to P^R in response to the reallocation of water to meet only the highest valued uses.

Figure 2.1. Consumer Willingness to Pay to Avoid a Supply Disruption



The economic loss calculation in this report places special significance on prevailing water rates in a region prior to a period of supply disruption. Urban water consumers are faced with a given set of water rates that are chosen by their local purveyor, and, given these rates, consumers are generally free to purchase their desired quantities of water. At lower water rates, consumers make landscaping choices that devote a greater quantity of water to outdoor irrigation uses than they would facing higher water rates, so that the potential for water conservation is greater (and the economic losses

are accordingly smaller) in regions with initially lower water rates. The reason is that consumers purchase a quantity of water that equates consumer willingness to pay for the last unit of water consumption to the water price established by the local rate structure.

Water rates combined with observed consumption levels at the prevailing rates provide information about the value of water to households at a single point on the demand curve. Because this report addresses the economic losses resulting from reduced water consumption below baseline levels, it is necessary to characterize the demand curve at consumption levels that are reduced below baseline levels. The economic loss calculation therefore requires making inferences on consumer willingness to pay for water units at successively higher levels of water rationing, as households are forced to dispense with increasingly higher valued uses of water. To characterize these values, we rely on regional water consumption data to estimate demand schedules across households in geographic regions served by individual water purveyors using an econometric model that is capable of explaining water consumption as a function of variables such as rates, income, urban density, management practices, and climatic conditions. By comparing agencies over time, and from one place to another, the econometric model traces out more complete demand information than could be gained by looking at a single agency at a single moment in time. As described in Section 3, the results of the statistical analysis are robust and significant at conventional levels used for hypothesis testing. Our results are also consistent with other, similar studies in the academic literature.

The first component used to measure the economic loss of a water shortage is to define consumer willingness to pay to avoid supply disruptions of given magnitudes. As described above, consumer willingness to pay to avoid a supply disruption that reduces water consumption from an initial level of Q^* units to a rationed level of Q^R units is represented by the shaded region of Figure 1. Making use of the estimated water demand curve for each region, consumer willingness to pay to avoid a supply disruption integrates the area under the demand curve between the quantities Q^* and Q^R.

The second component used to measure the economic loss of a given supply disruption is to account for the avoided cost of water delivery to individual water purveyors. Following a supply disruption, individual water purveyors deliver a smaller quantity of water to residential customers (as well as to commercial, industrial, and government customers), and this reduces the total cost of water distribution. The economic loss following a supply disruption in the residential segment of the market is the sum of consumers' willingness to pay to avoid a supply disruption net of the avoided cost of water delivery to residential households. The avoided cost of water delivery is the change in system-wide conveyance cost of delivering Q^R units of water to residential households relative to the cost of delivering the baseline level of Q^* units of water to residential households.

The methodology used to estimate each component is detailed below.

2.1. Consumer Willingness to Pay to Avoid Supply Disruptions

Economic losses are determined by both the magnitude and duration of the water supply disruption. Following Brozovic, Sunding and Zilberman (2007), we define the severity of the water supply interruption in region *i* at time *t* as $z_{it} \in [0,1]$, where z_{it} =0 corresponds to a complete outage and z_{it} = 1 corresponds to the baseline level of service. The water supply interruption in a given region at a given time accounts for adjustments at the agency level in the water portfolio through changes in groundwater pumping and mutual help agreements with other service providers.

Let $f_{it}(z_{it})$ denote the probability density function of residential water disruption z_{it} in region *i* at time *t* and let $W_i(z_{it})$ denote consumer willingness to pay to avoid a supply disruption z_{it} in region *i* at time *t*. For a period of duration *T* until baseline water service is reestablished, consumer willingness to pay to avoid a cumulative service disruption across *I* regions and *T* periods is given by

$$W^R = \sum_{t=1}^{T}\sum_{i=1}^{I}\int_0^1 W_i(x)\, f_{it}(x)dx\,. \tag{1}$$

For a given region and time, the computation of $W_i(z_{it})$ involves integrating the area under a demand curve for a shortage level of z_{it}.

This study adopts the approach of Jenkins et al. (2003) and Brozovic, Sunding and Zilberman (2007) in deriving an equation for the estimation of consumer willingness to pay to avoid water service disruptions. Specifically, residential water demand elasticities are estimated for each of *n* regions under a specification of constant elasticity of demand given by

$$P_i = A_i Q_i^{\frac{1}{\varepsilon_i}}, \qquad i = 1,2,3,\ldots,n, \tag{2}$$

where $\varepsilon_i < 0$ is the elasticity of water demand in region *i* and A_i is a parameter that scales the magnitude of demand to the price in each region.

Let P_i^* and Q_i^* respectively denote the retail water price and quantity of water consumed by residential households in region *i* under baseline conditions (prior to water rationing). For a given water shortage with an available level of water given by $Q_i(z_{it}) < Q_i^*$, it is helpful to define the relationship between these quantities in terms of the percentage of water that is rationed in region *i* at time *t*, r_{it}, as

$$Q_i(z_{it}) = (1 - r_{it})Q_i^*\,. \tag{3}$$

Making use of equations (2) and (3), consumer willingness to pay to avoid a supply disruption of magnitude z_{it} in region i at time t can be calculated as follows:

$$W_i(z_{it}) = \int_{Q_i(z_{it})}^{Q_i^*} P_i(Q)dQ_i = \int_{Q_i(z_{it})}^{Q_i^*} A_i Q_i^{1/\varepsilon_i} dQ_i$$

$$= \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* \left[1-(1-r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right]. \tag{4}$$

Consumer willingness to pay to avoid a supply disruption in equation (4) can be calculated for each region by constructing an aggregate demand curve to represent the residential water segment (see equation (2)). For regions in which residential customers pay volumetric water rates, P_i^* is the volumetric rate in region i, Q_i^* is the total quantity of water delivered to residences at that price in region i prior to a supply disruption, and ε_i is the elasticity of water demand for region i, which can be estimated from observations of rates and quantities in the region over time along with covariates such as income, urban density, and climatic conditions.

Consumer willingness to pay to avoid a supply disruption in equation (4) depends on the prevailing retail price charged to consumers in each region under baseline supply conditions, P_i^*. Intuitively, the reason for this is that the value of water conservation activities to households in regions with higher water rates is larger than the value of conservation in regions with lower water rates, so that consumers facing higher water rates under baseline supply conditions have greater motivation to engage in conservation activities prior to rationing than consumers facing lower baseline water rates. Water conservation is more forthcoming at lower water rates than at higher water rates, and consumer willingness to pay to avoid a given magnitude disruption in water supply is accordingly larger in regions with higher baseline water rates.

For regions in which residential customers pay inclining tiered prices for water, the calculation in equation (4) is complicated by the fact that different residences in the region pay different prices for the last unit of water consumed. In a tiered rate structure, households with a high level of monthly water use pay higher prices for the last unit of water consumed (and higher average prices per unit of water) than households with a lower level of use, which confounds the use of a representative water price for households in equation (4).

Consumer willingness to pay to avoid a supply disruption among households in a region with an inclining tiered rate structure and an arbitrary number of pricing tiers can be calculated as follows. Let h_i denote the number of households in region i and let Q_{ij}^* and P_{ij}^* denote the baseline level of water consumption and the equilibrium price paid for the last unit of water consumed by household j in region i, respectively, where j = 1,2,3,…,h_i is an index of households in region i. Next, suppose that households in region i can be characterized by constant elasticity of demand functions that share a

common elasticity of demand of $\varepsilon_i < 0$, so that water demand for household *j* in region *i* is given by

$$P_{ij} = A_{ij} Q_{ij}^{\frac{1}{\varepsilon_i}}, \quad j = 1,2,3,\ldots,h_i;\ i = 1,2,3,\ldots,n. \tag{5}$$

The difficulty in estimating household demand for a regional water purveyor with an inclining tiered rate structure is that different households in the region pay different prices for the last unit of water consumed. Household demand for water is larger at lower water rates than at higher water rates, while water prices rise with quantity on the supply side in an inclining tiered structure, and this implies that households consuming water on higher pricing tiers have different (i.e., greater) demand for water than households that meet their water needs exclusively on lower tiers. In general there are two ways to handle this issue. First, provided data exist on individual household purchasing behavior, individual demand curves can be estimated for the subset of households aligned on each tier of the rate structure, and then these demand curves can be aggregated to the purveyor level. Second, a representative demand curve can be estimated using aggregate data at the purveyor level using an appropriate price index that incorporates demand information from all pricing tiers. Given the lack of data to implement the first approach, we utilize the second approach, which is described in detail below.

Suppose all households in region *i* respond to a regional supply disruption by proportionately reducing water consumption from the baseline level. For a proportional rationing level of r_{it} across all households in region *i*, each household reduces water consumption to the level $Q_{ij}(z_{it}) = (1 - r_{it})Q_{ij}^*$, so that consumer willingness to pay across all households to avoid a supply disruption of a magnitude z_{it} is given by

$$\begin{aligned} W_i(z_{it}) &= \sum_{j=1}^{h_i} \frac{\varepsilon_i}{1+\varepsilon_i} P_{ij}^* Q_{ij}^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right] \\ &= \frac{\varepsilon_i}{1+\varepsilon_i} \hat{P}_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right], \end{aligned} \tag{6}$$

where $Q_i^* = \sum_{j=1}^{h_i} Q_{ij}^*$ is the aggregate quantity of water purchased by residential households in the region and

$$\hat{P}_i^* = \frac{\sum_{j=1}^{h_i} P_{ij}^* Q_{ij}^*}{\sum_{j=1}^{h_i} Q_{ij}^*} \tag{7}$$

is a price index that represents the weighted average of equilibrium water rates paid by the various households in region *i*. In the case of volumetric pricing, the price index in

equation (7) reduces to the volumetric water rate in region *i*, and the measure of consumer willingness to pay to avoid a supply disruption in equation (6) reduces to the measure in equation (4).

It should be noted that the price index in equation (7) is developed under a drought response scenario of proportional rationing of all rates in an inclining tiered rate structure. In the event that the shortage allocation plan in a given region seeks to protect lifeline customers by rationing water more severely among households on higher tiers of the rate structure than on lower tiers of the rate structure, the relevant price used to calculate economic losses would be larger than the index price in equation (7), and the economic losses commensurately would be greater than the value represented by the regional willingness to pay measure in equation (6).

2.2. Avoided Cost of Service

Economic losses that result from water shortage in a given market are mitigated to the extent that delivering a smaller quantity of water reduces the system-wide cost of water service. Because the overall cost of service includes large fixed costs that do not vary with the amount of water delivered through the system (e.g., infrastructure costs, repair and maintenance, administrative expenses, etc.), the avoided cost that results from water shortage is relatively small in relation to total cost. Throughout this report, the reduction in the cost of water service that occurs in response to a one-unit reduction in water deliveries is referred to as the avoided *marginal* cost of service. Examples of components of avoided marginal cost include the energy and chemical costs of treating water units that are no longer delivered, the reduction in conveyance costs, and the decrease in energy and chemical costs of wastewater treatment that arise from a smaller level of water delivery.

The avoided marginal cost of service in a given region depends on the mix of water sources available in each region between groundwater resources, local water supplies, and imported water, and on the distribution of the water supply disruption across sources. A disruption of relatively high-cost imported water supplies would entail a larger avoided cost of service component than a disruption of local water supplies by more greatly reducing procurement costs of water than similar magnitude disruption of local water supplies. Given the considerable variation in the water portfolios of regional purveyors, the avoided cost of service for units of water no longer delivered in response to a residential supply disruption can vary considerably across CUWA members.

Let c_{it} denote the avoided marginal cost of service in region *i* at time *t*. Summing the avoided cost per unit of water across the water rationed in the residential consumer market in region *i*, the avoided cost of service for a cumulative service disruption across *I* regions and *T* periods is given by

$$AC^R(z_{it}) = \sum_{t=1}^{T}\sum_{i=1}^{I}\int_0^1 c_i r_{it} Q_i^* f_{it}(x)dx\,, \tag{8}$$

where $r_{it}Q_i^* = Q_i^* - Q_i(z_{it})$ is the reduction in residential water deliveries for the shortage level z_{it}.

It is important to note that the marginal cost of water service can be substantially greater for an increase in water deliveries than for a decrease in water deliveries. In general, the marginal cost of water service rises with the quantity of water delivered, with the cost of acquiring new, untapped sources of supply being greater than the cost saving associated with reduced utilization of existing sources. The method represented by equation (8) treats the avoided marginal cost of water service from a supply reduction as constant, which results in conservative estimates that are likely to over-state actual avoided costs, particularly for large levels of supply disruption.

2.3. Loss Functions

The loss function in each region is characterized by consumer willingness to pay to avoid a supply disruption in equation (6) net of the avoided cost of service in equation (8). The avoided cost of service for a cumulative service disruption across *I* regions and *T* periods is given by

$$L^R = \sum_{t=1}^{T}\sum_{i=1}^{I}\int_0^1 Q_i^*\left(\frac{\varepsilon_i}{1+\varepsilon_i}\hat{P}_i^*\left[1-(1-r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right]-c_i r_{it}\right) f_{it}(x)dx\,. \tag{9}$$

The loss function (9) is calculated across CUWA members on an annualized basis for a supply disruption of various magnitudes under two specifications of the avoided marginal cost of service. First, losses to retail water customers are calculated gross of any avoided costs of service by setting the avoided marginal cost of service in each region to zero; i.e., $c_{it} = 0$ for all *i*. This case provides an upper bound for economic losses that overstates true economic losses by the avoided cost of service. Second, losses to retail water customers are calculated by setting the avoided marginal cost of service in each region to be equal to the retail price level under baseline service conditions; $c_{it} = \hat{P}_i^*$ for all *i*. This case, which assumes that prevailing prices in each region are set to recover only the marginal cost of service (i.e., that there are no fixed costs of service), provides a lower bound for economic losses by considering only the loss in consumer surplus above prevailing market prices in each region. True economic losses would range between these extremes according to the magnitude of the avoided cost component, and we discuss how the results can be amended to consider various levels of avoided marginal cost between these extremes in Section 5.

It is worthwhile to note that the lower bound on economic losses considered here is consistent with the economic loss methodology implemented in the contingent valuation survey in the CUWA report by Barakat & Chamberlin, Inc. (1994), with the important exception that the willingness to pay values calculated here are based on an estimated demand model that utilizes regional data on actual consumer behavior rather than on stated willingness to pay values. The lower bound on economic losses provides a

conventional measure of consumer surplus loss, which is consumer willingness to pay in the form of higher residential water bills to avoid a water shortage of a given magnitude. Total consumer willingness to pay to avoid a water shortage in equation (6) is larger than the lower bound value represented by consumer surplus loss, because it includes the portion of the residential water bill that consumers are prevented from purchasing as units of water are displaced during a shortage. The upper bound on economic losses captures the full measure of consumer willingness to pay to avoid a supply disruption, including the rate that households currently pay for these units under baseline supply conditions. The true economic loss in each region is consumer willingness to pay to avoid a supply disruption (the upper bound value) net of the reduction in total water delivery costs. The actual economic loss therefore aligns with the consumer surplus loss (the lower bound value) in the case where the reduction in water delivery cost per unit is the retail price charged per unit on residential water bills and aligns with consumer willingness to pay in the case where the reduction in water delivery cost is negligible following a water supply disruption.

3. Residential Water Demand Estimation

An important factor determining economic losses in the residential sector is the elasticity of demand. The elasticity of demand is a parameter that summarizes how the willingness to pay of consumers to avoid a water service disruption changes with the level of water consumption. Specifically, the price elasticity of demand for water at any price *P* and consumption quantity *Q* is given by $\varepsilon = \left(dQ / dP\right)(P / Q)$, which represents the percentage change in willingness to pay for a percentage change in water deliveries. In general, the price elasticity of demand for water in a given region depends on variables that are specific to each region such as climatic conditions, the income level of households, urban density, and best management practices employed to meet existing conservation goals. This section of the report presents estimated demand relationships using data for over two dozen California water utilities that are used to recover demand elasticities for regional water purveyors that comprise the major residential markets of CUWA member agencies.[2]

The price elasticity of demand for water was estimated using single-family residential price and consumption data from SFPUC and BAWSCA member agencies. Water consumption, marginal price, and customer data were taken from BAWSCA Annual Surveys over the period FY 1995-96 through FY 2004-05 (with the exception of FY 2002-03 for which price and consumption data for were unavailable) and from SFPUC over the period FY 1999-00 through FY 2004-05. The sample encompasses SFPUC and all BAWSCA agencies with the exception of Cordilleras, Guadalupe Valley Municipal Improvement District, Los Trancos, and Stanford University. In total, the sample contains 249 observations spanning 28 water agencies (27 BAWSCA members and SFPUC).

[2] SFPUC, "Measures to Reduce the Economic Impacts of a Drought-Induced Water Shortage in the SF Bay Area," May 3, 2007, pp. 19-21.

The regional estimates of the price elasticity of demand control for several pertinent factors apart from water rates that affect water consumption levels. The factors considered to influence regional water demand in the empirical model are average household income, average lot size, average daily summer temperature, average annual precipitation level, the extent to which best-management practices (BMPs) are employed in each region, and time trends. At a given level of water rates, residential water consumption levels can differ due to climatic differences across regions and differences in regional climate are proxied by regional variation in temperature and precipitation.

Socioeconomic factors such as typical household lot size and income in a region can influence both water consumption and the sensitivity of water consumption to changes in water rates. For equal income levels, households with larger lots tend to consume more water than households with smaller lots due to increased outdoor water use, and higher income households may be less responsive to changes in water rates than lower income households (lot size given) due to a smaller share of water cost in the household budget. Differences in BMP adoption rates across regions can also impact regional water demand, as regions that have worked harder to exploit conservation measures through BMP adoption may have lower overall water consumption levels, climate and socioeconomic variables given, than regions that have been less active in adopting BMPs, but may find further reductions in water supply to be less forthcoming in light of these previous conservation gains (i.e., “demand hardening”).

Average yearly single-family household consumption levels for each water agency was calculated by dividing the total single-family residential consumption level for the fiscal year by the number of single-family residential accounts for that fiscal year. A monthly average consumption level was created by dividing the yearly average by a factor of twelve. The equilibrium price of water for the typical user in each region was taken to be equal to the price charged ($/ccf) to a residential customer on the tier of the rate structure commensurate with the average monthly consumption level for that fiscal year.

Climatic and other exogenous agency-specific factors were used as controls. The weather variables used in the regression were average maximum daily temperature during the summer months of July, August, and September; and total annual precipitation. (Given the Mediterranean climate in California, there is little to no precipitation during summer months.) Each water agency was matched to the geographically closest weather station reporting to the Western Regional Climate Center.[3] Some water agencies shared the same weather data because there were only seven weather stations to the 28 water agencies in the regression data.

Average agency lot size was calculated by intersecting data on lot size by ZIP code with the with BAWSCA and SFPUC agency boundaries. Lot size data by ZIP code was acquired from DataQuick for the single family residential segment of the market, and this data was overlaid with spatial agency boundaries for BAWSCA and SFPUC

[3] Available at: http://www.dri.edu/summary/Climsmcca.html.

members using ArcView according to the area- and population-density-weighted average of the ZIP codes comprising each agency. Median household income for residences in each agency was similarly calculated by intersecting water agency boundaries with median household income by census tract, resulting in an area- and population-density-weighted average measure of median household income for each water agency.

The percent of California Urban Water Conservation Council (CUWCC) best management practices (BMPs) implemented, as reported in the BAWSCA Annual Survey report, was also included to control for variations in consumption behavior among the different agencies. SFPUC BMP implementation was derived from the 2005 San Francisco Urban Water Management Plan.[4] Unlike the BMP implementation data for BAWSCA members, the data on BMP implementation rates for SFPUC are available only at this single point in time.

Table 3.1 presents the results of four variations of the empirical model, with different interaction terms introduced between water rates and socioeconomic variables. All three interaction terms used in variations II-IV are statistically significant at conventional levels.

Table 3.1 Estimated residential water demand models

Dependent Variable: ln(water consumption)

	[I]		[II]		[III]		[IV]	
	Base Specification		With Rate-BMP Interaction		With Rate-BMP and Rate-Income Interactions		With Rate-BMP, Rate-Income, and Rate-Lotsize Interactions	
Variable	**coeff.**	**|t-statistic|**	**coeff.**	**|t-statistic|**	**coeff.**	**|t-statistic|**	**coeff.**	**|t-statistic|**
ln(rate per ccf at average use)	-0.1759	4.89	-0.5477	4.94	-1.1263	5.37	-0.9381	3.59
percent of BMPs implemented	-0.1845	2.45	-0.6988	4.08	-0.7524	4.55	-0.6018	3.11
average lot size (thousand sq. ft.)	0.0351	10.23	0.0361	10.11	0.0347	11.5	0.0548	5.97
"average median" household income (thousand dollars)	0.0053	8.82	0.0050	7.43	-0.0003	0.2	-0.0019	1.16
average daily maximum summer temperature (July, August, September)	0.0093	3.72	0.0120	4.88	0.0132	5.43	0.0146	5.7
annual precipitation (inches)	-0.0013	0.81	-0.0016	0.96	-0.0007	0.43	-0.0005	0.28
year	0.0041	0.9	0.0040	0.91	0.0036	0.84	0.0041	0.96
constant	-6.8200	0.75	-6.5400	0.74	-5.4100	0.62	-6.5828	0.77
Rate-BMP Interaction			0.6067	3.76	0.6770	4.5	0.4627	2.26
Rate-Income Interaction					0.0062	3.66	0.0078	5.19
Rate-Lotsize Interaction							-0.0218	2.27
R-squared	0.78		0.8		0.81		0.81	

Notes:
Robust t-statistics shown.

Sources:
BAWSCA, "Annual Survey FY 2004 - 2005," April 2006.
Excel file (<CP Accounts.xls>) received from SFPUC.
Excel file "Lotsize Data for Single Family Homes by Zip Code" received from DataQuick Information Systems on November 15, 2006.
Census 2000 Summary File 3 detailed tables, downloaded at: http://factfinder.census.gov/servlet/DatasetMainPageServlet?_lang=en.
Weather data from Western Regional Climate Center website: http://www.wrcc.dri.edu/summary/Climsmcca.html.

Controlling for weather and other agency-specific factors, the estimated price elasticity of water demand for the full sample of water agencies is ε = -0.18. This estimated value

[4] BMP implementation for prior years was not available at the time of the report, although it was noted that the CUWCC had additional data for some of the water agencies.

implies that a 10 percent increase in the equilibrium price of water across all regions would lead to a 1.8 percent decrease in single-family residential water consumption, an outcome consistent with numerous other studies in the academic literature.[5]

Regional differences in average household income, lot size, and BMP adoption specifications across water agencies suggest that residential demand elasticities are not the same for all agencies. To understand the importance of the interaction terms, consider the interaction between rate and BMP adoption. The coefficient on this interaction term is positive, while the estimates coefficients for BMP adoption and rate alone are negative. Thus, a greater level of BMP adoption by an agency leads to reduced water consumption among households in the agencies service region, but also makes residential water demand less responsive to changes in water rates. Put differently, the sign pattern on these coefficients supports the joint hypotheses that conservation measures lead to reduced water demand but also to significant demand hardening. Similarly, the interaction term on lot size suggests that households with larger lot sizes have higher demand for water but also express a greater responsiveness of water consumption to water prices, as would be the case when households respond to higher water rates by reducing landscape irrigation times in watering systems.

In general terms, the variations of the model that include interaction terms suggest that residential water demand is less responsive to changes in water rates in regions with high household income and high adoption rates for conservation practices, and more responsive to changes in water rates in regions with larger residential lot sizes. Among regional water providers in the scope of this study, the price elasticity of water demand ranges in the interval $\varepsilon_i \in (-0.50, -0.11)$.

After controlling for the influence of all other variables in the model, residential water demand at the household level does not differ significantly over time. Time trends in household water consumption are largely explained by changes in BMP adoption and water rates, and the econometric estimates of the regional demand elasticities are accordingly taken to be stable over time in calculating economic losses from residential supply disruptions in equation (9).

In terms of the residential loss functions, the impact of regional demand elasticity values is to raise economic losses from water service disruptions when demand is relatively inelastic (values of ε_i "close" to -0.11) and to lower economic losses in regions where demand is more elastic (values of ε_i "close" to -0.50).

[5] See, e.g., Renwick and Green (2000) for regional demand elasticities in California. For a survey of demand estimates in the literature, see Espey, Espey, and Shaw (1997) and Dalhuisen, Florax, de Groot, and Nijkamp (2003).

4. Water Rates

This section details the current economic environment of water rates across CUWA agencies. The index price used to characterize the water rate for households in each region is calculated from the summer rate schedule in cases where water purveyors charge seasonal water rates to residential customers. Typical summer water use among California households is roughly 50 percent larger in summer months than in winter months due to increased water utilization for outdoor irrigation. The overall level of water use on an annualized basis varies across regions according to climatic factors such as evapotranspiration rates and lot sizes.

For water purveyors that charge volumetric rates for water, the index price used for households in the region is the volumetric price. For water purveyors that implement a tiered rate structure, the relevant rate for the economic loss calculation depends on how prices are adjusted across tiers to implement a needed conservation level. In all cases, the economic loss calculation is made under the assumption that the prices on all tiers are proportionately adjusted. Alternatively, the analysis assumes that voluntary conservation measures are adopted in proportion to household consumption levels (i.e., that all households respond to a 10% conservation need by cutting back water use by 10%), so that conservation is no more likely to occur among customers on any particular tier of the rate structure. This assumption of proportional adjustment of water use on all rate tiers leads to a conservative measure of index prices in the sense that conservation may be more forthcoming among households on higher pricing tiers and because agencies implementing conservation through price changes may raise water rates to a greater degree on higher rate tiers than on lower rate tiers (or alternatively reduce the quantity of water that qualifies for the lower rates), facilitating a disproportionate level of conservation on higher tiers of the rate structure than on lower tiers of the rate structure.

Under proportional rate adjustment, the relevant water rate for the economic loss calculation in equation (9) is a weighted average of the prices paid by each household in the service area for the last unit of water consumed. For many water purveyors within CUWA agencies, water rates involve an inclining tiered structure, and the price index in equation (7) depends on the distribution of individual households across the pricing tiers, with the relevant rate for each household comprised of the rate paid for the last unit of water (i.e., the highest tier on which consumption takes place). That is, the price index is an index of marginal rates, which exceeds the average rate paid by households (total sales revenue divided by total water deliveries) because households on higher pricing tiers also pay lower rates on a portion of water purchased on lower tiers. Put differently, the price index in equation (7) would accord with the average rate paid by households (total sales revenue divided by total water deliveries) for each water purveyor in the case where all water units consumed by a household are priced at the rate on the highest tier of consumption. Because information is not available to construct such a price index, the index price for each water purveyor is taken to be the rate paid for the last unit of water consumed by a typical single family household in a

summer month, where typical consumption is based on average water use per single family meter.

Typical household consumption levels are derived by dividing annual water consumption among single family residential users by the number of residential meters. To align annual monthly water use by typical households to summer water use levels, an inflation factor of 4/3 is applied to proxy monthly consumption levels in summer months. Implicitly, this assumes that the distribution of annual water use for each household involves a 50% increase in summer water use (May-October) over winter water use (November-April) as households use water more intensively for outdoor irrigation purposes during summer months. The index price for each water purveyor is then taken to be the price paid for the last unit of water at this typical level of summer use. For most water purveyors considered in this study, the typical rate paid by single-family households for the last unit of consumption in summer months turns out to align with the median tier in the rate structure (frequently the second tier in a three-tiered rate structure). In cases where information on average water use per single family meter is not available, the typical household consumption level is taken to be on the median tier of the rate structure. In all cases, the rates used in this study are net of any additional surcharges charged to customers at higher elevation zones, as cost premiums to higher elevation zones are assumed to be exactly offset by the higher costs of pumping to these zones.

A number of CUWA members provide water at the wholesale level to regional water purveyors, for instance Metropolitan Water District of Southern California (MWDSC), and residential households in the service territory of these CUWA members receive water directly from the regional water purveyors (e.g., local municipalities and private water companies). In regions served by multiple water purveyors, rates for a typical household in the service territory of the CUWA member are constructed by computing the average rate charged by purveyors in the region, weighted by the share of water delivered by each purveyor.

5. Economic Losses

This section reports the economic losses for each member agency. Economic losses are aggregated across CUWA members in the case of a water supply disruption that uniformly reduces water deliveries by a constant proportion across all member agencies.

Table 5.1 shows the distribution of Municipal and Industrial (M&I) demand for CUWA member agencies with non-overlapping demands. M&I demand for the City of Los Angeles Department of Water and Power (LADWP), the City of San Diego Public Utilities Department (SDPUD), and San Diego County Water Authority (CWA) is included in the M&I demand for MWDSC to prevent double-counting of water deliveries.

Table 5.1. Municipal and Industrial Water Demand by Member Agency

CUWA MEMBER AGENCY	Representative Agency	M&I Demand (AF)	share
Alameda CWD	Alameda CWD	51,600	1.1%
Zone 7 Water Agency	Zone 7 Aggregate	49,610	1.0%
Contra Costa WD	Conta Costa Aggregate	49,768	1.0%
East Bay MUD	EBMUD	261,560	5.4%
Santa Clara Valley WD	SCVWD Aggregate	351,600	7.2%
San Francisco PUC	SFPUC Aggregate	298,809	6.1%
MWDSC	MWDSC Aggregate	3,796,681	78.1%
TOTAL		**4,859,628**	**100.0%**

M&I demand is itemized by MWDSC member agency in Table 5.2. Within San Diego CWA, SDPUC M&I demand is 204,039 AF (a 35.9% share of CWA demand).

Table 5.2. Municipal and Industrial Water Demand by MWDSC Member

MWD MEMBER AGENCY	Representative Agency	M&I Demand (AF)	share
Anaheim	City of Anaheim	72,743	1.9%
Beverly Hills	City of Beverly Hills	13,511	0.4%
Burbank	City of Burbank	25,546	0.7%
Calleguas MWD	CMWD Aggregate	156,702	4.1%
Central Basin MWD	CBMWD Aggregate	259,410	6.8%
Compton	City of Compton	9,321	0.2%
Eastern MWD	Eastern MWD	192,227	5.1%
Foothill MWD	FMWD Aggregate	20,353	0.5%
Fullerton	City of Fullerton	31,662	0.8%
Glendale	City of Glendale	33,024	0.9%
Inland Empire Utilities Agency	IEUA Aggregate	251,721	6.6%
Las Virgenes MWD	LVMWD	27,811	0.7%
Long Beach	City of Long Beach	69,575	1.8%
Los Angeles	LADWP	642,753	16.9%
MWD of Orange County	MWDOC Aggregate	490,893	12.9%
Pasadena	City of Pasadena	37,460	1.0%
San Diego CWA	SDCWA Aggregate	568,965	15.0%
San Fernando	City of San Fernando	3,311	0.1%
San Marino	City of San Marino	5,053	0.1%
Santa Ana	City of Santa Ana	44,556	1.2%
Santa Monica	City of Santa Monica	14,498	0.4%
Three Valleys MWD	TVMWD Aggregate	123,982	3.3%
Torrance	City of Torrance	30,660	0.8%
Upper San Gabriel Valley MWD	USGVMWD Aggregate	226,170	6.0%
West Basin MWD	WBMWD Aggregate	178,682	4.7%
Western MWD of Riverside County	WMWDRC Aggregate	266,090	7.0%
TOTAL		**3,796,681**	**100.0%**

Table 5.3 summarizes the index prices and demand elasticity values for each CUWA agency (and sub-agency). For MWDSC and San Diego CWA, the reported residential price is the agency-specific index price, which is calculated as the share-weighted average of the individual index prices based on the shares listed in Table 5.2, and the estimated demand elasticity is the predicted value of the econometric model for the entire region at the agency index price. The residential price index for all CUWA members combined is $1,307.40/AF.

Table 5.3. Municipal and Industrial Water Demand by MWDSC

CUWA Member Agency (Subagency)	Residential Price Index ($/AF)	Estimated demand elasticity
Alameda CWD	$1,102.51	-0.204
Zone 7 Water Agency	$1,132.86	-0.195
Contra Costa WD	$1,147.59	-0.111
East Bay MUD	$1,231.53	-0.102
Santa Clara Valley WD	$1,123.58	-0.348
San Francisco PUC	$2,182.43	-0.143
MWDSC	$1,267.95	-0.183
Los Angeles DWP	$1,954.32	-0.111
San Diego CWA	$1,645.44	-0.349
City of San Diego	$2,311.50	-0.265

Economic losses are calculated by incorporating the values in Tables 5.1-5.3 for each CUWA member in equation (6) and summing these values net of the marginal cost of service across members in equation (9). The aggregate results for the economic losses across CUWA members are presented two ways. First, a measure of total economic loss across all CUWA members is computed in a framework in which the entire M&I water supply disruption is mediated through the residential segment of each regional market. Second, a measure of average economic loss ($/AF) is calculated for each CUWA member and a quantity-weighted average across all CUWA members is reported. The measure of average economic loss in the residential sector depends only on the magnitude of the supply disruption in percentage terms and is invariant to the specification of the baseline quantity (Q_i^* in equation (9)) as residential demand or M&I demand. Put differently, if an agency responds to a 10% supply reduction by rationing all segments of the market proportionally by 10%, then the average economic loss in the residential sector would be the value reported here for a 10% supply disruption. The total economic loss reported here can be adjusted to account for only residential losses in a framework that separately accounts for economic losses in the commercial, industrial, and government segments of the market by multiplying the total economic loss reported below by the residential share of M&I deliveries.

Table 5.4 reports the upper and lower bounds for economic losses across all CUWA members. For each magnitude supply disruption, the total economic loss is the average

loss ($/AF) multiplied by the decrease in total M&I deliveries. The lower bound for economic losses ranges from $458/AF for a 10% supply disruption to $3,267/AF for a 30% supply disruption, and the upper bound for economic losses ranges from $1,765/AF for a 10% supply disruption to $4,574/AF for a 30% supply disruption. At all levels of supply disruption, the difference between the lower bound value and upper bound value of economic losses is given by the CUWA price index ($1,307.40/AF). The lower bound for economic losses treats this value as fully offset by the avoided cost of water delivery, so that CUWA members collectively save $1,307.40/AF in water procurement and distribution costs for each acre-foot of water foregone during a supply disruption. The upper bound, which is gross of avoided costs, is therefore larger by this amount.

Table 5.4. Economic Losses from a Cumulative 10%, 20%, and 30% Supply Disruption for CUWA Member Agencies

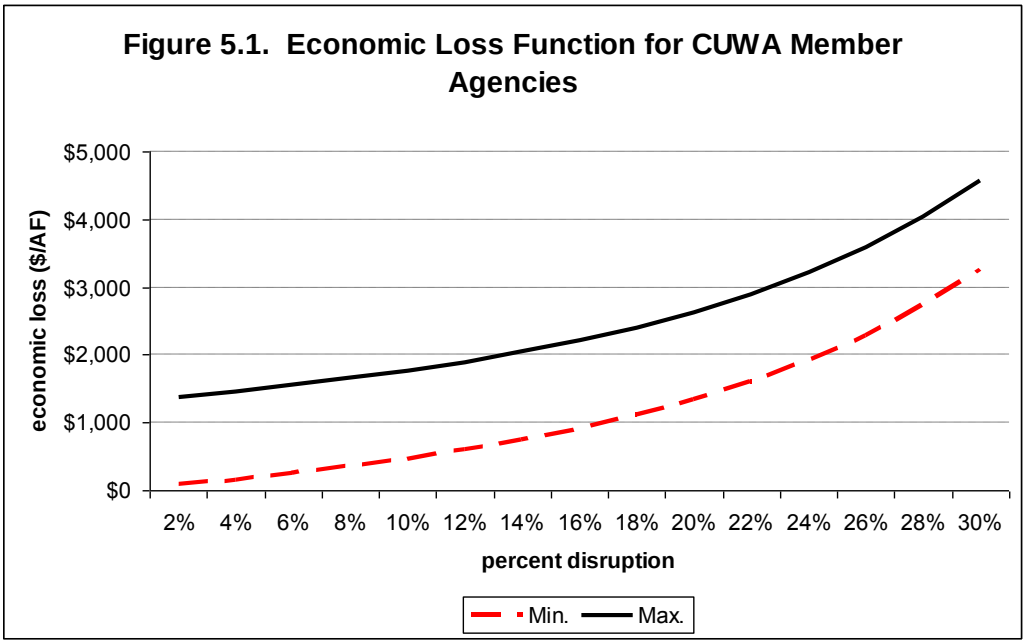
Scenario	10% disruption	20% disruption	30% disruption
Lower Bound			
Total Loss ($/year)	$222,329,354	$1,287,185,138	$4,763,843,296
Average Loss ($/AF)	$458	$1,324	$3,267
Upper Bound			
Total Loss ($/year)	$857,678,934	$2,557,884,299	$6,668,892,037
Average Loss ($/AF)	$1,765	$2,632	$4,574

In general, economic losses can be calculated for a given level of marginal cost (avoided unit cost) by deducting the marginal cost of water service from the upper boundary value for the average loss. For example, if the marginal cost of water service is $500/AF, actual economic losses for CUWA members would be $1,265/AF for a 10% supply disruption, $2,132/AF for a 20% supply disruption, and $4,074/AF for a 30% supply disruption.

Notice that the average economic loss is rising in the magnitude of the supply disruption. The reason is that consumer willingness to pay for an incremental unit of water is decreasing in the level of water consumption as the value of water applied to various end-uses declines with the total level of supply. In response to a water supply disruption, residential consumers select the least costly conservation activities before dispensing with higher valued uses of water.

Figure 5.1 depicts economic losses ($/AF) across CUWA members for different magnitudes of a water supply disruption. The dashed line represents the minimum loss scenario in which the avoided marginal cost of water delivery is equal to the baseline retail water rate in each region and the solid line represents the upper boundary of

losses, which is consumer willingness to pay to avoid a water service interruption gross of avoided marginal cost of water delivery.



It should be noted that economic losses in each region are calculated using the effective prices described in Section 4 of this report. Basing the loss calculation on the typical water use level of residential households in the service territory of each member agency implicitly assumes that a water supply disruption of a given magnitude is met with proportionate rationing on each tier of the pricing structure. For member agencies that meet a supply reduction by raising water rates predominantly on the higher tiers of the pricing structure, the actual economic losses would be larger than the losses described above.

There is considerable variation in economic losses across individual CUWA member agencies. Both prevailing water rates and the price elasticity of demand vary across CUWA member agencies, and these factors have an important bearing on the willingness to pay of consumers to avoid water shortages of various magnitudes. At the lower boundary of economic losses, the standard deviation in economic losses across CUWA members is $406/AF for a 10% supply disruption, $1,353/AF for a 20% supply disruption, and $3,895/AF for a 30% supply disruption. At the upper boundary of economic losses, the standard deviation in economic losses across CUWA members is $807/AF for a 10% supply disruption, $1,710/AF for a 20% supply disruption, and $4,216/AF for a 30% supply disruption.

The standard deviation in economic losses across CUWA members increases with the magnitude of the supply disruption at both the upper and lower boundary of economic losses. The reason is that average economic losses from a supply disruption rise at a

faster rate with the magnitude of the disruption in regions with less elastic household demand. An important factor that determines the elasticity of demand in each region is demand hardening resulting from the adoption of best-management practices for conservation in each region. Agencies that have intensively implemented BMPs for water conservation are less able to facilitate further conservation measures at a reasonably low cost to households in the event of a supply disruption, and consumer willingness to pay to avoid a supply disruption rises rapidly in the magnitude of the water shortage in these regions.

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Sonoma County Water Agency and Bureau of Reclamation

Phase 3 Engineering and Economic/Financial Analysis Report
North San Pablo Bay Restoration and Reuse Project

June 2008

Prepared in cooperation with:
North Bay Water Reuse Authority

NBWRA

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SONOMA COUNTY WATER AGENCY

DRAFT

Executive Summary

Recognizing the growing need for an integrated and regional approach to water management, four wastewater utilities and one water agency in the North San Pablo Bay region of California have joined forces to plan a project that would considerably expand the use of recycled water region-wide.

The proposed North San Pablo Bay Restoration and Reuse Project (Project) would build on commitments to long-term inter-agency cooperation to address common needs related to reliable water supplies and enhanced environmental restoration. As implementation of the Project would likely require external funding assistance, the investigation and development of the Project is being carried out in conformance to the requirements of the U.S. Department of the Interior's Bureau of Reclamation Public Law 102-575, Title XVI, which provides a mechanism for Federal participation and cost-sharing in approved water reuse projects.

The five participating agencies have organized themselves under a Memorandum of Understanding (MOU) as the North Bay Water Reuse Authority (Authority). The Authority members include:

- The Las Gallinas Valley Sanitary District (LGVSD)
- The Novato Sanitary District (Novato SD)
- The Sonoma Valley County Sanitation District (SVCSD)
- The Napa Sanitation District (Napa SD)
- The Sonoma County Water Agency (SCWA).

North Marin Water District and Napa County are also providing technical and financial support to the Authority.

The Authority members undertook cooperative planning efforts over a 5-year period – including 19 technical workshops as well as monthly institutional workshops, with extensive outreach to potential Project stakeholders – to define shared issues and develop feasible alternatives toward definition of a region-wide recycled water project that would enable them to address those issues.

This report, representing part of the third phase of a three-phase planning effort, presents an engineering feasibility evaluation and economic and financial analysis of the proposed project. The report describes the Project area and the key water management problems and needs within the Project area, identifies water reuse opportunities in the Project area, develops and analyzes alternative measures that could address the identified water management needs, presents an overview of associated legal and institutional requirements, compares the alternatives, presents an

economic and financial analysis of the proposed Project, and discusses potential environmental effects of the Project.

In short, this report provides the engineering and economic studies that guide the Authority's selection of a recommended Project for funding and implementation. Along with the environmental documentation that is currently underway, these three elements will form the complete Project feasibility study report.

Project Setting and Future Conditions

As shown in Figure ES-1, the initial study area encompasses approximately 318 square miles of land within Marin, Sonoma, and Napa Counties. This region extends some 10 to 15 miles inland of the tidal San Pablo Bay, with a total population of over 270,000 in the major urban centers of San Rafael, Novato, Petaluma, Sonoma, and Napa. The region supports agriculture, including predominantly some of the premier wine-grape growing land in North America, as well as light industry, commercial and institutional uses, parklands, and residential areas. It is an area of natural and cultivated appeal and productivity, all proximate to the additional cultural attractions of the greater San Francisco Bay Area.

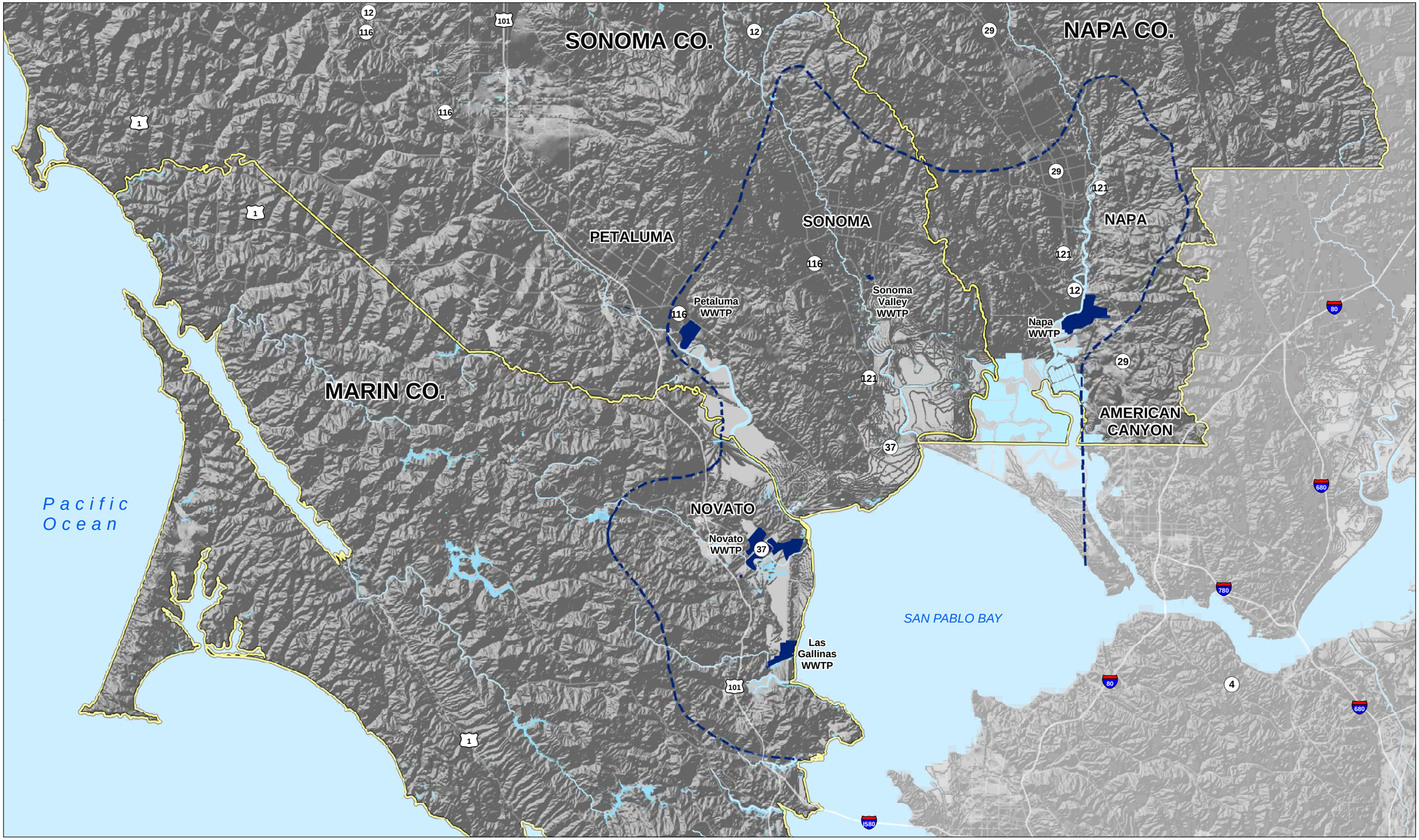
The waterways of this region – the Napa River, Sonoma Creek, and Petaluma River, as well as smaller streams, some of which support only seasonal flows – are tributary to the San Pablo Bay estuary. Although threatened until recently by development, the remaining tidal wetlands of the San Pablo Bay estuary serve in a vital ecological role as nurseries for fisheries and wintering areas for migratory waterbirds.

Local and regional planning projections indicate that there will be sustained pressures for residential growth in the study area, with estimates of 10-12 percent growth in most of the existing urban centers by the year 2020 (as compared to 2005 populations). Existing policies in principal cities will tend to favor concentrated rather than dispersed growth.

Agricultural land use is expected to remain relatively constant over a 20-year planning period, and all three County governments in the study area have explicit policies in place to protect agricultural lands. Given the high value of wine-grape culture, there is unlikely to be much change in the 75 percent of agricultural acreage committed to vineyards.

With the removal of Petaluma from the Project[1], total urban water use – including both residential and non-residential uses – in the study area is projected to increase from the 2005 level of 63,700 acre-feet per year (AFY) to about 72,800 AFY in 2020. Total water use for irrigation of agricultural lands is estimated at approximately 23,300 AFY at present.

[1] After initial evaluation was concluded for the Project, Petaluma decided not to participate in the Project. See Section 1.3 for a discussion of Petaluma's participation.



Basemap: U.S. Department of Agriculture, 2001

Legend

- Initial Study Area Boundary
- WWTPs

0 2.5 5 10
Miles

N

CDM

Figure ES-1
Initial Study Area

Meeting these water demands are sources that include surface water supplies (both internal and external to the study area), groundwater, and recycled water. SCWA supplies much of the study area with ***surface water*** conveyed from the Russian River and its tributaries in central Sonoma County, external to the study area. SCWA's reliable supplies to customers in the study area are 87,970 AF during a dry year.

Groundwater serves many agricultural users (and some residential users) as a primary source of supply and serves as a secondary source of supply for some urban users as well, notably the City of Sonoma and Valley of the Moon Water District. Although the total quantity of groundwater in the study area is unknown, groundwater pumping has been measured. The vast (80 percent) increase in pumping of groundwater in the past 30 years to support agricultural irrigation has resulted locally in groundwater outflow exceeding inflow, some impacts on groundwater quality, and a lowering of groundwater levels in some parts of the study area that are dependent on groundwater supplies.

Existing treatment and distribution infrastructure in the study area currently produce about 7,300 AFY of ***recycled water*** for irrigation and wetlands restoration purposes, which could increase to 11,250 AFY by 2020.

At first glance, average year and wet season conditions appear to yield sufficient water to meet total annual demand in the study area. This conclusion gives a distorted – and inaccurate – picture of water use in this area, however. In fact, the seasonal availability of some water sources (against the strong seasonality of agricultural demand), the potential for overdraft of groundwater with impacts on quality and quantity, and the growth pressures on the area's urban centers all argue for an effective, coordinated, and regional approach to the increased use of recycled water.

Problems and Needs

The water management concerns of the North San Pablo Bay study area can be summarized as follows:

- The agricultural economy, dominated by high-value vineyard agriculture, needs a highly reliable water supply to maintain and to expand its base.
- Urbanization of the greater San Francisco Bay area requires highly reliable water supplies.
- The vitally important estuarine ecosystem of the North San Pablo Bay area, which includes endangered species and vital wetlands, has been under intense pressure. Although protective and restorative measures are in place, the habitat requires a reliable supply of water.

- Surface waters are becoming less reliable sources of supply as they are already diverted by multiple users, have low flows in the summer (which coincides with the irrigation season), and can have low flows in dry years.

- Groundwater supplies are heavily pumped for agricultural and limited municipal uses and in some localities have marginal quality.

These concerns are all among those addressed in the planning issues originally agreed to by the participating agencies of the Authority.

Water Reuse Opportunities

The principal governing document for regulating the use of recycled water in California is the California Code of Regulations Title 22, Division 4, Chapter 3, commonly referred to as Title 22. Title 22 defines four levels of recycled water quality standards, with the most stringent being disinfected tertiary recycled water, which is suitable for unrestricted use in agricultural and landscape irrigation, as well as for environmental (wetlands) restoration.

These high-order uses are in fact the intended uses of recycled water under the Project. Some 34,000 acres of land in the study area appear suitable for irrigation, 75 percent of it being vineyards and the remainder comprising urban landscaping, dairy/pasturelands, other irrigated farmland, and orchards. The estimated maximum water use for irrigation of these lands in the study area is about 23,300 AFY at present.

The potential sources of disinfected tertiary recycled water are the four wastewater treatment plants (WWTPs) in the study area. The dry-season (June through October) discharge flows (in million gallons per day [mgd]) for these WWTPs are:

Recent WWTP Dry Weather Flows in North San Pablo Bay Study Area		
Wastewater Treatment Plant	***2002 Average Dry Weather Flow***	***Existing or Currently Planned Tertiary Treatment Capacity***
LGVSD WWTP	2.1 mgd	2.0 mgd currently delivered to Marin Municipal Water District for tertiary treatment
Novato SD WWTP	5.0 mgd	Existing capability for 0.5 mgd Title 22 disinfected tertiary treatment
SVCSD WWTP	2.6 mgd	Existing capability for 16.0 mgd Title 22 disinfected tertiary treatment
Napa SD WWTP	6.2 mgd	Existing capability for 8.8 mgd Title 22 disinfected tertiary treatment

All of the WWTPs deliver recycled water during the dry season, when the Regional Water Quality Control Board imposes restrictions on discharge of secondary effluent to waterways. SVCSD and Napa SD have the most extensive infrastructure in place for conveyance, storage and distribution of recycled water to local users. All the WWTPs currently have the capability to produce disinfected tertiary recycled water conforming to Title 22 requirements for unrestricted use. All of the agencies have

projects in various stages of planning and implementation to increase treatment capacity or plan to increase the local use of recycled water, if funding is available. Full implementation of those individual local projects would result in WWTP discharge and beneficial reuse at the following levels in 2020:

Potential Year 2020 WWTP Discharge and Beneficial Reuse Volumes in Study Area		
Wastewater Treatment Plant	***WWTP Flow (AFY)***	***Beneficial Reuse (AFY)***
LGVSD WWTP	3,671	902
Novato SD WWTP	8,673	1,015
SVCSD WWTP	5,506	3,000
Napa SD WWTP	9,800	4,540
TOTAL	27,650	9,457

The potential for use of recycled water in the study area is not limited by demand but rather by the limited capacity for tertiary treatment and by the lack of regional conveyance and storage networks that would deliver disinfected tertiary recycled water where and as needed. Acting individually and locally, the districts have only a very limited ability to maximize their potential for water reclamation and reuse. Adopting a regional outlook and plan, however, greatly expands the potential for beneficial water reuse by the Authority.

For purposes of developing and evaluating alternatives for a regional water recycling project, it is assumed that the WWTPs will have developed, at a maximum, the following capacities for producing Title 22 tertiary recycled water (increased to reflect the peak daily dry weather flow demands of the anticipated local users supplied by the WWTP), as a part of the overall Project investment and implementation. These values reflect the maximum treatment needed to implement the largest recycled water system. Actual treatment capacity will depend upon the alternative chosen.

Assumed Future Tertiary Treatment Capacity in WWTPs of the North San Pablo Bay Study Area	
Wastewater Treatment Plant	***Assumed Maximum Tertiary Capacity for Project***
LGVSD WWTP	3.1 mgd
Novato SD WWTP	10.4 mgd
SVCSD WWTP	16.0 mgd
Napa SD WWTP	17.9 mgd
TOTAL	47.4 mgd

These recycled water production values are assumed in the development and evaluation of Project alternatives, as described in the following section.

Formulation and Description of Project Alternatives

Working in close collaboration with the participating agencies of the Authority, the Project study team organized an array of Project options as characterized by existing, agency-identified, and potential recycled water projects in the study area; by the size of recycled water distribution network (basic regional, regional, and expanded regional) that would be involved; and by storage options (no new storage, partial storage, and full storage of recycled water supplies).

This process led to the formulation of six initial Project alternatives – one basic regional alternative, four expanded regional alternatives, and one interconnected regional system alternative. As each alternative had three possible storage options associated with it, there were a total of 18 alternatives considered.

Preliminary analysis indicated that the alternatives with "no new storage" would make insufficient use of recycled water to merit further consideration. Alternatives with "full storage", on the other hand, would be prohibitively costly to implement. Consolidation and rationalization of the remaining six "partial storage" options left three action alternatives to be carried forward for feasibility analysis.

These three action alternatives are defined as follows:

- ***Alternative 1 (Basic Regional System)*** – The most basic regional system of the three Project action alternatives, putting first emphasis on the implementation of recycled water projects local to each WWTP. Under this alternative, no WWTPs are connected for joint treatment, storage, or distribution of combined recycled water. Area-wide, the recipients of recycled water include the urban users in Novato, the existing SVCSD reuse area, the Sonoma Valley Recycled Water Project, Carneros East area, the Napa Milliken-Sarco-Tulocay (MST) Creeks area, and the Napa Salt Marsh restoration area.
- ***Alternative 2 (Regional System)*** – A larger regional recycled water system that takes advantage of increased storage capacity and additional pipelines to distribute recycled water more widely throughout the Project area than could be achieved under Alternative 1. Interconnectivity between WWTPs occurs between SVCSD and Napa SD to serve the Napa Salt Marsh Restoration Area during the restoration period, and between Novato SD and LGVSD to serve the Sears Point Area. Area-wide, the recipients of recycled water include the Peacock Gap golf course, urban users in Novato, agricultural users in the Sears Point Area, the existing SVCSD reuse area, the Sonoma Valley Recycled Water Project, the Southern Sonoma area, Carneros East area, the Napa MST area, and the Napa Salt Marsh restoration area.
- ***Alternative 3 (Interconnected Regional System)*** – A regional system that connects all four wastewater treatment plants in the Project area, thereby maximizing reuse by potentially enabling recycled water from any WWTP to be delivered to any area that needs recycled water. In actual operation, each WWTP would put first priority on delivery of recycled water to local projects, with excess recycled water being sent into the regional recycled water delivery system for use in more distant

locations of the Project area. Areawide, the "local" recipients of recycled water would include the Peacock Gap golf course, urban users in Novato, the existing SVCSD reuse area, the Sonoma Valley Recycled Water Project, the Napa MST area, and the Carneros East area. The "regional" recipients would include the agricultural users in Sears Point, the Southern Sonoma Valley, and the Central Sonoma Valley areas, as well as the Napa Salt Marsh restoration area.

Within the alternatives described above, the Authority members have collectively prioritized the projects within their individual service areas to identify a phased implementation plan under any of the alternatives being considered. The first phase (Phase 1) of alternative implementation includes projects that each member agency has defined to a level of detail that allows both for project-level environmental review in other sections of the feasibility study, and short-term readiness for design, funding, and construction. Each treatment plant puts first priority on the delivery of recycled water to its local projects. Local projects include the Novato urban users, the Sonoma Valley Recycled Water Project, the Napa MST area, and the Napa Salt Marsh restoration area.

A fourth alternative, the "No Action Alternative", assumes that there is no joint Project. It essentially represents the "current status" in which the potential need to develop additional potable water supplies continues to be a regional challenge, and additional treatment capacity and water recycling might occur strictly from the implementation of local plans for expansion, as funding is available.

Of the action alternatives, Alternative 1 has the lowest associated costs and provides the least recycled water supply; Alternative 3 has the highest costs and provides the greatest amount of recycled water. The differences in cost among the alternatives stems from the successively greater installation of pipelines, storage, treatment, and pumping facilities associated with each in turn.

The recycling benefits and costs of the alternatives are summarized below:

Summary of Recycling Capacity and Associated Costs of Alternatives of the North San Pablo Bay Restoration and Reuse Project

Action Alternative	*New Recycled Water Demand (Beneficial Reuse) Developed by the Alternative[(1)]*	*Total Recycled Water Demand in the Project Area (w/Project)*	*Discharge to Bay*	*Estimated Capital Costs (millions)*	*Estimated Annual Operations & Maintenance Costs (millions)*
No Action Alternative	0 AF	4,944 AF	22,711 AF	$270 M	--
Alternative 1 – Basic Regional System	6,455 AF	11,329 AF	16,256 AF	$210 M	$1.8 M
Alternative 2 – Regional System	11,215 AF	16,159 AF	11,496 AF	$378 M	$2.8 M
Alternative 3 – Interconnected Regional System	12,725 AF	17,669 AF	9,986 AF	$414 M	$3.1 M

(1) The new recycled water demand developed by the alternatives represents total beneficial reuse to customers. Additional recycled water is available from SVCSD and Napa SD for the Napa Salt Marsh which is not included in these totals, as the amount of water needed for the Napa Salt Marsh is unknown at this time. Supplying recycled water to the Napa Salt Marsh would further reduce discharges to San Pablo Bay.

Legal and Institutional Requirements

The following issues define the principal legal and institutional framework of the Project.

- ***Organizational structure*** – For purposes of joint planning, the five participating entities of this Project have executed an MOU to work as the North Bay Water Reuse Authority, with SCWA acting as Administrative Agency on behalf of the Authority. The participants may agree to form a joint powers authority when the Project becomes operational.

- ***Agency consultation*** – The Authority has initiated informal "information discussions" with the federal, state, and local agencies that will be required to review Project plans for conformance to applicable laws and regulations, particularly with regard to environmental documentation. The Authority has also conducted outreach to water districts within whose service areas the Project would deliver recycled water, both for informational purposes and to determine their interest in participating in the Project.

- ***Effects of recycled water use*** – The Project would alter the disposition of recycled water by reducing discharge into the San Pablo Bay and its tributaries and instead providing increased recycled water supply to agricultural, urban, and habitat restoration uses. The main economic benefit of the Project, to be weighed against its estimated costs, would be to increase the reliability of water supplies for urban and agricultural irrigation. Environmental benefits include a reliable water supply for the Napa Salt Marsh and potentially improved water quality in San Pablo Bay and its tributaries for fisheries and wildlife habitat.

- ***Water rights effects*** – The Project will not affect the water rights of downstream water users, as water downstream of the participating communities is brackish and not suitable for most potable and irrigation purposes. Potential recipients of recycled water are protected by California Water Code from any loss of their existing rights to surface water supplies.

- ***Regulatory requirements*** – The study team has identified some 25 Federal, State, and local agencies as well as private utilities that must be contacted for purposes of Project review, coordination/consultation, and permitting. Federal and State regulatory requirements having greatest bearing on the Project include Title 22, the California Department of Fish & Game Code, and the California Water Code.

It is affirmed that the Project will not adversely affect any of the participating agencies' contractual water supply obligations for recycled water; existing recycled water customers would continue to be served as they are now served.

Recommended Alternative

Based on the analysis presented, the Authority believes Alternative 1 is the most viable based on implementability, storage issues, and costs.

- Alternative 1 requires the least amount of system storage of the action alternatives, making use of existing storage or land available at the WWTPs. Implementing the larger recycled water distribution systems would require 1,400 to 1,800 AF of more storage.

- The capital costs of both Phase 1 of Alternative 1 and a fully-developed Alternative 1 are lower than the respective capital costs of the other alternatives. The cost of delivering recycled water must be cost effective for the member agencies to implement any alternative. Larger alternatives may be too costly (in terms of construction and environmental documentation) for the agencies to pursue without additional external funding at this time.

- At this time, implementation of Alternative 1 would begin with the projects identified as Phase 1, due to current funding opportunities. These projects have been recognized as those most ready for implementation due to the level of detailed analysis already prepared.

Economic and Financial Capability Analysis

The economic analysis evaluates whether the Project is cost-effective and would provide net economic benefits to the Authority region. The economic analysis uses the alternative cost method to determine water supply benefits of the Project. The Project's water supply benefits would occur by providing recycled water for urban landscape, agricultural, and environmental uses. The Project costs are compared to non-recycled projects that could potentially serve the same region and are indicative of new surface water supply costs for the region: the proposed Water Supply, Transmission, and Reliability Project (Water Project) for the Sonoma and Marin Counties portion of the Project area; and imported water to the MST area for the Napa County portion of the Project area[2]. Due to current funding opportunities, the Project costs evaluated are for the first set of projects implemented under Alternative 1, referred to as the Phase 1 set of projects. The following table summarizes the results.

[2] Although these non-recycled water supply projects would not serve agricultural users in Sonoma Valley or environmental water needs in the Napa Salt Marsh, this analysis assumes that those non-recycled water projects are representative of water supply costs in the region. Therefore, the project costs are used as alternative cost measurements for agricultural and environmental water supplies.

Phase 1 and Non-Recycled Projects Summary Cost Comparison			
	Alternative 1 Phase 1	***Water Project (Sonoma and Marin Counties Portion of Project area)***	***Import Water to MST Area (Napa County portion of Project area)***
Total Capital Costs	$121,000,000	$174,479,487	$95,700,000
Annual Capital Costs[(1)]	$4,702,725	$6,781,232	$3,719,428
Annual O&M Costs	$1,381,000	N/A[(2)]	N/A[(2)]
Total Annual Costs	$6,083,725	$6,781,232	$3,719,428
Supply (AF)	4,645	3,613	1,937
Dollar per acre-foot	$1,307	$1,877	$1,920

(1) Capital costs are annualized based on 50-year project life and 3 percent real discount rate.
(2) Not available

The Project would be less expensive to implement relative to both non-recycled water projects; therefore, it would have net economic benefits to the region. Based on the alternative cost method, the water supply benefits of the project would be between $1,877 and $1,920 per acre-foot. The Project would also provide various indirect benefits, including improved groundwater quality and levels and reduced operational costs for the member agencies. The economic analysis concludes that the Project would result in net benefits to the region.

The financial capability analysis discusses a preliminary funding plan for the local cost share of the Project. The Authority members have not yet developed a firm financing plan. The federal share of funding is expected to be $25 million. Preliminary discussions have indicated Authority members would finance the local share through State and local grants, if available, and loans and revenue bonds. Loans and bonds would be repaid primarily through user fees, both for wastewater service and for recycled water supply deliveries. Through signing the MOU, completing this feasibility study, and developing an environmental impact statement/environmental impact report, the Authority members have shown a commitment in implementing the Project. A final cost-sharing plan and a more thorough analysis of financial capability will be developed before a construction funding agreement with the United States is executed.

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CHANGE FOR THE BETTER WITH ENERGY STAR

Life Cycle Cost Estimate for 1 ENERGY STAR Qualified Residential Clothes Washer(s)

This energy savings calculator was developed by the U.S. EPA and U.S. DOE and is provided for estimating purposes only. Actual energy savings may vary based on use and other factors.

Enter your own values in the gray boxes or use our default values.

Choose the type of washing machine	Residential	
Number of units	1	
Electric rate ($/kWh)	$0.113	
Water rate ($/1000 gallons)	$4.529	
Gas rate ($/therm)	$1.330	
Average number of loads per week	7.5	
Type of water heating	Electric Water Heating	
Type of clothes dryer	Electric Dryer	
	ENERGY STAR Qualified Unit	**Conventional Unit**
Initial cost per unit (estimated retail price)	$750	$492

Annual and Life Cycle Costs and Savings for 1 Residential Clothes Washer(s)

	1 ENERGY STAR Qualified Unit(s)	1 Conventional Unit(s)	Savings with ENERGY STAR
Annual Operating Costs*			
Electricity costs	$63	$89	$25
Water costs	$26	$55	$30
Gas costs	$0	$0	$0
Total	**$89**	**$144**	**$55**
Life Cycle Costs*			
Operating costs (electricity, water, and maintenance)	$780	$1,260	$481
Electricity costs	$556	$777	$221
Water costs	$224	$483	$260
Gas costs	$0	$0	$0
Purchase price for 1 unit(s)	$750	$492	-$258
Total	**$1,530**	**$1,752**	**$223**
		Simple payback of initial additional cost (years)†	**4.7**

** Annual costs exclude the initial purchase price. All costs, except initial cost, are discounted over the products' lifetime using a real discount rate of 4%. See "Assumptions" to change factors including the discount rate.*

† A simple payback period of zero years means that the payback is immediate.

Summary of Benefits for 1 Residential Clothes Washer(s)

Initial cost difference	**$258**	
Life cycle savings	**$481**	
Net life cycle savings (life cycle savings - additional cost)	**$223**	
Simple payback of additional cost	**4.7**	**years**
Life cycle electricity saved	**2,464**	**kWh**
Life cycle air pollution reduction	**3,795**	**lbs of CO_2**
Air pollution reduction equivalence	**0.32**	**cars removed from the road for one year**
Air pollution reduction equivalence	**0.39**	**acres of forest planted**
Savings as a percent of retail price	**30%**	

Assumptions for Clothes Washers

Category	Value		Data Source
Power & Water			
ENERGY STAR Qualified Unit			
Initial Cost Per Unit	$750		Average retail price of a qualified model in 2009 from national retail data
Lifetime	11	years	Appliance Magazine, September 2008
Annual Water Consumption	5637	gal/yr	Average water consumption based on all qualified models, July 2009
Water Consumption (gal/Load) per unit	14.38	(gal/load)/unit	Calculated
Electricity Consumption (kWh/Load) per unit	1.436	(kWh/load)/unit	Calculated
Gas Consumption (therms/Load) per unit	0.00	(therms/load)/unit	Calculated
Selected Scenario			
	Electric Water Heating and Drying		
Electric Water Heating & Electric Drying			
Reference Case Annual Electricity use	563.0	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	1.44	kWh/load	Calculated
Electric Water Heating & Gas Drying			
Reference Annual Electricity use	192.00	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	0.49	kWh/load	Calculated
Reference Annual Gas Use	12.80	therms/yr	Average energy consumption based on all qualified models, July 2009
Gas consumption per load	0.03	therms/load	Calculated
Electric Water Heating with No Drying			
Reference Annual Electricity use	192.00	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	0.49	kWh/load	Calculated
Gas Water Heating & Gas Drying			
Reference Annual Electricity use	56.9	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	0.15	kWh/load	Calculated
Reference Annual Gas Use	20.8	therms/yr	Average energy consumption based on all qualified models, July 2009
Gas consumption per load	0.05	therms/load	Calculated
Gas Water Heating & Electric Drying			
Reference Annual Electricity use	390.00	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	0.99	kWh/load	Calculated
Reference Annual Gas Use	8.00	therms/yr	Average energy consumption based on all qualified models, July 2009
Gas consumption per load	0.02	therms/load	Calculated
Gas Water Heating with No Drying			
Reference Annual Electricity use	56.90	kWh/yr	Average energy consumption based on all qualified models, July 2009
Electricity use per load	0.15	kWh/load	Calculated
Reference Annual Gas Use	8.00	therms/yr	Average energy consumption based on all qualified models, July 2009
Gas consumption per load	0.02	therms/load	Calculated
Conventional Unit (New Unit)			
Initial Cost Per Unit	$492		Average retail price of a non-qualified model in 2009 from national retail pricing
Lifetime	11	years	Appliance Magazine, September 2008
Annual Water Consumption	12179	gal/yr	Average water consumption based on all non-qualified models, July 2009
Water Consumption per unit	31.07	gal/Load	Calculated
Electricity Consumption per unit	2.008	kWh/Load	Calculated
Gas Consumption per unit	0.00	therms/load	Calculated
Electric Water Heating & Electric Drying			
Reference Case Annual Electricity use	787	kWh/yr	Average energy consumption based on all non-qualified models, December 2008
Electricity use per load	2.01	kWh/load	Calculated
Electric Water Heating & Gas Drying			
Reference Annual Electricity use	333.00	kWh/yr	Calculated
Electricity use per load	0.85	kWh/load	Calculated
Reference Annual Gas Use	15.70	therms/yr	Calculated
Gas consumption per load	0.04	therms/load	Calculated
Electric Water Heating with No Drying			
Reference Annual Electricity use	333.00	kWh/yr	Calculated
Electricity use per load	0.85	kWh/load	Calculated
Gas Water Heating & Gas Drying			
Reference Annual Electricity use	80.7	kWh/yr	Average energy consumption based on all non-qualified models, December 2008
Electricity use per load	0.21	kWh/load	Calculated
Reference Annual Gas Use	29.8	therms/yr	Average energy consumption based on all non-qualified models, December 2008
Gas consumption per load	0.08	therms/load	Calculated
Gas Water Heating & Electric Drying			
Reference Annual Electricity use	487.00	kWh/yr	Calculated
Electricity use per load	1.24	kWh/load	Calculated
Reference Annual Gas Use	14.10	therms/yr	Calculated
Gas consumption per load	0.04	therms/load	Calculated
Gas Water Heating with No Drying			
Reference Annual Electricity use	80.70	kWh/yr	Calculated
Electricity use per load	0.21	kWh/load	Calculated
Reference Annual Gas Use	14.10	therms/yr	Calculated
Gas consumption per load	0.04	therms/load	Calculated
Usage (Reference Case)			
Residential and Commercial Clothes Washers			
Average number of loads per year (Res)	392	loads/year	DOE Federal Test Procedure 10 CFR 430, Appendix J1
Average number of loads per year (Commercial)	950	loads/year	Multi-family Laundry Association, 2002
Number of loads per week (Residential)	7.5	loads/week	Calculated
Number of loads per week (Commercial)	18.3	loads/week	Calculated
Discount Rate			
Commercial and Residential Discount Rate (real)	4%		A real discount rate of 4 percent is assumed, which is roughly equivalent to the nominal discount rate of 7 percent (4 percent real discount rate + 3 percent inflation rate).
Commercial Electricity Price	$0.1030	$/kWh	Source: US electric rate: Energy Information Administration, Annual Energy Outlook 2009 (Early Release) edition. (converted from 2007 to 2008 dollars).
Residential Electricity Price	$0.1127	$/kWh	Source: US electric rate: Energy Information Administration, Annual Energy Outlook 2009 (Early Release) edition. (converted from 2007 to 2008 dollars).

Water Rate per 1000 Gallons	$4.53	$/1000 gal	2006 Water and Wastewater Rate Survey, Raftelis Consulting
Commercial Gas Price	$1.18	$/therm	Source: US electric rate: Energy Information Administration, Annual Energy Outlook 2009 (Early Release) edition. (converted from 2007 to 2008 dollars).
Residential Gas Price	$1.33	$/therm	Source: US electric rate: Energy Information Administration, Annual Energy Outlook 2009 (Early Release) edition. (converted from 2007 to 2008 dollars).
Carbon Dioxide Emissions Factors			
Electricity Carbon Emission Factor	1.54	lbs CO_2/kWh	EPA's Climate Change Action Plan (CCAP) number for 2009.
Gas Emission Factor	116.97	lbs CO_2/MMBtu	EPA 2007
CO_2 Equivalents			
Annual CO_2 sequestration per forested acre	9,700	lbs CO_2/year	EPA's Greenhouse Gas Equivalencies Calculator. http://www.epa.gov/cleanenergy/energy-resources/calculator.html
Annual CO_2 emissions for "average" passenger car	12,037	lbs CO_2/year	EPA's Greenhouse Gas Equivalencies Calculator. http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Input and Summary

User Inputs:

Front-Loading Mkt-Share	40%	
Top-Loading Std-size Mkt-Share	60%	
Top-Loading Compact-size Mkt-S	0%	
Lifetime	14.3	*years*
Cycles per year	295	*cycles*
Duration of 1 Cycle	1	*hour*

Recovery Efficiency of Water Heaters

Gas Water Heater	75%
Oil Water Heater	75%

Discounting future values:

Discount Rate for NPV Determination	7.0%
Discount Rate for Energy Savings	7.0%
Year to discount to	2010

Relative Price Elasticity RP elasticity -0.34

Economic Growth Reference

Year standards starts	2015	
	FL	TL
Base case efficiency growth after 2015	0.00%	0.00%
Standards case efficiency growth after 2015	0.00%	0.00%

Front-Loading Clotheswasher

	Design	MEF	IMEF	Water Factor	Container Volume	RMC	Elec per cycle
			cu.ft./kWh/cyc	*gal / cu.ft*	*cu.ft.*	*%*	*kWh/cycle*
0	Front-Loading EL0	1.72	1.66	8.00	3.00	41%	0.61
1	Front-Loading EL1	1.72	1.67	7.50	3.00	41%	0.61
2	Front-Loading EL2	1.72	1.72	7.50	3.00	41%	0.61
3	Front-Loading EL3	1.80	1.80	7.50	3.00	41%	0.53
4	Front-Loading EL4	2.00	2.00	6.00	3.30	42%	0.36
5	Front-Loading EL5	2.20	2.20	4.50	3.41	39%	0.33
6	Front-Loading EL6	2.40	2.40	4.20	3.60	39%	0.20
7	Front-Loading EL7	2.60	2.60	3.80	3.83	36%	0.20
8	Front-Loading EL8	2.89	2.88	3.36	3.60	33%	0.12

Top-Loading Clotheswasher - Standard Size

Level	Efficiency Level	MEF	IMEF	Water Factor	Container Volume	RMC	Elec per cycle
			cu.ft./kWh/cyc	*gal / cu.ft*	*cu.ft.*	*%*	*kWh/cycle*
0	Top-Loading EL0	1.26	1.26	9.50	3.20	52%	0.869
1	Top-Loading EL1	1.40	1.40	9.50	3.50	54%	0.637
2	Top-Loading EL2	1.72	1.72	8.00	3.50	49%	0.378
3	Top-Loading EL3	1.80	1.75	7.50	3.90	38%	0.885
4	Top-Loading EL4	1.80	1.76	7.50	3.90	38%	0.885
5	Top-Loading EL5	1.80	1.80	7.50	3.90	38%	0.885
6	Top-Loading EL6	2.00	2.00	6.00	4.00	37%	0.736
7	Top-Loading EL7	2.26	2.26	4.48	4.10	37%	0.527

Base Case Weighted Average Energy/Water Use and Price - Front-Loading

	Energy Factor Standard		Annual Energy Use Electricity	Gas	Oil		Water Use Standard	
	kWh/yr		**kWh/yr**	*MMBTU/yr*	*MMBTU/yr*		*1000 gal/yr*	
2005	2.20	2005	227	1.05	0.04	2005	4.902	2005
2006	2.20	2006	227	1.05	0.04	2006	4.902	2006
2007	2.20	2007	227	1.05	0.04	2007	4.902	2007
2008	2.20	2008	227	1.05	0.04	2008	4.902	2008
2009	2.20	2009	227	1.05	0.04	2009	4.902	2009
2010	2.20	2010	227	1.05	0.04	2010	4.902	2010
2011	2.20	2011	227	1.05	0.04	2011	4.902	2011
2012	2.20	2012	227	1.05	0.04	2012	4.902	2012
2013	2.20	2013	227	1.05	0.04	2013	4.902	2013
2014	2.20	2014	227	1.05	0.04	2014	4.902	2014
2015	2.20	2015	227	1.05	0.04	2015	4.902	2015
2016	2.20	2016	227	1.05	0.04	2016	4.902	2016
2017	2.20	2017	227	1.05	0.04	2017	4.902	2017
2018	2.20	2018	227	1.05	0.04	2018	4.902	2018
2019	2.20	2019	227	1.05	0.04	2019	4.902	2019
2020	2.20	2020	227	1.05	0.04	2020	4.902	2020
2021	2.20	2021	227	1.05	0.04	2021	4.902	2021
2022	2.20	2022	227	1.05	0.04	2022	4.902	2022
2023	2.20	2023	227	1.05	0.04	2023	4.902	2023
2024	2.20	2024	227	1.05	0.04	2024	4.902	2024
2025	2.20	2025	227	1.05	0.04	2025	4.902	2025
2026	2.20	2026	227	1.05	0.04	2026	4.902	2026
2027	2.20	2027	227	1.05	0.04	2027	4.902	2027
2028	2.20	2028	227	1.05	0.04	2028	4.902	2028
2029	2.20	2029	227	1.05	0.04	2029	4.902	2029
2030	2.20	2030	227	1.05	0.04	2030	4.902	2030
2031	2.20	2031	227	1.05	0.04	2031	4.902	2031
2032	2.20	2032	227	1.05	0.04	2032	4.902	2032
2033	2.20	2033	227	1.05	0.04	2033	4.902	2033
2034	2.20	2034	227	1.05	0.04	2034	4.902	2034
2035	2.20	2035	227	1.05	0.04	2035	4.902	2035
2036	2.20	2036	227	1.05	0.04	2036	4.902	2036
2037	2.20	2037	227	1.05	0.04	2037	4.902	2037
2038	2.20	2038	227	1.05	0.04	2038	4.902	2038
2039	2.20	2039	227	1.05	0.04	2039	4.902	2039
2040	2.20	2040	227	1.05	0.04	2040	4.902	2040
2041	2.20	2041	227	1.05	0.04	2041	4.902	2041
2042	2.20	2042	227	1.05	0.04	2042	4.902	2042
2043	2.20	2043	227	1.05	0.04	2043	4.902	2043
2044	2.20	2044	227	1.05	0.04	2044	4.902	2044

Standards Case Weighted Average Energy/Water Use and Price - Front-Loading

	Energy Factor Standard		Annual Energy Use Electricity	Gas	Oil		Water Use Standard	
	kWh/yr		kWh/yr	*MMBTU/yr*	*MMBTU/yr*		*1000 gal/yr*	
2005	2.20	2005	227	1.05	0.04	2005	4.902	2005
2006	2.20	2006	227	1.05	0.04	2006	4.902	2006
2007	2.20	2007	227	1.05	0.04	2007	4.902	2007
2008	2.20	2008	227	1.05	0.04	2008	4.902	2008
2009	2.20	2009	227	1.05	0.04	2009	4.902	2009
2010	2.20	2010	227	1.05	0.04	2010	4.902	2010

2011	2.20	2011	227	1.05	0.04	2011	4.902	2011
2012	2.20	2012	227	1.05	0.04	2012	4.902	2012
2013	2.20	2013	227	1.05	0.04	2013	4.902	2013
2014	2.20	2014	227	1.05	0.04	2014	4.902	2014
2015	2.42	2015	222	0.99	0.04	2015	4.442	2015
2016	2.42	2016	221	0.99	0.04	2016	4.439	2016
2017	2.43	2017	221	0.99	0.04	2017	4.437	2017
2018	2.43	2018	221	0.99	0.04	2018	4.434	2018
2019	2.43	2019	221	0.99	0.04	2019	4.432	2019
2020	2.43	2020	221	0.99	0.04	2020	4.430	2020
2021	2.44	2021	221	0.99	0.04	2021	4.427	2021
2022	2.44	2022	221	0.99	0.04	2022	4.425	2022
2023	2.44	2023	221	0.99	0.04	2023	4.425	2023
2024	2.44	2024	221	0.99	0.04	2024	4.425	2024
2025	2.44	2025	221	0.99	0.04	2025	4.425	2025
2026	2.44	2026	221	0.99	0.04	2026	4.425	2026
2027	2.44	2027	221	0.99	0.04	2027	4.425	2027
2028	2.44	2028	221	0.99	0.04	2028	4.425	2028
2029	2.44	2029	221	0.99	0.04	2029	4.425	2029
2030	2.44	2030	221	0.99	0.04	2030	4.425	2030
2031	2.44	2031	221	0.99	0.04	2031	4.425	2031
2032	2.44	2032	221	0.99	0.04	2032	4.425	2032
2033	2.44	2033	221	0.99	0.04	2033	4.425	2033
2034	2.44	2034	221	0.99	0.04	2034	4.425	2034
2035	2.44	2035	221	0.99	0.04	2035	4.425	2035
2036	2.44	2036	221	0.99	0.04	2036	4.425	2036
2037	2.44	2037	221	0.99	0.04	2037	4.425	2037
2038	2.44	2038	221	0.99	0.04	2038	4.425	2038
2039	2.44	2039	221	0.99	0.04	2039	4.425	2039
2040	2.44	2040	221	0.99	0.04	2040	4.425	2040
2041	2.44	2041	221	0.99	0.04	2041	4.425	2041
2042	2.44	2042	221	0.99	0.04	2042	4.425	2042
2043	2.44	2043	221	0.99	0.04	2043	4.425	2043
2044	2.44	2044	221	0.99	0.04	2044	4.425	2044

National Impact Summary

		Front-Loading CW	Top-Loading CW	All Clothes-Washers	
Results presented for CSL					
Energy Saving (Cumulative to 2044)		-0.29	1.08	0.79	*quad*
Water Saving (Cumulative to 2044)		-0.03	4.28	4.25	*trillion gal.*
Energy Savings discounted at 7.0%		-0.07	0.27	0.20	*quad*
Water Savings discounted at 7.0%		0.00	1.07	1.06	*triillion gal.*
Discounted Incremental Equipment Cost	7%	8.92	-0.56	8.36	*billion $*
Discounted Oper. Cost Saving		-1.40	16.86	15.46	*billion $*
NPV (Cumulative to 2080)		-10.32	17.42	7.10	*billion $*
Market Share in 2015		60%	40%		
Market Share in 2030		62%	38%		

Front-Loading CSL CSL 6

Top-Loading CSL CSL 7

2015 Top-Loader Base Case MEF roll up to 1.72

● No ● Yes

WH Energy			Dryer Energy				
Elec	**Gas per cycle**	**Gas**	**Elec per cycle**	**Elec**	**Gas per cycle**	**Gas**	**Machine Energy**
kWh/yr	*MMBtu/cycle*	*MMBtu/yr*	*kWh/cycle*	*kWh/yr*	*MMBtu/cycle*	*MMBtu/yr*	*kWh/cycle*
67	0.003	0.482	1.11	131	0.004	0.75	0.113
67	0.003	0.482	1.11	131	0.004	0.75	0.113
67	0.003	0.482	1.11	131	0.004	0.75	0.113
58	0.002	0.421	1.11	131	0.004	0.75	0.113
40	0.002	0.286	1.23	145	0.005	0.83	0.163
36	0.002	0.262	1.16	137	0.004	0.79	0.154
22	0.001	0.158	1.24	146	0.005	0.84	0.164
22	0.001	0.156	1.21	143	0.005	0.82	0.167
13	0.001	0.095	1.04	122	0.004	0.70	0.173

WH Energy			Dryer Energy				
Elec	**Gas per cycle**	**Gas**	**Elec per cycle**	**Elec**	**Gas per cycle**	**Gas**	**Machine Energy**
kWh/yr	*MMBtu/cycle*	*MMBtu/yr*	*kWh/cycle*	*kWh/yr*	*MMBtu/cycle*	*MMBtu/yr*	*kWh/cycle*
95	0.004	0.687	1.52	179	0.006	1.02	0.28
70	0.003	0.504	1.72	203	0.007	1.16	0.28
42	0.002	0.299	1.56	184	0.006	1.05	0.23
97	0.004	0.700	1.31	154	0.005	0.88	0.08
97	0.004	0.700	1.31	154	0.005	0.88	0.08
97	0.004	0.700	1.31	154	0.005	0.88	0.08
81	0.003	0.582	1.29	152	0.005	0.87	0.08
58	0.002	0.416	1.32	156	0.005	0.89	0.08

Installed Price Standard		Hhld Income		TC/Income
$		*USD 2006*		
$1,074	2005	$47,820	2005	0.022
$1,074	2006	$48,049	2006	0.022
$1,074	2007	$48,279	2007	0.022
$1,074	2008	$48,510	2008	0.022
$1,074	2009	$48,742	2009	0.022
$1,074	2010	$48,976	2010	0.022
$1,074	2011	$49,210	2011	0.022
$1,074	2012	$49,445	2012	0.022
$1,074	2013	$49,682	2013	0.022
$1,074	2014	$49,920	2014	0.022
$1,074	2015	$50,159	2015	0.021
$1,074	2016	$50,399	2016	0.021
$1,074	2017	$50,640	2017	0.021
$1,074	2018	$50,882	2018	0.021
$1,074	2019	$51,126	2019	0.021
$1,074	2020	$51,370	2020	0.021
$1,074	2021	$51,616	2021	0.021
$1,074	2022	$51,863	2022	0.021
$1,074	2023	$52,111	2023	0.021
$1,074	2024	$52,361	2024	0.021
$1,074	2025	$52,611	2025	0.020
$1,074	2026	$52,863	2026	0.020
$1,074	2027	$53,116	2027	0.020
$1,074	2028	$53,370	2028	0.020
$1,074	2029	$53,626	2029	0.020
$1,074	2030	$53,882	2030	0.020
$1,074	2031	$54,140	2031	0.020
$1,074	2032	$54,399	2032	0.020
$1,074	2033	$54,659	2033	0.020
$1,074	2034	$54,921	2034	0.020
$1,074	2035	$55,184	2035	0.020
$1,074	2036	$55,448	2036	0.019
$1,074	2037	$55,713	2037	0.019
$1,074	2038	$55,980	2038	0.019
$1,074	2039	$56,248	2039	0.019
$1,074	2040	$56,517	2040	0.019
$1,074	2041	$56,787	2041	0.019
$1,074	2042	$56,787	2042	0.019
$1,074	2043	$56,787	2043	0.019
$1,074	2044	$56,787	2044	0.019

Price Standard		Hhld Income		TC/Income	RP Elast Drop
$		*USD 2006*			
$1,074	2005	$47,820	2005	0.022	2005
$1,074	2006	$48,049	2006	0.022	2006
$1,074	2007	$48,279	2007	0.022	2007
$1,074	2008	$48,510	2008	0.022	2008
$1,074	2009	$48,742	2009	0.022	2009
$1,074	2010	$48,976	2010	0.022	2010

$1,074	2011	$49,210	2011	0.022	2011	
$1,074	2012	$49,445	2012	0.022	2012	1.00
$1,074	2013	$49,682	2013	0.022	2013	1.00
$1,074	2014	$49,920	2014	0.022	2014	1.00
$1,107	2015	$50,159	2015	0.022	2015	0.78
$1,108	2016	$50,399	2016	0.022	2016	0.63
$1,108	2017	$50,640	2017	0.022	2017	0.54
$1,108	2018	$50,882	2018	0.022	2018	0.46
$1,109	2019	$51,126	2019	0.022	2019	0.44
$1,109	2020	$51,370	2020	0.022	2020	0.42
$1,109	2021	$51,616	2021	0.022	2021	0.39
$1,110	2022	$51,863	2022	0.021	2022	0.37
$1,110	2023	$52,111	2023	0.021	2023	0.35
$1,110	2024	$52,361	2024	0.021	2024	0.35
$1,110	2025	$52,611	2025	0.021	2025	0.35
$1,110	2026	$52,863	2026	0.021	2026	0.35
$1,110	2027	$53,116	2027	0.021	2027	0.34
$1,110	2028	$53,370	2028	0.021	2028	0.34
$1,110	2029	$53,626	2029	0.021	2029	0.34
$1,110	2030	$53,882	2030	0.021	2030	0.34
$1,110	2031	$54,140	2031	0.021	2031	0.34
$1,110	2032	$54,399	2032	0.020	2032	0.34
$1,110	2033	$54,659	2033	0.020	2033	0.33
$1,110	2034	$54,921	2034	0.020	2034	0.33
$1,110	2035	$55,184	2035	0.020	2035	0.33
$1,110	2036	$55,448	2036	0.020	2036	0.33
$1,110	2037	$55,713	2037	0.020	2037	0.33
$1,110	2038	$55,980	2038	0.020	2038	0.33
$1,110	2039	$56,248	2039	0.020	2039	0.33
$1,110	2040	$56,517	2040	0.020	2040	0.33
$1,110	2041	$56,787	2041	0.020	2041	0.33
$1,110	2042	$56,787	2042	0.020	2042	0.33
$1,110	2043	$56,787	2043	0.020	2043	0.33
$1,110	2044	$56,787	2044	0.020	2044	0.33

Assumptions:

Temp. Difference for Water Heating	70	*deg F*
Energy (kWh) needed to heat water	0.0024	*kWh/gal/deg F*

% of Units by Type of Water Heating		**Clothes Dryer Fuel Shares**	
Electric Water Heating	37%	Electric	40%
Gas Water Heating	59%	Gas	60%
Oil Water Heating	4%		

	elec	gas	oil
Recovery Efficiency of Electric Water Heaters	100%	75%	75%

				Annual Energy Use				
Machine Energy	**Standby**	**Standby Elec**	**Self-Cleaning Energy**	**Elec**	**Gas**	**Oil**	**Annual Water**	**Installed Price**
kWh/yr	watt/hr	kWh/yr	kWh/yr	kWh	MMBtu	MMBtu	1000 gal	
33.40	2.30	19.38	4.85	255.79	1.23	0.05	7.08	$1,040.68
33.40	1.70	14.32	4.85	250.74	1.23	0.04	6.64	$1,046.92
33.40	0.08	0.67	4.85	237.09	1.23	0.04	6.64	$1,042.55
33.40	0.08	0.67	4.85	228.58	1.17	0.04	6.64	$1,045.75
48.15	0.08	0.67	4.85	237.95	1.11	0.04	5.84	$1,050.55
45.33	0.08	0.67	4.85	224.34	1.05	0.04	4.53	$1,068.15
48.33	0.08	0.67	4.85	221.81	0.99	0.04	4.46	$1,104.96
49.21	0.08	0.67	4.85	219.10	0.97	0.04	4.30	$1,126.50
50.93	0.08	0.67	4.85	192.09	0.80	0.03	3.57	$1,157.77

				Annual Energy Use				
Machine Energy	**Standby**	**Standby Elec**	**Self-Cleaning Energy**	**Elec**	**Gas**	**Oil**	**Annual Water**	**Installed Price**
kWh/yr	watt/hr	kWh/yr	kWh/yr	kWh	MMBtu	MMBtu	1000 gal	
82.31	0.00	0.00	1.21	357.74	1.71	0.06	8.97	$499.51
82.90	0.00	0.00	1.21	357.31	1.67	0.06	9.81	$504.17
67.26	0.00	0.00	1.21	293.57	1.35	0.05	8.26	$512.14
24.19	2.30	19.38	1.21	296.09	1.58	0.05	8.63	$519.05
24.19	1.70	14.32	1.21	291.03	1.58	0.05	8.63	$524.92
24.19	0.08	0.67	1.21	277.38	1.58	0.05	8.63	$520.81
24.19	0.08	0.67	1.21	258.76	1.45	0.05	7.08	$537.35
22.72	0.08	0.67	1.21	237.96	1.31	0.04	5.42	$590.28

Base Case Weighted Average Energy/Water Use and Price - Top-Loading - Std Size

	Energy Factor Standard		Annual Energy Use Electricity	Gas	Oil		Water Use Standard	In
	kWh/yr		**kWh/yr**	*MMBTU/yr*	*MMBTU/yr*		*1000 gal/yr*	
2005	1.42	2005	345	1.7	0.1	2005	9.068	2005
2006	1.42	2006	345	1.7	0.1	2006	9.068	2006
2007	1.42	2007	345	1.7	0.1	2007	9.068	2007
2008	1.42	2008	345	1.7	0.1	2008	9.068	2008
2009	1.47	2009	345	1.6	0.1	2009	9.360	2009
2010	1.52	2010	338	1.6	0.1	2010	9.260	2010
2011	1.56	2011	328	1.6	0.1	2011	9.024	2011
2012	1.61	2012	318	1.5	0.1	2012	8.789	2012
2013	1.66	2013	309	1.5	0.1	2013	8.554	2013
2014	1.71	2014	299	1.4	0.1	2014	8.319	2014
2015	1.76	2015	289	1.4	0.1	2015	8.084	2015
2016	1.76	2016	289	1.4	0.1	2016	8.084	2016
2017	1.76	2017	289	1.4	0.1	2017	8.084	2017
2018	1.76	2018	289	1.4	0.1	2018	8.084	2018
2019	1.76	2019	289	1.4	0.1	2019	8.084	2019
2020	1.76	2020	289	1.4	0.1	2020	8.084	2020
2021	1.76	2021	289	1.4	0.1	2021	8.084	2021
2022	1.76	2022	289	1.4	0.1	2022	8.084	2022
2023	1.76	2023	289	1.4	0.1	2023	8.084	2023
2024	1.76	2024	289	1.4	0.1	2024	8.084	2024
2025	1.76	2025	289	1.4	0.1	2025	8.084	2025
2026	1.76	2026	289	1.4	0.1	2026	8.084	2026
2027	1.76	2027	289	1.4	0.1	2027	8.084	2027
2028	1.76	2028	289	1.4	0.1	2028	8.084	2028
2029	1.76	2029	289	1.4	0.1	2029	8.084	2029
2030	1.76	2030	289	1.4	0.1	2030	8.084	2030
2031	1.76	2031	289	1.4	0.1	2031	8.084	2031
2032	1.76	2032	289	1.4	0.1	2032	8.084	2032
2033	1.76	2033	289	1.4	0.1	2033	8.084	2033
2034	1.76	2034	289	1.4	0.1	2034	8.084	2034
2035	1.76	2035	289	1.4	0.1	2035	8.084	2035
2036	1.76	2036	289	1.4	0.1	2036	8.084	2036
2037	1.76	2037	289	1.4	0.1	2037	8.084	2037
2038	1.76	2038	289	1.4	0.1	2038	8.084	2038
2039	1.76	2039	289	1.4	0.1	2039	8.084	2039
2040	1.76	2040	289	1.4	0.1	2040	8.084	2040
2041	1.76	2041	289	1.4	0.1	2041	8.084	2041
2042	1.76	2042	289	1.4	0.1	2042	8.084	2042
2043	1.76	2043	289	1.4	0.1	2043	8.084	2043
2044	1.76	2044	289	1.4	0.1	2044	8.084	2044

Standards Case Weighted Average Energy/Water Use and Price - Top-Loading - Std size

	Energy Factor Standard		Annual Energy Use Electricity	Gas	Oil		Water Use Standard	
	kWh/yr		kWh/yr	*MMBTU/yr*	*MMBTU/yr*		*1000 gal/yr*	
2005	1.42	2005	345	1.65	0.06	2005	9.068	2005
2006	1.42	2006	345	1.65	0.06	2006	9.068	2006
2007	1.42	2007	345	1.65	0.06	2007	9.068	2007
2008	1.42	2008	345	1.65	0.06	2008	9.068	2008
2009	1.47	2009	345	1.64	0.06	2009	9.360	2009
2010	1.52	2010	338	1.60	0.06	2010	9.260	2010

2011	1.56	2011	328	1.55	0.06	2011	9.024	2011
2012	1.61	2012	318	1.50	0.06	2012	8.789	2012
2013	1.66	2013	309	1.45	0.05	2013	8.554	2013
2014	1.71	2014	299	1.41	0.05	2014	8.319	2014
2015	2.26	2015	238	1.31	0.04	2015	5.419	2015
2016	2.26	2016	238	1.31	0.04	2016	5.419	2016
2017	2.26	2017	238	1.31	0.04	2017	5.419	2017
2018	2.26	2018	238	1.31	0.04	2018	5.419	2018
2019	2.26	2019	238	1.31	0.04	2019	5.419	2019
2020	2.26	2020	238	1.31	0.04	2020	5.419	2020
2021	2.26	2021	238	1.31	0.04	2021	5.419	2021
2022	2.26	2022	238	1.31	0.04	2022	5.419	2022
2023	2.26	2023	238	1.31	0.04	2023	5.419	2023
2024	2.26	2024	238	1.31	0.04	2024	5.419	2024
2025	2.26	2025	238	1.31	0.04	2025	5.419	2025
2026	2.26	2026	238	1.31	0.04	2026	5.419	2026
2027	2.26	2027	238	1.31	0.04	2027	5.419	2027
2028	2.26	2028	238	1.31	0.04	2028	5.419	2028
2029	2.26	2029	238	1.31	0.04	2029	5.419	2029
2030	2.26	2030	238	1.31	0.04	2030	5.419	2030
2031	2.26	2031	238	1.31	0.04	2031	5.419	2031
2032	2.26	2032	238	1.31	0.04	2032	5.419	2032
2033	2.26	2033	238	1.31	0.04	2033	5.419	2033
2034	2.26	2034	238	1.31	0.04	2034	5.419	2034
2035	2.26	2035	238	1.31	0.04	2035	5.419	2035
2036	2.26	2036	238	1.31	0.04	2036	5.419	2036
2037	2.26	2037	238	1.31	0.04	2037	5.419	2037
2038	2.26	2038	238	1.31	0.04	2038	5.419	2038
2039	2.26	2039	238	1.31	0.04	2039	5.419	2039
2040	2.26	2040	238	1.31	0.04	2040	5.419	2040
2041	2.26	2041	238	1.31	0.04	2041	5.419	2041
2042	2.26	2042	238	1.31	0.04	2042	5.419	2042
2043	2.26	2043	238	1.31	0.04	2043	5.419	2043
2044	2.26	2044	238	1.31	0.04	2044	5.419	2044

nstalled Price Standard		Hhld Income		TC/Income
$		USD 2006		
$508	2005	$47,820	2005	0.011
$508	2006	$48,049	2006	0.011
$508	2007	$48,279	2007	0.011
$508	2008	$48,510	2008	0.011
$510	2009	$48,742	2009	0.011
$511	2010	$48,976	2010	0.010
$512	2011	$49,210	2011	0.010
$513	2012	$49,445	2012	0.010
$515	2013	$49,682	2013	0.010
$516	2014	$49,920	2014	0.010
$517	2015	$50,159	2015	0.010
$517	2016	$50,399	2016	0.010
$517	2017	$50,640	2017	0.010
$517	2018	$50,882	2018	0.010
$517	2019	$51,126	2019	0.010
$517	2020	$51,370	2020	0.010
$517	2021	$51,616	2021	0.010
$517	2022	$51,863	2022	0.010
$517	2023	$52,111	2023	0.010
$517	2024	$52,361	2024	0.010
$517	2025	$52,611	2025	0.010
$517	2026	$52,863	2026	0.010
$517	2027	$53,116	2027	0.010
$517	2028	$53,370	2028	0.010
$517	2029	$53,626	2029	0.010
$517	2030	$53,882	2030	0.010
$517	2031	$54,140	2031	0.010
$517	2032	$54,399	2032	0.010
$517	2033	$54,659	2033	0.010
$517	2034	$54,921	2034	0.009
$517	2035	$55,184	2035	0.009
$517	2036	$55,448	2036	0.009
$517	2037	$55,713	2037	0.009
$517	2038	$55,980	2038	0.009
$517	2039	$56,248	2039	0.009
$517	2040	$56,517	2040	0.009
$517	2041	$56,787	2041	0.009
$517	2042	$56,787	2042	0.009
$517	2043	$56,787	2043	0.009
$517	2044	$56,787	2044	0.009

Base Case	Weighted TC
2005	0.013
2006	0.014
2007	0.015
2008	0.015
2009	0.016
2010	0.016
2011	0.016
2012	0.016
2013	0.016
2014	0.016
2015	0.016
2016	0.016
2017	0.016
2018	0.016
2019	0.016
2020	0.016
2021	0.016
2022	0.016
2023	0.016
2024	0.016
2025	0.016
2026	0.016
2027	0.016
2028	0.016
2029	0.016
2030	0.015
2031	0.015
2032	0.015
2033	0.015
2034	0.015
2035	0.015
2036	0.015
2037	0.015
2038	0.015
2039	0.015
2040	0.015
2041	0.015
2042	0.015
2043	0.015
2044	0.015

Price Standard		Hhld Income		TC/Income		RP Elast Drop
$		USD 2006				
$508	2005	$47,820	2005	0.011	2005	
$508	2006	$48,049	2006	0.011	2006	
$508	2007	$48,279	2007	0.011	2007	
$508	2008	$48,510	2008	0.011	2008	
$510	2009	$48,742	2009	0.011	2009	
$511	2010	$48,976	2010	0.011	2010	

	Weighted TC
2005	0.013
2006	0.014
2007	0.015
2008	0.015
2009	0.016
2010	0.016

$512	2011	$49,210	2011	0.010	2011		2011	0.016
$513	2012	$49,445	2012	0.010	2012	1.00	2012	0.016
$515	2013	$49,682	2013	0.010	2013	1.00	2013	0.016
$516	2014	$49,920	2014	0.010	2014	1.00	2014	0.016
$590	2015	$50,159	2015	0.012	2015	0.78	2015	0.017
$590	2016	$50,399	2016	0.012	2016	0.63	2016	0.017
$590	2017	$50,640	2017	0.012	2017	0.54	2017	0.017
$590	2018	$50,882	2018	0.012	2018	0.46	2018	0.017
$590	2019	$51,126	2019	0.012	2019	0.44	2019	0.017
$590	2020	$51,370	2020	0.012	2020	0.42	2020	0.017
$590	2021	$51,616	2021	0.011	2021	0.39	2021	0.017
$590	2022	$51,863	2022	0.011	2022	0.37	2022	0.017
$590	2023	$52,111	2023	0.011	2023	0.35	2023	0.017
$590	2024	$52,361	2024	0.011	2024	0.35	2024	0.017
$590	2025	$52,611	2025	0.011	2025	0.35	2025	0.017
$590	2026	$52,863	2026	0.011	2026	0.35	2026	0.017
$590	2027	$53,116	2027	0.011	2027	0.34	2027	0.017
$590	2028	$53,370	2028	0.011	2028	0.34	2028	0.017
$590	2029	$53,626	2029	0.011	2029	0.34	2029	0.016
$590	2030	$53,882	2030	0.011	2030	0.34	2030	0.016
$590	2031	$54,140	2031	0.011	2031	0.34	2031	0.016
$590	2032	$54,399	2032	0.011	2032	0.34	2032	0.016
$590	2033	$54,659	2033	0.011	2033	0.33	2033	0.016
$590	2034	$54,921	2034	0.011	2034	0.33	2034	0.016
$590	2035	$55,184	2035	0.011	2035	0.33	2035	0.016
$590	2036	$55,448	2036	0.011	2036	0.33	2036	0.016
$590	2037	$55,713	2037	0.011	2037	0.33	2037	0.016
$590	2038	$55,980	2038	0.011	2038	0.33	2038	0.016
$590	2039	$56,248	2039	0.011	2039	0.33	2039	0.016
$590	2040	$56,517	2040	0.011	2040	0.33	2040	0.016
$590	2041	$56,787	2041	0.010	2041	0.33	2041	0.016
$590	2042	$56,787	2042	0.010	2042	0.33	2042	0.016
$590	2043	$56,787	2043	0.010	2043	0.33	2043	0.016
$590	2044	$56,787	2044	0.010	2044	0.33	2044	0.016

ABOUT COTATI

The City of Cotati is located 45 miles north of San Francisco in Sonoma County, California. The Water and Sewer Division serves 7,500 citizens in 2,000 homes. Residential water use accounts for over half of the city's total annual consumption. Cotati promotes the wise use of water resources by offering several conservation programs, partnerships, and rebates.

A COMMON PROBLEM

Like many municipalities, Cotati was faced with a mandate to reduce residential demand, but they had little engagement with existing programs, and even less internal resources to work on the problem.

About WaterSmart Software

WaterSmart Software helps water utilities make it easier for their customers to save water and money. Our software and services educate users about their household water use, comparison to others, and how to save. Incremental gains in water efficiency at the residential level translate into significant system-wide savings for WaterSmart's utility partners.

For more information, contact us at www.watersmartsoftware.com

5% Reduction in Residential Water Demand in 6 Months

The WaterSmart Solution

WaterSmart delivered Home Water Reports and provided access to the Consumer Web Portal to half the households in the Cotati service area. The other half of the service area remained the control group. WaterSmart delivered the first Home Water Reports in September 2011 and sent bi-monthly reports thereafter.

> *"WaterSmart's solution enables us to have sustained, personalized communications with our customers. The Home Water Reports generated a measurable increase in interest in the City's water conservation programs. We now have consumption, real estate and program participation information in one place, so we can make more intelligent, cost-effective choices."*
>
> ***-- Damien O'Bid, Director of Public Works / Engineering***

Results

5% Residential Water Demand Reduction

Households that received Home Water Reports and access to the Consumer Portal reduced their water use by over 5% compared to the control group. Approximately 70% of participating homes reduced their water use, and the average home saved 10 gallons per day.

> *"I always read the Home Water Reports. I requested a home water survey and upgraded our showerheads. I always try to see if we can beat our water use from the previous month."*
>
> ***-- C.T., Cotati Resident***

3x Increase in Program Participation

WaterSmart increased participation in rebate programs by targeting households with personalized water savings suggestions. Households that received Home Water Reports requested 3x as many water audits from the City of Cotati compared with those that did not.

14% Increase in Online Engagement

Our Home Water Reports drive engagement to our Consumer Web Portal where users can find simple-to-understand water use information, interactive graphs, rebate programs and water efficiency tips. In the first year, there was a 14% increase in online engagement.

2011 Water Supply Evaluation

A Risk-Based Approach To Evaluating Zone 7 Water Agency's Water Supply System

July 2011

Zone 7 Water Agency

Mission Statement

Zone 7 Water Agency is committed to providing a reliable supply of high quality water and an effective flood control system to the Livermore-Amador Valley. In fulfilling our present and future commitments to the community, we will develop and manage the water resources in a fiscally responsible, innovative, proactive and environmentally sensitive way.

2011 WATER SUPPLY EVALUATION

A RISK-BASED APPROACH TO EVALUATING ZONE 7 WATER AGENCY'S WATER SUPPLY SYSTEM

Zone 7 Water Agency

100 North Canyons Parkway

Livermore, CA 94551

(925) 454-5000

Version: July 2011

ZONE 7 WATER AGENCY

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Appendix A. Indoor/Outdoor Analysis

Appendix B. Key Policies

Appendix C. Key Supporting Information for Water Quality

Appendix D. Cost Estimates

Appendix E. Comprehensive List of Water Supply Options

Appendix F. Key Supporting Storage and Facility Outage Figures

Appendix G. Recycled Water Supply Estimates

Appendix H. Application for CEQA Exemption

ACRONYMS AND DEFINITIONS

The following terms and acronyms have been used throughout this Water Supply Evaluation to improve document clarity and readability.

ACWD	Alameda County Water District
AF	Acre-Feet
AFA	Acre-Feet Annually
APL	Altamont Pipeline
ASR	Aquifer Storage Recovery
AWTP	Altamont Water Treatment Plant
B.O.	Biological Opinion
BARDP	Bay Area Regional Desalination Project
BBID	Byron-Bethany Irrigation District
BDCP	Bay Delta Conservation Plan
Board	Zone 7 Board of Directors
Cal Water	California Water Service Company
CalSIM	California Statewide Integrated Model
Cawelo	Cawelo Water District
CCWD	Contra Costa Water District
CEQA	California Environmental Quality Act
CFS	Cubic Feet Per Second
CIP	Capital Improvement Program
Conservation Act	Water Conservation Act of 2009 (SBX 7-7 or 20 by 2020)
DAF	Dissolved Air Flotation
Delta	Sacramento-San Joaquin Delta
DHA	Dublin Housing Authority
DHCCP	Delta Habitat Conservation and Conveyance Plan
District	Alameda County Flood Protection and Water Conservation District
DSRSD	Dublin San Ramon Services District
DSS	Decision Support System
DVWTP	Del Valle Water Treatment Plant
DWR	Department of Water Resources
EBMUD	East Bay Municipal Utility District

EBRPD	East Bay Regional Parks District
EIR	Environmental Impact Report
EIS	Environmental Impact Study
Eto	Evapotranspiration
ExtendSIM	Extended Simulation Model
GIS	Geographic Information System
GPCD	Gallons Per Capita Per Day
GPQ	Groundwater Pumping Quota
GUI	Graphic User Interface
GWMP	Groundwater Management Plan
LARPD	Livermore Area Recreation and Parks District
Livermore	City of Livermore
LLNL	Lawrence-Livermore National Laboratory
M&I	Municipal and Industrial
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
Mg/L	Milligrams per Liter
MGD	Million Gallons Per Day
MGDP	Mocho Groundwater Demineralizaton Plant
Msl	Mean sea level
O&M	Operation and Maintenance
PHG	Public Health Goal
Pleasanton	City of Pleasanton
PPWTP	Patterson Pass Water Treatment Plant
Retailers	Cal Water, DSRSD, Livermore, Pleasanton or local water supply retailers
RO	Reverse Osmosis
RWQCB	Regional Water Quality Control Board
SBA	South Bay Aqueduct
SBPP	South Bay Pumping Plant
SCVWD	Santa Clara Valley Water District
SEI	Stockholm Environment Institute
Semitropic	Semitropic Water Storage District

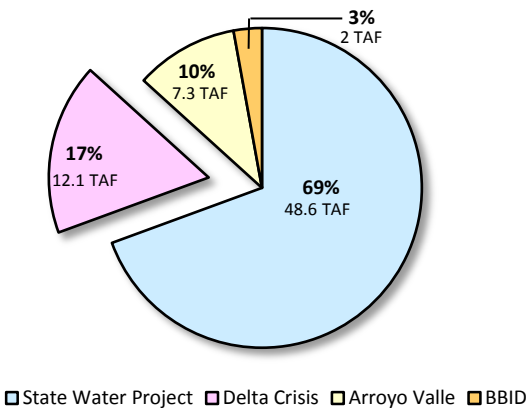
SFPUC	San Francisco Public Utilities Commission
SLR	San Luis Reservoir
SMP	Salt Management Plan
SWAN	Statewide Water Analysis Network
SWP	State Water Project
TAF	Thousand Acre-Feet
TDS	Total Dissolved Solids
UAFW	Unaccounted-For Water
UF	Ultrafiltration
VA	Veterans Association
Valley	Livermore-Amador Valley
WEAP	Water Evaluating and Planning
WQMP	Water Quality Management Program
WSE	Water Supply Evaluation
Yuba Accord	Lower Yuba River Accord
Zone 7	Zone 7 Water Agency

EXECUTIVE SUMMARY

PURPOSE AND OBJECTIVES

Over the past few decades, Zone 7 Water Agency (Zone 7) has developed a robust system that provides a reliable and sustainable treated and untreated water supply for the Livermore-Amador Valley (Valley). However, 80% of Zone 7's long-term average water supply – State Water Project (SWP) water – is currently subject to a very uncertain future due to legal and environmental constraints in the Sacramento-San Joaquin Delta (Delta). In fact, over the past few years, Zone 7's long-term average yield from the SWP has been reduced by over 12 thousand acre-feet (TAF), or about 17% of total supplies.

Figure ES-1. Water Supply Reduced from SWP



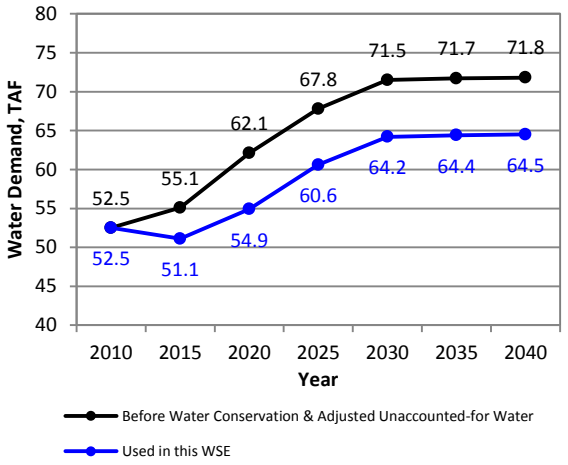
Consequently, Zone 7 staff developed a probability-based water supply model to help assess near-term and long-term risks of a water supply shortage. A preliminary analysis completed in November 2009 indicated that the chance of water supply shortages increased dramatically beyond 2015 as projected water demands began to exceed long-term average water supplies sometime between 2015 and 2020.[1] In light of this analysis, Zone 7 completed this Water Supply Evaluation (WSE) to help identify operational improvements and additional studies that will minimize near-term risks of water supply shortages and maximize long-term flexibility by evaluating potential new supply sources.

Due to the future uncertainty of the Delta, Zone 7 staff also evaluated the ability of various mixes of water supplies to meet different reliability targets to facilitate future discussions with the Zone 7 Board of Directors.

PROJECTED WATER DEMANDS

Zone 7 staff – in close coordination with its four Retailers – developed projected water demands for the Valley through buildout of adopted general plans. Zone 7 staff also estimated potential Valley-wide water conservation requirements associated with the Water Conservation Act of 2009 (Conservation Act), which was approximately 6 TAF. Of this amount, Zone 7 staff assumed that approximately 4 TAF was associated with traditional conservation measures (e.g., low-flow toilets) and that about 2 TAF was associated with additional recycled water. The demand projections also assume that Zone 7 can reduce its unaccounted-for water by approximately 1.3 TAF.

Figure ES-2. Projected Zone 7 Water Demands[2]



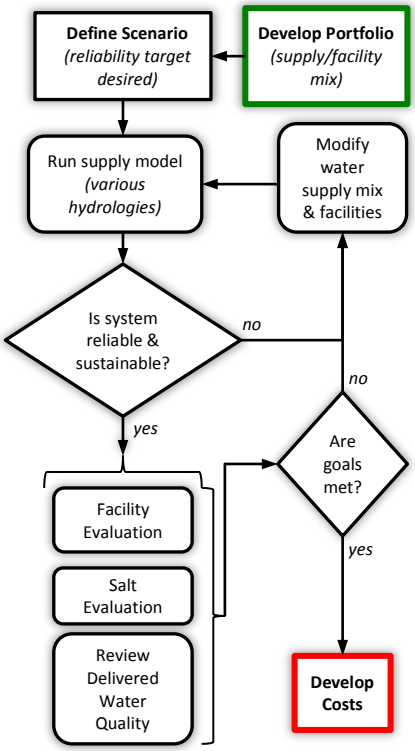
[1] Zone 7 Water Agency, 2009. Interoffice Memo – Water Supply Update. November 18.

[2] Figure ES-2 does not include additional demands associated with storage and demineralization losses, or artificial recharge.

METHODOLOGY FOR EVALUATION

Zone 7 staff considered water supply, facility needs, salt balance, and delivered water quality while evaluating the Current Plan and two backup portfolios under various scenarios (see Figure ES-3). Portfolios are mixes of different water supplies and facilities, while scenarios refer to different reliability targets.

Figure ES-3. Methodology



Water Supply Methodology

Zone 7 used Microsoft Excel, along with Frontline System's Risk Solver, to develop a new water balance model. Unlike typical water balance models, key water supplies were modeled as uncertain variables – their value was determined through Monte Carlo methods.

Climate Change

The SWP provides Zone 7 over 80% of its long-term average water supplies; hence, climate changes that reduce SWP allocations likely dominate the potential impacts of climate change on Zone 7's overall water supplies. Consequently, this analysis used DWR projections of SWP allocations that incorporated climate change.[3]

Definition of Reliability and Sustainability

Zone 7 staff used two criteria to evaluate the effectiveness of various water supply portfolios: reliability and sustainability. Zone 7 defined reliability based on the maximum shortage possible, but for completeness, also provided two additional pieces of information based on a risk curve developed for each scenario: (1) a mid-point shortage and (2) the percent of time no shortages are expected.

Zone 7 staff used the term sustainability to describe the trend of median storage levels. A decreasing median storage level would indicate that a particular water supply portfolio is relying on drought and emergency storage during normal hydrologic conditions, ultimately an unsustainable condition.

Water Facility Methodology

The portfolios involved different water supplies that drove facility needs. Therefore, Zone 7 staff compared and recommended facility production capacities necessary to meet current policies—both peak day and outage scenarios.

Salt Balance Methodology

One of Zone 7's goals is to balance long-term salt loading and removal within the Main Basin. Different water supply sources have different water quality characteristics, which could change salt loading. Consequently, Zone 7 staff conducted a preliminary analysis using updated salt balance models previously developed as part of the original Salt Management Plan (SMP). However, Zone 7 staff is recommending further evaluation as part of the planned Groundwater Management Plan update, which will include an SMP Update.

Delivered Water Quality Methodology

Zone 7 staff completed a qualitative review to determine potential positive or negative water quality impacts on Zone 7's system using the goals established in Zone 7's Water Quality Management Plan.

Cost Estimating Methodology

Zone 7 staff divided portfolio costs for each scenario evaluated into three categories: (1) water supplies, (2) water facilities, and (3) water quality. This allowed for a more refined comparison of portfolio and scenario costs.

[3] Allocations based on DWR's 2009 Reliability Report for the SWP.

EVALUATION OF THE CURRENT PLAN

The Current Plan assumes that the State of California implements a Delta Fix that restores the reliability of the SWP and that Zone 7 successfully implements its existing Capital Improvement Program (CIP). This portfolio also assumes Zone 7 can reduce unaccounted-for water, reduce demineralization losses, confirm the minimum yield of the Byron Bethany Irrigation District (BBID) contract, implement an enhanced in-lieu recharge program, and perfect its existing local water right permit.

Delta Fix Assumptions

The following assumptions for a fix in the Delta were used to evaluate the Current Plan:

- Long-term Average Yield: 75% of Table A
- Water Quality: ~20% Avg. Reduction in TDS
- Online between 2020 & 2030: assumed 2025
- Cost: $12 Billion ($140 Million to Zone 7)

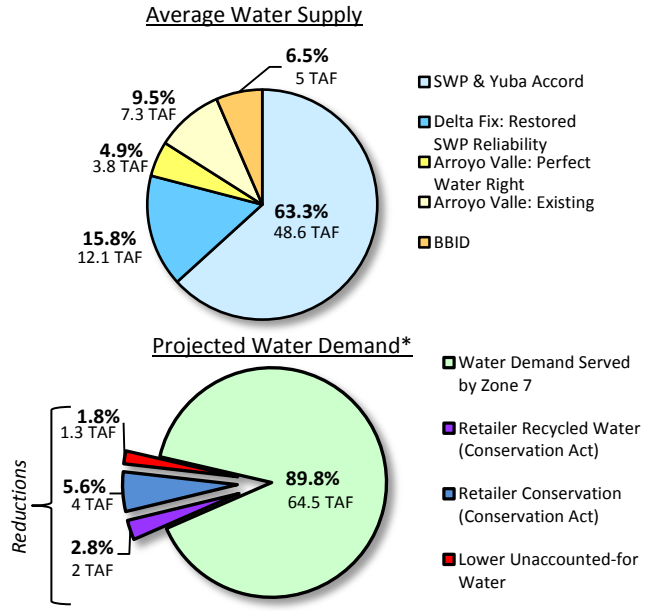
Reliability: 85 to 99%

Based on the analysis completed, Zone 7 staff found that the Current Plan provides a minimum reliability of 85%. More specifically, there is a less than 1% chance of a shortage larger than 15%, there is only about a 2% chance of a 10% shortage, and there will not likely be any shortages 96% of the time. Storage levels were found to be sustainable. Zone 7 staff identified two options for increasing reliability above 85%: (1) Chain of Lakes (COL) pipeline and (2) spot-market water for drought.

Facilities, Salt Balance, and Water Quality

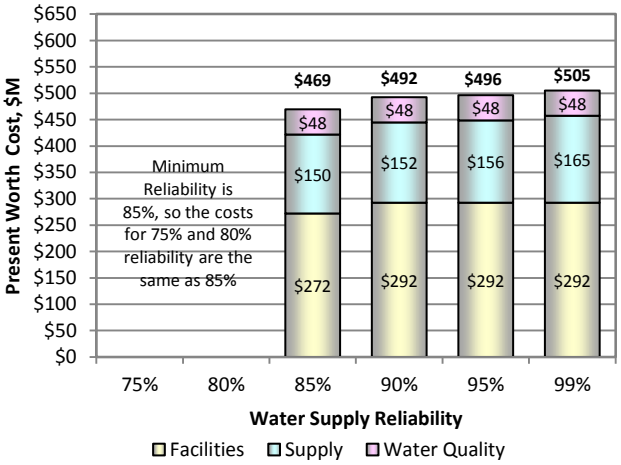
The current facility policies can be met once new treated-water capacity (~20 MGD by 2023) was constructed to meet maximum day demand. However, the construction schedule of new capacity influences the ability to meet facility outages. At least one more phase of demineralization is required to achieve salt balance, but staff recommends further evaluation as part of the GWMP/SMP Update. No potential negative delivered water quality impacts were identified as long as the Delta Fix reduces average TDS concentrations by ~20%.

Figure ES-4. Supply & Demand Mix: Current Plan



** Demands in this figure do not include water supply required for groundwater recharge or storage losses.*

Figure ES-5. Estimated Costs: Current Plan



Current Plan Results

- Minimum reliability is 85%
- COL Pipeline & Spot Market water required to increase reliability above 85%
- Still requires additional surface water treatment plant capacity: 20 MGD by 2023
- Still requires Well Master Plan wells & Chain of Lakes recharge
- With additional demineralization, no water quality impacts identified *(requires verification)*
- Cost Increase from 85 to 99%: < 10% *($469 to $505M)*

POTENTIAL BACKUP SUPPLY SOURCES

Starting in early 2010, Zone 7 staff began developing a comprehensive list of potential water supply options to help create backup portfolios in case the Current Plan assumptions change. The options ranged from the obvious to the unlikely, but the entire list was vetted internally, with the Retailers, and with the Zone 7 Board of Directors. Based on input received, Zone 7 staff then screened the options to develop two backup portfolios.

Supply Options Divided into Categories

For comparative purposes, the original 24 water supply options identified were divided into six different categories:

- Increased yield from existing supplies,
- New or additional water supplies,
- Stormwater runoff and rainfall capture,
- Recycled water,
- Desalination and demineralization, and
- Operational improvements.

The supply options ranged from simple operational improvements (e.g., reducing unaccounted-for water) to complex multi-partner arrangements (e.g., regional desalination).

Supply Options Screened Down to 12

Zone 7 staff then screened the 24 water supply options based on potential water supply yield, the associated technical and institutional barriers, and any unique contributions any particular supply added to Zone 7's water system. The remaining 12 water supply options (see Table ES-1) were then used to create two backup portfolios to augment the Current Plan.

Two Backup Portfolios: In-Valley and Intertie

The first backup portfolio focused only on those local supply options available to the Livermore-Amador Valley and eliminated imported sources; this group of supplies was called the "In-Valley" Portfolio. The second backup portfolio focused on the lowest unit cost options that also provided the highest water quality benefit; this option was called the "Intertie" Portfolio.

Table ES-1. Options Used to Develop Portfolios

Option	Average Yield, acre-feet annually	Amortized Cost, $/acre-foot[a]
Arroyo Valle – Perfection of Existing Permit	3,800	$20
Reduce Mocho Demineralization Losses	260	$30
Reduce Unaccounted-for Water Losses	1,300	$100
Enhance Existing In-Lieu Recharge	500 to 830	$110
Arroyo Las Positas Water Rights	750	$200
Arroyo Mocho Water Rights	900	$200
Confirm BBID Yield	3,000	$285
Intertie Supply: Long-term Leases	up to 10,900	$1,400
Recycled Water – Direct	up to 3,700	$1,500
Groundwater Injection: Recycled Water	2,800	$1,600
Intertie Supply: Regional Desalination	up to 9,300	$2,000
Recycled Water - Storage	up to 17,300	$2,400

[a] Based on 2010 ENR SF CCI. Amortized costs assume a 6% interest rate for 30 years.

In-Valley Portfolio: This portfolio focused mainly on recycled water supplies and acquisition of other local water rights.

Intertie Portfolio: This portfolio focused mainly on the lowest unit cost and highest quality water supplies.

EVALUATION OF BACKUP PORTFOLIO: IN-VALLEY

The In-Valley Portfolio assumes Zone 7 is able to work with the Retailers to develop new recycled water supplies. This portfolio also assumes acquisition of additional local water rights.

In-Valley Portfolio Assumptions

The following assumptions were used to evaluate the In-Valley Portfolio:

- Assumes SWP Yield: 60% of Table A Amount
- Potable demand reduction is available
- Recycled Supply Sources: Dublin San Ramon Services District (DSRSD), Livermore, and Pleasanton

Reliability: 75 to 99%

Based on the analysis completed, Zone 7 staff found that the In-Valley Portfolio could provide reliabilities ranging from 75 to 99% while also maintaining sustainable storage levels. The additional recycled water required, beyond existing programs and assumed conservation, ranges from 1,000 to 5,600 AF, and must be online by 2025.

Key Issue: Salt Balance

Based on the preliminary salt balance analysis, only a portion of the additional recycled water can be applied over the Main Basin without triggering more than one additional phase of demineralization. Zone 7 staff recommends re-evaluating as part of the GWMP/SMP Update.

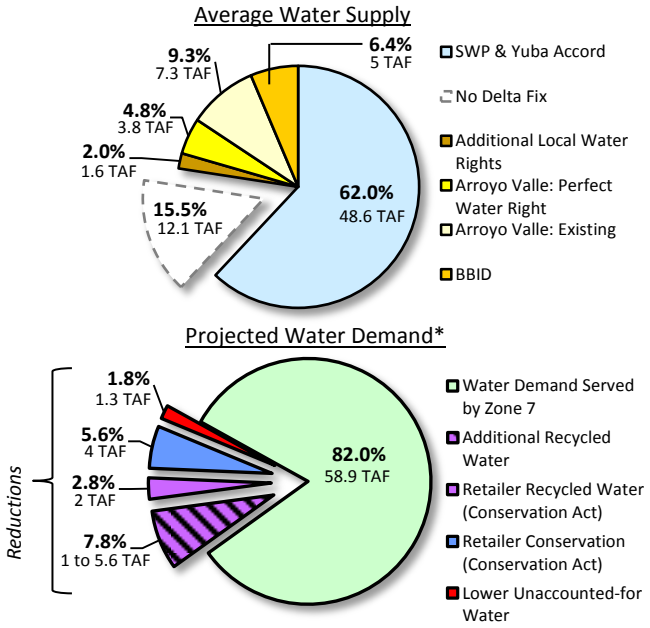
Key Issue: Potable Demand Reduction Required

The analysis in this WSE identified the potable demand reduction required. Zone 7 staff strongly recommends that the Retailers and Zone 7 work together to verify costs and potential recycled water demands in a separate study.

Facilities and Water Quality

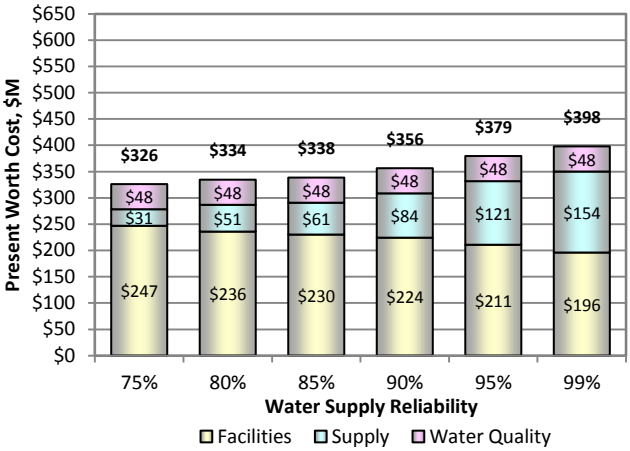
Zone 7 found that the current facility policies could be met by providing enough treated-water capacity (~7 to 15 MGD by 2024 to 2030) to meet maximum day demand. No potential negative delivered water quality impacts were identified as long as the amount of recycled water applied over the Main Basin is limited.

Figure ES-6. Supply & Demand Mix: In-Valley



** Demands in this figure do not include water supply required for groundwater recharge or storage losses.*

Figure ES-7. Estimated Costs: In-Valley



Backup Portfolio Results: In-Valley

- Minimum reliability is 75%
- Still requires additional surface water treatment plant capacity: 7 to 15 MGD between 2024 and 2030
- Still requires Well Master Plan wells & Chain of Lakes recharge
- With additional demineralization, no water quality impacts were identified *(requires verification)*
- Cost Increase from 75 to 99%: ~ 20% *($326 to $398M)*

EVALUATION OF BACKUP PORTFOLIO: INTERTIE

The Intertie Portfolio assumes Zone 7 constructs a new intertie with another water agency (e.g., EBMUD or SFPUC) and wheels new high quality water supply into Zone 7's water system. The Intertie Portfolio also assumes Zone 7 acquires additional local water rights.

Intertie Portfolio Assumptions

The following assumptions were used to evaluate the Intertie Portfolio:

- Assumes SWP Yield: 60 percent
- Water Quality Similar to EBMUD supply
- No added capacity for meeting peak demands

Reliability: 90 to 99%

If Zone 7 acquired at least 5,100 AF of normal/wet year supply, then the Intertie Portfolio provided a minimum reliability of 90%. Dry year supply needs were up to 5,600 AF depending on the reliability target evaluated. The new supplies would need to be online between 2020 and 2030. The analysis indicated that long-term storage levels were unsustainable if new normal/wet year water supplies were not continued beyond 2038.

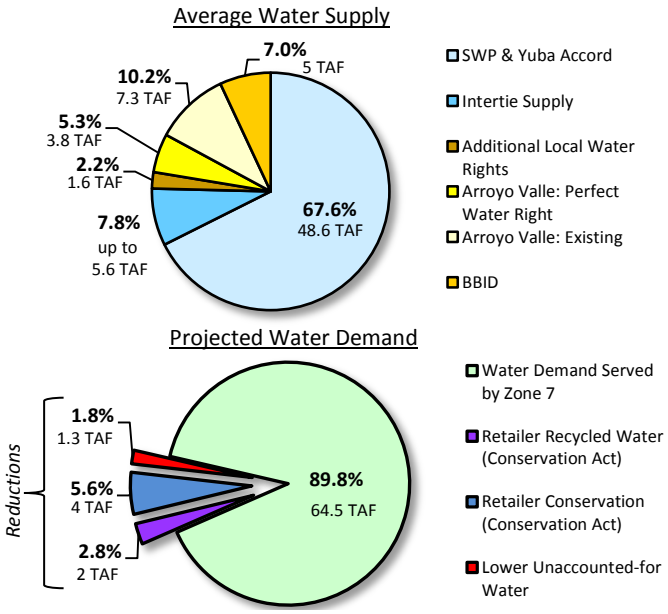
Key Issue: Uncertainty of Supply Source

Preliminary discussions with EBMUD staff indicate that normal/wet year water cannot be wheeled to Zone 7 via EBMUD's Freeport project because it is only used during dry years. Additional discussions with EBMUD indicate that there are no normal/wet year water supplies available in the Mokelumne watershed, and due to source water constraints, EBMUD may not currently have a source of supply they can use to participate in a groundwater-banking program with Zone 7. The most likely source of normal/wet year water is regional desalination *(requires additional study)*.

Facilities, Salt Balance, and Water Quality

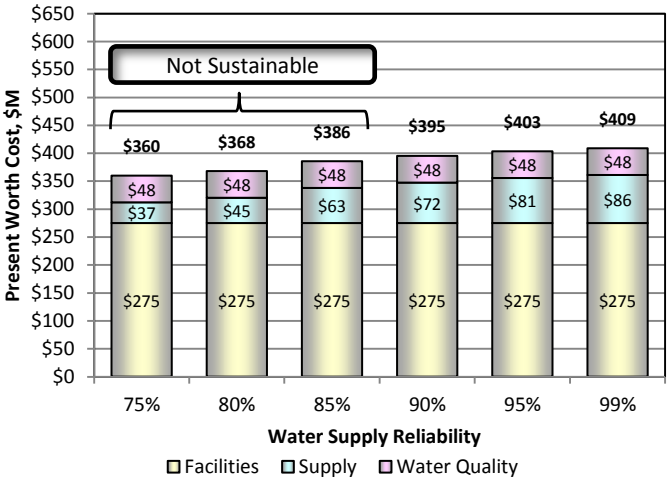
The analysis completed for the Intertie Portfolio yielded similar results to the Current Plan: (1) ~20 MGD of additional treated-water capacity by 2023, (2) Zone 7 staff recommends verifying salt balance results as part of the GWMP/SMP Update, and (3) no potential negative delivered water quality impacts were identified.

Figure ES-8. Supply & Demand Mix: Intertie



** Demands do not include water supply required for groundwater recharge or storage losses.*

Figure ES-9. Estimated Costs: Intertie



Backup Portfolio Results: Intertie

- Minimum reliability to achieve sustainability is 90%
- Still requires additional surface water treatment plant capacity: 20 MGD by 2023
- Still requires Well Master Plan wells & Chain of Lakes recharge
- No water quality impacts anticipated
- Cost Increase from 75 to 99%: ~ 14% *($360 to $409M)*

RECOMMENDED NEAR-TERM ACTIONS

Based on the analysis completed as part of this WSE, Zone 7 staff recommends a series of "no regret" actions that will help minimize near-term risks of water supply shortages, and several additional studies necessary to confirm key assumptions made for both the In-Valley and Intertie Portfolios. Figure ES-11 provides a preliminary schedule for key actions and studies.

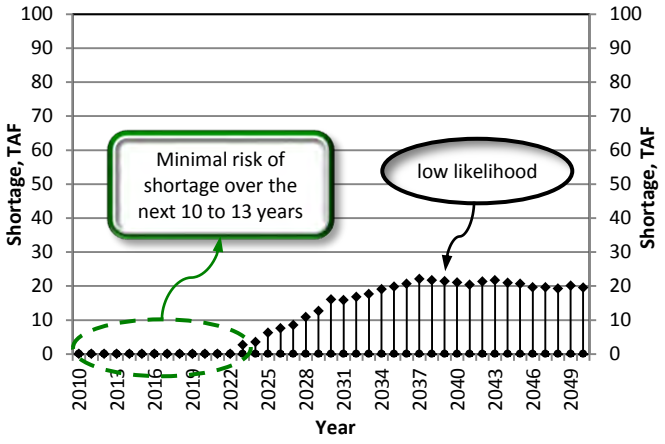
"No Regret" Actions

All of the following activities are lowest-cost alternatives and within local control (i.e., either Zone 7 or the Retailers):

- Reducing Unaccounted-for Water,
- Minimizing demineralization brine losses,
- Confirming available supply under existing contract with BBID,
- Enhancing existing in-lieu recharge program,
- Continued support of the Conservation Act,
- Working with Retailers to develop a water conservation tracking methodology, and
- Continuing to implement the Well Master Plan and Chain of Lakes projects.

These no regret actions will help Zone 7 minimize the risk of shortages larger than 1% for the next 10 to 13 years, until completion of a major new water supply project, which can take over 10 years to complete.

Figure ES-10. Benefits of No Regret Actions



Recommended Studies: Current Plan

The key to improving reliability under the Current Plan is to work with the other SWP contractors and other stakeholders to increase the reliability of the SWP; consequently, Zone 7 staff recommends continued participation in any studies and other efforts potentially leading toward increased reliability of the SWP and sustainability of the Delta.

Recommended Studies: In-Valley Portfolio

Zone 7 and the Retailers may need to develop as much as 7,600 AF of additional recycled water supply—above the 5,900 AF already planned by the Retailers—to meet various reliability targets under the In-Valley Portfolio. This is a significant amount of recycled water; Zone 7 staff therefore recommends:

- Refining potential water quality assumptions as part of the GWMP/SMP update,
- Identifying or linking feasible potable demand reduction using recycled water irrigation, and
- Identifying feasible recycled water storage options – both local and non-local.

Recommended Studies: Intertie Portfolio

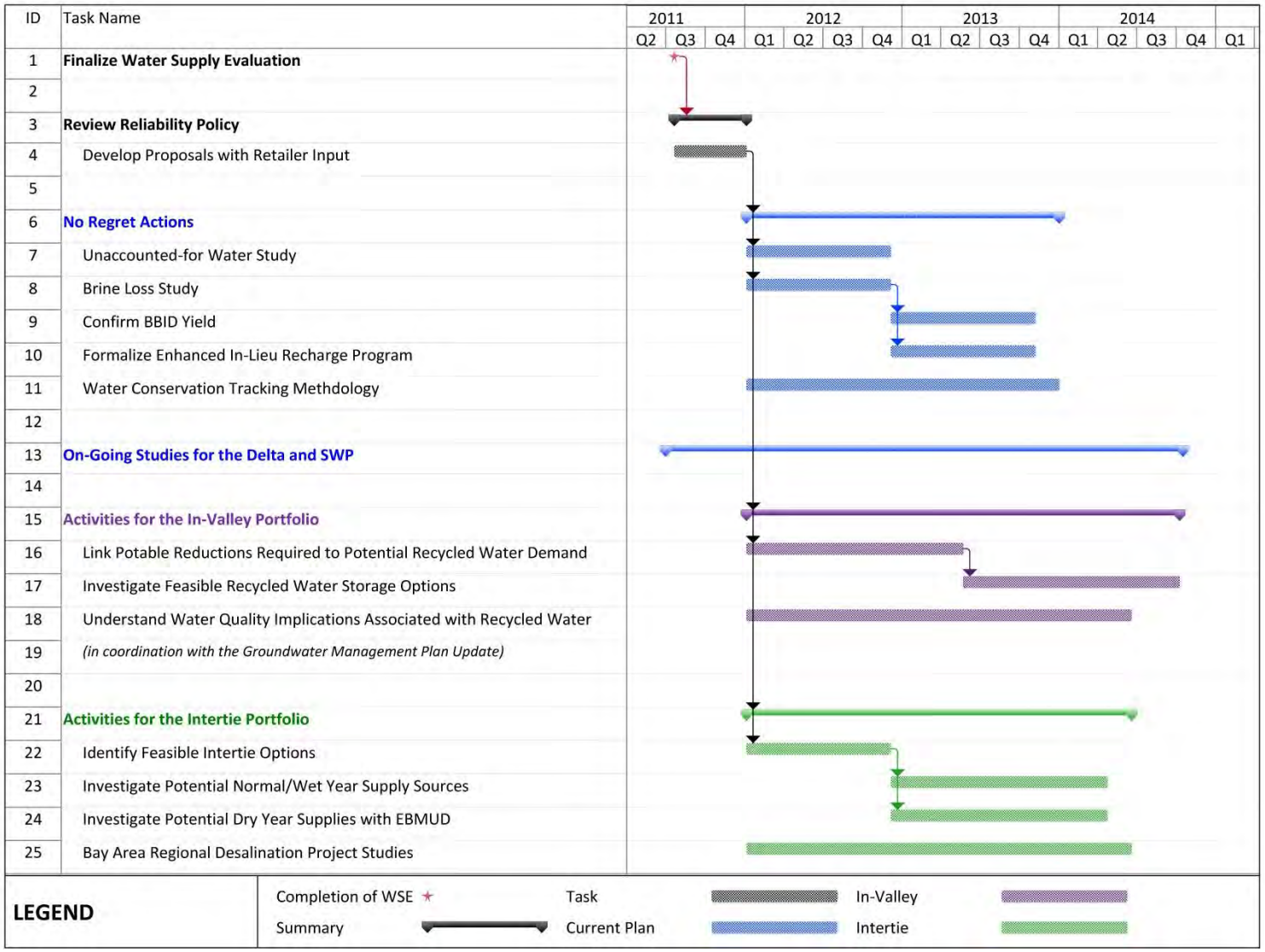
The water supply yields and costs for each potential supply source under the Intertie Portfolio are still uncertain at this time; consequently, Zone 7 staff recommends:

- Identifying feasible options for a new intertie with another water agency,
- Continuing to participate in studies for the Bay Area Regional Desalination Project, and
- Confirming available water supplies.

Recommend Reviewing Reliability Policy

This analysis indicated that costs and individual portfolios are not strong drivers, but that other factors (e.g., demand hardening and uncertainty) could drive changes in the reliability policy. Zone 7 staff recommends working with the Retailers to develop several proposals for changing the existing reliability policy for the Zone 7's Board of Directors to consider.

Figure ES-11. Measures of Success: Preliminary Schedule of Next Steps



1. PURPOSE AND OBJECTIVES

Over the past few decades, Zone 7 Water Agency (Zone 7) has developed a robust water supply system that allowed Zone 7 to store excess water in the wet years and draw on these reserves during dry years to provide a reliable and sustainable water supply for the Livermore-Amador Valley (Valley). However, approximately 80% of Zone 7's water supply is Table A water purchased from the Department of Water Resources (DWR) – the reliability of Table A water is subject to a very uncertain future due to legal and environmental constraints in the Sacramento-San Joaquin Delta.

In response to this challenge, Zone 7 staff developed a probability-based water supply model that uses Monte Carlo methods to help assess near-term and long-term risks of water supply shortages within its water supply system. In November 2009, Zone 7 staff completed a preliminary evaluation of the existing system. This analysis indicated that the reliability of Zone 7's existing water supply system (both supplies and drought storage combined) could decrease from 100 percent to approximately 97 percent in the next five years, 91 percent in the next 10 years, and to 65 percent over the next 20 years.[4] The risk and magnitude of potential shortages increased dramatically beyond 2015 as projected demands exceeded long-term average supplies, and the likelihood of having sufficient stored water during drought periods was significantly lower.[4]

In light of these results, Zone 7 completed this Water Supply Evaluation (WSE) to:

(1) Develop a diverse set of water supply options and corresponding portfolios to help identify supplemental studies necessary to assist Zone 7 in refining associated yields and limits,

(2) Evaluate the ability for various water supply portfolios to meet future reliability targets, and

(3) Identify low-cost, zero-impact actions that will minimize near-term risks of water supply shortages, while maximizing flexibility.

This WSE presents the work plan that outlines minor operational improvements and additional studies necessary to minimize risk until more is known regarding a Delta fix and does not layout a roadmap of major water supply acquisitions and facility improvements over the next 30 years. Therefore, this WSE is not a master planning document that provides a "blueprint" for major water supply investments. Many of the portfolios still have supply ranges and costs that require further analysis before an actual project or program can be developed. Consequently, based on an initial evaluation completed by Zone 7 environmental staff,[5] Zone 7 filed an exemption to the California Environmental Quality Act (CEQA) for this WSE.

[4] Zone 7 Water Agency, 2009. Interoffice Memo – Water Supply Update. November 18.

[5] Appendix H provides the CEQA exemption filed.

2. DESCRIPTION OF ZONE 7 WATER AGENCY AND ITS SERVICE AREA

Zone 7 Water Agency (Zone 7) is a public agency that supplies water, manages the local groundwater basin, and provides flood control services for the Livermore-Amador Valley. This section provides an overview of the history and primary functions of Zone 7, along with a description of the area served.

2.1 ZONE 7 WATER AGENCY: HISTORY AND PRIMARY FUNCTION

The Alameda County Flood Control and Water Conservation District (District) was created in 1949 by the California State Legislature to provide control of flood and storm waters and to conserve water for beneficial uses in ten zones in Alameda County. The District is also vested with the power to store water in surface or underground reservoirs within or outside of the District for the common benefit of the District; conserve and reclaim water for present and future use within the District; appropriate and acquire water and water rights; and import water into the District.

The District is further authorized by the District Act to prevent interference with or diminution of, or to declare rights, in the natural flow of any stream or surface or subterranean supply of waters used or useful for any purpose of the District. Additionally, the District has the authority to prevent contamination that would render surface or subsurface water unfit for beneficial use in the District and to levy replenishment assessments upon the production of groundwater from all water-producing facilities, whether public or private, within the District.

In the mid-1950s, the Livermore-Amador Valley—designated as Zone 7 of the District—was primarily rural in character, with a population of approximately 30,000 people. The area faced a number of problems, including groundwater overdraft, poor drainage and flood hazards, and uncertainty over the status of future water supplies. It was against this backdrop that the residents of the Livermore-Amador Valley voted, in 1957, to create Zone 7 as a separate agency governed by a seven-member board of directors (Zone 7 Board). Each director is elected at-large by residents within Zone 7's service area to a four-year term. The Zone 7 Board sets policy and provides direction to agency management and staff.

In 2003, the legislature passed Assembly Bill 1125 and gave the Zone 7 Board full authority and autonomy to govern matters solely affecting Zone 7 independently of the District's governing body, the Alameda County Board of Supervisors, which governs the other nine zones of the District.

2.1.1 Key Management and Administrative Activities

Zone 7's key functions include:

- providing treated and untreated water supply;
- monitoring and protecting surface water and groundwater quality;
- operating and maintaining a water treatment and transmission system; and
- managing regional flood and storm water for public safety and protection of property.

Under Zone 7's Groundwater Management Program, Zone 7 also administers oversight of the local groundwater basin, the Livermore Valley Groundwater Basin, and prevents groundwater overdraft. The Main Basin is the portion of the Livermore Valley Groundwater Basin that contains high-yielding aquifers and good quality groundwater. Within this capacity, Zone 7 monitors groundwater extractions and imports water to both artificially recharge the Main Basin (thereby supplementing natural recharge) and

to provide water to Retailers and other users (thereby reducing pumping demands on the Main Basin). Zone 7's groundwater management policies and programs are described in the Groundwater Management Plan[6]. Every year Zone 7 completes an annual report for its Groundwater Management Program. The most recent report was completed in May 2010 for the 2009 water year[7].

2.1.2 Wholesale Water Supply

This Water Supply Evaluation (WSE) focuses on Zone 7's key function as a water wholesaler for the Livermore-Amador Valley, also known as the Tri-Valley Area[8]. Zone 7 supplies untreated water for agriculture and golf courses, and treated drinking water to four retail water supply agencies (Retailers):

- California Water Service Company (Cal Water),
- Dublin San Ramon Services District (DSRSD),
- City of Livermore (Livermore), and
- City of Pleasanton (Pleasanton).

These Retailers deliver water for municipal and industrial (M&I) purposes within their individual service areas. While the Retailers represent most of the demand on Zone 7's system, Zone 7 does also sell treated water directly to several commercial/institutional customers.[9]

2.2 SERVICE AREA

Zone 7's water service area is located about 40 miles south-east of San Francisco, and encompasses an area of approximately 425 square miles of the eastern portion of Alameda County, including the Livermore-Amador Valley, Sunol Valley, and portions of the Diablo Range. Zone 7's service area also overlies the Alameda Creek Watershed. This watershed encompasses almost 700 square miles, and extends from Altamont Pass to the east, San Francisco Bay to the west, Mount Diablo to the north, and Mount Hamilton to the south. Figure 2-1 illustrates the location of Zone 7's service area.

2.2.1 Major Streams and Arroyos in the Service Area

Major streams in Zone 7's service area include the Arroyo del Valle, Arroyo Mocho, Arroyo Las Positas, Alamo Canal, South San Ramon Creek, and Tassajara Creek (see Figure 2-1). Both the Arroyo del Valle and Arroyo Mocho originate in the woodland forests of the Burnt Hills region in Santa Clara County, in the sub-watershed above Lake Del Valle. The Arroyo del Valle and Arroyo Mocho have the largest drainage areas within the Zone 7 service area.

The Arroyo del Valle flows into Lake Del Valle above Lang Canyon, and then continues its journey below the Del Valle Dam and flows westerly through a regional park on the southern border of Livermore and reaches Pleasanton. The Arroyo del Valle then flows southwesterly through the historical downtown area of Pleasanton and joins the Arroyo de la Laguna. It is used by Zone 7 for groundwater recharge.

The Arroyo Mocho remains a natural waterway as it flows southwest through the oak woodlands east of Livermore, and then flows through the southern portion of Livermore; from there, it becomes an improved channel and proceeds through the gravel mining area west of Livermore and meets the Arroyo

[6] Jones and Stokes, 2005. Groundwater Management Plan for the Livermore-Amador Valley Groundwater Basin.

[7] Zone 7 Water Agency, 2010. Annual Report for the Groundwater Management Program: 2009 Water Year.

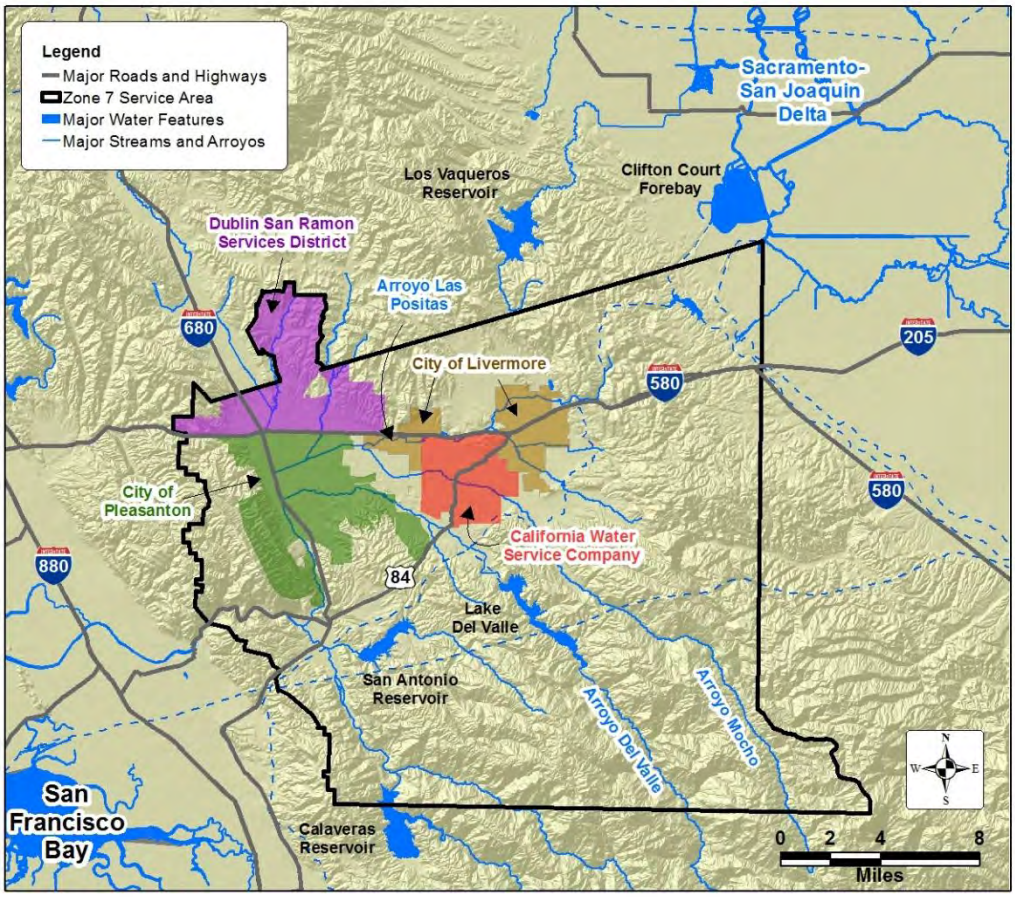
[8] The Tri-Valley Area includes the City of Dublin, City of Livermore, City of Pleasanton, and part of the City of San Ramon.

[9] These customers are described in more detail in Section 3.

Las Positas in Pleasanton. This stream is also a major component of Zone 7's groundwater recharge program. At the request of Zone 7, the Department of Water Resources (DWR) releases water into both Arroyo Mocho and Arroyo del Valle for groundwater recharge purposes that also provide secondary aesthetic and environmental benefits.

The Arroyo Las Positas mainly flows westerly along I-580, and is fed by the Arroyo Seco, Altamont Creek, Cayetano Creek, Collier Canyon Creek, and Cottonwood Creek. In northeast Pleasanton, the Arroyo Las Positas joins the Arroyo Mocho, where the streambed becomes a wide, trapezoidal-shaped flood control channel. The Arroyo Mocho then flows into the Arroyo de la Laguna, which is a tributary of Alameda Creek.

Figure 2-1. Location of Service Area and Major Streams and Arroyos



2.3 EXISTING WATER USE SECTORS

Zone 7's service area is home to a diverse, vibrant, and rapidly growing community that supports a population of approximately 220,000 people and a myriad of vital and dynamic commercial, agricultural, and industrial enterprises. The eastern reaches of Zone 7's service area include oil wells and acres of energy generating windmills, while other areas include large employers such as AT&T, Oracle, Providian Financial, SAP, and Lawrence Livermore National Laboratory. This area also supports a number of award-winning wineries. Examples of industrial water users include: Applied Biosystems (biotech), Clorox

Services Company (chemical company), Roche Molecular Systems (medical research and development), and A-1 Enterprise (waste hauler).

As discussed previously, Zone 7 provides wholesale treated water to the Retailers, who use this water for M&I purposes within their service areas; through this arrangement, Zone 7 indirectly serves approximately 66,000 residential, commercial, industrial, institutional, and landscape water use accounts. Two of the Retailers—DSRSD and Livermore—also provide recycled water for landscape irrigation to supplement treated water supply. In addition to supplying treated water, Zone 7 also supplies raw or untreated water to agricultural uses and golf courses in the service area; agricultural uses primarily consist of vineyards in the southern portion of the Livermore Valley, but also produces olives, pistachios, and prime beef.

As shown in Table 2-1, water accounts within Zone 7's service area are primarily residential (90%).[10]

Table 2-1. 2009 Accounts by Water Use Sectors Directly and Indirectly Served by Zone 7[(a)]

Water Use Sector	Accounts	% of Total
Single-Family Residential	57,198	86%
Multi-Family Residential	2,327	4%
Commercial/Institutional	3,807	6%
Industrial	175	0.3%
Landscape	1,844	3%
Agriculture	14	0.02%
Other	868	1%
Total	66,233	100%

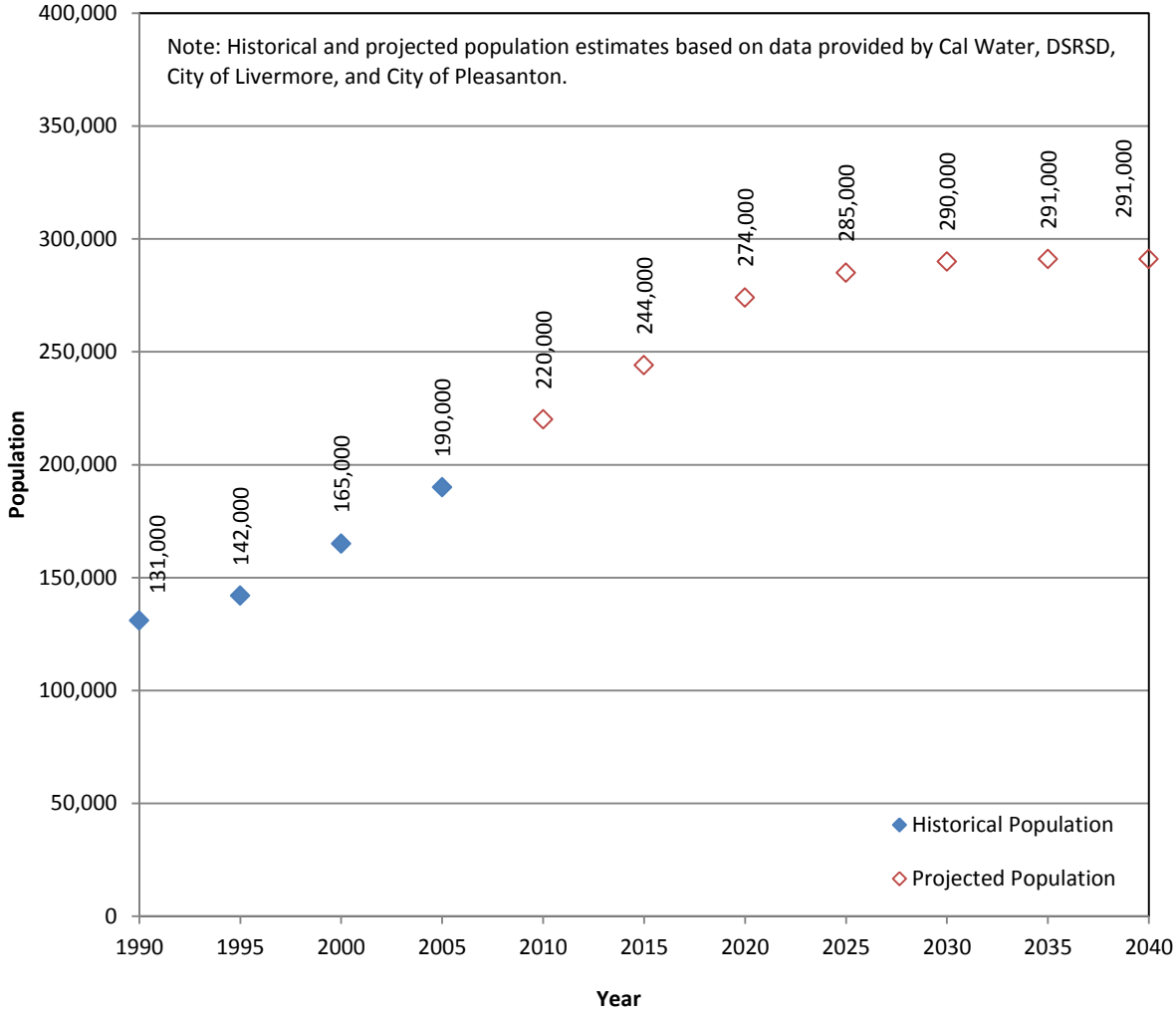
[(a)] Based on data provided by the Retailers and data from Zone 7's annual water supply reports. These values do not include recycled water, but do include untreated surface water provided to agriculture.

2.4 POPULATION GROWTH

As shown on Figure 2-2, the population within Zone 7's service area increased 65% between 1990 and 2009, and is projected to grow by another 35% by 2040, from 216,000 in 2009 to 291,000; a majority of the projected growth occurs within the next 10 years.

[10] Water demands in the service area are discussed in detail in Section 3.

Figure 2-2. Historical and Projected Population within Zone 7's Service Area

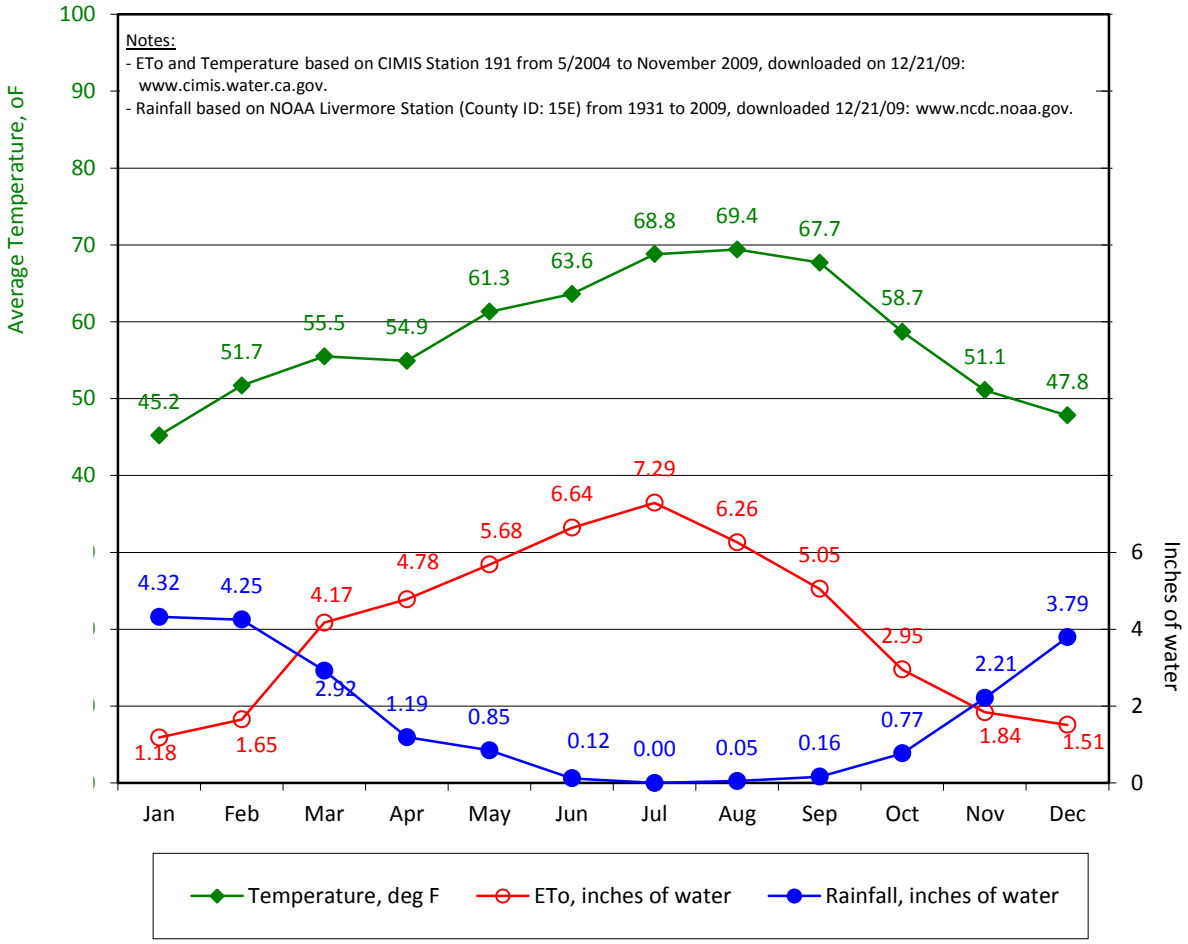


2.5 CLIMATE

The climate within Zone 7's service area is best described as Mediterranean, characterized by hot, dry summers and cool, moist winters. Figure 2-3 provides data for average temperatures, rainfall, and evapotranspiration rates (ETo)[11] within Zone 7's service area over the year. Average annual precipitation is approximately 14.6 inches of water, while total evapotranspiration is approximately 49 inches of water; average monthly temperatures vary from 45 to 69 degrees Fahrenheit throughout the year.

[11] Evapotranspiration based on standard grass as reference.

Figure 2-3. Climate Data for the Zone 7 Service Area



3. HISTORICAL AND PROJECTED WATER DEMANDS

The purpose of this section is to describe the historical and projected water demands used for the analysis completed in this Water Supply Evaluation (WSE), including assumptions regarding water conservation and other forms of demand reduction, for Zone 7 Water Agency (Zone 7).

3.1 HISTORICAL WATER DEMANDS SERVED BY ZONE 7

Historically, treated water provided to water supply retailers (California Water Service Company [Cal Water], Dublin San Ramon Services District [DSRSD], City of Livermore [Livermore], and City of Pleasanton [Pleasanton]; collectively referred to as the "Retailers") have represented nearly 90% of the demand on Zone 7's water supply system. Raw or untreated water served to agricultural customers make up most of the remaining 8-10% of demand; treated water served directly to retail commercial/institutional customers represents a minor fraction. Water losses through Zone 7's treated water transmission system also exert a small but significant demand (2-4%) on Zone 7's water supplies; these system losses are referred to as "unaccounted-for water".

Table 3-1 presents historical water demands met by Zone 7 within its service area between 1990 and 2009. As shown, water use currently served by Zone 7 has approximately doubled since the early 1990s. A majority of this increase is associated with water served to the Retailers. Table 3-1 also indicates that unaccounted-for water increased by 1,000 to 2,000 acre-feet (AF) after 2003; potential reasons for this increase are discussed in Section 3.3.4. Including water pumped directly by three of the four retailers from the Main Basin as part of their groundwater pumping quotas (GPQs), the total demand in the Livermore-Amador Valley has averaged approximately 44,000 and 53,000 acre-feet annually (AFA) over the last 20 and last 5 years, respectively.[12]

Table 3-2 presents the historical Municipal and Industrial (M&I) per capita demand served by Zone 7 and the Retailers (includes all groundwater pumping). M&I demand is derived by subtracting untreated surface water demand from the total water demand listed in Table 3-1. As shown in Table 3-2, per capita demands have stayed above the historical average of 213 gallons per capita per day (gpcd) over the last ten years; however, more recently, there has been a downward trend and the five-year average of 215 gpcd is now very close to the historical average.[13]

Figure 3-1 compares historical M&I per capita demand to precipitation, which is used as an inverse indicator of outdoor water demands. As shown, the demand pattern is generally responsive to the pattern of precipitation: that is, with an increasing rainfall trend, there is a decreasing trend in water demand.

[12] Note that recycled water used for irrigation is not included in these demands; recycled water is discussed in Section 6.2.2.

[13] As discussed in Section 6.21, future reduction of daily per capita consumption has been mandated statewide by state legislation passed in 2009.

Table 3-1. Historical Water Demand in the Zone 7 Service Area, acre-feet

Year	Total Municipal and Industrial Water Use Served by Zone 7				Untreated Water for Agriculture[d]	Total Demand on Zone 7	Retailer Pumping (GPQs)	Total Water Demand
	Retailers[a]	Zone 7 Retail[b]	UAFW[c]	Total				
1990	23,869	1,070	1,876	26,815	3,170	29,985	5,882	35,867
1991	14,831	500	754	16,085	1,845	17,930	9,730	27,660
1992	20,714	1,010	1	21,725	2,344	24,069	6,447	30,516
1993	23,926	1,200	59	25,185	1,782	26,967	4,146	31,113
1994	22,734	680	691	24,105	1,985	26,090	6,598	32,688
1995	28,519	1,190	316	30,025	3,481	33,506	1,819	35,325
1996	29,901	790	4	30,695	4,329	35,024	2,920	37,944
1997	28,802	780	63	29,645	6,287	35,932	7,602	43,534
1998	26,640	510	5	27,155	4,370	31,525	7,573	39,098
1999	32,292	240	3	32,535	5,607	38,142	6,934	45,076
2000	34,632	270	423	35,325	5,899	41,224	6,826	48,050
2001	36,601	320	24	36,945	4,845	41,790	7,237	49,027
2002	38,176	260	4	38,440	3,523	41,963	6,981	48,944
2003	38,169	370	1,321	39,860	3,359	43,219	6,911	50,130
2004	42,371	770	819	43,960	3,422	47,382	6,573	53,955
2005	38,912	282	1,676	40,870	3,309	44,179	6,583	50,762
2006	40,414	316	1,064	41,794	3,488	45,282	6,581	51,863
2007	43,132	312	1,940	45,384	3,642	49,026	6,434	55,461
2008	42,982	270	1,649	44,901	4,164	49,065	6,026	55,091
2009	38,083	233	1,900	40,216	4,920	45,136	6,569	51,705
Historical Average	32,285	569	730	33,583	3,789	37,372	6,319	43,691
10-Year Average	39,347	340	1,082	40,770	4,057	44,827	6,672	51,499
5-Year Average	40,700	300	1,600	42,600	3,900	46,500	6,400	53,000

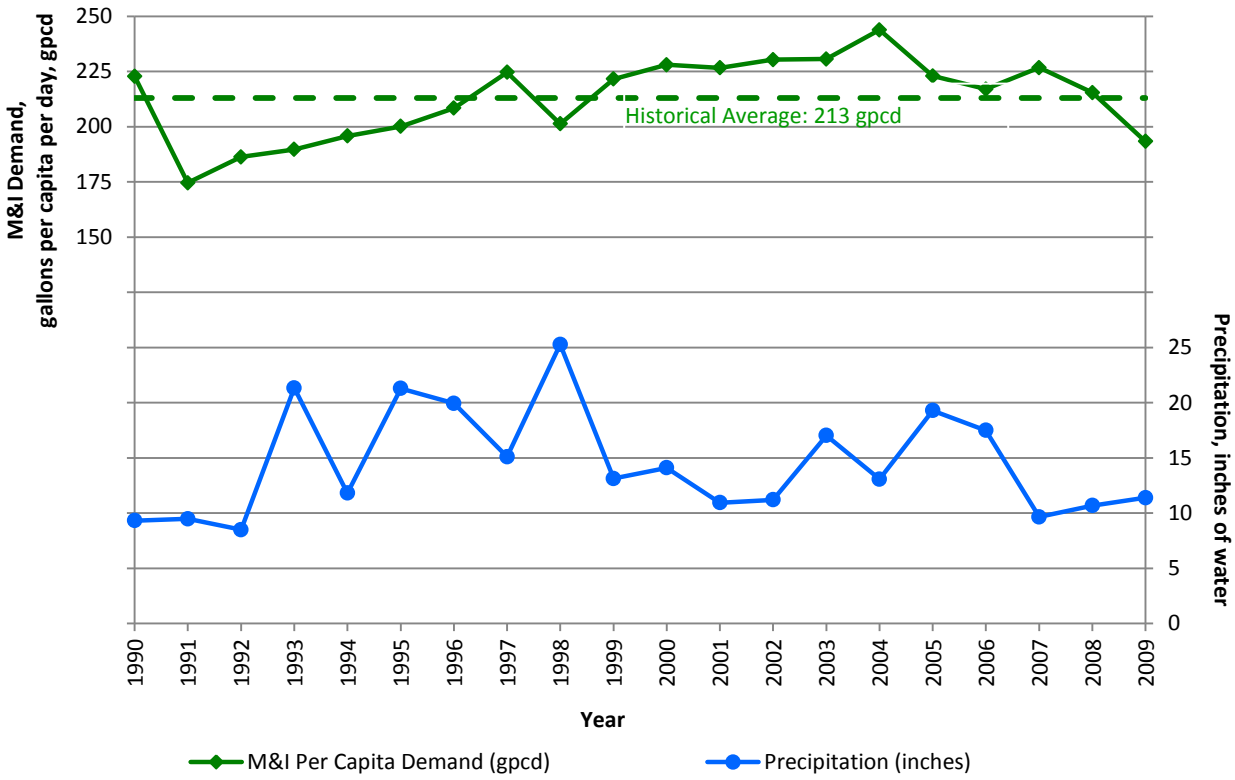
[a] Data collected from the Retailers and from the Zone 7 Annual Supply Reports (WR OM1 and WR OM3). Includes groundwater pumping quota for DSRSD (but not for the other retailers).
[b] Zone 7 directly serves six customers with potable water - data based on historical records.
[c] Unaccounted-for water (UAFW) is based on the difference between total production and actual deliveries. Production is water purchased from the State Water Project plus Zone 7 groundwater pumping minus brine concentrate losses (beginning in 2009 when the demineralization facility started operating).
[d] Zone 7 serves 74 customers through 7 accounts with untreated surface water.

Table 3-2. Historical M&I Per Capita Water Demands in the Zone 7 Service Area

Year	Total Water Demand in the Service Area, gallons per day[a]	Total Municipal and Industrial (M&I) Demand in the Service Area, gallons per day[b]	Total Population[c]	M&I Per Capita Demand, gpcd	Precipitation, inches[d]
1990	32,018,113	29,188,313	131,000	223	9
1991	24,692,006	23,045,009	132,000	175	9
1992	27,240,758	25,148,312	135,000	186	8
1993	27,774,133	26,183,375	138,000	190	21
1994	29,180,194	27,408,221	140,000	196	12
1995	31,533,975	28,426,551	142,000	200	21
1996	33,871,819	30,007,400	144,000	208	20
1997	38,862,055	33,249,766	148,000	225	15
1998	34,902,155	31,001,137	154,000	201	25
1999	40,238,273	35,233,007	159,000	222	13
2000	42,893,609	37,627,680	165,000	228	14
2001	43,765,482	39,440,439	174,000	227	11
2002	43,691,729	40,546,812	176,000	230	11
2003	44,750,192	41,751,675	181,000	231	17
2004	48,164,287	45,109,531	185,000	244	13
2005	45,314,135	42,360,252	190,000	223	19
2006	46,297,583	43,183,909	199,000	217	17
2007	49,508,893	46,257,746	204,000	227	10
2008	49,178,982	45,461,856	211,000	215	11
2009	46,156,104	41,764,111	216,000	193	11
Historical Average			166,200	213	15
10-Year Average			190,100	224	13
5-Year Average			204,000	215	14

[a] Data collected from the Retailers and from the Zone 7 Annual Supply Reports (WR OM1 and WR OM3). Includes all groundwater pumped for and by the Retailers.
[b] Total water demand minus untreated water for agriculture served by Zone 7.
[c] Data provided by the Retailers.
[d] Source: http://wwwcimis.water.ca.gov/.

Figure 3-1. Comparison of Historical Municipal and Industrial (M&I) Per Capita Demand to Precipitation



3.2 BREAKDOWN OF WATER ACCOUNTS AND USE BY SECTOR IN 2009

As a wholesale water agency, Zone 7 does not track water use by individual water use sectors (e.g., Single Family Residential or Commercial). However, Zone 7 indirectly serves these sectors by supplying water to the Retailers. Tables 3-3a and 3-3b present the breakdowns of water accounts and water use by sector in the service area, including those customers served directly by Zone 7 and including the water produced by the Retailers using their groundwater pumping quotas. Agricultural accounts, which are served untreated surface water by Zone 7, are included, while recycled water accounts are not included in these tables.

As shown in Table 3-3b, three of the top water use sectors by volume are: residential (54%), commercial/institutional (16%), and landscape (13%).

Table 3-3a. Breakdown of Water Accounts by Sector in the Service Area in 2009[a]

Water Use Sector	Cal Water	DSRSD	Livermore[b]	Pleasanton	Zone 7	Total	% of Total
Single-Family Residential	16,466	13,303	7,988	19,441	-	57,198	86%
Multi- Family Residential	82	2,000	20	225	-	2,327	4%
Commercial/Institutional	1,301	432	1,084	984	6	3,807	6%
Industrial	1	168	-	6	-	175	0.3%
Landscape	-	420	440	984	-	1,844	3%
Agriculture	-	-	-	7	7	14	0.02%
Other	19	676	173	-	-	868	1%
Total	17,869	16,999	9,705	21,647	13	66,233	100%

[a] Based on data provided by Cal Water, DSRSD, Livermore, and Pleasanton, and Zone 7's annual water supply reports. These values do not include recycled water, but do include untreated surface water provided to agriculture.

[b] The City of Livermore has developed new estimates that are included in their draft Urban Water Management Plan; these estimates were not available in time to include as part of this evaluation.

Table 3-3b. Breakdown of Water Use by Sector in the Service Area in 2009, acre-feet[a]

Water Use Sector	Cal Water	DSRSD	Livermore[c]	Pleasanton	Zone 7	Total	% of Total
Single-Family Residential	7,597	4,722	3,224	9,484		25,027	49%
Multi-Family Residential[b]	561	1,196	N/A	760		4,726	5%
Commercial/Institutional	2,483	1,423	2,576	1,504	233	6,010	16%
Industrial	-	261	-	73		334	1%
Landscape		1,463	436	4,679		6,577	13%
Agriculture		-	-	-	4,920	4,920	10%
Other	14	6	-	-		20	0%
Unaccounted-for Water	359	457	129	916	1,900	3,762	7%
Total[d]	11,014	9,528	6,365	17,416	7,053	51,375	100%

[a] Based on data provided by Cal Water, DSRSD, Livermore, and Pleasanton, and Zone 7's annual water supply reports. These values do not include recycled water, but do include untreated surface water provided to agriculture. These values include the total potable water supply provided by the Retailers to their customers, and therefore include groundwater-pumping quotas in 2009: DSRSD – 645 AF, Pleasanton – 3,505 AF, and Cal Water – 3,064 AF.

[b] For Livermore, this value is included under commercial/institutional.

[c] The City of Livermore has developed new estimates that are included in their draft Urban Water Management Plan; these estimates were not available in time to include as part of this evaluation.

[d] Note that because of the different accounting methods used by the various agencies, there is a minor discrepancy (<1%) between the total shown here (51,375 AF) and the total shown in Table 3-1 (51,705 AF).

3.3 PROJECTED WATER DEMANDS

Projected water requirements for Zone 7 were estimated by evaluating demands from the Retailers, Zone 7's retail customers, and untreated water customers. Demands were also adjusted to account for potential future water conservation savings, unaccounted-for water and other system losses, and water required to maintain a sustainable groundwater basin. Each of these factors is discussed in more detail below.

3.3.1 Treated Water Retailer Demands

Zone 7 obtained projected water demands from each of the retailers through a series of stakeholder and one-on-one meetings. Zone 7 staff met with and collected water demand and supply information from the four retailers in June, August, and September 2009, and in January 2010, as part of the development of the 2010 Urban Water Management Plan. Additional information was provided by the Retailers throughout 2010. For example, as part of its operational planning, Zone 7 annually collects demand projections ("Delivery Requests") for the next five years; the 2010 Delivery Requests were one of the sources of data used to estimate near-term (2010-2015) demands.

Retailer water demands consist of three components: treated water supplied by Zone 7, groundwater pumped by the Retailers under their groundwater-pumping quotas (GPQ), and recycled water. Table 3-4 presents the amounts of water supply required from Zone 7 by the Retailers. These amounts do not include groundwater pumped by three of the four retailers under their GPQ to meet the rest of their demands: Cal Water (3,069 AF), Pleasanton (3,500 AF), and Livermore (31 AF); Zone 7 pumps DSRSD's GPQ of 645 AF and this amount is included in the table. DSRSD and Livermore currently produce recycled water to supplement their water supplies; recycled water demands are not included in the table.

The water demand projections presented in Table 3-4 do not account for additional water conservation efforts that may be implemented by the Retailers to comply with the Water Conservation Act of 2009; the associated potential future water conservation in the Zone 7 service area is discussed in Section 3.3.5.

Table 3-4. Projected Treated Water Demands from Retailers, acre-feet[a]

Year	Demands from Zone 7					GPQs [a]	Total Retailer Demands in the Service Area
	Cal Water	DSRSD	Livermore	Pleasanton	TOTAL		
2010	9,160	13,057	7,160	16,400	45,777	6,569	52,346
2011	9,160	13,222	7,160	16,600	46,142	6,569	52,711
2012	9,230	13,351	7,210	16,800	46,591	6,569	53,160
2013	9,290	13,556	7,220	17,020	47,086	6,569	53,655
2014	9,340	13,840	7,310	17,210	47,700	6,569	54,269
2015	9,400	14,076	7,390	17,460	48,326	6,569	54,895
2016	9,840	14,297	7,800	17,820	49,756	6,569	56,325
2017	10,050	14,774	7,900	18,040	50,763	6,569	57,332
2018	10,260	15,187	8,000	18,260	51,707	6,569	58,276
2019	10,490	15,603	8,100	18,480	52,673	6,569	59,242
2020	10,730	16,139	8,200	18,700	53,768	6,569	60,337
2021	10,990	16,552	8,200	18,900	54,642	6,569	61,211
2022	11,270	16,995	8,200	19,100	55,565	6,569	62,134
2023	11,560	17,416	8,200	19,300	56,476	6,569	63,045
2024	11,870	17,836	8,200	19,500	57,406	6,569	63,975
2025	12,210	18,157	8,200	19,700	58,267	6,569	64,836
2026	12,230	18,474	8,200	19,900	58,804	6,569	65,373
2027	12,250	18,714	8,200	20,100	59,264	6,569	65,833
2028	12,280	18,907	8,200	20,300	59,687	6,569	66,256
2029	12,300	19,071	8,200	20,500	60,071	6,569	66,640
2030	12,330	19,169	8,200	20,700	60,399	6,569	66,968
2031	12,350	19,224	8,200	20,700	60,474	6,569	67,043
2032	12,380	19,224	8,200	20,700	60,504	6,569	67,073
2033	12,400	19,224	8,200	20,700	60,524	6,569	67,093
2034	12,420	19,224	8,200	20,700	60,544	6,569	67,113
2035	12,450	19,224	8,200	20,700	60,574	6,569	67,143
2036	12,470	19,224	8,200	20,700	60,594	6,569	67,163
2037	12,500	19,224	8,200	20,700	60,624	6,569	67,193
2038	12,520	19,224	8,200	20,700	60,644	6,569	67,213
2039	12,550	19,224	8,200	20,700	60,674	6,569	67,243
2040	12,570	19,224	8,200	20,700	60,694	6,569	67,263

[a] Groundwater pumping quotas for Cal Water (3,069 AF), Pleasanton (3,500 AF), and Livermore (31 AF). Zone 7 pumps DSRSD's GPQ of 645 AF and this amount is included under DSRSD's Zone 7 demand.

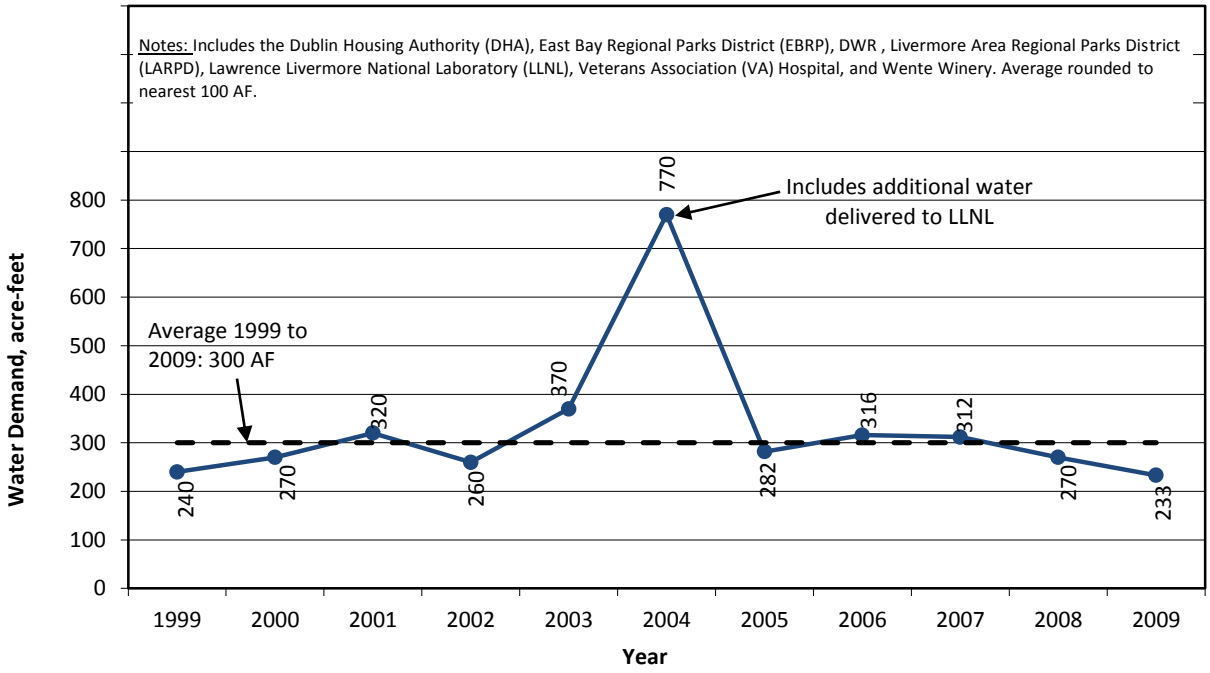
3.3.2 Zone 7 Retail Demands

Zone 7 provides treated water directly to a number of commercial/institutional customers within the service area. These customers currently include the East Bay Regional Parks District (EBRPD), Department of Water Resources (DWR)[14], Livermore Area Regional Parks District (LARPD), Lawrence Livermore National Laboratory (LLNL), Veterans Association (VA) Hospital, and Wente Winery.

Figure 3-2 illustrates the historical water demand from Zone 7's retail customers between 1999 and 2009. As shown on Figure 3-2, water demand for these direct retail customers has been relatively steady for the past 10 years with the exception of 2004. The spike in water demand in 2004 is the result of additional water supplied to LLNL resulting from an interruption in supplies normally provided to LLNL by the San Francisco Public Utilities Commission.

For planning purposes in this analysis, Zone 7 staff assumed that the long-term (2015-2040) water demands for Zone 7's retail customers would be equal to the average demand observed over the past 10 years, which is approximately 300 AF after rounding to the nearest 100 AF. The additional water demand spike resulting from LLNL is relatively infrequent, and can likely be accommodated using existing facilities if necessary. In the near-term (2010-2014), direct retail water demands were based on customers' projections as presented in their 2010 Delivery Requests. Table 3-5 summarizes the projected supply required from Zone 7 for its retail customers.

Figure 3-2. Historical Zone 7 Retail Customer Demand, acre-feet



[14] DWR has a storage/corporation yard located along the South Bay Aqueduct that requires treated water.

Table 3-5. Projected Demands from Zone 7's Retail Customers, acre-feet[(a)]

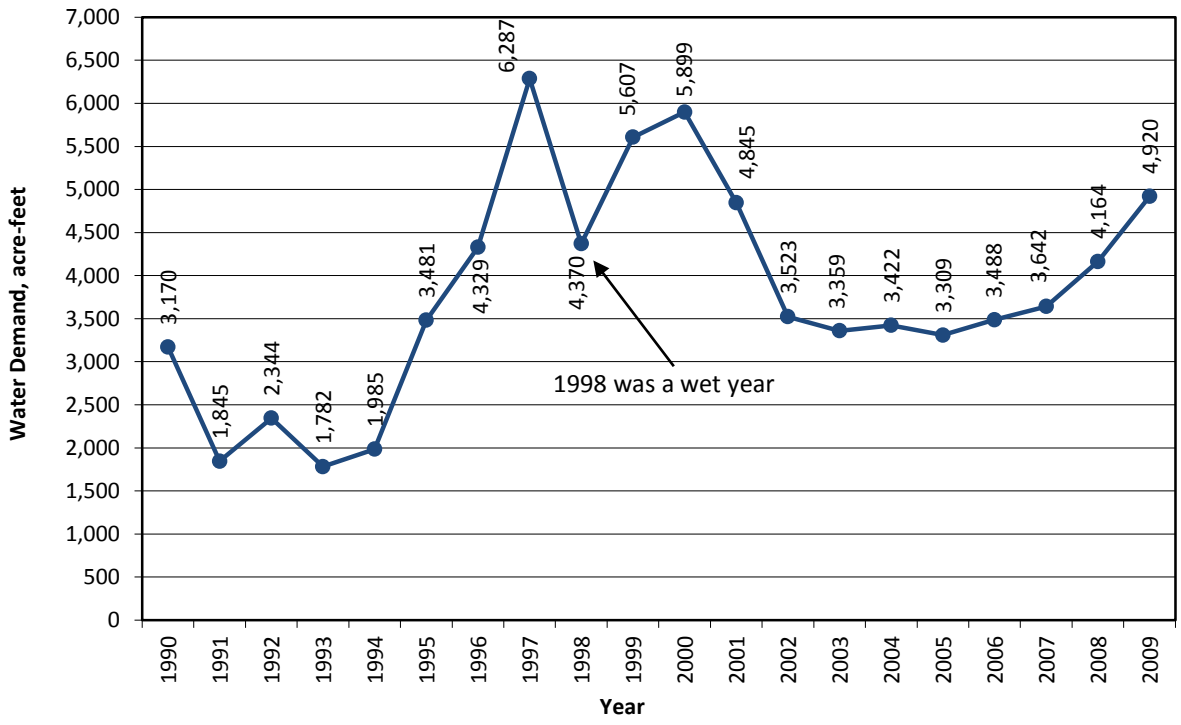
Year	Demand (AF)
2010	285
2011	285
2012	285
2013	235
2014	235
2015-2040	300

3.3.3 Zone 7's Untreated Water Demands

Zone 7 currently supplies untreated surface water to seven turnout customers through eleven South Bay Aqueduct (SBA) turnouts. These seven turnout customers then branch into 74 different untreated water customers.

Figure 3-3 presents historical untreated water demands between 1985 and 2009. As shown on Figure 3-3, untreated water demands significantly increased between 1994 and 1997, and then experienced a significant decrease between 1999 and 2009; 1998 was a wet year (i.e., demands were being partially met by rainfall), while 2008 and 2009 is response to drought conditions. This large decrease is the result of agricultural acreage being taken out of production and water conservation efforts—water conservation has reduced agricultural unit water use from about 1.5 to 0.7 AF/acre (a 50% decrease).

Figure 3-3. Historical Zone 7 Untreated Water Demand



Based on the 2010 Delivery Requests, untreated water demands are expected to remain constant at approximately 4,500 AFA over the next five years. However, Zone 7 has existing contractual obligations

up to 8,250 AFA (or 8,300 AFA after rounding to the nearest 100 AFA); it is unknown when untreated water demands could increase to 8,300 AF. Consequently, for planning purposes, it was assumed that untreated water demand would increase linearly from 4,500 AF in 2015 to 8,300 AF in 2030 and remain at that level through 2040. Table 3-6 presents the projected supply required for Zone 7's untreated water customers.

Table 3-6. Projected Demands from Zone 7's Untreated Water Customers, acre-feet[(a)]

Year	Demand
2010	4,500
2011	4,500
2012	4,500
2013	4,500
2014	4,500
2015	4,500
2016	4,738
2017	4,975
2018	5,213
2019	5,450
2020	5,688
2021	5,925
2022	6,163
2023	6,400
2024	6,638
2025	6,875
2026	7,113
2027	7,350
2028	7,588
2029	7,825
2030-2040	8,300

[(a)] Assumes demand increases linearly from 4,500 AF in 2014 to 8,250 AF in 2030; demands rounded to the nearest 100 AF for planning purposes.

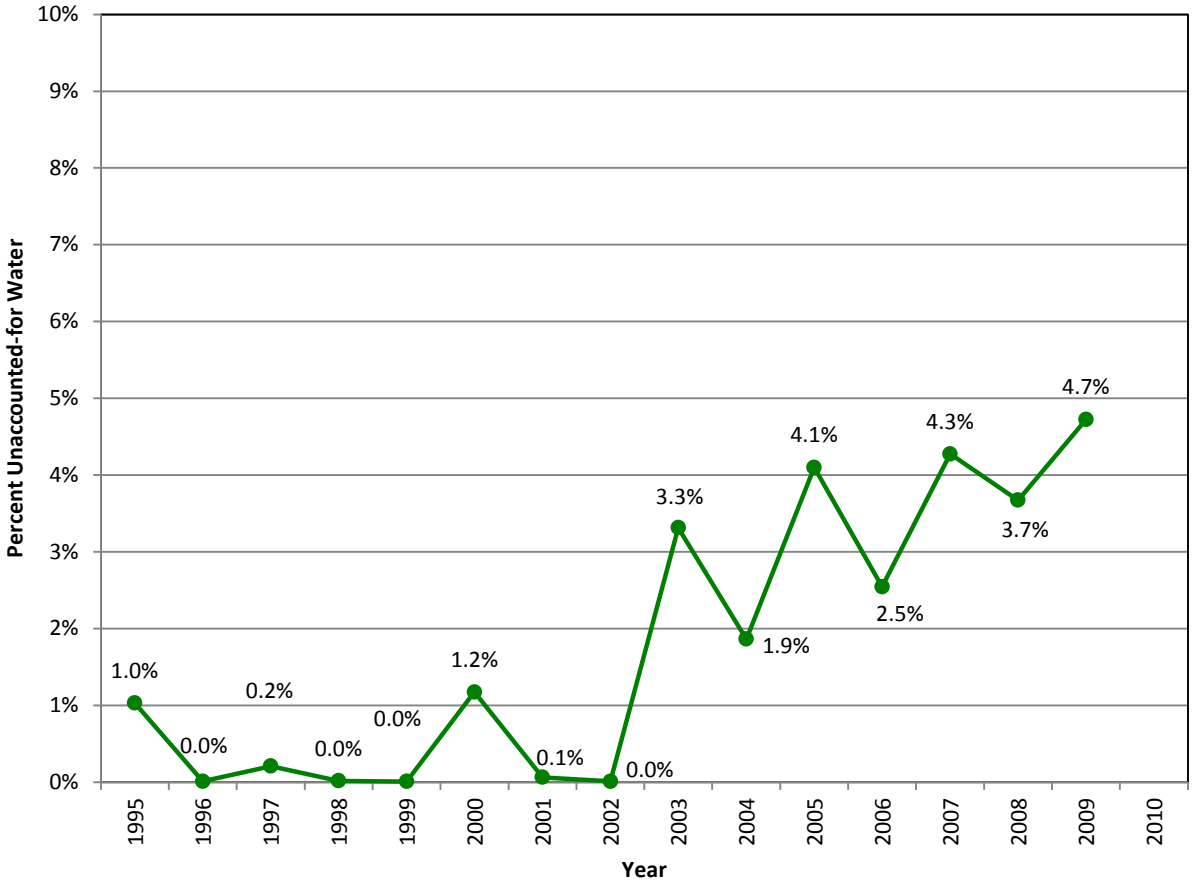
3.3.4 Zone 7's Unaccounted-for Water

Unaccounted-for water is generally defined as the difference between total production (water delivered from the SBA to water treatment plants and groundwater pumped from Zone 7 wells[15]) and the total deliveries made at each of Zone 7's transmission system turnouts. Figure 3-4 illustrates historical unaccounted-for water within Zone 7's system from 1995 to 2009 as a percentage of total production. As shown on Figure 3-4, between 1995 and 2002, unaccounted-for water was typically very low at less

[15] Since 2009, this amount is net of groundwater demineralization losses through brine concentrate disposal.

than 1.2%; however, starting in 2003, it increased significantly, and has averaged approximately 4% between 2003 and 2009.

Figure 3-4. Historical Zone 7 Unaccounted-for Water (Acre-Feet and % of Total Production)



Possible causes for the increase include:

- water losses associated with Zone 7's water treatment plants,
- water losses associated with system flushing,
- meter accuracy and reading errors, and/or
- transmission system leakage.

As described in Section 6.3.2, Zone 7 plans to investigate the cause/s of the upward trend in unaccounted-for water in the next few years and hopes to reduce its percentage down to 2% or less of total water production. Assuming that this improvement occurs starting in 2012, Table 3-7 presents the projected supply lost due to unaccounted-for water.

Note that losses through the disposal of brine concentrate from the demineralization facility are accounted for separately and incorporated into "storage losses" as discussed in Section 3.3.7.

Table 3-7. Supply Required for Zone 7's Unaccounted-for Water, acre-feet[(a)]

Year	Unaccounted-for Water
2010	1,900
2011	1,900
2012	1,000
2013	1,000
2014	1,000
2015	1,000
2016	1,000
2017	1,000
2018	1,100
2019	1,100
2020	1,100
2021	1,100
2022	1,100
2023-2040	1,200

(a) Unaccounted-for water is based on total projected demands and an average unaccounted-for water percentage loss of 2% of total water production starting in 2012.

3.3.5 Projected Demand Reductions Under the Water Conservation Act of 2009

In November 2009, the California legislature passed the Water Conservation Act of 2009 (Conservation Act), also known as Senate Bill SBX7-7. The Conservation Act created a framework for future planning and actions by water supply retailers and agricultural water suppliers to reduce California's water use. More specifically, the Conservation Act requires water supply retailers to reduce their per capita water consumption 20 percent from their baseline by 2020.

Although Zone 7 is not directly subject to the requirements of the Conservation Act because it is a wholesale water agency, Zone 7 fully supports the existing and planned efforts of the Retailers to comply with this new law. To estimate the potential additional water conservation savings (equivalently, demand reductions) that can result from implementation of the Conservation Act, Zone 7 calculated a service area-wide average baseline daily per capita water consumption in accordance with DWR guidelines[16]. The resulting value was 227 gallons per capita per day (gpcd) based on the total potable water demand in the service area over the ten-year period from 1999 to 2008[17]. The total potable water demand included retailer demands from Zone 7, groundwater pumping quotas, direct retail demand, and unaccounted-for water. The period 1999 to 2008 was chosen as it resulted in the highest baseline value and most conservative estimate for water supply planning purposes.

[16] DWR, 2010. Methodologies for Calculating Baseline and Compliance Urban Per Capita Water Use.

[17] For water providers using less than 10% recycled water in 2008, any ten-year sequence between 1995 and 2010 can be used for the baseline calculation.

The regional target for daily per capita consumption was subsequently calculated assuming a 20% reduction from the baseline, resulting in a target of 181 gpcd by 2020. Zone 7 adjusted the total projected demands from the Retailers (including GPQs), direct retail customers, and untreated water customers to reflect a reduction of unaccounted-for water (UAFW) from 4% to 2% as discussed in Section 3.3.4. Applying the 181 gpcd target to the population projections (Section 2.4) and the adjusted total projected demands results in an estimated target demand reduction of 6,000 AF in the Livermore-Amador Valley by 2020. The interim demand reduction target for 2015 was assumed to be half of this amount at 3,000 AF in accordance with DWR guidelines. Demand reductions were assumed to increase linearly to the 2015 and 2020 targets.

Note that these water conservation estimates were developed by Zone 7 for planning purposes only; retailers will be calculating their individual targets for compliance with the Conservation Act as presented in their individual 2010 Urban Water Management Plans.

The water conservation or demand reduction calculations are summarized in Table 3-8 below.

Table 3-8. Projected Water Conservation or Demand Reduction Under the Water Conservation Act of 2009, acre-feet[a]

Year	Estimated Required Demand Reduction
2010	0
2011	600
2012	1,200
2013	1,800
2014	2,400
2015	3,000
2016	3,600
2017	4,200
2018	4,800
2019	5,400
2020	6,000
2021	6,000
2022	6,000
2023	6,000
2024	6,000
2025	6,000
2026	6,000
2027	6,000
2028	6,000
2029	6,000
2030	6,000
2031	6,000
2032	6,000
2033	6,000
2034	6,000
2035	6,000
2036	6,000
2037	6,000
2038	6,000
2039	6,000
2040	6,000

[a] Projected service area-wide water conservation savings estimated by Zone 7 based on data provided by Cal Water, DSRSD, Livermore, and Pleasanton.

3.3.6 Projected Supply Required for Zone 7's Artificial Recharge Activities

As discussed in more detail in Section 4.2, Zone 7 considers the Livermore Valley Groundwater Basin as a storage facility and not a long-term water supply because Zone 7 only pumps groundwater it has

artificially recharged using its surface water supplies. The portion of the Livermore Valley Groundwater Basin that contains high-yielding aquifers and good quality groundwater is used for storage and supply; this portion of the basin is referred to as the Main Basin.

Planning-level analysis completed by Zone 7 staff indicates that Zone 7 could recharge, based on a long-term average, as much as 9,200 AFA via artificial recharge activities in the Arroyo Mocho and Arroyo del Valle.[18] Although Zone 7 will eventually have additional recharge capacity available via the Chain of Lakes (see Section 4.2), existing artificial recharge capacity is limited to the local arroyos.

The amount of water Zone 7 will be using to recharge the Main Basin will vary from year to year depending upon the availability of excess water, storage available in the Main Basin, recharge capacity, available facilities, and other operational factors such as planned extraction of groundwater supply. For planning purposes, the modeling of Zone 7's water supply system, which is described in more detail in Section 5, performs a yearly analysis of artificial recharge activities based on the water supply mix and reliability being analyzed.

3.3.7 Projected Supply Required for Storage and Demineralization Losses

Zone 7's groundwater storage facilities, both local (Main Basin) and non-local (Semitopic Water Storage District [Semitropic] and Cawelo Water District [Cawelo]), are described in detail in Section 4.2. There are different storage losses associated with these facilities: 10% loss for the Main Basin and Semitropic, and 50% loss for Cawelo. The amounts of water placed into storage will vary yearly depending on availability of excess water, storage available in the Main Basin, recharge capacity, available facilities, and other operational factors such as planned extraction of groundwater supply; consequently, storage losses, which are calculated as a percentage of the amount of water placed into storage, will vary yearly. Over time, however, these storage losses will generally decrease as the amounts of water placed into storage decrease (e.g., because the storage facilities are full or there is no excess water available to bank).

Water is also lost through the disposal of brine concentrate from the Mocho Groundwater Demineralization Facility (for more details, see Sections 4.3.4 and 6.3.3) and any future demineralization facilities (see Section 6.5.1). The demineralization losses will vary according to the operation of these facilities.

For planning purposes, the modeling of Zone 7's water supply system performs a yearly analysis of artificial recharge or groundwater banking activities based on the water supply portfolio and reliability policy being analyzed.

3.3.8 Summary of Projected Water Demands

As described in the previous sections, incoming water supplies are used to meet demands from the Retailers, Zone 7's direct retail customers, and untreated water customers. Water supplies are also lost through UAFW, and losses through storage and demineralization activities. The projected demands provided by the Retailers[19] during the data collection for the WSE in 2009 and 2010 (Section 3.3.1) are expected to be lowered as a result of the Water Conservation Act of 2009 (see Section 3.3.5). Furthermore, Zone 7 plans to lower UAFW losses from 4% to 2% of treated water production.

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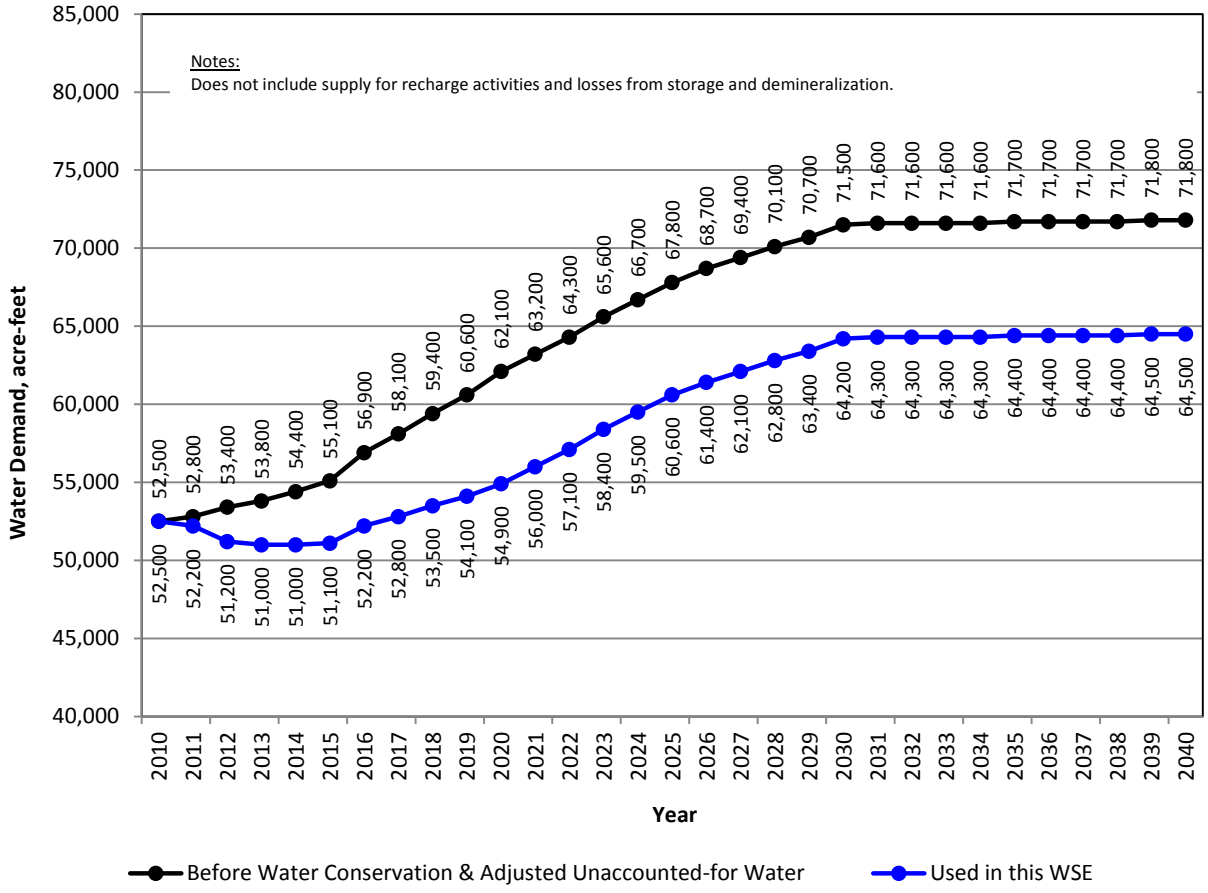
[18] Zone 7 staff used its newly developed water supply model to estimate the average and median recharge capacities along the Arroyo Mocho and Arroyo del Valle. This analysis indicated that the median and average were nearly identical at approximately 9,200 AF. Actual recharge may be significantly more or less than this estimate.

[19] Projections of retailer demands were provided by the Retailers during 2009 and 2010 during the development of the Water Supply Evaluation.

Figure 3-5 shows the projected water demands from the Retailers, retail customers, and untreated water customers with and without the adjustments described above. The Water Supply Evaluation used the lowered projected demands that account for the reductions associated with the Conservation Act and UAFW. At buildout in 2040, the Zone 7 water demand is estimated to be 64,500 AF.

Figure 3-5. Summary of Projected Water Demands from the Retailers, Retail Customers, and Untreated Water Customers



Additionally, the water demand projections presented in Figure 3-5 are planning-level estimates that will likely change in the future. As described in Sections 6 and 8, however, Zone 7 evaluated a myriad of water supply options that have a range of potential water supply yields; Zone 7 staff believes the scope of these options is sufficiently broad and flexible enough to absorb future changes in these estimates.

4. DESCRIPTION OF THE EXISTING WATER SYSTEM

The purpose of this section is to describe the existing water supply system of Zone 7 Water Agency (Zone 7). This system includes three major components: 1) water supplies, 2) water storage facilities, and 3) facilities used to convey, extract, and treat raw water, and facilities used to transmit treated water.

4.1 WATER SUPPLIES

The average yields presented for each water supply below are based on historical data and are therefore representative of historical hydrologic conditions. As part of this Water Supply Evaluation (WSE), Zone 7 developed a new model to incorporate variations in historical hydrologic sequence. Based on this model, Zone 7 analyzed probable water system operations—including water supply availability by source—on a year-by-year basis, resulting in a more rigorous estimate of supply availability. The methodology and criteria used in the WSE are described in detail in Section 5.

4.1.1 Imported Surface Water - State Water Project

Imported surface water is by far Zone 7's largest water source, providing approximately 90% of the treated water supplied to its customers on an annual basis, either directly or after storage. Zone 7 imports surface water from the State Water Project (SWP) and from the Byron Bethany Irrigation District, but the SWP by itself represents approximately 80% of Zone 7's supply.

The SWP is the nation's largest publicly-built water storage and conveyance system and currently serves water to over 25 million people throughout California. It was built and is operated and managed by the California Department of Water Resources (DWR). In addition to delivering water, the SWP also generates power, controls floods, provides recreational facilities, and enhances habitat for fish and wildlife.

Supply from the SWP is delivered via the SBA. Approximately 90% of Zone 7's existing supply is conveyed through the SBA.

SWP water primarily originates within the Feather River watershed, is captured in and released from Lake Oroville, and flows through the Sacramento-San Joaquin Delta (Delta) before it is conveyed by the South Bay Aqueduct (SBA) to Zone 7 or by the California Aqueduct to other south-of-Delta SWP contractors. Zone 7 entered into a 75-year agreement with DWR to receive water from the SWP in November 1961. Including Zone 7, there are 29 SWP contractors spread across California, serving areas as far north as Plumas County and as far south as San Diego County.

Within Zone 7, SWP water is used directly to meet treated water demands from municipal and industrial customers—both wholesale and retail—and untreated water demands from agricultural customers. Water from the SWP can also be stored in Lake Del Valle for later use as described in Section 4.2.1. In addition to aboveground storage, SWP water is used to artificially recharge the local groundwater basin as discussed below in Section 4.2.2, or fill non-local groundwater banks as discussed in Sections 4.2.4 and 4.2.5. Aquifer storage of surface water supplies is a major component of Zone 7's water supply reliability efforts.

4.1.1.1 Table A Allocation and Carryover

The primary allocation agreement between DWR and its SWP contractors is recorded in Articles 12(a) and 18(a) of the agreements and is based on each contractor's annual water delivery request. Each contractor is limited to an annual contractual amount as specified in Article 6(c) and Table A (hence, water that falls under this contractual limit is commonly referred to as "Table A" water). As previously noted, Zone 7 first entered into an agreement with DWR in 1961. As the SWP was expanded and as Zone 7 demands increased over the years, Zone 7's Table A amount was increased, reaching the amount of 46,000 acre-feet annually (AFA) in 1997.

Since 1997, Zone 7 has increased its supply from the SWP through a series of five permanent transfers. In December 1999, Zone 7 secured Table A SWP allocations from Lost Hills Water District of 15,000 AFA and Berrenda Mesa Water District of 7,000 AFA. In December 2000, 10,000 AFA of SWP allocation from Belridge Water Storage District was acquired. An additional 2,219 AFA was obtained from the same source in October 2003. Finally, 400 AFA of water was acquired from the Tulare Lake Basin Water Storage District in 2003. Together, these transfers have raised Zone 7's current Table A allocation to 80,619 AFA through 2036 with an option to renew for another 75 years.

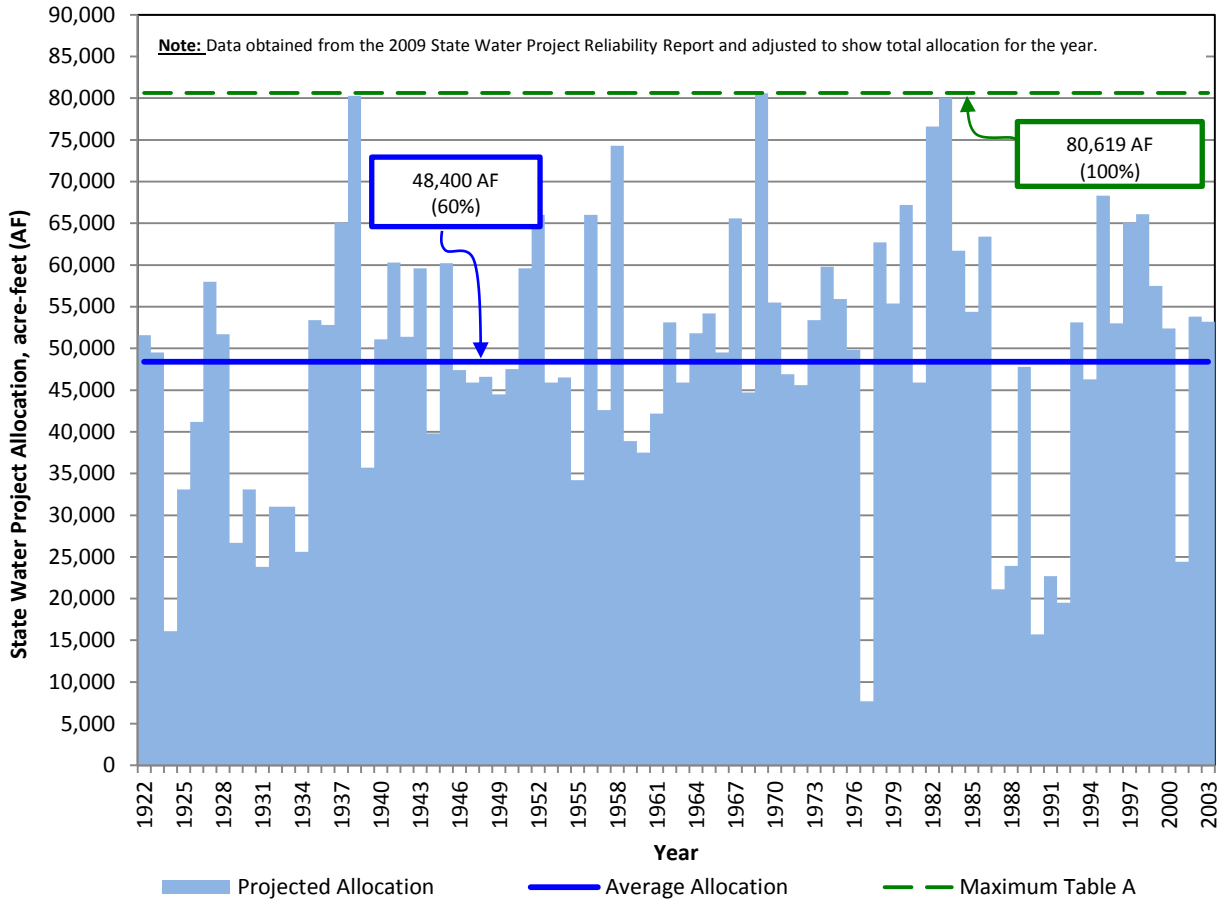
Zone 7 has the ability to carryover Table A water from one year to another via storage in San Luis Reservoir

In practice, the actual amount of SWP water available to Zone 7 under the Table A allocation process varies from year to year due to hydrologic conditions, water demands of other contractors, SWP facility capacity, and environmental/regulatory requirements. In January 2010, DWR issued the State Water Project Delivery Reliability Report for 2009[20], which estimates a long-term average yield of 60% of Table A amounts, equivalent to 48,400 AFA for Zone 7. This is equivalent to a median yield in a normal water year of 51,400 AFA (approximately 64%) to Zone 7. Figure 4-1 shows the projected allocations from the SWP.

The projected long-term average yield of the SWP has decreased by 15% since 2007, when it was at 75%. This decrease reflects the impacts of Delta pumping restrictions resulting from concerns over threatened/endangered species in the Delta and the predicted impacts of climate change. This 15% reduction translates to a total loss of 12,100 AF of water supply.

[20] DWR, 2010. State Water Project Delivery Reliability Report for 2009. (Available at http://baydeltaoffice.water.ca.gov/swpreliability/index.cfm).

Figure 4-1. Projected Allocations from the State Water Project



As a SWP contractor, Zone 7 has the option to carry over unused Table A water from one year to the next when there is available storage in San Luis Reservoir (SLR). The SLR is located approximately 70 miles southeast of Livermore. This "carryover" water is also called Article 12e and 56c water. Article 12e water must be taken by March 31 of the following year, while Article 56c water may be carried over as long as SLR storage is available. When SLR is full, and Article 21 water is available (see next section), a portion of carryover stored by each contractor is "spilled" or converted back to general SWP supplies, effectively reducing each contractor's carryover balance. The total amount of spill is equal to the amount of Article 21 water and is split amongst the contractors in proportion to their maximum Table A contract amounts.

The amount that Zone 7 can carry over from one year to the next depends on DWR's allocation for that year. For example, if the allocation is equal to or less than 50 percent of Zone 7's Table A amount, then carryover is limited to 25% of Zone 7's total Table A amount, or approximately 20,200 AFA (0.25 x 80,619 AFA). However, if allocations are equal to or greater than 75% of Zone 7's Table A amount, then carryover is limited to 50% of Zone 7's total Table A amount, or approximately 40,300 AFA (0.50 x 80,619 AFA). For drought protection, Zone 7 typically aims to have a total of 10,000 to 15,000 AF of carryover water available at all times to supplement the current year's allocation in case a dry year occurs.

4.1.1.2 Article 21 Water (Interruptible or Surplus Water)

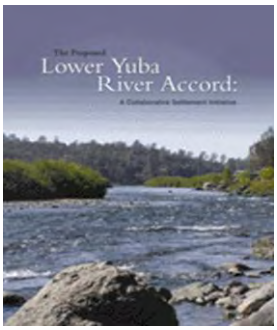
Under Article 21 of Zone 7's contract with DWR, Zone 7 also has access to excess water supply from the SWP that is available only if: 1) it does not interfere with SWP operations or Table A allocations, 2) excess water is available in the Delta, and 3) it will not be stored in the SWP system. The amount of Article 21 water available is calculated as the pumping capacity available at Banks Pumping Plant minus the contractor demands. If there is no demand for Article 21 water, this excess water flows out to the ocean. Per the State Water Project Reliability Report for 2009[20], the projected yield from Article 21 is very low and represents neither a significant nor a reliable water supply for Zone 7.

4.1.1.3 Article 56d Water (Turnback Pool Water)

Article 56d is a contract provision that allows SWP contractors with unused Table A water to sell their water to contractors who have water needs that exceed their allocation for the year. Historically, only a few SWP contractors have been in a position to make Turnback Pool water available for purchase, particularly in normal or dry years. Zone 7 currently does not anticipate a significant amount of water supply to be available under Article 56d.

4.1.1.4 Yuba Accord

In 2008, Zone 7 entered into a contract with DWR to purchase additional water under the Lower Yuba River Accord (Yuba Accord). The contract expires in 2025. There are four different types ("Components") of water available; Zone 7 has the option to purchase Components 2 and 3 water during drought conditions, and Component 4 water when the Yuba County Water Agency has determined that it has excess water available to sell.



In addition to protecting fish habitat, the Yuba Accord made additional water supplies available to SWP contractors.

The annual amount of water supply available to Zone 7 during dry years under the Yuba Accord is relatively small. For long-term planning, Zone 7 estimates an average yield of 250 AFA under the Yuba Accord. This yield was estimated by assuming a maximum yield of 676 AF (Components 2 and 3 only; Component 4 not included) during critical dry years and zero yield during wet years.

4.1.2 Imported Surface Water - Byron Bethany Irrigation District

The Byron Bethany Irrigation District (BBID) diverts water from the Delta pursuant to a "Notice of Appropriation of Water" dated May 18, 1914[21]. Zone 7 entered into a water transfer demonstration project in 1994 with BBID, which provided a minimum supplemental water supply of 2,000 AFA to Zone 7 with a potential to purchase up to 5,000 AFA. This original agreement was valid for five years. In 1998, Zone 7 and BBID agreed to convert the demonstration project into a long-term 15-year contract, renewable every five years up to a total of 30 years. In August 2010, the contract was extended through 2030 with an option to extend through 2039 and beyond.

Like SWP supplies, water purchased from BBID is delivered to Zone 7 via the SBA. While Zone 7 has had a contract with BBID since 1998, Zone 7 has historically requested less than the full amount available; this may change in the future as demands and available supplies change. Zone 7 also plans to investigate

[21] Source: Mountain House Master Plan.

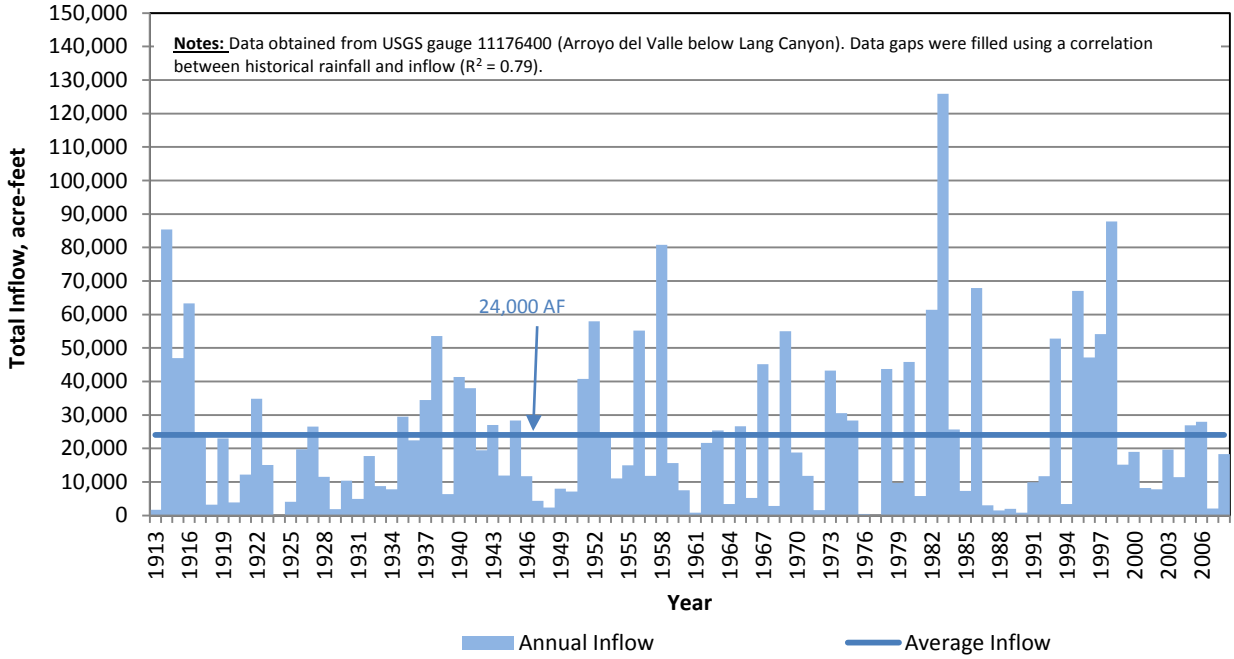
whether the minimum yield of 2,000 AFA can be increased over the long-term; this effort is described in more detail in Section 6.3.1.

4.1.3 Local Runoff - Arroyo Del Valle

Supply from Arroyo del Valle is stored in Lake Del Valle

Zone 7, along with Alameda County Water District (ACWD), has a water right permit to divert flows from Arroyo del Valle[22]. Runoff from the Arroyo del Valle watershed above Lake Del Valle is stored in the lake, which is managed by DWR. A review of historical runoff from Arroyo del Valle over 1913 to 2008[23] indicates that the average total inflow into Lake Del Valle has been approximately 24,000 AFA (Figure 4-2). A maximum annual inflow of 126,000 AF was observed in 1983. Inflows into Lake Del Valle, after accounting for permit conditions, are equally divided between ACWD and Zone 7; however, total diversions cannot exceed 60,000 AFA. Based on historical conditions and existing facilities, the average yield to Zone 7 is projected to be 7,300 AFA from local runoff. Section 6.3 discusses future facilities that will be used to increase the yield under the existing permit.

Figure 4-2. Historical Total Inflows into Lake Del Valle from Arroyo del Valle



4.2 WATER STORAGE FACILITIES

Zone 7 has three options for local storage: storage in Lake Del Valle, storage in the Livermore Valley Groundwater Basin and, in the future, surface storage in the Chain of Lakes. Zone 7 also has access to

[22] Permit 11319 (Application 17002).

[23] Note that actual data is only available for the following years: 1912 (partial)-1930, 1942, 1944-1952, 1958–present. Gaps were filled using correlations with local rainfall.

groundwater banking or storage facilities in Kern County through the Semitropic Water Storage District and the Cawelo Water District.

Water stored in the local groundwater basin and the aquifers in Kern County represent water previously stored from Zone 7's surface water supplies during wet years; therefore, they do not make a net contribution to Zone 7's water supply over the long-term and in fact result in some operational losses as described further below. Very importantly, however, they provide a source of water during drought years. Note that the banked water supplies in Kern County are only accessible when the SBA (described in Section 4.3.1) is operational.

Each of Zone 7's storage options is described below.

4.2.1 Local Storage: Lake Del Valle

Lake Del Valle is a 77,110 acre-foot reservoir with a 235-foot high dam that is located approximately 10 miles southeast of Livermore. It was constructed by DWR in 1968 to provide recreation and fish and wildlife enhancement, flood control for Alameda Creek, and storage for SWP water delivered through the South Bay Aqueduct (see Section 4.3.1)[24]. It normally stores from 25,000 to 40,000 AF, with the remaining capacity left available for flood control. The storage capacity available to Zone 7 ranges from 7,000 to 10,000 AFA depending on lake drawdown and hydrology.

The 1.5-mile Del Valle Branch Pipeline, which branches off the SBA downstream of the Patterson Pass Water Treatment Plant (see Section 4.3.2), is used for filling the lake, as well as releasing water from it. Water is pumped into the lake and released by gravity flow. Lake Del Valle is used to store runoff from the Arroyo del Valle watershed above the lake (the rights to which are shared between Zone 7 and ACWD) and to store imported surface water deliveries from the SWP for the three SBA contractors (Zone 7, ACWD, and Santa Clara Valley Water District). In the late summer/early fall, DWR typically lowers the lake level to 25,000 AF in anticipation of runoff from winter storm events, and to provide flood control capacity.

Water supply in Lake Del Valle is made available to the SBA contractors via the SBA through operating agreements with DWR. As in the case of SWP water taken directly from the SBA, water released from Lake Del Valle is also used by Zone 7 to artificially recharge the Main Basin, as discussed further in Section 4.2.2.

4.2.2 Local Storage: Livermore Valley Groundwater Basin and Recharge Facilities

Zone 7 overlies the Livermore Valley Groundwater Basin (DWR Basin 2-10), which extends from the Pleasanton Ridge east to the Altamont Hills and from the Livermore Uplands north to the Tassajara Uplands[25]. The portion of the Livermore Valley Groundwater Basin that contains high-yielding aquifers and good quality groundwater is called the Main Basin, which is composed of the Castle, Bernal, Amador, and Mocho II sub-basins.

The Main Basin has an estimated storage capacity of 254,000 AF and receives an annual average natural recharge of approximately 13,400 AFA through percolation of rainfall, natural stream flow, and irrigation waters, and inflow of subsurface waters[26]. This natural recharge is considered the long-term natural sustainable yield of the Main Basin, or the amount that can be pumped without lowering the long-term

[24] DWR, 2001. South Bay Aqueduct (Bethany Reservoir and Lake Del Valle).

[25] DWR, 2003. California's Groundwater - Bulletin 118 Update 2003.

average groundwater volume in storage. The long-term natural sustainable yield is based on over a century of hydrologic records and projections of future recharge conditions.

Zone 7 uses the Main Basin as a storage facility and not a source of long-term water supply because Zone 7 only pumps groundwater it has artificially recharged using its surface water supplies. As the groundwater basin manager, Zone 7's policy is to maintain groundwater levels above historical lows in the Main Basin through its artificial recharge operations. SWP water or runoff from Arroyo del Valle (stored in and released from Lake Del Valle) is used to recharge the Main Basin by releasing water from turnouts along the SBA and the Del Valle Branch Pipeline into the Arroyo Mocho and Arroyo del Valle for percolation down to the aquifers. The streams' total recharge capacity varies depending on hydrologic conditions, with higher recharge capacities occurring during dry years. The long-term average recharge capacity through the Arroyo Mocho and Arroyo del Valle is estimated at 9,200 AFA, as noted in Section 3.3.7.

Zone 7 established historical lows based on the lowest measured groundwater elevations in various wells in the Main Basin; historical lows correspond to a groundwater storage volume of about 128,000 AF.[26] In general, the difference between water surface elevations when the Main Basin is full and water surface elevations when the Main Basin is at historical lows defines Zone 7's available operational storage. Operational storage is about 126,000 AF based on Zone 7's experience operating the Main Basin.

Before the construction of the SWP in the early 1960s, groundwater was the sole water source for the Livermore-Amador Valley. This resource has gone through several periods of extended withdrawal and subsequent recovery. In the early 1960s, when approximately 110,000 AF of groundwater was extracted, the Main Basin reached its historical low of 128,000 AF. The Main Basin was then allowed to recover from 1962 to 1983. It was during this era that Zone 7 first conducted a program of groundwater replenishment by recharging imported surface water via its streams ("in-stream recharge") for storage in the Main Basin, began supplying treated surface water to customers to augment groundwater supplies, and regulating municipal pumping by contractually establishing GPQs as discussed above. Figure 4-3 shows Zone 7's total annual artificial recharge amounts from 1974 to 2009.

[26] Zone 7, 2010. Annual Report for the Groundwater Management Program – 2009 Water Year. May.

Figure 4-3. Zone 7 Historical Artificial Recharge

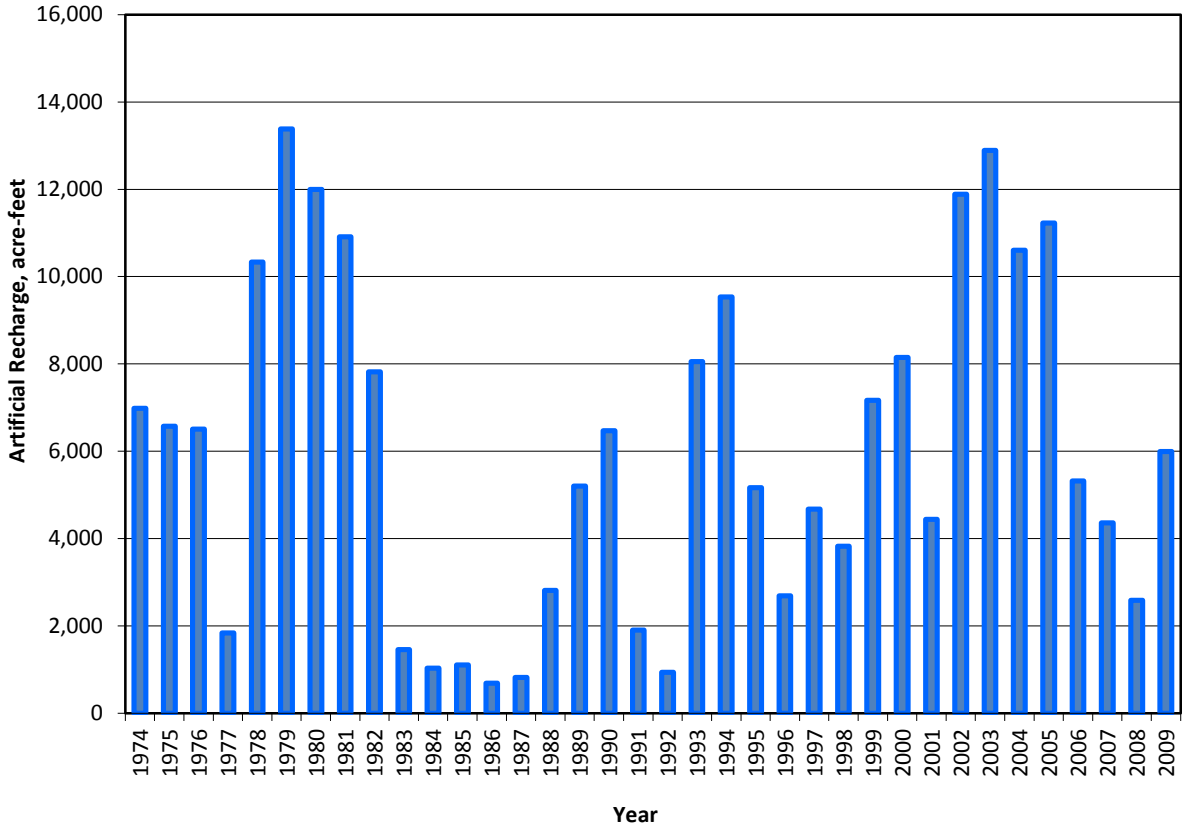
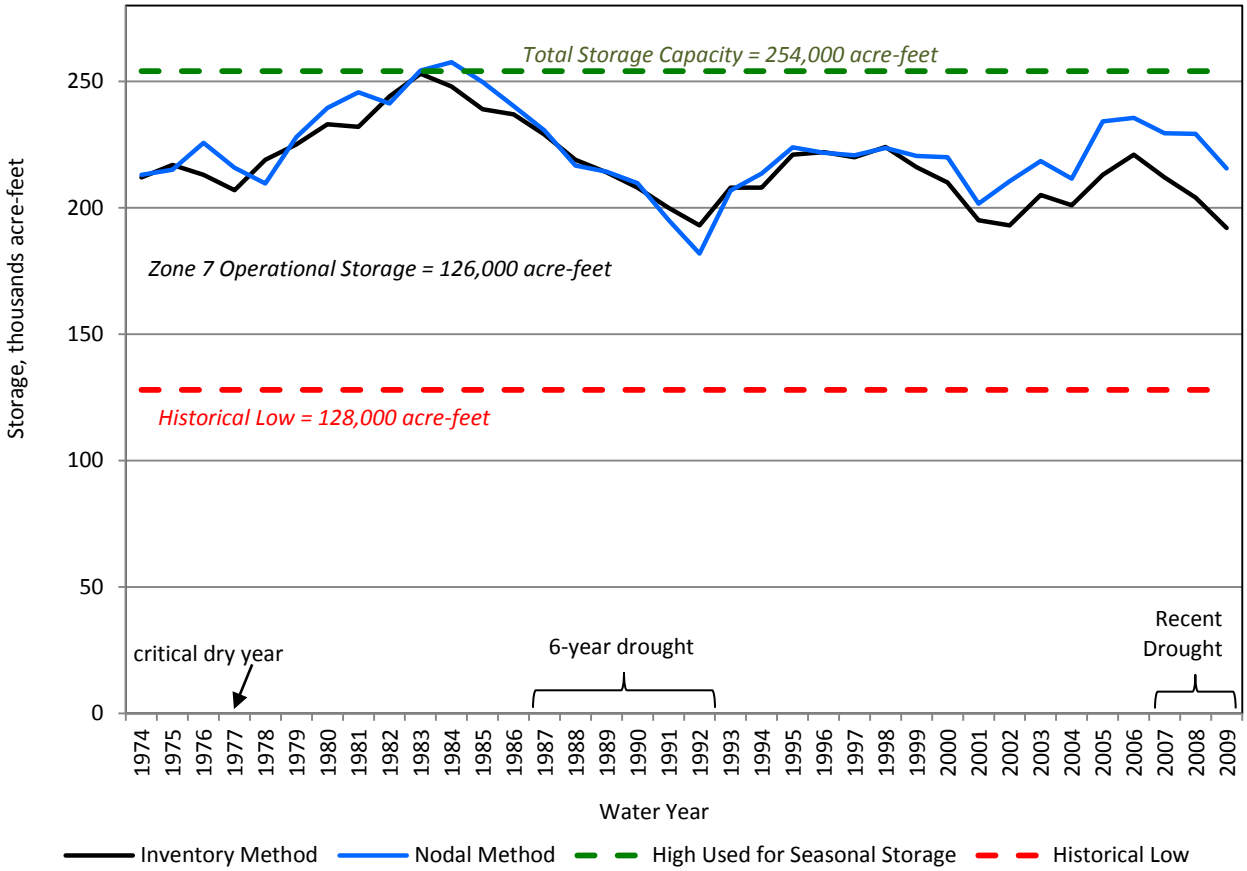


Figure 4-4 shows the volumes of storage in the Main Bain between 1974 and 2009. As shown, the Main Basin went through an extended withdrawal from 1987 to 1992 due to drought. Figure 4-4 also shows the Main Basin responding to the drought that started in 2007. At the end of the 2009 water year, there was 204,000 AF[27] of stored water in the Main Basin; of this amount, 76,000 AF of groundwater was available for Zone 7's use (as noted above, the Main Basin is to be maintained at or above 128,000 AF at all times). This left 50,000 AF of available storage capacity for recharge activities at the end of the 2009 water year.

[27] Calculated as the average of the results from the two storage calculation methods. See Table 4.2-4 of the 2009 Annual Report for the Groundwater Management Program included as a CD attachment.

Figure 4-4. Main Basin Groundwater Storage



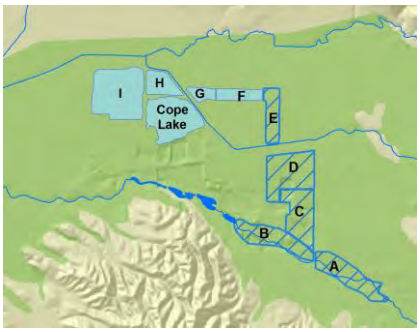
During high demands, groundwater is used to supplement surface water supply delivered via the SBA. Groundwater is also used when the SBA is out of service due to maintenance and improvements or when Zone 7's surface water treatment plants are operating under reduced capacity due to construction, repairs, etc. As mentioned previously, the Main Basin is a key component of Zone 7's drought and emergency management efforts; Zone 7 taps into its stored groundwater when there may be insufficient surface water supply available due to emergency or drought conditions. Finally, Zone 7 pumps groundwater out of the Main Basin during normal water years to help reduce the salt loading in the Main Basin. Salt issues in the Main Basin are discussed in more detail in Section 4.3.4.

Zone 7's stream recharge capacity is 9,200 AFA on average, which means that Zone 7 can pump an equivalent 9,200 AFA on average from the Main Basin; this pumping allows for operational flexibility (i.e., short-term storage of surface water supplies to be extracted when demands increase) and salt removal.

More detailed descriptions of the Main Basin are available in Zone 7's Groundwater Management Plan (GMP).[28]

[28] Jones & Stokes, 2005. Groundwater Management Plan for Livermore-Amador Valley Groundwater Basin.

4.2.3 Local Storage: Chain of Lakes – Lake I and Cope Lake



The Chain of Lakes is located over the Main Basin, and will enhance Zone 7's existing artificial recharge activities

The Chain of Lakes refers to a series of ten mined out or active gravel quarry pits that have been or will be transferred to Zone 7 for water resource management applications. These applications might include surface storage of stormwater or other local runoff, surface storage of water from the SWP, use as groundwater recharge basins once mining has been completed, and flood control along the Arroyo Mocho and Arroyo Las Positas. The ten quarry pits or lakes are named Cope Lake, and Lakes A through I.

Although the Chain of Lakes will ultimately cover approximately 2,000 acres and store approximately 100,000 AF of water, Zone 7 currently only owns Cope Lake and Lake I. Zone 7 expects to take ownership of Lake H sometime within the next five years, while the remaining lakes will be transferred to Zone 7 over the next 20 years.

4.2.4 Non-Local Storage: Semitropic Water Storage District

The Semitropic Water Storage District (Semitropic), which started as an irrigation district, began a groundwater storage or banking program in the early 1990s in response to problems with groundwater overdraft, rising costs, water shortages, and poor agricultural economy[29]. It is one of eight water storage districts in California and is the largest in Kern County. The total capacity of Semitropic's groundwater storage bank is 1.65 million AF.

Zone 7 originally acquired a storage capacity of 65,000 AF in Semitropic's groundwater banking program in 1998. Subsequently, Zone 7 agreed to participate in Semitropic's Stored Water Recovery Unit, which increased pumpback capacity and allowed Zone 7 to purchase an additional 13,000 AF of storage capacity towards a total of 78,000 AF. The storage agreement is in effect through December 31, 2035.

During non-drought periods, Zone 7 can store up to 5,883 AFA into the Semitropic groundwater bank. There is a 10% loss associated with water transferred into Semitropic. During a drought year, Zone 7 has the ability to request up to 9,100 AF of pumpback and any amount up to 8,645 AF of exchange water; the availability of exchange water depends on projected SWP allocation. Pumpback is water that is pumped out of the Semitropic aquifer and into the California Aqueduct for distribution to SWP contractors. Exchange water is water that is transferred between Zone 7 and Semitropic by adjusting the amounts of Table A water allocated between Zone 7 and Semitropic. Note that water taken out of storage from Semitropic requires delivery via the SBA to Zone 7.

4.2.5 Non-Local Storage: Cawelo Water District

Similar to the arrangements with Semitropic, Zone 7 has 120,000 AF of groundwater banking storage available with the Cawelo Water District (Cawelo), as executed in an agreement in 2006. The agreement is in effect through December 31, 2035.

Zone 7 only receives storage credit for 50% of the water provided to Cawelo. Per the existing contract, Zone 7 can normally only send 10,000 AF in any given year during non-drought periods to Cawelo;

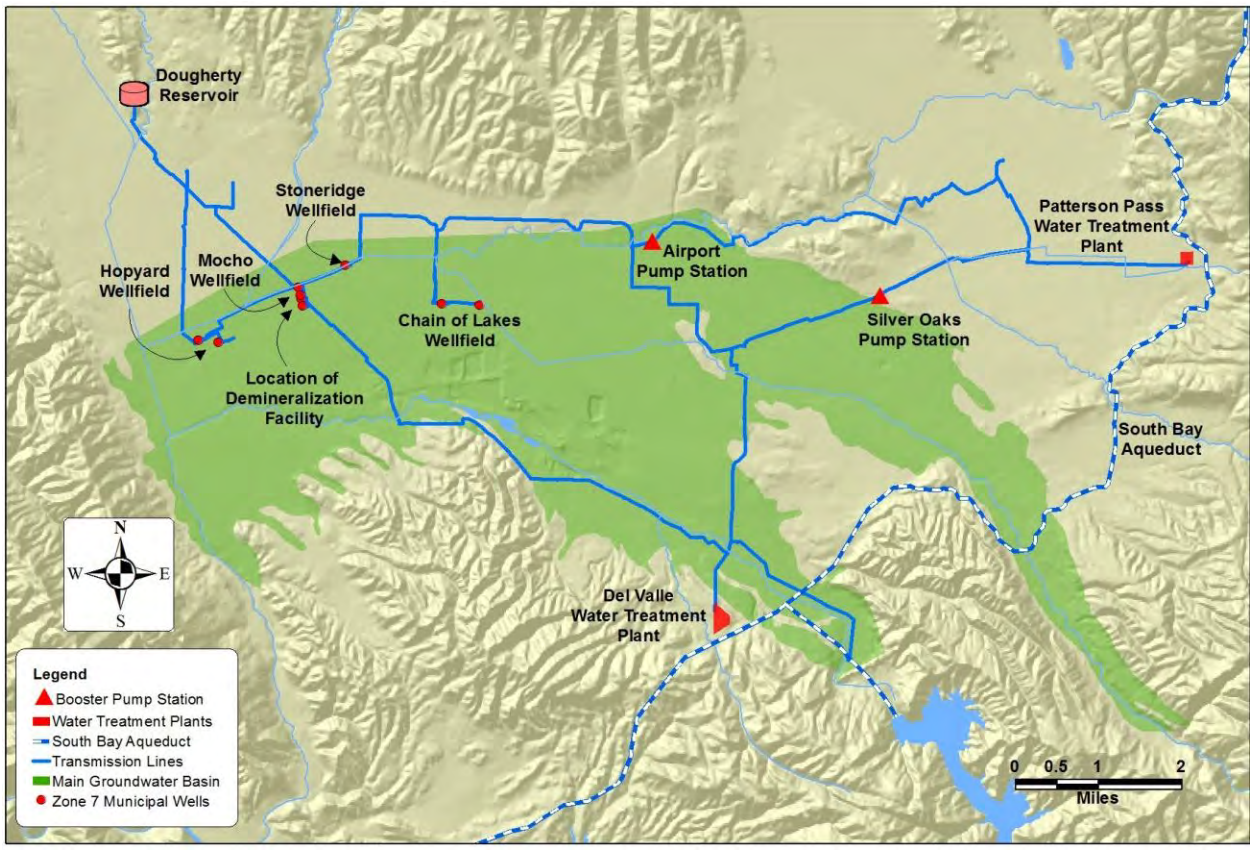
[29] http://www.semitropic.com

therefore, the maximum contractual credit is 5,000 AFA. During droughts, Zone 7 has the ability to request up to 10,000 AFA of pumpback (or exchange water) from Cawelo.

4.3 WATER FACILITIES

Zone 7 has a robust water supply system consisting of an aqueduct, surface water treatment plants, groundwater wells, a groundwater demineralization facility, booster pump stations, reservoirs, and transmission pipelines. Key facilities are discussed below, while Figure 4-5 illustrates the location of Zone 7's major water system facilities.

Figure 4-5. Zone 7's Major Treated Water System Facilities



4.3.1 Raw Water Conveyance – South Bay Aqueduct

Zone 7 imports surface water from the SWP through the South Bay Aqueduct (SBA) for direct use by untreated water users and for treatment, storage, and recharge for municipal and industrial customers. The SBA, which is operated by DWR, starts from the 4,808 AF Byron Bethany Reservoir in the northeastern corner of Zone 7's service area near Tracy, then leaves the service area southwest of San Antonio Reservoir.

The SBA is made up of pipelines and open channels. The South Bay Pumping Plant (SBPP) lifts water 566 feet into the first reach of the SBA, discharging water through pipelines to the eastern ridge of the Diablo Range[24], where the SBA becomes an open channel. Nine miles downstream, some water is diverted to the Patterson Reservoir, which serves Zone 7's Patterson Pass Water Treatment Plant (see Section 4.3.2). From that point, water flows nine more miles to where the Del Valle Branch Pipeline meets the SBA, and where some water can be pumped to Lake Del Valle for storage. The SBA converts to a pipeline for the rest of its length, terminating in a steel tank east of downtown San Jose. Zone 7 and the other two SBA contractors (Alameda County Water District and Santa Clara Valley Water District) divert water from the SBA at various turnouts.

In 2012, DWR is expected to complete improvements to the SBA that will provide significantly increased capacity to serve Zone 7. These improvements include expansion of the SBPP, raised linings on open channel sections, enlarged pipelines, improved pipeline lining, enlargement of Patterson Reservoir, and construction of a new 425-AF raw water reservoir (Dyer Reservoir). Dyer Reservoir is located near one of the proposed sites for a future Zone 7 water treatment plant. Zone 7's current plans for enhanced surface water treatment capacity is discussed in Section 6.4.1.

The 425-AF Dyer Reservoir under construction in January 2011 as part of the South Bay Aqueduct Enlargement Project.

4.3.2 Water Treatment Plants

Zone 7 operates two surface water treatment plants: the Del Valle Water Treatment Plant (DVWTP) and the Patterson Pass Water Treatment Plant (PPWTP).

4.3.2.1 Del Valle Water Treatment Plant

The DVWTP is located in the southern portion of Livermore and along the SBA, downstream of Lake Del Valle. It can therefore receive 100% Delta water from the SBA, 100% Lake Del Valle water, or a blend of the two sources. It became operational starting in 1975, and was expanded twice, in 1979 and 1990, to its current rated capacity of 40 MGD.

DVWTP is a conventional treatment plant whose processes include coagulation, flocculation, clarification, granular media filtration, and chlorine disinfection. In addition, chloramine is used to maintain a disinfectant residual in the distribution system.[30] Clarification at the DVWTP is achieved using two technologies that operate as parallel treatment trains: upflow solids contact clarifiers (Superpulsators) and dissolved air flotation (DAF) clarifiers. The 10 MGD DAF clarification process was installed at DVWTP in 2007 to improve the reliability of the DVWTP.

[30] Zone 7, 2009. Del Valle Water Treatment Plant Site Specific BMPs Plan. September.

4.3.2.2 Patterson Pass Water Treatment Plant

The PPWTP is located along the SBA, just south of Interstate 580, and has a capacity of 19 MGD.[31] Because PPWTP is upstream of Lake Del Valle, it is not able to receive water from this water supply source[32] and relies on 100% Delta water. The Patterson Reservoir, a 100-AF raw water reservoir located adjacent to the PPWTP and operated by DWR, provides supply to PPWTP in case of disruptions to water supply from the Delta. The reservoir also provides pre-settling and equalization of raw water quality of the influent to PPWTP.

There are two separate, parallel treatment plants at the PPWTP site: a conventional plant and an ultrafiltration (UF) plant. The 12-MGD conventional plant consists of coagulation, flocculation, sedimentation, and granular media filtration processes. The 7-MGD UF plant consists of solids contact clarification as a pretreatment to UF membranes. Both plants utilize chloramine for maintaining a disinfectant residual in the distribution system. The two plants share the same water source, finished-water clearwell, and solids handling facilities, but are operated independently of each other by Zone 7 staff. The UF plant was designed to be a temporary pilot facility to test UF membranes for a future water treatment plant, and it is intended to be replaced when it is no longer viable.

4.3.3 Zone 7 Groundwater Wells

Zone 7 owns and operates nine municipal supply wells located in four wellfields: the Chain of Lakes, Hopyard, Mocho, and Stoneridge. These wellfields are located on the west side of Zone 7's service area, and therefore primarily serve retailers on the west side of Zone 7's system (Dublin San Ramon Services District and the City of Pleasanton). Together, the wellfields have a combined peak capacity of 41 MGD; however, the newest two wells, which are located in the Chain of Lakes wellfield and represent approximately 9 MGD in capacity, are primarily intended for emergency or drought conditions. Therefore, under normal operating conditions, Zone 7 plans on a peak capacity of 32 MGD from the wells. Table 4-1 lists the capacities of the various wells and wellfields.

There are no regulatory requirements for treating Zone 7's groundwater; however it is chloraminated to match the disinfectant residual in the treated water produced by the surface water treatment plants.

[31] Zone 7, 2009. Patterson Pass Water Treatment Plan Site Specific BMPs Plan. September.

[32] PPWTP can put water supply diverted under an existing water right permit to beneficial use through exchanges with other SWP contractors.

Table 4-1. Zone 7 Groundwater Wells

Facility	Peak Capacity		Sustained Capacity[a]
	GPM	MGD	MGD
Hopyard Wellfield			
Hopyard 6	3,800	5.5	5
Hopyard 9	1,110	1.6	1
Mocho 1 and 2 Wellfield			
Mocho 1	2,290	3.3	3
Mocho 2	2,220	3.2	3
Mocho 3 and 4 Wellfield[b]			
Mocho 3	4,170	6.0	5
Mocho 4	3,680	5.3	5
Stoneridge Wellfield	4,580	6.6	6
Total for Normal Operations	**21,850**	**32**	**29**
Chain of Lakes Wellfield			0
Chain of Lakes 1	2,500	3.6	3
Chain of Lakes 2	3,500	5.0	5
Additional Capacity	**6,000**	**9**	**8**

[a] Estimated as 90% of peak capacity.

[b] This does not include the reduction in net water production due to brine concentrate losses when the demineralization facility (see Section 4.3.4) is operating.

4.3.4 Mocho Groundwater Demineralization Plant

Reverse osmosis membrane modules at the Mocho Groundwater Demineralization Plant

The Main Basin is characterized by relatively good quality groundwater that meets all state and federal drinking water standards; groundwater is chloraminated simply to match the disinfectant residual in the distribution system. However, there has been a slow degradation of groundwater quality as evidenced by rising total dissolved solids (TDS) and hardness levels over the last few decades. To address this problem, Zone 7 developed a Salt Management Plan (SMP)[33], which was approved by the Regional Water Quality Control Board in 2004 as a condition of the Master Waste Reuse Permit and incorporated into Zone 7's Groundwater Management Plan (GMP) in 2005[34].

In accordance with Zone 7's GMP, Zone 7 completed construction of a 6.1-MGD demineralization facility at the Mocho Wellfield in 2009. This facility is referred to as the "Phase 1 Demineralization Facility" in Zone 7's Capital Improvement Program, reflecting Zone 7's plans to install additional demineralization facilities depending on the performance of the first facility and future needs.

[33] Zone 7 Water Agency, 2004. Salt Management Plan.

[34] Jones and Stokes, 2005. Groundwater Management Plan for the Livermore-Amador Valley Groundwater Basin.

Employing a reverse osmosis membrane-based treatment system, the Mocho Groundwater Demineralization Plant simultaneously allows for the removal and export of concentrated minerals or salts from the Main Basin[35] and the delivery of treated water with reduced TDS and hardness levels to Zone 7's customers. Only a portion of the groundwater pumped from the Mocho wellfield is treated at the demineralization facility; demineralized water is blended with non-demineralized water to achieve a target salt concentration (measured as total dissolved solids or TDS). Section 5.4 contains a more detailed discussion of Zone 7's Water Quality Management Program, including water quality goals and strategies.

4.3.5 Treated Water Transmission System

Zone 7's treated water transmission system consists of approximately 43 miles of pipelines ranging from 12 to 42 inches in diameter. Elevations across the transmission system range from 600 to 680 feet above mean sea level (msl) on the east side of the service area to approximately 330 feet above msl on the west side of the service area.

Construction of El Charro Pipeline in 2009

[35] The brine concentrate resulting from the treatment system is exported to the San Francisco Bay via a regional wastewater export pipeline.

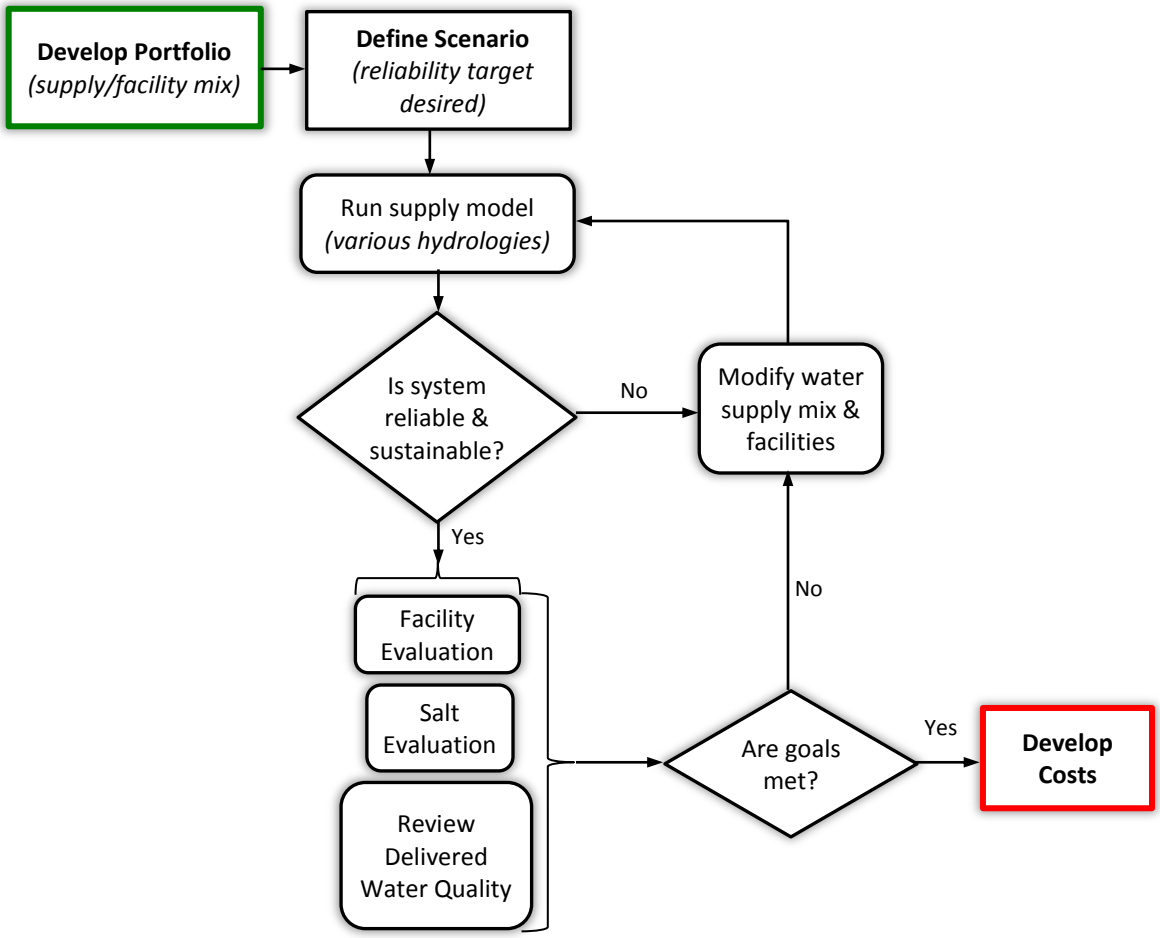
5. METHODOLOGY AND CRITERIA USED TO EVALUATE THE WATER SYSTEM

As part of evaluating each water system portfolio in this Water Supply Evaluation (WSE), Zone 7 Water Agency (Zone 7) considered new water supply options, water facilities required for meeting maximum day demands, salt balance of the underlying groundwater basin, and the delivered water quality goals established as part of Zone 7's Water Quality Management Program (WQMP). The purpose of this section is to describe the methodology and criteria used for analyzing each of these key areas as listed below:

- 5.1 Probability-Based Water Supply Methodology and Criteria
- 5.2 Water Facility Evaluation Methodology and Criteria
- 5.3 Salt Balance Methodology and Criteria
- 5.4 Qualitative Approach to Delivered Water Quality

Figure 5-1 illustrates the process used for the analysis completed in this WSE.

Figure 5-1. Methodology and Approach



5.1 PROBABILITY-BASED WATER SUPPLY METHODOLOGY AND CRITERIA

The purpose of this section is to describe the probability-based water supply model developed by Zone 7 staff to help quantify the reliability of Zone 7's water system. More specifically, this section describes the objectives of the model; the need for Monte Carlo methods; the software package selected to meet these objectives; how climate change was incorporated into the analysis; and how the model works. This section also provides definitions for system reliability and sustainability as used in this WSE.

5.1.1 Objectives of the Probability-Based Water Supply Model

Traditional long-term water supply planning assumes that subjecting a water supply system to a repeat of historical hydrology is a good predictor for future system reliability. Historically, Zone 7 has used this traditional approach, and evaluated the reliability and sustainability of its water supply system assuming a repeat of the historical sequence of wet, normal, and dry years, which has important impacts on storage reserves and the ability to meet water demands during dry years.[36]

In the last few years, however, legal and environmental concerns have introduced significant uncertainty into the future of Zone 7's largest water supply source, the State Water Project (SWP). DWR modeling projects that the long-term average yield from Zone 7's SWP supplies decreased from 75% to approximately 60% between 2007 and 2010.[37] Moreover, the expected year-to-year allocations of State Water Project supplies will become more uncertain as additional endangered species are identified in the Sacramento-San Joaquin Delta (Delta), the ecosystem of the Delta continues to decline, and more lawsuits are filed. All of these factors make it difficult to plan future water supply activities assuming a repeat of historical hydrology, especially for a storage-rich system like Zone 7's, where the number of normal and wet years between droughts required to replenish storage reserves is as important as planning for minimal water supply deliveries during critical dry years.

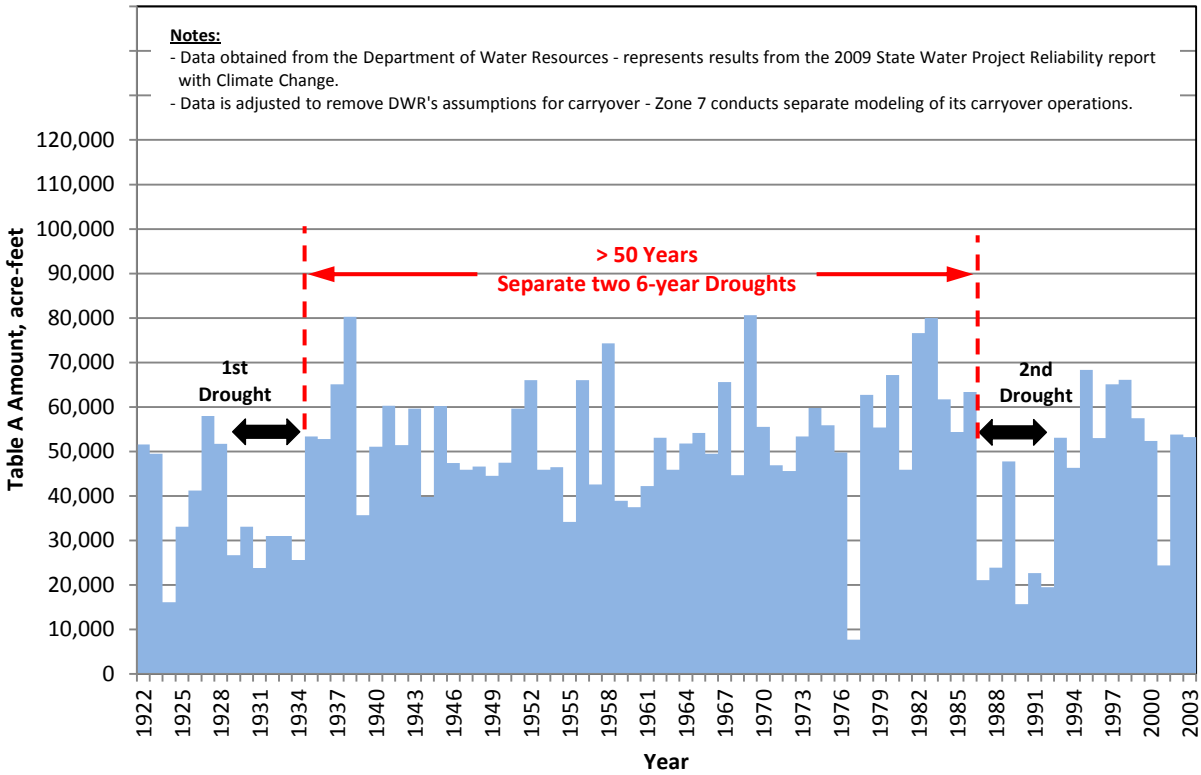
For example, the current historical sequence published in DWR's 2009 Reliability Report separates two six-year droughts by over 50 years (see Figure 5-2), which raises the following questions:

- What happens if less than 50 years separate the last six-year drought (1987 to 1992) from the next six-year drought?
- What is the probability of having sufficient drought storage before the next six-year drought if less than 50 years separate the two droughts?
- What are the implications of having droughts longer than six years?
- What is the likelihood of a water supply shortage if Zone 7 did not have over 50 years to prepare for the next six-year drought?
- What are the implications of having a critical dry year (e.g., 1977 conditions) fall right after a long drought?

[36] The historical hydrologic sequence for State Water Project supplies was obtained from CalSIM modeling completed by the Department of Water Resources, while actual historical data was used to develop the historical sequence for other supplies (e.g., runoff from Arroyo del Valle).

[37] See Section 4.1.1 for more detail.

Figure 5-2. Projected State Water Project Allocations to Zone 7



Based on these questions and other similar questions, it became clear that Zone 7 required a new water supply model that could vary the hydrologic sequence, help quantify the risk of water supply shortages, and identify the future long-term water system investments or follow-up studies necessary to minimize near-term risk of water supply shortages (i.e., the next five years).

Consequently, the main objective of developing the probability-based water supply model was to evaluate the ability of Zone 7's water supply system to handle varying hydrologic sequences, and then use the results to help:

1. Quantify the likelihood of having a water supply shortage through buildout of Zone 7's service area or the chance of having sufficient storage to allow Zone 7 to meet water demands during drought conditions, and
2. Identify the future water supply projects and follow-up studies required to maximize flexibility while minimizing risk.

5.1.2 Applicability of Monte Carlo Methods for Analyzing Zone 7's Water Supply System

Choosing only one variation or even several variations of the historical hydrologic sequence would not meet the objectives of the probability-based water supply model because any sequence not randomly selected would yield biased results—one could manipulate the sequence chosen to yield positive or negative outcomes. Additionally, if too few sequences are analyzed, then the chance of a shortage or the probability of having sufficient drought protection could be under- or over-estimated.

To eliminate this, the probability-based water supply model needed to have the ability to generate random sequences from the historical hydrologic data to stress Zone 7's existing water supply system. It

also needed to have the ability to run a sufficient number of randomly generated sequences so that the probabilities of various outcomes could be determined. The Monte Carlo method was used in this WSE to conduct this type of risk analysis.

5.1.2.1 Applicability of Monte Carlo Analysis to Meeting Objectives

The Monte Carlo method was originally developed by physicists working on the atomic bomb in the 1940's , and relies on repeated random sampling of probability distributions to generate results. The results of a Monte Carlo simulation provide thousands of different outcomes that one can use to identify the probability of different scenarios. For example, a Monte Carlo simulation helps Zone 7 staff quantify the probability of having sufficient drought storage by subjecting the existing water supply system to thousands of different sequences of Table A deliveries from the SWP, and then reviewing how often deliveries exceed demands, allowing Zone 7 to store water.

5.1.3 Software Used to Develop the Model

In addition to evaluating the existing water supply model, Zone 7 staff also evaluated three different software packages for constructing the probability-based water supply model. The pros and cons of each software package, including the existing sustainability model, are discussed below, followed by a discussion of the selected software.

5.1.3.1 Existing Water Supply Model

Zone 7 staff has an existing water balance model that was originally created in Lotus 1-2-3 and converted to Microsoft Excel. This existing water balance model simulates a repeat of the historical hydrologic sequence used by DWR in its CalSIM II model. As part of this effort, Zone 7 staff reviewed the potential for using this model.

After initial testing, however, Zone 7 staff found that the macros necessary to create and run Monte Carlo methods were extremely slow, and that Zone 7 staff would need to modify the model extensively to capture and display the necessary statistical information. Moreover, a Microsoft Excel-based statistics program (see Risk Solver below) already existed that could be used to create a new model.

5.1.3.2 Extend Simulation Model (ExtendSIM)

ExtendSIM is a software package sold by Imagine That, Inc., which allows a user to create a Decisions Support System (DSS) model for most processes; Santa Clara Valley Water District (SCVWD) used this model to support their 2005 Integrated Water Resources Planning Study. ExtendSIM has a graphic user interface (GUI) and can use Monte Carlo methods for evaluating long-term water supplies.

Zone 7 staff downloaded a demonstration version of the software, and found that it had a friendly user interface, but would likely require extensive training. Additionally, it appeared that the output of the model would still require additional processing in Microsoft Excel and/or Geographic Information System (GIS)-based software.

Depending on the version and needs, ExtendSIM costs from $1,000 to $5,000 plus a maintenance fee that would cost another $100 to $500 per year.[38] Additionally, Zone 7 staff would need outside training and guidance to develop, run, and analyze Zone 7's existing water supply system.

[38] Costs based on data obtained in the summer of 2009.

5.1.3.3 Water Evaluation and Planning (WEAP) System

The WEAP system is a software package licensed through the Stockholm Environment Institute (SEI), which allows a user to create a water balance model based on user inputs. The software uses a GUI that runs within its own shell; other key mapping data from Zone 7's GIS could be pulled into the model. DWR is also working to develop a Statewide Water Analysis Network (SWAN) based on WEAP, and used the WEAP system as part of the 2009 California Water Plan update.

Zone 7 staff downloaded and evaluated the demonstration version of the WEAP system, and found that setting up a water balance model was simple, and would be an excellent replacement for our existing water balance model. During the trial, however, it was found that the software could use sequences chosen by the user, but not randomly create new sequences based on probability distribution functions (i.e., it could not implement Monte Carlo methods).[39]

The WEAP system would cost Zone 7 approximately $3,000 every two years, not including training.[40] During the time the software is licensed, an unlimited number of users can use it simultaneously and all upgrades and technical support are free.

5.1.3.4 Risk Solver

Risk Solver is an application by Frontline Systems that runs within Microsoft Excel, and was designed for conducting risk analysis using Monte Carlo methods. The software includes standard probability distribution functions and an extensive set of tools for analyzing the enormous amounts of data generated by Monte Carlo simulations. Zone 7 staff is unaware of another water agency currently using this software to analyze the risks with their water balance models.

Zone 7 staff downloaded a trial version of the software, and found that it was simple to use, and was only limited by the number of equations or formulae one can add to Microsoft Excel. Unlike ExtendSIM or the WEAP model, however, Risk Solver did not have a GUI.

Frontline Systems sells permanent licenses for its Risk Solver application for approximately $1,000 plus an annual maintenance fee of $200.[41] All updates and technical support are provided as long as the maintenance fees are paid.

5.1.3.5 Software Package Selected for the New Model

Only two of the software packages reviewed (ExtendSIM and Risk Solver) allowed the user to implement Monte Carlo methods; the WEAP model might be a good alternative in the future if SEI modifies it for direct use of Monte Carlo methods rather than relying on third-party software. ExtendSIM would require extensive training, while Risk Solver required a basic understanding of statistical methods. Assuming that the lowest cost option for ExtendSIM was purchased, then the cost for ExtendSIM and Risk Solver would be about the same (not including training).

Most of Zone 7's data and modeling information, however, is already in Microsoft Excel, and creating a new water balance model based on the Risk Solver software was much easier than learning an entirely new software package. Additionally, most Zone 7 staff use Microsoft Excel, which makes information transfer seamless – only specially trained Zone 7 staff could run and process ExtendSIM models.

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[39] Subsequent review conducted in 2010 indicated that third-party software exists that allows WEAP modeling to incorporate Monte Carlo methods. Zone 7 staff may consider implementing WEAP in the next update of its Water Supply Evaluation.

[40] Costs based on data obtained in the summer of 2009.

[41] Costs based on data obtained in the summer of 2009.

Consequently, Zone 7 staff chose Frontline Systems Risk Solver to create Zone 7's risk model. Table 5-1 compares the software packages reviewed.

Table 5-1. Comparison of Software Packages Reviewed

Software	Ability to Directly Use Monte Carlo Methods	Training Required	Cost[(b)]
Existing Water Supply Model - Excel[(a)]	Yes, but macros slow	No	$0
ExtendSIM	Yes	Yes	$1,000 to $5000 + maintenance ($100-$500/year)
Water Evaluation and Planning Model	No[(a)]	Minimal	$3,000 every two years
Risk Solver	Yes	No	$1,000 + maintenance ($200/year)

(a) Subsequent review conducted in late 2010 indicated that third-party software exists that allows WEAP modeling to incorporate Monte Carlo methods.

(b) Based on costs data obtained in the summer of 2009.

5.1.4 Brief Description of How the Probability-Based Water Supply Model Functions

Zone 7's new model is essentially a water balance model created in Microsoft Excel; however, unlike typical water balance models, key water supplies are modeled as uncertain variables (i.e., variables without a known value) – their value is determined by randomly selecting numbers from a probability distribution function (i.e., through Monte Carlo methods). The major inputs treated as uncertain variables included local rainfall and SWP Table A allocations. The model itself runs by randomly generating a 40-year sequence of local rainfall and SWP Table A deliveries, and then conducting a water balance using that sequence. Each Monte Carlo simulation uses a different sequence. Zone 7 ran 30,000 sequences (i.e., trials) for each 40-year evaluation—or about 1.2 million years per evaluation.[42]

5.1.5 Incorporation of Climate Change into the New Model

As discussed in Section 4, allocations from the State Water Project makeup over 80% of Zone 7's long-term average water supplies; hence, climate changes that reduce State Water Project allocations likely dominate the potential impacts of climate change on Zone 7's overall water supplies. Consequently, the analysis in this WSE used DWR projections that incorporated climate change, but did not include an extensive analysis of the impacts of climate change on local water supplies (e.g., runoff from Arroyo del Valle).[43]

5.1.6 Definition of Portfolio and Scenario Used in the Analysis

For comparative purposes, Zone 7 staff used two different terms to describe each evaluation completed: (1) portfolios and (2) scenarios. Portfolios refer to the mix of different water supplies and facilities, while scenarios refer to different reliability targets evaluated.

[42] Based on numerous simulations, 30,000 trials appeared to yield consistent results without adding too much modeling time.

[43] State Water Project Allocations were obtained from the State Water Project Delivery Reliability Report 2009.

5.1.7 Definition of Reliability and Sustainability Used for this Water Supply Evaluation

Zone 7 staff used two criteria to evaluate the effectiveness of various water supply portfolios: (1) Reliability and (2) Sustainability. Each is discussed below.

5.1.7.1 Definition of Reliability

After developing the probability-based water supply model, Zone 7 staff reviewed the reliability policies for various water agencies in the Bay Area, including a separate survey commissioned by Dublin San Ramon Services District (DSRSD) in 2008, to help define reliability for planning purposes in this WSE. Based on this review, Zone 7 staff found that most water supply agencies use a maximum potential shortage to define reliability. For example, a maximum shortage of 25% implies a reliability of 75%.[44] Although this definition does indicate the maximum potential shortage, it does not express other key conditions. For example, it does not communicate the percent of time the agency will have no shortage or the frequency of shortages that are less than 25%.

Figure 5-3 presents an example risk curve at buildout developed using Zone 7's probability-based water supply model. As shown on Figure 5-3, using the maximum shortage to define the reliability only provides one point on the risk curve – this particular example shows a maximum shortage of 25%, which would imply a reliability of 75 percent. This risk curve, however, shows that in addition to a maximum, there are also ranges of shortages that are less than 25%.

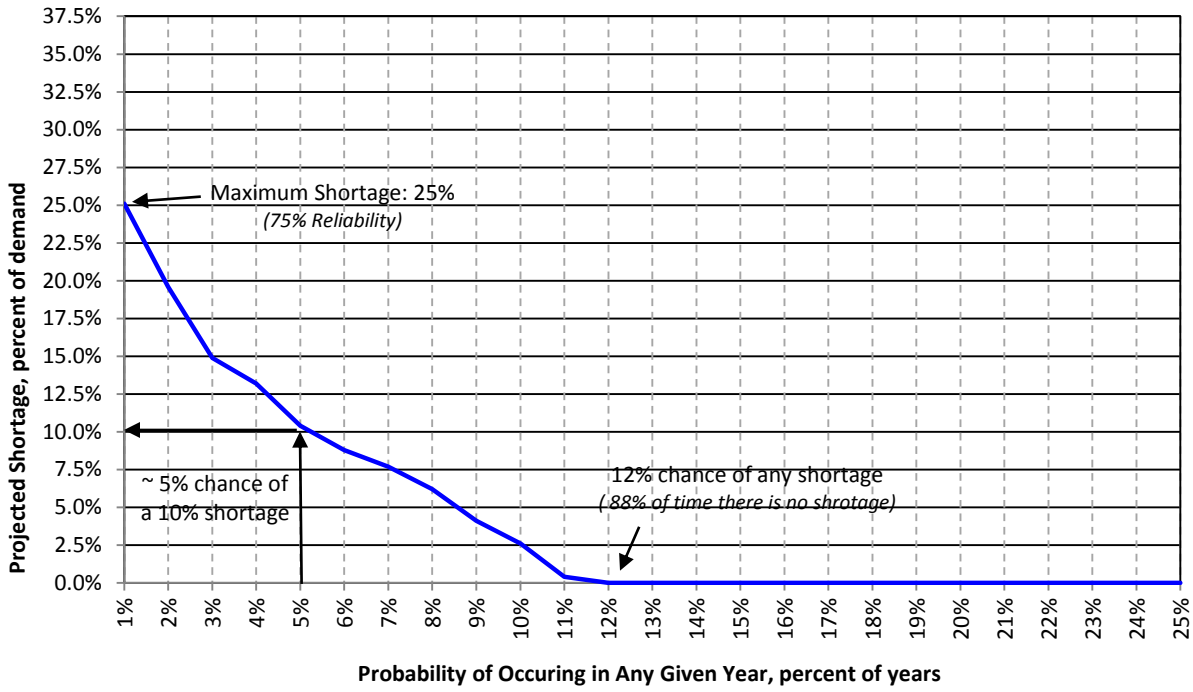
Consequently, for planning-level purposes in this WSE, Zone 7 staff defined reliability using the maximum shortage, but also added two other elements (the frequency of shortages less than the maximum and the percent of time the agency will have no shortages) to help communicate the entire risk curve. Using the example presented in Figure 5-3, the reliability would be 75 percent; however, the following information would also be included for clarity:

- a maximum shortage of 25%,
- a 5% chance of a 10% or larger shortage in any given year, and
- no shortages 88% of the time.

Zone 7 shared and discussed this definition with all four water supply retailers during workshops in November 2010, January 2011, and March 2011, while the same information was presented to Zone 7's Delta Committee in December 2010 and March 2011. Both the water supply retailers and the Delta Committee agreed that this definition of reliability was appropriate for comparative purposes in this WSE.

[44] WYA, 2008. Evaluation of Water Supply Reliability Policies for Other Bay Area and California Water Systems. November 12.

Figure 5-3. Example Risk Curve at Equilibrium[45] from the Water Supply Model



5.1.7.2 Definition of Sustainability

The term "sustainability" has been increasingly used since the 1990s. The term is generally used to imply conditions that can be maintained over the long-term. For this WSE, Zone 7 uses sustainability to describe projected long-term storage level for Zone 7's water supply system. Projected storage levels indicate whether storage is being mined to meet water demands, or more generally, whether Zone 7's water supply system can meet projected water demands during normal years without depleting drought storage reserves.

Figures 5-4 and 5-5 present example output from the probability-based water supply model for total storage within Zone 7's water supply system; Figure 5-4 presents an unsustainable scenario, while Figure 5-5 presents a sustainable scenario. As shown, the trend of median storage levels over the entire planning horizon was used to determine whether a particular scenario was sustainable over the long-term, with increasing or stable median storage levels indicating sustainability.

Zone 7 shared and discussed this definition with all four water supply retailers during workshops in November 2010, January 2011, and March 2011, while the same information was presented to Zone 7's Delta Committee in December 2010 and March 2011. Both the water supply retailers and the Delta Committee agreed that this definition of sustainability was appropriate for planning-level purposes in this WSE.

[45] Equilibrium in this case represents build out demands, after all new supplies or facilities are constructed.

Figure 5-4. Example of an Unsustainable Scenario Based on Total "End of Year" Storage

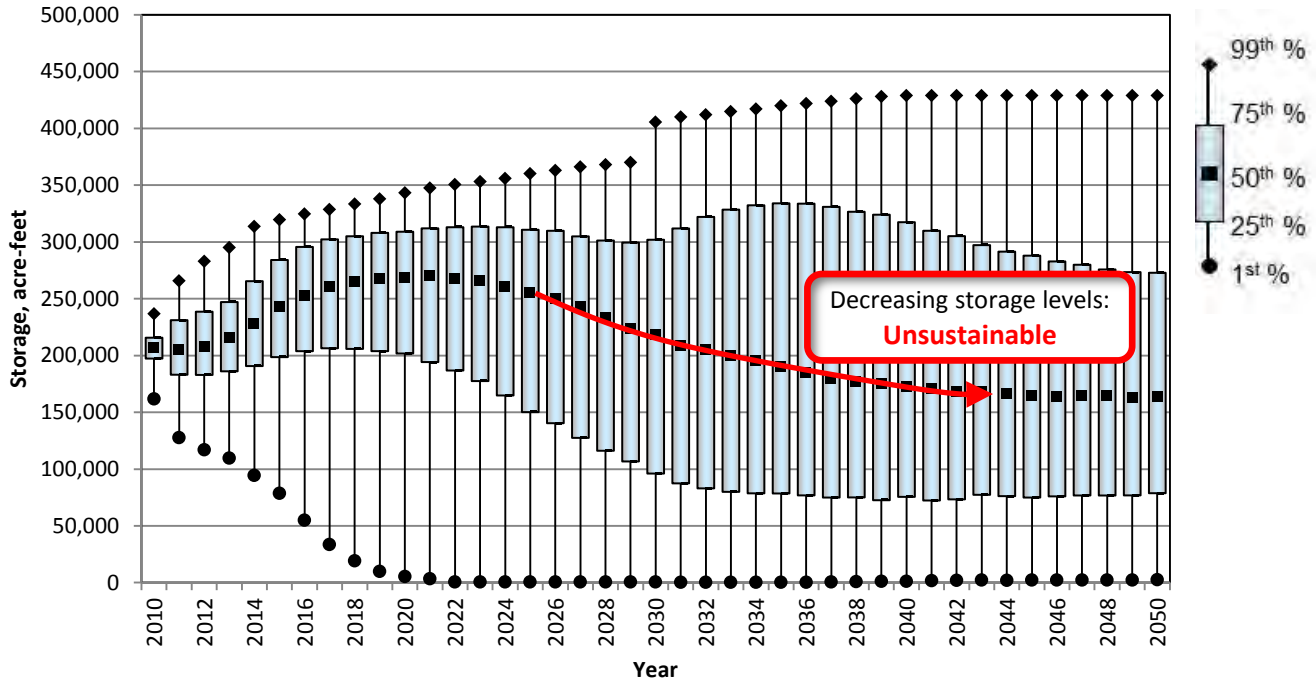
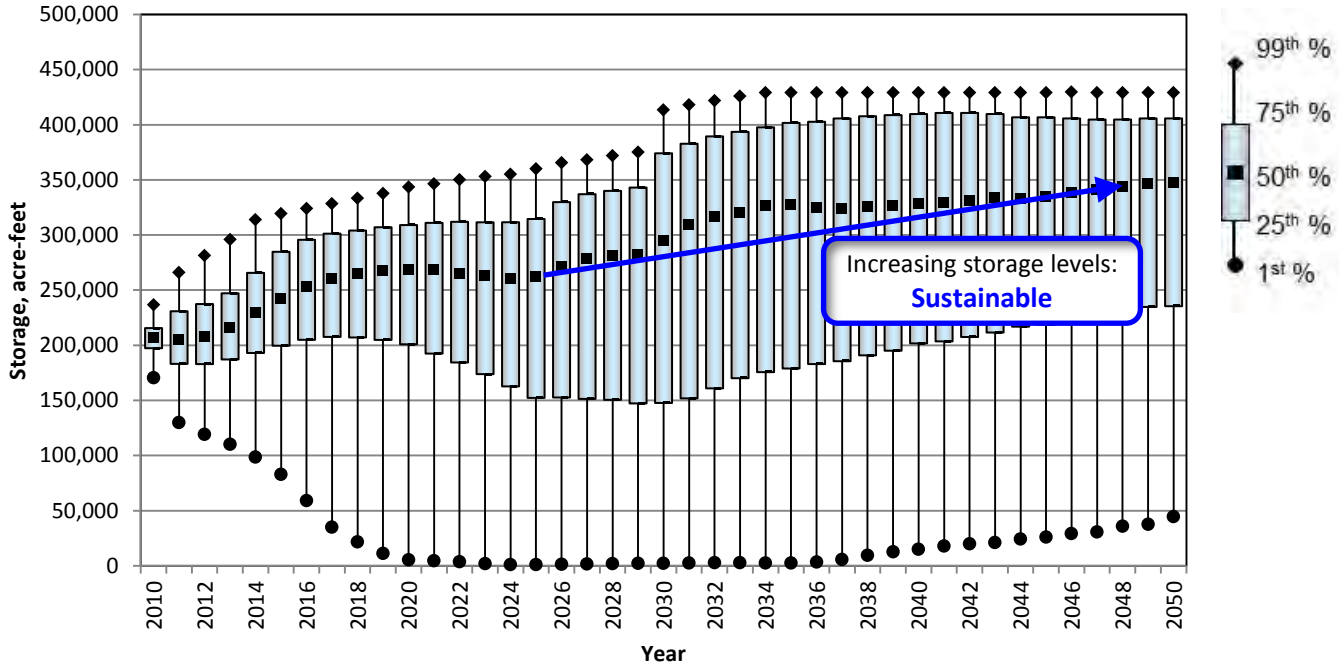


Figure 5-5. Example of a Sustainable Scenario Based on Total "End of Year" Storage



5.2 WATER FACILITY METHODOLOGY AND CRITERIA

Each of the scenarios evaluated in this WSE involved different water supply sources that could influence facility needs. This is especially true for potable water demand reductions achieved through recycled water, which removes outdoor use from the potable water system; thereby, reducing maximum day

demands (i.e., the day of the year with the highest water use). Consequently, for comparative purposes in this WSE, Zone 7 staff evaluated the ability for each water supply portfolio to meet maximum day demands, meet monthly demands during a single dry year, and meet the outage criteria established in Zone 7's existing water reliability policy[46] for facilities.

No actual hydraulic modeling was completed in support of this analysis; instead, the production capacity of existing and planned facilities was compared to projected maximum day demand and drought demand in a Single Dry Year over the entire planning horizon to determine whether established goals could be met. The following subsections present the methodology and criteria used to evaluate potential facility needs:

- 5.2.1 Summary of Facility Policies and Criteria Used in the Evaluation
- 5.2.2 Facilities and Production Assumptions for Normal Operation
- 5.2.3 Facilities and Production Assumptions for a Single Dry Year
- 5.2.4 Facilities and Production Assumptions for Outage Scenarios

5.2.1 Summary of Facility Policies and Criteria Used in the Evaluation

Table 5-2 summarizes the policies and criteria used to evaluate facility needs associated with each water supply portfolio.

Table 5-2. Summary of Policies and Criteria Used

Policy/Criteria	Goal	Comments
Facility Sizing	Meet 100% of Maximum Day Demands during Normal Operation	Analysis is based on a peaking factor of 2.0 times the average day demand.
	Meet 100% of Maximum Day Demands during a Single Dry Year	Required to determine the maximum groundwater production required.
Reliability Policy (Resolution 04-2662)	Meet 75% of maximum day demands with a major facility out of service.	Analysis reviewed the impact of the largest well field,[(a)] PPWTP,[(b)] DVWTP,[(c)] or the SBA[(d)] individually being out of service.

(a) Largest Well Field – Mocho Wellfield
(b) PPWTP – Patterson Pass Water Treatment Plant
(c) DVWTP – Del Valle Water Treatment Plant
(d) SBA – South Bay Aqueduct

5.2.1.1 Level of Service Criteria for Evaluating Facility Outages

As previously presented in Table 5-2, Zone 7 endeavors to meet 75% of maximum day demand with a major facility out of service. The typical water customer, however, does not likely fully understand the implications of this policy. Consequently, for communication purposes in this WSE, Zone 7 staff, with

[46] Resolution 04-2662, see Appendix B.

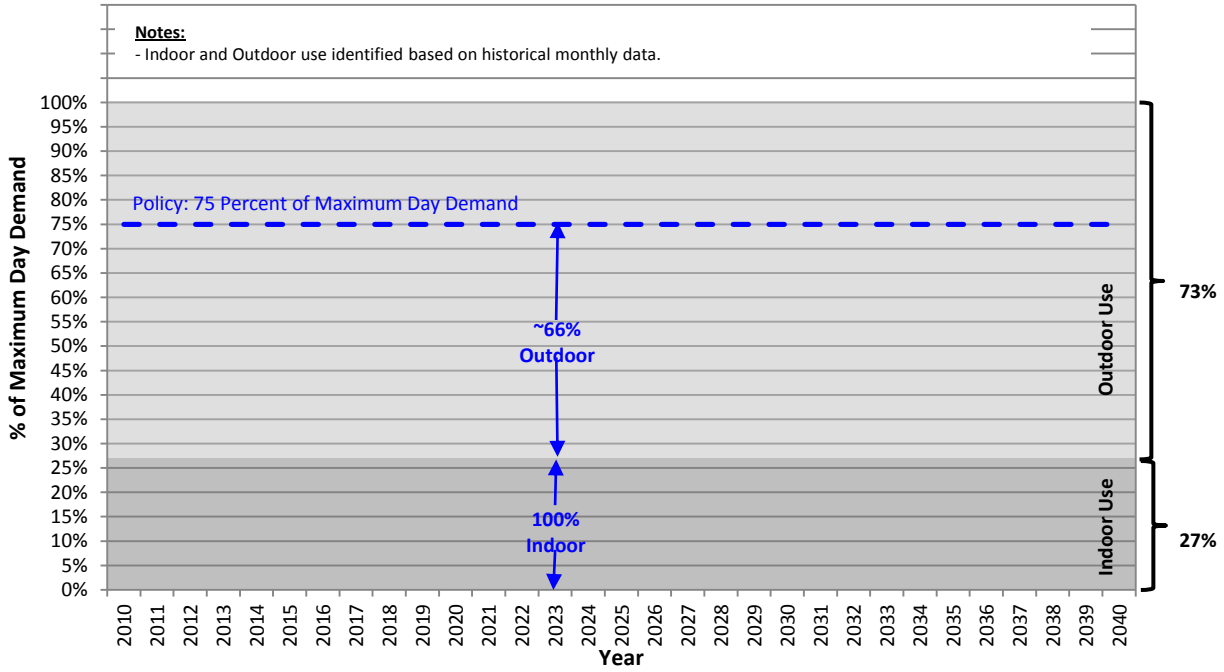
input from the local water supply retailers, also used a concept called "level of service" to help describe the reliability policy associated with facility outages.

Specifically, Zone 7 staff reviewed potable water deliveries to all four of the local water supply retailers to estimate indoor and outdoor use on the maximum day (i.e., the day of the year with the highest water use); dividing the projected maximum day demand into outdoor and indoor water use allowed expression of the facility outage criteria in different terms. This review indicated that approximately 73% of projected demand on the maximum day is associated with outdoor water uses (e.g., irrigation), while the remaining 27% was associated with indoor uses (e.g., drinking water, showers, and washing machines).[47]

Figure 5-6 compares the estimated outdoor and indoor uses on the maximum day to the current reliability policy associated with facility outages, assuming the ratio of indoor and outdoor use is consistent over time for the maximum day demand.[48] As shown on Figure 5-6, meeting 75% of the maximum day demand could also imply meeting 100% of indoor use and approximately 66% or almost two-thirds of outdoor use.

Hence, the "level of service" provided by Zone 7's current reliability policy for facility outages could be interpreted as meeting 100% of indoor water use and approximately 66% of outdoor water use.

Figure 5-6. Level of Service Interpretation of Current Facility Outage Policy



5.2.2 Facility and Production Assumptions for Normal Operation

The first criterion Zone 7 staff uses to size facilities is to provide sufficient production capacity to meet maximum day demands (called "peaking capacity") during normal operations (i.e., production

[47] A detailed description of the indoor and outdoor analysis is provided as Appendix A.

[48] The ratio of indoor to outdoor use will likely change as additional water conservation and recycled water programs are implemented in the Livermore-Amador Valley. Zone 7 staff will continue to monitor uses over time, and will make changes in this ratio as required. This ratio, however, provides an initial baseline, and helps explain the implications of the current policy.

requirements without a drought or facility outages). The comparison of total production capacity to maximum day demands helps determine the need for additional capacity. Table 5-3 summarizes the total production capacity available for all water supply portfolios during normal operation.

As shown in Table 5-3, the combined one day peaking capacity of the Del Valle Water Treatment Plant, Patterson Pass Conventional Plant, and the Patterson Pass Ultrafiltration Plant is 59 MGD, while the total production capacity including groundwater wells is 91 MGD. For planning-level purposes in this WSE, new groundwater production capacity associated with the Well Master Plan[49] (including the Chain of Lakes wells 1 and 2 completed in 2010) was only assumed available during droughts or outage scenarios; consequently, Table 5-3 also indicates that the maximum groundwater production capacity available to meet maximum day demand does not exceed 32 MGD.

Table 5-3. Existing Production Capacity for Normal Operation

Facility		Production Capacity to Meet the Maximum Day Demand, MGD[(a)]
Surface Water	Del Valle Water Treatment Plant	40
	Patterson Pass Conventional Plant	12
	Patterson Pass Ultrafiltration Plant	7
	Total Surface Water Production	*59*
Groundwater	Hopyard Wellfield	7
	Mocho Wellfield	18
	Stoneridge Wellfield	7
	Total Groundwater Production	*32*
Total Production		**91**

(a) Production capacities rounded to the nearest MGD for planning-level purposes.

5.2.3 Facilities and Production Assumptions for a Single Dry Year

During a single dry year, surface water supplies for Zone 7's treatment plants are severely limited, and although Zone 7 has access to additional supply in non-local storage (Semitropic Water Storage District [Semitropic] and Cawelo Water District [Cawelo]), the majority of Zone 7's water supply under this condition is previously-stored surface water in the local groundwater basin. Consequently, Zone 7 staff also evaluated the monthly groundwater production capacity required under each portfolio to determine the portion of water demands during a single dry year that could be met with total planned groundwater production capacity.

Table 5-4 presents the existing and planned groundwater production capacity assumed available during a single dry year. The production capacities presented in Table 5-4 represent 3-month sustainable well production capacities, not peak capacity, because the analysis of single dry year conditions considers the use of groundwater over a longer period of time - not a single day of operation. The maximum

[49] CH2MHILL, 2003. Draft Report Well Master Plan. October.

groundwater production capacity over a 3-month period is lower than during a single day of operation due to increased groundwater level drawdown caused by extended use of certain well fields.

As shown in Table 5-4, the maximum monthly groundwater production capacity during drought conditions will increase to 45 MGD by buildout, while the maximum total annual groundwater production capacity will increase to 34,400 acre-feet.[50] During drought and facility outage conditions, new wells are allowed to be placed in service.

Table 5-4. Assumed Groundwater Production Capacities during Drought Conditions[a,b]

Year	Sustainable Production Capacity over Three Months, MGD	Approximate Maximum Annual Quantity that can be Pumped in a Single Year, AF
2010	32.6	28,000
2020	37.6	30,100
2025	40	32,200
2030	45	34,400

(a) Actual production capacities depend on initial groundwater levels. Production values shown are based on the Well Master Plan, and assume that the groundwater basin is about 80 percent full.

(b) The increase from 2010 to 2030 is based on potential capacity associated with new wellfields identified in the Well Master Plan, including additional Chain of Lakes wells, Busch Valley wells, and Bernal wells.

5.2.4 Facility and Production Assumptions for Outage Scenarios

Zone 7 staff evaluated the ability of existing and planned facilities to meet maximum day demands without a major facility in operation. The major facility outages evaluated included the following:

- Largest wellfield (Mocho Wells 1, 2, 3 and 4),
- Patterson Pass Water Treatment Plant,
- Del Valle Water Treatment Plant, and
- South Bay Aqueduct (SBA) Pumping Plant.

The first three scenarios assumed that 100 percent of the facilities production capacity was out of service. However, the last scenario (SBA Pumping Plant out of service), assumed that only the PPWTP was out of service; the DVWTP can still operate because it can use surface water supply from Lake Del Valle. Table 5-5 presents the peak capacity associated with groundwater wells. As shown on Table 5-5, the peak capacity was used instead of the sustainable capacity because this particular evaluation reviewed an outage on the highest water use day of the year and lasting up to 30 days. Table 5-5 also shows that the capacity of the Del Valle Water Treatment Plant was limited to 22 MGD; this limitation reflects contractual capacity constraints in the Del Valle Branch pipeline, the pipeline that connects Lake Del Valle to the SBA – additional capacity could be available depending on the use by the other two SBA contractors.

[50] The maximum groundwater production capacities are tied to beginning of year groundwater levels. The capacities in Table 5-4 assume the groundwater basin is about 80 percent full.

Table 5-5. Assumed Production Capacities during Outage Scenarios

Facility		Facility Outage Scenario			
		Largest Wellfield[a]	Patterson Pass Water Treatment Plant	Del Valle Water Treatment Plant	SBA Pumping Plant
Surface Water	Del Valle Water Treatment Plant	40	40	0	22[c]
	Patterson Pass - Conventional	12	0	12	0
	Patterson Pass – Ultrafiltration	7	0	7	0
Groundwater[b]	2010	22	40	40	40
	2020	30	48	48	48
	2025	34	52	52	52
	2030	42	60	60	60

(a) Largest wellfield is the Mocho Wellfield. The current peak capacity of the Mocho Wellfield is 18 MGD.
(b) Assumes the demineralization facility is not operating.
(c) DVWTP was limited to 22 MGD to account for capacity limitations in the Del Valle Branch pipeline.

5.3 SALT BALANCE METHODOLOGY AND CRITERIA

As the basin manager for over forty years, one of Zone 7's key water quality objectives is to prevent the buildup of salts (calcium, magnesium, sodium, chloride, and other minerals) in the Livermore Valley Groundwater Basin. As part of its groundwater management activities, Zone 7 estimates the salt loading within the Main Basin to determine whether the buildup of salts is positive or negative. Typically, Zone 7 staff estimates salt loading by quantifying the amount of salt (measured as Total Dissolved Solids or TDS) entering or leaving the Main Basin: if the loading is positive, the regional water quality is deemed to be degrading; and if the loading is negative, then basin quality is deemed to be improving.

Zone 7 is preparing to update its Groundwater Management Plan (GWMP), which will also include an update of the Salt Management Plan (SMP). Zone 7 plans to start this effort in the next 6 to 12 months, and hopes to complete the update over the next several years. However, because each of the scenarios evaluated in this WSE involved different water supply sources and strategies (e.g., quality, quantity, and timing) that could affect salt loading within the Main Basin, Zone 7 staff performed a preliminary evaluation of potential salt loading for each scenario using a mass balance approach.

The purpose of this section is to describe the salt model used by Zone 7 staff to help estimate the potential salt loading associated with each scenario. More specifically, this section provides a brief overview of Zone 7's existing Salt Management Program and a description of the modifications made to the existing salt model in support of this WSE.

5.3.1 Previous Salt Planning and Mitigation Activities

In 2004, Zone 7 prepared a SMP to address the increasing level of total salts and to protect the long-term water quality of the Main Basin. The Regional Water Quality Control Board (RWQCB) required the SMP as part of the Master Water Recycling Permit (RWQCB Order No. 93-159, issued jointly to Zone 7, the City of Livermore, and Dublin San Ramon Services District) and approved the Final SMP in October 2004. Zone 7 incorporated the SMP into its GWMP in 2005. As part of the SMP, Zone 7 developed a spreadsheet model to calculate existing and future salt loading, and recalibrated its numeric groundwater model to project salt transport within the basin (Section 5.3.1.2). As planned for in the SMP, Zone 7 increased its groundwater pumping and constructed a demineralization facility to mitigate a portion of projected salt loading.

5.3.1.1 Salt Management Plan

The SMP identified potential salt management strategies to offset the long-term average salt loading to the Main Basin. The viable alternatives evaluated generally fell into three categories:

- Managing artificial recharge to take advantage of low-TDS imported water when available,
- Pumping and delivering more higher-TDS groundwater, which would result in more salts being exported through local wastewater disposal systems; and
- Constructing and operating a groundwater demineralization facility to remove salts that are exported as waste by-products (reverse osmosis concentrate/brine) to the San Francisco Bay, and blend the low-salt effluent with groundwater or Zone 7 system water.

The SMP also evaluated 15 basic salt management strategies (referred to as 'studies') as possible viable plans for managing water facilities to meet customer demands under any hydrologic conditions. Each of the salt management strategies was evaluated using screening criteria that included technical feasibility, timing, economics, impacts on delivered water quality, and public or institutional acceptance. One of the significant conclusions from the SMP was that certain composite salt management strategies (i.e., approaches using several individual salt management strategies) were most promising.

As discussed previously, Zone 7 is preparing to update its Groundwater Management Plan (GWMP), which will also include an update of the SMP strategies.

5.3.1.2 Salt Loading Models

As part of the SMP, Zone 7 used two methods to evaluate the viability of the strategies to remove salt from the Main Basin while minimizing negative impacts to delivered water quality; these methods included:

- A spreadsheet model to calculate existing salt loading and future steady-state salt loading, and
- An updated and recalibrated numerical groundwater basin model for groundwater flow (Visual Modflow) and solute transport (modeled as TDS using MT3D).

For this WSE, the SMP's spreadsheet model approach, described in detail below, was modified to compare the different WSE alternatives. As this WSE is a planning-level evaluation of different alternatives, the groundwater model, which provides salt migration detail within the basin, was not used, but may be used to evaluate specific alternatives as part of the GWMP update.

Historical salt loading calculations included data and information collected from Zone 7's various monitoring programs. These took into account the addition and removal of minerals in the Main Basin

by tracking the salt mass associated with the basin inflow (recharge) and outflow (discharge) components.

In general, salts are added to the Main Basin through the recharge and application of water from:

- Natural stream recharge,
- Artificial supplemental stream recharge,
- Applied water (irrigation) recharge where salts are concentrated about 6 to 10 times through the evapo-transpiration of irrigated water, and
- Subsurface groundwater inflow (i.e., seepage from adjacent sub-basins).

In general, salts are removed from the Main Basin through:

- Wastewater export where a portion of the export includes pumped groundwater,
- Reverse osmosis treatment (demineralization) of groundwater pumped from the Mocho Wellfield. The salts stripped from the source water are also exported from the Valley via a treated wastewater export line,
- Mining area discharge and export,[51] and
- Groundwater basin overflow (i.e., that portion of groundwater discharging to creeks and arroyos that flow out of the basin.

The net salt loading is calculated by multiplying the volume of each inflow and outflow component by its respective Total Dissolved Solids (TDS) concentration, and then subtracting the results.[52]

For the SMP, Zone 7 also calculated a 'steady state' salt loading for evaluating various salt mitigation alternatives. These steady-state calculations forecasted salt loading for a given set of land use conditions (e.g., water demand and urbanized acreage over the Main Basin). Values for parameters that are primarily weather dependent, such as natural stream recharge, were calculated using long-term average values. Then the volume of recharge and demand components was adjusted so there was no net change in storage to eliminate the effects of changes in salt loading simply due to changes in Main Basin volume. Salt concentrations for each of these parameters were estimated based on existing and probable future conditions.

5.3.2 Salt Loading Calculations for this WSE

Zone 7 modified the steady-state method used in the SMP for calculating salt loading to evaluate the salt loading impacts from each of the scenarios evaluated in this WSE. Modifications were made in order to calculate planning-level comparisons of both the short- and long-term salt loading on the Main Basin, and to identify the need for salt mitigation, if any, for each of the scenarios. The primary modification was to convert the steady-state calculations to transient calculations where water volumes and salt concentrations can change annually over time. The following components of the salt loading calculations were provided as transient outputs from the probability-based water supply model:

- Volumes of Artificial and Natural Recharge

[51] It should be noted that evaporation of groundwater in the mining area ponds has the effect of concentrating salts in the Main Basin as water is removed but the associated salts are left behind.

[52] Each year, Zone 7 calculates the net salt loading using volumes and concentrations measured as part of Zone 7's monitoring programs.

- Municipal Pumping
- Groundwater Basin Overflow
- Mining and Evaporation Losses
- TDS concentrations of State Water Project delivered water
- Number of additional demineralization facilities
- Retailer Demand
- Volume of Additional Recycled Water

Some of the other transient components that were not supplied by the probability-based water supply model (e.g., TDS concentration of groundwater pumped) were recalculated every year based on previous year's outputs. Other components that were not likely to change much over time (e.g., TDS concentration of natural stream recharge), or were not considered to have a significant effect on salt loading (e.g., volume of agricultural pumping) were held constant throughout the calculations.

For the In-Valley Portfolio, which included significant additional volumes of recycled water, the percentage of recycled water applied over the Main Basin was adjusted so that the long-term salt loading would be neutral or negative. It was assumed that the remainder of that recycled water would be applied over the fringe basins, or would require additional salt mitigation.

5.3.3 Methodology used to Evaluate the Results

The tons of salt added and removed from the Main Basin for each forecast year were calculated by multiplying the water volume for each supply and demand component by its corresponding TDS concentration. The salt loading effect of each change in supply or demand was evaluated using tables and graphs that show annual basin-wide salt loading.

Long-term salt loading was evaluated after equilibrium was reached (i.e., when all supply alternatives had been implemented and demand had stabilized). Average long-term salt loading, which was calculated for years 2030 to 2050, was used to evaluate whether or not additional phases of salt mitigation (e.g., demineralization) were required.

5.3.4 Limitations of the Salt Modeling Methodology

The intent of modeling salt loading as part of this WSE was to allow additional water quality comparisons of the scenarios; the intent was not to update the SMP. Consequently, the salt loading calculations include several fundamental and intentionally simplifying assumptions that were necessary for the planning-level analysis completed as part of this WSE. The key simplifying assumptions included:

1. The Main Basin is well mixed. In reality, this is not the case; salt concentrations in the upper aquifer and in the western portion of the basin are typically higher than those in the lower aquifer and in the eastern portion of the Main Basin, respectively.
2. The location of where recycled water is applied has no impact. The current model does not account for the location of the recycled water applied over the Main Basin. It is possible that certain areas of the Main Basin will be more or less susceptible to applied recycled water than others. This will be further evaluated as part of the GWMP/SMP update.
3. The primary strategy for mitigating the buildup of salts is assumed to be through additional groundwater pumping with demineralization facilities. However, the SMP update will evaluate if this is still the case.

4. Supply and demand components each have associated TDS concentrations based on recent and historical monitoring data and a few assumed (otherwise unmeasurable) values.
5. All salts applied through irrigation eventually make their way to the underlying groundwater. In actuality, vadose zone processes can delay salt transport for decades.
6. Salts removed by plant uptake and added by the application of fertilizers are considered to cancel each other.
7. For water applied over the Main Basin, percolate quality is assumed to be primarily a function of the differing percent of applied water that recharges throughout the area due to site specific variations in soil characteristics.
8. The concentration of subsurface inflow from the fringe basins into the Main Basin is constant. However, it is possible that the application of recycled water over the fringe basin will indirectly impact the Main Basin as subsurface inflow, especially to the north of the Main Basin. Unfortunately, the nature of the boundary between the fringe basins and the Main Basin is not well understood at this time and will be further evaluated as part of the SMP update.

5.4 QUALITATIVE APPROACH TO DELIVERED WATER QUALITY

For comparative purposes, each scenario was reviewed to ensure that it met the goals of the Water Quality Policy, and that the anticipated delivered water quality would meet the treated water quality targets established by the Water Quality Management Program (WQMP). The review did not include actual quantitative analysis or use of a hydraulic model; instead, each scenario was evaluated qualitatively to determine the potential positive or negative water quality impact on Zone 7's system. The purpose of this section is to briefly describe Zone 7's WQMP and the key factors considered as part of the qualitative review.

5.4.1 Description of the Water Quality Policy and WQMP

Zone 7's Water Quality Policy and its WQMP, adopted by the Zone 7 Board of Directors in 2003, were developed after extensive discussions and in cooperation with local water supply retailers, as well as other interested stakeholders. The Water Quality Policy[53] addresses several treated and untreated water goals. The treated water goals include:

- meeting or exceeding the public health requirements for drinking water, which include continual compliance with all State and Federal primary Maximum Contaminant Levels (MCLs), while reaching applicable Public Health Goals (PHGs) or MCL Goals (MCLGs), as close as feasible; and
- deliver water that is aesthetically acceptable by meeting all State and Federal secondary MCLs, mitigating earthy-musty taste and odor events from surface water supplies,[54] minimizing chlorinous odor, and reducing hardness to "moderately hard" among the retailers.

The WQMP established specific water quality targets and recommended mitigation projects that were driven by the Policy goals. The water quality targets are, for the most part, more stringent than regulatory standards to assist in guiding operations, and in the planning and design of capital projects

[53] A copy of the Water Quality Policy can be found in Appendix B.

[54] The qualitative review completed in this WSE focused on mineral water quality.

necessary to meet the Policy goals. These water quality targets also serve as operational guidelines and design criteria for future facilities.

The recommended method of mitigating hardness in the groundwater delivered by Zone 7 (typically between 240 and 650 mg/L as $CaCO_3$) is the use of wellhead demineralization. Demineralization can produce extremely soft water (less than 10 mg/L hardness) for blending with untreated groundwater to reduce delivered hardness to a level that is similar to surface water (typically less than 150 mg/L). As discussed in the previous section, groundwater pumping and demineralization has also been identified by the SMP as a key component in the management of the salt loading within the groundwater basin, so coordination with the SMP was also considered in developing recommendations for demineralization projects for water quality purposes.

To assist in the periodic updates of the WQMP, a Joint Water Quality Resolution[55] was signed between Zone 7 and two of its retailers, DSRSD and City of Pleasanton, in August 2005. This Joint Resolution includes several Policy Principles to be considered by all three agencies when developing projects and operational guidelines relating to improving water quality. There are five general areas associated with these Policy Principles: (1) General Policies, (2) Operations, (3) Facilities, (4) Education, and (5) Funding. Overall, these Policy Principles call for support of projects and operational guidelines that would improve and better equalize delivered water quality but must not result in any degradation of the existing delivered water quality for east-side retailers.[56]

5.4.2 Description of Qualitative Approach to Delivered Water Quality

Each of the scenarios evaluated in this WSE involved different water supply sources that had different water quality characteristics and might require groundwater demineralization to mitigate the potential additional salt loading to the Main Basin. Consequently, each scenario could change the delivered water quality in Zone 7's system; therefore, Zone 7 staff evaluated each water supply portfolio under each scenario by qualitatively answering the following basic questions:

- *Does the anticipated treated water quality meet the treated water goals of the Water Quality Policy, and more specifically, does it meet the treated water quality targets set forth in the WQMP?*
- *Does the anticipated treated water provide similar or better delivered water quality than existing supplies?*

The second question is to ensure that each portfolio does not degrade existing treated water quality.

As Zone 7 staff reviewed the potential influence of each water supply portfolio on delivered water quality, special attention was given to TDS and hardness. TDS accounts for all dissolved solids, while two specific compounds (calcium and magnesium) cause hardness. At high levels, TDS also has aesthetic impacts, imparting a salty taste to the water. The SMP uses TDS to monitor the amount of salt loading within the groundwater basin, while the WQMP focused on reducing the aesthetic and economic impacts of hard water.

Hence, Zone 7 staff reviewed the TDS and hardness associated with each source of supply in each portfolio. If overall TDS and hardness for each source of supply were better than current sources, then it was considered as a potential candidate for improving delivered water quality.

[55] A copy of the Joint Water Quality Resolution can be found in Appendix B.

[56] The east-side of Zone 7's system generally receives more surface water.

6. CURRENTLY PLANNED FACILITIES AND ACTIONS

The purpose of this section is to discuss the programs and projects that Zone 7 is already undertaking, or already plans to undertake, in order to improve the reliability of the water supply for the Livermore-Amador Valley. The components included in this "Current Plan"—broken down by water supplies, facility improvements, and water quality—are identified in Table 6-1 and discussed in more detail in the following sections.

Table 6-1. Components of the Current Plan

Type	Component
Water Supplies	Long-Term Delta Fix
	Potable Demand Reductions
	Confirmation of Minimum Yield from BBID Contract
	Reduction of Unaccounted-for-Water
	Reduction of Brine Losses
	Enhanced In-Lieu Recharge Program
	Arroyo del Valle: Perfection of Existing Permit
Facility Improvements	Increased Surface Water Treatment Capacity
	Increased Groundwater Pumping Capacity
	Increased Transmission System Capacity
	Arroyo Mocho Diversion Structure
	Arroyo del Valle Diversion Structure
	Reliability Intertie
Water Quality	Phase 2 Demineralization Facility

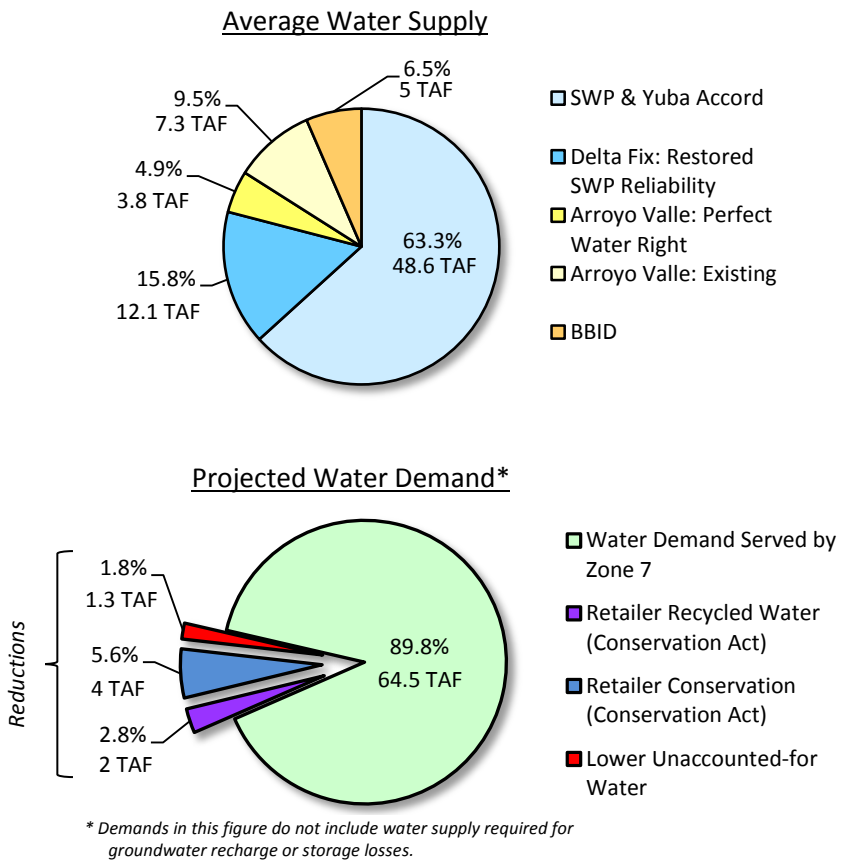
6.1 WATER SUPPLIES

Under the Current Plan, Zone 7's water supply and demand balances are expected to be improved in several ways. In addition to restored yield from the SWP from the Delta Fix, additional supplies are expected through confirming the yield from the Byron Bethany Irrigation District (BBID) contract, and perfection of the Arroyo del Valle water right permit made possible through facility improvements[57]. Potable water demands are also expected to decrease through the implementation of the Water

[57] Future facilities required to full perfect the existing water right permit include the Chain of Lakes, which are currently being quarried; Zone 7 does not have control over how fast the quarry operators complete their activities.

Conservation Act of 2009. Losses are minimized through the reduction of unaccounted-for water and brine losses from the Mocho Groundwater Demineralization Plant. Finally, an enhanced in-lieu recharge program will provide more locally stored water supply during dry years until additional recharge capacity is available via the Chain of Lakes. Figure 6-1 provides a summary of projected average water supply and water demands under the Current Plan.

Figure 6-1. Projected Supply and Demand Mix: Current Plan



6.1.1 Long-Term "Delta Fix"

As described in Section 4.1, Zone 7 currently has a long-term contract with the Department of Water Resources (DWR) for a maximum annual amount of 80,619 acre-feet (AF) of Table A water from the State Water Project (SWP), which translates to a long-term average yield (currently at 60%) of 48,400 acre-feet annually (AFA). This amount represents over 80% of Zone 7's supply and is therefore critical to the overall reliability of Zone 7's water supply system. Each year, DWR allocates a portion of this annual amount—up to 100%—depending on hydrologic conditions, DWR's operation of the SWP, and legal and environmental constraints.

6.1.1.1 New Legal and Environmental Constraints

From 2005 to 2009, DWR reduced the projected long-term average allocation of Table A water from approximately 75% to 60% due to projected impacts associated with pumping restrictions in the Delta

and climate change. Pumping restrictions—as described in the Biological Opinions (B.O.) issued in December 2008 and June 2009 by the two federal fish agencies[58]—result from concerns over threatened and endangered species in the Delta, with the Delta smelt and certain salmon species being of particular concern. This decrease in reliability from the SWP has reduced Zone 7's sustainable water supplies by approximately 12,100 acre-feet (AF).[59]

6.1.1.2 Delta Fix: BDCP and DHCCP

A diverse stakeholder group is working together on the Bay Delta Conservation Plan (BDCP) in order to simultaneously address threatened and endangered species protection and the restoration of the reliability of water traveling through the Delta. The BDCP is a 50-year plan that would address the challenges facing the Delta with an ecosystem-based approach. In parallel, the Delta Habitat Conservation and Conveyance Plan (DHCCP) is developing alternatives for conveying SWP (and Central Valley Project [CVP]) water across the Delta in an environmentally-sound manner. The DHCCP will develop an Environmental Impact Report (EIR)/Environmental Impact Study (EIS), along with the preliminary design needed to support a decision and ultimately to construct alternative Delta conveyance facilities. Together, the BDCP and DHCCP processes are expected to result in a "Delta Fix".

Stakeholder groups involved in the BDCP and DHCCP development include DWR, fish and wildlife agencies, SWP and CVP contractors, environmental organizations, and other groups. As a contractor of the SWP that is highly reliant on water supply coming through the Delta, Zone 7 is actively engaged in the development of the BDCP and the DHCCP. Notably, Zone 7's General Manager is a member of the DHCCP Executive Committee.

The BDCP is evaluating both canal and tunnel systems as isolated conveyance options through the Delta, with capacities ranging from 3,000 to 15,000 cfs (Figure 6-2). As of December 2010, DWR has identified a tunnel system as the likely candidate. A dual-conveyance system is envisioned, with new primary intakes in the North Delta on the Sacramento River and an isolated conveyance system transporting water under the Delta to the existing Clifton Court Forebay in the South Delta. The existing South Delta diversion facility will be used as a stand-by facility, either used in conjunction with the new North Delta facility to optimize water quality and minimize fish impacts or used on its own when needed due to maintenance or repair requirements.

[58] The December 15, 2008 US Fish and Wildlife Service B.O. evaluated impacts to the delta smelt. The June 4, 2009 National Marine Fisheries Service B.O. evaluated impacts to winter-run and spring-run Chinook salmon, steelhead, green sturgeon, and resident killer whales.

[59] Reduction = 80,619 AF x (75% - 60%)

Figure 6-2. Isolated Conveyance Option in the Delta Being Considered in the BDCP[60]

[60] Source: http://baydeltaconservationplan.com/. Accessed March 2011.

6.1.1.3 Delta Fix Assumptions

Current plans indicate a goal of having a new Delta conveyance system in place between 2020 and 2030. For planning purposes, Zone 7 has assumed a new system to be available by 2025 that would restore SWP long-term water supply reliability to conditions before the B.O.s were issued, at approximately 75% (60,500 AFA for Zone 7). The alternative Delta conveyance facilities are also expected to result in a minimum allocation of approximately 10%.

In addition to improved reliability, the isolated conveyance option is expected to result in lower salinity levels, as well as other improved water quality parameters (e.g., total dissolved organic carbon). Table 6-2 below summarizes the anticipated changes in total dissolved solids (TDS) levels in the SWP supply used directly by Zone 7, and SWP supply used for recharge activities (Appendix C contains more detailed information on the variability of TDS levels in the SBA and in the vicinity of the proposed new intakes on the Sacramento River). Recharge is most active between the months of April and October, which generally coincides with lower TDS levels in the SBA. Furthermore, in case of levee failures, an isolated conveyance facility will better protect the SWP supply from salinity and organic carbon spikes, and other potentially drastic water quality impacts.

Table 6-2. Expected Improvements in TDS Levels Resulting from Delta Fix

SWP Supply	Existing TDS Levels (mg/L)	TDS Levels After Delta Fix (mg/L)*	% Reduction
Direct Use	240	190	~21%
Main Basin Recharge	220	172	~22%

*Based on current TDS levels at the Sacramento River at Hood water quality station.

The tunnel option is expected to cost approximately $12 billion dollars with costs shared amongst SWP and CVP contractors. The capital cost to Zone 7 is estimated to be approximately $140 million dollars to be paid over 40 years.

The determination of whether a Delta Fix will be implemented—and, if so, the final selection of the conveyance facility type and sizing—will likely not be determined until the environmental review process has been completed in the next two years. Zone 7 hopes to have more definitive answers by 2013 or 2014.

6.1.2 Potable Demand Reductions

As discussed in Section 3.3.5, a demand reduction of 6,000 AF is expected from the implementation of the Water Conservation Act of 2009 (Conservation Act) by the water supply retailers (California Water Service Company [Cal Water], Dublin San Ramon Services District [DSRSD], City of Livermore [Livermore], and City of Pleasanton [Pleasanton]; collectively referred to as the "Retailers") in Zone 7's service area. The reduction is expected to be achieved through traditional conservation approaches and increased use of recycled water in the Livermore-Amador Valley as described below.

6.1.2.1 *Traditional Water Conservation*

The traditional water conservation approach involves Best Management Practices such as the installation of water-efficient appliances such as toilets, washing machines, showerheads, etc.; improved landscape irrigation management; leak detection and control; tiered conservation pricing; and metering. For planning purposes, Zone 7 has assumed that these methods will achieve two-thirds (approximately 4,000 AFA) of the necessary demand reduction under the Conservation Act for the service area.

6.1.2.2 *Recycled Water for Conservation Act Compliance*

Recycled water is an increasingly important component of the total supply portfolio for the Livermore-Amador Valley. While Zone 7 does not produce or distribute recycled water directly, recycled water is produced by two retailers within the Zone 7 service area that also manage wastewater: DSRSD and Livermore. Together, these two retailers served 3,100 AF of recycled water in 2009. By 2030, DSRSD and Livermore are planning to serve 5,900 AFA of recycled water, accounting for the projected development and growth in recycled water infrastructure in their service areas.

Zone 7 assumed that additional recycled water use beyond that planned by DSRSD and Livermore would be used to meet the potable water demand reductions required under the Conservation Act. For planning purposes, Zone 7 assumed that increased production and use of recycled water will contribute towards one-third (approximately 2,000 AFA) of the demand reduction required under the Conservation Act. This assumption allowed Zone 7 to evaluate the potential implications of using recycled water for all scenarios.

Zone 7 is working with the Retailers to evaluate increasing local recycled water supplies.

As the groundwater basin management agency, however, Zone 7 is cognizant of the potential salt loading impacts arising out of recycled water use. Consequently, Zone 7 has taken a pro-active approach to mitigate such impacts, particularly within the Main Basin. Zone 7 is also aware that expansion of recycled water use over the groundwater basin may require additional measures to mitigate associated additional salt loading. Therefore, Zone 7 staff is recommending that any relevant changes to recycled water programs be incorporated into the planned update of the Groundwater Management Plan and Salt Management Plan.[61]

6.1.3 Confirmation of Minimum Yield from BBID Contract

Zone 7 currently has a contract with the Byron Bethany Irrigation District (BBID) that can provide up to 5,000 AFA, but the minimum yield is limited to 2,000 AFA; the contract is valid through 2030 with an option to extend through 2039 and beyond[62]. Zone 7 plans to monitor closely the available supply from

[61] Zone 7 Water Agency, 2004. Salt Management Plan.

[62] See Section 4.1.2 for more details.

BBID over the next several years and will work with BBID to determine if a higher minimum yield is possible.

For planning purposes, Zone 7 expects to spend approximately $100,000 in investigating how the BBID contract yield can be maximized, and hopes to complete the study by 2013.

6.1.4 Reduction of Unaccounted-for-Water

Zone 7 plans to undertake an investigation to reduce unaccounted-for water from 4% to 2% of total demand. Historical records indicate that unaccounted-for water losses were less than 2% between 1995 and 2002. After 2002, unaccounted-for water losses increased to about 4% on average. Zone 7 has assumed that UAFW can be reduced from 4% to 2% of total production by the end of 2012. By 2020, this decrease in UAFW is estimated to result in approximately 1,200 AF of annual demand reduction.

For planning purposes, this effort is estimated to cost approximately $500,000 in capital costs and $100,000 in annual operation and maintenance costs. An investigation into UAFW is planned to be completed before the end of 2012.

6.1.5 Reduction of Brine Losses at the Mocho Groundwater Demineralization Plant

The Mocho Groundwater Demineralization Plant (MGDP, or Phase 1 Demineralization Plant) uses reverse-osmosis membranes to desalinate groundwater. This process removes and concentrates the salts in a brine solution that is ultimately discharged via a regional wastewater export pipeline to the San Francisco Bay. A portion of the influent water is lost through the disposal of this brine solution or concentrate. The percentage of the influent water that is ultimately produced by the desalination process is commonly called the recovery rate. Brine disposal is regulated under a permit, which specifies the allowable concentrations of constituents such as metals, etc. in the brine.

Influent or raw water quality data collected during the design of the MGDP indicated that certain constituents (e.g., Arsenic) were present in levels below the detection limit. To be conservative, the concentrations of these constituents were assumed to be at the detection limit; these concentrations were then used to calculate the amount of water needed in the brine to keep constituent levels below discharge limits. This translated to setting MGDP operational parameters at a 20 percent brine loss, or, equivalently, a recovery rate of 80 percent even though recovery rates as high as 85 to 90% are possible. Now that actual brine water quality data is available from the MGDP operations, Zone 7 plans to review this data to determine whether the MGDP can be operated effectively with a 15% loss or 85% recovery rate without exceeding constituent discharge limits. This change could potentially result in an additional 260 AFA of supply.

For planning purposes, Zone 7 expects to spend approximately $100,000 in investigating how the recovery from the Mocho Groundwater Demineralization Plant can be increased, and hopes to complete the study by the end of 2013.

6.1.6 Formalization of Enhanced In-Lieu Recharge Program

Per existing contracts with Zone 7's retailers, Zone 7 has the option of implementing in-lieu recharge, an agreement in which a retailer reduces pumping of its GPQ from the Main Basin and instead receives additional surface water as replacement. This has the effect of maintaining greater storage in the Main Basin, essentially increasing the ability of Zone 7 to “recharge” the Main Bain without being limited by the recharge capacity of the streams.

Zone 7 plans to develop a framework for exercising existing in-lieu recharge components of the current contracts with the retailers to optimize groundwater storage in the Main Basin. Although this enhanced

storage would not provide new water supplies, it would increase the rate at which drought storage can be replenished during drought recovery, which would reduce the chance of a shortage.

For planning purposes, this effort is estimated to cost approximately $200,000; Zone 7 hopes to have this in place within the next few years.

6.1.7 Arroyo del Valle: Perfection of Existing Water Rights Permit

Zone 7 and Alameda County Water District (ACWD) have water right permits to divert flows from Arroyo del Valle. Inflows into Lake Del Valle—after accounting for permit conditions—are equally divided between ACWD and Zone 7. Unlike ACWD, however, Zone 7 is still perfecting its water right; perfection of the water right is contingent on Zone 7 taking full ownership of the Chain of Lakes, which is expected to occur sometime around 2030. Zone 7 projects that it may be able to add over 3,000 AFA to its long-term water supplies upon perfection of the water right.

For planning purposes, Zone 7 expects to spend approximately $1 million in preparing for increased capture of Arroyo del Valle water beginning in 2030.

6.2 CURRENTLY PLANNED FACILITY IMPROVEMENTS

Zone 7's current plans also include facility improvements for water supply and reliability, not only for the long-term, but also during peak demand periods over the course of the year.

6.2.1 Increased Surface Water Treatment Capacity

Zone 7 is evaluating the merits of either building a new water treatment plant or expanding the existing PPWTP.

Zone 7 requires additional surface water treatment capacity to meet both max day demands and facility outage conditions. Between 2004 and 2007, Zone 7 completed the design of the Altamont Water Treatment Plant (AWTP) and Altamont Pipeline (APL), and awarded a contract for constructing the first half of the APL, called the Livermore Reach, in April 2008. Zone 7 completed construction and testing of the Livermore Reach in September 2009. The Livermore Reach was constructed first because it provides a valuable interconnection within Zone 7's existing transmission system regardless of whether Zone 7 constructed the AWTP or remaining portion of the APL.

Based on a slower than anticipated growth in Municipal and Industrial (M&I) water demands and the concerns over capital and energy costs, Zone 7 decided to conduct a peer review of the proposed AWTP site and treatment process before proceeding with construction. The peer review was completed in December 2009.[63] Based on the analysis completed, the only viable alternative to the existing AWTP site was the expansion of the existing Patterson Pass Water Treatment Plant (PPWTP) (described in Section 4.3.2). The analysis also indicated that economics alone would not necessarily determine whether expanding the PPWTP is better for Zone 7's long-term needs because the difference in costs between the two options is within the contingency estimates typically used for planning purposes for Zone 7's Capital Improvement Program (CIP).

Zone 7 will continue to plan for the construction of a new surface water treatment plant, while

[63] WQTS, 2009. Peer Review of the Altamont Water Treatment Plant Site and Treatment Process Report.

monitoring future max day demands and potential changes resulting from the implementation of the Water Conservation Act of 2009. Key factors to include in the final determination of the plant location and size are the projected average and max day demands, the capacity available in the South Bay Aqueduct (SBA), and any revisions to existing policies. Potential sizing and costs of new water treatment plant under the Current Plan is discussed in Section 7.

6.2.2 Increased Groundwater Pumping Capacity

Section 5.2 describes the need for additional wells in the Main Basin to provide supply reliability during drought, meet demands during facility outages, and reduce localized drawdown of groundwater levels below historical lows, as previously identified in the Well Master Plan[64]. The additional wells will also provide Zone 7 with improved ability to manage groundwater levels, groundwater flow, salt build-up and removal, and delivered water quality. In 2010, two new wells with peak capacities of 3.6 and 5 MGD were installed in the Chain of Lakes wellfield as Phase 1 of the Well Master Plan implementation. Additional wells are planned to be constructed over the next twenty years or so, resulting in a total sustainable production capacity of 45 MGD during drought conditions.

Similar to existing wells, groundwater pumped from the new wells will require chemical treatment prior to entering the distribution system, likely using chloramination. Based on site-specific considerations, treatment may occur in a building adjacent to the well/s; there may be a common treatment system for multiple wells or individual treatment systems. Conveyance facilities will need to be constructed to connect new wells to the existing distribution system. New pipes will likely range in size from 10 to 36 inches in diameter.

The total cost of the additional new wells is estimated at $64 million in capital costs, with the next well expected to be in-service by 2020. Additional annual O&M costs are expected to be around $200,000.

6.2.3 Increased Transmission System Capacity

As noted in Section 6.4.1, Zone 7 plans to construct a new surface water treatment plant to accommodate max day demands and facility outages through buildout. Zone 7's transmission system will need to be expanded accordingly to handle the higher flows. For cost comparison purposes only, Zone 7 has assumed a new surface water treatment plant at the PPWTP site, which will require the construction of a larger-diameter transmission pipeline leaving the PPWTP.

The total capital cost of this pipeline is estimated at $16.8 million. The construction of this pipeline—or the equivalent facility—will be coordinated with the construction of the new water treatment plant. For planning purposes, additional annual O&M costs are estimated at $50,000 for the new pipeline.

6.2.4 Arroyo Mocho Diversion Structure

As described in Section 4.2.3, Zone 7 expects to take ownership of Lake H—one of the quarry pits or lakes in the Chain of Lakes—sometime in the next five years. Lake I, which is already owned by Zone 7, and Lake H are intended to be used as artificial groundwater recharge percolation ponds. To deliver water to Lakes H and I for recharge, Zone 7 will release excess water into the Arroyo Mocho; a new diversion structure will then divert water from Arroyo Mocho to Lake H. Water will flow

Zone 7 is evaluating enhanced artificial groundwater recharge using Lakes H and I.

[64] CH2M Hill, 2003. Well Master Plan.

into Lake I through an existing conduit and then recharge into the Main Basin. Zone 7's enhanced artificial recharge capacity in the Main Basin will increase the rate at which storage reserves are replenished during drought recovery, which will reduce the chance of a water supply shortage. The addition of surface water to the lakes will also help offset evaporative losses from the groundwater basin due to the existence of the gravel quarry pits, and help protect the groundwater basin from salt build-up

For planning purposes, Zone 7 expects to spend approximately $2 million in capital costs for the Arroyo Mocho diversion structure, which is expected to be online sometime after 2014. Additional annual O&M costs are estimated at $200,000.

6.2.5 Arroyo del Valle Diversion Structure

It is anticipated that seven of the ten lakes in the Chain of Lakes (Lakes A to G) will not be dedicated to Zone 7 until after 2030. After mining of Lake A is completed, sometime around 2030, Zone 7 will have the ability to move its water supplies into the Chain of Lakes. Zone 7 is already planning to construct a diversion structure to move the water into Lakes A through I. Similar to the Arroyo Mocho diversion structure, permits will likely need to be obtained for this facility. Operational regulatory requirements will likely require the installation of fish screens, screen cleaning devices, monitoring equipment and automatic controls.

For planning purposes, the total capital cost for the Arroyo del Valle diversion structure is estimated at $5 million. It is expected to be in service by 2030, in time for when Zone 7 takes full ownership of the Chain of Lakes. Additional annual O&M costs are estimated at $250,000.

6.2.6 Feasibility Investigation of a Reliability Intertie

Section 4.1 describes Zone 7's critical dependence on water supplies being transported via the SBA—supplies that represent approximately 90% of Zone 7's incoming water (the SWP by itself represents approximately 80% of Zone 7's supply). Furthermore, during a drought, Zone 7's water supply stored in Kern County will need to be transported through the SBA as well. An outage of the SBA or major disruptions in the Delta that would prevent water transport to the SBA could potentially have catastrophic impacts to Zone 7's service area. In such an event, Zone 7 would be fully reliant on available water stored in Lake Del Valle—shared along with the two other SBA contractors—and on groundwater stored in the Main Basin. The severity of water shortage would depend on the timing of the event (e.g., winter versus late spring, middle of a drought period or after a series of wet years), which has significant implications on the amount of local water that would be available to Zone 7.

Delta and SBA outages and disruptions could result from terrorist acts, major storm events, and earthquakes. Earthquakes, in particular, are a major concern. The Greenville fault crosses the SBA in several locations. According to DWR's Delta Risk Management Study Phase 1 Report[65], "*a major earthquake of magnitude 6.7 or greater in the vicinity of the Delta Region has a 62 percent probability of occurring sometime between 2003 and 2032*." DWR further states that "*A seismic event is the single greatest risk to levee integrity in the Delta Region*" and that "*there is a 40 percent probability of a major earthquake causing 27 or more islands to flood…in the 25-year period from 2005 to 2030*." Recent estimates indicate that a major earthquake event could result in disruptions of SWP supplies for up to a year[66].

[65] DWR, 2009. Delta Risk Management Study (DRMS) Phase 1 Report

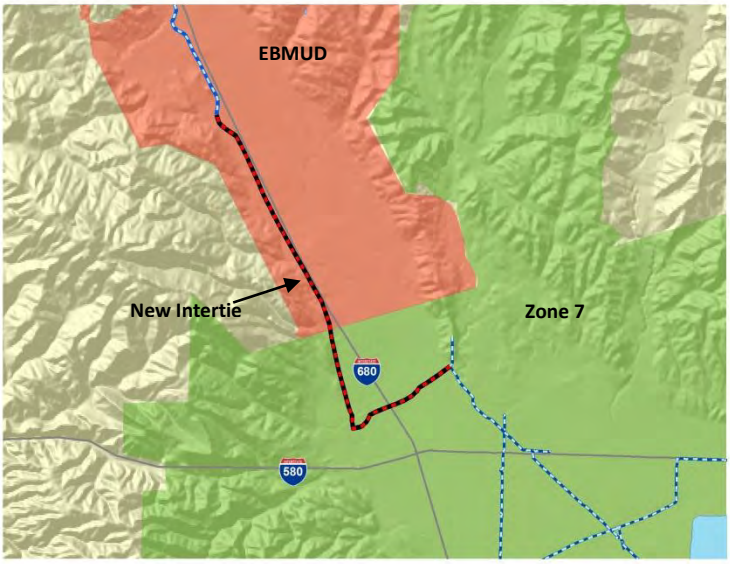
[66] DWR, 2009. 2009 State Water Project Delivery Reliability Report.

One way to help mitigate the significant risk to Zone 7's water supply under Delta/SBA outage conditions is to construct a new intertie with another water supply agency that would provide an additional means of acquiring water during such events. The most logical agency to connect to is the East Bay Municipal Utility District (EBMUD), whose service area is contiguous to the northwest portion of Zone 7's service area in the cities of Dublin and San Ramon. In fact, DSRSD already has three small interties with EBMUD ranging in size from 0.7 to 1.4 MGD. Another option could include connecting to the San Francisco Public Utilities Commission (SFPUC) facilities located on the eastern side of Zone 7's service area.

Zone 7 staff is still working with both EBMUD and SFPUC staff to better define potential benefits and roles in a new intertie project. Similar to Zone 7, EBMUD and SFPUC are partners in the Bay Area Regional Desalination Project (BARDP)[67], which would make use of a new intertie.

Zone 7 plans to investigate the feasibility of a reliability intertie with EBMUD and other agencies, including factors such as flow capacities under various conditions, possible site locations, etc. Figure 6-3 illustrates a potential alignment for the intertie with EBMUD. Based on this alignment and a 24-inch diameter pipeline, Zone 7 estimates a total capital cost of $18 million, with a potential in-service year of 2018.

Figure 6-3. Potential Alignment of a Reliability Intertie with EBMUD



6.3 WATER QUALITY: PHASE 2 DEMINERALIZATION FACILITY

A second demineralization facility with a planned capacity of 6.2 MGD of delivered water is already included in Zone 7's current Capital Improvement Program. Similar to Phase 1, Phase 2 is expected to remove salt from the Main Basin and have the added benefit of providing water with lower hardness and TDS levels, in accordance with Zone 7's Water Quality Management Program.

Zone 7 staff is recommending that the timing and sizing of Phase 2 be evaluated as part of the Salt and Nutrient Management Plan update, which will be part of the Groundwater Management Plan update

[67] Discussed in Section 9.2.

planned to be completed over the next several years. For comparison purposes, the Water Quality costs are based on a demineralization facility with capital costs totaling $36 million and annual O&M costs of $1.4 million.

7. EVALUATION OF THE CURRENT PLAN

The purpose of this section is to present the analysis and results of using the probability-based water supply model to determine the reliability provided by the Current Plan, and if necessary, present any potential changes to the Current Plan required to increase the reliability. As discussed in Section 6, the Current Plan assumed that the State of California implements a Delta Fix, and the local water supply retailers reduce potable demands mandated by the Water Conservation Act of 2009 (Conservation Act). The Current Plan also assumes that Zone 7 Water Agency (Zone 7) successfully reduces its unaccounted-for water, reduces brine losses, increases the minimum yield from its contract with Byron-Bethany Irrigation District (BBID), and enhances its an in-lieu recharge program.

The following subsections present the results:

- 7.1 Baseline Reliability for the Current Plan: 85%
- 7.2 Potential Measures for Increasing Reliability Above 85%
- 7.3 Reliability for the Current Plan: 90 to 99%
- 7.4 Facilities Evaluation for the Current Plan
- 7.5 Salt Management Evaluation for the Current Plan
- 7.6 Observations Regarding Delivered Water Quality
- 7.7 Cost Estimates for the Current Plan: 85 to 99%

7.1 BASELINE RELIABILITY FOR THE CURRENT PLAN: 85%

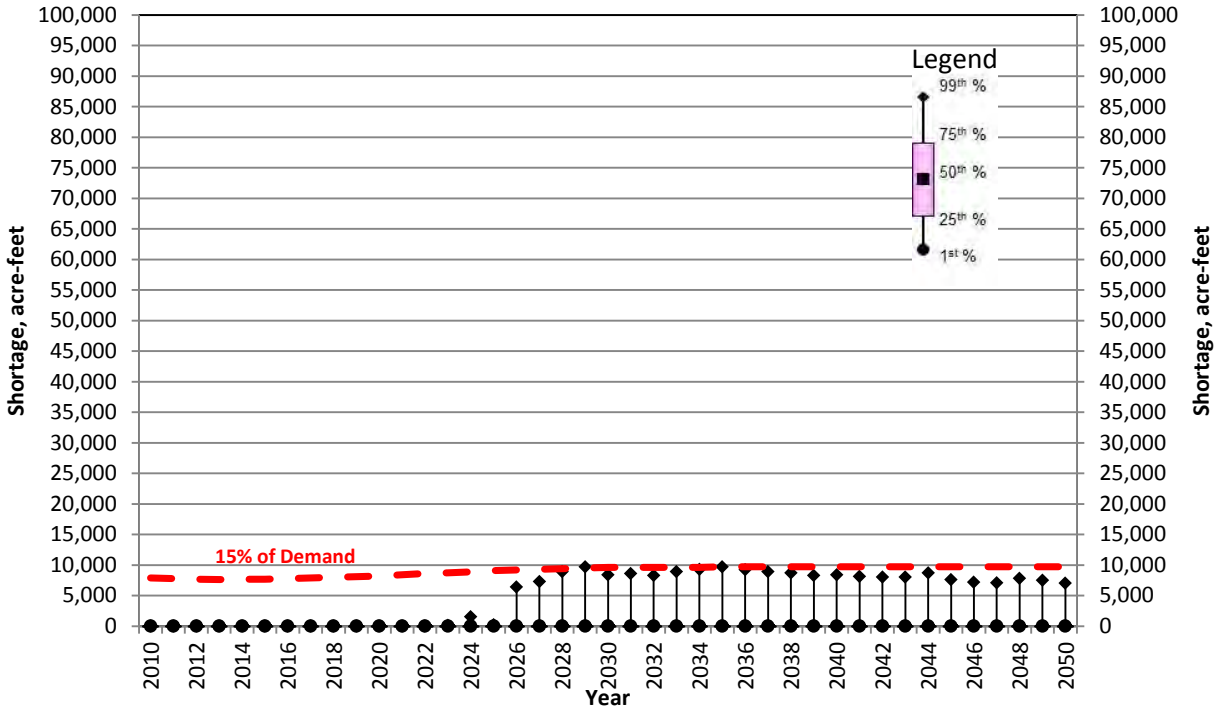
Zone 7 staff evaluated the ability of the water supplies and facilities included in the Current Plan (see Section 6) to prevent water supply shortages, while maintaining drought and emergency storage at a sustainable level. For this evaluation, Zone 7 staff first reviewed the risk of potential water supply shortages and corresponding reliability, and then reviewed the sustainability of system-wide storage, which included the Main Basin, Semitropic Water Storage District (Semitropic), Cawelo Water District (Cawelo), State Water Project (SWP) Carryover, and the Chain of Lakes.[68]

7.1.1 Risk of Potential Water Supply Shortages

Figure 7-1 presents the risk of potential shortages under the Current Plan. As shown on Figure 7-1, there is less than 1% chance of a shortage equal to or larger than 15%; the Current Plan mitigates the risk of shortages larger than 15% of projected water demands.

[68] Key source-specific storage results were included in Appendix F.

Figure 7-1. Risk of Potential Shortages for the Current Plan



7.1.2 Reliability of the Current Plan

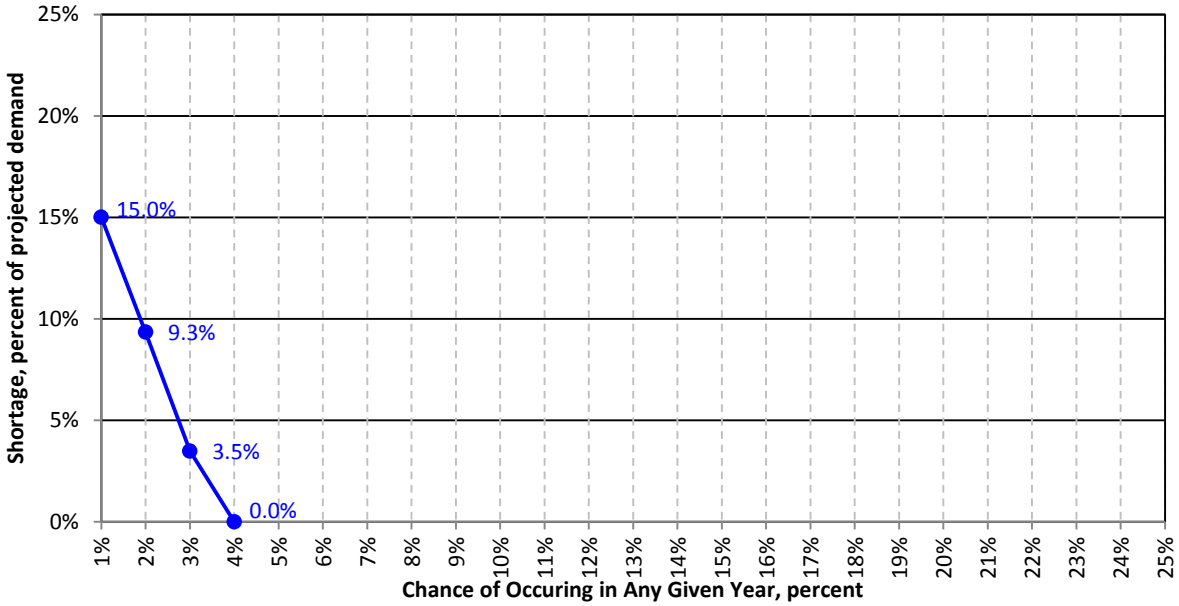
As discussed in Section 5, this Water Supple Evaluation (WSE) defined reliability based on three factors: (1) the maximum shortage, (2) the frequency of smaller shortages, and (3) the percent of the time with no shortages. Figure 7-2 presents the risk curve for the worst-case[69] observed over the entire period from 2010 and 2050 under the Current Plan.

As shown on Figure 7-2, the Current Plan provides a reliability of 85% (i.e., there is a less than 1% chance of a shortage larger than 15% of projected demands). Additionally, there is only about a 1.9% chance of a 10% shortage and no shortages are expected 96 percent of the time (i.e., 1 minus 0.04). The risk of small shortages is extremely low due to the Zone 7's groundwater pumping ability and the large amount of pump back associated with Semitropic and Cawelo.

The risk of shortages presented on Figure 7-2 appears relatively low (96 percent of the time there is no shortage), indicating that the water supply system is robust under the assumptions of the Current Plan. However, these results are dependent on the assumptions previously presented in Section 6; particularly, the assumptions that conveyance in the Sacramento-San Joaquin Delta (Delta) would increase the long-term reliability of the State Water Project to 75% of Table A amounts and the Tri-Valley successfully achieves 6,000 acre-feet (AF) of potable water demand reduction through water conservation and recycled water projects. As discussed in subsequent sections of this WSE, additional studies are required to confirm these assumptions.

[69] The largest shortage was limited to 15%; consequently, the worst-case was selected by choosing the year with the most frequent shortages less than 15%, or in this case, 2035.

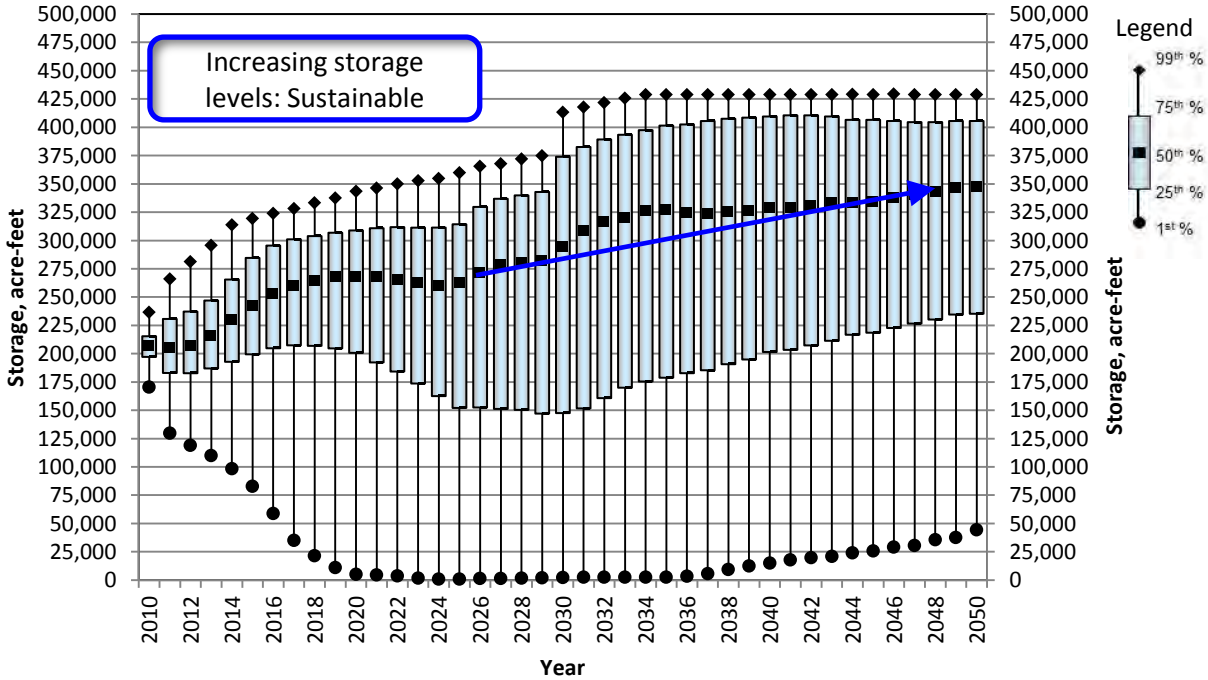
Figure 7-2. Reliability Curve for the Current Plan: 85%



7.1.3 Sustainability of the Current Plan

Figure 7-3 presents likely system-wide storage available to Zone 7 through 2050 using the supplies and facilities associated with the Current Plan. As shown in Figure 7-3, the Current Plan – without any additional modifications – appears to be sustainable.

Figure 7-3. Sustainability of the Current Plan at a Reliability of 85%



7.2 POTENTIAL MEASURES FOR INCREASING RELIABILITY ABOVE 85%

Zone 7 staff reviewed potential measures that could be taken to increase the reliability above 85%. The additional measures required beyond those already incorporated in the Current Plan (see Section 6) to increase reliability above 85% (i.e., reduce the maximum shortage to less than 15%) depend on the reasons for the shortages.

As shown previously on Figure 7-1, the maximum shortage possible under baseline conditions for the Current Plan is approximately 10,000 AF (about 15% of 64,500 acre-feet). A review of the probability-based water supply model results indicates that this 15% shortage can occur during several different drought conditions and for several different reasons. For example, an extremely severe drought lasting only five years or less can cause the shortages observed, while the same magnitude shortage can occur after a very long, but less severe, drought (e.g., more than 6 years). During these various drought scenarios, it appears that the following conditions, or any combination thereof, generally lead to highest shortages predicted:

a. There is insufficient pumpback capacity from non-local storage,

b. Groundwater levels are likely at historical lows – either at key well fields or basin-wide, or

c. There is no access to surface water previously stored in the Chain of Lakes for recharge.

In light of the challenges associated with the State Water Project (SWP), Zone 7 is continually looking for ways to reduce reliance on SWP facilities; therefore, increasing pumpback or buying into another SWP groundwater-banking program were not attractive options for improving reliability under the Current Plan. Although additional wells could help increase the rate at which Zone 7 can withdraw water from some portions of the Main Basin during drought, they would not increase the quantity of stored surface water available.

Zone 7 staff also considered locating a new water treatment plant at the Chain of Lakes. However, the drought conditions resulting in shortages greater than 15% do not occur frequently; therefore, the new water treatment plant would likely be idle for most of the time. Additionally, preliminary estimates indicated that the capital costs a new water treatment plant would be about twice the capital costs of a new pipeline, while the maintenance costs would likely be ten times higher.[70]

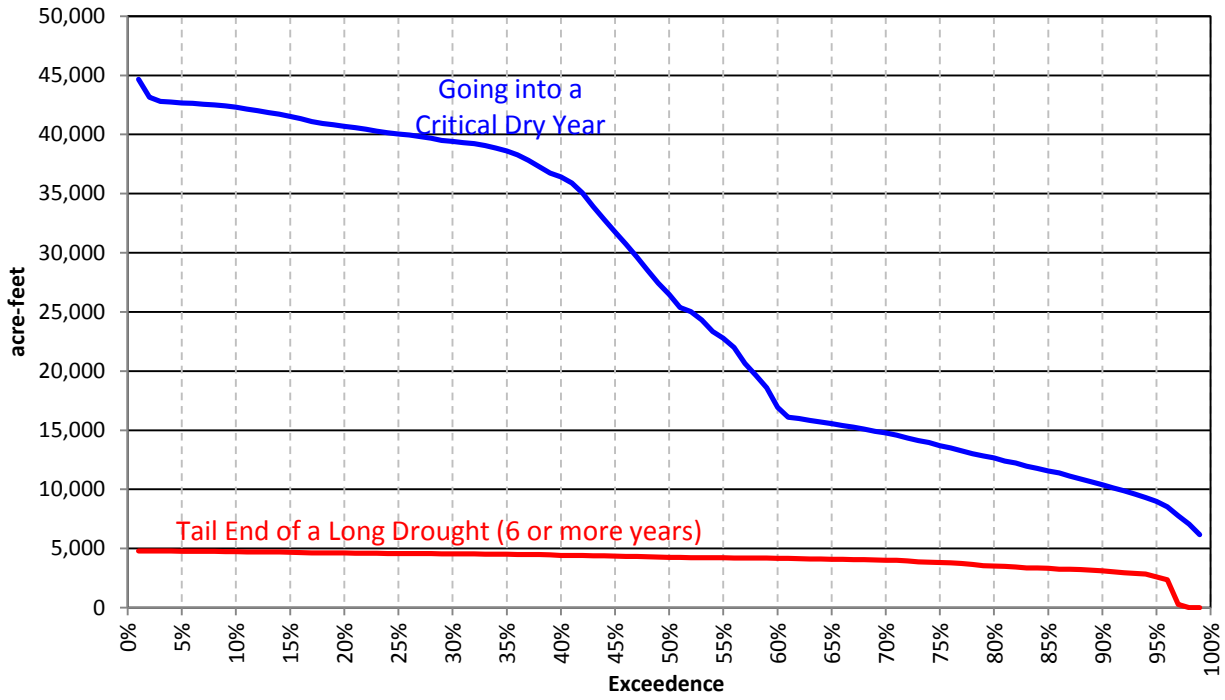
Consequently, Zone 7 staff reviewed two potential options for addressing these conditions: (1) constructing a pipeline from the Chain of Lakes to the Del Valle Water Treatment Plant and (2) purchasing spot-market water. Each is discussed in more detail below. These two options are not mutually exclusive, and if necessary, can be combined.

7.2.1.1 Pipeline Connecting the Chain of Lakes Pipeline to the Del Valle Water Treatment Plant

Using the probability-based water supply model, Zone 7 staff estimated the potential surface water supply available for use going into a critical dry year and at the end of a six-year drought to develop a range of potential supply in storage. Figure 7-4 compares the likelihood of having surface water in the Chain of Lakes under both conditions. As shown on Figure 7-4, the amount of surface water in the Chain of Lakes going into a critical dry year can range from about 5,000 to well over 40,000 AF, while the amount of surface water available for longer droughts (i.e., more than six years) is about 5,000 AF or less.

[70] The initial cost estimate ($38 million) was based on a pipeline, pump station, and demineralization type plant located near Lake I.

Figure 7-4. Potential Surface Water Available in the Chain of Lakes for the Current Plan after 2030



For planning-level purposes in this WSE, Zone 7 staff estimated the costs of constructing a pipeline from the Chain of Lakes to the Del Valle Water Treatment Plant assuming that up to 10,000 AF is transferred over a 9-month period (i.e., about 12 MGD). Figure 7-5 illustrates one potential alignment and the associated costs.[71] As shown on Figure 7-5, the pipeline would tie into future lakes; these lakes are not expected to be available to Zone 7 until sometime around 2030.

7.2.1.2 Spot Market Water

Spot market water refers to water purchased, delivered, and used in a single year.[72] The SWP would be the main conveyance and/or source of spot market water for Zone 7; however, if a new reliability intertie is constructed with another water agency (e.g., with East Bay Municipal Utilities District) then Zone 7 could potentially buy water on the "open market" – especially in markets north of the Sacramento-San Joaquin Delta. The open market refers to water supply available for single-year use that is not associated with the State Water or Central Valley Projects. [73]

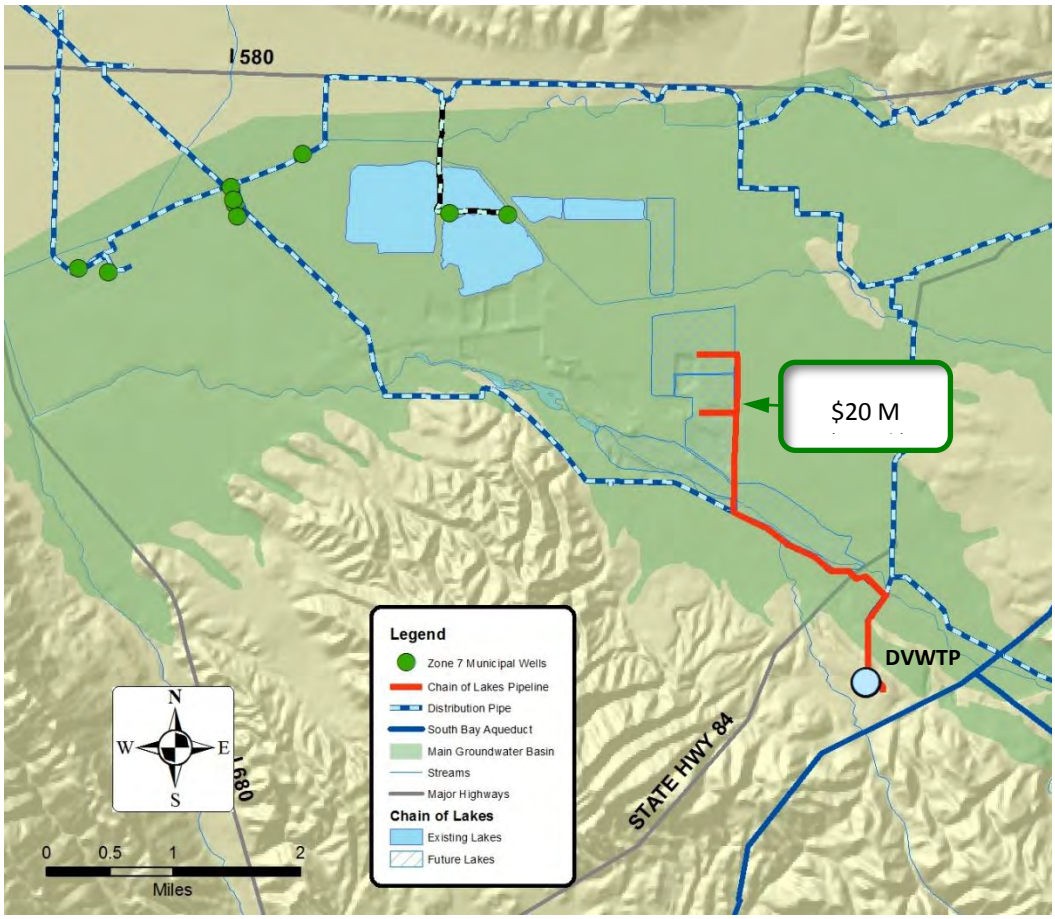
For planning-level purposes in this WSE, Zone 7 staff assumed that, if necessary, spot market water would be purchased via the SWP to improve reliability beyond that provided by a Chain of Lakes pipeline. Based on discussions with Zone 7 staff tracking State Water Project operations, the current rate for spot market water can be as high as $600 per acre-foot.

[71] Detailed cost estimates are provided in Appendix D.

[72] Howitt and Hank, 2005. Incremental Water Market Development: The California Water Sector 1985 to 2005. Canadian Water Resources Journal. Vol. 30(1): 73-82.

[73] Howitt and Hank, 2005. Incremental Water Market Development: The California Water Sector 1985 to 2005. Canadian Water Resources Journal. Vol. 30(1): 73-82.

Figure 7-5. Chain of Lakes Pipeline to Del Valle Water Treatment Plant



7.3 RELIABILITY FOR THE CURRENT PLAN: 90 TO 99%

Zone 7 staff evaluated the ability to increase the reliability of the Current Plan beyond 85% by adding a pipeline from the Chain of Lakes to Del Valle Water Treatment Plant and if necessary, purchasing spot market water. Zone 7 staff completed this evaluation for 90, 95, and 99% reliability scenarios; each is discussed below.

7.3.1 Reliability of the Current Plan: Increased to 90%

Under this scenario, shortages are kept equal to or below 10% of projected water demands through the purchase of spot market water between 2027 and 2030 and the installation of a Chain of Lakes pipeline by 2030 (Figure 7-6). Up to 3,500 AF of spot market water may need to be purchased to keep shortages equal to or lower than 10% (i.e., to maintain a 90% reliability policy). In addition to achieving 90% reliability, this scenario also results in no shortages 96% of the time (Figure 7-7) and sustainable system-wide storage (Figure 7-8).

Figure 7-6. Risk of Potential Shortages for the Current Plan: 10%

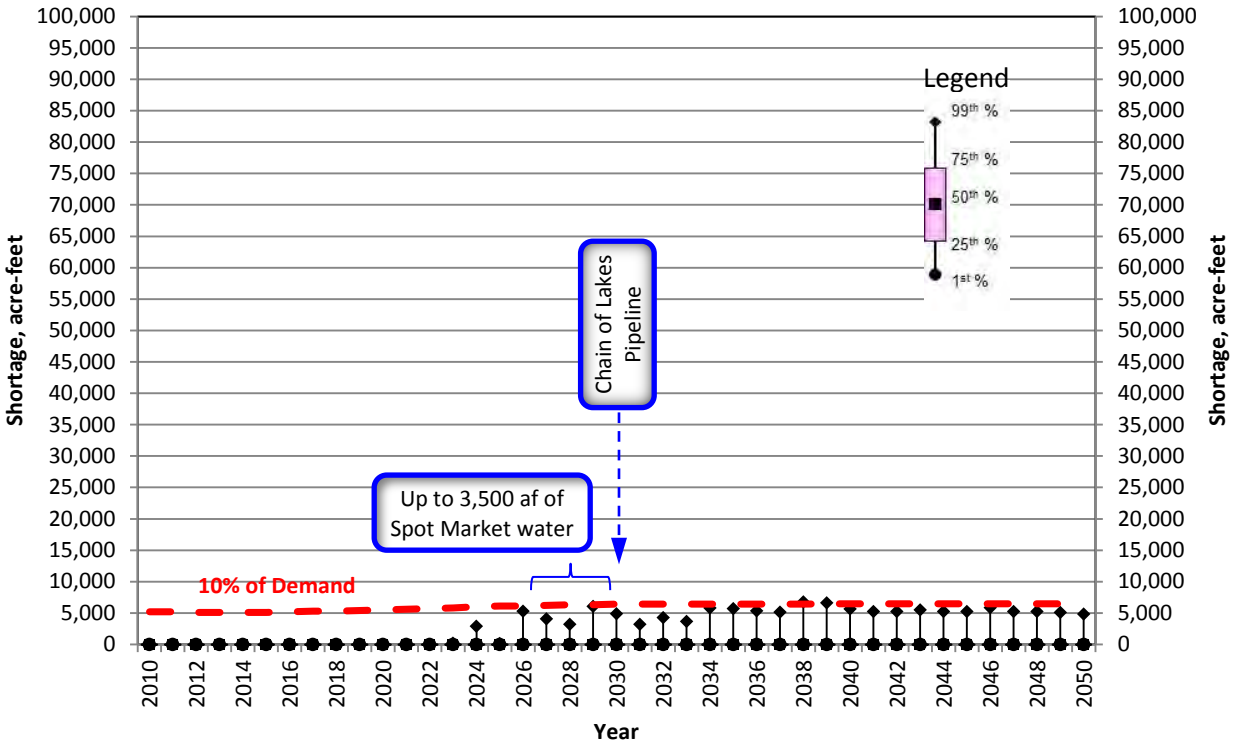


Figure 7-7. Reliability Curve for the Current Plan: 90%

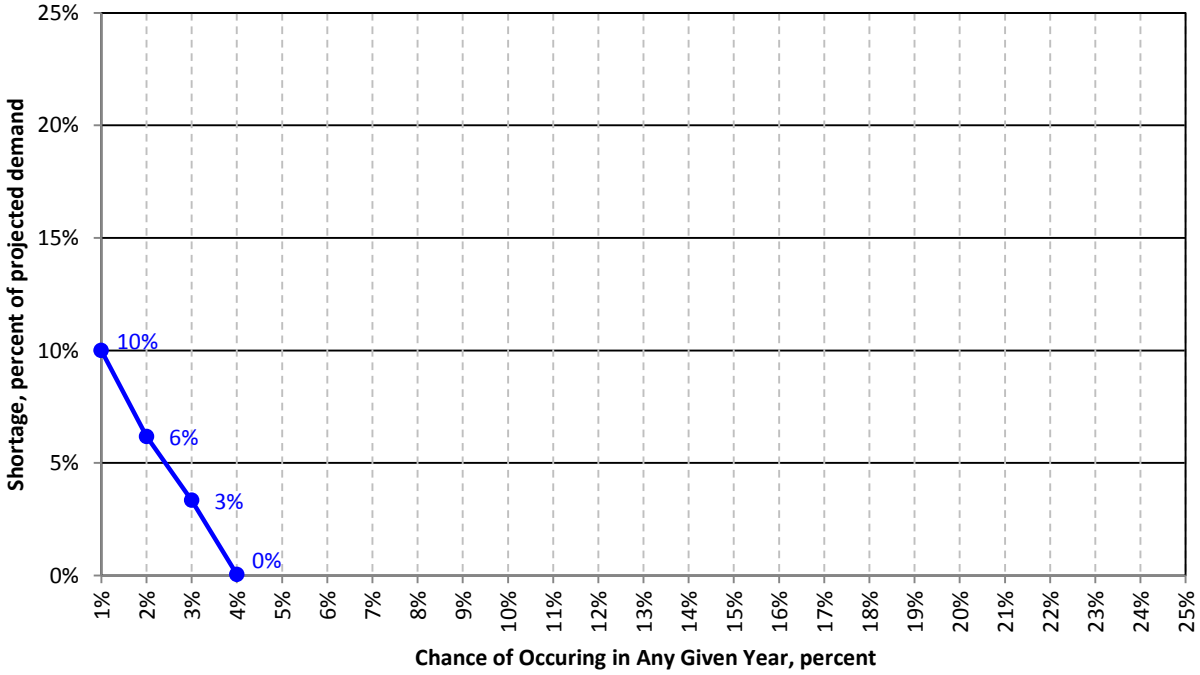
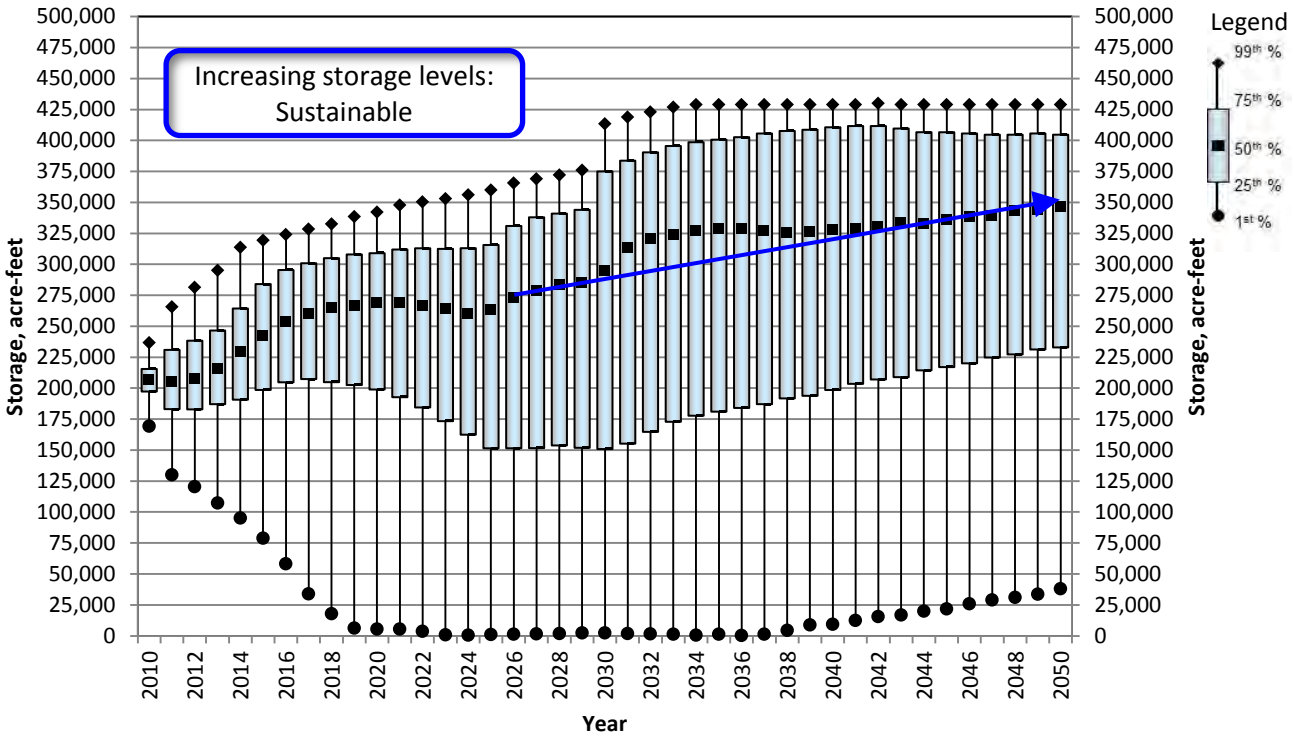


Figure 7-8. Sustainability of the Current Plan at a Reliability of 90%



7.3.2 Reliability of the Current Plan: Increased to 95%

Under this scenario, shortages are kept equal to or below 5% of projected water demands through the purchase of spot market water, as needed, starting in 2024 and the installation of a Chain of Lakes pipeline by 2030 (Figure 7-9). Up to 6,000 AF of spot market water may need to be purchased to keep shortages equal to or lower than 5% (i.e., to maintain a 95% reliability policy). In addition to achieving 95% reliability, this scenario also results in no shortages 98% of the time (Figure 7-10) and sustainable system-wide storage (Figure 7-11).

Figure 7-9. Risk of Potential Shortages for the Current Plan: 5%

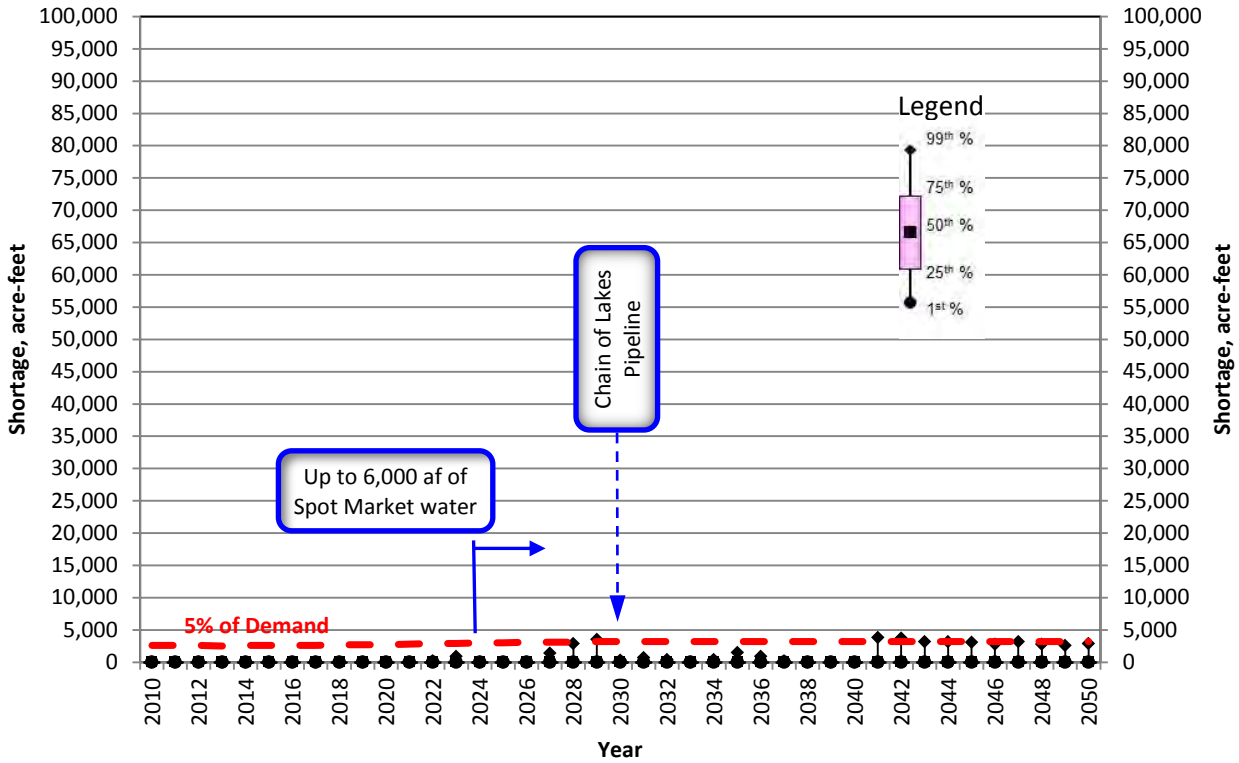


Figure 7-10. Reliability Curve for the Current Plan: 95%

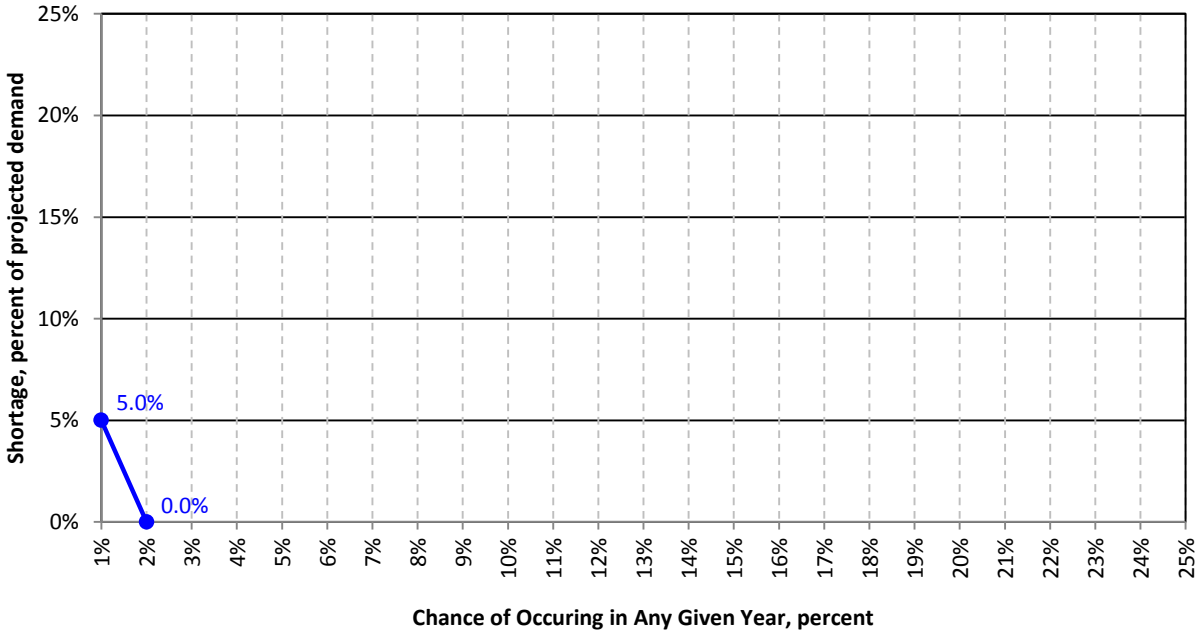
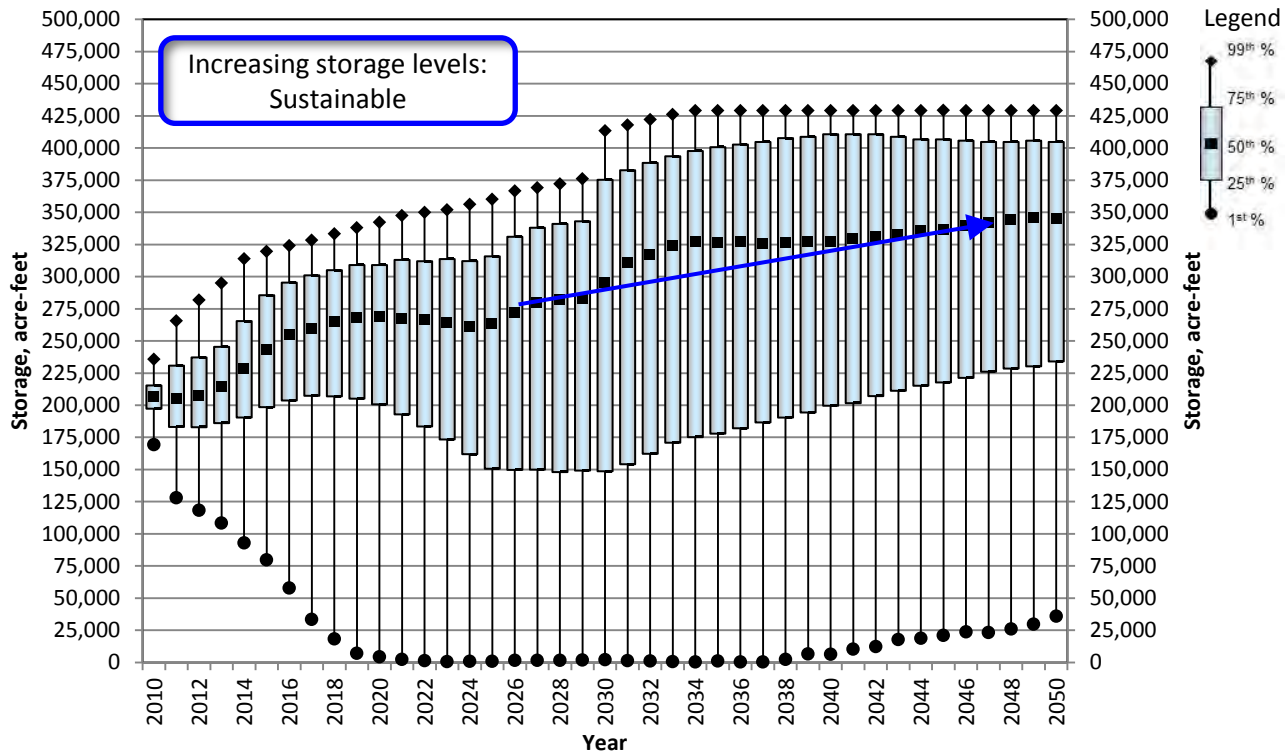


Figure 7-11. Sustainability of the Current Plan at a Reliability of 95%



7.3.3 Reliability of the Current Plan: Increased to 99%

Under this scenario, shortages are kept below 1% of projected water demands through the purchase of spot market water, as needed, starting in 2024 and the installation of a Chain of Lakes pipeline by 2030 (Figure 7-12). Up to 10,000 AF of spot market water may need to be purchased to keep shortages equal to or lower than 1% (i.e., to maintain a 99% reliability policy). In addition to achieving 99% reliability, this scenario also results in no shortages more than 98% of the time (Figure 7-13) and sustainable system-wide storage (Figure 7-14).

Figure 7-12. Risk of Potential Shortages for the Current Plan: < 1%

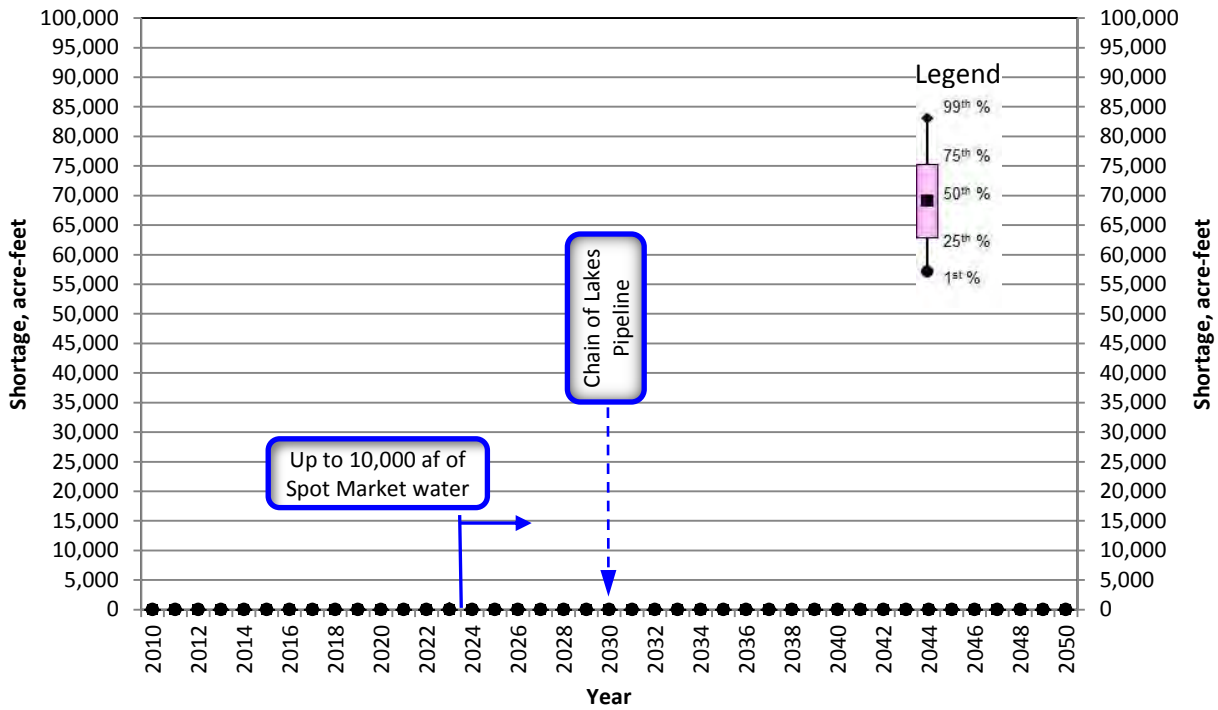


Figure 7-13. Reliability Curve for the Current Plan: 99%

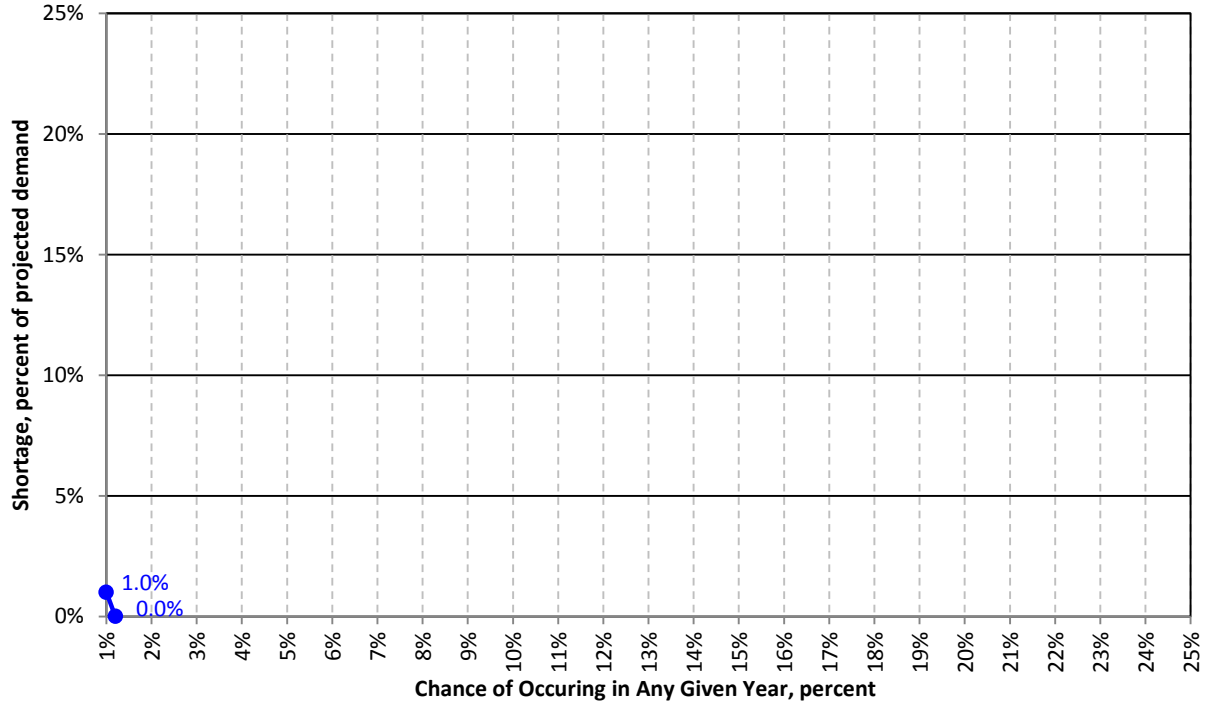
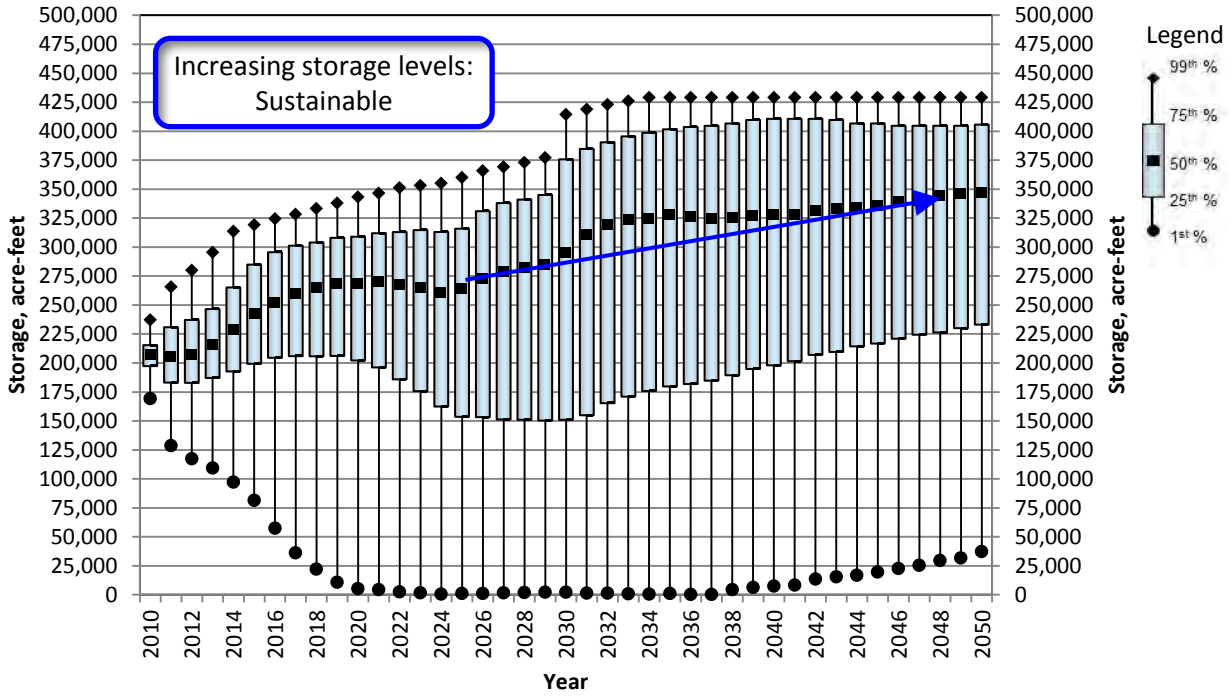


Figure 7-14. Sustainability of the Current Plan at a Reliability of 99%



7.4 FACILITIES EVALUATION FOR THE CURRENT PLAN

Zone 7 staff reviewed the capacities of existing and planned facilities associated with the Current Plan to meet 100% of maximum day demands under normal conditions and 75% of maximum day demands assuming one major facility is out of service. Each condition is discussed below.

7.4.1 Maximum Day Demand for the Current Plan

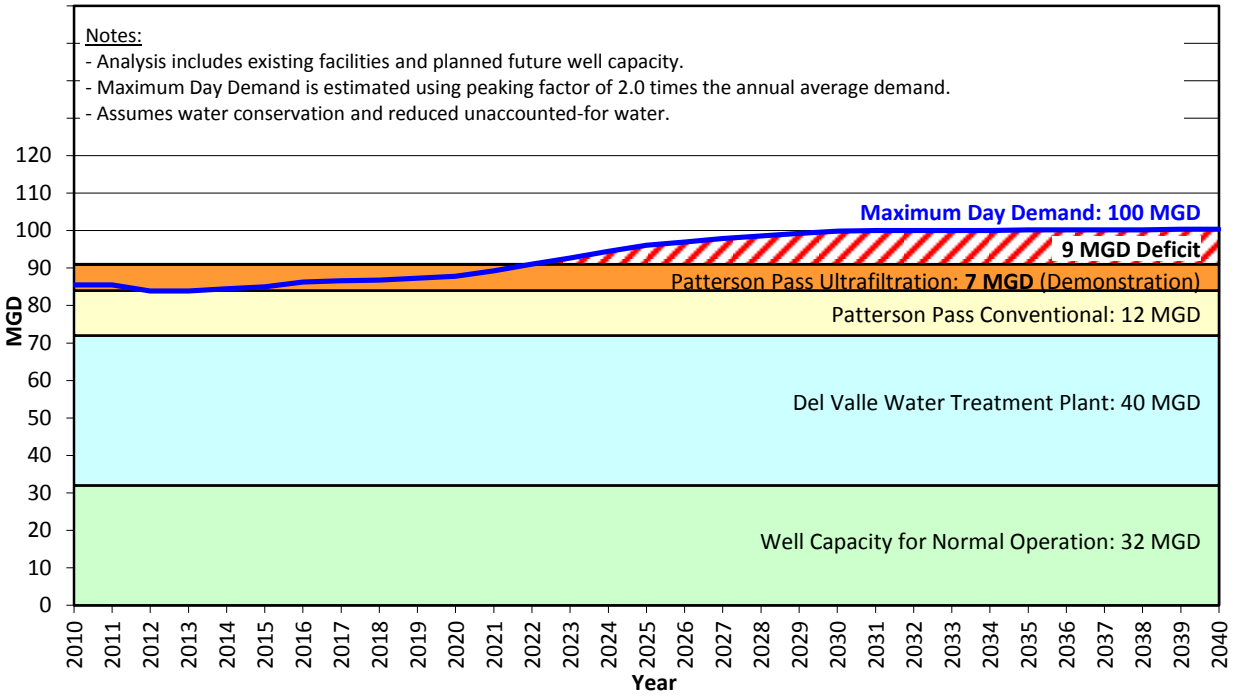
Figure 7-15 compares the capacity of existing and planned facilities associated with the Current Plan with projected maximum day demands.[74] Based on this comparison, Zone 7 can meet 100% of maximum day demands through 2022, but will require additional surface water treatment capacity by 2023 (9 million gallons per day [MGD]). However, the temporary ultrafiltration (UF) plant at the Patterson Pass Water Treatment Plant (PPWTP) will need to be replaced; therefore, the total new surface water treatment capacity required is at least 16 MGD (9 plus 7 MGD).

This analysis is dependent on the assumptions for potable demand reductions associated with the Water Conservation Act of 2009, and a 1,000 to 2,000 AF fluctuation in these assumptions could easily translate into 2 to 4 MGD of additional treatment capacity.[75] Consequently, for planning-level purposes in this WSE, the cost estimates for an initial expansion of water treatment plant capacity were based on a 20 MGD facility.

[74] Projected water demands were previously discussed in Section 3; the maximum day is obtained by multiplying by 2.

[75] 2, 000 acre-feet is about 1.8 MGD, which translates to about 3.6 MGD on the maximum day assuming a peaking factor of 2.

Figure 7-15. Current Plan: Ability to Meet Maximum Day Demand



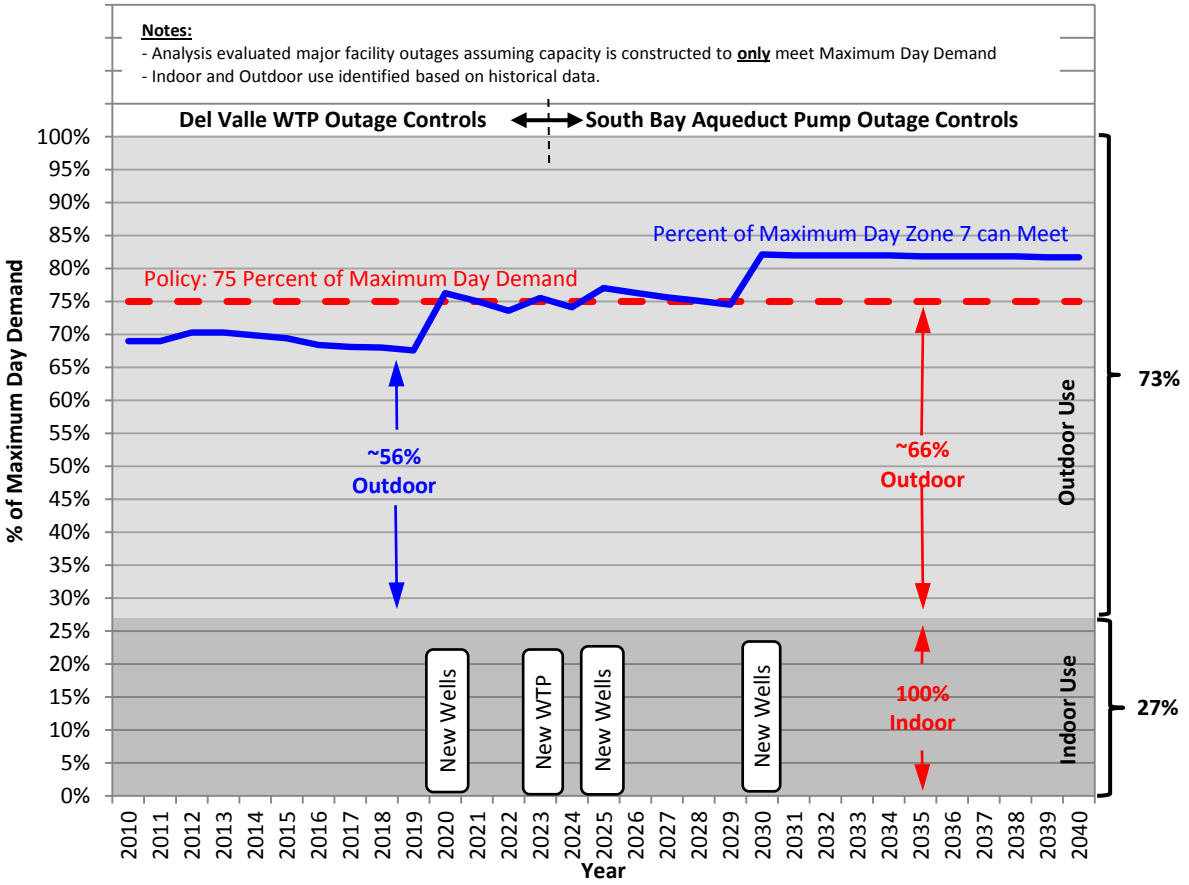
7.4.2 Level of Service for the Current Plan with a Major Facility Outage

Zone 7 staff evaluated the ability of existing and planned facilities associated with the Current Plan (see Section 6) to meet the current facility outage policy. Figure 7-16 presents the results of this evaluation by comparing the percent of maximum day demand that the Current Plan facilities can meet over time. For discussion purposes, Figure 7-16 splits the maximum day demand into indoor and outdoor use,[76] and presents the current facility schedule. The current facility schedule reflects delayed construction associated with reduced demands caused by the current economic downturn.

As shown on Figure 7-16, the current policy is to meet 75% of maximum day demand with a major facility out of service; however, another interpretation of the policy is to meet 100% of indoor use and 66% outdoor use during the same conditions. Figure 7-16 clearly shows, with a major facility outage, that existing facilities can meet 100% of indoor water needs, but only about 56% of outdoor needs until 2020. As new facilities come online, Zone 7 is increasingly able to meet and eventually exceed the existing policy.

[76] Zone 7 staff reviewed historical monthly data to split projected water demands into indoor and outdoor use. This analysis is provided as Appendix A.

Figure 7-16. Ability of Current Plan to Meet Maximum Day Demand during an Outage



7.4.2.1 Consideration: Level of Service during a Maximum Month

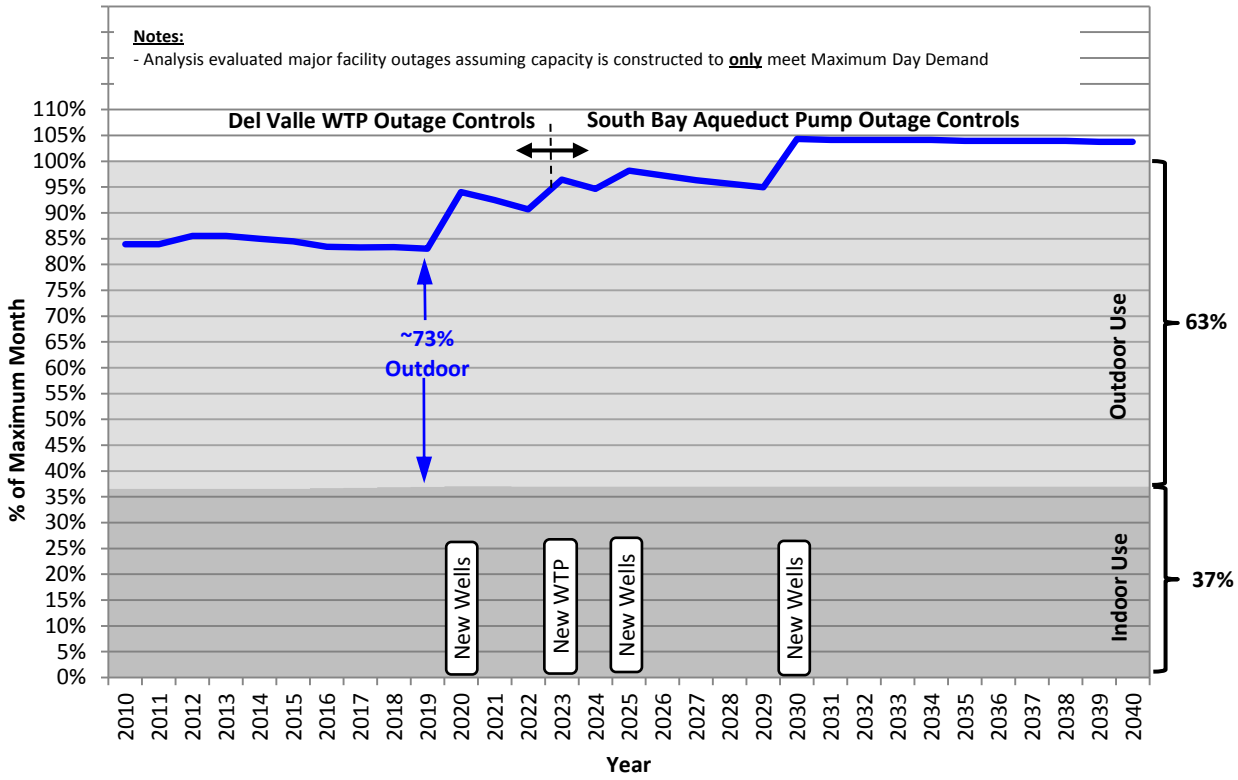
The assumptions presented on Figure 7-16 are relatively conservative. For example, one scenario evaluated assumes that all of the treatment capacity associated with the Del Valle Water Treatment Plant happens to be lost on the highest water use day of the year (i.e., the maximum day), which typically occurs between 1 to 5 out of 365 days – less than 2 percent of the time. Additionally, barring a major emergency (e.g., an earthquake, Delta levee failure, or transmission line burst), it would take multiple, simultaneous, failures of internal plant equipment to lose all treatment capacity for an entire day.[77]

Consequently, for discussion purposes in this WSE, Zone 7 staff also reviewed the same outage scenarios over the highest water use month (i.e., the maximum month) instead of the maximum day demand. Figure 7-17 presents the same analysis completed for the maximum month.

As shown on Figure 7-17, existing facilities can meet 100% of indoor use and almost three-quarters of the outdoor use during the highest water use month and therefore, about a 25% reduction in water use would be required over a 30-day period. Assuming the typical residential customer waters their lawn four times per week during the hottest month of the year, then a 25% reduction could be achieved by only watering their lawn about three times a week.

[77] Based on conservations with Zone 7 operations staff.

Figure 7-17. Ability of Current Plan to Meet Maximum Month Demand during an Outage



7.5 SALT MANAGEMENT EVALUATION FOR THE CURRENT PLAN

Zone 7 is preparing to update its Groundwater Management Plan (GWMP), which will also include an update of the Salt Management Plan (SMP). As part of this update, Zone 7 staff will conduct a more rigorous analysis of potential salt and nutrient loading in the Main Basin – a rigorous analysis of salt loading was not completed as part of this WSE.

Each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics that could influence future salt loading in the Main Basin. Consequently, Zone 7 staff completed a preliminary review of the potential salt loading associated with the Current Plan for comparative purposes in this WSE.[78] As discussed in Section 5, this review involved using spreadsheet models previously developed as part of Zone 7's original SMP to evaluate whether net salt loading in the Main Basin associated with the Current Plan was either increasing or decreasing. Preliminary results indicate that a new demineralization facility may be required to achieve decreasing salt loading under the Current Plan. The GWMP/SMP update will further evaluate this finding.

7.6 OBSERVATIONS REGARDING DELIVERED WATER QUALITY

As discussed previously in Section 5, conducting hydraulic modeling to quantify potential benefits to delivered water quality was beyond the scope of this WSE; however, each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics. Consequently, a qualitative review of each scenario was completed to evaluate whether the scenario

[78] Zone 7 will evaluate nutrients as part of the SMP update.

had the potential for improving or degrading delivered water quality. The potential benefits to delivered water quality of the Current Plan fall into two categories: (1) those associated with the Delta Fix and (2) those associated with the groundwater demineralization activities. Both are discussed below.

7.6.1 Potential Delivered Water Quality Benefits of a Delta Fix

Based on information gathered via Zone 7's participation in the Bay Delta Conservation Plan (BDCP) and the Delta Habitat Conservation and Conveyance Plan (DHCCP), it is likely that any solution in the Delta will also involve conveyance of water supplies from the Sacramento River during various conditions resulting in dual conveyance. The total dissolved solids (TDS) concentration of water in the Sacramento River is significantly lower than the TDS concentration of supply conveyed through the Delta.[79]

As discussed in Section 6, it was assumed that overall TDS concentrations would only decrease by about 20% due to the dual conveyance nature[80] of potential solutions being evaluated for the Delta. Even a 20% decrease in TDS concentration, however, will likely improve overall delivered water quality for the Valley, both delivered water quality and the quality of water used for recharge of the Main Basin.

7.6.2 Potential Delivered Water Quality Benefits Associated with Demineralization

As previously discussed in Section 7.5, Zone 7 staff conducted a preliminary evaluation of salt loading associated with the Current Plan, and although it is recommended that future salt mitigation strategies be evaluated as part of the Salt Management Plan Update, another phase of demineralization is in Zone 7's existing Capital Improvement Program. Therefore, a second phase was also included in the cost estimates of the Current Plan for comparative purposes in this WSE. Another phase of demineralization will have a direct positive influence on delivered water quality because it treats groundwater before it enters Zone 7's distribution system.[81]

7.7 COST ESTIMATES FOR THE CURRENT PLAN: 85 TO 99%

The purpose of this section is to provide planning-level cost estimates for each reliability scenario evaluated under the Current Plan portfolio. For illustrative purposes, the cost estimates were divided into three categories: (1) facilities, (2) water supply, and (3) water quality. The facilities component of the cost estimates represent hard construction, such as water treatment plants, diversion structures, and groundwater wells, while the water supply component generally represents the cost of purchasing or acquiring water. The cost estimate for water quality reflects a second phase of demineralization; however, as discussed previously, future salt mitigation needs further evaluation as part of the GWMP/SMP update.

In all cases, the costs are presented in 2010 dollars based on an Engineering News Record San Francisco Construction Cost Index. The following planning-level cost contingencies were also applied as necessary:

- Construction Contingency: 25 percent
- Planning and Environmental: 10 percent
- Design and Implementation: 10 percent

[79] This was based on an analysis of historical EC levels in the Sacramento River near Hood and current deliveries to Zone 7's Patterson Pass Water Treatment Plan. Average TDS concentrations in the Sacramento River are less than 100 mg/L, while average concentrations of raw water delivered to Zone 7's PPWTP is about 240 mg/L.

[80] Dual conveyance may only bypass the Delta for a portion of the year.

[81] The benefits of demineralization were thoroughly analyzed as part of the 2003 Water Quality Management Program report.

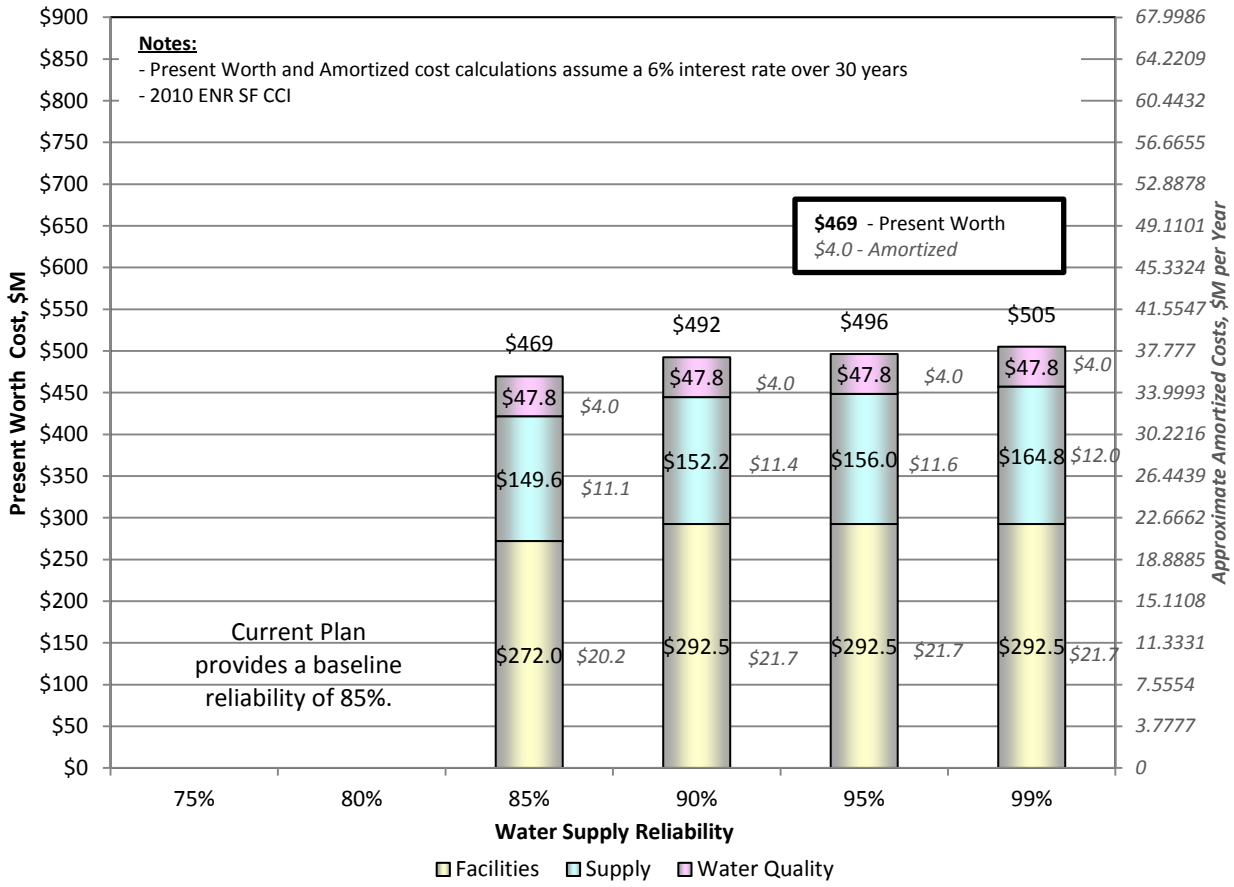
- Construction Management: 10 percent

Appendix D contains a more detailed description of the cost estimates used and preliminary schedules developed for each scenario that were used to develop present worth and amortized values.

7.7.1 Observations Regarding the Cost of Reliability

As shown on Figure 7-18, the facility costs increase between 85% and 90% reliability due to the construction of the Chain of Lakes pipeline. Supply costs increase proportionally depending on the amount of spot market water required. Water quality costs are the same because all of the scenarios assume the need to construct a second demineralization facility. Overall, there is a less than 10% increase portfolio costs when comparing an 85 and 99% reliability target.

Figure 7-18. Cost of Reliability for the Current Plan



8. POTENTIAL BACKUP SUPPLY SOURCES IF CURRENT PLAN CHANGES

When Zone 7 Water Agency (Zone 7) staff began evaluating the reliability of Zone 7's water supply system and develop a plan for addressing near-term risks, one of the first key tasks was development of a list of potential supply options for enhancing Zone 7's system. In particular, the options represent potential ways in which Zone 7 can continue to provide a reliable supply of water if the Current Plan, as described in Section 6, radically changes.

In 2009, Zone 7 began the task by developing a draft comprehensive list meant to capture a range of ideas—from the obvious to the unlikely—then solicited review and input from within Zone 7. This step helped to provide additional context—both historical and current—that could be used to evaluate the potential benefits and limitations (e.g., technical feasibility, institutional barriers, etc.) of the various options. The options were then presented to the Retailers, who provided additional feedback as a group and in separate meetings. The Delta Committee of the Zone 7 Board of Directors (Board) and subsequently the entire Board were both presented with the refined list of water supply options for their input in mid-2010.

The supply options were classified into several strategies:

- *Increased yield from existing supplies* – This strategy looks at ways in which the yields from Zone 7's existing water supply sources (i.e., State Water Project, Arroyo del Valle, and Byron Bethany Irrigation District) can be increased.
- *New or additional water supplies* – This strategy looks at new sources of surface water and groundwater that can potentially be acquired through new contracts with other agencies.
- *Stormwater runoff and rainfall capture* – Options under this strategy include not only the acquisition of new water rights for local waterways at the agency level but also the implementation of rainfall capture at the user level.
- *Recycled water for Livermore-Amador Valley* – This strategy considers both the conventional use of centrally-produced recycled water and the less common reuse of wastewater at the end-user level.
- *Desalination/Demineralization* – This strategy includes the desalination or demineralization of surface water and groundwater supplies either for the direct use of Zone 7 or for the purpose of a water exchange program.
- *Operational Improvements* – Activities considered under this strategy are designed to increase the efficiency of Zone 7's water system through the reduction of losses from the system and the enhanced recharge capacity of the Main Basin.

Zone 7 staff then screened the water supply options based on potential water supply yield, the associated technical and institutional barriers, and any unique contributions any particular supply added to Zone 7's water system. The remaining options were then used to augment the Current Plan (Section 6) and create two backup portfolios (Section 9); only low-cost, low-impact options were used to augment the Current Plan. Appendix E presents a table summary of the comprehensive list of water supply options, including their yields and costs; the table also identifies those that have been included in the portfolios analyzed in this Water Supply Evaluation (Current Plan and Backup Portfolios). Options that have not been selected for inclusion in the portfolios at this time may be re-considered in future evaluations in light of new technologies, regulatory developments, etc. Details of the cost estimates and associated assumptions for the various options were previously presented in Appendix D.

Table 8-1 lists the options that were ultimately selected for the Backup Portfolios (In-Valley and Intertie Portfolios), including their average yields and amortized unit costs. Note that some of these options are also included in the Current Plan.

Descriptions of the individual options considered for the Backup Portfolios (see Table 8-2) are presented in the following pages and in Section 9, and are grouped according to strategy. The descriptive sheets include estimated yields, availability during various hydrologic conditions, costs, benefits, and limitations. They also indicate whether the option has been included in the Backup Portfolios. The average yield is the long-term average supply available over various hydrologic conditions; in some cases, the supply is only available during normal/wet years or during dry years, or the yields differ between the different hydrologic conditions. Timing indicates the projected timeframe that the supply would become available to Zone 7, after planning, design, CEQA, and construction; near-term occurs between 2011 and 2015, mid-term occurs between 2016 and 2025, and long-term occurs between 2026 and 2040. The amortized costs in dollars per acre-foot include capital, and operation and maintenance costs (expenses necessary to maintain the supply such as power and chemicals); for comparative purposes, the costs were amortized based on 6 percent interest over a 30 year term.

Note that the supply options are not all designed for implementation by Zone 7—some are implemented at the user level, as described above, and some may be implemented by the individual retailers. While capital and O&M costs have been estimated where possible, sources of funding for the various options may vary.

Table 8-1. Water Supply Options Included in the Backup Portfolios

Option	Average Yield, acre-feet annually	Amortized Cost, $/acre-foot[(a)]
Arroyo Valle – Perfection of Existing Permit	3,800	$20
Reduction of Brine Losses Mocho Demineralization Losses	260	$30
Reduction of Unaccounted-for Water	1,300	$100
Enhance Existing In-Lieu Recharge	500 to 830	$110
Arroyo Las Positas Water Rights	750	$200
Arroyo Mocho Water Rights	900	$200
Confirm BBID Yield	3,000	$285
Intertie Supply: Long-term Leases	up to 10,900	$1,400
Recycled Water – Direct	up to 3,700	$1,500
Groundwater Injection: Recycled Water	2,800	$1,600
Intertie Supply: Regional Desalination	up to 9,300	$2,000
Recycled Water - Storage	up to 17,300	$2,400

[(a)] Based on 2010 ENR SF CCI. Amortized costs assume a 6% interest rate for 30 years.

Table 8-2. Supply Options Considered for the Backup Portfolios

Supply Option **Page Number**

Increased Yield from Existing Supplies

Modified Operation of Lake Del Valle *116*

New or Additional Supplies

Additional Water from the State Water Project *117*
Long-Term Non-State Water Project Lease or Transfer *118*
Los Vaqueros Reservoir Expansion *119*
Transfers via Purchase of Agricultural or M&I Land *120*

Stormwater Runoff and Rainfall Capture

Acquisition of Arroyo Las Positas Water Rights *121*
Acquisition of Arroyo Mocho Water Rights *122*
Acquisition of Tassajara and San Ramon Valley Creeks Water Rights *123*
End-User Local Rain Capture for Irrigation *124*
End-User Local Rain Capture for Recharge *125*

Recycled Water for Livermore-Amador Valley

Acquisition of Yara Yara Well *126*
Agricultural Waste Stream Reuse *127*
Commercial/Industrial Waste Stream Reuse *128*
End-User Graywater Reuse for Residential Irrigation *129*
Groundwater Injection with Highly Treated Recycled Water *130*
Recycled Water – Direct and Indirect Use *131*

Desalination/Demineralization

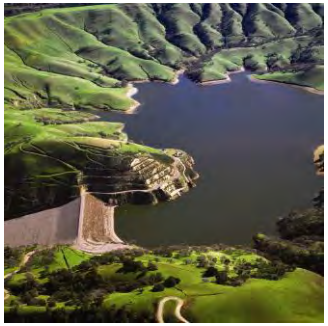
ACWD Entitlement Exchange via Demineralization *132*
Bay Area Regional Desalination Project *133*
Fringe Basin Development *134*

Operational Improvements

Aquifer Storage and Recovery in the Main Basin *135*
In-Stream Infiltration via Swales *136*
Reduction of Cawelo and Semitropic Losses *137*
Reduction of Well Start-Up Waste *138*

DESCRIPTION

This option increases the amount of water that can be captured under Zone 7's existing Arroyo del Valle water right by lowering the lake an additional 5,000 acre-feet annually (AFA) during November and December when recreational use of the lake is minimal. It would require minor modifications of Lake Del Valle infrastructure and operation during the rainy season. Specifically, the level of Lake Del Valle would be lowered to 20,000 AF, instead of 25,000 AF as is currently practiced, at the beginning of the rainy season. This change will allow for increased capture of stormwater runoff between November and April. The intake for the East Bay Regional Parks District (EBRPD) would need to be lowered to allow continued access when the lake level is below 25,000 AF.



Zone 7 could increase the yield of its existing permit through modified operation of Lake Del Valle in the winter.

The water supply yield for Zone 7 was estimated based on historical flows and water right conditions for Zone 7's existing permit. The capital cost, including coordination of an institutional agreement and moving the EBRPD intake, was estimated at $500,000 to $1 million, pending participation by ACWD.

Yield:	600 AFA (average)
Availability:	Normal/wet years only
Cost ($/AF):	$140-200
Timing:	Mid-term

POTENTIAL BENEFITS	• Makes use of existing facilities and rights.
LIMITATIONS	• Requires institutional agreement with DWR, EBRPD, and ACWD. • Minimal amount of water.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time, pending success of planned water conservation and recycled water programs

DESCRIPTION

Under this option, Zone 7 would increase its contractual maximum supply from the State Water Project (SWP)—commonly referred to as the Table A amount—by purchasing a transfer from one of the other SWP contractors. The availability of this transfer depends on the willingness of other contractors to sell and the price Zone 7 is willing to pay.

Lake Oroville and Oroville Dam, keystone of the SWP. (Source: http://www.water.ca.gov/swp/)

Zone 7 analyzed historical and recent sales in the water market, resulting in an estimated capital cost of $10,000 to $12,500/ acre-foot (AF). Capital costs included a transfer fee paid to the contractor, and amounts paid to the Department of Water Resources (DWR) to cover bond surcharges, the Delta Charge, and the Transportation charge over a 30-year period. Annual O&M costs, consisting of power and chemicals, were estimated at $130/AF. The total amortized cost ranged between $840-1,050/AF.

The transfer fee on a per AF basis was adjusted to reflect the effective yield of the contract amount, which is 60% based on a long-term average projection from DWR. This is the expected long-term yield for Zone 7's existing Table A amount published in DWR's 2009 Reliability of SWP report.

Yield:	60% of transfer amount (average) 10-30% of transfer amount (dry)
Availability:	Varies with hydrologic conditions
Cost ($/AF):	$840-1,050
Timing:	Near/Mid-term

POTENTIAL BENEFITS	• Makes use of existing SBA infrastructure.
LIMITATIONS	• Subject to market conditions. • Increased dependence on the SWP system - does not diversify portfolio. • Uncertainty of the Delta Fix.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time until more is known about the potential yields of the Delta Fix.

DESCRIPTION

This option involves the purchase or long-term transfer of water from a non-State Water Project (SWP) contractor. This transaction would be similar to the contract Zone 7 holds with the Byron Bethany Irrigation District, which provides a minimum water supply of 2,000 acre-feet annually (AFA) to Zone 7 with a potential to purchase up to 5,000 AFA. This is a 20-year contract, renewable every five years up to a total of 30 years. However, unlike the water from the BBID contract, which is delivered through the South Bay Aqueduct, Zone 7 would seek water that can be delivered via a new intertie with another major agency (e.g., East Bay Municipal Utility District). This would have the added benefit of diversifying Zone 7's portfolio.

The availability of other transfers similar to the BBID contract depends on the willingness of other contractors to sell and the price Zone 7 is willing to pay. Based on discussions with other agencies, a long-term lease could cost about $200-300/AF, an amount that would be paid annually based on deliveries. There will also be wheeling costs for conveying water to Zone 7. For planning-level purposes, the wheeling costs were based on assumptions provided via participation in the Bay Area Regional Desalination Project - $600-1,000/AF. The amortized cost, not including the intertie, is estimated at $900-1,400/AF.

Yield:	Depends on contract provisions
Availability:	Depends on contract provisions
Cost ($/AF):	$900-1,400
Timing:	Near/Mid-term

POTENTIAL BENEFITS	• Makes use of a new reliability intertie. • Potential for high-quality water wheeled to Zone 7. • Diversified Zone 7 water supply portfolio.
LIMITATIONS	• Subject to market conditions. • Uncertainty of supply source - particularly, in normal/wet years. • Uncertainty of wheeling costs.
INCLUDED IN PORTFOLIO ANALYSIS?	• YES.

DESCRIPTION

Los Vaqueros Reservoir was constructed by the Contra Costa Water District (CCWD) in 1997 to allow for storage of higher-quality Delta water when it is available and to provide emergency storage.

Los Vaqueros Reservoir. (Source: http://www.ccwater.com/)

In 2010, the CCWD Board approved the expansion of the Los Vaqueros Reservoir from 100,000 to 160,000 acre-feet (AF), providing opportunities for other water agencies to use any excess capacities in the reservoir and associated conveyance facilities (e.g., intake pumps in the Delta). Two such opportunities identified by CCWD involved 1) storage of environmental water for the State Water Project and the Central Valley Project by shifting pumping to CCWD's intake pumps and 2) supply reliability deliveries to the South Bay Aqueduct (SBA) Contractors, including Zone 7[82]. For the latter, stored water in the reservoir would be used to make up delivery reductions due to the Delta pumping restrictions stipulated in Biological Opinions. This water would be derived from a new water right acquired in the Delta, assuming there is unappropriated Delta water supply available.

Yield:	0-8,300 AFA
Availability:	Depends on water right limitations
Cost ($/AF):	$330-2,200
Timing:	Near/Mid-term

The potential capital costs were estimated based on a buy-in fee, and construction costs for new/expanded conveyance facilities and the expanded reservoir. For a potential 8,300 AF yield, Zone 7's capital cost were estimated to range between $32 to 212 million. Annual O&M costs were expected to range between $420,000 to $2.8 million. The lower costs represent the scenario where state and federal contractors participate and share the costs, along with the SBA contractors.

POTENTIAL BENEFITS	• Makes use of shared facilities.
LIMITATIONS	• The 8,300 AF is based on the assumption that unappropriated Delta Water rights exist - this is not likely true.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time - this option does not appear to provide additional supply.

[82] For more details, see CDM, 2009. Delta Water Supply Reliability Report. May.

DESCRIPTION

Under this option, new water supplies are acquired through the purchase of agricultural and/or municipal/industrial land. Associated water rights and/or contracts would be transferred as part of the purchase.

Significant institutional, legal, and political barriers would likely prevent implementing this supply option. Most irrigation districts and cities would likely oppose any such activities. Consequently, these options were not evaluated as part of this analysis.

Yield:	Depends on contract provisions
Availability:	Depends on contract provisions
Cost ($/AF):	Not analyzed
Timing:	Near/Mid-term

POTENTIAL BENEFITS	• Depending on source and delivery mechanism, can potentially diversify water supply portfolio.
LIMITATIONS	• Significant institutional and political barriers.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to potenitally insurrmountable institutional and political barriers.

DESCRIPTION

This supply would involve the acquisition of a new water right permit on the Arroyo Las Positas to put water to beneficial use. This supply would require the completion of the diversion structure at Arroyo Las Positas, a project recommended under the StreamWISE Program[83] for flood control purposes; the structure would allow the diversion of water to the Chain of Lakes for detention storage.

Based on available data from the Arroyo Las Positas Near El Charro gage station[84], annual estimated inflows range between 1,400 to 26,000 AF. Assuming that 12.5 to 25% of the total inflow is potentially available for diversion after accounting for existing water rights and environmental needs, Zone 7 estimates an average annual yield between 750 to 1,500 AF, with a dry year yield less than 200 AF. This yield already accounts for poor water quality during low flows (i.e., less than 100 cfs).

The total estimated capital cost for acquiring a new water right on the Arroyo Las Positas is $1.6 million, including permit application fees, environmental analysis, and legal costs. The diversion structure was not included in the capital cost since its primary purpose will be flood control, independent of any water right acquisition. The annual O&M cost is estimated at $12,000. If a decision is made to pursue an Arroyo Las Positas water right – after additional feasibility studies – then the process for acquiring a new water right could take 10 to 15 years; for evaluation purposes as part of the backup portfolios, a new water right was assumed available in 2025.

Yield:	750-1,500 AFA (average) <200 AFA (dry)
Availability:	Depends on hydrologic conditions
Cost ($/AF):	$100-200
Timing:	Mid-term

POTENTIAL BENEFITS	• Local supply. • Portfolio diversification. • Reduces reliance on the Delta.
LIMITATIONS	• Ability to obtain water rights - significant study is required. • Yield may be substantially lower pending prior rights and potential environmental needs.
INCLUDED IN PORTFOLIO ANALYSIS?	• Yes, but only for backup portfolios - additional study is required.

[83] StreamWISE is a suite of multi-benefit projects designed to implement the Stream Management Master Plan. This program is designed to provide flood protection as well as environmental benefits. More information can be found at: http://www.zone7water.com/streamwise/index.html.

[84] Source: Zone 7's monthly database maintained by Water Resources.

DESCRIPTION

This supply would involve the acquisition of a new water right permit on the Arroyo Mocho to put water to beneficial use. The construction of the Arroyo Mocho Diversion Structure, which is already planned to be completed in 2014 (for more details, see section 6.4.4), could allow for the perfection of any acquired water right.

Zone 7 completed a preliminary analysis of data available from the Arroyo Mocho Near Livermore and Arroyo Mocho at Hagemann gage stations[85] to estimate total monthly inflows to the Arroyo Mocho between 1913 and 2008. Estimated annual inflows range between 150 to 23,000 acre-feet (AF), with an average annual inflow of 7,000 AF. Assuming that only 12.5 to 25% of the total inflow is potentially available for diversion after accounting for existing water rights and environmental needs, Zone 7 estimates an average annual yield between 900 to 1,800 AF, with a dry year yield of less than 200 AF.

The total estimated capital cost for acquiring a new water right on the Arroyo Mocho is $1.8 million, including permit application fees, environmental analysis, and legal costs. The annual operation and maintenance (O&M) cost is estimated at $12,000. If a decision is made to pursue an Arroyo Mocho water right – after additional feasibility study – then the process for acquiring a new water right could take 10 to 15 years; for evaluation purposes as part of the backup portfolios, a new water right was assumed available in 2025.

Yield:	900-1,800 AFA (average) <200 AFA (dry)
Availability:	Depends on hydrologic conditions
Cost ($/AF):	$100-200
Timing:	Mid-term

POTENTIAL BENEFITS	• Local supply. • Portfolio diversification. • Reduces reliance on the Delta.
LIMITATIONS	• Ability to obtain water rights - significant study is required. • Yield may be substantially lower pending prior rights and potential environmental needs.
INCLUDED IN PORTFOLIO ANALYSIS?	• Yes, but only for the backup portfolios - additional study is required.

[85] Source: Zone 7's monthly database maintained by Water Resources.

DESCRIPTION

This supply would involve the acquisition of new water rights on the Tassajara Creek and San Ramon Valley Creek.

There is insufficient flow data to evaluate the potential yields of these creeks. Furthermore, limited water quality data indicate poor water quality from Tassajara Creek. Finally, these creeks are downstream of the Chain of Lakes, and there is no practical or feasible way to capture, store, and/or treat the flows from these creeks.

Due to its obvious limitations, this option was not analyzed in detail.

Yield:	Not analyzed
Availability:	Depends on hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Local supply. • Portfolio diversification. • Reduces reliance on the Delta.
LIMITATIONS	• Tassajara Creek has poor water quality. • No practical or feasible way to capture, store, and treat this supply.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time as there does not appear to be an economically feasible way to capture water.

DESCRIPTION

Under this option, residential, commercial, industrial, and institutional customers would install equipment to capture rainwater from rooftops. Drainpipes transfer rainwater collected from rooftops to storage tanks placed aboveground, as on the figure shown, or underground. Rain capture (or rainwater harvesting) is practiced all over the world; examples of industrialized countries where this practice is widespread include Australia and Germany.

Source: http://www.irainharvest.com/

The amount of water supply made available from this option depends on hydrology (i.e., rainfall) and equipment sizing. The analysis assumed an average roof size and storage of two months of available supply. Costs vary depending on the ability to retrofit existing accounts with rain capture equipment. Capital costs were estimated to range between $4,000 to $20,000 per system. Costs associated with regulatory oversight or inspection of the systems were not included. It was assumed that this supply would not provide peak day capacity because there is little to no control over customer use of captured water. There is always a minimum amount of rainfall; dry year supply is estimated based on a minimum historical rainfall of 5.2 inches.

Yield:	220-860 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	$73,600-79,300
Timing:	Mid-term

POTENTIAL BENEFITS	• Direct household contribution. • Decentralized supply: does not require Zone 7 system enhancements. • Portfolio diversification - reduced reliance on the Delta.
LIMITATIONS	• Zone 7 does not have land-use authority. • Potentially significant oversight costs. • Difficulty of predicting supply impacts since users are responsible for implementation. • High costs.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to costs and difficulty regulating end-user (cannot enforce compliance).

DESCRIPTION

This option represents encouraging low-impact development through the use of pervious surfaces to allow for improved management of stormwater and enhanced groundwater recharge, particularly in developed areas.

Supply would be generated by directing onsite stormwater to vegetated or rock swales, which are broad and shallow channels that facilitate the permeation of water into the ground. Swales can be covered primarily with vegetation, or with rocks. Both can act as a pre-filter for runoff.

Drain rock is used to prevent erosion of this vegetated swale at Zone 7 Water Agency's office building – drain rock can also enhance recharge if placed over permeable areas of the groundwater basin.

The amount of water supply potentially available from this option depends on hydrology (i.e., rainfall) and swale design. In general, costs vary depending on the swale system design. There will also be costs associated with regulatory oversight or inspection of the systems. Due to its obvious limitations, this option was not analyzed in detail; however, the cities may want to consider including this concept into land development ordinances.

Yield:	Not analyzed
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Local supply. • Swales can enhance landscaping. • Reduces reliance on the Delta
LIMITATIONS	• Zone 7 does not have land-use authority. • Potentially significant oversight costs. • Difficulty of predicting impacts on supply since users are responsible for implementation and maintenance.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to difficulty of regulating end-user (cannot enforce compliance).

DESCRIPTION

This option involves purchasing an existing well located just outside the Camp fringe sub-basin in the DSRSD service area. The well could be used to offset peak DSRSD recycled water demands for irrigation, potentially reducing storage needs. The quality of groundwater from this well is not as good as that of the groundwater in the Main Basin; therefore, this well would be more appropriate for non-potable application.

Preliminary analysis by Zone 7 staff indicates that the Yara Yara well is unlikely to sustain 0.75 MGD for long periods, given its location in the Tassajara Formation outside of the fringe basins.

The capital cost of this small well was assumed to be about $4 million with an annual O&M cost of $28,000 (based on discussions with the local water supply retailers). These costs do not include additional pipelines required to connect the well to DSRSD's recycled water system. In addition, the costs assume that the well operates at 0.75 MGD for 122 days per year (based on irrigation needs).

Yield:	280 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	$1,140
Timing:	Near-term

POTENTIAL BENEFITS	• Drought-resistant supply.
LIMITATIONS	• Relatively poor water quality suitable for nonpotable applications only. • Low yield.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to low yield and potentially poor water quality.

DESCRIPTION

The Livermore-Amador Valley is home to a number of wineries and their vineyards, as well as other agricultural enterprises. The potential water supply savings from the reuse of process wastewater and the residual capture of stormwater runoff at the five largest vineyards in the area was evaluated.

A vineyard in Livermore. (Source: http://www.murrietaswell.com/)

Process wastewater and stormwater runoff at the five largest vineyards—with a total acreage of 1,726 acres—were estimated at 57 AFA, which is a relatively small amount of water relative to the water supply needs of the Zone 7 service area. While this water may be usefully captured and reused by individual landowners, this does not appear to be a viable supply option for Zone 7.

Yield:	<100 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Drought-resistant supply.
LIMITATIONS	• Minimal amount of water. • Possible water quality issues. • Potential constraints from the RWQCB.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to low yield.

DESCRIPTION

There are potential opportunities to reduce water consumption at commercial and industrial facilities by implementing wastewater reuse programs. Examples of such efforts include graywater application for toilet flushing and/or irrigation. However, these types of improvements are likely to be implemented as part of water conservation programs, particularly in response to the Water Conservation Act of 2009. Zone 7 and the retailers all have robust conservation programs in place. Zone 7, therefore, did not investigate this option further.

Yield:	Not analyzed
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Near to long-term

POTENTIAL BENEFITS	• Drought-resistant supply.
LIMITATIONS	• Not analyzed.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time as it will likely be implemented by others.

DESCRIPTION

Over 2009-2010, the California Plumbing Code[86] was modified to facilitate the reuse of graywater by residences for outdoor use, primarily irrigation. Under this option, water from washing machines, sinks, showers, and/or bathtubs would be collected, filtered, and applied to lawns or gardens for irrigation. Permit requirements vary depending on the source of the graywater; for example, use of graywater from washing machines would not require a permit.

A garden irrigated with graywater. (Source: http://greywateraction.org/)

A key goal for graywater reuse is the reduction in the demand for potable water. The "yield" or, more appropriately, demand reduction from this option depends on whether graywater reuse systems are installed only in new developments or in existing residences as well. Installation of such systems would occur over time. The capital cost of a graywater system consisting of a pump, pipelines, and a filter is estimated at $2,500 per unit, with an O&M cost of $375 annually.

Yield:	1,200 to 5,400 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	$3,700-6,600
Timing:	Near to long-term

The impact of irrigating with graywater on groundwater quality in the Main Basin is an important consideration and would need to be evaluated.

POTENTIAL BENEFITS

- Direct household contribution.
- Decentralized supply: does not require Zone 7 system enhancements.
- Diversifies supply portfolio.
- Reduces reliance on the Delta.

LIMITATIONS

- Difficulty of predicting impacts on supply since users are responsible for implementation and maintenance.
- Potential water quality impacts to the Main Basin.
- High cost.

INCLUDED IN PORTFOLIO ANALYSIS?

- Not at this time due to cost and difficulty enforcing end-user compliance.

[86] Title 24, Part 5, Section 16A: "Nonpotable Water Reuse Systems"

DESCRIPTION

This program would inject up to 2.5 MGD (2,800 AFA) of recycled water that has been treated using reverse osmosis (RO) technology. Recycled water provides significant reliability since it is a drought-resistant supply; furthermore, the RO process produces water with extremely low total dissolved solids content, which would benefit salt management of the Main Basin.

Reverse Osmosis membranes – similar to those at Zone 7's Mocho Demineralization Facility – would provide highly treated recycled water for injection into the Main

Capital costs range between $34 and $40 million, depending on the level of effort required to rehabilitate an existing RO unit, cost to purchase secondary effluent, and participation by the City of Livermore. They include rehabilitation of an existing RO unit, a new pipeline for Zone 7's Demineralization Facility, and a new injection well. Annual maintenance is estimated at $1.4 million.

Yield:	2,800 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	$1,500-1,600
Timing:	Near/mid-term

POTENTIAL BENEFITS

- Drought-resistant supply.
- Use of existing equipment.
- Potentially improves salt loading in the Main Basin.
- Reduces reliance on the Delta.

LIMITATIONS

- Potential for strong public opposition.

INCLUDED IN PORTFOLIO ANALYSIS?

- YES.

DESCRIPTION

By 2030, the City of Livermore and the Dublin San Ramon Services District (DSRSD) expect a total demand of 5,900 AFA for recycled water in their service areas. In response to the Water Conservation Act of 2009, Zone 7 expects that an additional 2,000 AFA will be used in the service area by 2020 to reduce potable water use.

Use of recycled water for irrigation. (Source: http://www.derwa.org/)

Under this option, additional recycled water for irrigation—beyond the amounts listed above—is used to further reduce potable water demands. One of the challenges with recycled water use for irrigation is that wastewater—and therefore recycled water—is generally produced evenly throughout the year, while irrigation demand usually peaks in the warmer months; storage facilities would address this discrepancy. Where recycled water can be applied is another important issue that needs to be addressed. Given its salt content, it can potentially have a significant impact on salt loading in the Main Basin, which may require mitigation. Recycled water may also contain other contaminants of concern.

Capital and O&M costs were estimated for various scenarios and varied widely depending on the amounts of recycled water produced and the need for storage under indirect use. However, the amortized costs were consistent and ranged between $1,500 to $2,400 per AF. This cost range does not include any salt impact mitigation. Detailed studies examining demands, use patterns, storage options and costs, contaminants in recycled water, and potential salt loading impacts to the Main Basin will need to be completed to determine the feasible amounts of additional recycled water use in the Livermore-Amador Valley.

Yield:	2,600 to 16,000 AFA – depends on demand – additional analysis required.
Availability:	All hydrologic conditions
Cost ($/AF):	$1,500-$2,400
Timing:	Near to long-term

POTENTIAL BENEFITS	• Local supply. • Diversifies supply portfolio. • Recharges the Main Basin. • Reduces reliance on the Delta.
LIMITATIONS	• Groundwater salt loading and contaminant impacts. • Limited by demand and/or space for storage facilities. • Potable demand reductions requires additional study.
INCLUDED IN PORTFOLIO ANALYSIS?	• Yes, see "In-Valley" Portfolio.

ACWD Entitlement Exchange via Demineralization — **Desalination/Demineralization**

DESCRIPTION

This water supply option includes construction of a Phase 3 Desalination Facility by Zone 7 for the Alameda County Water District (ACWD). In exchange, Zone 7 would receive a water supply along the South Bay Aqueduct (i.e, State Water Project Table A water) at 80% of yield.

The capital cost is estimated at $80 million and the annual O&M costs are estimated at $6 million.

Yield:	4,100 AFA
Availability:	All hydrologic conditions
Cost ($/AF):	$2,900
Timing:	Mid-term

POTENTIAL BENEFITS	• Potential diversification of Zone 7 water supply portfolio.
LIMITATIONS	• Initial conversations with ACWD indicate the potential yield may be much smaller, if anything. • Cost estimates are likely too low.
INCLUDED IN PORTFOLIO ANALYSIS?	• YES, however, other options appear more cost effective.

DESCRIPTION

Since 2003, the Bay Area's four largest water agencies—Contra Costa Water District (CCWD), East Bay Municipal Utility District (EBMUD), San Francisco Public Utilities Commission (SFPUC), and Santa Clara Valley Water District (SCVWD)—have been working together to evaluate the feasibility of a regional desalination facility to improve water supply reliability for the more than five million people served by these agencies.

In May 2010, Zone 7 officially joined the BARDP. As a partner in the BARDP, Zone 7 is evaluating the feasibility of receiving up to 5,600 AFA under all hydrologic conditions, or only during normal/wet years. For Zone 7, desalinated water offers the significant benefits of providing a drought-resistant supply and diversifying Zone 7's water supply portfolio, both of which increase Zone 7's system reliability.

At this time, the most likely location for a desalination plant is in eastern Contra Costa County, where CCWD has existing water rights and other water rights may be available for purchase. The desalination plant can potentially produce up to 20 MGD of desalinated water (10,000 to 25,000 AFA), depending on the water rights obtained. Desalinated water would have to be wheeled through EBMUD for delivery to Zone 7 via a new intertie. The BARDP partners are planning to have something online by 2020.

Yield:	5,600 AFA (normal/wet) 1,500-5,600 AFA (dry)
Availability:	All hydrologic conditions
Cost ($/AF):	$1,400-2,000
Timing:	Mid-term

Zone 7's share of the capital cost is estimated at $42 million (does not include the intertie), with annual O&M costs estimated at $2.6-4.4 million depending on the amount of water that Zone 7 receives. Wheeling costs through EBMUD will be refined as part of a hydraulic modeling study to be undertaken starting in mid-2011; the current estimate of $600 to $1,000 /AF is included in the amortized cost listed above.

POTENTIAL BENEFITS	• Drought-resistant supply. • Diversifies supply portfolio. • High-quality water supply. • Makes use of new intertie.
LIMITATIONS	• Potentially highly variable costs due to the need for wheeling through another system. • Ability to obtain the necessary water rights for the BARDP.
INCLUDED IN PORTFOLIO ANALYSIS?	• Yes, as a potential source of supply for the Intertie Portfolio.

DESCRIPTION

As part of this option, Zone 7 would construct new wells in the fringe basins of the Livermore Valley Groundwater Basin; fring basins are generally lower yielding poorer quality portions of the basin.

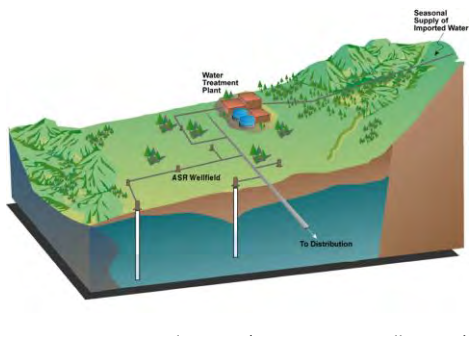
Based on existing data, Zone 7 believes that the potential yields from the fringe basins, including Mocho Sub-Basin I, are extremely low and that any groundwater pumped would likely require demineralization. A significant amount of additional study would be required to more accurately establish potential yields and costs.

Yield:	Not analyzed
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Local supply. • Reduced salt loading in the Main Basin.
LIMITATIONS	• Likely very low yields. • Likely requires demineralization, which will increase costs.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to low yields and potentially poor water quality.

DESCRIPTION

Zone 7's ability to conjunctively use the local groundwater basin can potentially be enhanced through the injection and storage of surface water and its subsequent recovery. This option, called Aquifer Storage and Recovery (ASR), re-evaluates previous ASR efforts by Zone 7, and is a possible back-up option in case recharge within the Chain of Lakes turns out to be limited.



Starting in 1997, Zone 7 retrofited Hopyard Well 6 for ASR use. Between 1997 and 2000, a total of 3,200 AF was injected into the well to pilot-test ASR operations. Clogging problems resulted in lost production capacity (a 50% decrease) and the eventual shutdown of ASR operations. Possible causes of clogging include: air binding by entrained air bubbles, bacterial growth in and near the well screen, suspended solids in the injection water, and chemical reactions between the injected water and native groundwater and/or aquifer matrix[87].

The capital cost is estimated at $2.4 million with an estimated O&M cost of $600,000. These costs reflect the additional analysis (e.g., bench testing) required to address the clogging issues observed during the previous attempt to implement an ASR program. The costs only include the retrofit of Chain of Lakes wells 1 and 2 for use as injection wells.

Yield:	3,000 AFA of additional recharge in the Main Basin (normal/wet years)
Availability:	Normal/wet years only
Cost ($/AF):	$260/AF of additional storage
Timing:	Mid-term

POTENTIAL BENEFITS	• Makes use of existing facilities. • Increased availability of local storage.
LIMITATIONS	• Potentially recurring technical issues related to well clogging. • Does not provide additional supply. • Potentially the same benefits as the Chain of Lakes operations.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to like benefit already planned as part of the Chain of Lakes.

[87] CH2M Hill, 2000. ASR Test Results for the Hopyard 6 Well.

In-Stream Infiltration via Swales

Operational Improvements – Increased Recharge

DESCRIPTION

Under this option, Zone 7's ability to recharge imported surface water through the Arroyo Mocho is enhanced through the construction of swales, which are broad and shallow channels that facilitate the permeation of water into the ground. Ponds would be constructed to increase the head on the streams and increase recharge; these ponds could be constructed to also facilitate environmental needs. This option represents a back-up option in case recharge in the Chain of Lakes turns out to have lower capacity than expected. The option is limited to Arroyo Mocho because a cursory review of available areas to construct eliminated Arroyo del Valle as a potential project.

Based on the construction of swales at two "example" sites (Madeiros Parkway and Robertson Park), as described in the StreamWISE Program[88], the capital cost is estimated at $7.8 million with O&M cost estimated at $1.6 million annually.

Yield:	830 AFA of additional recharge in the Main Basin (normal/wet years)
Availability:	Normal/wet years only
Cost ($/AF):	$2,600/AF of additional storage
Timing:	Mid-term

POTENTIAL BENEFITS	• Increased availability of local storage. • Improved reliability.
LIMITATIONS	• Does not provide additional supply. • Potentially the same benefits as the Chain of Lakes projects.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to like benefit already planned as part of the Chain of Lakes.

[88] StreamWISE is a suite of multi-benefit projects designed to implement the Stream Management Master Plan. This program is designed to provide flood protection as well as environmental benefits. More information can be found at: http://www.zone7water.com/streamwise/index.html.

DESCRIPTION

The losses associated with the use of Zone 7's non-local groundwater banks in Kern County District and Cawelo Water District) are specified in contracts. Storage in Semitropic Water Storage District (Semitropic) is associated with a ten percent loss while fifty percent of the water placed into storage in Cawelo Water District is lost as compensation to Cawelo Water District. The institutional and political hurdles to reducing the water losses specified in the contracts are significant, and likely insurmountable. This is particularly true in the case of Semitropic, where the contract involves many different parties.

Groundwater banking facilities at Semitropic Water Storage District. (Source: http://www.semitropic.com/Facilities.htm)

Yield:	Not analyzed
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Makes use of existing supplies.
LIMITATIONS	• Significant institutional/political barriers.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to potentially insurrmountable institutional and political barriers.

DESCRIPTION

During well start-up, the initial groundwater pumped is directed to waste. An estimate of the potential water supply savings from the capture of water discharged to waste during the startup of existing groundwater wells indicates that the savings are within the rounding error of future water supply needs (e.g., < 100 AF). For example, data from 2006 to 2008 indicate a total average annual waste of 34 AF.

While more efficient operation of Zone 7 facilities will continue to be a goal, this option was not analyzed in detail due to the minimal yield expected.

Yield:	<100 AF
Availability:	All hydrologic conditions
Cost ($/AF):	Not analyzed
Timing:	Not analyzed

POTENTIAL BENEFITS	• Local supply. • No new infrastructure needed.
LIMITATIONS	• Low yield.
INCLUDED IN PORTFOLIO ANALYSIS?	• Not at this time due to low yield.

9. DESCRIPTION OF BACKUP PORTFOLIOS

This section describes the Backup Portfolios evaluated as potential alternatives to the Current Plan: the In-Valley Portfolio and the Intertie Portfolio. These portfolios were developed with input from the Retailers.

9.1 IN-VALLEY PORTFOLIO

Recognizing the complexity of challenges facing the Delta, and the uncertainty of the future reliability of the water supplies from the State Water Project (SWP) as discussed in Section 6.1, it is necessary to consider an alternative that reduces reliance on the Delta. This alternative is the In-Valley Portfolio, an alternative that focuses on supplies locally available in the Livermore-Amador Valley. The key difference in portfolio components between the In-Valley Portfolio and the Current Plan described in Section 6 is the assumption that the long-term Delta Fix does not happen or does not fully restore lost yield. Increased use of recycled water and the development of additional local water rights fill in the supply deficit. Figure 9-1 shows the alternative supply and demand mix under the In-Valley Portfolio.

Figure 9-1. Projected Supply and Demand Mix: In-Valley Portfolio

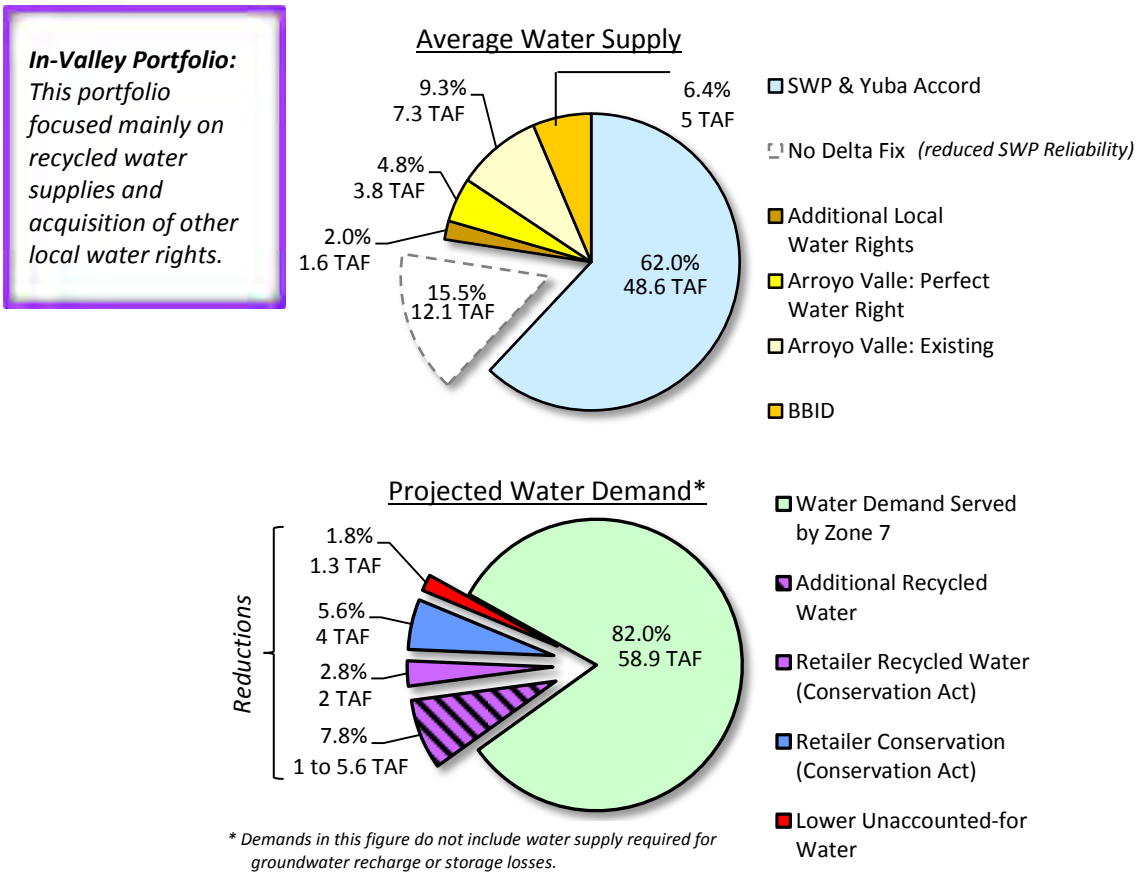


Table 9-1 lists the full set of components included in the In-Valley Portfolio, broken down by water supplies, water facilities, and water quality. As indicated in Table 9-1, a number of the components are

already being implemented under the Current Plan and are therefore already described in Section 6. The other components are described in the following sections.

Table 9-1. Components of the In-Valley Portfolio

Type	Component	Included in Current Plan (see Section 6)
Water Supplies	*Potable Demand Reductions*	*Yes*
	Maximization of Supply from BBID Contract	*Yes*
	Reduction of Unaccounted-for-Water	*Yes*
	Reduction of Brine Losses	*Yes*
	Enhanced In-Lieu Recharge Program	*Yes*
	Arroyo del Valle: Perfection of Existing Permit	*Yes*
	Arroyo Mocho Water Rights	**No**
	Arroyo Las Positas Water Rights	**No**
	Additional Recycled Water – Direct Use	**No**
	Additional Recycled Water - Storage	**No**
Facility Improvements	*Increased Surface Water Treatment Capacity*	*Yes*
	Increased Groundwater Pumping Capacity	*Yes*
	Increased Transmission System Capacity	*Yes*
	Arroyo Mocho Diversion Structure	*Yes*
	Arroyo del Valle Diversion Structure	*Yes*
	Reliability Intertie	*Yes*
Water Quality	*Phase 2 Demineralization Facility*	*Yes*

9.1.1 Arroyo Mocho Water Rights

This supply would involve the acquisition of a new water right on the Arroyo Mocho. The construction of the Arroyo Mocho Diversion Structure, which is planned to be completed in 2014[89], could allow for the perfection of any permitted water right.

[89] For more details, see section 6.4.4.

Zone 7 analyzed available data from the Arroyo Mocho Near Livermore and Arroyo Mocho at Hagemann gage stations[90] to estimate total monthly inflows to the Arroyo Mocho between 1913 and 2008. Estimated annual inflows range between 150 acre-feet (AF) in 1924 and 23,000 AF in 1916, with an average annual inflow of 7,000 AF. Assuming that 12.5 to 25% of the total inflow is potentially available for diversion after accounting for environmental needs and prior rights, Zone 7 estimates an average annual yield between 900 to 1,800 AF, with a dry year yield less than 200 AF.[91]

The total estimated capital cost for acquiring a new water right on the Arroyo Mocho was estimated at $1.8 million, including permit application fees, environmental analysis, and legal costs. The annual operation and maintenance (O&M) cost is estimated at $12,000. Acquisition of a new water right is typically a lengthy process; for planning purposes, Zone 7 has assumed a 10-year process. Zone 7 is still investigating the need for new water rights, and if a decision is made to pursue an Arroyo Mocho water right beginning in 2014, a new water right may be available starting in 2025.

9.1.2 Arroyo Las Positas Water Rights

This supply would involve the acquisition of a new water right on the Arroyo Las Positas. Use of this supply may require the completion of the diversion structure at Arroyo Las Positas, a project recommended in the Stream Management Master Plan for flood protection purposes. The structure would allow the diversion of water from Arroyo Las Positas to the Chain of Lakes for detention storage to be returned to the arroyo once storm flows subside.

Zone 7 analyzed available data from the Arroyo Las Positas Near El Charro gage station to estimate total monthly inflows between 1913 and 2008. Because there is limited data available from this station, Zone 7 used rainfall correlation to fill in the inflow data gaps.

Natural runoff from the Alkali Sink and inflow from the groundwater basin diminish the water quality in the Arroyo Las Positas during low flows. The total dissolved solids (TDS) concentration of groundwater near the Chain of Lakes typically range between 500 to 1,000 mg/L during low flows; to minimize salt loading in the Main Basin, Zone 7 would generally only recharge with water with TDS levels below 500 mg/L. Consequently, Zone 7 also considered water quality data for the Arroyo Las Positas from October 2001 to September 2008, which indicated that TDS levels can be elevated up to 1,500 mg/L at flows less than 100 cubic feet per second (cfs); at above 100 cfs, TDS decrease to less than 500 mg/L[92]. If a water right is acquired for the Arroyo Las Positas, diversion may be limited to periods of flows greater than 100 cfs for salt management purposes.

Estimated annual inflows range between 1,400 AF in 1924 and 26,000 AF in 1983, with an average annual inflow of 6,000 AF. Assuming that 12.5 to 25% of the total inflow is potentially available for diversion after accounting for environmental needs and prior rights, Zone 7 estimates an average annual yield between 750 to 1,500 AF, with a dry year yield less than 200 AF.

The total estimated capital cost for acquiring a new water right on the Arroyo Las Positas is $1.6 million, including permit application fees, environmental analysis, and legal costs. The construction of the diversion structure was not included in this analysis of the capital costs since the proposed use of the structure will be for flood protection, and its construction is independent of any water right acquisition. Analysis of capital funding and final determination of the structure's use will be reevaluated once more

[90] Source: California Data Exchange Center

[91] These values are preliminary, and need much more robust analysis.

[92] TDS calculated as 0.7 x electrical conductivity (EC). EC data provided by G. Gates.

specific flood protection project needs have been defined and once key lakes of the Chain of Lakes are transferred to Zone 7 ownership. The annual O&M cost is estimated at $12,000. Similar to the Arroyo Mocho water right, if a decision is made to pursue an Arroyo Las Positas water right beginning in 2014, a new water right may be available starting in 2025.

9.1.3 Additional Recycled Water – Direct Use and With Storage

There are multiple existing and planned recycled water programs in the Livermore-Amador Valley. The City of Livermore and the Dublin San Ramon Services District (DSRSD) have been producing and serving recycled water for many years. By 2030, DSRSD and Livermore are planning for a total demand of 5,900 acre-feet annually (AFA), accounting for the projected development and growth in recycled water infrastructure in their service areas. Section 6.2 describes the demand reductions required under the Water Conservation Bill of 2009, and Zone 7's assumption that one-third of this demand reduction—approximately 2,000 AFA—will be met through the implementation of additional recycled water projects.

In-Valley Portfolio: focusing on local water supply sources.

In the In-Valley Portfolio, additional recycled water—beyond the programs and demands described above—is used to further reduce potable water demands in order to meet the required system reliability. Potential wastewater sources are DSRSD and the cities of Pleasanton and Livermore[93]. Appendix G provides a summary of the analysis used to estimate the amounts of recycled water supply available in the Livermore-Amador Valley.

9.2 INTERTIE PORTFOLIO

The key feature of the Intertie Portfolio is that it focuses on new water supplies entering Zone 7's water transmission system through an intertie with another agency. For example, water supply can be delivered via an intertie with the East Bay Municipal Utility District (EBMUD) system in the western portion of Zone 7's service area. The feasibility investigation of a reliability intertie with EBMUD, which is part of the Current Plan and described in Section 6.4.6, will consider the use of this intertie for this purpose.

Zone 7 staff is still working with EBMUD and San Francisco Public Utilities Commission (SFPUC)to better define potential benefits and roles in a new intertie project. The Bay Area Regional Desalination Project (BARDP)[94] could potentially make use of a new intertie. Secondary to the BARDP, shared use of the Freeport Regional Water Project, when excess capacity exists, is a potential opportunity for Zone 7 created by an intertie with EBMUD.

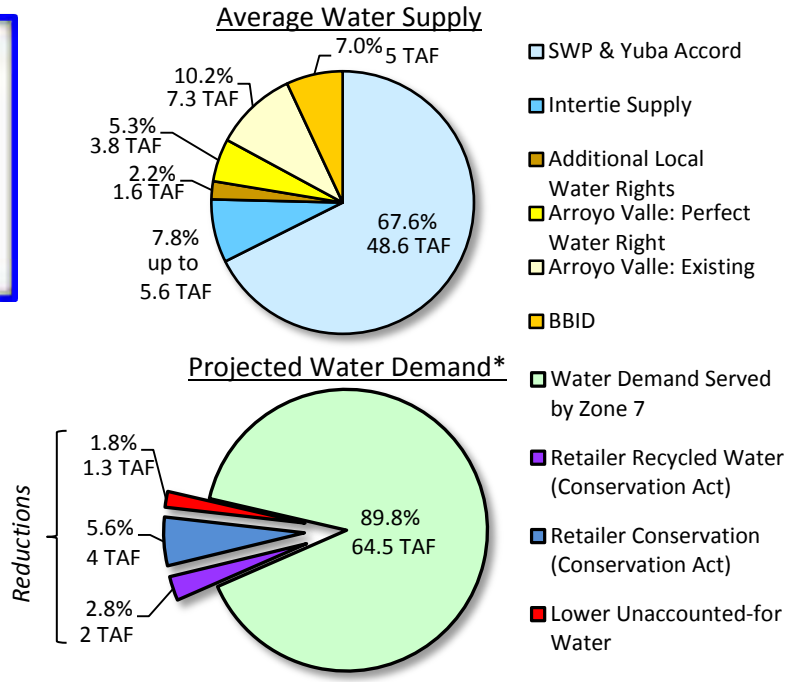
A significant potential benefit of this portfolio is that it represents a more diverse water supply portfolio, with reduced dependence on the Delta and the SWP facilities, and consequently increased reliability. Figure 9-2 shows the alternative supply and demand mix under the Intertie Portfolio.

[93] Cal Water's service area is located within the City of Livermore, where wastewater is collected by the City.

[94] Discussed in Section 9.2.

Figure 9-2. Projected Supply and Demand Mix: Intertie Portfolio

Intertie Portfolio: *This portfolio focused mainly on the lowest unit cost and highest quality water supplies.*



** Demands in this figure do not include water supply required for groundwater recharge or storage losses.*

Table 9-2 lists the full set of components included in the Intertie Portfolio, broken down by water supplies, water facilities, and water quality. As indicated in Table 9-2, a number of the components are already being implemented under the Current Plan and are therefore already described in Section 6. The other components are described in the following sections.

Table 9-2. Components of the Intertie Portfolio

Type	Component	Included in Current Plan (see Section 6)
Water Supplies	*Potable Demand Reductions*	*Yes*
	Maximization of Supply from BBID Contract	*Yes*
	Reduction of Unaccounted-for-Water	*Yes*
	Reduction of Brine Losses	*Yes*
	Enhanced In-Lieu Recharge Program	*Yes*
	Arroyo del Valle: Perfection of Existing Permit	*Yes*
	Arroyo Mocho Water Rights	**No**
	Arroyo Las Positas Water Rights	**No**
	Intertie Supply	**No**
Facility Improvements	*Increased Surface Water Treatment Capacity*	*Yes*
	Increased Groundwater Pumping Capacity	*Yes*
	Increased Transmission System Capacity	*Yes*
	Arroyo Mocho Diversion Structure	*Yes*
	Arroyo del Valle Diversion Structure	*Yes*
	Reliability Intertie	*Yes*
	Chain of Lakes Pipeline	*Yes*
Water Quality	*Phase 2 Demineralization Facility*	*Yes*

9.2.1 Arroyo Mocho Water Rights

The acquisition of a new water right for the Arroyo Mocho is also part of the In-Valley portfolio and is therefore described previously in Section 9.1.1.

9.2.2 Arroyo Las Positas Water Rights

The acquisition of a new water right for the Arroyo Las Positas is also part of the In-Valley portfolio and is therefore described previously in Section 9.1.2.

9.2.3 Intertie Supply

Zone 7 has identified a couple of potential options for obtaining new water supply that can be wheeled through a new EBMUD intertie: a regional desalination project or permanent water transfer/long-term lease. Zone 7 will continue to investigate other possible sources of supply that can similarly be delivered via an intertie with another agency.

9.2.3.1 Bay Area Regional Desalination Project

Since 2003, the Bay Area's four largest water agencies—Contra Costa Water District (CCWD), East Bay Municipal Utility District (EBMUD), San Francisco Public Utilities Commission (SFPUC), and Santa Clara Valley Water District (SCVWD)—have been working together to evaluate the feasibility of a regional desalination facility to improve water supply reliability for the more than five million people served by these agencies. The project, called the Bay Area Regional Desalination Project (BARDP), has the following benefits[95]:

- minimize potential adverse environmental impacts associated with the construction of separate desalination plants in close proximity to one another and construction of other new facilities;
- provide substantial cost savings through economies of scale, such as pooling resources and sharing of project administration, as compared to individual projects conducted separately by the agencies;
- promote a strong regional cooperation concept by joint ownership, operation, and management of a regional desalination facility that will serve the needs of multiple water providers in northern California;
- provide water during emergencies such as earthquakes or levee failures;
- provide a supplemental water supply source during extended droughts; and
- allow major facilities, such as treatment plants, water pipelines, and pump stations, to be taken out of service for maintenance or repairs.

In May 2010, Zone 7 officially joined the BARDP. As a partner in the BARDP, Zone 7 is evaluating the feasibility of receiving up to 5,600 AF every year, or only during normal/wet years, depending on Zone 7's needs and those of the other BARDP partners. For Zone 7, desalinated water offers the significant benefits of providing a drought-resistant supply and diversifying Zone 7's water supply portfolio, both of which increase Zone 7's system reliability.

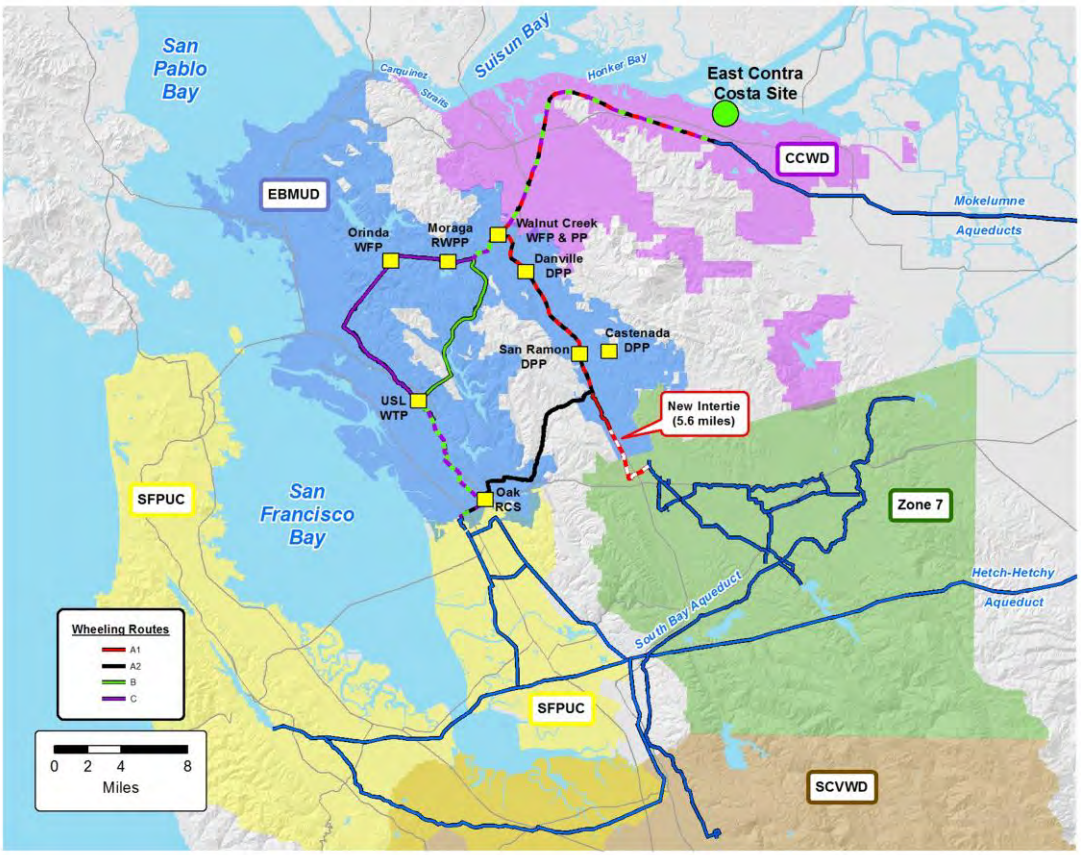
At this time, the most likely location for a desalination plant is in East Contra Costa, where CCWD has existing water rights. The desalination plant can potentially produce up to an average 20 million gallons per day of desalinated water, depending on the water rights obtained for the BARDP. Desalinated water would have to be wheeled through EBMUD's distribution system for delivery to Zone 7, as well as to

[95] MWH, 2010. Bay Area Regional Desalination Project: Pilot Testing at Mallard Slough – Pilot Plant Engineering Report.

SFPUC and SCVWD, as illustrated on Figure 9-3. A new intertie would therefore play a critical role in a desalinated water supply for Zone 7, as described above.

The BARDP partners are planning to adopt a Memorandum of Agreement in mid-2011 that describes future site-specific studies intended to address the BARDP's potential environmental impacts, costs, and water production and delivery capacities. A public outreach effort will also be undertaken to begin addressing stakeholder concerns. The costs of these studies will be shared equally amongst the partners. The studies and the outreach will provide additional valuable information on evaluating the BARDP's feasibility.

Figure 9-3. Potential Wheeling Routes for Desalinated Water Produced by the BARDP at an East Contra Costa site.



9.2.3.2 Permanent Water Transfers or Long-Term Lease

Zone 7 is investigating possible opportunities for permanent water transfers or long-term leases from a non-State Water Project (SWP) contractor. This transaction would be similar to the contract Zone 7 holds with the Byron Bethany Irrigation District, which is a 20-year contract, renewable every five years up to a total of 30 years[96]. However, unlike the water from the BBID contract, which is delivered through

[96] See Section 4.1.2 for more details.

the South Bay Aqueduct, Zone 7 would seek water that can be delivered via a new intertie with another major agency as described above. This would have the added benefit of diversifying Zone 7's portfolio.

Costs associated with such a transfer or lease will likely include a payment upon contract execution, annual costs based on water delivery amounts, and wheeling costs similarly based on delivery amounts. In general, the availability of other transfers similar to the BBID contract depends on the willingness of other contractors to sell and the price Zone 7 is willing to pay.

10. EVALUATION OF BACKUP PORTFOLIO: IN-VALLEY

The purpose of this section is to present the analysis and results of using the probability-based water supply model to determine the reliability provided by the In-Valley Portfolio. As discussed in Section 9-1, the In-Valley Portfolio assumed that Zone 7 Water Agency (Zone 7) is able to work with the local water supply retailers to develop significant recycled water supplies beyond those already planned and assumed in this WSE for meeting the Water Conservation Act of 2009 (Conservation Act). The In-Valley Portfolio also assumed that Zone 7 successfully reduces its unaccounted-for water, reduces brine losses, increases the minimum yield from its contract with BBID, and enhances the existing in-lieu recharge program.

The following subsections present the results:

- 10.1 Reliability for the In-Valley Portfolio: 75 to 99%
- 10.2 Observations Regarding the Amount of Potable Water Demand Reduction
- 10.3 Facilities Evaluation for the In-Valley Portfolio
- 10.4 Salt Management Evaluation for the In-Valley Portfolio
- 10.5 Observations Regarding Delivered Water Quality
- 10.6 Cost Estimates for the In-Valley Portfolio: 75 to 99%

10.1 RELIABILITY FOR THE IN-VALLEY PORTFOLIO: 75 TO 99%

Zone 7 staff evaluated the ability of the water supplies and facilities included in the In-Valley Portfolio to prevent water supply shortages, while maintaining drought and emergency storage at a sustainable level. For this evaluation, Zone 7 staff first reviewed the risk of potential water supply shortages and corresponding reliability, and then reviewed the sustainability of system-wide storage, which included the Main Basin, Semitropic Water Storage District (Semitropic), Cawelo Water District (Cawelo), State Water Project (SWP) Carryover, and the Chain of Lakes.[97] Additionally, per discussions with the water supply retailers, Zone 7 did not evaluate reliabilities less than 75%. Each is discussed in more detail below.

10.1.1 Reliability of the In-Valley Portfolio: 75%

Under this scenario, shortages are kept equal to or below 25% of projected water demands through the development of an additional 1,000 acre-feet (AF)[98] of recycled water supply by 2025 (Figure 10-1).[99] In addition to achieving 75% reliability, this scenario also results in no shortages 94% of the time (Figure 10-2) and sustainable system-wide storage (Figure 10-3).

[97] Key individual storage results were included in Appendix F.

[98] This is 1,000 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 8,900 AF of recycled water use in the Livermore-Amador Valley.

[99] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-1. Risk of Potential Shortages for the In-Valley Portfolio: 75%

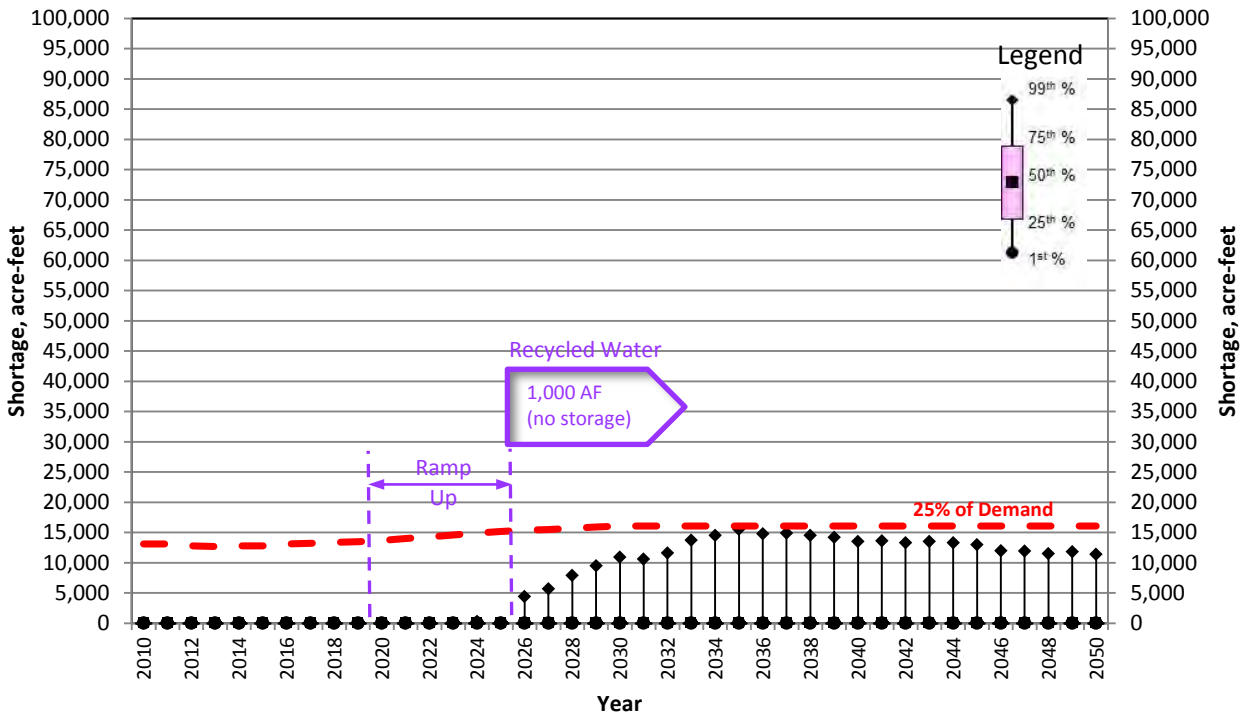


Figure 10-2. Reliability Curve for the In-Valley Portfolio: 75%

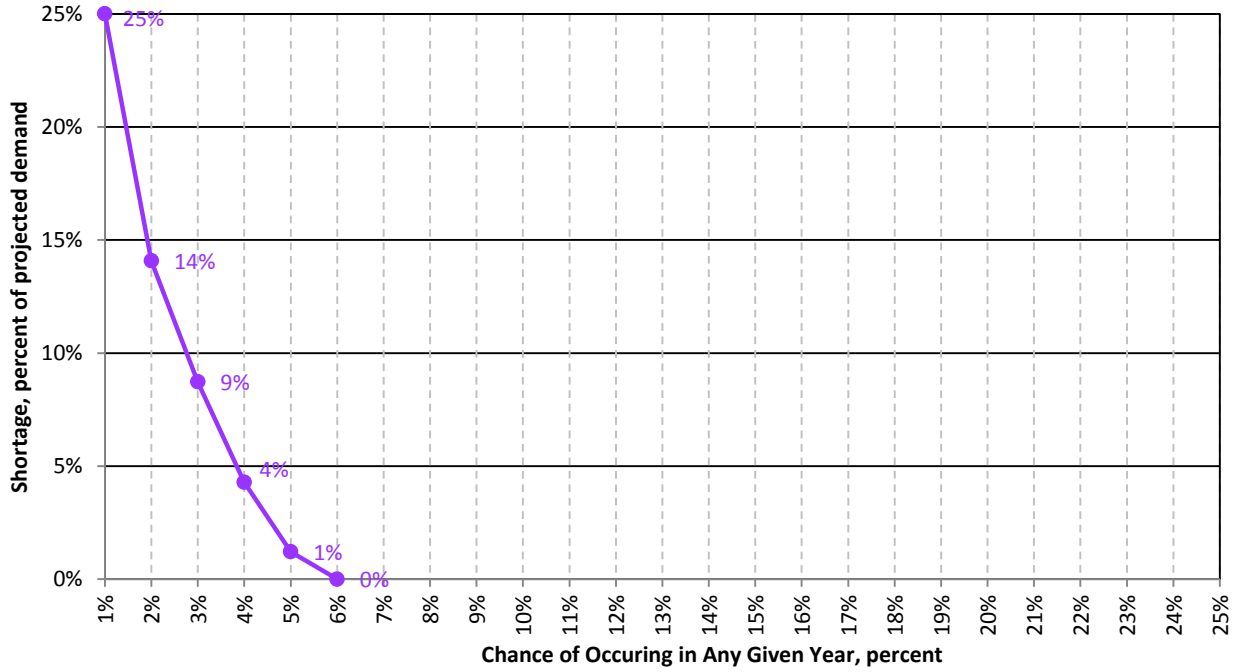
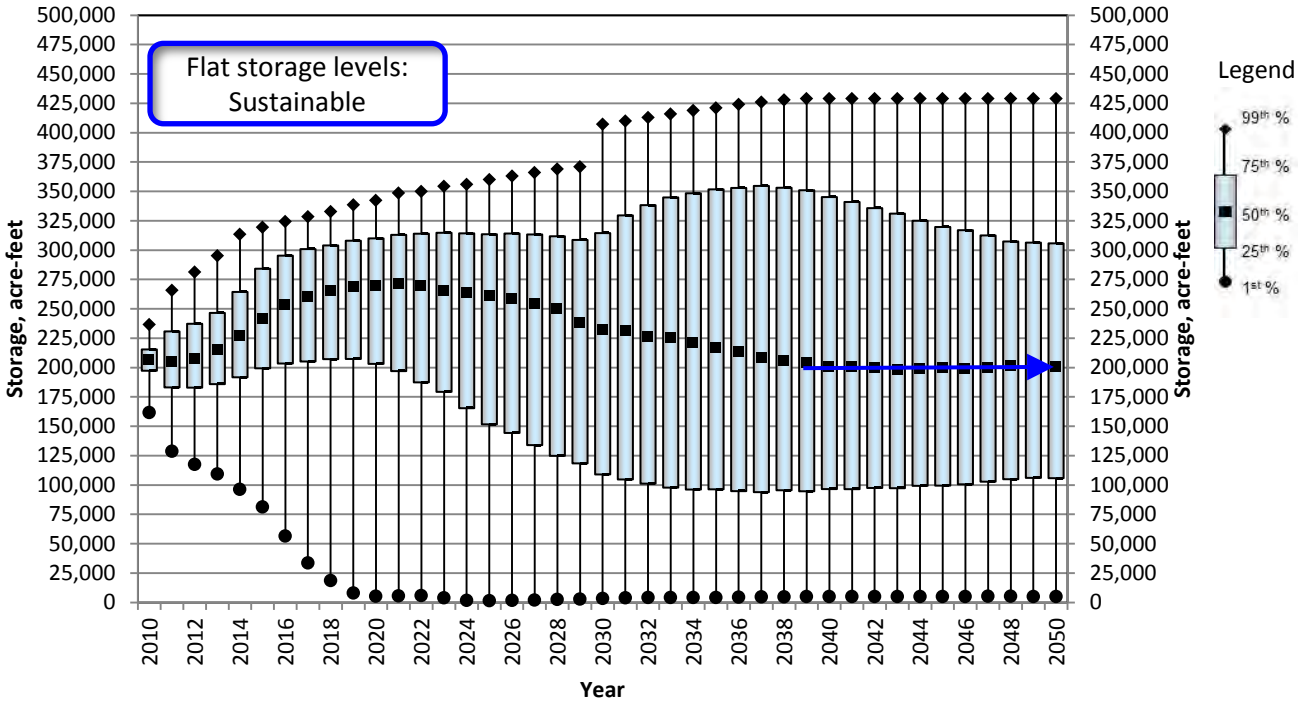


Figure 10-3. Sustainability of the In-Valley Portfolio at a Reliability of 75%



10.1.2 Reliability of the In-Valley Portfolio: 80%

Under this scenario, shortages are kept equal to or below 20% of projected water demands through the development of an additional 1,800 AF[100] of recycled water supply by 2025 (Figure 10-4).[101] In addition to achieving 80% reliability, this scenario also results in no shortages 95% of the time (Figure 10-5) and sustainable system-wide storage (Figure 10-6).

[100] This is 1,800 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 9,700 AF of recycled water use in the Livermore-Amador Valley.

[101] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-4. Risk of Potential Shortages for the In-Valley Portfolio: 80%

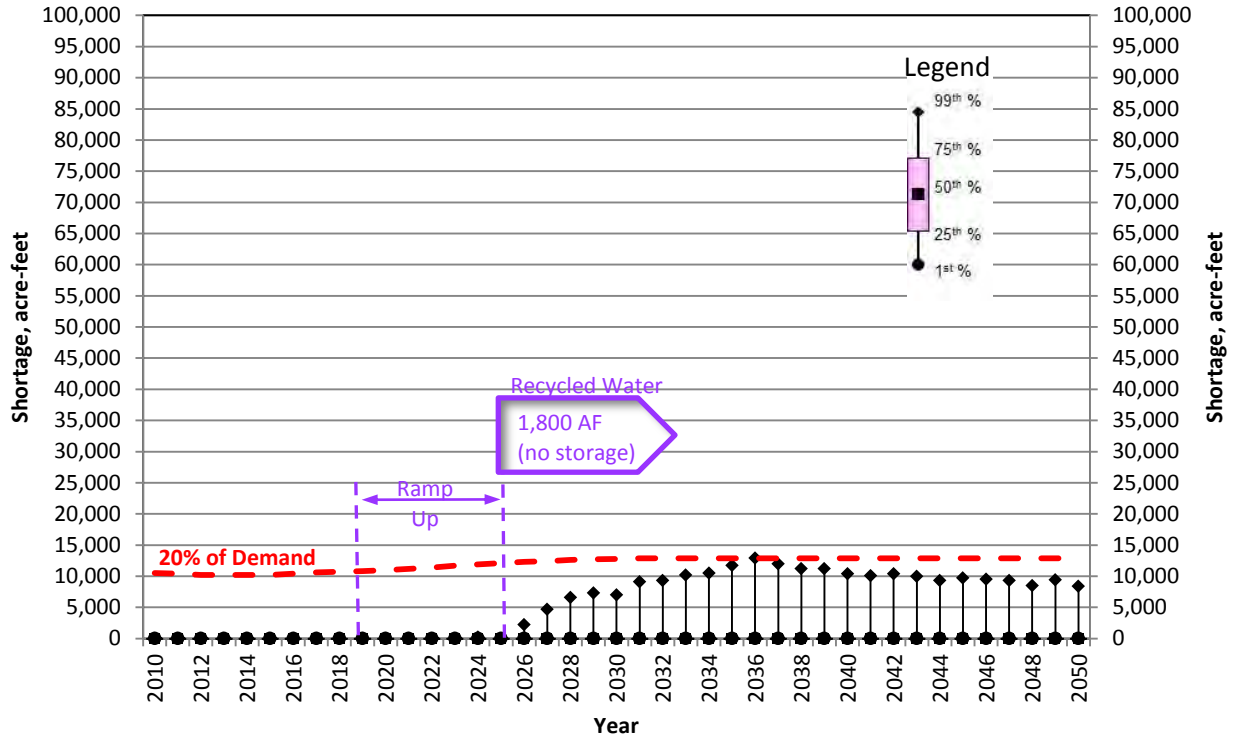


Figure 10-5. Reliability Curve for the In-Valley Portfolio: 80%

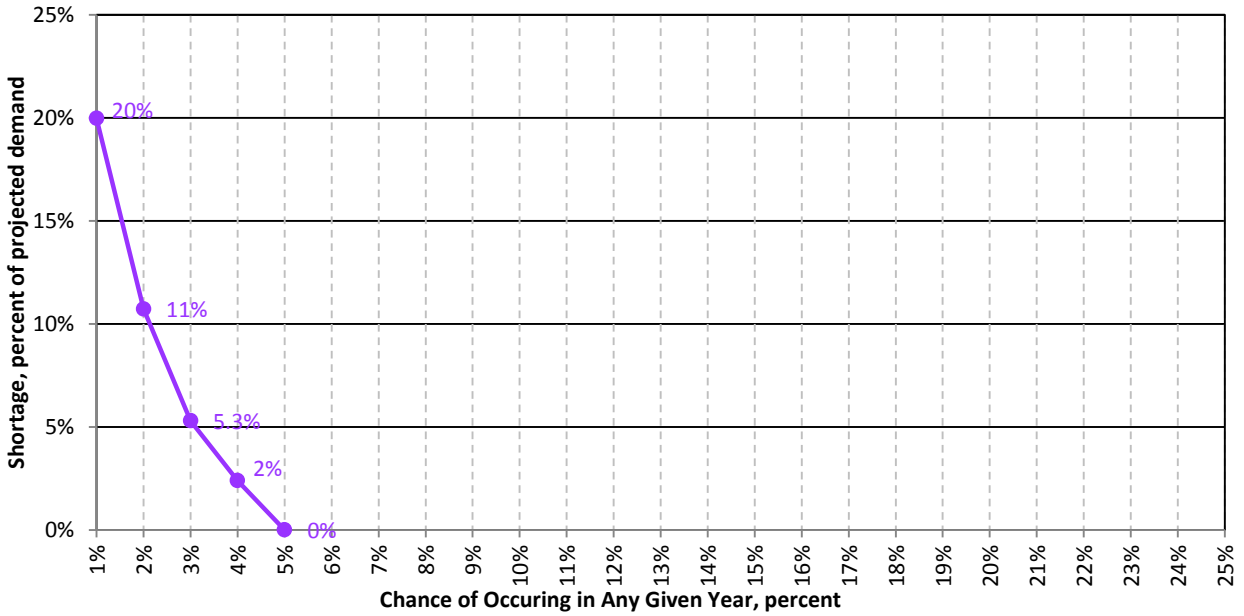
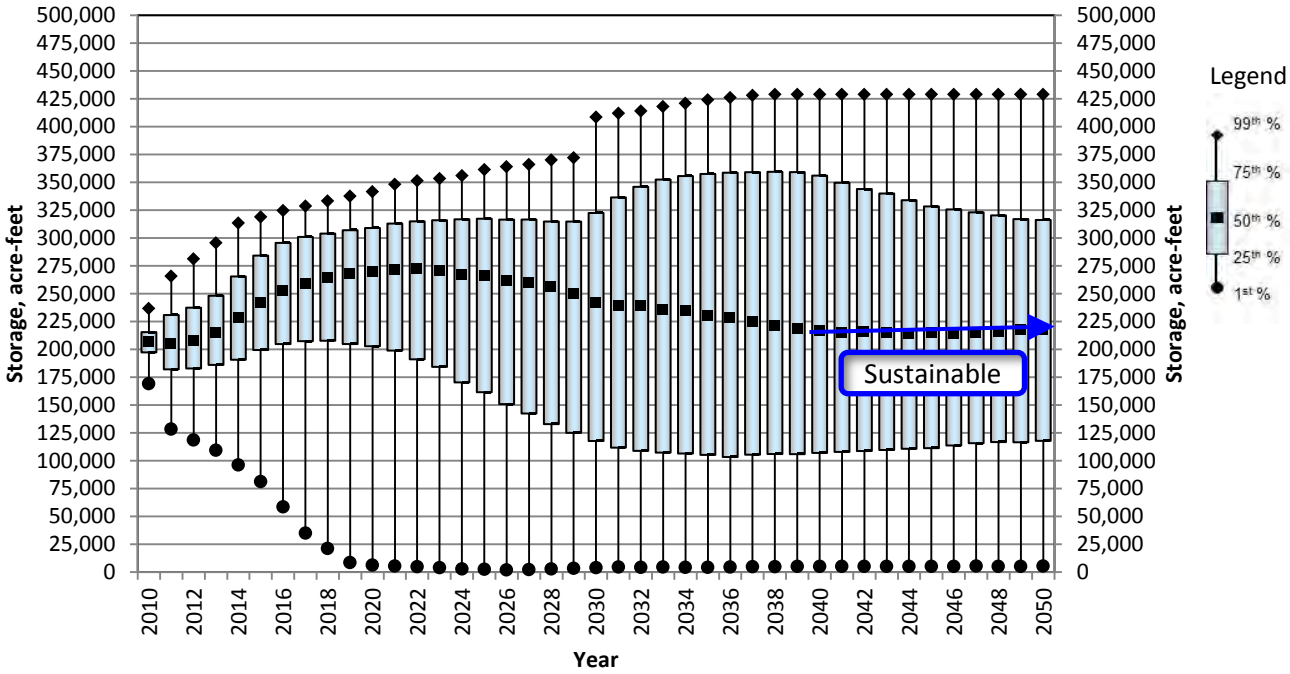


Figure 10-6. Sustainability of the In-Valley Portfolio at a Reliability of 80%



10.1.3 Reliability of the In-Valley Portfolio: 85%

Under this scenario, shortages are kept equal to or below 15% of projected water demands through the development of an additional 2,200 AF[102] of recycled water supply by 2025 (Figure 10-7).[103] In addition to achieving 85% reliability, this scenario also results in no shortages 95% of the time (Figure 10-8) and sustainable system-wide storage (Figure 10-9).

[102] This is 2,200 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 10,100 AF of recycled water use in the Livermore-Amador Valley.

[103] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-7. Risk of Potential Shortages for the In-Valley Portfolio: 85%

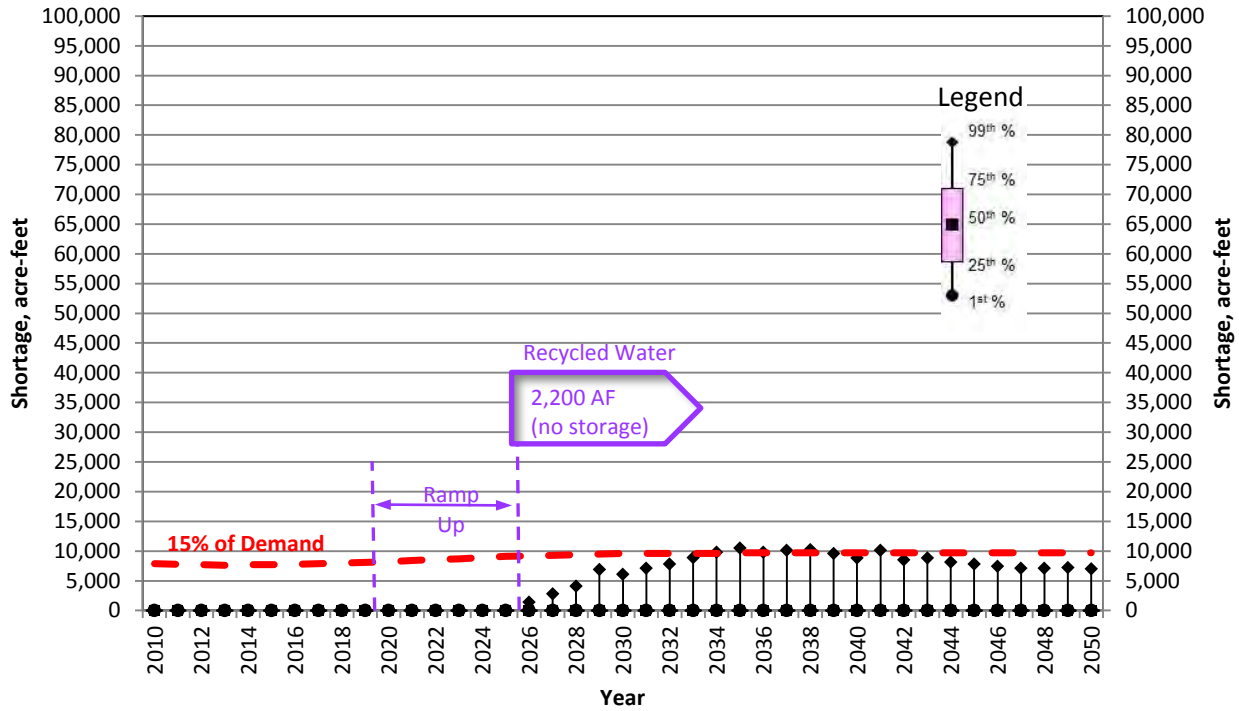


Figure 10-8. Reliability Curve for the In-Valley Portfolio: 85%

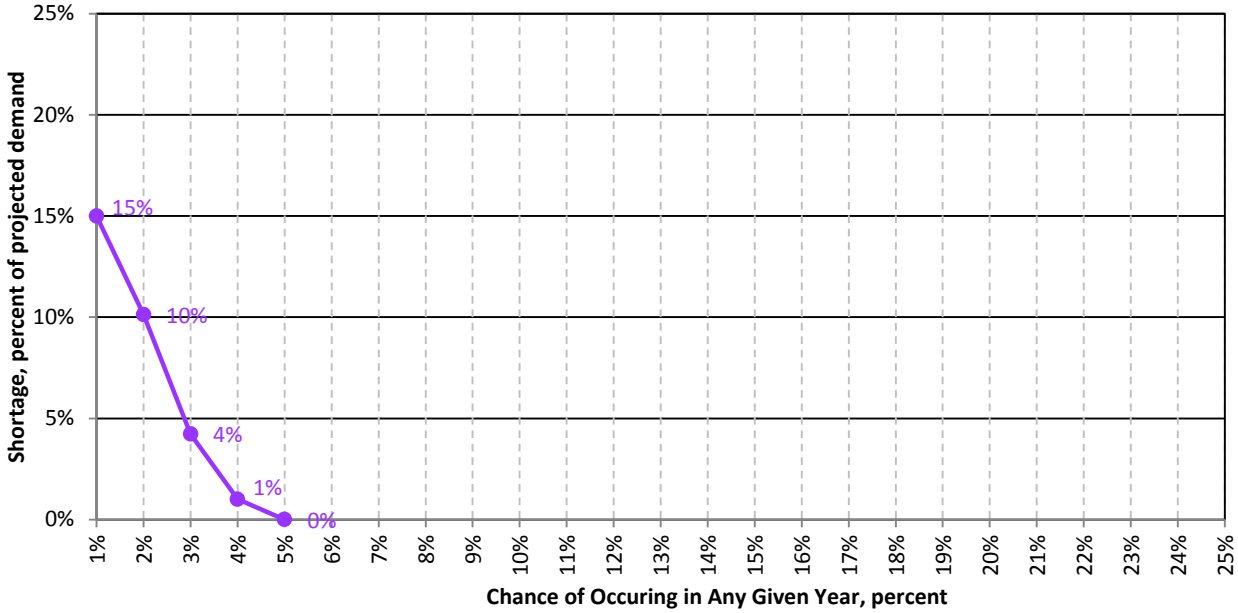
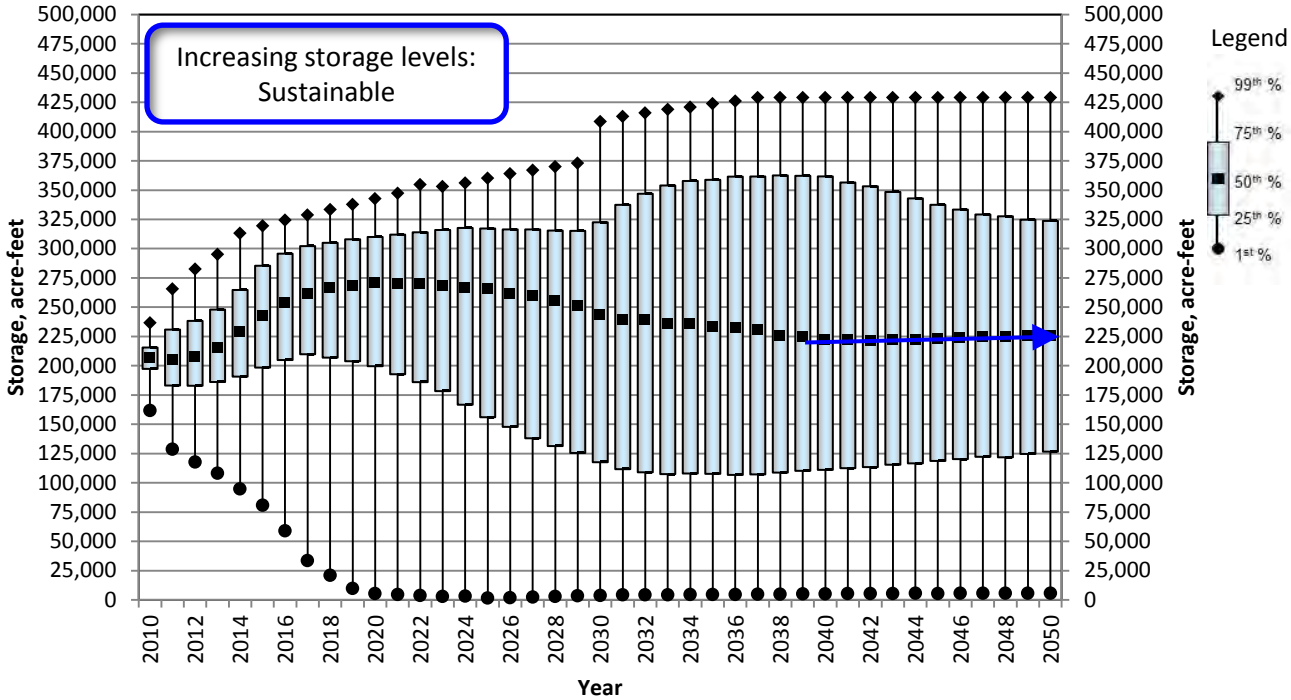


Figure 10-9. Sustainability of the In-Valley Portfolio at a Reliability of 85%



10.1.4 Reliability of the In-Valley Portfolio: 90%

Under this scenario, shortages are kept equal to or below 10% of projected water demands through the development of an additional 3,200 AF[104] of recycled water supply by 2025 (Figure 10-10).[105] In addition to achieving 90% reliability, this scenario also results in no shortages 96% of the time (Figure 10-11) and sustainable system-wide storage (Figure 10-12).

[104] This is 3,200 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 11,100 AF of recycled water use in the Livermore-Amador Valley.

[105] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-10. Risk of Potential Shortages for the In-Valley Portfolio: 90%

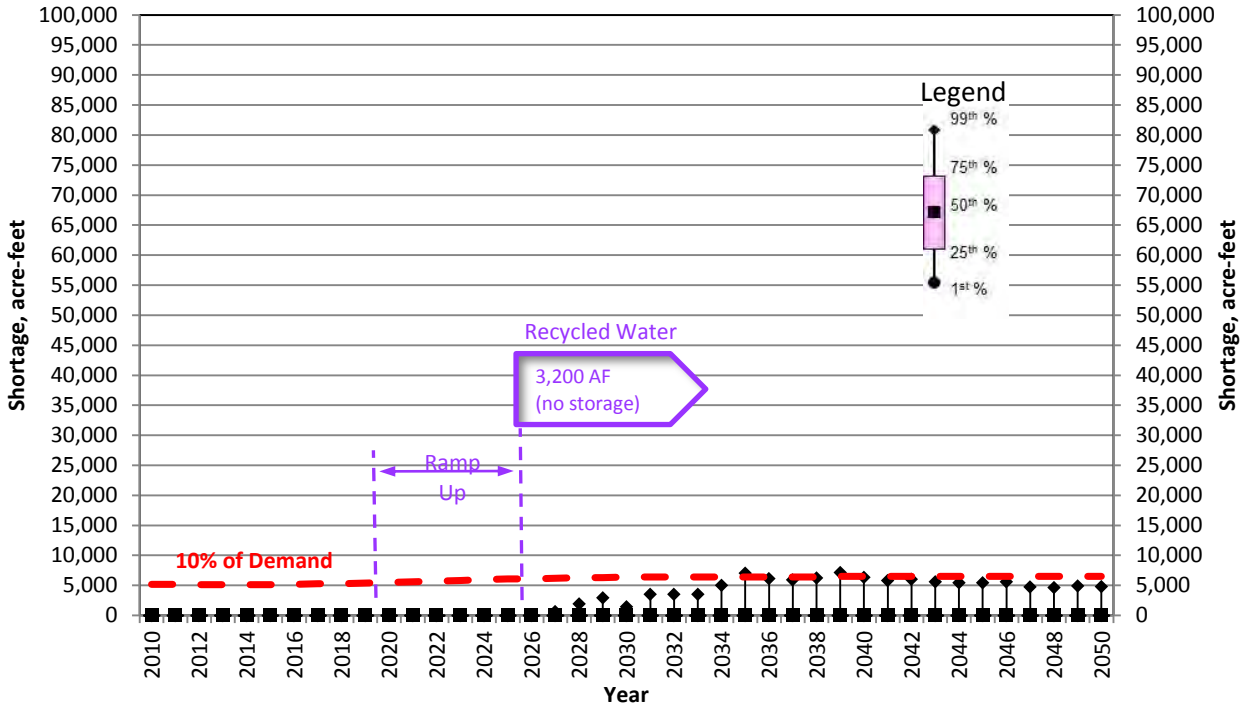


Figure 10-11. Reliability Curve for the In-Valley Portfolio: 90%

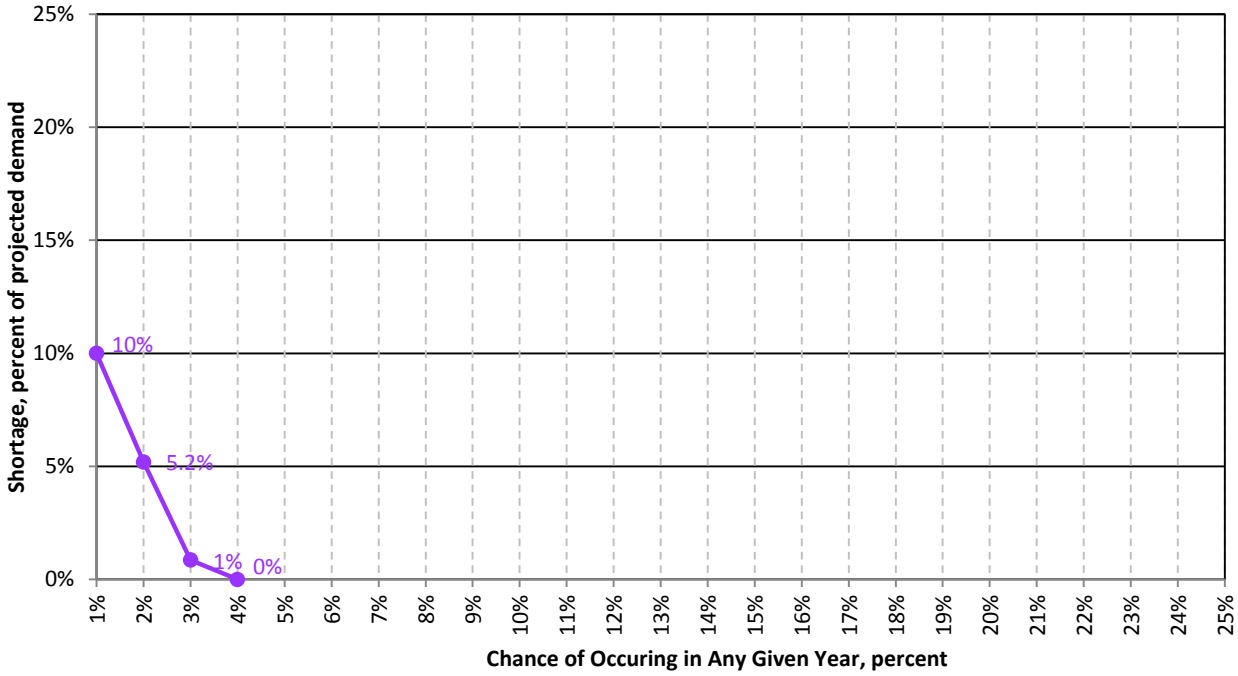
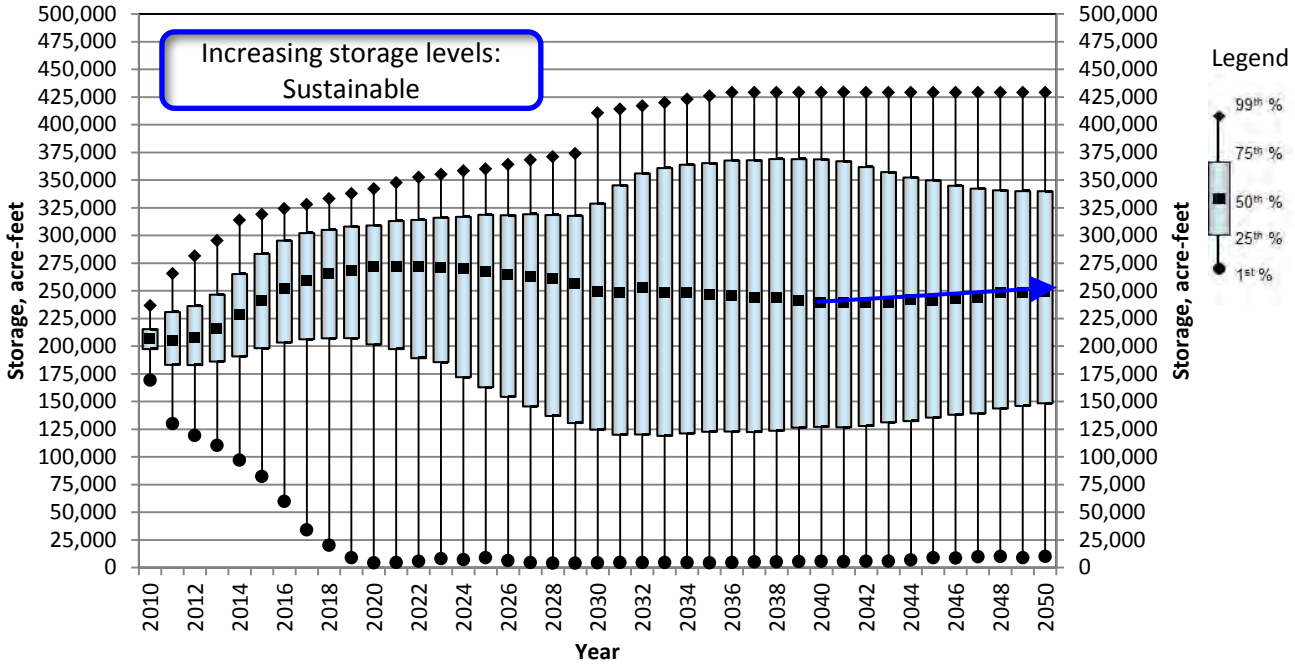


Figure 10-12. Sustainability of the In-Valley Portfolio at a Reliability of 90%



10.1.5 Reliability of the In-Valley Portfolio: 95%

Under this scenario, shortages are kept equal to or below 5% of projected water demands through the development of an additional 4,300 AF[106] of recycled water supply by 2025 (Figure 10-13), of which, approximately 1,100 AF[107] requires storage.[108] In addition to achieving 95% reliability, this scenario also results in no shortages 98% of the time (Figure 10-14) and sustainable system-wide storage (Figure 10-15).

[106] This is 4,300 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 12,200 AF of recycled water use in the Livermore-Amador Valley.

[107] See Appendix G for more detail on recycled water storage estimates.

[108] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-13. Risk of Potential Shortages for the In-Valley Portfolio: 95%

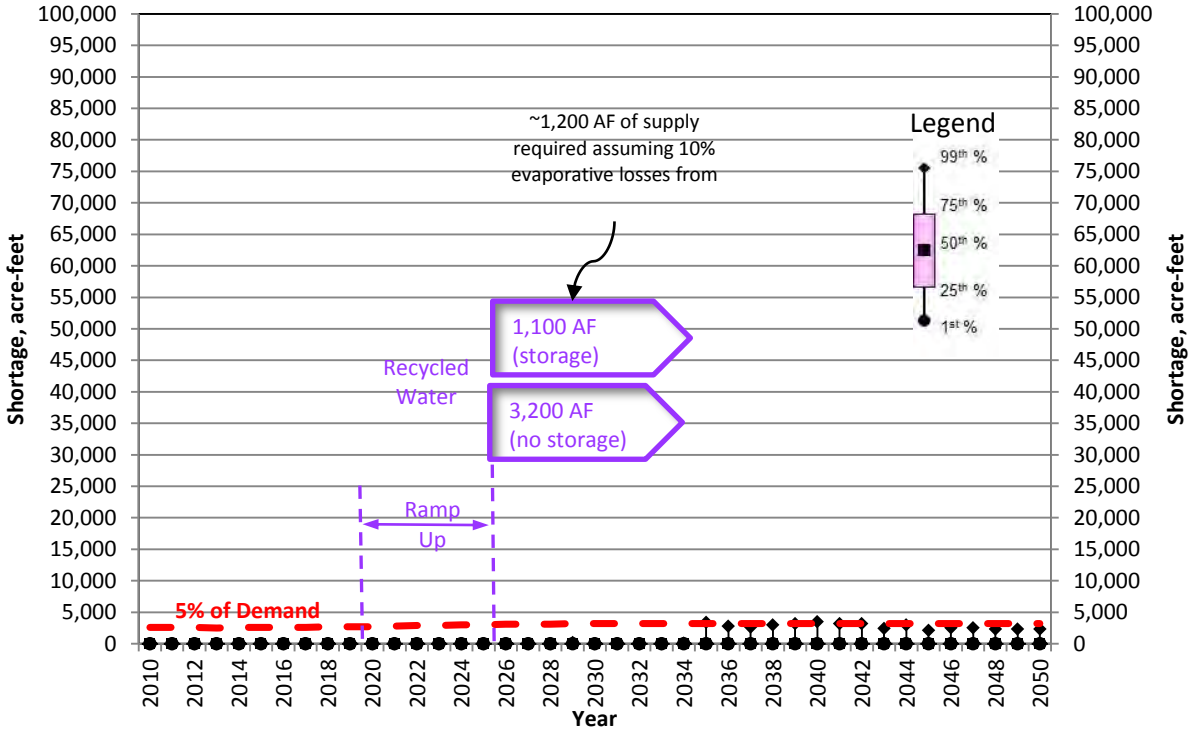


Figure 10-14. Reliability Curve for the In-Valley Portfolio: 95%

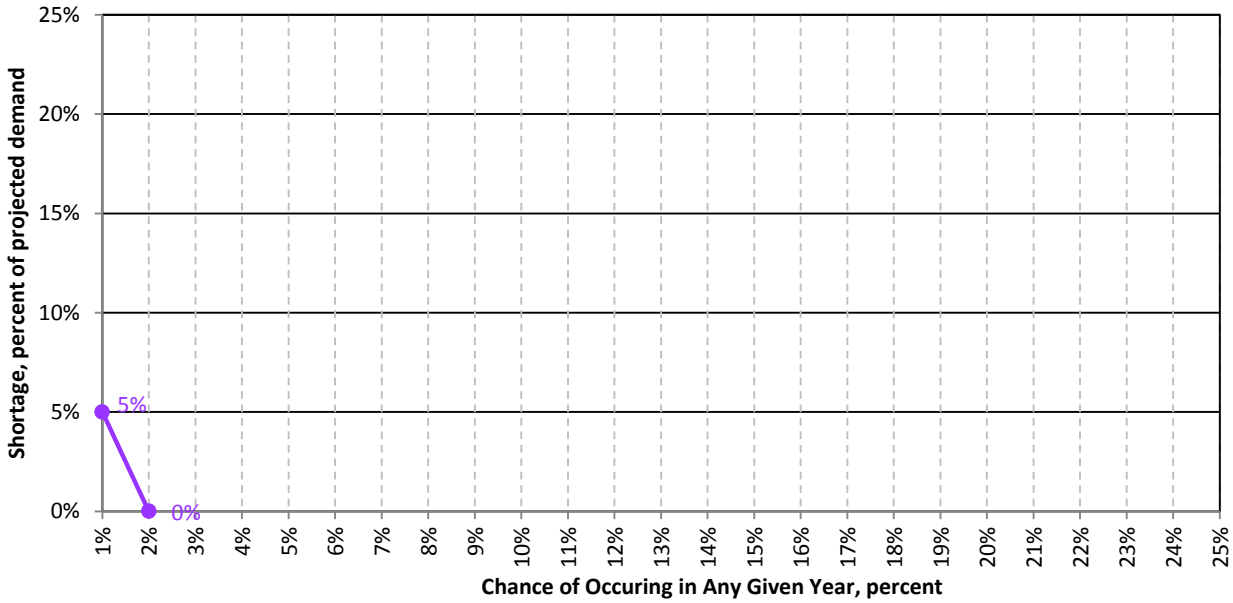
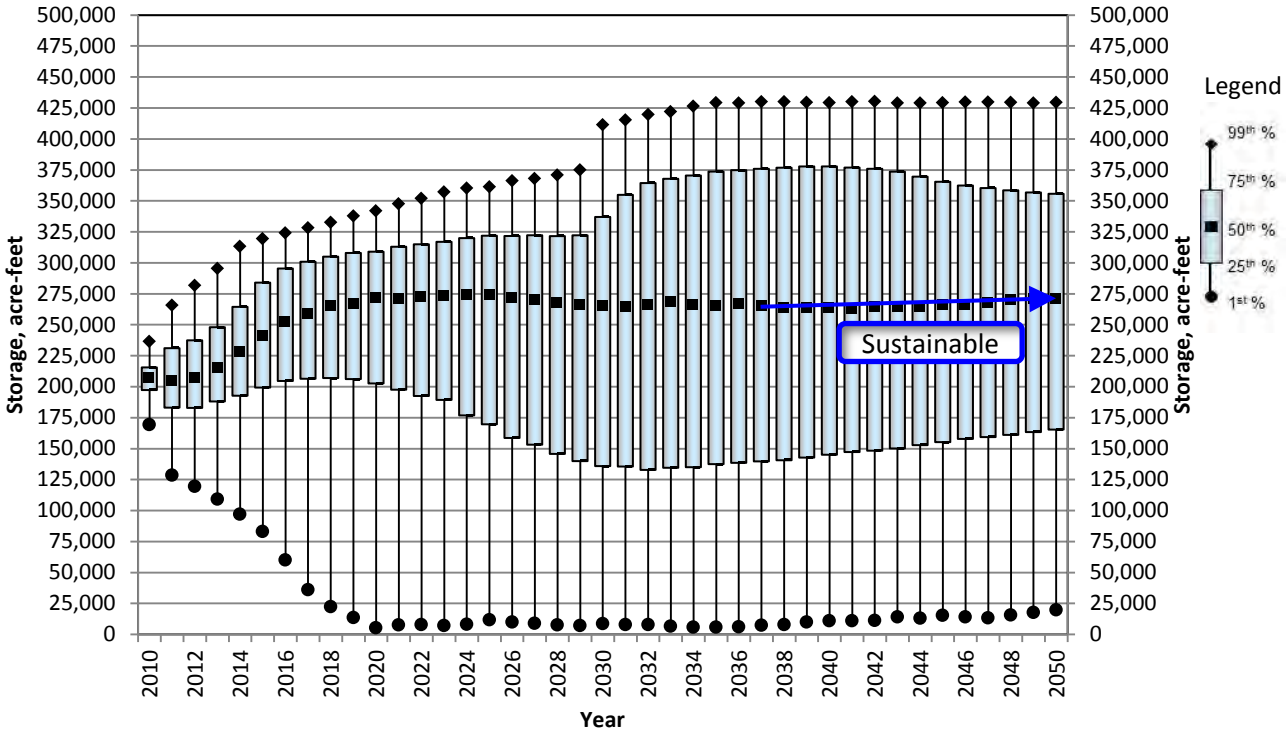


Figure 10-15. Sustainability of the In-Valley Portfolio at a Reliability of 95%



10.1.6 Reliability of the In-Valley Portfolio: 99%

Under this scenario, shortages are kept equal to or below 1% of projected water demands through the development of an additional 5,600 AF[109] of recycled water supply by 2025 (Figure 10-16), of which, approximately 2,400 AF[110] requires storage.[111] In addition to achieving 99% reliability, this scenario also results in no shortages 98% of the time (Figure 10-17) and sustainable system-wide storage (Figure 10-18).

[109] This is 5,600 AF more than the amount of recycled water already planned by water supply retailers (5,900 AF) and recycled water assumed developed to help meet the Conservation Act (2,000 AF), or a total of 13,500 AF of recycled water use in the Livermore-Amador Valley.

[110] See Appendix G for more detail on recycled water storage estimates.

[111] Note that a 5-year ramp-up period was assumed to account for potential recycled water demand located far from treatment facilities (e.g., a park at the far end of a retailer distribution system).

Figure 10-16. Risk of Potential Shortages for the In-Valley Portfolio: 99%

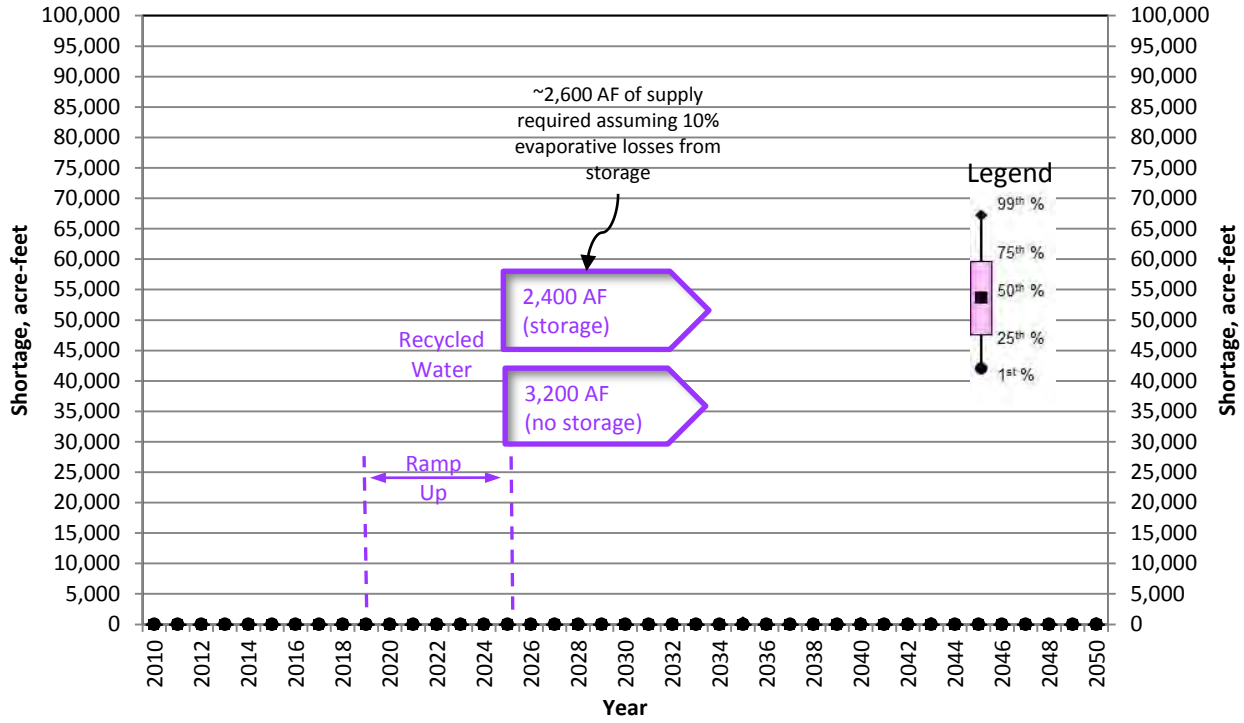


Figure 10-17. Reliability Curve for the In-Valley Portfolio 99%

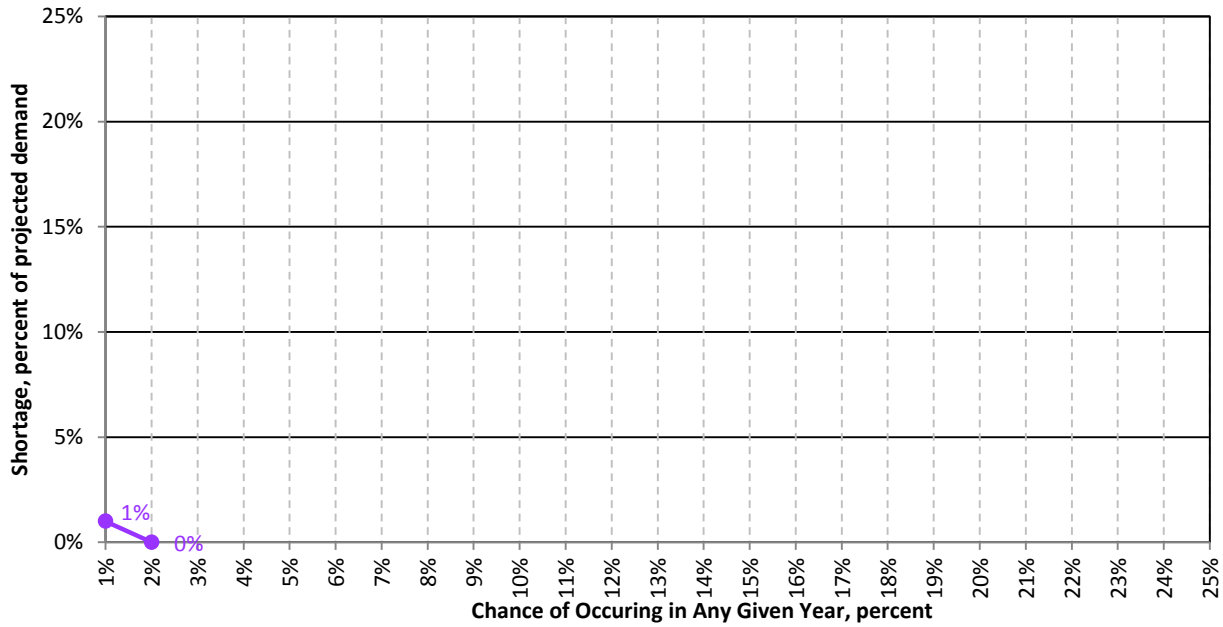
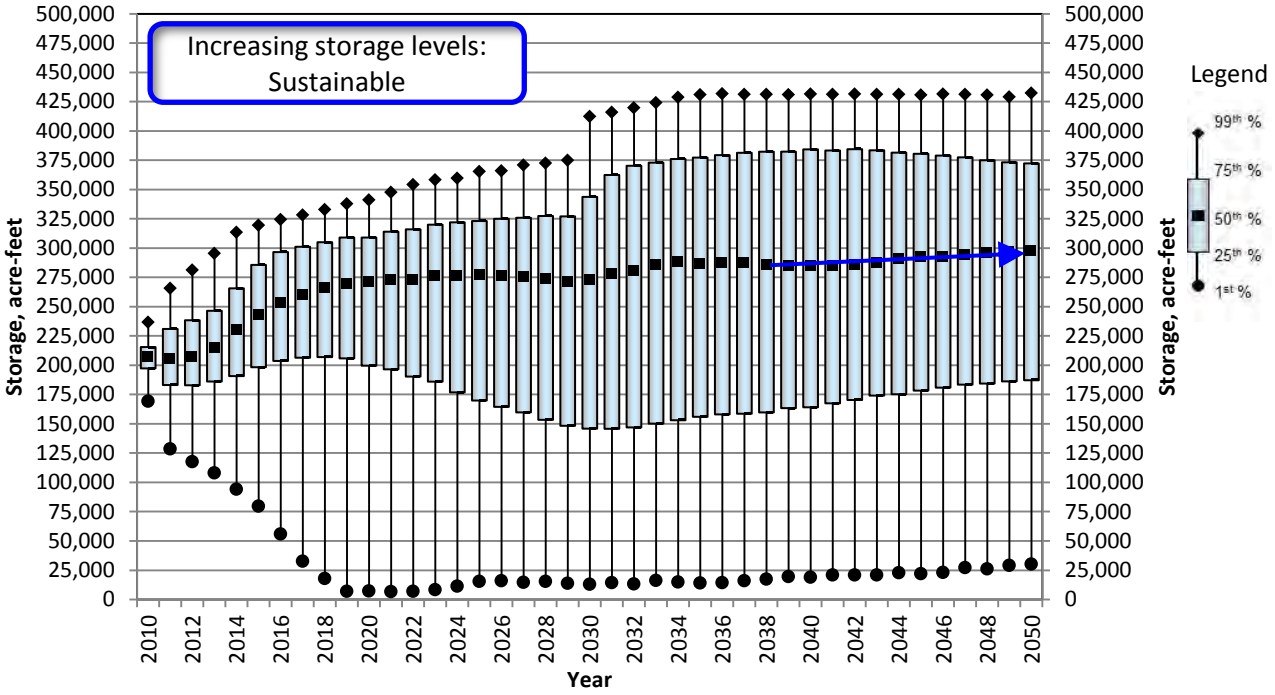


Figure 10-18. Sustainability of the In-Valley Portfolio at a Reliability of 99%



10.2 OBSERVATIONS REGARDING THE AMOUNT OF POTABLE WATER DEMAND REDUCTION REQUIRED

The amount of recycled water presented in this section represents the potable demand reduction required to achieve the reliability targets evaluated, and was limited based on available recycled water supply. The analysis did not consider whether a corresponding amount of recycled water demand *actually existed* in the system. The intent of the analysis completed in this WSE was to determine the potable demand reduction required – completing a detailed valley-wide recycled water system master plan was beyond the scope of this study. However, this does not mean that the potable reductions required should not be matched with actual irrigable area within the Livermore-Amador Valley.

As previously shown, the additional potable demand reduction required beyond existing plans or water conservation assumptions ranges from 1,000 to 5,600 AF, depending on the target evaluated. Assuming that a typical sports park uses about 40-inches[112] of water per year, approximately 300 to 1,700 acres[113] of irrigable area currently served potable water would need to be converted to recycled water. This is a significant amount of parks and other types of landscaping, and requires additional study – beyond the scope of this WSE – to confirm the feasibility of converting this much area to recycled water.

Consequently, as discussed further in Section 12, Zone 7 staff strongly recommends working with the water supply retailers to complete a separate more detailed study that analyzes potential recycled water demands within each of their respective service areas, including facility and timing requirements,

[112] WYA, 2005. Dublin San Ramon Services District – Water Master Plan Update – Section 10. December. Historical use on Dublin Sports Grounds.

[113] 40-inches of water is about 3.3 feet of water, therefore, the area required is 1,000 AF divided 3.3 Feet, or 300 acres. Similarly, 5,600 AF divided by 3.3 feet is about 1,700 acres.

and then compares these potential demands to the required potable demand reduction determined in this WSE.

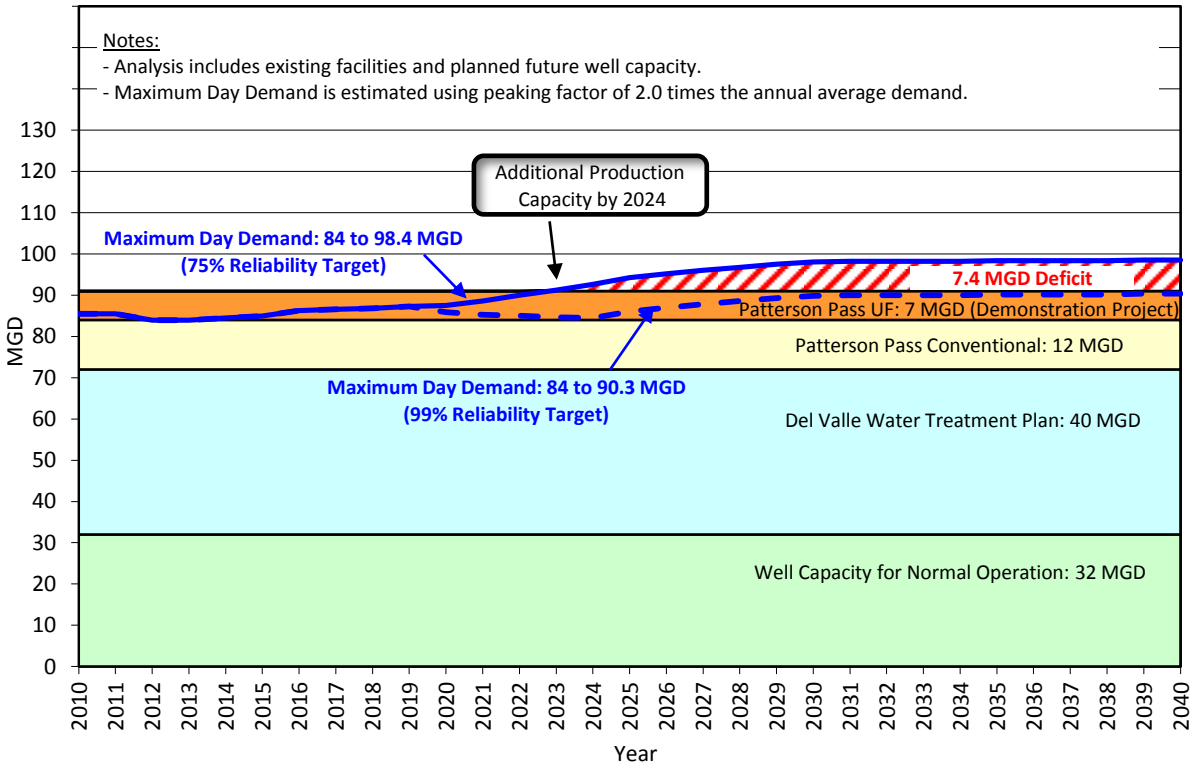
10.3 FACILITIES EVALUATION FOR THE IN-VALLEY PORTFOLIO

Zone 7 staff reviewed the capacities of existing and planned facilities associated with the In-Valley Portfolio to meet 100% of maximum day demands under normal conditions and 75% of maximum day demands assuming one major facility is out of service. Each condition is discussed below.

10.3.1 Maximum Day Demand for the In-Valley Portfolio

Increased use of recycled water to reduce potable water demands is expected to reduce the maximum day demand on Zone 7's potable water system. Figure 10-19 compares the capacity of existing and planned facilities associated with the In-Valley Portfolio with projected maximum day demands associated with a 75 and 99% reliability target.[114] Based on this comparison, Zone 7 can meet 100% of maximum day demands through 2023, but will require additional capacity by 2024 (7.4 million gallons per day [MGD]) under the 75% reliability scenario. However, the temporary ultrafiltration (UF) plant at the Patterson Pass Water Treatment Plant (PPWTP) needs to be replaced and therefore, the total maximum capacity required is about 15 MGD (8 plus 7 MGD). Figure 10-19 also shows that no additional capacity is required, beyond replacement of the existing UF plant, for the 99 percent reliability target due to a reduction in the projected maximum day demand associated with significant recycled water use (i.e., potable demand reductions).

Figure 10-19. In-Valley Portfolio: Ability to Meet Maximum Day Demand



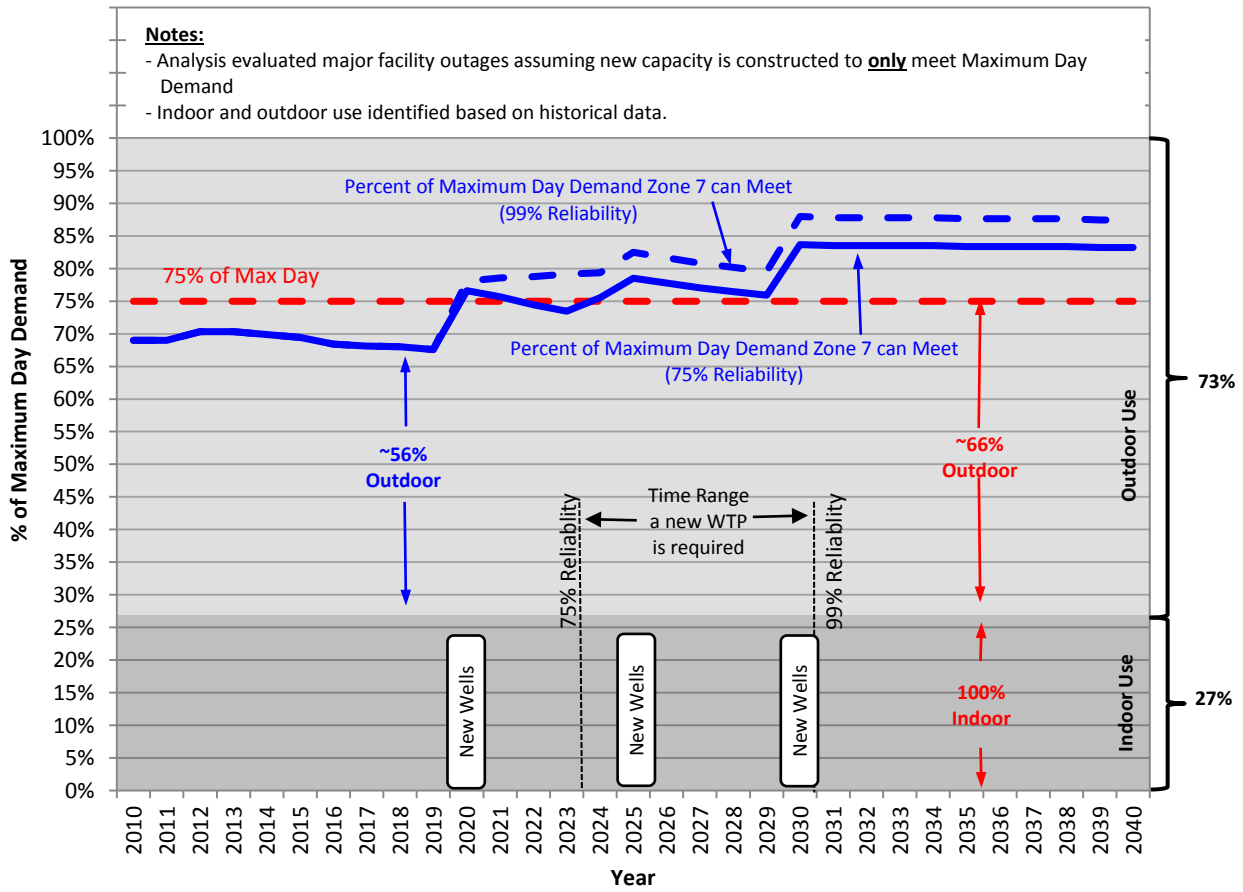
[114] Projected water demands were previously discussed in Section 3.

10.3.2 Level of Service for the In-Valley Portfolio with a Major Facility Outage

Zone 7 staff evaluated the ability of existing and planned facilities associated with the In-Valley Portfolio (see Section 9) to meet the current facility outage policy. Figure 10-20 compares the percent of maximum day demand that In-Valley Portfolio facilities can meet to the current policy over time for both a 75% and 99% reliability target. For discussion purposes, Figure 10-20 splits the maximum day demand into indoor and outdoor use,[115] and presents the current facility schedule. The current facility schedule reflects delayed construction associated with reduced demands caused by the current economic downturn.

As shown on Figure 10-20, the current policy is to meet 75% of maximum day demand with a major facility out of service; however, another interpretation of the policy is to meet 100 percent of indoor use and 66 percent outdoor use during the same conditions. Figure 10-20 clearly shows that existing facilities can meet 100% of indoor water needs, but only about 56% of outdoor needs until 2020. As new facilities come online, Zone 7 is increasingly able to meet, and eventually exceed, the existing policy requirements.

Figure 10-20. Ability of In-Valley Portfolio to Meet Maximum Day Demand during an Outage



[115] Zone 7 staff reviewed historical monthly data to split projected water demands into indoor and outdoor use. This analysis is provided as Appendix A.

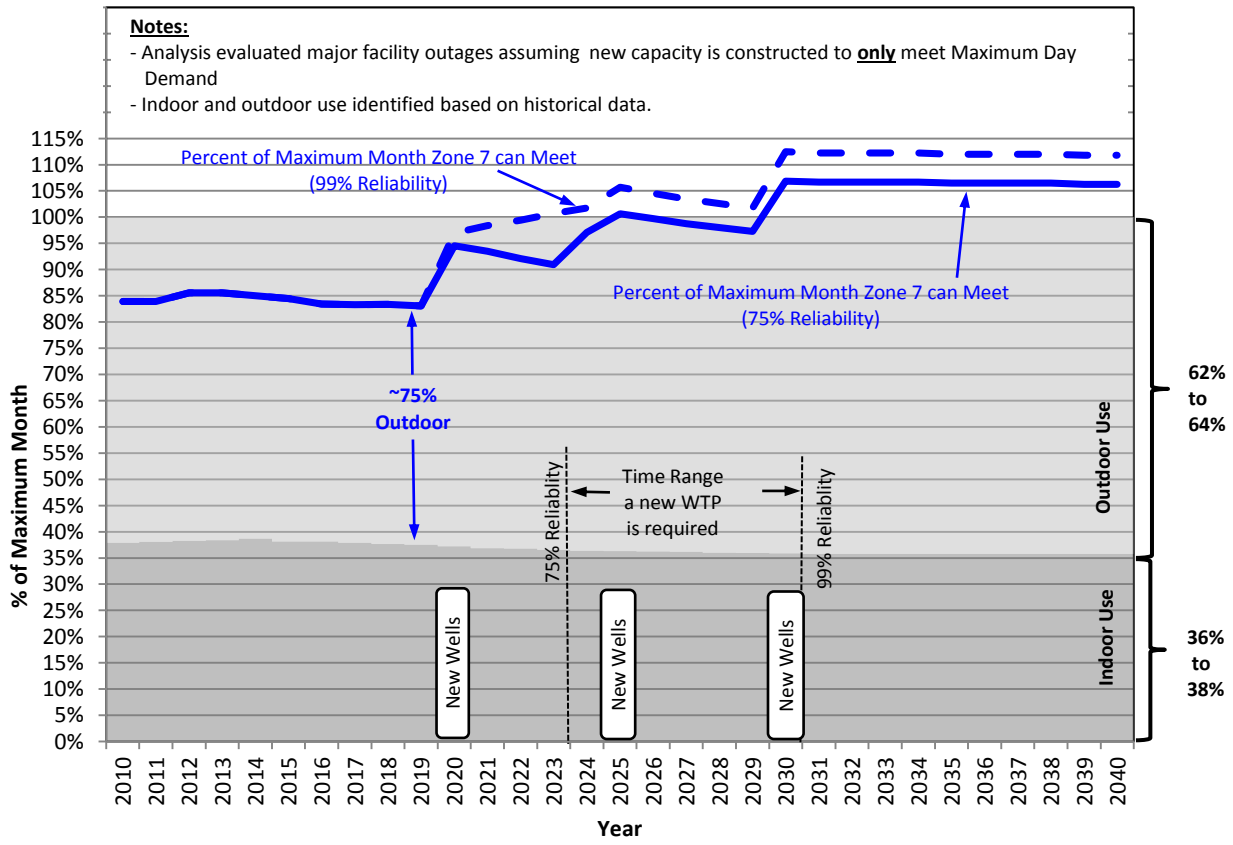
10.3.2.1 Consideration: Level of Service during a Maximum Month

The assumptions presented in Figure 10-20 are relatively conservative. For example, one scenario evaluated assumes that all of the treatment capacity associated with the Del Valle Water Treatment Plant happens to be lost on the highest water use day of the year (i.e., the maximum day), which typically occurs between 1 to 5 out of 365 days – less than 2% of the time. Additionally, barring a major emergency (e.g., an earthquake, Delta levee failure, or transmission line burst), it would take multiple, simultaneous, failures of internal plant equipment to lose all treatment capacity for an entire day.[116]

Consequently, for discussion purposes in this WSE, Zone 7 staff also reviewed the same outage scenarios over the highest water use month (i.e., the maximum month) instead of the maximum day demand. Figure 10-21 presents the same analysis completed for the maximum month.

As shown on Figure 10-21, existing facilities can meet 100% of indoor use and almost three-quarters of the outdoor use during the highest water use month and therefore, about a 25% reduction in water use would potentially be required over a 30-day period. Assuming the typical residential customer waters their lawn four times per week during the hottest month of the year, then a 25% reduction could be achieved by only watering their lawn about three times a week.

Figure 10-21. Ability of In-Valley Portfolio to Meet Maximum Month Demand during an Outage



[116] Based on conservations with Zone 7 operations staff.

10.4 SALT MANAGEMENT EVALUATION FOR THE IN-VALLEY PORTFOLIO

Zone 7 is preparing to update its Groundwater Management Plan (GWMP), which will also include an update of the Salt Management Plan (SMP). As part of this update, Zone 7 staff will conduct a more rigorous analysis of potential salt and nutrient loading in the Main Basin – a rigorous analysis of salt loading was not completed as part of this WSE.

However, each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics that could influence future salt loading in the Main Basin. Consequently, Zone 7 staff completed a preliminary review of the potential salt loading associated with the In-Valley Portfolio for comparative purposes in this WSE.[117] As discussed in Section 5, this review involved using spreadsheet models previously developed as part of Zone 7's original SMP to evaluate whether net salt loading in the Main Basin associated with the In-Valley Portfolio was either increasing or decreasing. Preliminary results indicate that a new demineralization facility may be required to achieve decreasing salt loading under the In-Valley Portfolio. The GWMP/SMP will further evaluate this finding.

Table 10-1 presents the percentage of the total additional recycled water that was assumed over the Main Basin. This percentage was based on limiting the total future demineralization capacity to 12.4 MGD (two equal phases), which is about 10,500 AF per year assuming it is only operated for nine months. Zone 7 staff found it was difficult to operate three equal phases of demineralization without exceeding potential recharge limits associated with the Arroyos and the Chain of Lakes.[118]

Consequently, Zone 7 staff recommends evaluating the need for additional demineralization and the potential for recharging enough water supplies into the Main Basin to support over 10,000 AF of normal operational groundwater pumping as part of the more rigorous analysis planned as part of the GWMP/SMP update.

Table 10-1. Recycled Water Over the Main Basin: In-Valley Portfolio[a,b]

Reliability, percent	Recycled Water for Conservation	Additional Recycled Water	Total Recycled Water	Applied Over Main Basin, percent
75	2,000	1,000	3,000	67
80	2,000	1,800	3,800	53
85	2,000	2,200	4,200	48
90	2,000	3,200	5,200	42
95	2,000	4,300	6,300	41
99	2,000	5,600	7,600	41

(a) Preliminary numbers are provided in Appendix C.

(b) Analysis assumed 2,000 acre-feet of recycled water is applied over the main basin

[117] Zone 7 will evaluate nutrients as part of the SMP update.

[118] Zone 7 can only pump groundwater it has previously recharged; therefore, its demineralization capacity is limited to its recharge capacity.

10.5 OBSERVATIONS REGARDING DELIVERED WATER QUALITY

As discussed previously in Section 5, conducting hydraulic modeling to quantify potential benefits to delivered water quality was beyond the scope of this WSE; however, each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics. Consequently, a qualitative review of each scenario was completed to evaluate whether the scenario had the potential for improving delivered water quality. The potential benefit to delivered water quality associated with the In-Valley Portfolio is linked with potential groundwater demineralization activities necessary to mitigate potential salt loading.

As previously discussed in Section 10.4, Zone 7 staff conducted a preliminary evaluation of salt loading associated with the In-Valley Portfolio, and although it is recommended that future salt mitigation strategies be evaluated as part of the GWMP/SMP Update, another phase of demineralization is in Zone 7's existing Capital Improvement Program. Additionally, a second phase was also included in the cost estimates of the In-Valley Portfolio for comparative purposes in this WSE. Another phase of demineralization will have a direct positive influence on delivered water quality because it treats groundwater before it enters Zone 7's distribution system.[119]

10.6 COST ESTIMATES FOR THE IN-VALLEY PORTFOLIO: 75 TO 99%

The purpose of this section to provide planning-level cost estimates for each reliability scenario evaluated under the In-Valley Portfolio. For illustrative purposes, the cost estimates were divided into three categories: (1) facilities, (2) water supply, and (3) water quality.

The facilities component of the cost estimates represent hard construction, such as water treatment plants, diversion structures, and groundwater wells, while the water supply component generally represented the cost of purchasing or acquiring water. For the In-Valley Portfolio, however, the recycled water supply costs also included the necessary tertiary treatment facilities, tanks, and pipeline costs. The cost estimate for water quality reflects a second phase of demineralization; however, as discussed previously, future salt mitigation will be further evaluated as part of the GWMP/SMP update.

In all cases, the costs are presented in 2010 dollars based on an Engineering News Record San Francisco Construction Cost Index. The following planning-level cost contingencies were also applied as necessary:

- Construction Contingency: 25 percent
- Planning and Environmental: 10 percent
- Design and Implementation: 10 percent
- Construction Management: 10 percent

Appendix D contains a more detailed description of the cost estimates used and preliminary schedules developed for each scenario that were used to develop present worth and amortized values.

10.6.1 Observations Regarding the Cost of Reliability

Figure 10-22 presents the Portfolio costs for each reliability scenario evaluated. As shown on Figure 10-22, the potable system facility costs for a 99% reliability target are about 20% ($51 million) lower than the facility costs for a 75% reliability target. This decrease is associated with smaller potable water

[119] The benefits of demineralization were thoroughly analyzed as part of the 2003 Water Quality Management Program report.

treatment facilities caused by the potable demand reductions associated with additional recycled water use.

Figure 10-22 also indicates that the supply costs for a 99% reliability target are about 390% ($123 million) higher than the supply costs for a 75% reliability target, while the water quality costs remain the same.[120] However, increasing supply costs are offset by decreasing facility costs.[121] Overall, the total Portfolio costs for a 99% reliability target are only about 22% higher than the Portfolio costs for a 75% reliability target.

Figure 10-22. Cost of Reliability for the In-Valley Portfolio

[120] The water quality costs are constant because the costs are based on only one additional phase of demineralization.

[121] As recycled water use increases, supply costs increase due to the construction of additional recycled water facilities; at the same time, facility costs primarily associated with surface water treatment plant capacity decrease due to associated potable demand reductions on Zone 7's water system.

11. EVALUATION OF BACKUP PORTFOLIO: INTERTIE

The purpose of this section is to present the analysis and results of using the probability-based water supply model to determine the reliability provided by the Intertie Portfolio. As discussed in Section 9, the Intertie Portfolio assumed that Zone 7 Water Agency (Zone 7) is able to construct a new intertie with another water agency (e.g., East Bay Municipal Utility District [EBMUD] and wheel high quality water supplies into Zone 7's water system. The supply could consist of several sources, including but not limited to the Bay Area Regional Desalination Project or long-term water leases and/or transfers. The Intertie Portfolio also assumed that Zone 7 successfully reduces its unaccounted-for water, reduces brine losses, increases the minimum yield from its contract with BBID, and enhances the existing in-lieu recharge program.

The following subsections present the results:

- 11.1 Reliability for the Intertie Portfolio: 75 to 99%
- 11.2 Facilities Evaluation for the Intertie Portfolio
- 11.3 Salt Management Evaluation for the Intertie Portfolio
- 11.4 Observations Regarding Delivered Water Quality
- 11.5 Cost Estimates for the Intertie Portfolio: 75 to 99%

11.1 RELIABILITY FOR THE INTERTIE PORTFOLIO: 75 TO 99%

Zone 7 staff evaluated the ability of the water supplies and facilities included in the Intertie Portfolio to prevent water supply shortages, while also maintaining drought and emergency storage at a sustainable level. For this evaluation, Zone 7 staff first reviewed the risk of potential water supply shortages and corresponding reliability, and then reviewed the sustainability of system-wide storage, which included the Main Basin, Semitropic Water Storage District (Semitropic), Cawelo Water District (Cawelo), State Water Project (SWP) Carryover, and the Chain of Lakes.[122] Additionally, per discussions with the water supply retailers, Zone 7 did not evaluate reliabilities less than 75%. Each is discussed in more detail below.

11.1.1 Reliability of the Intertie Portfolio: 75%

Under this scenario, shortages are kept equal to or below 25% of projected water demands assuming Zone 7 is able to develop and use 5,100 acre-feet (AF) of normal/wet year water supply between 2030 and 2038 (Figure 11-1); the supply was stopped after 2038 because it would not be needed at that time to achieve 75% reliability. In addition to achieving a reliability of 75%, this scenario also results in no shortages 94% of the time (Figure 11-2). However, stopping the new supply after 2038 makes system-wide storage unsustainable (Figure 11-3); the sustainability of drought and emergency storage is tied to the availability of normal/wet year water supplies. Consequently, this scenario is reliable but unsustainable.

[122] Key individual storage results were included in Appendix F.

Figure 11-1. Risk of Potential Shortages for the Intertie Portfolio: 75%

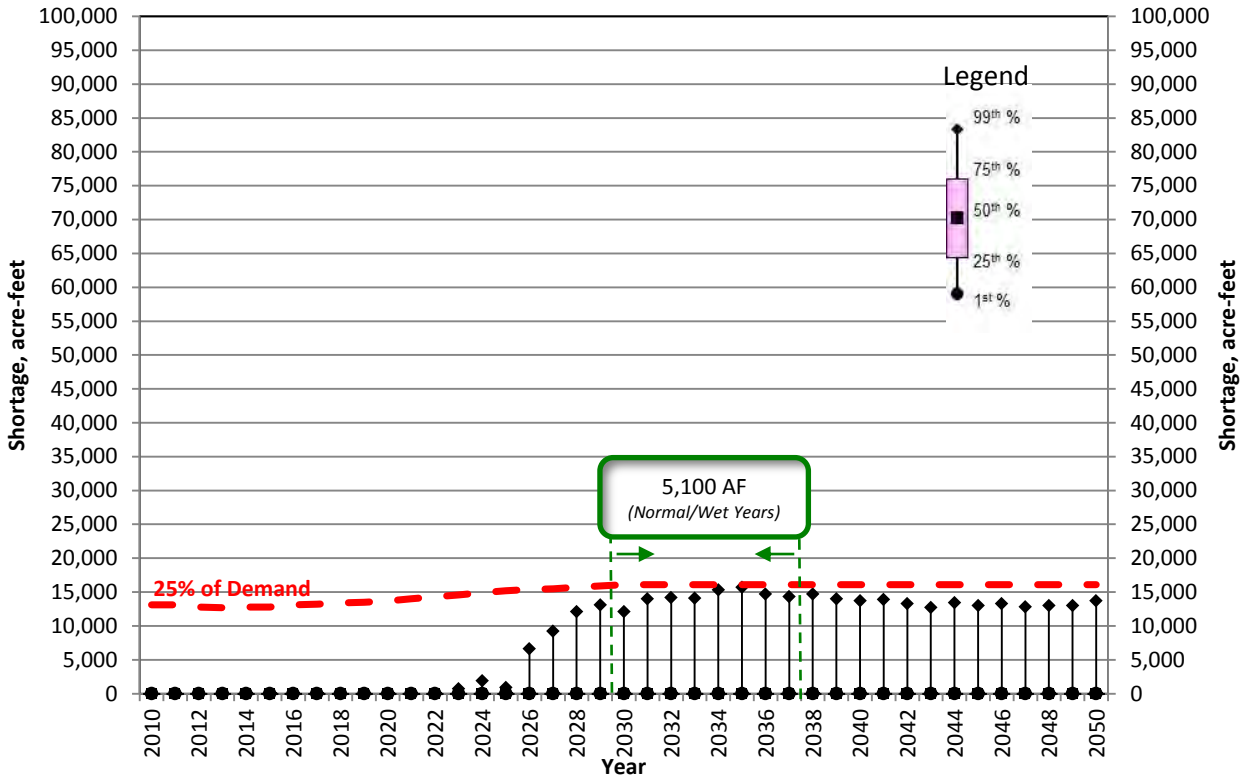
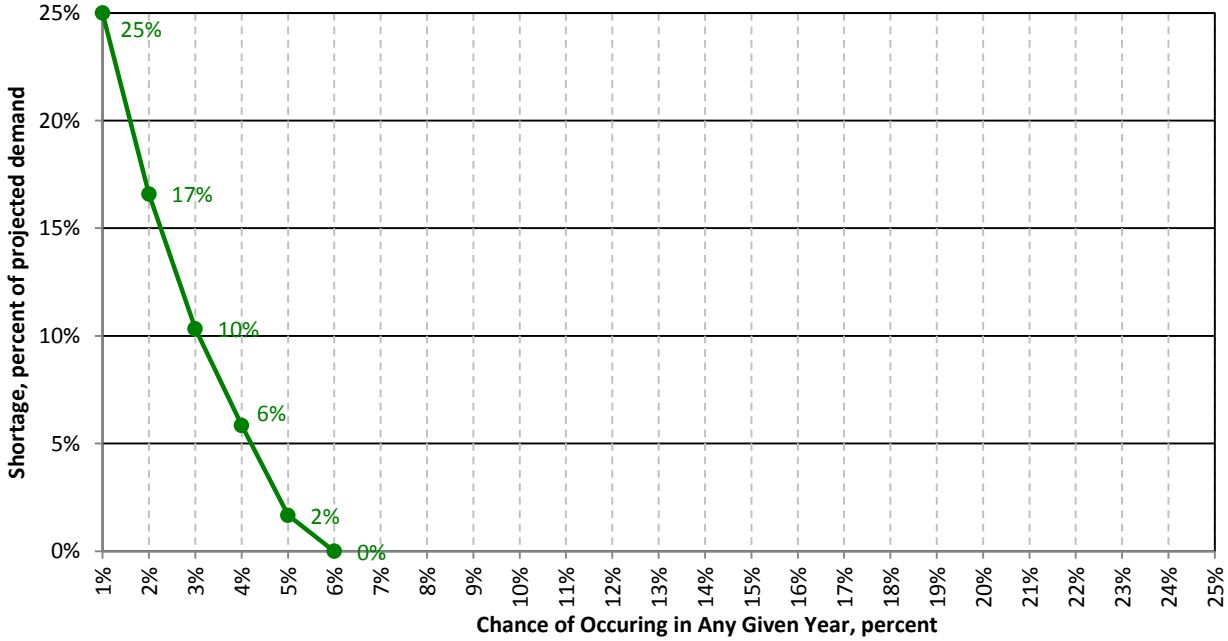
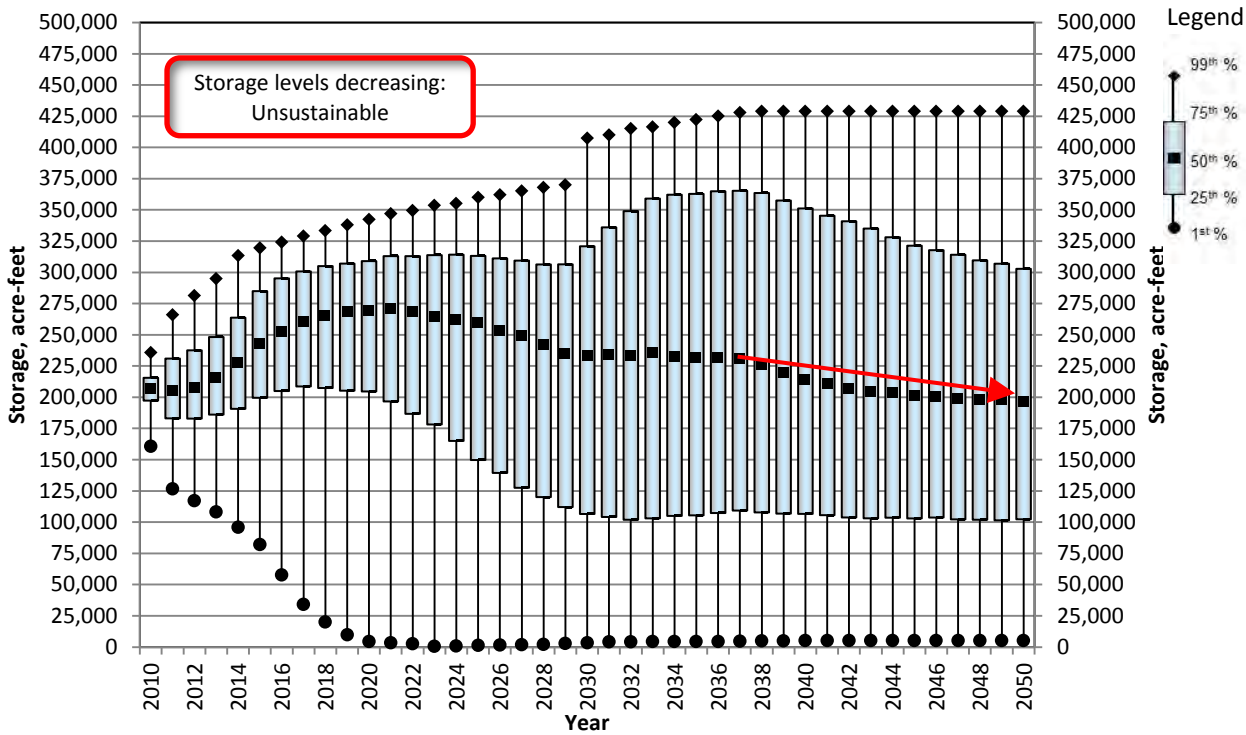


Figure 11-2. Reliability Curve for the Intertie Portfolio: 75%[123]



[123] Presents the risk curve for the worst-case observed over the entire period from 2010 to 2050.

Figure 11-3. Sustainability of the Intertie Portfolio at a Reliability of 75%



11.1.2 Reliability of the Intertie Portfolio: 80%

Under this scenario, shortages are kept equal to or below 20% of projected water demands assuming Zone 7 is able to develop and use 5,100 acre-feet (AF) of normal/wet year water and 1,100 AF of dry year water supply between 2029 and 2039 (Figure 11-4). The supply was stopped after 2039 because it would not be needed at that time to achieve 80% reliability. In addition to achieving a reliability of 80%, this scenario also results in no shortages 94% of the time (Figure 11-5). However, stopping the new supply after 2039 makes system-wide storage unsustainable (Figure 11-6); the sustainability of drought and emergency storage is tied to the availability of normal/wet year water supplies. *Consequently, this scenario is reliable but unsustainable.*

Figure 11-4. Risk of Potential Shortages for the Intertie Portfolio: 80%

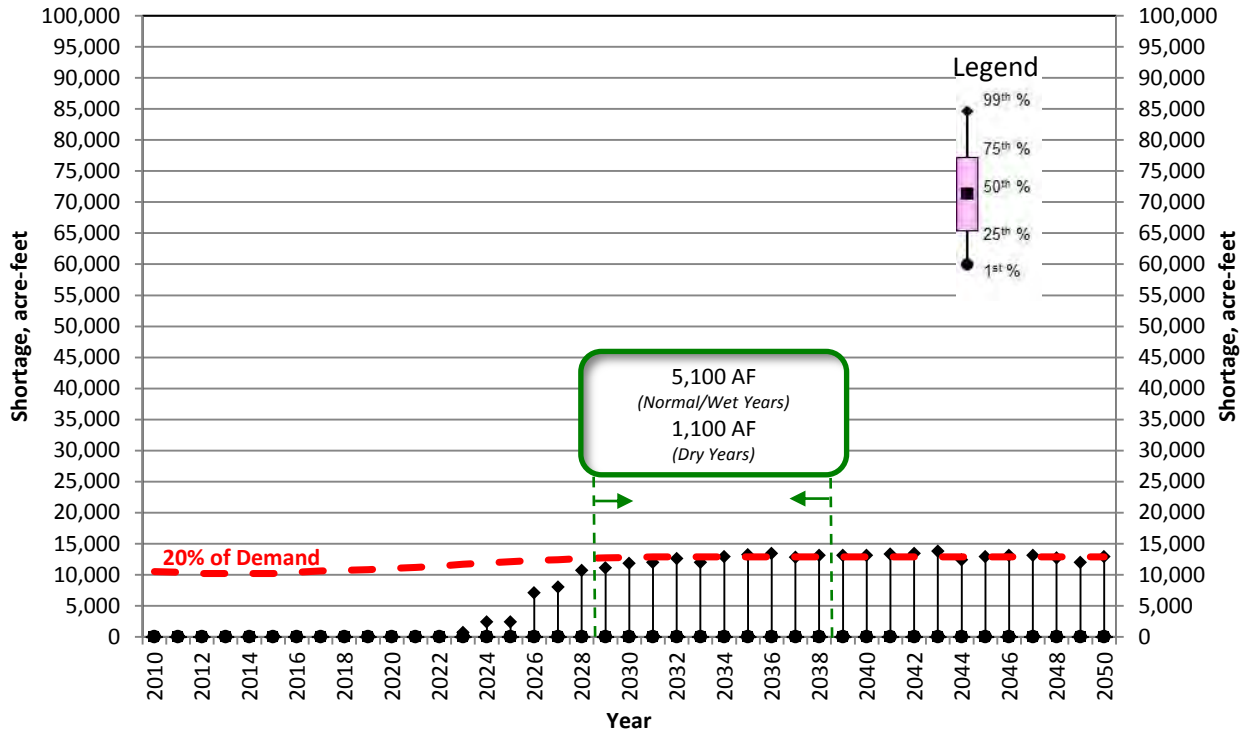


Figure 11-5. Reliability Curve for the Intertie Portfolio: 80%

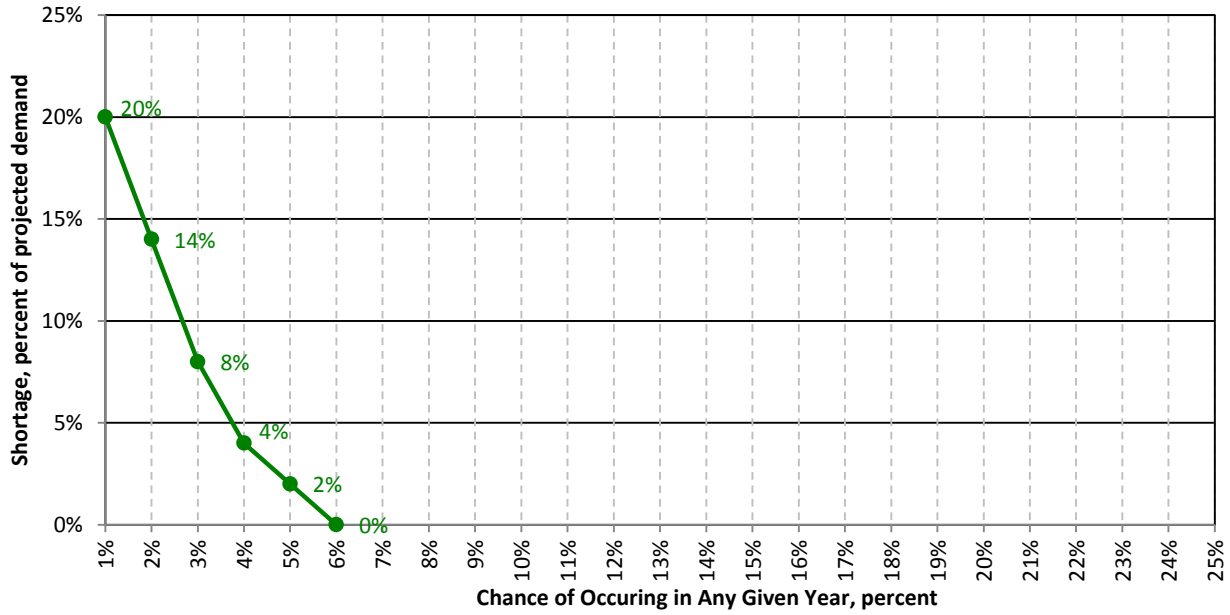
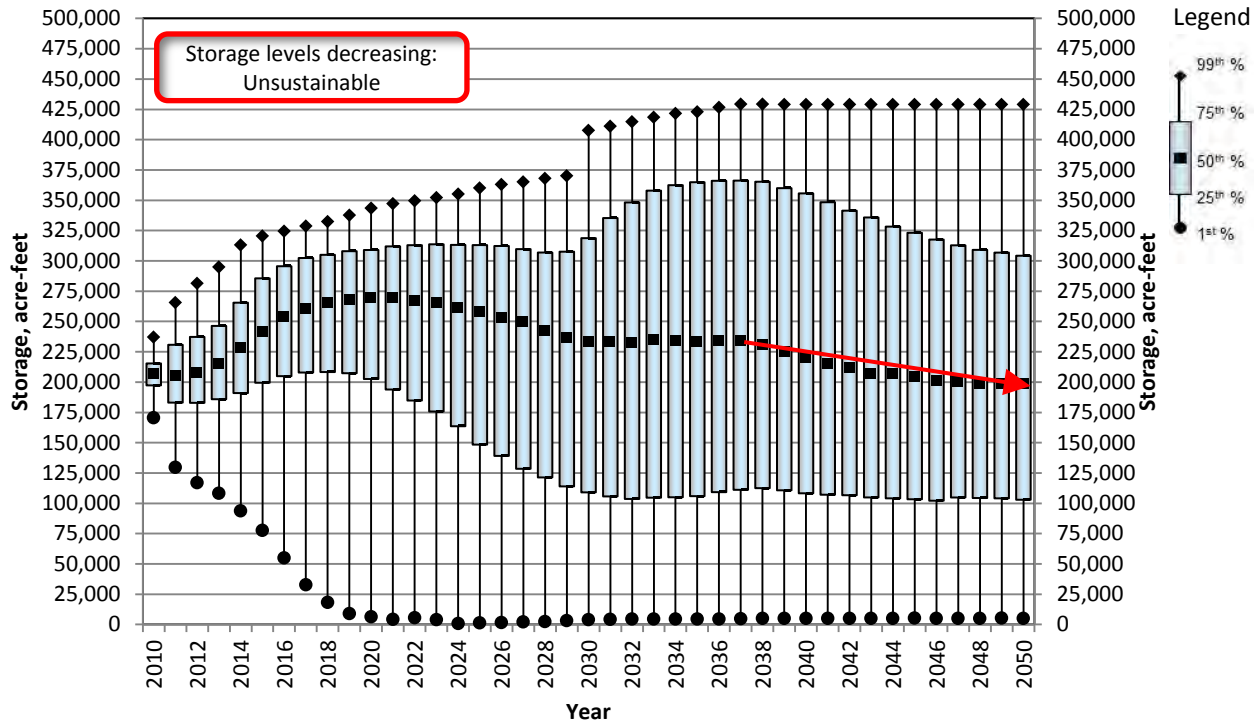


Figure 11-6. Sustainability of the Intertie Portfolio at a Reliability of 80%



11.1.3 Reliability of the Intertie Portfolio: 85 Percent

Under this scenario, shortages are kept equal to or below 15% of projected water demands assuming Zone 7 is able to develop and use 5,100 acre-feet (AF) of normal/wet year water and 1,900 AF of dry year water supply between 2029 and 2039, and 1,600 AF of dry year supply, perpetually, after 2039. (Figure 11-7). The supply was stopped at different periods because it would not be needed at that time to achieve 85% reliability. In addition to achieving a reliability of 85%, this scenario also results in no shortages 95% of the time (Figure 11-8). However, stopping the new normal/wet year supply after 2039 makes system-wide storage unsustainable (Figure 11-9); the sustainability of drought and emergency storage is tied to the availability of normal/wet year water supplies. *Consequently, this scenario is reliable but unsustainable.*

Figure 11-7. Risk of Potential Shortages for the Intertie Portfolio: 85%

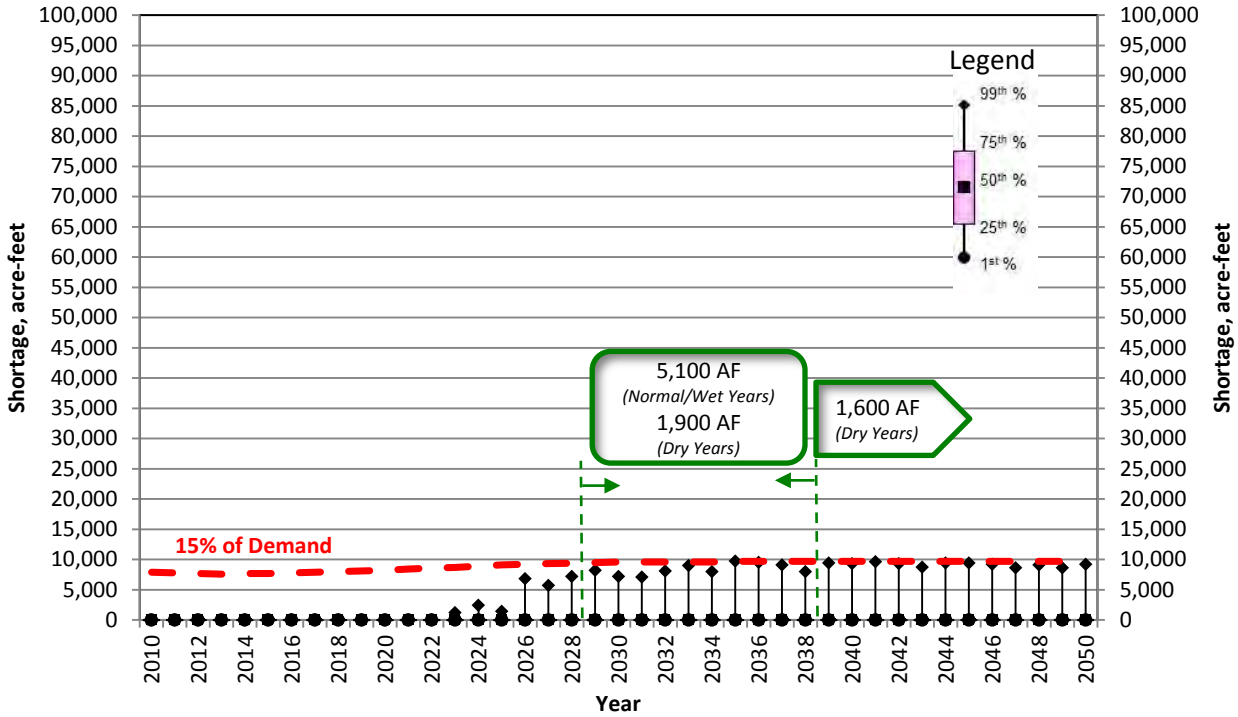
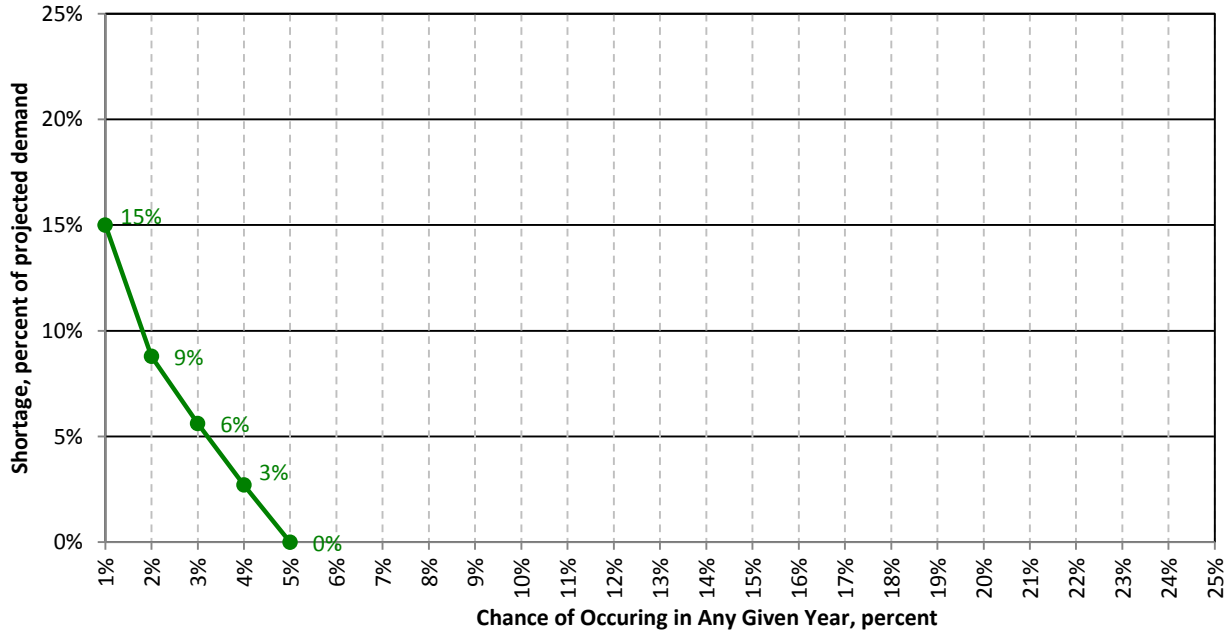
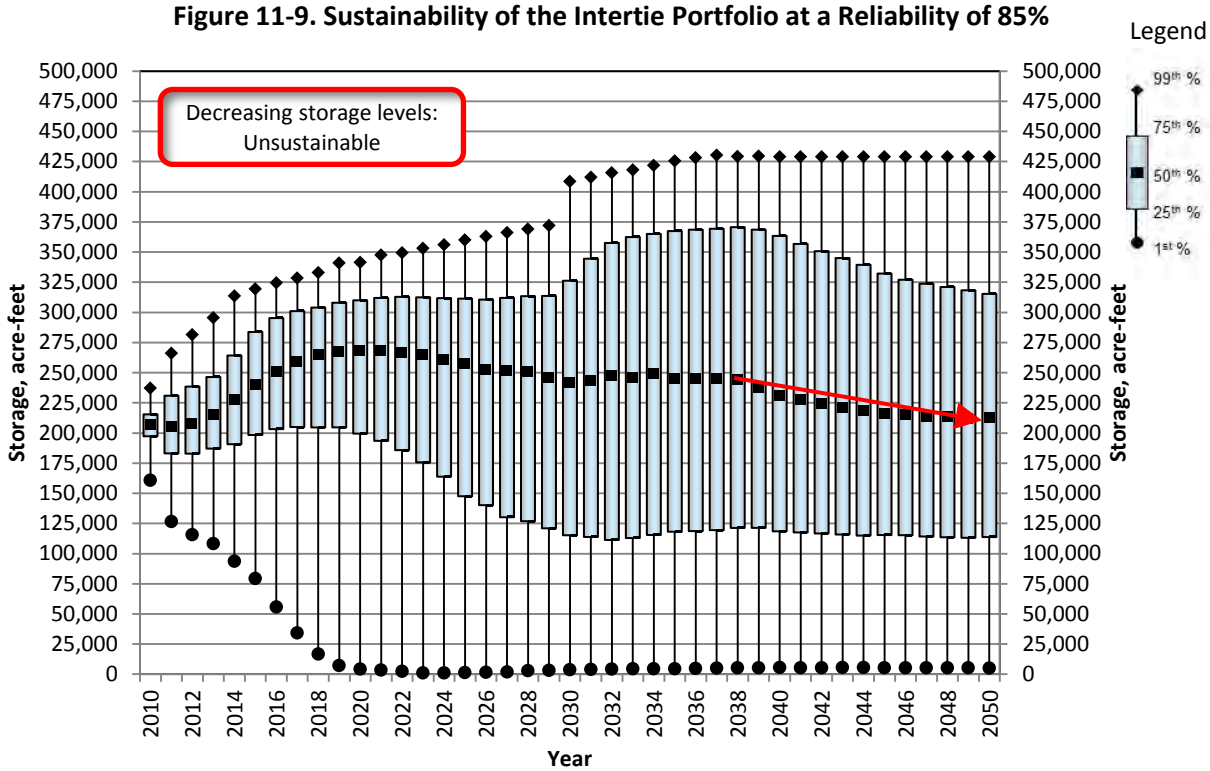


Figure 11-8. Reliability Curve for the Intertie Portfolio: 85%[124]



[124] Presents the risk curve for the worst-case observed over the entire period from 2010 to 2050.

Figure 11-9. Sustainability of the Intertie Portfolio at a Reliability of 85%



11.1.4 Reliability of the Intertie Portfolio: 90%

Under this scenario, shortages are kept equal to or below 10% of projected water demands assuming Zone 7 is able to develop and use 5,100 acre-feet (AF) of normal/wet year water and 2,200 AF of dry year water supply starting in 2026, and another 1,500 AF of dry year supply between 2029 and 2037. (Figure 11-10). The 1,500 AF of dry year supply was stopped after 2037 because it would not be needed at that time to achieve 90% reliability. In addition to achieving a reliability of 90%, this scenario also results in no shortages 96% of the time (Figure 11-11) and sustainable system-wide storage (Figure 11-12).

Figure 11-10. Risk of Potential Shortages for the Intertie Portfolio: 90%

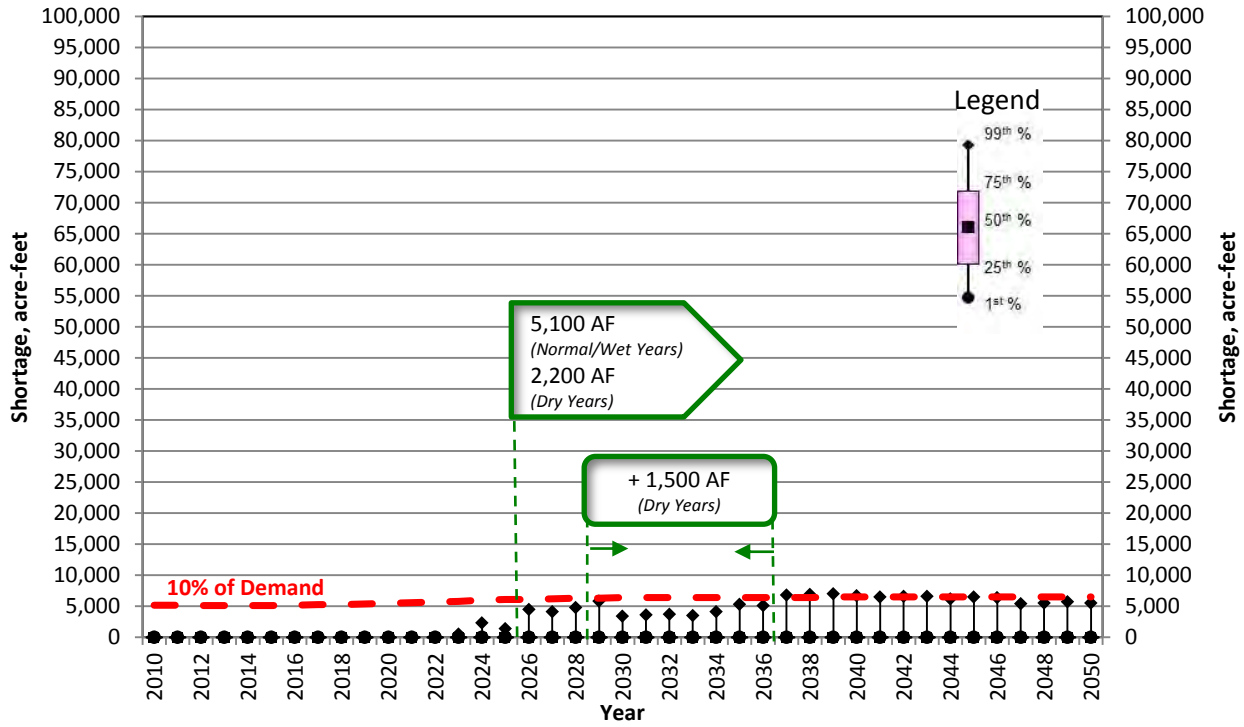


Figure 11-11. Reliability Curve for the Intertie Portfolio: 90%

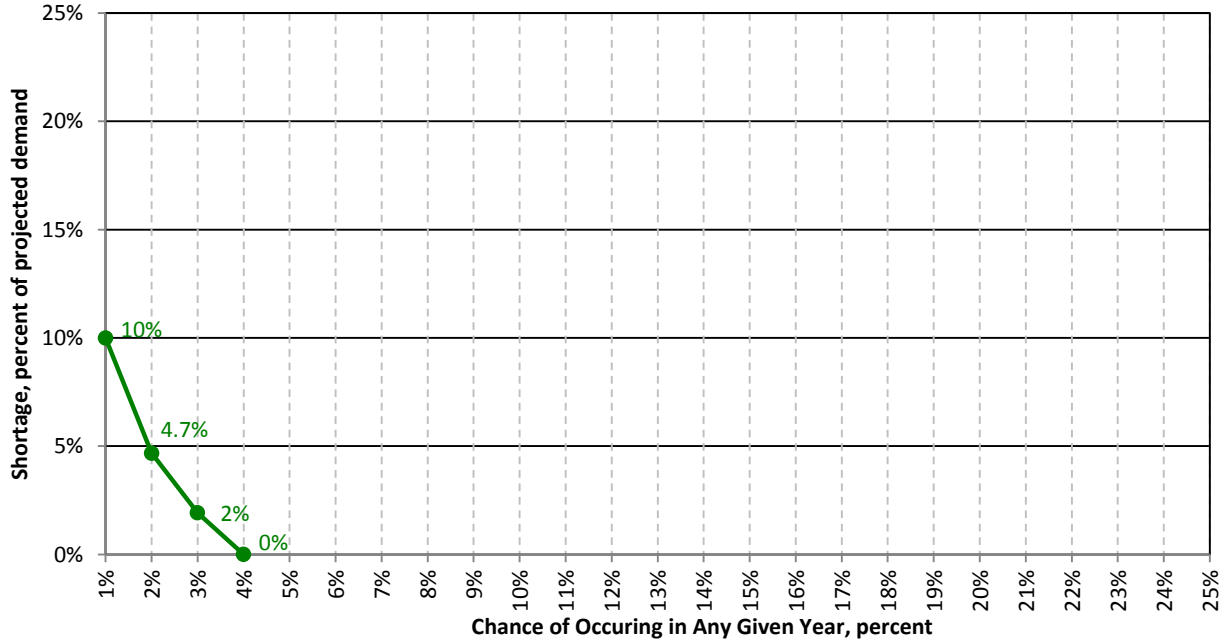
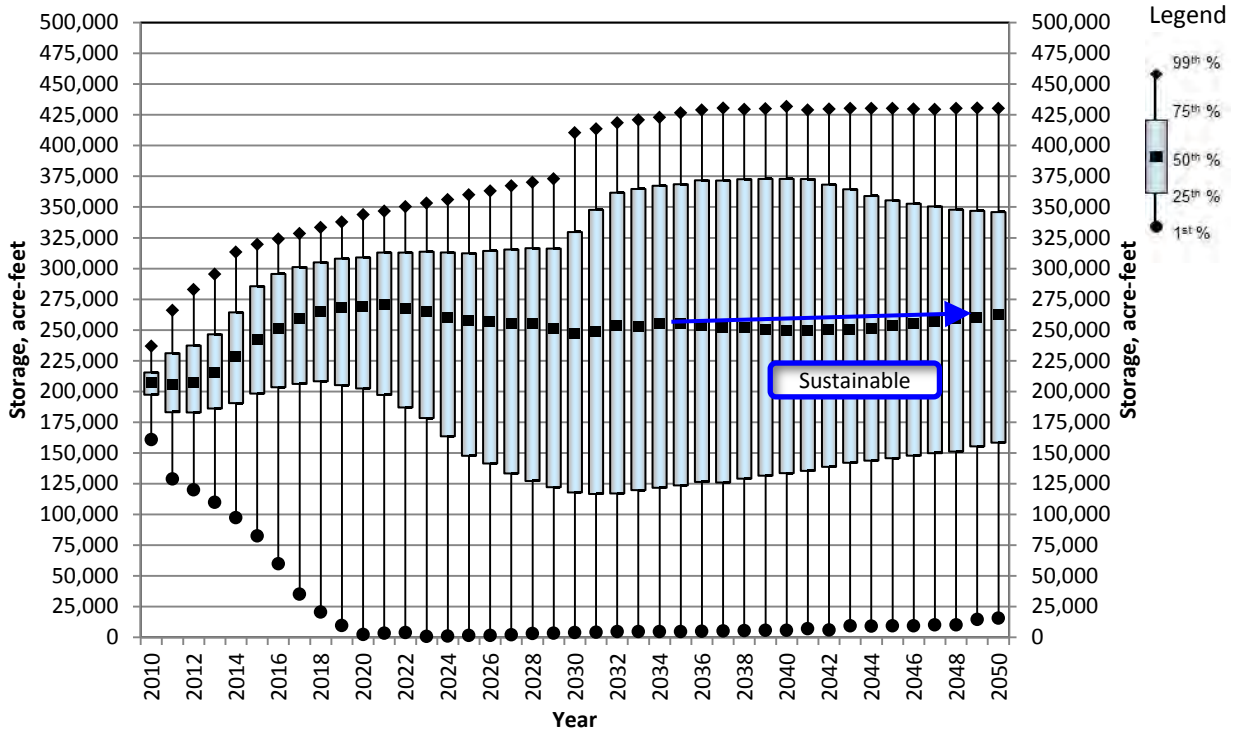


Figure 11-12. Sustainability of the Intertie Portfolio at a Reliability of 90%



11.1.5 Reliability of the Intertie Portfolio: 95%

Under this scenario, shortages are kept equal to or below 5% of projected water demands assuming Zone 7 is able to develop and use 5,100 acre-feet (AF) of normal/wet year water and 3,800 AF of dry year water supply starting in 2026, and another 1,500 AF of dry year supply between 2029 and 2037 (Figure 11-13). The 1,500 AF of dry year supply was stopped after 2037 because it would not be needed at that time to achieve 95% reliability. In addition to achieving a reliability of 95%, this scenario also results in no shortages 97% of the time (Figure 11-14) and sustainable system-wide storage (Figure 11-15).

Figure 11-13. Risk of Potential Shortages for the Intertie Portfolio: 95%

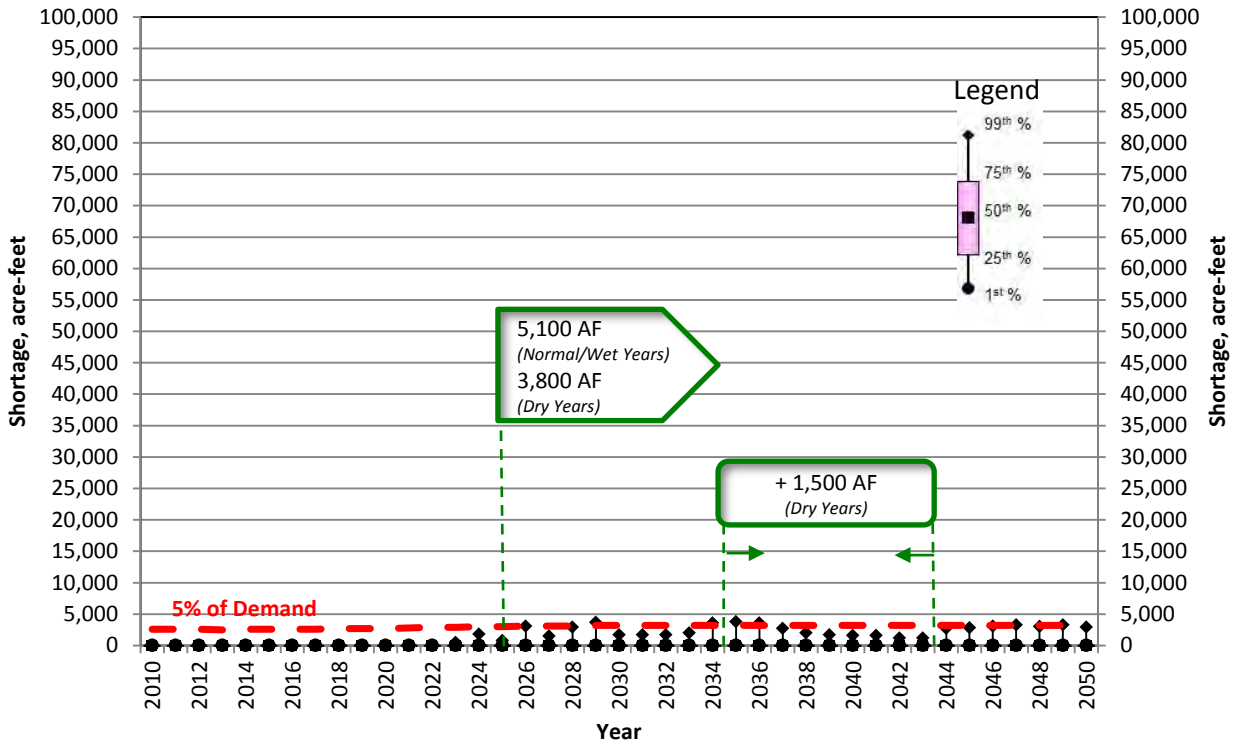


Figure 11-14. Reliability Curve for the Intertie Portfolio: 95%

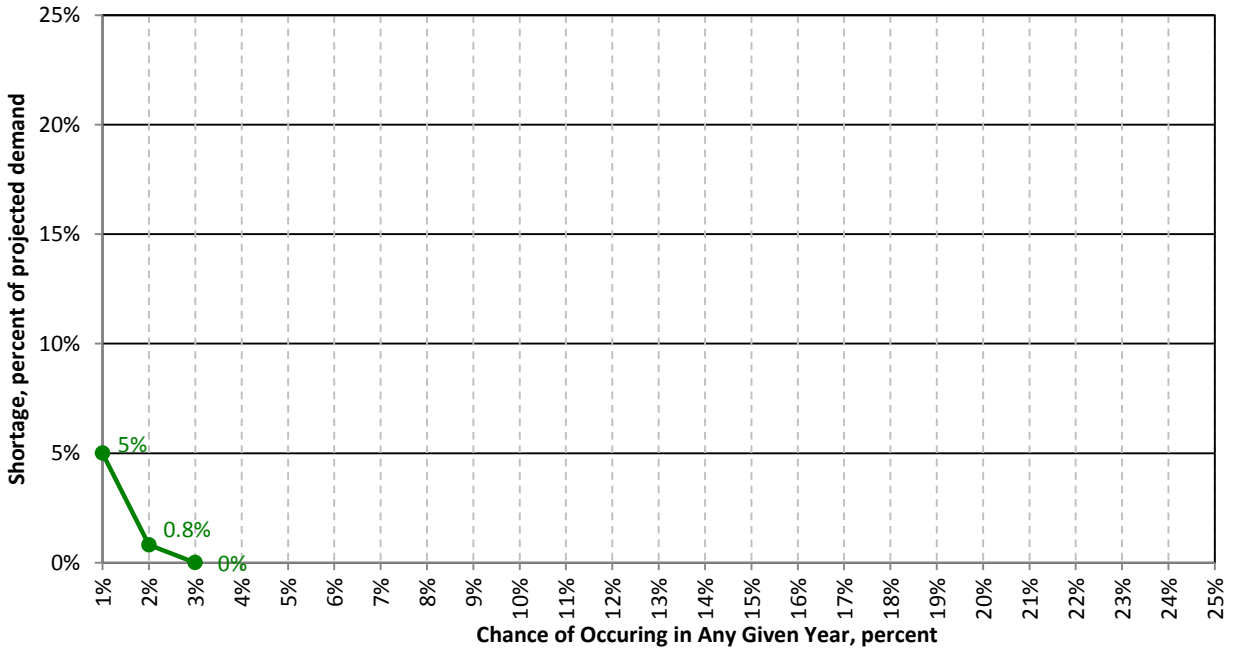
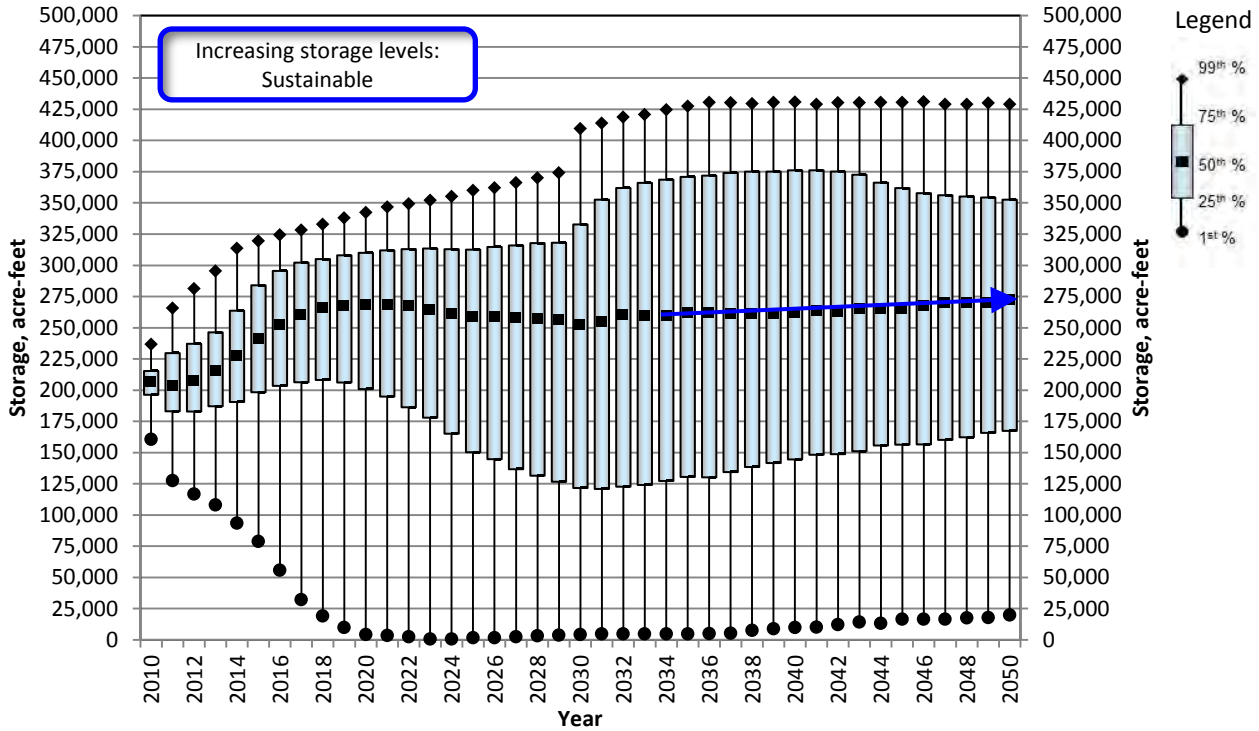


Figure 11-15. Sustainability of the Intertie Portfolio at a Reliability of 95%



11.1.6 Reliability of the Intertie Portfolio: 99%

Under this scenario, shortages are kept equal to or below 1% of projected water demands assuming Zone 7 is able to develop and use 5,600 acre-feet (AF) of water supply that is available during all water year types starting in 2024 (Figure 11-16). In addition to achieving a reliability of 99%, this scenario also results in no shortages 98% of the time (Figure 11-17) and sustainable system-wide storage (Figure 11-18).

Figure 11-16. Risk of Potential Shortages for the Intertie Portfolio: 99%

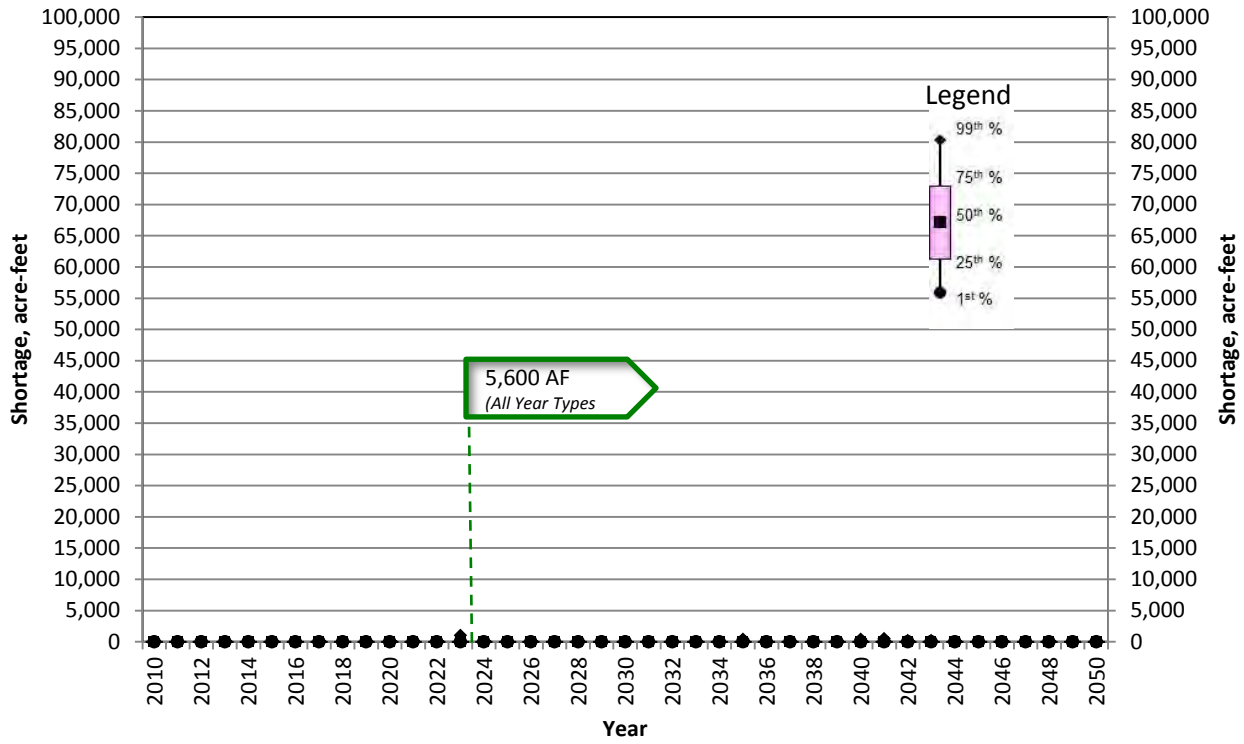


Figure 11-17. Intertie Portfolio at a Reliability of 99%

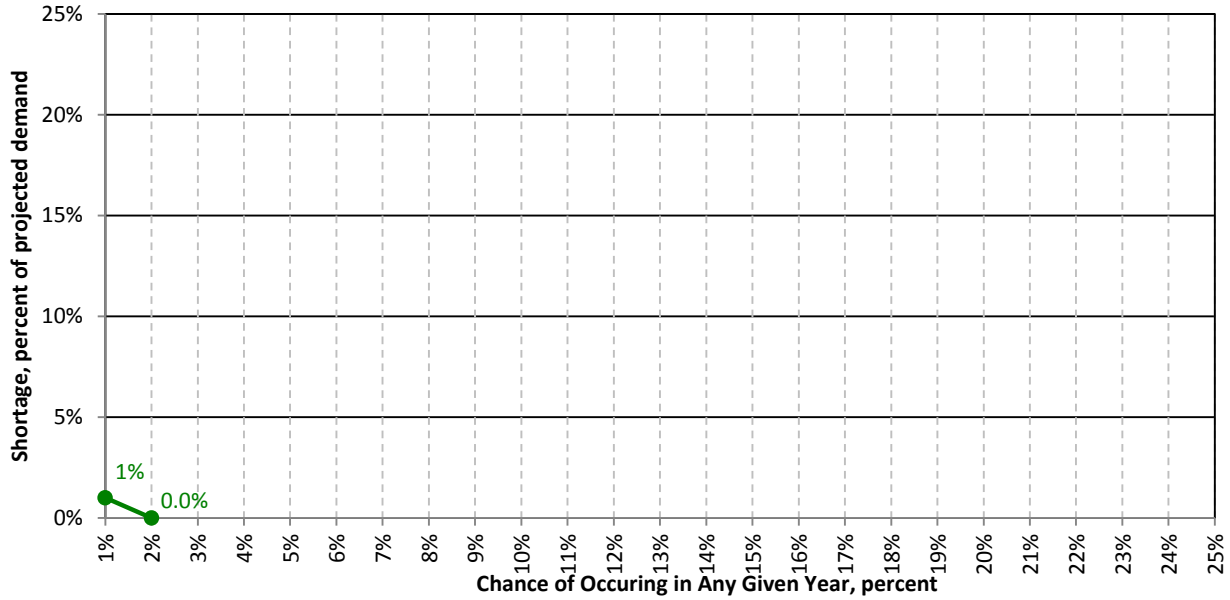
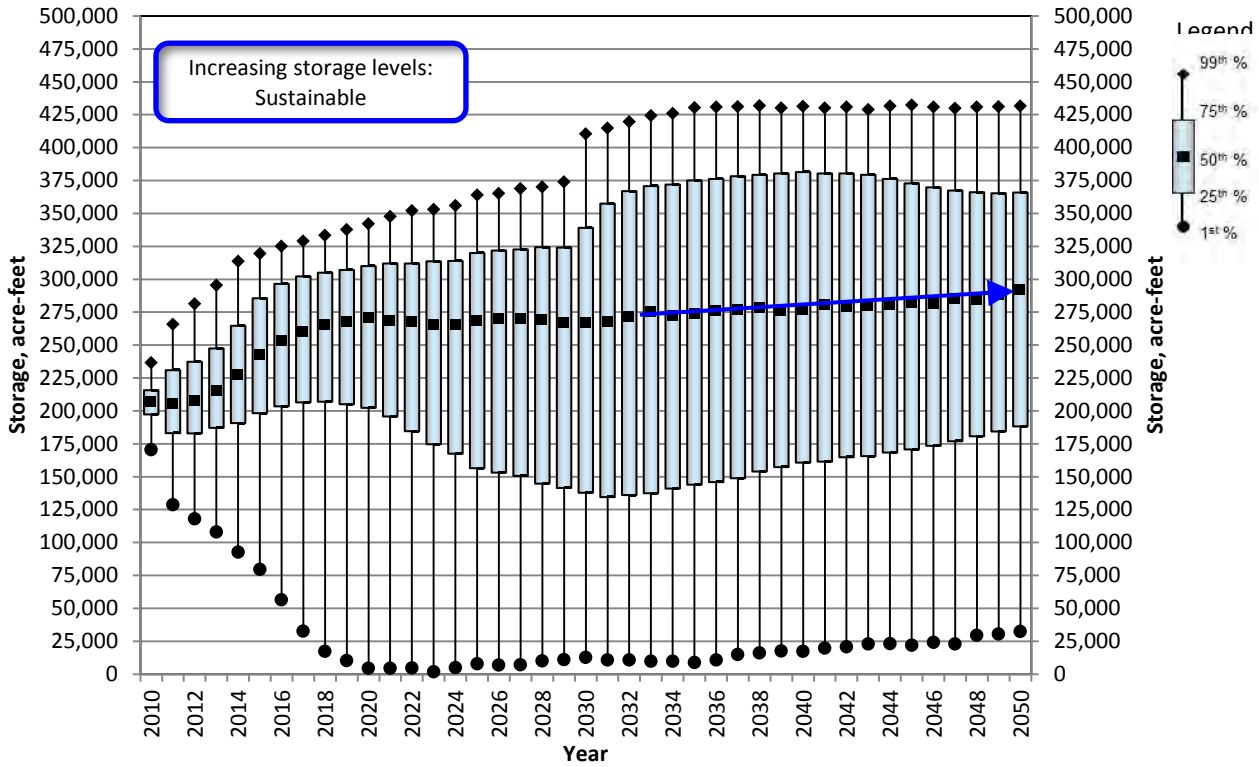


Figure 11-18. Sustainability of the Intertie Portfolio at a Reliability of 99%



11.2 FACILITIES EVALUATION FOR THE INTERTIE PORTFOLIO

Zone 7 staff reviewed the capacities of existing and planned facilities associated with the Intertie Portfolio to meet 100 percent of maximum day demands under normal conditions and 75% of maximum day demands assuming one major facility is out of service. Each condition is discussed below.

11.2.1 Maximum Day Demand for the Intertie Portfolio

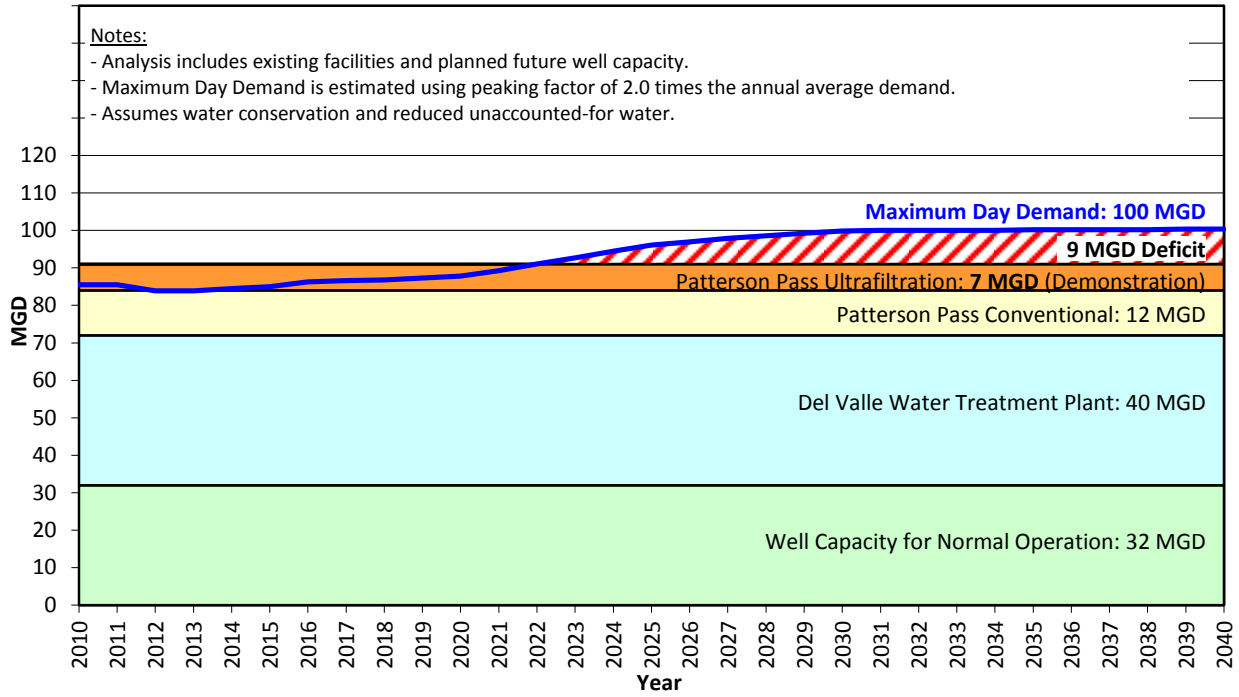
Figure 11-19 compares the capacity of existing and planned facilities associated with the Intertie Portfolio with projected maximum day demands.[125] Based on this comparison, Zone 7 can meet 100% of maximum day demands through 2022, but will require additional capacity by 2023 (9 million gallons per day [MGD]). However, the temporary ultrafiltration (UF) plant at the Patterson Pass Water Treatment Plant (PPWTP) will need to be replaced; therefore, the total new capacity required is at least 16 MGD (9 plus 7 MGD).

This analysis is dependent on the assumptions for potable demand reductions associated with the Water Conservation Act of 2009, and a 1,000 to 2,000 AF fluctuation in these assumptions could easily translate into 2 to 4 MGD of additional treatment capacity.[126] Consequently, for planning-level purposes in this WSE, the cost estimates for an initial expansion of water treatment plant capacity were based on a 20 MGD facility.

[125] Projected water demands were previously discussed in Section 3; the maximum day is obtained by multiplying by 2.

[126] 2, 000 acre-feet is about 1.8 MGD, which translates to about 3.6 MGD on the maximum day assuming a peaking factor of 2.

Figure 11-19. Intertie Portfolio: Ability to Meet Maximum Day Demand



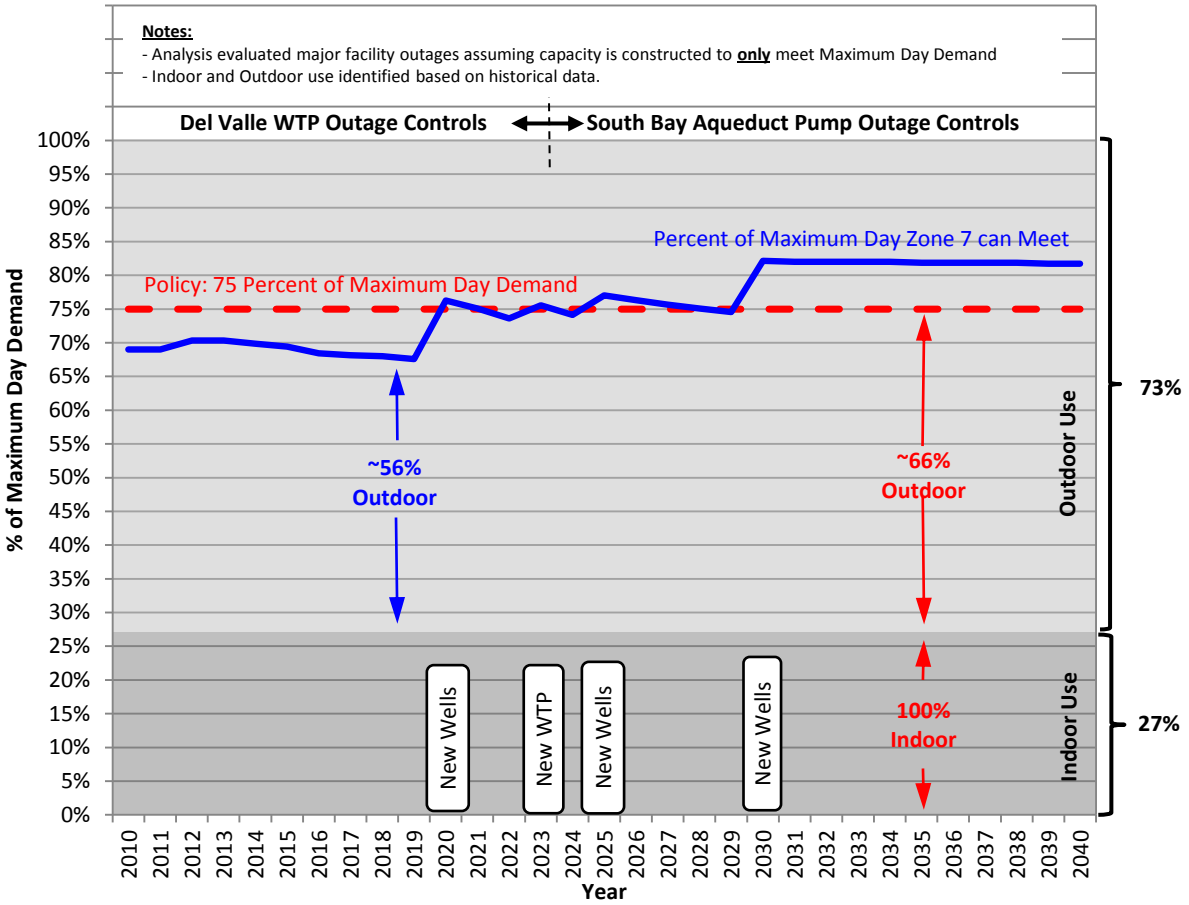
11.2.2 Level of Service for the Intertie Portfolio with a Major Facility Outage

Zone 7 staff evaluated the ability of existing and planned facilities associated with the Intertie Portfolio to meet the current facility outage policy. Figure 11-20 presents the results of this evaluation by comparing the percent of maximum day demand Intertie Portfolio facilities can meet to the current policy over time. For discussion purposes, Figure 11-20 splits the maximum day demand into indoor and outdoor use,[127] and presents the current facility schedule. The current facility schedule reflects delayed construction associated with reduced demands caused by the current economic downturn.

As shown on Figure 11-20, the current policy is to meet 75% of maximum day demand with a major facility out of service; however, another interpretation of the policy is to meet 100% of indoor use and 66% outdoor use during the same conditions. Figure 11-20 clearly shows, with a major facility outage, that existing facilities can meet 100% of indoor water needs, but only about 56% of outdoor needs until 2020. As new facilities come online, Zone 7 is increasingly able to meet and eventually exceed the existing policy.

[127] Zone 7 staff reviewed historical monthly data to split projected water demands into indoor and outdoor use. This analysis is provided as Appendix A.

Figure 11-20. Ability of the Intertie Portfolio to Meet Maximum Day Demand during an Outage



11.2.2.1 Consideration: Level of Service during a the Maximum Month

The assumptions presented on Figure 11-20 are relatively conservative. For example, one scenario evaluated assumes that all of the treatment capacity associated with the Del Valle Water Treatment Plant happens to be lost on the highest water use day of the year (i.e., the maximum day), which typically occurs between 1 to 5 out of 365 days – less than 2 percent of the time. Additionally, barring a major emergency (e.g., an earthquake, Delta levee failure, or transmission line burst), it would take multiple, simultaneous, failures of internal plant equipment to lose all treatment capacity for an entire day.[128]

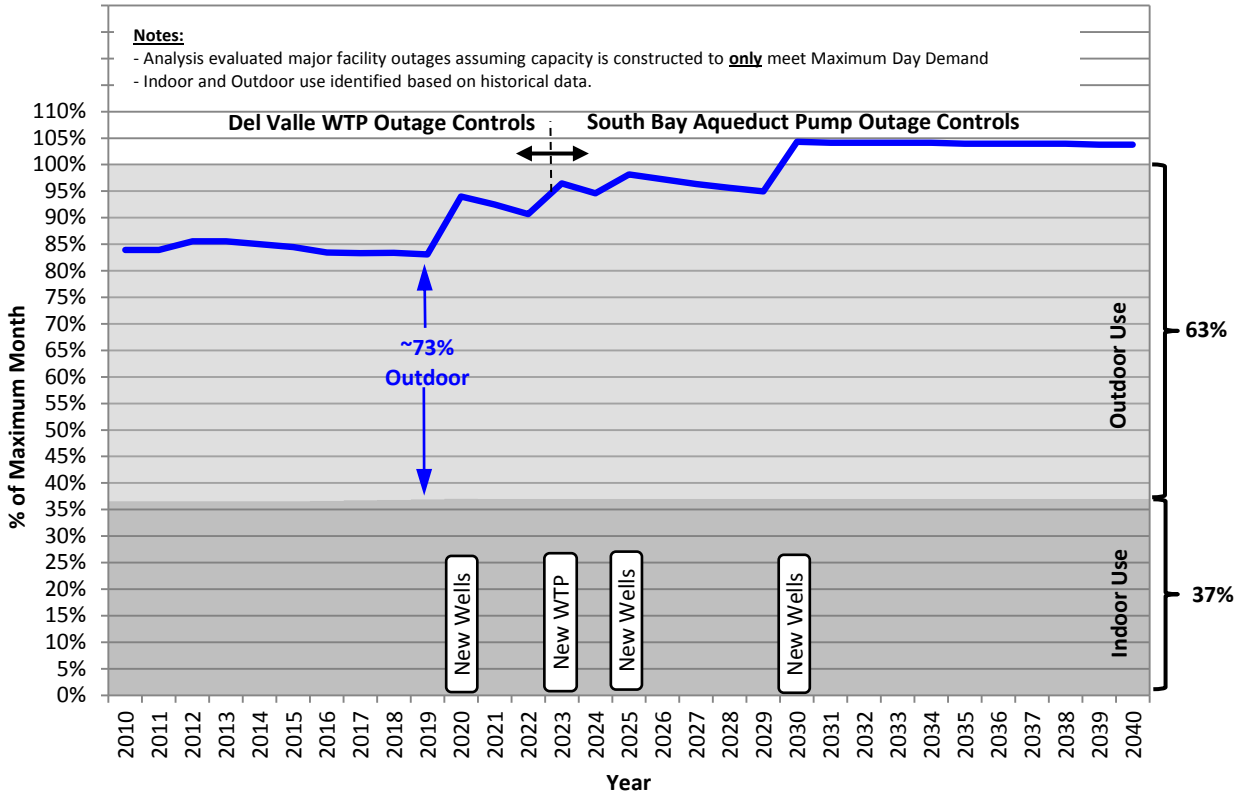
Consequently, for discussion purposes in this WSE, Zone 7 staff also reviewed the same outage scenarios over the highest water use month (i.e., the maximum month) instead of the maximum day demand. Figure 11-21 presents the same analysis completed for the maximum month.

As shown on Figure 11-21, existing facilities can meet 100% of indoor use and almost three-quarters of the outdoor use during the highest water use month and therefore, about a 25% reduction in water use would be required over a 30-day period. Assuming the typical residential customer waters their lawn

[128] Based on conservations with Zone 7 operations staff.

four times per week during the hottest month of the year, then a 25% reduction could be achieved by only watering their lawn about three times a week.

Figure 11-21. Ability of the Intertie Portfolio to Meet Maximum Month Demand during an Outage



11.3 SALT MANAGEMENT EVALUATION FOR THE INTERTIE PORTFOLIO

Zone 7 is preparing to update its Groundwater Management Plan (GWMP), which will also include an update of the Salt Management Plan (SMP). As part of this update, Zone 7 staff will conduct a more rigorous analysis of potential salt and nutrient loading in the Main Basin – a rigorous analysis of salt loading was not completed as part of this WSE.

Each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics that could influence future salt loading in the Main Basin. Consequently, Zone 7 staff completed a preliminary review of the potential salt loading associated with the Intertie Portfolio for comparative purposes in this WSE.[129] As discussed in Section 5, this review involved using spreadsheet models previously developed as part of Zone 7's original SMP to evaluate whether net salt loading in the Main Basin associated with the Current Plan was either increasing or decreasing. Preliminary results indicate that a new demineralization facility may be required to achieve decreasing salt loading under the Current Plan. The GWMP/SMP update will further evaluate this finding.

[129] Zone 7 will evaluate nutrients as part of the SMP update.

11.4 OBSERVATIONS REGARDING DELIVERED WATER QUALITY

As discussed previously in Section 5, conducting hydraulic modeling to quantify potential benefits to delivered water quality were beyond the scope of this WSE; however, each of the scenarios evaluated in this WSE involved different water supply sources with different water quality characteristics. Consequently, a qualitative review of each scenario was completed to evaluate whether the scenario had the potential for improving delivered water quality. The potential benefits to delivered water quality associated with the Intertie Portfolio fall into two categories: (1) those associated with the quality of supplies delivered via the intertie, and (2) those associated with the groundwater demineralization activities. Both are discussed below.

11.4.1 Potential Delivered Water Quality Benefits of the Intertie Portfolio

The quality of water supplies delivered via the intertie associated with the portfolio directly impact delivered water quality. For illustrative purposes, Table 11-1 compares the hardness and total dissolved solids of Zone 7's transmission system to those of EBMUD's system. As shown in Table 11-1, this portfolio would likely benefit delivered water quality.

Table 11-1. Comparison of Key Water Quality Constituents

Constituent	Zone 7[(a)]	EBMUD Walnut Creek System[(b)]
Hardness, mg/l	105 – 470	12 – 20
TDS, mg/l	297 – 709	45

(a) Source: Zone 7's 2009 Consumer Confidence Report

(b) Source: EBMUD's 2009 Annual Water Quality Report

11.4.2 Potential Delivered Water Quality Benefits Associated with Demineralization

As previously discussed, Zone 7 staff conducted a preliminary evaluation of salt loading associated with the Intertie Portfolio, and although it is recommended that future salt mitigation strategies be evaluated as part of the GWMP/SMP update, another phase of demineralization is in Zone 7's existing Capital Improvement Program. Therefore, a second phase was also included in the cost estimates of the Intertie Portfolio for comparative purposes in this WSE. Another phase of demineralization will have a direct positive influence on delivered water quality because it treats groundwater before it enters Zone 7's distribution system.[130]

11.5 COST ESTIMATES FOR THE INTERTIE PORTFOLIO: 75 TO 99%

The purpose of this section is to provide planning-level cost estimates for each reliability scenario evaluated under the Intertie Portfolio. For illustrative purposes, the cost estimates were divided into three categories: (1) facilities, (2) water supply, and (3) water quality. The facilities component of the cost estimates represent hard construction, such as water treatment plants, diversion structures, and groundwater wells, while the water supply component generally represented the cost of purchasing or acquiring water.

[130] The benefits of demineralization were thoroughly analyzed as part of the 2003 Water Quality Management Program report.

In all cases, the costs are presented in 2010 dollars based on an Engineering News Record San Francisco Construction Cost Index. The following planning-level cost contingencies were also applied as necessary:

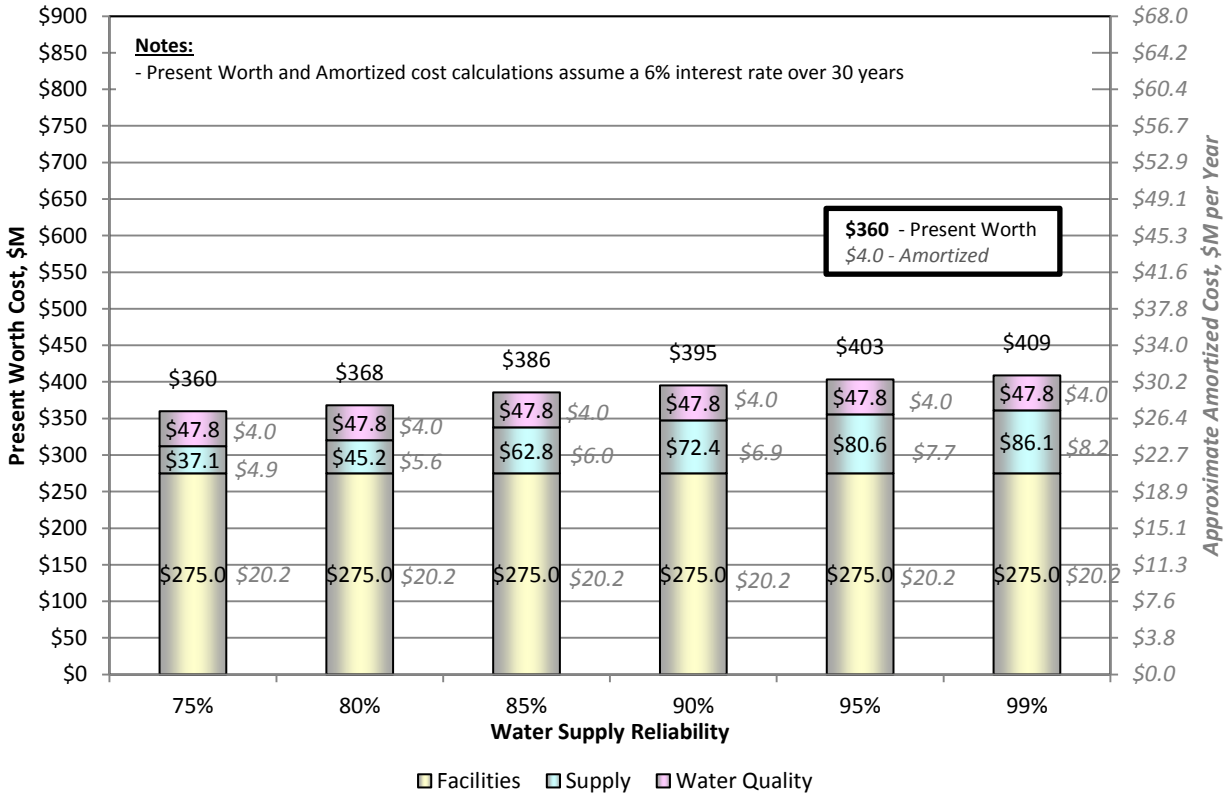
- Construction Contingency: 25 percent
- Planning and Environmental: 10 percent
- Design and Implementation: 10 percent
- Construction Management: 10 percent

Appendix D contains a more detailed description of the cost estimates used and contains preliminary schedules developed for each scenario that were used to develop present worth and amortized values.

11.5.1 Observations Regarding the Cost of Reliability

As shown on Figure 11-22, the facility costs do not increase between 75 and 99% reliability because the Intertie Portfolio does not provide supply on the maximum day demand. Supply costs increase proportionally depending on the amount of new supply acquired. Water quality costs are the same because all of the scenarios assume the need to construct a second demineralization facility. Overall, the total portfolio costs for a 99% reliability scenario are only about 14% ($49 million) higher than the portfolio costs for a 75% reliability scenario.

Figure 11-22. Cost of Reliability for the Intertie Portfolio



12. RECOMMENDED NEAR-TERM ACTIONS

The purpose of this section is to present the recommended "no regret" actions that will help minimize the risk of water supply shortages, while also maximizing Zone 7 Water Agency's (Zone 7) ability to adjust to an uncertain future. This section also outlines the additional studies necessary to confirm key assumptions made in this Water Supply Evaluation (WSE), while also summarizing the observations made regarding reliability, Zone 7 staff's recommendation to review the existing Reliability Policy after completion of this WSE, and a preliminary schedule for next steps.

The following subsections present the recommended near-term actions based on the analysis completed as part of this WSE:

- 12.1 Recommended No Regret Actions to Minimize Near Term Risk
- 12.2 Anticipated Benefits of the Recommended No Regret Actions
- 12.3 Additional Studies Required to Confirm Key Assumptions and Limitations
- 12.4 Observations and Proposed Next Steps Regarding Zone 7's Reliability Policy
- 12.5 Measures of Success: Preliminary Schedule for Next Steps

12.1 RECOMMENDED NO REGRET ACTIONS TO MINIMIZE NEAR-TERM RISK

Based on the analysis completed in this WSE, Zone 7 staff has the following recommendations to help improve near-term reliability, while also ensuring Zone 7 and the local water supply retailers have sufficient time to complete the additional studies necessary to confirm key assumptions made in this WSE. A more complete description of each action was previously provided in Section 6 or 7 since these actions are part of the Current Plan. All of the recommendations are lowest-cost alternatives and within the control of either Zone 7 or the local water supply retailers.

- *Confirm water supply available from the existing contract with Byron Bethany Irrigation District (BBID):*

  Zone 7 plans to work with BBID to complete a study that will help determine whether the minimum yield within Zone 7's existing contract with BBID can be modified, potentially adding 3,000 acre-feet (AF) of minimum water supply.

- *Minimize or reuse brine losses from the existing Mocho Groundwater Demineralization Plant:*

  In addition to working with Dublin San Ramon Services District (DSRSD) to develop and implement ways of capturing and reusing brine losses from the plant, Zone 7 staff also plans to use actual water quality results – not available at the time the facility was originally permitted – to reduce brine losses to 15 percent instead of 20 percent. This activity will potentially add 260 to 1,300 AF of supply.[131]

[131] The range in potential supply associated with reoperation of the Mocho Groundwater Demineralization plant depends on the quantity of brine loss that Zone 7 and DSRSD are able to capture and reuse, and depends on how much of the reuse results in potable demand reduction.

- *Reduce Unaccounted-for Water Losses:*

  Historically, Zone 7's transmission system has observed 2 percent unaccounted-for water losses; however, recent data suggests that unaccounted-for water within Zone 7's transmission system is increasing (i.e., above 4 percent). Consequently, Zone 7 plans to complete an investigation to reduce unaccounted-for water losses from 4 to 2 percent of total water production, which could reduce future water supply needs by 900 to 1,300 AF.

- *Work with Retailers to develop Additional Water Conservation and Recycled Water Programs:*

  In November 2009, the California legislature passed the Water Conservation Act of 2009 (Conservation Act), which required water supply retailers to reduce their per capita water consumption 20 percent from their baseline by 2020. Zone 7 plans to work with and help the water supply retailers meet their targets, which will likely happen via a combination of traditional water conservation measures[132] and increased use of recycled water. Initial estimates by Zone 7 staff indicate this new requirement may reduce future water supply needs by about 6,000 AF. As part of this, Zone 7 staff also recommends working with the water supply retailers to develop a water conservation tracking methodology.

- *Continue Implementing the Well Master Plan and Chain of Lakes Projects*

  Protecting local groundwater resources for the use and benefit of the Tri-Valley area is one of Zone 7's primary goals; the local groundwater basin also helps meet reliability goals during droughts or emergency conditions. Hence, Zone 7 staff recommends continuing to implement both the Well Master Plan and the Chain of Lakes projects to enhance Zone 7's ability to recharge and pump water from the groundwater basin.

- *Enhance Zone 7's Existing In-Lieu Recharge Program*

  Zone 7 staff already reduces its own groundwater pumping during wet years to help replenish and maintain groundwater supplies. Zone 7 plans to work with the water supply retailers during wet years to reduce the use of their groundwater-pumping quota and instead, use more surface water provided by Zone 7.

Zone 7 staff estimates that the total potential increase in water supply, or decrease in water demand, resulting from these actions could range from 10,000 to 12,000 AF.

12.2 ANTICIPATED BENEFITS OF THE RECOMMENDED NO REGRET ACTIONS

Zone 7 staff evaluated the ability of the water supplies and facilities included in the list of no regret actions to prevent water supply shortages, while also maintaining drought and emergency storage at a sustainable level over the next 5 to 10 years. For this evaluation, Zone 7 staff first reviewed the risk of potential water supply shortages and then reviewed the sustainability of system-wide storage, which included the Main Basin, Semitropic Water Storage District (Semitropic), Cawelo Water District (Cawelo), State Water Project (SWP) Carryover, and the Chain of Lakes.[133] Each is discussed below in more detail.

[132] Traditional water conservation measures in this WSE mean activities such as use of low-flow toilets, ET controllers, or high-efficiency washers, and improved landscape irrigation management.

[133] Key individual storage results were included in Appendix F.

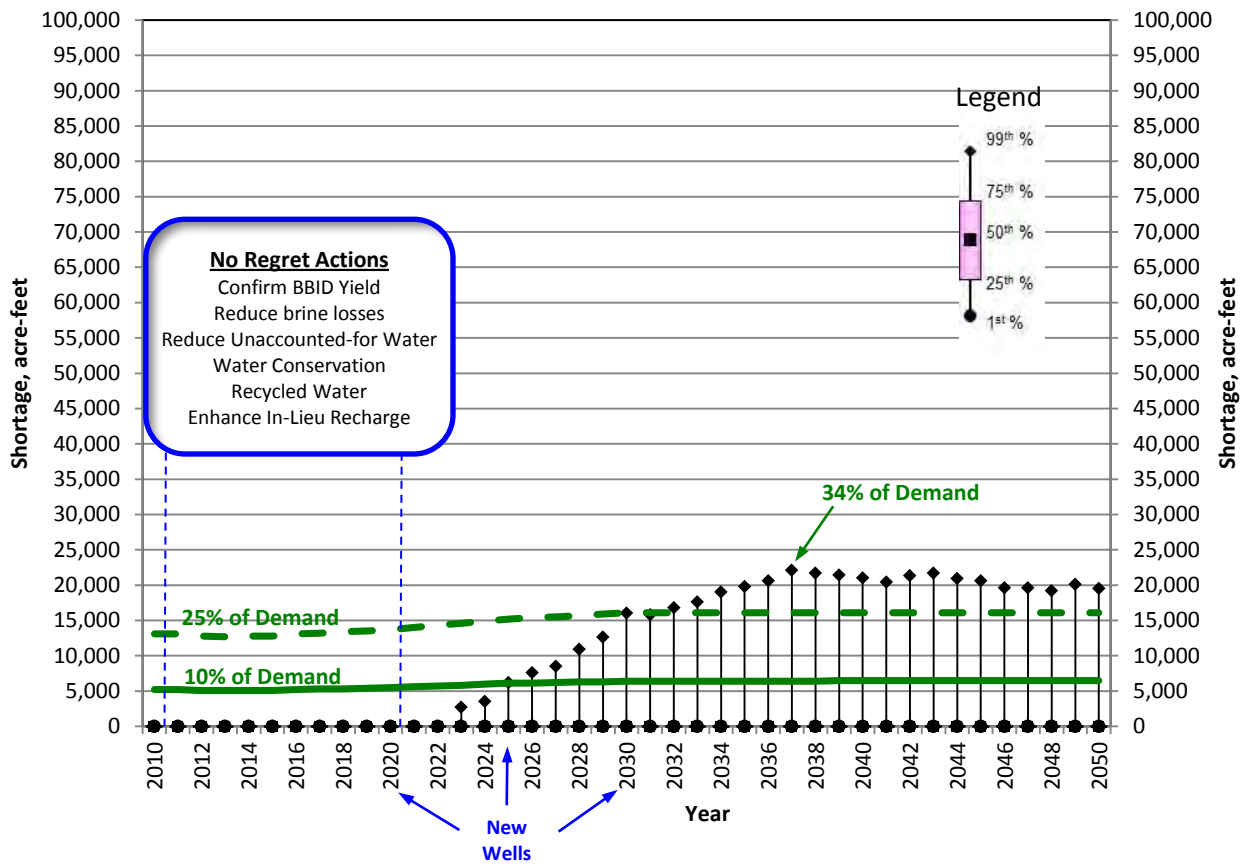
12.2.1 Reliability after Implementing No Regret Actions

Figures 12-1 and 12-2 present potential shortages and sustainability assuming Zone 7 and the local water supply retailers successfully implement no regret actions.

As shown on Figure 12-1, there is a less than 1% chance of a water supply shortage between 2011 and 2022 as long as Zone 7 and the local water supply retailers can successfully implement the no regret actions. Hence, implementing the no regret actions helps decrease the chance of shortages over the next 10 to 13 years, thereby, providing Zone 7 and local water supply retailers additional time to further investigate and refine the portfolios developed as part of this WSE. This is important, as a major new water supply project can take 10 to 15 years to implement.

Figure 12-1 also indicates that there is a risk of shortages larger than 10% between 2025 and 2050, and that the maximum potential shortage is over 30%.

Figure 12-1. Risk of Potential Shortages after Implementing No Regret Actions[134]

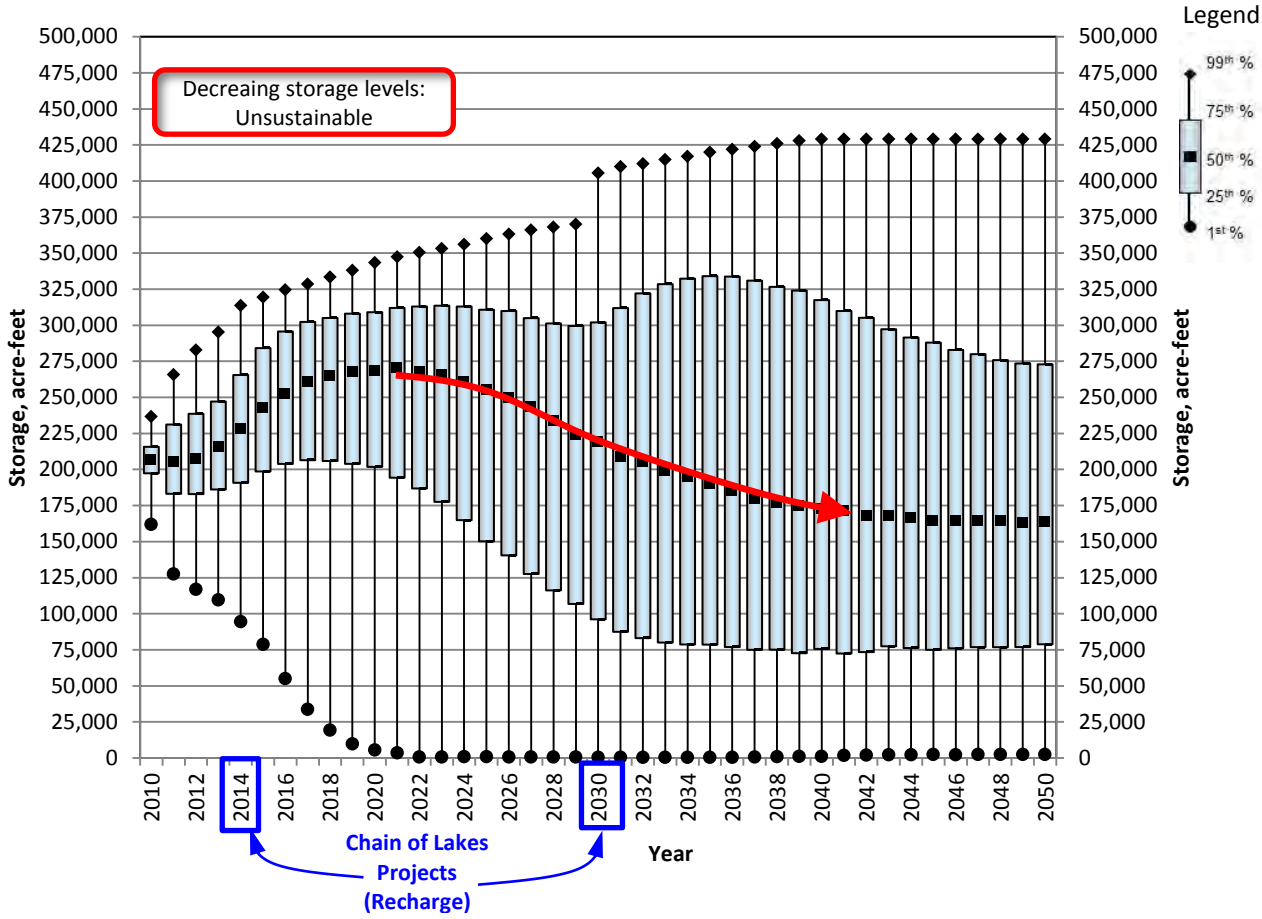


As shown on Figure 12-2, implementing no regret actions alone does not make total storage sustainable over the long-run; however, these actions do dramatically increase storage levels over the next 10 to 13

[134] The shortages presented in Figure 12-1 are projections assuming the State of California cannot implement a Delta Fix and no further action is taken by Zone 7.

years, which increases the likelihood of having sufficient drought and emergency storage until a new major water supply project[135] can be completed.

Figure 12-2. Sustainability of Total Storage after Implementing No Regret Actions



12.3 ADDITIONAL STUDIES REQUIRED TO CONFIRM KEY ASSUMPTIONS AND LIMITATIONS

Based on the analysis completed in this WSE and discussions with the local water supply retailers, Zone 7 staff recommends completing several new studies over the next few years to help confirm key assumptions used in this WSE and better define limitations associated with some of the portfolios (e.g., potential potable water demand reductions from recycled water). The purpose of this section is to provide a brief description of each study, including its intended goals and objectives.

12.3.1 Recommendation for the Current Plan: Continued Participation in Delta Fix Efforts

The key to improving water supply reliability under the Current Plan is the successful implementation of the Delta Fix, with SWP reliability restored to 75% by 2025. Even if the Livermore-Amador Valley (Valley) develops additional non-SWP water supplies, the State Water Project will continue to meet the majority

[135] Examples of a new major project include a fix in the Delta that improves State Water Project reliability, additional recycled water programs, and the Bay Area Regional Desalination Project.

of existing and future water demands – the reliability of the State Water Project and sustainability of the Sacramento-San Joaquin Delta (Delta) will therefore always be important for the Valley.

Consequently, Zone 7 staff recommends continued participation in any efforts potentially leading toward restored reliability of the State Water Project and improving the sustainability of the Delta, particularly, the Bay Delta Conservation Plan and the Delta Habitat Conservation and Conveyance Plan studies.

12.3.2 Recommended Studies for the In-Valley Portfolio: Understanding Water Quality and Demand

As previously discussed in Section 10, Zone 7 and the local water supply retailers may need to develop anywhere from 3,000 to 7,600 AF[136] of additional recycled water – above the 5,900 AF[137] already planned – to meet reliability targets ranging from 75 to 99%. This represents approximately 8,900 to 13,500 AF of total recycled water use in the Livermore-Amador Valley. This is a significant amount of recycled water, and assuming a sufficient number of potential recycled water customers, could increase total recycled water use in the Valley by approximately 128% over current plans. Additionally, some of the recycled water may require storage.

Consequently, Zone 7 staff recommends studying the potential water quality impacts of increased recycled water use as part of the planned Groundwater Management Plan Update (GWMP Update) and associated Salt Management Plan Update (SMP Update), while also working with the retailers to incorporate "valley-wide" recycled water demand estimates to ensure required potable water demand reductions are feasible. Zone 7 staff also recommends working with the local water supply retailers to complete a study that identifies potential recycled water storage options. Both are discussed below in more detail.

12.3.2.1 Understand Water Quality Implications Associated with Additional Recycled Water Use

Although an analysis was completed in this WSE to help compare the potential salt loading implications of each portfolio evaluated, Zone 7 staff plans to complete a much more rigorous analysis as part of the GWMP Update, which will include the SMP Update. As part of these updates, Zone 7 recommends analyzing the influence that applying 3,000 to 7,600 AF of additional recycled water may have on the water quality of the basin, focusing on answering the following questions:

- What is the best salt management strategy for allowing development of additional recycled water supplies?
- How much recycled water can be applied over the Main Basin without triggering extensive salt mitigation?
- Does it matter where the recycled water is applied over the Main Basin?
- Based on a qualitative review, would applying recycled water in large quantities increase nutrient loading or contaminants of emerging concern in the groundwater basin; if so, what are the appropriate mitigation strategies?

[136] Includes 2,000 AF of recycled water assumed implemented by the Retailers to meet water conservation targets under the Water Conservation Act of 2009.

[137] Both Dublin San Ramon Services District and the City of Livermore have existing recycled water systems; both systems together already plan to produce 5,900 AF by 2030.

Developing estimates or answers to these questions is vital to understanding the potential limits – from a water quality perspective – on the amount of recycled water Zone 7 and the local water supply retailers can develop and rely on in the future.

12.3.2.2 Link Potable Demand Reduction via Recycled Water with Potential Customers

Even if Zone 7 and the local water supply retailers can develop an additional 3,000 to 7,600 AF of additional recycled water in a way that protects local groundwater resources, additional analysis is necessary to determine whether sufficient demand exists for such large amounts of recycled water.

For example, 1,000 to 5,600 AF of additional recycled water may require converting 300 to 1,700 acres of land currently irrigated with potable water to recycled water (see Section 10). Assuming the average park or school within the Valley is about 20 acres would imply the need to convert anywhere from 50 to 280 parks to recycled water—this is a large, potentially unfeasible number. Additionally, the unit costs developed for the In-Valley Portfolio were based on previous studies that identified the infrastructure necessary to convert mostly parks and schools. Converting other types of land uses (e.g., commercial and multi-family) could significantly increase the costs.

Consequently, Zone 7 staff recommends completing a study – in cooperation with the local water supply retailers – that estimates the potential recycled water demand in the Valley, using the potable demand reductions identified in this WSE to help better refine cost estimates and schedules of construction. In particular, the study should focus on answering the following questions:

- How much recycled water demand exists in the Valley?
- Where is the recycled water demand located?
- How would cost estimates change if other land use types (e.g., commercial) were converted to recycled water?
- How long would it take to construct a recycled water system able to achieve the potable demand reductions identified in this WSE?

Developing estimates or answers to these questions is vital to understanding the potential limits – from a quantity perspective – on the amount of recycled water Zone 7 and the local water supply retailers can develop and rely on in the future.

12.3.2.3 Identify Feasible Recycled Water Storage Options

Based on the analysis completed in this WSE, Zone 7 staff identified the potential need for recycled water storage for potable demand reductions between 3,200 and 5,600 AF. Developing and implementing a recycled water storage facility could take 10 or more years; consequently, Zone 7 staff recommends completing a study that looks into feasible recycled water storage alternatives—both local and near Sunol. In particular, the study should focus on answering the following questions:

- What are the potential storage options and where are they located?
- How long will it take to develop identified options and do they provide enough storage?
- What are the costs of the various options identified: capital, and operation and maintenance?
- What are the permits required to construct options identified?
- Is there potential grant funding available for recycled water storage projects?

Providing answers to these questions will help Zone 7 and the local water supply retailers determine the feasibility of developing recycled water storage and the role that additional recycled water programs will play in improving water supply reliability for the Livermore-Amador Valley.

12.3.3 Recommended Studies for the Intertie Portfolio

As discussed in Section 11, Zone 7 may need to develop as much as 5,600 AF of normal/wet year water supply and as much as 5,600 AF of dry year supply using several potential sources that are conveyed to Zone 7 through a new intertie. The analysis completed in this WSE helped establish these potential water supply needs; however, additional study and analysis is necessary to better refine potential costs and supply yields.

Consequently, Zone 7 staff recommends working with EBMUD and other potential water agencies to understand intertie options, determine the feasibility of potential normal/wet year water supplies identified, determine the availability of dry year water supplies, and continue to participate in feasibility studies for the Bay Area Regional Desalination Project (BARDP). Each is discussed below in more detail.

12.3.3.1 Identify Feasible Options for a New Intertie with another Water Agency

Based on the analysis completed for this WSE (see Section 11), Zone 7 staff recommends investigating feasible options for reliability interties with other water agencies, focusing on potential options with both East Bay Municipal Utility District (EBMUD) and San Francisco Public Utilities Commission (SFPUC) – EBMUD and SFPUC are the closest major water agencies to Zone 7's conveyance and transmission system. In particular, the feasibility study should focus on answering the following questions:

- Are there intertie options with EBMUD and SFPUC, and are they feasible?
- What size are the intertie options, and can they meet the needs of both agencies involved?
- Which intertie options provide the most flexibility for future supplies?
- What are the associated costs for each intertie option identified?
- How long would it take to design and construct an intertie?
- Is there grant funding available for an intertie?
- What other benefits might an intertie offer?

Answering these questions will help confirm the best approach for increasing reliability and flexibility via an intertie with another water agency.

12.3.3.2 Identify Potential Normal/Wet Year Supply Options Available

Based on preliminary discussions with EBMUD staff, it appears that normal/wet year water cannot be wheeled to Zone 7 via EBMUD's Freeport project because EBMUD only operates the Freeport project during dry years. Additionally, subsequent discussions with EBMUD indicate that there are no normal/wet year water supplies available in the Mokelmune watershed, and due to source water constraints, EBMUD may not currently have a source of supply they can use to participate in a potential groundwater-banking program with Zone 7.

Consequently, Zone 7 staff recommends completing a study that looks into potential sources of normal/wet year water supply that can be wheeled through new interties with either EBMUD or SFPUC. The study should focus on answering the following questions:

- Is there normal/wet year water supply available?

- What is the quantity of normal/wet year supply?
- What is the water quality of possible supply sources?
- What types of exchanges and programs are required to wheel the water?

Answering these questions will help refine the limits associated with the Intertie Portfolio.

12.3.3.3 Determine the Availability of Dry Year Water Supplies and Refine Wheeling Costs

As previously shown in Section 11, wheeling dry year water supply via a new intertie with EBMUD can improve the long-term reliability of Zone 7's system. However, additional information and analysis is required to fully understand the limitations and benefits of such an arrangement; particularly, EBMUD's ability and willingness to wheel water, the cost to wheel water through EBMUD's systems, the potential yields and cost of the actual water supply, and whether short-term or long-term agreements to wheel water are even feasible. Consequently, Zone 7 staff recommends working with EBMUD to better understand these constraints and limitations over the next few years.

12.3.3.4 Continued Participation in Planning Efforts for Regional Desalination

As described in Section 9, Zone 7 is one of five partners[138] reviewing the feasibility of a new regional desalination facility. This regional facility is another potential source of water supply for Zone 7, particularly, normal/wet year water that could be used directly or to maintain existing drought and emergency storage reserves. Additionally, all five partners are working together to investigate and secure grant funding sources for this project, including Water Resources Development Act Funding that potentially pays 75 percent of project costs. Zone 7 staff recommends continuing to participate in the feasibility studies for this project, especially those studies that confirm water supply sources, refine wheeling constraints and costs, and evaluate environmental impacts and energy needs.

12.4 OBSERVATIONS AND PROPOSED NEXT STEPS REGARDING ZONE 7'S RELIABILITY POLICY

As part of this WSE, Zone 7 staff evaluated the influence costs and the mix of water supplies in each portfolio potentially have on the reliability and sustainability of Zone 7's water system. The purpose of this section is to summarize Zone 7 staff's observations regarding reliability and recommended next steps.

12.4.1 Relationship of Costs to System Reliability

Figures 7-18, 10-22, and 11-22 previously presented costs estimates for the Current Plan, In-Valley Portfolio, and Intertie Portfolio, respectively, for reliability targets ranging from 75 to 99%. Table 12-1 compares the percentage increase in costs from 75 to 99% reliabilities associated with each portfolio.

As shown in Table 12-1, the cost components of the Current Plan are less sensitive to the reliability target (i.e., only about 10%), while the supply costs for the In-Valley and Intertie Portfolios are very sensitive (i.e., 130 to 390% increase). However, Table 12-1 also shows that percentage increase in total portfolio costs from 75 to 99% reliability only varies from 10 to 20% ($36 to $72 million) – this small increase is well within the planning-level accuracy of this WSE and typical contingencies used as part of Zone 7's Capital Improvement Program.

[138] The five partners include East Bay Municipal Utility District, San Francisco Public Utilities Commission, Contra Costa Water District, Santa Clara Valley Water District, and Zone 7 Water Agency.

Table 12-1. Estimated Cost Increase from 75 to 99% Reliability Target[a]

Cost Component	Current Plan		In-Valley		Intertie	
	$, million	%	$, million	%	$, million	%
Facility Costs	20.5	7.5	(50.9)	(20)[b]	0	0
Supply Costs	15.2	10	122.6	390	49	132
Water Quality Costs[c]	--	--	--	--	--	--
Total Costs	35.7	8	71.7	22	49	14

(a) Costs are in Present Worth dollars.

(b) The percentage increase is negative because the cost of recycled water facilities were included in the supply cost and the size of potable water facilities decrease as more potable demand reduction is achieved via recycled water.

(c) The water quality costs were based on an additional phase of demineralization for all scenarios under each portfolio; however, future salt mitigation strategies – including the pros and cons of demineralization – will be evaluated as part of the GWMP Update, which will include an update of the SMP.

12.4.2 Reliability Target that Achieves Sustainability

The Intertie Portfolio needs at least 5,100 AF of normal/wet year water supply to maintain a sustainable level of drought and emergency storage. Additional analysis completed by Zone 7 staff indicated that securing such a normal/wet year water supply for the Intertie Portfolio beyond 2030 result in at least 85 to 90% reliability in the long-term. Hence, a certain level of reliability is achieved while securing sufficient water supply to maintain sustainable storage levels.

Table 12-2 compares the reliability target required under each portfolio to achieve sustainability. As shown in Table 12-2, maintaining sustainable levels of storage provides a minimum reliability of 85% for both the Current Plan and the Intertie Portfolio, while the In-Valley Portfolio appears to provide a minimum 75% reliability. The In-Valley Portfolio likely supports a lower reliability target because the supply source varies less with hydrologic conditions – potable demand reductions automatically yield more normal/wet year water that can be used to replenish storage reserves and more dry year water for use during dry conditions.

Table 12-2. Minimum Reliability Target that Achieves Sustainability

Current Plan	In-Valley Portfolio	Intertie Portfolio
85%	75%	90%

12.4.3 Potential of Demand Hardening and Implications to Reliability Target

Table 12-3 presents the estimated potable water demand reductions assumed for the Current Plan and both backup portfolios. As shown in Table 12-3, Zone 7 expects potable water demands to decrease by 8.5 to 20% over the next 10 to 20 years. Most of this decrease is associated with water use reductions achieved through assumed water conservation efforts or new recycled water programs; in either case, this reduction is likely to be permanent. This implies that water demands will become less flexible and more difficult to reduce during drought conditions (i.e., water demands associated with the constituency of the Livermore-Amador Valley will become harder).

Table 12-3. Potential Future Potable Demand Reductions Assumed in this WSE

Current Plan	In-Valley Portfolio	Intertie Portfolio
8.5%	8.5%	11 to 19%

Additionally, as previously discussed in Section 5, each reliability target evaluated is based on the maximum potential shortage, or, in this case, the maximum amount of voluntary water conservation. For example, a reliability target of 85% implies a potential voluntary reduction in water use of up to 15% during severe drought conditions. If 10 to 20% of typical water use has already been permanently eliminated, then asking for an additional 15% reduction is effectively asking for a 25 to 35% total reduction from typical water use under the most severe drought conditions.

By comparison, Zone 7 staff has estimated that the total "valley-wide" voluntary water use reduction observed during the most recent drought (2007 to 2010) and the last six-year drought (1987 to 1992) was approximately 10 and 20%,[139] respectively. Consequently, under the most severe drought conditions for example, an 85% reliability target could result in total reductions that exceed historical observations by approximately 10 to 15%.

12.4.4 Recommended Next Steps Regarding Zone 7's Existing Reliability Policy

Based on the analysis completed as part of this WSE, Zone 7 staff recommends working with the local water supply retailers to develop several proposals for changing the existing reliability policy for Zone 7's Board of Directors to consider. Zone 7 staff recommends initiating this effort shortly after completing this WSE.

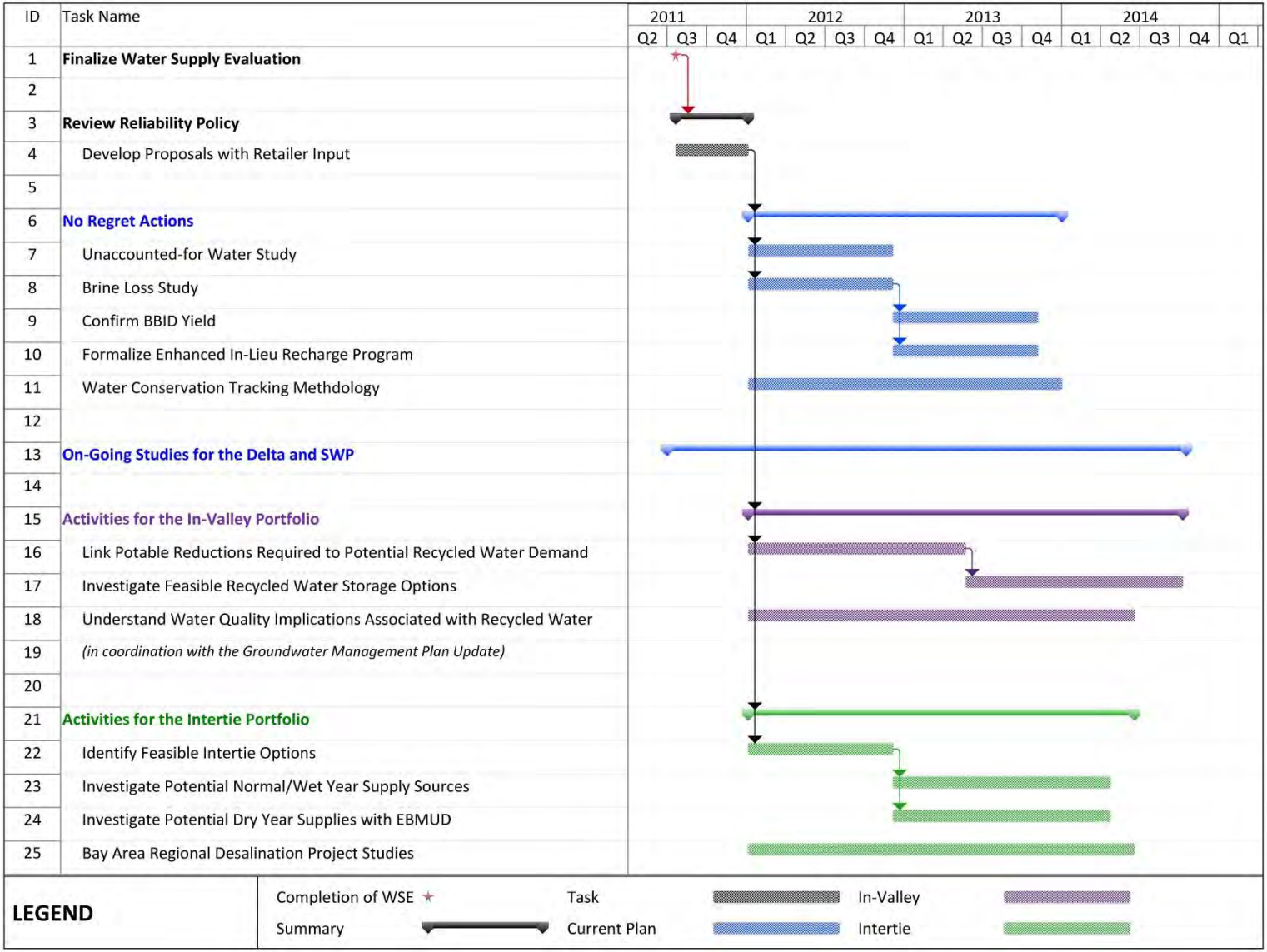
12.5 MEASURES OF SUCCESS: PRELIMINARY SCHEDULE FOR NEXT STEPS

As previously discussed above, Zone 7 staff is recommending a series of additional studies that will help refine the limits of each portfolio evaluated as part of this WSE. The ability of Zone 7 to work with the local water supply retailers to implement the no regret actions is crucial to minimizing near-term risks of water supply shortages, while completing the recommended studies over the next few years to verify key assumptions is vital to maximizing the flexibility to change directions. Both elements are critical as successfully implementing the recommended no regret actions and understanding the limits of each portfolio are necessary to ensure that Zone 7 is properly positioned pending the outcome of a solution implemented by the State of California for the Delta.

This section presents a preliminary schedule for completing near-term actions recommended in this section. Figure 12-3 presents the preliminary schedule; this preliminary schedule provides a method for measuring the success of implementing no regret actions, while also refining each water supply portfolio. As shown on Figure 12-3, Zone 7 staff recommends working with the retailers to develop proposals for changing Zone 7's existing reliability policy over the next six to seven months, and hopes to complete the major studies by late 2013 and early 2014.

[139] Valley-wide demands were obtained from Zone 7's own turnout records and additional data provided by the local water supply retailers as part of Urban Water Management Plan activities and data collected in support of this WSE. Individual water use reductions for each local water supply retailer and Zone 7's own system differed significantly.

Figure 12-3. Measures of Success: Preliminary Schedule of Next Steps



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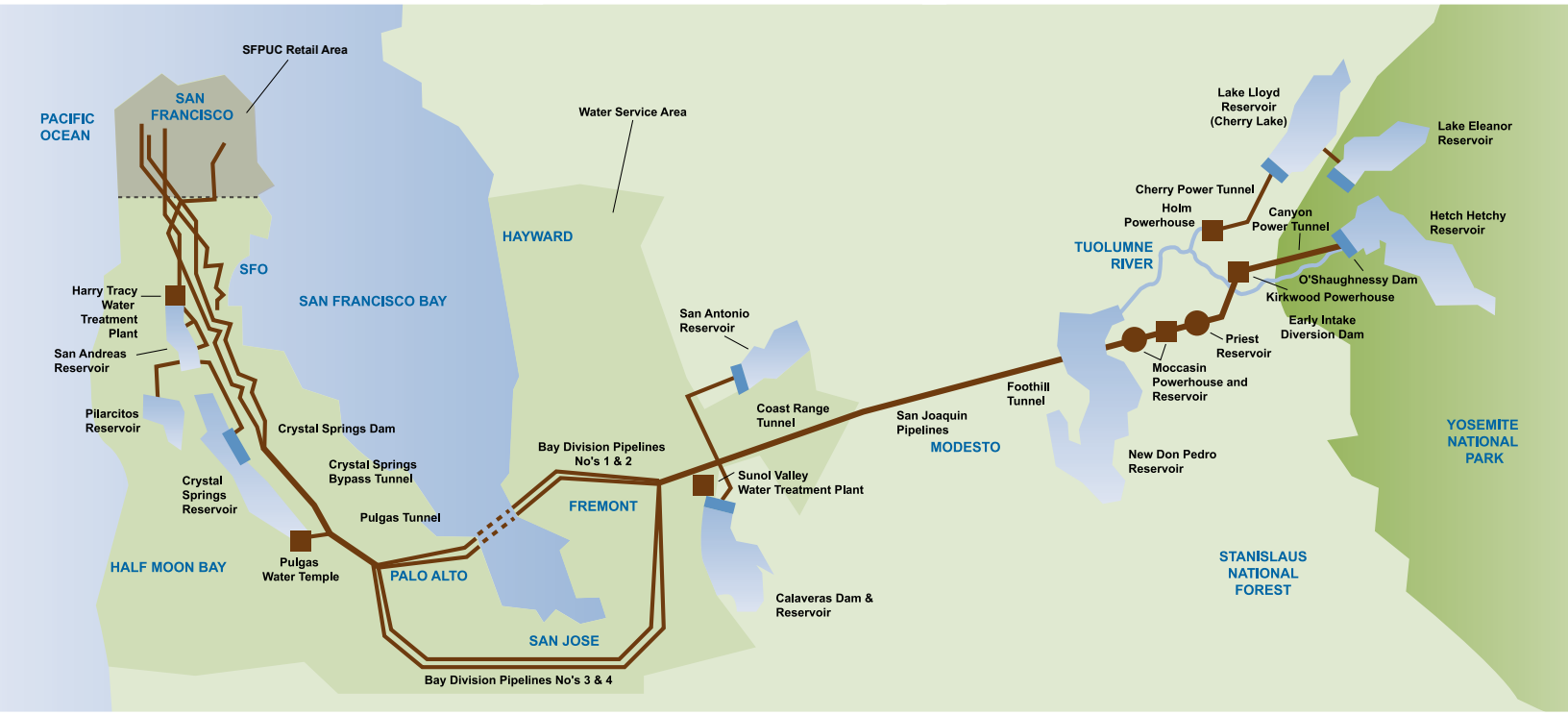
for the City and County of San Francisco

Prepared by: The San Francisco Public Utilities Commission

June 2011



San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

2010 Urban Water Management Plan

for the City and County of San Francisco

Prepared by: The San Francisco Public Utilities Commission

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CONTACT SHEET

San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

2010 Urban Water Management Plan
For the City and County of San Francisco

San Francisco Public Utilities Commission (SFPUC)

Date plan submitted to the Department of Water Resources: June 22, 2011

Name of person preparing this plan: Steven R. Ritchie, Assistant General Manager, Water

Phone: (415) 934-5736

Fax: (415) 934-5750

E-mail address: SRitchie@sfwater.org

The Water supplier is: San Francisco Public Utilities Commission

The Water supplier is a: Wholesale and retail supplier

Utility services provided by the water supplier include:
Surface Water, Groundwater, and Recycled Water

Is This Agency a Bureau of Reclamation Contractor? No

Is This Agency a State Water Project Contractor? No

ABBREVIATIONS

AB	Assembly Bill
ABAG	Association of Bay Area Governments
Act	California Urban Water Management Planning Act
ACWD	Alameda County Water District
AMI	Area Median Income
BACWA	Bay Area Clean Water Agencies
BAWSCA	Bay Area Water Supply and Conservation Agency
BDPL	Bay Division Pipeline
bg	billion gallons
BMP	Best Management Practice
CAP	Community Assistance Program
CCF	hundred cubic feet (volume of water, equivalent to 748 gallons)
CCWD	Contra Costa Water District
CEQA	California Environmental Quality Act
CII	commercial, industrial, and institutional
City	City and County of San Francisco
CUWCC	California Urban Water Conservation Council
DHS	State of California Department of Health Services
DMMs	demand management measures
DSOD	Division of Safety of Dams
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
EIR	Environmental Impact Report
EOP	Emergency Operations Plan
ERRP	Emergency Response and Recovery Plan
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FY	fiscal year
GED	gallons per employee-day
gpcd	gallons per capita per day
gpf	gallons per flush
gpm	gallons per minute
HECW	high-efficiency clothes washing
HET	high-efficiency toilet
HTWTP	Harry Tracy Water Treatment Plant

IRWMP	Bay Area Integrated Regional Water Management Plan
ISA	interim supply allocation
ISG	individual supply guarantee
IWSAP	Interim Water Shortage Allocation Plan
mgd	million gallons per day (flow or usage rate of water)
MID	Modesto Irrigation District
MOU	Memorandum of Understanding
NSMCSD	North San Mateo County Sanitation District
PEIR	Program Environmental Impact Report
PG&E	Pacific Gas and Electric Company
PUMA	Piloting Utility Modeling Applications for Climate Change
RISA	Regional Integrated Sciences and Assessment
RWMP	Recycled Water Master Plan
RWS	Regional Water System
RWSAP	Retail Water Shortage Allocation Plan
SB	Senate Bill
SCS	Sustainable Communities Strategy
SCVWD	Santa Clara Valley Water District
SFPUC	San Francisco Public Utilities Commission
SFUSD	San Francisco Unified School District
SIC	Standard Industrial Classification
SVWTP	Sunol Valley Water Treatment Plant
SWRCB	State Water Resources Control Board
TID	Turlock Irrigation District
ULFT	ultra-low-flush toilet
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet
UWMP	Urban Water Management Plan
WPCP	water pollution control plant
WSA	Water Supply Agreement between SFPUC and its Wholesale Customers
WSAP	Water Shortage Allocation Plan
WSIP	Water System Improvement Program
WSMP	Water Supply Master Plan
Zone 7	Zone 7 Water Agency
°C.	degrees Celsius

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PREFACE

Nearly 2.5 million people rely on water supplied by the San Francisco Public Utilities Commission (SFPUC) water system to meet their daily water needs. The Hetch Hetchy Regional Water System draws approximately 85% of its water from Hetch Hetchy Reservoir in the Upper Tuolumne River Watershed delivering water 167 miles by gravity through an aqueduct system to Bay Area reservoirs and customers. The remaining water supply is drawn from local surface waters in the Alameda and Peninsula watersheds.

The SFPUC has prepared this 2010 Urban Water Management Plan (UWMP) for the City and County of San Francisco in accordance with the requirements of the 1983 California Urban Water Management Planning Act (Act), California Water Code Division 6, Part 2.6, Sections 10610 through 10656, as amended. **Appendix A** contains a copy of the Act. The purpose of the Act is to assure that water suppliers plan for long-term reliability, conservation and efficient use of California's water supplies to meet existing and future demands.

The Act requires all urban water suppliers to prepare an UWMP every 5 years. The 2010 UWMPs are due to the California Department of Water Resources by July 1, 2011. As defined by Section 10617, an urban water supplier is a supplier (either publicly or privately owned) that provides water for municipal purposes to more than 3,000 customers (either directly or indirectly) or that supplies more than 3,000 acre-feet of water annually.

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SECTION 1: PLAN PREPARATION

This section summarizes the actions taken by the San Francisco Public Utilities Commission (SFPUC) to assure agency coordination and public participation throughout the development of this 2010 Urban Water Management Plan (UWMP) for the City and County of San Francisco (City).

1.1 AGENCY COORDINATION

Coordination with City Agencies: The SFPUC coordinated with City agencies in developing elements of this 2010 UWMP and the documents referenced herein. The SFPUC consulted with the San Francisco Planning Department in developing growth projections. City agencies were notified regarding the SFPUC's intent to review the 2005 UWMP and prepare an updated 2010 UWMP. These City agencies received a copy of the draft 2010 UWMP and notification of the date and time of the public hearing, and comments received from the agencies on the proposed 2010 UWMP were reviewed and addressed, as appropriate. Documentation relating to these efforts and communications is provided in **Appendix B**.

Regional Interagency Coordination: The SFPUC coordinated with the Bay Area Water Supply and Conservation Agency (BAWSCA) on the development of this 2010 UWMP. BAWSCA is a public agency representing the wholesale agencies served by the SFPUC–i.e., Wholesale Customers of the SFPUC Regional Water System (RWS). Enabled by Assembly Bill (AB) 2058, BAWSCA was established on May 27, 2003 to represent the interests of 24 cities and water districts, as well as 2 private utilities in Alameda, Santa Clara and San Mateo counties that purchase water on a wholesale basis from the RWS.

At BAWSCA's request, the SFPUC provided water supply reliability information for distribution to all BAWSCA members. In addition, the SFPUC provided water supply reliability information directly to Cordilleras Mutual Water Company.

The SFPUC also worked with BAWSCA and the Wholesale Customers to obtain purchase projections through the year 2035. These projections are presented in **Table 17**.

In addition to coordinating with BAWSCA and its member agencies, the SFPUC also communicated with other Bay Area water agencies, including East Bay Municipal Utility District (EBMUD), Santa Clara Valley Water District (SCVWD), Contra Costa Water District (CCWD), and Zone 7 Water Agency (Zone 7).

All Wholesale Customers and other Bay Area water agencies also received mailings regarding the SFPUC's intent to review the 2005 UWMP and prepare a 2010 UWMP. The agencies also received instructions to download the draft 2010 UWMP and notification of the date and time of the public hearing on the draft document. Comments received were reviewed and addressed, as appropriate. Documentation of related communications and coordination efforts is on file with the SFPUC.

1.2 PUBLIC PARTICIPATION

The SFPUC has always actively encouraged public participation in its urban water management planning efforts. For the 2010 UWMP update, the following measures were taken:

- Notification of Intent to update the UWMP was mailed on March 11, 2011 to all cities and counties within which the SFPUC provides water, as well as to other interested parties. A list is provided in **Appendix B**.

- A public hearing was held on May 24, 2011 during an SFPUC Commission Meeting. A notice of the hearing was advertised as specified in California Government Code 6066. Additional noticing was printed in local community papers on May 9, 2011 and May 16, 2011 to reach a more diverse local population. Public comment on the draft 2010 UWMP was taken at the public hearing, as well as for a period prior to and after the hearing.

- Comments on the draft UWMP were also taken at the May 16, 2011 meeting of the Citizens Advisory Committee, which was publicly noticed on the SFPUC website.

- The draft 2010 UWMP was made available for review prior to the public hearing at the San Francisco Main Public Library and the main offices of the SFPUC. A copy was also posted online at **www.sfwater.org**.

- In addition to notification of the general public (i.e., general City Retail and Wholesale Customers), other measures were taken to inform large SFPUC Retail Customers, such as the San Francisco Jail, Lawrence Livermore National Laboratory, Treasure Island, Hunters Point Shipyard, and Groveland Community Services District. These large Retail Customers received mailings regarding the SFPUC's intent to review the 2005 UWMP and prepare an updated 2010 UWMP. They also received a copy of the draft 2010 UWMP and notification of the date and time of the public hearing on the draft document.

- An adoption hearing was held on June 14, 2011 during an SFPUC Commission meeting.

Documentation of the notification and outreach actions identified above is included in **Appendix B**.

1.3 PLAN ADOPTION, SUBMITTAL AND IMPLEMENTATION

The SFPUC prepared this 2010 UWMP update and presented it to the SFPUC Commission for adoption on June 14, 2011. Please refer to **Appendix C** for a copy of the SFPUC Resolution adopting this 2010 UWMP update.

Within 30 days of SFPUC Commission approval, the adopted 2010 UWMP was submitted to the California Department of Water Resources (DWR), and a copy was provided to the California State Library and to any city or county within which the SFPUC provides water. In addition, throughout this 30-day period, the SFPUC made this adopted 2010 UWMP available for public review during normal business hours. The SFPUC will implement this adopted 2010 UWMP in accordance with the California Urban Water Management Planning Act.

Following adoption of the 2005 UWMP, the SFPUC implemented water supply planning programs, such as recycled water and groundwater, identified in the UWMP. These programs were ultimately reflected in the adopted Water System Improvement Program (WSIP), which details project implementation schedules and budgets.

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SECTION 3: SYSTEM SUPPLIES

This section summarizes current and projected SFPUC water supplies and describes the various sources of water supplies available to meet the retail and wholesale water demands. This section also summarizes the options used, or being considered, by the SFPUC to maximize resources and minimize the need to import water from the RWS watersheds.

3.1 SFPUC REGIONAL WATER SUPPLY SOURCES

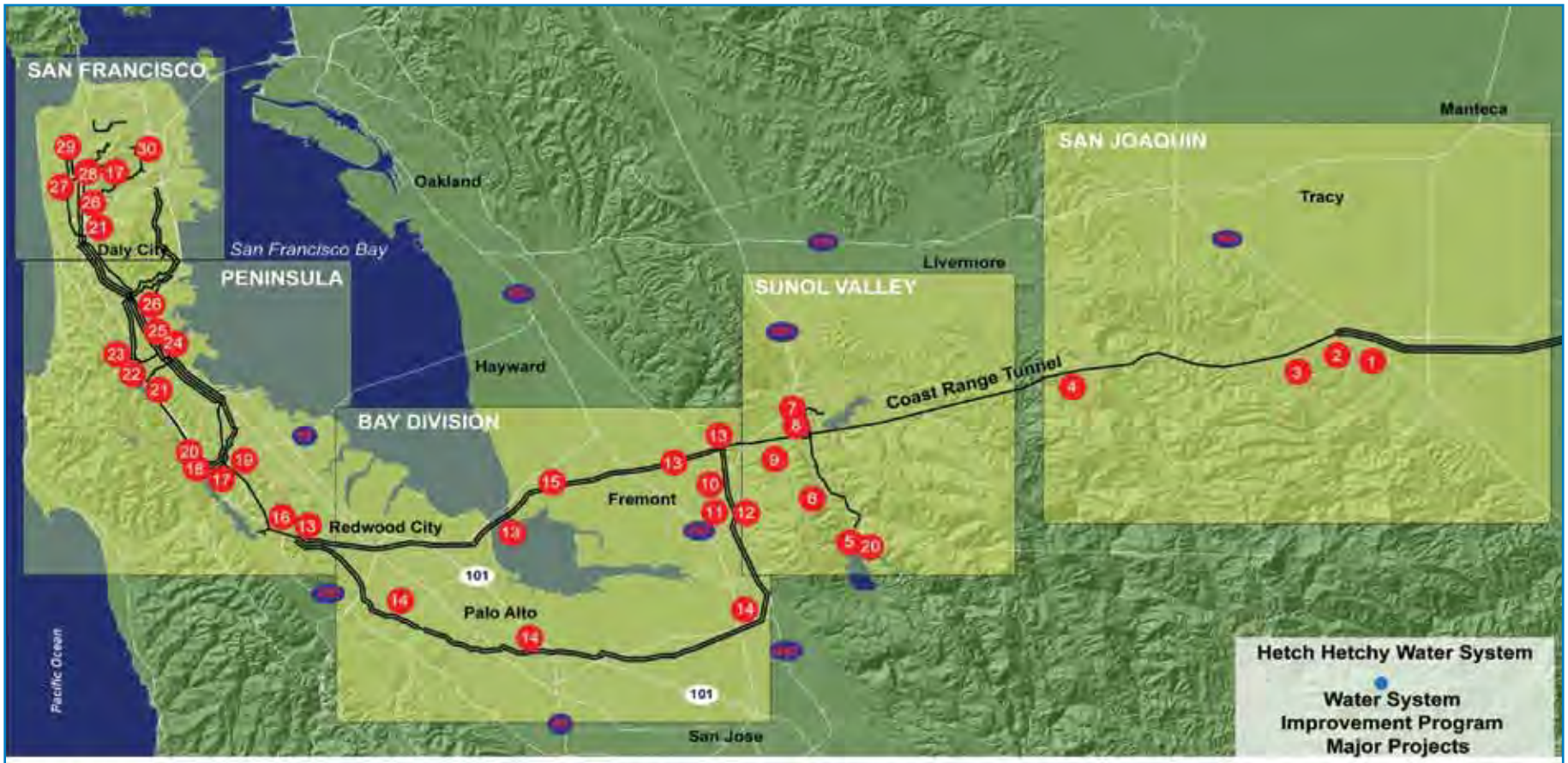
The SFPUC serves its retail and wholesale water demands with an integrated operation of local Bay Area water production and imported water from the Hetch Hetchy Project. The local watershed facilities are operated to conserve local runoff for delivery. Water demands that are not met by local runoff are met with water diverted from the Tuolumne River through the Hetch Hetchy Project. On average, the Hetch Hetchy Project provides over 85% of the water delivered by the SFPUC. During drought, the water received from the Hetch Hetchy Project can amount to over 93% of the total water delivered.

The amount of water available to the SFPUC is constrained by hydrology, physical facilities, and the institutional parameters that allocate the water supply of the Tuolumne River. Due to these constraints, the SFPUC is very dependent on reservoir storage to maximize the reliability of its water supplies. More importantly, reservoir storage provides water supply carry-over capability. During dry years, the SFPUC has a very small share of Tuolumne River runoff available and the local Bay Area watersheds produce very little water. Reservoir storage is critical during drought cycles because it enables the SFPUC to carry-over water supply from wet years to dry years.

3.1.1 SFPUC Water System Improvement Program

To enhance the ability of the SFPUC water system to meet the service goals for water quality, seismic reliability, delivery reliability, and water supply, the SFPUC is undertaking the WSIP. The WSIP is a 4.6 billion dollar, multi-year, capital program to upgrade the RWS. The program will deliver improvements that enhance the SFPUC's ability to provide reliable, affordable, high-quality drinking water to its Wholesale Customers and Retail Customers in an environmentally sustainable manner. **Figure 5** lists the WSIP projects and their locations. The goals and objectives of the WSIP are presented in **Table 6**.

Figure 5: SFPUC Water System Improvement Program (WSIP)



1. San Joaquin Pipeline System
2. Rehabilitation of Existing San Joaquin Pipelines
3. Tesla Treatment Facility
4. Lawrence Livermore Water Quality Improvement
5. Calaveras Dam Replacement
5. Calaveras Reservoir Upgrades
5. San Antonio Backup Pipeline
6. SVWTP Expansion & Treated Water Reservoir
7. Upper Alameda Creek Filter Gallery
8. Alameda Siphon #4
8. San Antonio Pump Station Upgrade
9. New Irvington Tunnel
10. BDPL No. 4 Condition Assessment PCCP Sections
11. Seismic Upgrade of BDPL Nos. 3 & 4
12. BDPL Nos. 3 & 4 Crossover/Isolation Valves
13. BDPL Reliability Upgrade - Tunnel
13. BDPL Reliability Upgrade - Pipeline
13. BDPL Reliability Upgrade - Relocation of BDPL Nos. 1 & 2
14. BDPL Nos. 3 & 4 Crossovers
15. SFPUC / EBMUD Intertie
16. Pulgas Balancing - Inlet/Outlet Work
16. Pulgas Balancing - Discharge Channel Modifications
16. Pulgas Balancing - Structural Rehabiliation & Roof Replacement
16. Pulgas Balancing - Modifications of the Existing Dechlorination Facility
17. Crystal Springs Pipeline No. 2 Replacement
18. Lower Crystal Springs Dam Improvements
19. New Crystal Springs Bypass Tunnel
20. Adit Leak Repair - Crystal Springs/Calaveras
21. Crystal Springs/San Andreas Transmission Upgrade
22. HTWTP Long-Term Improvements
23. HTWTP Short-Term Improvements - Demo Filters
23. HTWTP Short-Term Improvements - Coagulation & Flocculation/Remaining Filters
24. Capuchino Valve Lot Improvements
25. Peninsula Pipelines Seismic Upgrade
26. Baden and San Pedro Valve Lots Improvements
27. Regional Groundwater Storage and Recovery
28. San Andreas Pipeline No. 3 Installation
29. Sunset Reservoir - North Basin
30. University Mound Reservoir - North Basin

WSIP Project in Various Locations

- Standby Power Facilities - Various Locations
- Pipeline Repair & Readiness Improvements
- SCADA System - Phase II
- System Security Upgrades
- Cross Connection Controls
- Programmatic EIR
- Habitat Reserve Program
- Watershed Environment Improvement Program

Table 6: WSIP Goals and Objectives

PROGRAM GOAL	SYSTEM PERFORMANCE OBJECTIVE
Water Quality: maintain high water quality	• Design improvements to meet current and foreseeable future federal and state water quality requirements. • Provide clean, unfiltered water originating from Hetch Hetchy Reservoir and filtered water from local watersheds. • Continue to implement watershed protection measures.
Seismic Reliability: reduce vulnerability to earthquakes	• Design improvements to meet current seismic standards. • Deliver basic service to the three regions in the service area (East/South Bay, Peninsula, and San Francisco) within 24 hours after a major earthquake. Basic service is defined as average winter-month usage, and the performance objective for design of the regional system is 229 mgd. The performance objective is to provide delivery to at least 70% of the turnouts in each region, with 104, 44, and 81 mgd delivered to the East/South Bay, Peninsula, and San Francisco, respectively. • Restore facilities to meet average-day demand of up to 300 mgd within 30 days after a major earthquake.
Delivery Reliability: increase delivery reliability and improve ability to maintain the system	• Provide operational flexibility to allow planned maintenance shutdown of individual facilities without interrupting customer service. • Provide operational flexibility to minimize the risk of service interruption due to unplanned facility upsets or outages. • Provide operational flexibility and system capacity to replenish local reservoirs as needed. • Meet the estimated average annual demand of 300 mgd under the conditions of one planned shutdown of a major facility for maintenance concurrent with one unplanned facility outage due to a natural disaster, emergency, or facility failure/upset.
Water Supply: meet customer water needs in non-drought and drought periods	• Meet average annual demand of 265 mgd from the SFPUC watersheds for Retail and Wholesale Customers during non -drought years for system demands through 2018. • Meet dry-year delivery needs through 2030 while limiting rationing to a maximum 20% system-wide reduction in water service during extended droughts. • Diversify water supply options during non-drought and drought periods. • Improve use of new water sources and drought management, including groundwater, recycled water, conservation, and transfers.
Sustainability: enhance sustainability in all system activities	• Manage natural resources and physical systems to protect watershed ecosystems. • Meet, at a minimum, all current and anticipated legal requirements for protection of fish and wildlife habitat. • Manage natural resources and physical systems to protect public health and safety.
Cost-effectiveness: achieve a cost-effective, fully operational system	• Ensure cost-effective use of funds. • Maintain gravity-driven system. • Implement regular inspection and maintenance program for all facilities.

3.1.2 Phased WSIP Variant

As required under the California Environmental Quality Act (CEQA), the San Francisco Planning Department prepared a Program Environmental Impact Report (PEIR) for the WSIP. The PEIR evaluated the potential environmental impacts of the proposed WSIP projects and identified potential mitigations to those impacts. The PEIR also evaluated several alternatives to meet the SFPUC service area's projected increase in water demand between now and 2030. The water supply improvement options investigated included 10 alternatives using various water supply combinations from the local watersheds; the Tuolumne and Lower Tuolumne River; ocean desalination; and additional recycled water, groundwater, and conservation. The PEIR was certified by the San Francisco Planning Commission on October 30, 2008. On the same day, the SFPUC adopted the Phased WSIP Variant option in Resolutions No. 08-200.

At the request of the SFPUC, the San Francisco Planning Department studied the Phased WSIP Variant as part of the environmental analysis. The SFPUC identified this variant to consider a program scenario that involved full implementation of all proposed WSIP facility improvement projects to achieve public health, seismic safety, and delivery reliability goals as soon as possible, but phased implementation of a water supply program to meet projected water purchases through 2030. Deferring the 2030 water supply element of the WSIP until 2018 would allow the SFPUC and its Wholesale Customers to focus first on implementing additional local recycled water, groundwater, and demand management actions while minimizing additional diversions from the watersheds.

The Phased WSIP Variant establishes a mid-term planning milestone in 2018 when the SFPUC would reevaluate water demands through 2030 in the context of then-current information, analysis, and available water resources. The SFPUC has historically made annual average deliveries ranging from 285 mgd in 1987 to 265 mgd in 2005 from local watersheds (Peninsula and Alameda Creek) and the Tuolumne River Watershed. Annual average deliveries in 2005 provided the baseline year for the Phased WSIP. The Phased WSIP Variant would meet the projected 2018 purchase requests of 285 mgd from the RWS by capping purchases from the watersheds at 265 mgd; the remaining 20 mgd would be met through water efficiencies and conservation, water recycling and local groundwater use: 10 mgd by Wholesale Customers and 10 mgd in the City. By December 31, 2018, the SFPUC will reevaluate water system demands and supply options and conduct additional studies and environmental reviews necessary to address water supply needs after 2018. Additionally, in response to the SFPUC's adoption of the Phased WSIP Variant, the Wholesale Customers, through the BAWSCA, an agency they elected to create, began developing a Long-Term Reliable Water Supply Strategy to meet the projected water needs of its member agencies and their customers through 2035 and to increase their water supply reliability under normal and drought conditions.

The Phased WSIP Variant includes the following water supply elements:

- Water supply delivery to RWS customers through 2018 only of 265 mgd average annual target delivery originating from the watersheds. This includes 184 mgd for the Wholesale Customers and 81 mgd for Retail Customers.

- Water supply sources include 265 mgd average annual from the Tuolumne River and local watersheds and 20 mgd of water conservation[6], recycled water and local groundwater developed within the SFPUC's service area (10 mgd Retail; 10 mgd Wholesale);
- Water supply projects to meet dry-year demands with no greater than 20% system-wide rationing in any one year:
  - Restoration of Calaveras Reservoir capacity;
  - Restoration of Crystal Springs Reservoir capacity;
  - Westside Basin Groundwater Conjunctive Use;
  - Water Transfer with Modesto Irrigation District (MID)/Turlock Irrigation District (TID); and
- Reevaluation of 2030 demand projections, potential RWS purchase requests, and water supply options by December 31, 2018 and a separate SFPUC decision no later than 2018 regarding RWS future water deliveries after 2018.

3.1.3 Future Regional Supplies

In addition to the supply options discussed above, the SFPUC is exploring a range of additional options to improve water supply reliability in future years for the purposes of managing the water supply loss associated with instream flow release requirements (discussed further in Section 5). In adopting the Calaveras Dam Replacement Project and the Lower Crystal Springs Dam Improvements Project, the SFPUC committed to providing instream flow releases below Calaveras Dam and Lower Crystal Springs Dam, as well as bypass flows below Alameda Creek Diversion Dam. The instream flow release requirements for Alameda Creek and San Mateo Creek represent a potential decrease in available water supply of an average annual 3.9 mgd and 3.5 mgd, respectively, for a total of 7.4 mgd average annually[7]. These instream flow release requirements could potentially create a shortfall in meeting the SFPUC demands of 265 mgd and slightly increase the SFPUC's dry year water supply needs. If a shortfall occurs, it is anticipated at the completion of construction of both the Calaveras Dam Replacement Project and the Lower Crystal Springs Dam Improvements Project in approximately 2015 and 2013, respectively, when the SFPUC will be required to provide instream flow releases.

The SFPUC is committed to meeting its contractual obligation to its Wholesale Customers of 184 mgd and its delivery reliability goal of 265 mgd with no greater than 20% rationing in any one year of a drought.

6 Water conservation is accounted for as a demand reduction.

7 This water supply decrease assumes the adopted WSIP program element of an average annual target delivery of 265 mgd. The analysis also assumes that all of the water supply components of the adopted WSIP are implemented and all WSIP projects are implemented, including the Upper Alameda Creek Filter Gallery project, which in accordance with the Program Environmental Impact Report (PEIR) assumptions is estimated to recapture up to 6300 acre-feet (AF) per year (5.6 mgd).

The following actions are currently being considered:

- Development of additional conservation and recycling
- Development of additional groundwater supply
- Water transfer from MID and/or TID
- Increase in Tuolumne River supply
- Revising the Upper Alameda Creek Filter Gallery Project capacity
- Development of a desalination project

These other future supplies have been included with projected RWS supplies to offset the instream flow release requirements, maintaining a total of 265 mgd from the RWS watersheds through 2035.

3.1.4. Summary of RWS Supplies

As discussed above, deliveries from the RWS watersheds are limited to an average annual of 265 mgd through 2018. As a decision on future water deliveries beyond 2018 has not yet been made, the 2010 UWMP assumes that the 265 mgd supply limitation extends to 2035.

Table 7: SFPUC RWS Supplies to Retail and Wholesale Customers in Normal Years

SFPUC RWS WATERSHEDS (MGD)[1]	2010	2015	2020	2025	2030	2035
Retail Customers	81.0	81.0	81.0	81.0	81.0	81.0
Wholesale Customers	184.0	184.0	184.0	184.0	184.0	184.0
TOTAL (MGD)	**265.0**	**265.0**	**265.0**	**265.0**	**265.0**	**265.0**

1. The RWS watershed supply reflects a 7.4-mgd reduction in total regional system supplies due to instream flow release requirements beginning in 2015, offset by other future supplies to be developed.

3.2 SFPUC RETAIL WATER SUPPLY SOURCES

The RWS provides more than 97% of the City's retail water supplies. A small portion (less than 3%) of the retail water demand is met through locally produced groundwater and secondary treated recycled water.

3.2.1 Local Groundwater

San Francisco overlies all or part of seven un-adjudicated groundwater basins. These groundwater basins include the Westside, Lobos, Marina, Downtown, Islais Valley, South, and Visitation Valley basins. The Lobos, Marina, Downtown and South basins are located wholly within the City limits, while the remaining three extend south into San Mateo County. The portion of the Westside Basin aquifer located within San Francisco is referred to as the North Westside Basin. With the exception

of the Westside and Lobos basins, all of the basins are generally inadequate to supply groundwater for municipal supply due to low yield, contamination or potential subsidence concerns.

Early in its history, San Francisco made use of local groundwater, springs, and spring-fed surface water. By 1913, it was estimated that San Francisco was using approximately 8.5 mgd of groundwater from private and City wells, springs, and Lobos Creek, which is fed by springs. Prior to the completion of Calaveras Reservoir on Alameda Creek, part of the City's water supply was also from Lake Merced, which was significantly spring-fed at the time. Lake Merced was substantially lowered by diversions in the 1920s and early 1930s, the latter as a result of diverting from the lake for emergency water supply during drought conditions from 1929 to 1932.

In the 1930's, the Sunset well field was installed on the west side of San Francisco and groundwater was extracted for a short period of time, from late 1930 through mid-1935. Pumping rates were reported to be up to 6 mgd. After imports of water from the Hetch Hetchy Reservoir began in October, 1934, the municipal water supply system began to rely almost exclusively on surface water from the Alameda and Peninsula watersheds and from the Hetch Hetchy Water and Power Project.

Local groundwater use, however, has continued in the City. Since 1926, groundwater has been pumped from wells located in Golden Gate Park and the San Francisco Zoo. Based on flow meter data, about 1.5 mgd is produced by these wells. The groundwater is mostly used in the Westside Groundwater Basin by the City's Recreation and Park Department for irrigation in Golden Gate Park and at the Zoo. These wells are located in the North Westside Groundwater Basin. DWR has not identified this basin as overdrafted, or as projected to be overdrafted in the future. There is currently no adopted groundwater management plan for the SFPUC's groundwater basins.

About 0.7 mgd of groundwater is delivered to the Castlewood community in Pleasanton from a well field operated by the SFPUC. This groundwater is drawn from the Central Groundwater Sub Basin in the Livermore/Amador Valley. DWR has not identified this basin as over-drafted, nor as projected to be over-drafted in the future. These wells are metered and have been in operation for several decades. The system serving Castlewood is not connected to the RWS.

3.2.2 Local Recycled Water

The following summarizes the quantity and quality of wastewater generated and disposed of in the retail system, and the past and current use of recycled water.

Wastewater Generation, Collection, Treatment, and Disposal: San Francisco's wastewater collection, treatment, and disposal system consists of a combined sewer system (which collects both sewage and storm water), three water pollution control plants (WPCPs) and outfalls to San Francisco Bay and the Pacific Ocean. The collection and conveyance system consists of approximately 900 miles of various sizes of underground sewer pipes, transport/storage structures, and pump stations located throughout the City. Two of the City's water pollution control plants, the Southeast WPCP and Oceanside WPCP, provide secondary treatment and operate

year-round, while the third plant, the North Point WPCP, operates only during wet weather and provides primary treatment. Ultimate disposal of treated wastewater effluent is currently through outfalls to both San Francisco Bay and the Pacific Ocean. **Table 8** and **Table 9** summarize the actual and projected volumes of San Francisco wastewater collected, treated and discharged to the Bay and Ocean.

Table 8: Wastewater Collection and Treatment

WASTEWATER	2005	2010	2015	2020	2025	2030	2035
Collected & treated (mgd)	106.9	96.0	98.1	96.3	95.8	96.7	98.2
Volume that will meet recycled water standard (mgd)	0	0	2	4	4	4	4

Table 9: Disposal of Wastewater (non-recycled)

DISPOSAL & TREATMENT METHOD	2010	2015	2020	2025	2030	2035
Secondary Effluent to Deep Water Outfalls (mgd)	80.3	82.5	80.6	80.1	81.0	82.6
Secondary Effluent to Islais Creek (mgd)	5.7	5.7	5.7	5.7	5.7	5.7
Primary Effluent to Deep Water Outfalls (mgd)	9.9	9.9	9.9	9.9	9.9	9.9
TOTAL (MGD):	**96.0**	**98.1**	**96.3**	**95.8**	**96.7**	**98.2**

Past and Current Recycled Water Use: From 1932 to 1981, the City's McQueen Treatment Plant, using an activated sludge process, provided recycled water to Golden Gate Park for irrigation and flow augmentation of its streams and lakes. Due to changes in State regulations, the plant could no longer meet standards, and the City closed the McQueen plant and discontinued use of recycled water in Golden Gate Park.

In 1991, the San Francisco Board of Supervisors passed Ordinances 390-91 and 391-91 that outline specific components to be addressed in a Recycled Water Master Plan (RWMP), designate recycled water use areas within San Francisco, and require the installation of dual-plumbing systems for recycled water use within the designed recycled water use areas for the following situations:

- New or remodeled buildings and all subdivisions with a total area of 40,000 square feet or more
- New and existing irrigated areas of 10,000 square feet or more

The SFPUC first developed a RWMP that outlined a phased water recycling project for San Francisco in 1996. However, the Plan was not implemented due to limited funding. An updated RWMP was subsequently completed in 2006. The 2006 RWMP identifies recycled water project alternatives and a plan for implementation of recycled water projects in the City. These projects will help the City meet its long-term water demands with a local resource in a more reliable and sustainable manner.

Currently, recycled water use in San Francisco is limited, but the SFPUC is moving forward with expanding the use within the City. Disinfected secondary-treated recycled water from the SFPUC's Southeast WPCP is used on a limited basis for wash-down operations, and is provided to construction contractors for soil compaction and dust control and other nonessential construction purposes. Current use of recycled water for these purposes does not materially contribute to reducing the retail demands.

3.3 FUTURE RETAIL WATER SUPPLY SOURCES

To reliably and sustainably meet the future water needs of its Retail Customers, the SFPUC is diversifying its water supply portfolio through the development of local water supplies such as increasing recycled water and groundwater production. Projects related to these efforts are described below.

3.3.1 San Francisco Groundwater Supply Project

The San Francisco Groundwater Supply Project proposes the construction of up to six wells and associated facilities in the western part of San Francisco to extract up to 4 mgd of groundwater from the northern Westside Basin for distribution in the City. The extracted groundwater, which would be used both for regular and emergency water supply purposes, would be disinfected and blended with imported surface water before entering the municipal drinking water system. The environmental review for this project began in December 2009. Construction is expected to be complete by 2015.

3.3.2 Recycled Water Supply Projects

Recycled water projects being developed in San Francisco (retail service area) are the Harding Park, Pacifica, and proposed Westside and Eastside Recycled Water Projects. These projects would provide up to 4 mgd of recycled water to a variety of users in San Francisco – primarily for landscape irrigation, toilet flushing, and industrial purposes – and are detailed below.

- The Harding Park Recycled Water Project would use available recycled water from the North San Mateo County Sanitation District (NSMCSD) located in Daly City, to irrigate Harding Park and Fleming Park golf courses in San Francisco. The SFPUC has partnered with the NSMCSD for this proposed project. The Harding Park Project has completed environmental review and design. Construction has begun and will be completed in June 2012.

- The Pacifica Recycled Water Project will provide recycled water to irrigate the Sharp Park Golf Course in Pacifica (which is owned by the City) and other nearby areas. When completed, the project will save approximately 40 million gallons of drinking water each year. SFPUC has partnered with the North Coast County Water District on this project. Construction has begun and will be completed by December 2011.

- The proposed Westside Project would construct a tertiary recycled water plant and associated pipelines to replace surface and groundwater currently used to irrigate Golden Gate Park, Lincoln Park and Golf Course, and the Presidio Golf Course. Additionally recycled water would be used for various non-potable uses in Golden Gate Park, including those at the California Academy of Sciences. The environmental review process was initiated with the release of the Notice of Preparation in September 2010.

- Currently, the SFPUC is conducting a recycled water demand assessment of potential users and uses in the Eastside of San Francisco. The assessment is examining the potential uses of recycled water for irrigation, toilet flushing, and various commercial and industrial applications. The WSIP contains funding for planning, design, and environmental review for the proposed Eastside Recycled Water Project.

In addition, the planned Candlestick Point-Hunters Point Shipyard Phase II, Treasure Island-Yerba Buena Island, and Parkmerced development projects may include the development of recycled water to help offset potable demand. These new projects could produce up to 1.5 mgd of recycled water. This represents additional recycled water supply and has not been included as part of SFPUC's local supplies. In the event that recycled water is produced at the project sites, recycled water could offset as much as 1.5 mgd in total San Francisco retail potable water demand.

Regional Recycled Water Planning Efforts: The SFPUC is working with local agencies to develop recycled water projects that will benefit the SFPUC and local partners by reducing demands for SFPUC regional system water, and/or freeing up groundwater that could be used for potable supplies. In addition, these projects would reduce wastewater discharges into San Francisco Bay and the Pacific Ocean.

- The SFPUC, the Cities of South San Francisco and San Bruno, and California Water Service Company (Bayshore District) are jointly pursuing a project to produce and distribute recycled water in the South San Francisco and San Bruno areas. Recycled water for the project will be produced at the South San Francisco/San Bruno Water Quality Control Plant jointly operated by the Cities of South San Francisco and San Bruno.

- The SFPUC is also exploring opportunities to partner with Daly City on a recycled water expansion project and with Redwood City to provide recycled water to the Menlo Country Club.

Additional regional recycled water partnership opportunities with other Bay Area agencies will be evaluated as opportunities arise.

The SFPUC is a member of the Bay Area Clean Water Agencies (BACWA) Recycled Water Committee. BACWA is composed of Bay Area wastewater agencies that discharge into the San Francisco Bay estuary. The purpose of the Recycled Water Committee is to further regional water recycling efforts from a wastewater agency perspective. The SFPUC is currently serving as the Chair of this committee.

The City is also an active member of the International, California Section, and Northern California

Chapter of the WateReuse Association. The international organization is dedicated to increasing the amount of recycled water produced and used in a beneficial and efficient manner in the United States and abroad. The California Section focuses on promoting this mission in California.

3.3.3 Proposed Actions to Encourage Use of Recycled Water

To encourage the use of recycled water in San Francisco, the City adopted Ordinances 390-91 and 391-91[8]. As mentioned previously, these ordinances require the installation of dual-plumbing systems within a specific geographic area for the following situations:

- New or remodeled buildings and all subdivisions with a total of 40,000 square feet or greater, for uses such as irrigation, toilet flushing, and industrial processes
- New and existing landscaped areas of 10,000 square feet or larger, for irrigation

The City also passed Ordinance 175-91[9], which requires the use of non-potable water for soil compaction and dust control for construction and demolition projects.

The SFPUC also initiated a Large Landscape Grant Program in 2009. Retail Customers in San Francisco with 2.5 acres or more of irrigated landscapes are eligible to apply. Grant funding is available for water-saving and recycled water retrofits that reduce potable water use for landscape irrigation.

3.3.4 Recycled Water Optimization Plan

As mentioned in the above section, the San Francisco Board of Supervisors passed Ordinances 390-91 and 391-91, which require the installation of dual-plumbing systems in buildings and subdivisions and landscaped areas within a specific geographic area. In addition, Ordinance 175-91 was also passed requiring the use of non-potable water for soil compaction and dust control for construction and demolition projects.

Also, as discussed previously in Section 3.2.2, the 2006 RWMP identifies recycled water project alternatives and a plan for implementation of recycled water projects in the City. The SFPUC is working with retail customers located outside San Francisco to develop recycled water projects that will benefit the SFPUC and local partners by reducing demands for SFPUC Regional System water, and/or freeing up groundwater that could be used for potable supplies. In addition, these projects would reduce wastewater discharges into San Francisco Bay and the Pacific Ocean. Examples of these projects are described below.

Table 10 summarizes the current and projected uses of recycled water in San Francisco, assuming the proposed projects described above are developed.

8 San Francisco Public Works Code, Article 22, Sections 1200-1210. Note that this Ordinance was amended in 1994 by Ordinance 393-94, which expanded the designated recycled water use area to include Treasure Island, Yerba Buena Island, and Hunters Point Shipyard4. .

9 San Francisco Public Works Code, Article 21, Sections 1100-1107.

Table 10: Recycled Water Uses - Current and Projected

USE TYPE[1]	2005[2]	2010[2]	2015	2020	2025	2030	2035
Irrigation (mgd) [3]	0	0	0.3	2.68	2.68	2.68	2.68
Lake Fill (mgd) [4]	0	0	0	0.4	0.4	0.4	0.4
Com/Ind (mgd) [5]	0	0	0	1.0	1.0	1.0	1.0
TOTAL (MGD)	**0**	**0**	**0.30**	**4.08**	**4.08**	**4.08**	**4.08**

1. Indirect potable reuse has been evaluated and determined to be economically infeasible at this time.
2. 2005 and 2010 reflect actual values.
3. Includes landscape irrigation. Demand for agricultural irrigation for the SFPUC's retail service area is negligible, and therefore economically infeasible.
4. Includes wildlife habitat enhancement, wetland recharge, and groundwater recharge.
5. Com / Ind = Commercial / Industrial.

3.3.5 Summary of Current and Future Retail Water Supplies

Table 11 provides a breakdown of current and projected water supply sources for meeting SFPUC retail water demand over the next 25 years.

Table 11: SFPUC Retail Water Supplies 2010 – 2035 (Normal Year)

CURRENT AND FUTURE WATER SUPPLY SOURCES	2010	2015	2020	2025	2030	2035
RWS Watersheds – Retail Supply [1]	**81**	**81**	**81[1]**	**81[1]**	**81[1]**	**81[1]**
Groundwater Sources [2]						
In-City Irrigation Purposes	1.5	1.5	0.3	0.3	0.3	0.3
Groundwater at Castlewood and Sunol	0.7	0.7	0.7	0.7	0.7	0.7
Treated for Potable (previously used for in-City irrigation purposes)	0.0	0.0	1.2	1.2	1.2	1.2
Groundwater Subtotal	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**	**2.2**
Future Water Supply Sources						
Groundwater: Potable from North Westside Groundwater Basin	0.0	2.8	2.8	2.8	2.8	2.8
Recycled Water	0.0	0.3	4.0	4.0	4.0	4.0
Future Supply Subtotal	**0.0**	**3.1**	**6.8**	**6.8**	**6.8**	**6.8**
TOTAL SUPPLY	**83.2**	**86.3**	**90.0**	**90.0**	**90.0**	**90.0**

1. Assumes 2018 supply limitation extends to 2035.
2. Groundwater currently serves irrigation to Golden Gate Park, the San Francisco Zoo, and the Great Highway median. A groundwater reserve of 0.3 mgd for irrigation purposes will remain as part of the SFPUC's non-potable groundwater supply (SFPUC 2008 Phased WSIP Variant). Castlewood and Sunol projected supplies remain unchanged over the 20-year planning horizon.

3.4 WATER QUALITY

As discussed previously, the SFPUC's retail demand is primarily met with water from the RWS watersheds, with a small portion (less than 3%) from local groundwater supplies and recycled water. Each of these sources delivers high-quality water relative to its intended use. Supplies from the RWS are of extremely high quality, used for both potable and non-potable uses. Existing groundwater and recycled water supplies are currently used for non-potable applications.

It has been assumed in this UWMP that these existing supplies will be available in the future. The SFPUC does not anticipate that future, water quality issues will alter the SFPUC's current water management strategies or supply reliability. This section provides information on the water quality of the SFPUC's existing retail water supplies.

3.4.1 Quality of Regional Water System Supplies

The SFPUC RWS watersheds deliver high-quality water. The current surface water supplies available to the RWS include the Tuolumne River and supplies from local Bay Area reservoirs. The majority of the water supply originates in the upper Tuolumne River watershed high in the Sierra Nevada, remote from human development and pollution. This pristine water, referred to as Hetch Hetchy water, is protected in pipes and tunnels as it is conveyed to the Bay Area, requiring only primary disinfection and pH adjustment to control corrosion in the pipelines.

The USEPA and the DHS have approved the use of this drinking water source without requiring filtration at a treatment plant. However, local water from the Alameda and Peninsula Watersheds requires filtration to meet drinking water quality requirements. The filtered and treated water from the local watersheds is blended with Hetch Hetchy water, and most customers receive water from a blended source. System water quality, including both raw water and treated water, is continuously monitored and tested to assure that water delivered to customers meets or exceeds federal and State drinking water/public health requirements.

The SFPUC will continue to rely on these high-quality water sources. No degradation of water quality is anticipated in the future.

3.4.2 Quality of Local Water Supplies

Quality of local groundwater and recycled water supplies is discussed in the following paragraphs.

Groundwater Supplies: Based on semi-annual monitoring, the groundwater currently used for irrigation and other non-potable uses in San Francisco meets or exceeds the quality needed for these end uses.

Plans for development of additional groundwater in San Francisco include plans for potable supply in the North Westside Groundwater Basin. As part of this effort, the groundwater quality at new

proposed well sites is being sampled for all drinking water parameters. The groundwater would be disinfected and blended with imported surface water before entering the municipal drinking water system. Based on information collected to date, the water quality of this blended water would meet drinking water standards.

Recycled Water Supplies: Recycled water in San Francisco is currently being used on a limited basis for in-plant wash-down purposes. This recycled water undergoes secondary treatment at SFPUC's Southeast Water Pollution Control Plant and meets the Title 22 California Code of Regulation requirements for recycled water use for non-potable uses.

Recycled water projects being developed in San Francisco (retail service area) are the Harding Park, Pacifica, and proposed Westside and Eastside recycled water projects. These projects would provide up to 4 mgd of recycled water to a variety of users in San Francisco primarily for landscape irrigation and toilet flushing. This recycled water will undergo tertiary treatment, which will result in water quality sufficient to meet the needs and requirements associated with each end use.

This section focuses on the projection of the SFPUC's water demands. Retail demands are based on recent demographic information and a detailed analysis of the SFPUC's retail water use characteristics. Wholesale Customer demands for SFPUC supplies are based on projections developed by Wholesale Customers. This section also presents the baseline and target per capita water consumption rate, as required by SB X7-7.

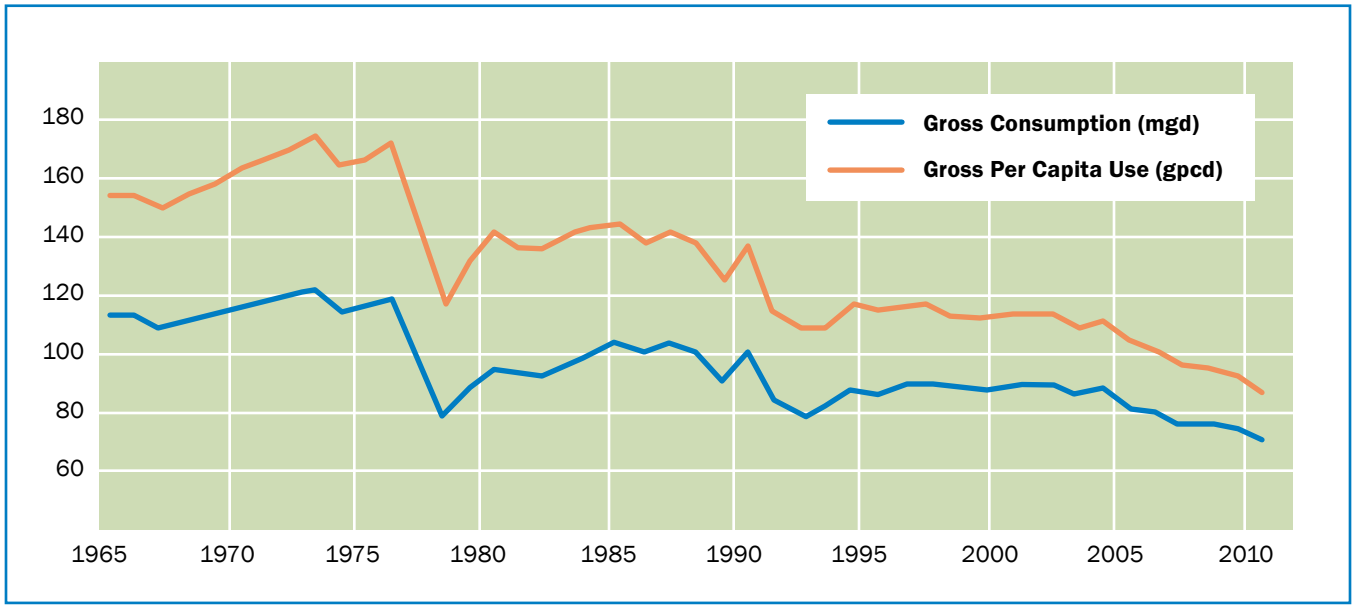
4.1 RETAIL WATER DEMANDS

Water use within San Francisco is currently below historic consumption. Both the total consumption and the per capita use of water have been on a general decline in San Francisco since the mid-1970s. Many factors have contributed to this reduction in water use, including significant changes to the mix of industrial and commercial businesses and their associated water demand, and the general characteristics of water use by San Francisco water customers. In particular, the severe droughts of 1976-77 and 1987-92, changes in plumbing codes, and conservation programs (either voluntarily embraced by residents and businesses or mandated by San Francisco), have apparently affected water demands.

Figure 6 shows the historical record of retail water deliveries by San Francisco for the 1965 through 2010 period in terms of both total deliveries and gross per capita consumption (gallons per capita per day, or gpcd).

While the gross per capita consumption is not a true measure of the water used by an individual (since it includes water use by all categories of customers, e.g., industrial, commercial and losses), it does provide insight when comparing water use among regions. The current per capita consumption rate by San Francisco in-City water customers is 85.6 gpcd, one of the lowest in the state.

Figure 6: Historical San Francisco Water Consumption



4.1.1 Current Retail Demand

All of the SFPUC's Retail Customers have been metered since 1916. In 2010, total SFPUC retail water use was 77.7 mgd. Of this demand, in-City Retail Customers used approximately 71 million gallons per day (mgd)[10]. Water use by suburban Retail Customers totaled approximately 4.1 mgd, and groundwater irrigation use was approximately 2.2 mgd.

Water use in 2010 was lower than expected. This decreased demand can be attributed to three main reasons. First, the very wet spring and cool summer California experienced in 2010 depressed urban water demand across the state. Second, 2008 and 2009 were both dry and the SFPUC asked its customers to reduce their water consumption by 10%. While rainfall returned to normal or above normal in 2010, the reductions in water use have continued. Third, the sharp economic decline which started in 2008 pushed down commercial and industrial demands. When preparing the 2005 UWMP, the number of jobs in 2010 was projected to be 692,420. According to the 2010 estimates from the California Employment Development Department, the number of jobs in 2010 was closer to 545,000.

Residential Water Use: Single-family units comprise approximately 32% of the total households in San Francisco, and use approximately 40% of the total water delivered to the residential sector. The remainder of residential water (60%) is used by multi-family units such as apartments.

Combined, the single-family and multi-family residential sectors have a current per capita consumption rate of approximately 50 gpcd. Due to San Francisco's moderate climate and high density housing, residential water use is used almost entirely indoors. For multi-family units, the average outdoor water use is considered negligible. Outdoor water use makes up less than 10% of single-family residential uses, on average.

Non-residential Water Use: Non-residential water use accounts for approximately 30% of San Francisco's retail water demands. This includes all sectors of water users not designated as residential, such as manufacturing, transportation, trade, finance, and government employment sectors, and the large services sector.

Unaccounted for Water Loss: Unaccounted for Water Loss represents both unbilled authorized consumption (including metered high pressure fire fighting consumption, unmetered main flushing, street cleaning and dust control and low pressure fire hydrant use) and unbilled unauthorized consumption (including water lost to the system through all types of leaks, breaks and overflows). These losses are assumed to be approximately 6.9% of total in-City demand. Meter under-registration is also considered unbilled unauthorized consumption and is captured in the demand calculations for each billing sector. It is assumed that meter under-registration is 2.2% of residential demand and 2.1% of non-residential demand. Total loss in the City due to meter under-registration, unbilled authorized consumption and unbilled unauthorized consumption is approximately 9% of in-City demand.

10 This only refers to in-City retail demand, not total retail demand (which includes Retail Customers outside of the city and county boundary, such as Lawrence Livermore National Laboratory), and this does not include groundwater.

4.1.2 Projected Retail Water Demands

Projected water use for the SFPUC's in-City Retail Customers was estimated using the City's Retail Water Use Models. The models were first developed in 2004 and updated in 2010. These models have incorporated economic and demographic forecast data, including projections of population, housing stock and employment. These forecast data were based on the ABAG reports *Projections 2002, Projections 2009*, and *Draft Projections 2011* (developed as part of the Bay Area's Sustainable Communities Strategy). These reports summarize demographic projections for the City at 5-year intervals as well as California Department of Finance estimates and projections 10-year intervals. These projections were reviewed and refined by the San Francisco Planning Department using up-to-date planning information for the City.

Results of the water demand forecasts show that SFPUC's in-City retail water demand will only slightly increase (**Table 12**), even though the household population in San Francisco is expected to increase by nearly 12% for the same period (year 2010 through year 2035). The projected increase in in-City retail water demands is due to estimated growth in business and industry, which will translate into a commensurate increase in water use. The expected increase in water use in the non-residential sector, however, is expected to be partially balanced by decreases in water use in the residential sector.

The decreased water use forecast for the residential sectors is attributed primarily to market penetration of current plumbing codes within the residential sectors. Market penetration will increase as time progresses, resulting in an increase in water savings due to the installation of more water-efficient fixtures.

A decrease in water use can also be expected, in both the residential and non-residential sectors, as a result of water conservation programs. The SFPUC has increased its water conservation programs in an effort to achieve new water savings by 2018. The SFPUC's conservation program is based on the SFPUC Retail Demand Model Update and Calibration Technical Memorandum (The Demand Study) (**Appendix D**), which identified water savings and implementation costs associated with a number of water conservation and efficiency measures. The Demand Study evaluated the costs and benefits of implementing various conservation measures using an end-use model. These estimates include new conservation programs such as high-efficiency toilet replacement in low-income communities and water-efficient irrigation systems for large irrigators (e.g., municipal parks and commercial landscaping). Through its conservation program, the SFPUC anticipates reducing gross per capita consumption to 82 gpcd by 2020 for an average daily savings of approximately 6 mgd.[11] Demand reduction due to local conservation is accounted for in the demand projection shown in **Table 12**.

11 Per capita estimates were calculated based on household population. SBX7-7 per capita estimates contained in Section 4.1.5 were calculated based on the total population data obtained from the Department of Finance.

Table 12: San Francisco Retail Water Demands

WATER USE ENTITY	2005[1] (mgd)	2010[1] (mgd)	2015 (mgd)	2020 (mgd)	2025 (mgd)	2030 (mgd)	2035 (mgd)
IN-CITY CUSTOMERS							
Single-Family Residential [2]	18.4	16.4	17.9	17.1	16.5	16.0	15.8
Multi-Family Residential [2]	27.7	25.1	28.9	28.4	28.2	28.3	28.6
Non Residential[2]	24.8	23.5	25.6	26.5	27.5	28.7	29.9
Other In-City Demands [2,3]	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Losses[4]	8.2	6.3	5.0	4.9	5.0	5.0	5.1
In-City Subtotal [5]	**79.3**	**71.4**	**77.7**	**77.1**	**77.3**	**78.2**	**79.7**
In-City Subtotal w/Conservation[6]	**79.3**	**71.4**	**73.6**	**71.7**	**71.2**	**72.1**	**73.7**
SUBURBAN RETAIL CUSTOMERS [7]							
Other Retail Customers [8]	4.4	3.0	3.8	3.8	3.8	3.8	3.8
Lawrence Livermore Lab	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Groveland CSD	0.4	0.7	0.8	0.8	0.8	0.8	0.8
Suburban Retail Subtotal	**5.2**	**4.1**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**
GROUNDWATER CUSTOMERS							
City Irrigation Uses [9]	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Castlewood & Sunol Golf Course [10]	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Groundwater Subtotal	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Total Retail Demand [11]	**86.7**	**77.7**	**80.7**	**78.9**	**78.5**	**79.2**	**80.9**

1. 2005 and 2010 data are based on actual billing data (SFPUC, 2010). 2015-2035 are projections from the SFPUC Retail Demand Model Update and Calibration Technical Memorandum (April 2011).
2. Water demands reflect the adjusted demand, taking into consideration the potential savings due to plumbing codes.
3. Builders and Contractors, Docks & Shipping
4. Losses reported for 2005 and 2010 include meter under-registration. Losses in 2015 – 2035 exclude meter under-registration because they are included in the retail demand projections for residential and non-residential sectors. Meter under-registration losses estimated at 2.2% of residential and 2.1% of non-residential sector demands. System losses excluding meter under-registration estimated at 6.86% of sector demand.
5. "In-City subtotal" refers to demand that includes code-driven savings from changes in state and federal plumbing codes and regulations.
6. "In-City Subtotal with Conservation" refers to demand that includes code-driven savings plus savings from SFPUC-initiated conservation programs.
7. Suburban retail customer future demands do not include active conservation savings. The SFPUC plans on working with the suburban Retail Customers on conservation activities, but has not yet quantified the savings. Accordingly, demands are kept constant through 2035, but will be adjusted as more information becomes available.
8. The San Francisco County Jail, San Francisco International Airport, and other suburban or municipal accounts.
9. Irrigation at Golden Gate Park, the Great Highway median, and the San Francisco Zoo.
10. 100% of Castlewood demand (0.4 mgd) is met by groundwater wells in Pleasanton and 75% of Sunol Golf course demand (0.3 mgd) met by subsurface diversions of surface water at the Sunol Filter Galleries. Projected demands are based on average use from 2000-2010 and remain unchanged over the 25 year planning horizon.
11. This refers to the sum of "in-City subtotal with conservation", suburban retail subtotal, and groundwater subtotal.

4.1.3 Non-residential Water Demands

Average employee-use rates, gallons per employee-day (GED), have been estimated for the various employment categories in the development of the end-use study. These values range from approximately 18 GED for the government category to approximately 94 GED for the agriculture and mining category.

Table 13 provides a breakdown by industry type of the SFPUC's projected water demands for the retail non-residential sector for 2005 through 2035 in 5-year increments.

Table 13: SFPUC Projected Retail Non-Residential Water Demands

INDUSTRY[1]	2005 (mgd)	2010 (mgd)	2015 (mgd)	2020 (mgd)	2025 (mgd)	2030 (mgd)	2035 (mgd)
Ag. & Mining	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Manufacturing	2.0	2.1	2.1	2.4	2.5	2.7	2.8
Transportation	0.7	0.6	0.6	0.6	0.6	0.6	0.7
Information	1.5	1.5	1.5	1.6	1.7	1.8	1.9
Retail Trade	2.5	2.4	2.4	2.5	2.9	3.0	3.2
F.I.R.E.[2]	1.5	1.5	1.4	1.5	1.6	1.7	1.8
Services	15.7	15.4	16.9	17.8	18.5	19.5	20.5
Government	0.5	0.4	0.4	0.5	0.5	0.5	0.5
Total without Conservation [3]	**25.0**	**24.6**	**26.1**	**27.5**	**29.0**	**30.5**	**32.1**
Total with Conservation	**24.8**	**23.5**	**25.6**	**26.5**	**27.5**	**28.7**	**29.9**

1. Projections from the SFPUC Retail Demand Model Update and Calibration Technical Memorandum.
2. FIRE = finance, insurance, and real estate.
3. Totals calculated using gallon-per-day equivalents (GED) and employment estimates and projections and do not include passive or active conservation savings.

4.1.4 Water Demands of Lower Income Households

The future water use of planned lower income housing (less than 80% of the AMI) is estimated by multiplying the planned future housing units for lower income residents by the average number of persons per household and the estimated per capita water use.

As described in Section II.A of the 2009 San Francisco Housing Element (page 1.41), ABAG, in coordination with the California State Department of Housing and Community Development (HCD), determine the Bay Area's regional housing need based on regional trends, projected job growth and existing needs. San Francisco's fair share of the regional housing need for January 2007 through June 2014 was calculated as 31,190 units, or about 4,160 units per year total. This estimate includes units for all adjusted median income (AMI) categories: extremely low (less than 30% of AMI), very low (31% - 50% of AMI), low (51% - 80% of AMI), moderate (81% - 120% of AMI), and above moderate (greater than 120% of AMI) categories. Planned housing units for the extremely low, very low, and low categories total 3,294, 3,295, and 5,535, respectively, for a total number of planned lower housing units of 12,124 units between 2007 and 2014. Assuming a consistent number of units are build per year, approximately 1,617 units will be built per year between 2007 and June of 2014. It is assumed that approximately 4,851 of the planned 12,124 units were built between 2007 and 2010, leaving 7,273 additional units to be constructed in between January of 2011 and June of 2014.

As described in the SFPUC Retail Demand Model Update and Calibration Technical Memorandum (**Appendix D**), the average persons per household in single-family and multi-family households are estimated to be approximately 3.1 and 2.0, respectively, by 2015. Because the distribution of single-family versus multi-family planned housing units is currently unknown, it is assumed that the planned units will house approximately 2.55 persons per household, the average of the projected values for single- and multi-family households. As a result, it is estimated that approximately 18,546 residents will occupy planned lower income housing units by June of 2014.

As described in Section 4.2, per capita water use in the SFPUC's retail water service area is currently approximately 85.6 gpcd. Water use in planned lower income housing units is therefore estimated to be approximately 1.6 mgd (18,546 people x 85.6 gpcd) by June of 2014.

This estimated future lower income water demand is included in the retail water demand projections presented in **Table 12**, which include all demands of existing and planned lower-income housing. The SFPUC has always included lower income households as part of the overall city demand in its planning efforts, and all demands presented in Section 4 include lower income demands. Updates to the Urban Water Management Planning Act require that entities separately calculate the water demands for lower income households in this UWMP, and this estimate reflects the SFPUC's best effort to do so. Please note that the SFPUC does not use this number for any planning purposes.

4.1.5 Methodology Used to Project Retail Water Demands

The SFPUC uses disaggregated end-use models to project its retail water demands. San Francisco's water demand is segregated into three distinct categories of water use: non-residential (industrial, commercial and municipal uses); multi-family residential (e.g. townhouses and apartments); and single-family residential. The remainder of San Francisco's water demands such as unaccounted for water and minor uses such as docks and shipping are forecast through trend analysis.

Future non-residential water use is projected using relationships between employment within San Francisco and employee use of water. These coefficients are segregated by type of business or service enterprise, which is based on SIC codes. Appropriate employee-use rates within San Francisco's model were determined by extensive review of industry literature.

Two separate end-use models estimate multi-family and single family residential water use. These models rely on a disaggregation of household end-use of water, such as the number and volume of toilet flushes, duration of showering, and the size and frequency of use of washing machines and dishwashers. These data were derived from available residential end-use monitoring studies.[12]

The models have been verified with water delivery records for historical periods, including periods of time when water demands were affected by drought-induced rationing programs. Water use projections through the year 2035 were developed using these models. The water use projections incorporate the effects of water-saving plumbing code requirements, among other factors. **Appendix D** contains a detailed discussion of the methodology.

12 End-use studies include the Residential End Uses of Water Study (American Water Works Association Research Foundation, 1999) and the California Single-Family Water Use Efficiency Study (Prepared by Aquacraft, Inc. with Stratus Consulting & the Pacific Institute. Sponsored by the California Department of Water Resources, Draft Final April 2011).

4.1.6 Differences between 2005 and 2010 Water Demand Projections

Although the SFPUC used the same methodology to project retail water demands in the 2005 UWMP, a few key assumptions were updated in the models used for the 2010 UWMP, resulting in lower projected water demands. The SFPUC Retail Demand Model Update and Calibration Technical Memorandum in **Appendix D** contains a detailed description of these changes. **Table 14** contains a summary of these key changes.

Table 14: Updated Demand Model Assumptions

UPDATED ASSUMPTIONS	CHANGES FROM 2005
Population, housing, and employment projections	Since the 2005 UWMP, new population, employment and housing projections were released. Updates were primarily based on data obtained from Association of Bay Area Governments (ABAG), California Department of Finance, and the City's Planning Department. The updated projections resulted in increased water demands in the multi family sector in 2030 due to a projected increase of 37,081 households. However, the revised projections decreased the employment projections in 2030 by 130,370 jobs, which resulted in decreased water demands in the non-residential sector.
Water Loss	The model was updated to more accurately account for water loss due to meter under-registration. The original model specification included water losses due to customer meter under-registration, both within each billing sector's projected water demand and as a component of the Unaccounted-for-Water causing the model to overestimate in-City retail demands.
Conservation Savings	The original model projected 4.5 mgd of active water conservation savings by 2030. The suite of conservation measures included in the 2004 model was updated to better reflect the mix of conservation measures and technologies that the SFPUC expects to implement in the near future. Additionally savings from new regulations were added into the model, including the City's 2009 Retrofit on Resale (ROR) ordinance, the phase-in of high-efficiency toilet standards under AB 715, California Energy Commission's (CEC) proposed efficiency standards for residential clothes washers, and California's and the City's green building standards. These changes resulted in 2.0 mgd of additional conservation savings.
Other Retail Customer Demands	The demands associated with "other Retail Customers" were updated to reflect a decrease in water use over the past 10 years by these customers. Additionally the groundwater demands of Castlewood and Sunol were removed from this category as these demands are already captured under the groundwater demands.
City Irrigation Demands	City Irrigation demands were updated based on new data. In 2005, City irrigation demands were projected to be 2.5 mgd. Based on the latest metered data, city irrigation demands have been decreased to 1.5 mgd.

The changes summarized above result in decrease in demand of nearly 9.0 mgd in 2030 between the 2005 UWMP and the 2010 UWMP. The 2005 UWMP did not project 2035 demands.

4.2 PER CAPITA WATER USE: BASELINE AND TARGET

SBx7-7 (California Water Code section 10608 [e]) requires the SFPUC to include the following in its UWMP.

- Baseline daily per capita water use: how much water is used within an urban water supplier's distribution system area on a per-capita basis. It is determined using water use and population estimates from a defined range of years.

- Urban water use target: how much water is planned to be delivered in 2020 to each resident within an urban water supplier's distribution system area, taking into account water conservation practices that currently are and plan to be implemented.

- Interim urban water use target: the planned daily per capita water use in 2015, a value halfway between the baseline daily per capita water use and the urban water use target.

In 2015 and 2020, the SFPUC will report on daily per capita water use to assess progress toward meeting the interim and 2020 urban water use targets developed herein.

4.2.1 Baseline Daily Per Capita Water Use

As described in *Methodologies for Calculating Baseline and Compliance Urban Per Capita Water Use (For the Consistent Implementation of the Water Conservation Act of 2009)*, the Water Conservation Bill of 2009 requires each urban retail water supplier to include in its UWMP an estimate of base daily per capita water use, expressed in gpcd, for a continuous multiyear base period. The Water Code specifies two different base periods for calculating Base Daily Per Capita Water Use:

- A 10- to 15-year continuous period used to calculate baseline per capita water use per Section 10608.20.

- A continuous 5-year period used to determine whether the 2020 per capita water use target meets the legislation's minimum water use reduction requirement per Section 10608.22.

Because the SFPUC's current and past recycled water use is minimal (<1 mgd; much less than the 10% of 2008 water use needed to justify a 15-year baseline), the SFPUC will utilize a 10-year baseline. Water use data from fiscal year (FY) 2000/01 to FY 2009/10 have been used for this analysis.

Base Daily Per Capita Water Use has been calculated for the 10-year period as follows:

Step 1: Estimate distribution system area

Step 2: Estimate Service Area Population for each year in the base period

Step 3: Calculate Gross Water Use for each year in the base period (in gallons/day)

Step 4: Calculate Annual Daily Per Capita water use for each year in the base period by dividing Gross Water Use by Service Area Population

Step 5: Calculate Base Daily Per Capita Water Use as the average per capita water use

Step 1: Estimate Distribution System Area (10-Year Baseline). The distribution system area is the SFPUC's in-City Retail System, shown in **Figure 7**.

Figure 7: Distribution System Area and Metering Locations

Step 2: Estimate Service Area Population for Base Period (10-Year Baseline). As shown in **Table 15**, the retail population was developed for the period from FY 00/01 to FY 09/10 based on Department of Finance total population data for the City and County of San Francisco (2000 – 2009).

Step 3: Calculate Gross Water Use (10-Year Baseline). Gross water use for the City is provided in **Table 15**. Gross water use was developed by compiling water from the SFPUC's own sources delivered to Retail Customers (total production minus deliveries to Wholesale Customers). Changes in in-City storage were then factored in to develop gross water use. The SFPUC compiles daily flow data for the County-line meters, System Input and In-Line Meters, and daily reservoir water level data. The meters, water level sensors, and associated metering equipment are all inspected, tested, calibrated, and maintained according to the applicable meter calibration and maintenance frequency by an independent metering consultant. These include annual pitot tube tests, quarterly secondary meter equipment testing and calibration, cleaning, flushing, inspecting, and lubricating. The flow quantities are expected to be accurate and no meter error adjustment is necessary. Gross water use is shown in rows 1 through 5 in **Table 15**.

Step 4: Calculate Annual Daily Per Capita Water Use (10-Year Baseline). Annual Daily Per Capita Water Use was calculated by dividing gross water use by population. Annual Daily Per Capita Water Use is shown on the last row in **Table 15**.

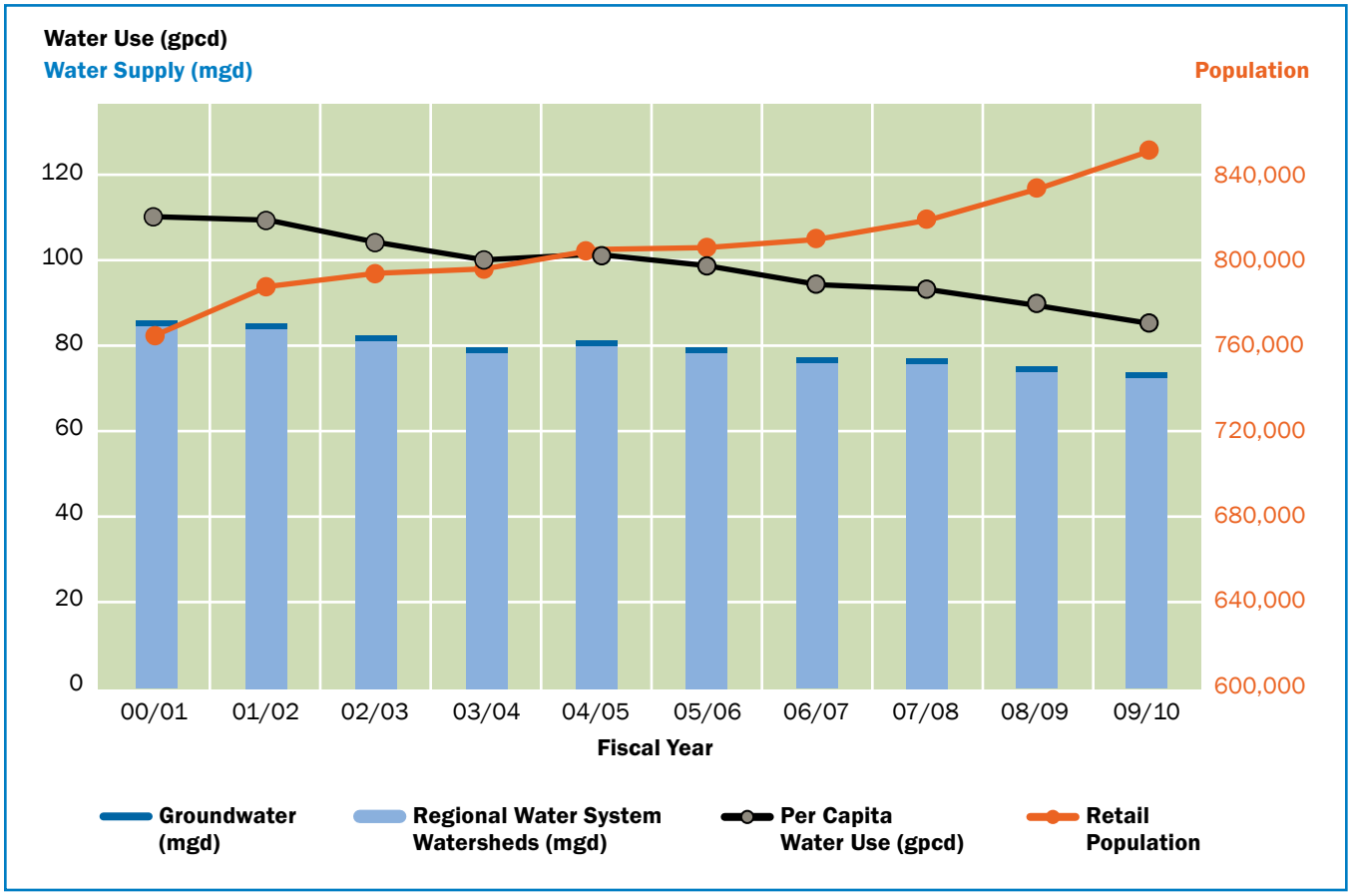
Step 5: Calculate Base Daily Per Capita Water Use (10-Year Baseline). Base Daily Per Capita Water Use is calculated as the average of per capita water use, or 98.4 gpcd.

Table 15: SFPUC In-City Retail Gross Water Use from FY 00/01 to FY 09/10 (mgd)

	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10
Own Sources [1]	85.4	85.4	82.5	79.6	80.6	79.4	76.8	76.7	75.0	72.5
Imported Sources	0	0	0	0	0	0	0	0	0	0
Volume Exported	0	0	0	0	0	0	0	0	0	0
Change in Storage	-0.01	0.00	0.15	0.02	-0.09	0.00	0.03	0.00	-0.01	0.06
Gross Water Use	85.4	85.4	82.3	79.6	80.7	79.4	76.8	76.7	75.0	72.4
Retail Population [2]	776,733	785,654	793,462	798,574	802,512	807,382	813,929	823,940	836,360	846,601
Per Capita Use (gpcd) [3]	**110.0**	**108.7**	**103.8**	**99.6**	**100.6**	**98.3**	**94.3**	**93.1**	**89.7**	**85.6**

1. All sources are metered, and all meters are calibrated annually.
2. Population data from California Department of Finance for City and County of San Francisco (http://www.dof.ca.gov/research/demographic/reports/estimates/e-5/2001-10/view.php), 2000-2001 / 2008-2009.
3. Per capita water use has been calculated in compliance with the requirements of the Water Conservation Bill of 2009.

Figure 8: SFPUC In-City Retail 10-Year Gross Water Use



4.2.2 Urban Water Use Target

The SFPUC has elected to use Method 3 of the four approved methods provided for by the Water Conservation Bill of 2009 for determining urban water use targets. The SFPUC in-City Retail distribution system is contained entirely within the San Francisco Bay hydrologic region. The hydrologic region baseline, interim, and 2020 targets are 157, 144, and 131 gpcd, respectively. To calculate the SFPUC urban water use targets using Method 3, 95% of the interim and 2020 targets are calculated, yielding interim and 2020 urban water use targets of 136.8 and 124.5 gpcd, respectively.

4.2.3 Confirmation of Urban Water Use Target

California Water Code Section 10608.22 requires confirmation of the base daily per capita water use using a 5-year base period to assure that the use target meets a minimum threshold. The 5-year continuous base period is to end no earlier than December 31, 2007, and no later than December 31, 2010. The SFPUC has used the 5-year period from FY 05-06 to FY 09/10 for calculation of the 5-year baseline.

Calculation of Base Daily Per Capita Water Use for the 5-year period is calculated in the same way as for the 10-year period (see above):

Step 1b: Estimate distribution system area

Step 2b: Estimate Service Area Population for each year in the base period

Step 3b: Calculate Gross Water Use for each year in the base period (expressed in gallons per day)

Step 4b: Calculate Annual Daily Per Capita water use for each year in the base period by dividing Gross Water Use by Service Area Population

Step 5b: Calculate Base Daily Per Capita Water Use as the average per capita water use

Each calculation step for determining Base Daily Per Capital Water Use for the 5-year period is shown below.

Step 1: Estimate Distribution System Area (Five-Year Baseline). The distribution system area is the SFPUC's in-City retail distribution system, shown previously in **Figure 7**.

Step 2: Estimate Service Area Population for Base Period (5-Year Baseline). As shown in **Table 16**, the retail population was developed for the period from FY 00/05 to FY 09/10 based on Department of Finance total population data for the City and County of San Francisco (2005 – 2009).

Step 3: Calculate Gross Water Use (5-Year Baseline). Gross water use for the City of San Francisco is provided in **Table 16**. As discussed previously, gross water use was developed by compiling water from the SFPUC's own sources delivered to Retail Customers (total production minus deliveries to Wholesale Customers). Changes in in-City storage were then factored in to develop gross water use.

The SFPUC compiles daily flow data for the County-line meters, System Input and In-Line Meters, and daily reservoir water level data. The meters, water level sensors, and associated metering equipment are all inspected, tested, calibrated, and maintained according to the applicable meter calibration and maintenance frequency by an independent metering consultant. These include annual pitot tube tests, quarterly secondary meter equipment testing and calibration, cleaning, flushing, inspecting, and lubricating. The flow quantities are expected to be accurate and no meter error adjustment is necessary.

Step 4: Calculate Annual Daily Per Capita Water Use (5-Year Baseline). Annual Daily Per Capita Water Use was calculated by dividing gross water use by population. Annual Daily Per Capita Water Use is shown on the last row in **Table 16**.

Step 5: Calculate Base Daily Per Capita Water Use (5-Year Baseline). Base Daily Per Capita Water Use is calculated as the average of per capita water use, or 92.2 gpcd.

Table 16: SFPUC In-City Retail Gross Water Use from FY 00/05 to FY 09/10

	05/06	06/07	07/08	08/09	09/10
Own Sources (mgd)[1]	79.4	76.8	76.7	75.0	72.5
Imported Sources (mgd)	0	0	0	0	0
Volume Exported (mgd)	0	0	0	0	0
Change in Storage (mgd)	0.00	0.03	0.00	-0.01	0.06
Gross Water Use (mgd)	79.4	76.8	76.7	75.0	72.4
Retail Population[2]	807,382	813,929	823,940	836,360	846,601
Per Capita Use (gpcd)[3]	**98.3**	**94.3**	**93.1**	**89.7**	**85.6**

1. All sources are metered, and all meters are calibrated annually.
2. Population data from California Department of Finance for City and County of San Francisco (http://www.dof.ca.gov/research/demographic/reports/estimates/e-5/2001-10/view.php), 2005 - 2009.
3. Per capita water use has been calculated in compliance with the requirements of the Water Conservation Bill of 2009.

The SFPUC's in-City Retail Base Daily Per Capita Water Use for the 5-year period from 05/06 to 09/10 is 92.2 gpcd. Because this is below 100 gpcd, no adjustments to the urban water use target are needed (California Water Code Section 10608.22).

4.2.4 Water Use Reduction Plan

The SFPUC's in-City Retail current Base Daily Per Capita Water Use is 92.2 gpcd, which is below both the interim and 2020 urban water use targets of 136.8 and 124.5 gpcd, respectively; therefore, the SFPUC is already in compliance with the requirements of the Water Conservation Bill of 2009.

Although it is already in compliance with the Water Conservation Bill, the SFPUC remains committed to implementing conservation as an important component of its water supply portfolio, and will continue its efforts to minimize retail water demands through conservation. In 2010, the SFPUC conducted a detailed analysis on the effectiveness of its water conservation measures. The analysis projected a total savings potential of 5.0 mgd by 2018 and 6.0 mgd by 2035 from active conservation. Detail of the analysis is documented in the SFPUC Retail Demand Model Update and Calibration Technical Memorandum (**Appendix D**), which was developed as part of the 2011 Retail Water Conservation Plan. This Plan is intended to serve as a living document that will be reviewed and updated periodically as part of the SFPUC's adaptive management approach.

4.3 WHOLESALE WATER DEMANDS

The SFPUC provides water to 27 Wholesale Customers in San Mateo, Alameda and Santa Clara Counties under contractual agreements. These entities receive over two-thirds of the SFPUC's RWS watershed supply. Of the 27 Wholesale Customers (**Figure 3**), 14 derive 100% of their water from the SFPUC.

4.3.1 Wholesale Water Contractual Obligations and Demands

The following sections describe the various water supply contracts and other contractual obligations that the SFPUC has entered into with its Wholesale Customers.

1984 Settlement Agreement and Master Water Sales Contract: Between 1984 and 2009, the SFPUC provided water to its Wholesale Customers under the terms of the 1984 Settlement Agreement and Master Water Sales Contract (1984 Agreement). The 1984 Agreement created a total "Supply Assurance" of 184 mgd (measured on an annual average basis) for 25 of the Wholesale Customers. The Cities of San Jose and Santa Clara are served wholesale water on an interruptible basis and such sales are not deemed to be within the Supply Assurance. The Supply Assurance is not a guarantee of water delivery in every year, but may be reduced due to emergencies, water shortages, drought, or system maintenance and repair. Of the 25 Wholesale Customers within the Supply Assurance, 24 have Individual Supply Guarantees (ISG) within the 184 mgd. The City of Hayward does not have an ISG because it had previously negotiated a permanent, all requirements individual contract. The City of Hayward continues to receive water under a contract entered into in 1960 with no expiration date or limitation in supply. Under the 184 mgd Supply Assurance, the 24 Wholesale Customers with ISGs would be required to reduce their allocation to accommodate the needs of the City of Hayward in the event that Hayward's water use exceeds its estimated share of the Supply Assurance.

2009 Water Supply Agreement: The 1984 Agreement expired on June 30, 2009. In July 2009, the SFPUC entered into the Water Supply Agreement (WSA) with the Wholesale Customers. The WSA continues the existing 184 mgd Supply Assurance. The WSA includes an "Interim Supply Limitation", which limits water sales to Retail and Wholesale Customers from the RWS watersheds to 265 mgd through 2018 based upon the water supply variant adopted by the SFPUC in its approval of the WSIP in Res. No. 08-200. Under the Interim Supply Limitation, Retail Customers receive 81 mgd and the Wholesale Customers receive 184 mgd from the RWS. The 184 mgd Interim Supply Limitation includes 9 mg of demand allocated to the Cities of San Jose and Santa Clara, but both cities retain their temporary, interruptible status.

As part of the implementation of the Interim Supply Limitation, on December 14, 2010 the SFPUC established each individual Wholesale Customer's share of the Interim Supply Limitation, referred to as "Interim Supply Allocations" (ISAs – see SFPUC Res. No. 10-0213). The ISAs are effective until December 31, 2018 and do not affect the Supply Assurance or the ISGs. The ISGs and ISAs are listed in **Table 17**.

Environmental Enhancement Surcharge: If combined sales to Wholesale and Retail Customers exceed the Interim Supply Limitation of 265 mgd, the SFPUC will impose an Environmental Enhancement Surcharge on Retail Customers if sales exceed 81 mgd and on individual Wholesale Customers whose purchases exceed their ISAs. As described in Section 4.04 of the WSA, the SFPUC plans to establish the Environmental Enhancement Surcharge concurrently with the budget-coordinated rate process to be effective for water sales in FY 2011/12 through 2017/18. The SFPUC is in the process of developing the methodology and amount of this volume-based charge.

2018 Water Supply Decisions: Subject to completion of necessary CEQA review and the exercise of retained discretion by the SFPUC to reject or modify proposed projects, the WSA requires the SFPUC to make the following decisions by December 31, 2018:

- Whether to make San Jose and Santa Clara permanent customers, to the extent that the SFPUC determines that long-term water supplies are available.

- Whether to provide water in excess of the supply assurance to meet wholesale demands through the year 2030, and whether to offer a corresponding increase in the supply assurance.

Wholesale Demands: **Table 17** and **Table 18** show the demands of the Wholesale Customers on the SFPUC RWS. **Table 17** shows the unrestricted purchase projections of the Wholesale Customers through 2035 assuming the 265 mgd supply limitation from the RWS watersheds ends in 2018. **Table 18** shows the wholesale customer demands for the same time period, assuming the 265 mgd supply limitation extends beyond 2018.

Table 17: SFPUC Wholesale Customer Water Demands (mgd)[1]

Wholesale Customer	ISG[2]	ISA[3]	2005	2010	2015	2020	2025	2030	2035
Alameda County Water District	13.76	13.76	10.80	10.81	13.76	13.76	13.76	13.76	13.76
City of Brisbane / Guadalupe Valley Municipal Improvement District	0.98	0.96	0.68	0.58	0.98	1.02	1.04	1.06	*1.07*
City of Burlingame	5.23	4.97	4.52	3.93	4.69	4.84	4.94	5.05	5.24
California Water Service Company	35.68	35.68	34.83	32.57	33.70	31.73	32.43	33.16	33.91
Coastside County Water District	2.18	2.18	1.75	1.82	2.18	2.18	2.18	2.18	2.18
Cordilleras Mutual Water Association	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
City of Daly City	4.29	4.29	6.94	3.21	4.29	4.29	4.59	4.89	5.37
City of East Palo Alto	1.96	1.96	2.02	1.81	2.37	2.48	2.64	2.82	3.04
Estero Municipal Improvement District	5.90	5.85	5.21	4.9	5.70	5.30	5.40	5.40	5.90
City of Hayward	22.08	22.92	18.51	17.25	22.00	23.60	25.80	28.10	30.70
Town of Hillsborough	4.09	3.72	3.37	2.97	3.72	4.09	4.09	4.09	4.09
City of Menlo Park	4.46	4.1	3.38	3.04	3.96	4.13	4.44	4.62	*4.46*
Mid-Peninsula Water District	3.89	3.71	3.30	2.87	3.70	3.80	3.80	3.90	*3.89*
City of Millbrae	3.15	3.13	2.43	2.24	3.20	3.30	3.30	3.40	*3.41*
City of Milpitas	9.23	8.96	6.67	6.28	7.07	7.69	8.25	8.80	*8.90*
City of Mountain View	13.46	11.43	10.53	8.95	10.64	10.72	11.16	11.62	12.11
North Coast County Water District	3.84	3.67	3.42	3.02	3.62	3.70	*3.70*	3.70	3.76
City of Palo Alto	17.08	14.7	12.08	10.99	12.67	12.91	13.12	13.84	*13.90*
Purissima Hills Water District	1.63	1.63	2.01	1.75	1.74	1.74	1.80	1.84	1.84
City of Redwood City	10.93	10.88	11.11	9.61	11.20	11.40	11.50	11.60	*11.62*
City of San Bruno	3.25	2.65	3.11	1.46	2.65	3.25	3.25	3.25	*3.28*
City of San Jose [4,5]	0.00	4.13	4.40	4.13	4.50	6.34	6.34	6.34	6.34

Wholesale Customer	ISG[2]	ISA[3]	2005	2010	2015	2020	2025	2030	2035
City of Santa Clara [4]	0.00	4.13	4.14	2.35	4.50	4.50	4.50	4.50	4.50
Stanford University	3.03	2.91	2.32	2.14	2.70	2.90	3.10	3.30	3.50
City of Sunnyvale	12.58	10.59	8.76	9.92	8.93	8.93	8.93	8.93	8.93
Westborough County Water District	1.32	1.08	1.06	0.84	0.89	0.88	0.87	0.85	0.84
Total:	**184.0**	**184.0**	**167.4**	**149.5**	**175.4**	**179.5**	**184.9**	**191.0**	**196.5**

1. Projections reflect SFPUC unrestricted purchase projections provided by Wholesale Customers, regardless of ISG or ISA. Italicized values indicate interpolation or extrapolation. Wholesale Customers projections are currently being updated through individual Urban Water Management Planning processes, and therefore may change.
2. Individual Supply Guarantee (ISG) refers to each Wholesale Customer's share of the 184 mgd Supply Assurance as defined in section 3.01 of the 2009 Water Supply Agreement between the City and County of San Francisco and Wholesale Customers (2009 WSA). The Supply Assurance is the 184 mgd maximum annual average metered supply of water dedicated by San Francisco to public use in the wholesale service area (not including the cities of San Jose and Santa Clara). Hayward's ISG value was calculated as 184 mgd less the total of permanent customer ISG values (161.91 mgd).
3. ISA refers to each Wholesale Customer's share of the 265 mgd Interim Supply Limitation through 2018.
4. The Cities of San Jose and Santa Clara are provided water by the SFPUC on a temporary, interruptible basis. Subject to the process requirements for interruption or reduction of supply provided in Section 4.06 of the WSA, the SFPUC will continue to supply water to San Jose and Santa Clara on a temporary, interruptible basis pending a decision by the Commission, pursuant to Section 4.05H of the WSA, as to whether to make San Jose and Santa Clara permanent customers of the RWS. Per the WSA, the combined annual average water usage of San Jose and Santa Clara shall not exceed 9 mgd average annual supply.
5. In a letter to BAWSCA, the City of San Jose indicated a desire to purchase between 4.50 and 6.34 mgd from the SFPUC between 2020 and 2035; however, pending the 2018 decisions by the SFPUC regarding whether to (1) grant permanent status to San Jose and Santa Clara, and (2) increase the Supply Assurance, the WSA limits combined purchases to the cities to 9.0 mgd on a temporary, interruptible basis.

For the purposes of the supply and demand comparisons provided in Section 5.7, it is assumed that the 265 mgd supply limitation extends beyond 2018. Projected Wholesale Customer demands have been limited to 184 mgd. Prior to 2018, this 184 mgd includes the demands of San Jose and Santa Clara. After 2018, subject to the process requirements for interruption or reduction of supply provided in Section 4.06 of the WSA, the SFPUC will continue to supply water to San Jose and Santa Clara on a temporary, interruptible basis pending a decision by the Commission, pursuant to Section 4.05H of the WSA, as to whether to make San Jose and Santa Clara permanent customers of the RWS. Per the WSA, the combined annual average water usage of San Jose and Santa Clara shall not exceed 9 mgd average annual supply.

Table 18 presents wholesale demands under this assumption.

Table 18: SFPUC Wholesale Customer Purchase Projections with Extended 265 mgd Supply Limitation[1]

Purchase Projections (mgd)	2005	2010	2015	2020	2025	2030	2035
Wholesale Customer Purchase Projections	167.4	149.5	175.4	177.6	183.1	184.0	184.0

1. Projected Wholesale Customer demands limited to 184 mgd. Prior to 2018, 184 mgd includes the demands of San Jose and Santa Clara. After 2018, San Jose and Santa Clara will be supplied on a temporary and interruptible basis, with their total supply not exceeding 9 mgd assuming supply is available (decision to be made by end of 2018).

SECTION 5: WATER SUPPLY RELIABILITY

This section addresses the reliability of both the SFPUC RWS and deliveries to the SFPUC's Retail Customers. As previously described, the Retail Customers' water supply comes from the SFPUC RWS watersheds and local water supply sources (groundwater and recycled water). Approximately 32% of the SFPUC's RWS supply is delivered to Retail Customers, and the remaining 68% is delivered to Wholesale Customers.

5.1 RWS SUPPLY RELIABILITY

The SFPUC's regional water supply system reliability is expressed in terms of the system's ability to deliver water during droughts. Reliability is defined by the amount and frequency of water delivery reductions (deficiencies) required to balance customer demands with available supplies in droughts. The SFPUC plans its water deliveries anticipating that a drought more severe than the worst drought ever experienced may occur. This section discusses both system-wide deficiencies and anticipated retail deficiencies that the City may experience.

The SFPUC's RWS watershed supplies have experienced infrequent, short-term outages as a result of water quality events. Because Hetch Hetchy water is not filtered, it is subject to strict water quality standards set by the California Department of Public Health. However, as a result of weather events, turbidity levels can exceed standards requiring the Hetch Hetchy supply to be diverted to local storage (in the case of short-term events) or shut off (in the case of longer-term events) until turbidity levels drop to within standards. During these periods, the SFPUC's entire supply comes from the Sunol Valley Water Treatment Plant and the Harry Tracy Water Treatment Plant, both of which are supplied by local Bay Area reservoirs.

Table 19 summarizes the legal, environmental, water quality, climatic, and other factors potentially resulting in inconsistency of supply. As described previously, the RWS may be subject to volume reductions due to required instream flow releases as well as climatic variation. Groundwater supplies are typically limited by the quality and quantity of available supplies. Institutional arrangements governing potential water transfers may affect their availability, and climatic variability may impact the availability of surface water in some years. Recycled water is limited by water quality requirements that legally restrict recycled water supply for some uses.

Table 19: Factors Potentially Affecting Consistency of Supplies

WATER SUPPLY SOURCES	LEGAL	ENVIRONMENTAL	WATER QUALITY	CLIMATIC	OTHER (SPECIFY)
Regional Water System		✓		✓	
Groundwater			✓	✓	
Water Transfer				✓	Institutional
Recycled Water	✓		✓		

5.1.1 Estimating the Frequency and Magnitude of SFPUC RWS Supply Deficiencies

The total amount of water the SFPUC has available to deliver to Retail and Wholesale Customers during a defined period of time depends on several factors, including the amount of water that is available to SFPUC from natural runoff, the amount of water in reservoir storage, and the amount of that water that must be released from the SFPUC's system for purposes other than customer deliveries (e.g., releases below Hetch Hetchy reservoirs to meet Raker Act and instream flow release requirements, and future releases from Lower Crystal Springs and Calaveras Reservoirs to support anadromous fisheries).

The 1987-92 drought profoundly highlighted the shortfall between the SFPUC's water supplies and its demands. Other than during the drought of 1976-77, drought sequences in the past did not seriously affect the ability of the SFPUC RWS to sustain full deliveries to its Retail and Wholesale Customers. Based on the 1987-92 drought experience, the SFPUC assumes its "firm" capability to be the amount the system can be expected to deliver during historically experienced drought periods. In estimating this firm capability, the SFPUC assumes the potential recurrence of a drought such as that which occurred during 1987-92, plus an additional 2-year period of limited water availability. This drought sequence is referred to as the "design drought" and serves as the basis for planning and modeling of future drought scenarios.

5.1.2 SFPUC's Normal Year and Design Drought

For planning purposes, the SFPUC "normal year" is based on historical hydrology under conditions that allow the reservoirs to be filled over the course of the snowmelt season, allowing full deliveries to customers.

The SFPUC Design Drought, used for planning and modeling of future drought scenarios, is based on historic droughts and hydrology. As detailed below, it is a drought sequence that is more severe than what the SFPUC RWS has historically experienced.

The 1987-92 drought defines the most extreme recorded drought for SFPUC water deliveries, and establishes the basis for the Design Drought sequence. The drought covered a 6½-year period from July 1986 (when the SFPUC reservoirs were full) to about November/December 1992 (when the SFPUC reservoirs reached minimum storage). Although the SFPUC reservoir system began to recover with precipitation during the last 6 months of the drought, from July 1992 through December 1992, SFPUC customer purchases exceeded SFPUC inflow and the SFPUC system storage continued to decline through November/December 1992. Because the last 6 months of the 1987-92 drought includes the beginning of this recovery period, it has been removed from the SFPUC's Design Drought.

In summary, the design drought sequence used by the SFPUC for reliability planning totals an 8½-year period and is based on the following factors:

- **Historical Hydrology:** The 6 years of hydrology from the historical drought (July 1986 to June 1992);

- **Prospective Drought:** A 2½-year period which includes the 1976-1977 drought (to represent a drought sequence worse than historical); and
- **System Recovery Period:** The last 6 months of the Design Drought are the beginning of the system recovery period. The precipitation begins in the fall, and by approximately the month of December the SFPUC reservoir inflow exceeds customer demands and SFPUC system storage begins to recover.

For the purposes of the required UWMP 3-year drought sequence for 2010, years two through four of the SFPUC Design Drought sequence are used. **Table 20** summarizes the expected reductions in available water supply in normal, single dry, and multiple dry years. Section 5.2.5 describes the available water supply for years 2015-2035.

Table 20: Year 2010 SFPUC System Water Availability During Normal and Drought Scenarios

	AVERAGE / NORMAL WATER YEAR	SINGLE DRY WATER YEAR[2]	MULTIPLE DRY YEARS[1]		
			YEAR 1	YEAR 2	YEAR 3
Regional Water System Watersheds	100%	90%	90%	80%	80%
Groundwater [3]	100%	100%	100%	100%	100%
Recycled Water [3]	100%	100%	100%	100%	100%

1. The multiple dry years shown in this table reflect years 2-4 of the SFPUC 8.5-year design drought for year 2010, and years 6-8 of the SFPUC 8.5-year design drought for years 2015 through 2035.
2. Measured as percentage of normal year availability.
3. Groundwater and recycled water are San Francisco local supplies and are only available for use in the retail service area.

At current delivery levels, the SFPUC RWS can be expected to experience up to a 25% shortage 15 to 20% of the time during multiple-year drought sequences. Therefore, the SFPUC is faced with the necessity to develop a long-term strategy to accommodate or rectify the potential of future water shortages throughout its wholesale and retail operations.

5.2 DRY YEAR WATER SUPPLY OPTIONS

As an established major water supplier for the Bay Area region, the SFPUC is responsible for securing and managing its existing system supplies and planning for future needs, as well as securing its own retail supply.

The WSIP water supply program includes development of dry year supplies for the RWS. The PEIR included an analysis of dry year water supply transfers from the senior water rights holders on the Tuolumne River, MID and TID; a groundwater conjunctive use project (the Groundwater Storage and Recovery Project); and a regional desalination project. The SFPUC is investigating the possibility of a dry year water transfer with MID and TID for 2 mgd, and the SFPUC is implementing the Groundwater Storage and Recovery Project.

The SFPUC's WSIP provides goals and objectives to improve the supply reliability and delivery reliability of the RWS. The goals and objectives of the WSIP related to water supply are presented in **Table 21**.

Table 21: WSIP System Performance Objectives

PROGRAM GOAL	SYSTEM PERFORMANCE OBJECTIVE
Water Supply: meet customer water needs in non-drought and drought periods	• Meet average annual water demand of 265 mgd from the SFPUC watersheds for Retail and Wholesale Customers during non-drought years for system demands through 2018. • Meet dry year delivery needs through 2018 while limiting rationing to a maximum 20% system-wide reduction in water service during extended droughts. • Diversify water supply options during non-drought and drought periods. • Improve use of new water sources and drought management, including groundwater, recycled water, conservation, and transfers.

The adopted WSIP included several water supply elements to address the WSIP water supply goals and objectives, which together will allow the SFPUC to meet at least 80% of its customer demand during droughts. The SFPUC will continue to rely on rationing up to no more than 20% in any one year of a drought.

The following describes the dry year projects of the adopted WSIP to augment all year type water supplies during drought:

- Restoration of Calaveras Reservoir capacity
- Restoration of Crystal Springs Reservoir capacity
- Groundwater Storage and Recovery Project
- Water transfer with MID/TID

5.2.1 Restoration of Calaveras Reservoir Capacity

The adopted WSIP includes the Calaveras Dam Replacement Project, which restores the reservoir capacity of Calaveras Dam from 38,100 acre-feet to 96,850 acre-feet, returning about 60,000 acre-feet of reservoir storage to the SFPUC water system. The restored capacity provides storage for emergency and drought water supplies, providing up to 7 mgd over the SFPUC design drought. In general, a restored Calaveras Reservoir provides 40% of the SFPUC's local system storage capacity. Nearly 66% of local water system yield comes through Calaveras Reservoir from the Alameda Creek watershed. The Environmental Impact Report (EIR) was certified and the project was adopted by the SFPUC in January 2011. Construction is expected to be completed in 2015.

5.2.2 Restoration of Crystal Springs Reservoir Capacity

The adopted WSIP includes the Lower Crystal Springs Dam Improvements Project, which will increase the average storage of the reservoir from 15.4 billion gallons to 17.8 billion gallons with a maximum normal operating level of 287.8 feet, providing an additional 2.4 billion gallons of storage to the SFPUC water system. The restored capacity provides storage for emergency and drought water supplies, providing up to an additional 0.5 mgd over the SFPUC design drought. The Project EIR was certified and the project was adopted by the SFPUC in October 2010. Construction is expected to be completed in 2013.[13]

5.2.3 Regional Groundwater Storage and Recovery Project

The proposed Regional Groundwater Storage and Recovery Project is an in-lieu conjunctive use project that would balance the use of both groundwater and surface water to increase water supply reliability during dry years or in emergencies. The proposed project is located in the South Westside Basin in northern San Mateo County and is sponsored by the SFPUC in coordination with its partner agencies, the California Water Service Company, the City of Daly City and the City of San Bruno. The partner agencies currently purchase wholesale surface water from the SFPUC and also independently operate groundwater production wells for drinking water and irrigation.

The proposed Regional Groundwater Storage and Recovery Project would extract stored groundwater from the South Westside Basin groundwater aquifer in San Mateo County for delivery to the RWS and the partner agencies. During years of normal or heavy precipitation, the proposed project would provide surface water to the partner agencies to reduce the amount of groundwater pumped (sometimes called "in lieu recharge"). Over time, the reduced pumping would result in the storage of approximately 61,000 acre-feet of water (more than the supply contained in the Crystal Springs Reservoir on the SFPUC Peninsula Watershed). The project would consist of installing up to 16 new wells to pump the stored groundwater during a drought. The new wells would allow recovery of the stored water at a rate of up to 7.2 mgd for a 7.5-year dry period. The water would be in compliance with the California DPH requirements for drinking water supplies. The proposed project would include construction of well pump stations, disinfection units, and piping. The proposed project is currently undergoing environmental review. EIR certification is expected in September 2012, and construction is expected to begin in May 2013.[13]

5.2.4 Water Transfer with Modesto Irrigation District/Turlock Irrigation District

The adopted WSIP includes a water transfer between the SFPUC and its partners on the Tuolumne River. Certification of the WSIP PEIR, in October 2008, has allowed the SFPUC to move forward in securing a dry year water transfer in the Tuolumne River basin from the senior water rights holders: MID and TID. The water transfer would yield an average of 2 mgd over the design drought.

13 This UWMP reflects that this supply will be available during the 2015-2020 time increment because information in this document is presented in 5-year increments and this supply will be available during the majority of this time period. The SFPUC believes there will be sufficient supply for the three-year drought period analyzed in this document.

5.2.5 Summary of Dry Year Supplies

The dry year water supplies described above will allow the SFPUC to meet at least 80% of its customer demand during droughts. The SFPUC will continue to rely on rationing up to no more than 20% in any one year of a drought. This UWMP assumes that these resources will be available to the RWS in the volumes and timeframes indicated in **Table 22**.

Table 22: Dry Year Water Supply Reliability Water Supply Options (2010 to 2035)

SUPPLY OPTION[1]	SUPPLY AVAILABLE(MGD)					
	2010	2015	2020	2025	2030	2035
Crystal Springs Reservoir Storage Recovered to 22.1 bg [2,3]	0	0.5	0.5	0.5	0.5	0.5
Regional Groundwater Storage and Recovery (mgd)	0	7.2	7.2	7.2	7.2	7.2
Calaveras Reservoir Storage Recovered to 31.5 bg	0	7	7	7	7	7
Water Transfers (mgd)	0	2.0	2.0	2.0	2.0	2.0

1. Water supply option schedule information from SFPUC WSIP, as adopted by the SFPUC on 11/29/05.
2. bg = Billion gallons
3. Crystal Springs Reservoir has a maximum storage capacity of 22.1 billion gallons (at 291.8 feet). When the Lower Crystal Springs Dam Improvement is complete, the reservoir will be operated normally at 287.8 feet (4 feet below capacity) based on permit conditions.

With current water supplies, the SFPUC experiences shortages between 10% and 25% at the planning level demand of 265 mgd. **Table 23** illustrates the delivery reduction sequence over the design drought. Implementation of the WSIP water supply projects will improve the SFPUC's water supply reliability, particularly in the earlier years of the drought, however, as the drought progresses the SFPUC continues to experience multiple years of 20% rationing as shown in **Table 23**. For the purposes of the UWMP multiple dry-year sequence, the SFPUC uses years 2-4 of the design drought for year 2010 supply and demand comparisons and uses years 6-8 for the supply and demand comparisons for 2015-2035. Any sequence of years can be used in the analysis, however, the SFPUC chose to use the worst sequence of years from 2015-2035 to demonstrate that even with the WSIP water supply projects in place the SFPUC system is still subject to multiple years of 20% shortage at a planning level demand of 265 mgd.

Table 23: SFPUC Design Drought Water Delivery Reduction Sequence

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 8.5
	% REDUCTION OVER DESIGN DROUGHT								
RWS Watersheds 2010 (pre-WSIP)	0%	10%	20%	20%	20%	20%	20%	25%	25%
RWS Watersheds 2015-2035 (post-WSIP)	0%	0%	10%	10%	20%	10%	20%	20%	20%

Continued progress on the dry year supply projects is an important component of the SFPUC's dry year water supply program. As discussed previously, in adopting the Calaveras Dam Replacement Project and the Lower Crystal Springs Dam Improvements project, the SFPUC agreed to provide instream flow releases below Calaveras Dam and Lower Crystal Springs Dam, as well as bypass flows below Alameda Creek Diversion Dam, to obtain required federal and state resource agency permits for construction of these projects. The instream flow release requirements for Alameda Creek and San Mateo Creek represent a potential decrease in available annual average water supply of 3.9 mgd and 3.5 mgd, respectively, for a total shortfall of 7.4 mgd on an average annual basis.[14] These instream flow releases could potentially create a shortfall in meeting the SFPUC demands of 265 mgd and slightly increase the SFPUC's dry year water supply needs. The effects of such a shortfall, if any, would occur upon the completion of construction of both the Calaveras Dam Replacement Project and the Lower Crystal Springs Dam Improvements project in approximately 2015 and 2013, respectively, at the time when the SFPUC will be required to provide the instream flow releases.

The SFPUC is currently exploring other future supplies to offset the 7.4 mgd in instream flow release requirements. These projects may include:

- Development of additional conservation and recycling
- Development of additional groundwater supplies
- Additional water transfer volumes from MID and/or TID
- Increase in Tuolumne River supply
- Revising the Upper Alameda Creek Filter Gallery Project capacity
- Development of a desalination project

Section 3.3 provides additional information on the SFPUC's planned future water supply projects.

5.3 BAY AREA REGIONAL EFFORTS TO IMPROVE WATER SUPPLY RELIABILITY

The following projects and efforts currently underway or completed will help the SFPUC RWS meet its water supply reliability needs. Some of these projects are reflected in the SFPUC's current strategy for meeting water supply needs. As the remainder of these projects move through the planning stages they will continue to inform the SFPUC water supply strategy.

14 This water supply decrease assumes the adopted WSIP program element of an average annual target delivery of 265 mgd. The analysis also assumes that all of the water supply components of the adopted WSIP are implemented and all WSIP projects are implemented, including the Upper Alameda Creek Filter Gallery project, which in accordance with the Program Environmental Impact Report (PEIR) assumptions is estimated to recapture up to 6300 acre-feet (AF) per year (5.6 mgd).

5.3.1 Desalination

The SFPUC's investigations of desalination as a water supply source have focused primarily on the potential for regional facilities. The proposed Bay Area Regional Desalination Project is a joint venture between the SFPUC, CCWD, EBMUD, SCVWD, and Zone 7 Water Agency.

The regional desalination project would provide an additional source of water during emergencies, provide a supplemental water supply source during extended droughts, allow other major water facilities to be taken out of service for maintenance or repairs, and increase supply reliability by providing water supply from a regional facility. The Bay Area Regional Desalination Project will produce 10 to 50 mgd.

5.3.2 Regional Interties

Regional interties help increase the reliability of the SFPUC RWS by allowing for water exchanges during emergencies, water shortages or maintenance.

- **EBMUD-Hayward SFPUC Intertie:** In 2002, the SFPUC formed a partnership with EBMUD and the City of Hayward to construct Skywest Pump Station and 1.5 miles of pipeline to link their systems. These facilities are now completed and can convey up to 30 mgd among these three agencies to boost water supply reliability when needed. EBMUD and the SFPUC own these facilities jointly, while the City of Hayward maintains and operates them in coordination with EBMUD and the SFPUC.
- **Milpitas Intertie:** The SFPUC and SCVWD constructed a 40 mgd intertie between their two systems to exchange water during emergencies and planned maintenance. The intertie was recently used during maintenance of one of SCVWD's water treatment plants.
- **South Bay Aqueduct Interties:** The SFPUC has in the past used one permanent and one temporary intertie to the SBA for water transfers, which if reactivated would enable the SFPUC to receive SWP water.

5.3.3 Bay Area Integrated Regional Water Management Plan

The SFPUC is an active participant in the nine-county Bay Area Integrated Regional Water Management planning process. The Integrated Regional Water Management Plan (IRWMP) was first completed in November 2006 and most recently amended in December 2010. The IRWMP covers water supply and water quality, wastewater and water recycling, storm water and flood protection, and habitat protection and ecosystem restoration objectives and efforts in the Bay Area. The IRWMP also identifies integrated and collaborative projects among Bay Area agencies. DWR has recently recommended over $800,000 in Proposition 84 grant funding for the Bay Area region to be used to update the Bay Area IRWMP.

5.4 DROUGHT RESPONSE

This section presents the SFPUC's water shortage contingency plan and includes the following information:

- An overview of SFPUC's response to past water shortage experiences;
- A summary of the procedures for allocating reduced deliveries from the SFPUC RWS; and
- A summary of the SFPUC's retail plan for responding to water shortages.

5.4.1 Past Experience with Water Shortages

Every water system has vulnerabilities in terms of its ability to provide a safe and reliable supply of water. Water shortages can occur in a number of ways. Very localized shortages can occur due to distribution system problems and system shortages can occur due to major facility failures. Yet, beyond system facility contingencies, there exists the potential vulnerability to drought, which limits the amount of water that is available over a series of years. This latter type of contingency is not necessarily caused by physical facility limitations. Within the past 25 years, San Francisco has experienced both localized shortages due to earthquakes and system-wide shortages due to drought.

The SFPUC's past experiences with water shortages, due to drought and earthquakes, have helped shape its current plans and policies relative to water shortage preparedness and response:

- In 1987-92 San Francisco experienced a serious drought. This 6-year drought provides an example of how various stages of action were taken in times when the operational capabilities of Hetch Hetchy and other water supplies available to the SFPUC were taxed to a point that forced drastic actions to avoid running out of water.

- Following the October 17, 1989 Loma Prieta earthquake, the SFPUC worked with the Mayor's Office of Emergency Response to reconnect service to those who were impacted by the earthquake. Most of the homes that lost water service were reconnected to the water system's lines within 72 hours.

- In April 2007, below normal precipitation and snow pack caused the SFPUC to initiate a 10% voluntary reduction in water use in the service area. The call for a voluntary reduction continued through 2009.

The 1987-92 drought illustrated the deficit between the SFPUC's water supplies and its demands. Other than the 1976-77 drought, drought sequences in the past did not seriously affect the ability of the SFPUC to maintain full deliveries to its customers. As the SFPUC progressed into the drought and reservoir storage continued to decline, it became evident that full water deliveries could not be sustained without a risk of running out of water before the drought was over. This circumstance became a reality in early 1991 when the Hetch Hetchy Reservoir became so depleted (less than 25,000 acre-feet of storage in a reservoir with over 360,000 acre-feet of capacity)

that minimum instream flow releases and anticipated demands required the SFPUC to initiate programs to achieve a 45% reduction in system-wide water deliveries to balance water supplies with deliveries. Fortunately, unexpected runoff provided relief from the severity of that instance of water shortage; however, the drought was far from over. **Appendix E** provides a more detailed summary of San Francisco's 1987-92 drought experience and the actions taken at the time.

5.4.2 Water Shortage Allocation Plan

As the 1987-1992 drought progressed and reservoir storage continued to decline, it became apparent that continued full deliveries could not be sustained without the risk of running out of water before the drought ended.

To provide some level of assurance that water could be delivered continuously throughout a drought (although at reduced levels), the SFPUC adopted a drought planning sequence and associated operating procedures that trigger different levels of water delivery reduction rationing relative to the volume of water actually stored in SFPUC reservoirs. Each year, during the snowmelt period, the SFPUC evaluates the amount of total water storage expected to occur throughout the RWS. If this evaluation finds the projected total water storage to be less than an identified level sufficient to provide sustained deliveries during drought, the SFPUC may impose delivery reductions or rationing.

SFPUC's response to water shortages also included the adoption of new agreements regarding how water would be allocated in future drought periods. In connection with the adoption of the WSA, the Wholesale Customers and San Francisco adopted the Water Shortage Allocation Plan (WSAP) which outlines procedures for allocating water from the RWS to retail and Wholesale Customers during system-wide shortages of 20% or less.

In connection with the adoption of the WSA, the Wholesale Customers and San Francisco adopted the Water Shortage Allocation Plan (WSAP) which outlines procedures for allocating water from the RWS to retail and Wholesale Customers during system-wide shortages of 20% or less (Tier 1 Plan). Section 3.11.C of the WSA authorizes the Wholesale Customers to adopt a methodology for allocating the collective wholesale allocation among the individual Wholesale Customers (see "Tier 2 Drought Implementation Plan" discussion).

For shortages in excess of 20%, the SFPUC will meet with the wholesale customers to determine if modifications to the Tier 1 Plan can be agreed upon by the SFPUC and the wholesale customers. If they cannot agree, the SFPUC may allocate water in its discretion, subject to challenge by the wholesale customers, unless all of the wholesale customers direct that a particular Tier 2 allocation methodology be used.

Regional Water Shortage Allocations: During a drought, it is expected that the Retail and Wholesale Customers would experience a reduction in the amount of water received from the RWS. The WSAP provides specific allocations of the available water supply between the Retail and Wholesale Customers collectively associated with varying system-wide shortages of up to 20%, as shown in **Table 24.**

Table 24: Retail / Wholesale Water Allocation during System-wide Water Shortage

LEVEL OF SYSTEMWIDE REDUCTION IN WATER USE REQUIRED	SFPUC SHARE OF AVAILABLE WATER	WHOLESALE CUSTOMERS SHARE (COLLECTIVELY)
5% or less	35.5%	64.5%
6% through 10%	36.0%	64.0%
11% through 15%	37.0%	63.0%
16% through 20%	37.5%	62.5%

In addition to providing an allocation method, the WSAP also includes provisions for transfers, banking and excess use charges. See **Appendix G** for the full text of the WSAP.

According to the WSAP allocations presented above in **Table 24**, **Table 25** and **Table 26** show SFPUC RWS Retail and Wholesale supply schedules during normal, single dry year, and multiple dry year periods. For the purposes of this analysis, the SFPUC assumed a delivery goal of 265 mgd. System-wide shortages were applied to a demand of 265 mgd and the subsequent allocations between retail and wholesale collectively.

Table 25: SFPUC Retail RWS Allocations in Normal, Dry and Multiple Dry Years

	NORMAL YEAR		SINGLE DRY YEAR		MULTIPLE DRY YEARS[1]					
					YEAR 1		YEAR 2		YEAR 3	
	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)
2010	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1
2015	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1
2020	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1
2025	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1
2030	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1
2035	81.0	100	81.0	100.0	81.0	100.0	79.5	98.1	79.5	98.1

1. Under the WSAP, the SFUPC retail allocations at a 10% shortage are 85.86 mgd. However, due to the Phased WSIP Variant, only 81 mgd of RWS supply is shown.

Table 26: SFPUC Wholesale RWS Allocations in Normal, Dry and Multiple Dry Years

	NORMAL YEAR		SINGLE DRY YEAR		MULTIPLE DRY YEARS[1]					
					YEAR 1		YEAR 2		YEAR 3	
	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)	(mgd)	(%)
2010	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0
2015	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0
2020	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0
2025	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0
2030	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0
2035	184.0	100	152.6	83.0	152.6	83.0	132.5	72.0	132.5	72.0

1. Under the WSAP, the SFUPC wholesale allocations at a 10% shortage are 64% of available supply or 152.6 mgd; at a 20% shortage, the SFPUC wholesale allocations are 62.5% of available supply or 132.5 mgd.

Retail Water Shortage Allocation Plan: The RWSAP was adopted to formalize a three-stage program of action to be taken in San Francisco to reduce water use during a drought. In accordance with the RWSAP, prior to the initiation of any water delivery reductions in San Francisco, whether it be initial implementation of reduction delivery or increasing the severity of water shortage, the SFPUC will outline a drought response plan to address the following: the water supply situation; proposed water use reduction objectives; alternatives to water use reductions; methods to calculate water use allocations and adjustments; compliance methodology and enforcement measures; and budget considerations.

This drought response plan will be presented at a regularly scheduled SFPUC Commission meeting for public input. The meeting will be advertised in accordance with the requirements of California Water Code Section 6066 of the Government Code, and the public will be invited to comment on the SFPUC's intent to reduce deliveries.

Depending on the level of water demand and the desired objective for water use reduction, one, two or all three stages of the RWSAP may be required. **Table 27** identifies the water shortage stages of action. Additional information is provided in **Appendix F**.

Table 27: SFPUC Retail Water Shortage Stages of Action

STAGE	ACTIONS	TRIGGER PT. (% SYSTEM SHORTAGE)	TARGET WATER USE REDUCTION (%)
1 - Voluntary	• Voluntary rationing request of customers • Customers are alerted to water supply conditions • Remind customers of existing water use prohibitions	10-20%	5 – 10%
	• Customers are alerted to water supply conditions		
	• Remind customers of existing water use prohibitions		
	• Education on, and possible acceleration of, incentive programs (e.g., toilet rebates)		
2 - Mandatory	• All Stage 1 actions implemented	21-50%	11 – 20%
	• All customers receive an "allotment" of water based on the Inside/Outside allocation method (based on base year water usages for each account)		
	• Water use above the "allocation" level will be subject to excess use charges, installation of flow restrictor devices and shut-off of water		
3 - Mandatory	• Same actions as in Stage 2 with further reduced allocations	>50%	>20%

Table 28 summarizes potential prohibitions that may be enforced during a drought. **Appendix E** discusses various measures employed during the 1987-92 drought in an attempt to achieve a 45% reduction in Retail Customer demands (as applied to the pre-drought demand). These measures included absolute limitations on water use based on residential customer classification and a proportion of historical use within the non-residential sectors. Although not anticipated to be required in the near-term, San Francisco would employ similar procedures to accommodate system-wide water shortages in excess of 20%, if necessary.

The Retail Water Shortage Allocation plan is provided in **Appendix F**.

Table 28: Potential Prohibitions That May Be Enforced During a Drought

#	WATER SHORTAGE CONTINGENCY – MANDATORY PROHIBITIONS[1]	STAGE
1	Water waste, including but not limited to, any flooding or runoff into the street or gutters, was prohibited.	2, 3
2	Hoses could not be used to clean sidewalks, driveways, patios, plazas, homes, businesses, parking lots, roofs, awnings or other hard surfaces areas.	2, 3
3	Hoses used for any purpose had to have positive shutoff valves.	2, 3
4	Restaurants served water to customers only upon request.	2, 3
5	Potable water was not to be used to clean, fill or maintain levels in decorative fountains.	2, 3
6	Use of additional water was not allowed for new landscaping or expansion of existing facilities unless low water use landscaping designs and irrigation systems were employed.	2, 3
7	Water service connections for new construction were granted only if water saving fixtures or devices were incorporated into the plumbing system.	2, 3
8	Use of potable water for consolidation of backfill, dust control or other non-essential construction purposes was prohibited.	2, 3
9	Irrigation of lawns, play fields, parks, golf courses, cemeteries, and landscaping of any type with potable water would be reduced by at least the amount specified for outside use in the adopted rationing plan.	2, 3
10	Verified water waste as determined by the Water Department would serve as prima facie evidence that the allocation assigned to the water account is excessive; therefore, the allocation was subject to review and possible reduction, including termination of service.	2, 3
11	Water used for all cooling purposes was to be recycled.	2, 3
12	The use of groundwater and/or reclaimed water for irrigation of golf courses, median strips, and similar turf areas was strongly encouraged.	2, 3
13	The use of groundwater and/or reclaimed water for street sweepers/washers was strongly encouraged.	2, 3

1. Prohibitions prescribed in the 1987-92 drought that **may be** enforced during a future drought.

Wholesale Customer Water Shortage Plan (Tier 2 Drought Implementation Plan, or DRIP):

Section 3.11.C of the WSA authorizes the Wholesale Customers to adopt a methodology for allocating the collective wholesale allocation among the individual Wholesale Customers. In 2000, the Wholesale Customers adopted the Interim Water Shortage Allocation Plan among Suburban Customers, which details how the SFPUC water allocated to wholesale customers collectively was to be allocated to each individual Wholesale Customer. The Tier 2 Drought Implementation Plan (DRIP), which was adopted by the Wholesale Customers, provides an update to the 2000 Interim Water Shortage Allocation Plan Among Suburban Customers. The allocation included in the DRIP is based on a formula that takes two primary factors into account: (1) each agency's Supply Assurance from SFPUC, with certain exceptions, and (2) each agency's purchases from SFPUC during the 3 years preceding adoption of the Plan. **Appendix G** contains a copy of the Tier 1 WSAP.

5.4.3 Mechanisms to Determine Reductions in Water Use

All SFPUC Retail and Wholesale Customers are metered. Monthly water use reports are prepared by the SFPUC's Customer Service Bureau. Based on a comparison between months the SFPUC is able to determine reductions in water use for both wholesale and Retail Customers.

5.4.4 Revenue and Expenditure Impacts During Water Shortages

If the SFPUC declares a water shortage emergency under Water Code section 350 and implements the WSAP, the SFPUC may raise water rates independently of coordination with the annual budget process to make up for lost revenue due to reduced water use (WSA Section 6.03C). The SFPUC also maintains an unappropriated fund balance that can be used to offset the effects of revenue shortfalls caused by drought.

5.5 PREPARATION FOR CATASTROPHIC WATER SUPPLY INTERRUPTION

The SFPUC has various planning documents which, in combination, address its emergency preparedness and planned response in case of a catastrophic interruption of water supplies due to power outages, earthquakes or other disasters. Additionally, the SFPUC WSIP, previously discussed in this document, includes capital projects related to seismic reliability and overall system reliability.

5.5.1 Emergency Preparedness Plans

Following the 1989 Loma Prieta Earthquake, the SFPUC created a departmental SFPUC Emergency Operations Plan (EOP). The SFPUC EOP was originally released in 1992, and has been updated approximately every 2 years. The latest EOP update will be released in Spring 2011. The EOP addresses a broad range of potential emergency situations that may affect the SFPUC and supplements the City and County of San Francisco's EOP, which was prepared by the Department of Emergency Management and most recently updated in 2008. Specifically, the purpose of the SFPUC EOP is to describe its emergency management organization, roles and responsibilities, and emergency policies and procedures.

In addition, SFPUC divisions and bureaus have their own EOPs (in alignment with the SFPUC EOP), which detail that entity's specific emergency management organization, roles and responsibilities, and emergency policies and procedures. The SFPUC tests its EOPs on a regular basis by conducting emergency exercises. Through these exercises, the SFPUC learns how well the plans and procedures will or will not work in response to an emergency. EOP improvements are based on the results of these exercises and real-world event response and evaluation. The SFPUC also has an emergency response training plan that is based on federal, State and local standards and exercise and incident improvement plans. SFPUC employees have emergency training requirements that are based on their emergency response roles.

5.5.2 Emergency Drinking Water Planning

In February 2005, the SFPUC Water Quality Bureau published the *City Emergency Drinking Water Alternatives* report. The purpose of this project was to develop a plan for supplying emergency drinking water in the City after damage and/or contamination of the SFPUC raw and/or treated water systems resulting from a major disaster. Since the publication of this report, the SFPUC has implemented a number of projects to increase its capability to support the provision of emergency drinking water during an emergency. These projects include:

- Completion of many WSIP projects and other capital upgrades to improve security, detection, and communication
- Public Information and materials for home and business
- Designation and identification of 67 emergency drinking water hydrants throughout San Francisco
- Construction of a disinfection and fill station at the existing San Francisco Zoo well, and obtaining a permit to utilize this well as a standby emergency drinking water source
- Purchase of emergency-related equipment, including water bladders and water bagging machines, to help with distribution post-disaster
- Coordination of planning with City departments, neighboring jurisdictions and other public and private partners to maximize resources and supplies for emergency response

With respect to emergency response for the SFPUC RWS, the SFPUC has prepared the SFPUC Regional Water System Emergency Response and Recovery Plan (ERRP), completed in 2003 and updated in 2006. The purpose of the ERRP is to describe the SFPUC RWS emergency management organizations, roles and responsibilities within those organizations, and emergency management procedures. This contingency plan addresses how to respond to and to recover from a major RWS seismic event, or other major disaster. The ERRP complements the other SFPUC emergency operations plans at the department, division and bureau levels for major system emergencies.

The SFPUC has also prepared in the *SFPUC Regional Water System Notification and Communications Plan*. This plan, which has been updated several times since it was first prepared in 1996 (most recently in July of 2010), provides contact information, procedures and guidelines to be implemented by the following entities when a potential or actual water quality problem arises: the SFPUC Water Supply and Treatment Division, Water Quality Division, SFPUC wholesale customers, BAWSCA, and City Distribution Division (considered to be a customer for the purposes of this plan). The plan treats water quality issues as potential or actual supply problems, which fall under the emergency response structure of the ERRP.

5.5.3 Power Outage Preparedness and Response

The SFPUC's water transmission system is primarily gravity fed, from the Hetch Hetchy Reservoir to the City. Within San Francisco's in-City distribution system, the key pump stations have generators in place and all others have connections in place that would allow portable generators to be used.

Although water conveyance throughout the RWS would not be greatly impacted by power outages because it is gravity fed, the SFPUC has prepared for potential regional power outages as follows:

- The Tesla Treatment Facility, the Sunol Valley Water Treatment Plant, and the San Antonio Pump Station, have back-up power in place in the form of generators or diesel powered pumps.
- Both the Harry Tracy Water Treatment Plant and the Baden Pump Station have back-up generators in place.
- Administrative facilities that will act as emergency operation centers also have back-up power.
- Additionally, as described in the next section, the WSIP includes projects which will expand the SFPUC's ability to remain in operation during power outages, seismic and other emergency situations.

5.5.4 Capital Projects for Seismic Reliability and Overall System Reliability

As discussed previously, the SFPUC is also undertaking a WSIP to enhance the ability of the SFPUC water system to meet identified service goals for water quality, seismic reliability, delivery reliability, and water supply.

As illustrated previously, the WSIP projects include several projects located in San Francisco to improve the seismic reliability of the in-City distribution system, including more wells that can be used as emergency drinking water sources. The WSIP also incorporates many projects related to the SFPUC RWS to address both seismic reliability and overall system reliability. All WSIP projects are expected to be completed by 2016.

In addition to the improvements that will come from the WSIP, San Francisco has already constructed the following system interties for use during catastrophic emergencies, short-term facility maintenance and upgrade activities, and in times of water shortages:

- A 40 mgd system intertie between the SFPUC and SCVWD (Milpitas Intertie);
- A 35 mgd intertie with EBMUD allowing EBMUD to serve the City of Hayward's demand and/or supply the SFPUC directly (and vice versa); and,
- One permanent and one temporary intertie to the South Bay Aqueduct, which would enable the SFPUC to receive State Water Project water.

The WSIP intertie projects include the EBMUD-Hayward-SFPUC Intertie. The WSIP also includes projects related to standby power facilities at various locations. These projects will provide for standby electrical power at 6 critical facilities to allow these facilities to remain in operation during power outages and other emergency situations. Permanent engine generators will be provided at 4 locations (San Pedro Valve Lot, Millbrae Facility, Alameda West, and Harry Tracy Water Treatment Plant), while hookups for portable engine generators will be provided at 2 locations (San Antonio Reservoir and Calaveras Reservoir).

5.6 SUPPLY & DEMAND COMPARISON OF THE RETAIL WATER SYSTEM

This section provides an assessment of the reliability of the SFPUC retail water supply during normal, dry and multiple dry years.

The Tier 1 allocation in the WSAP translates to 81 mgd of available retail water supplies from the RWS in year 2 of a drought and 79.5 mgd of retail water supplies from the RWS in years 3 and 4 of a multi-year drought.

The following tables for supply and demand comparison assume that the recycled water and groundwater projects in San Francisco are adopted and constructed. Currently, the Planning Department is undertaking environmental review for the Westside Recycled Water project and the San Francisco Groundwater Project. The SFPUC is undertaking feasibility studies for recycled water projects on the Eastside of San Francisco and anticipates that those projects have the potential to develop an additional 2 mgd of water supply. The tables below assume these projects come on line prior to 2020; however, the SFPUC might need to rely on the full 81 mgd supply from the SFPUC watersheds. In addition, ABAG and the Metropolitan Transportation Authority are required under SB375 to allocate additional growth in the nine county Bay Area in a manner that limits GHG emissions. ABAG has recently released its draft Vision Scenario to meet these objectives. The Vision Scenario places additional housing units and jobs in San Francisco through 2035 beyond what the SFPUC included in its demand projection analysis. The Vision Scenario currently reflects 19,000 more housing units and 16,000 more jobs than were included in the demand projections. If the growth in the Vision Scenario is promoted, it could result in increased retail demands on the RWS.

Normal Years: **Table 29** compares current and projected supply and demand of the SFPUC retail system. It indicates that during normal precipitation years, the SFPUC has adequate supplies to meet its projected retail water demands.

Single Dry Year: **Table 30** illustrates the level of single dry year water delivery shortage that could occur with the projected 5-year increments of water demands. As shown in this table, the SFPUC is projected to have sufficient supply to meet demands in a single dry year in all scenarios.

Table 29: Projected Normal Year Retail System Water Supply and Demand Comparison

SUPPLY / DEMAND	2010	2015	2020	2025	2030	2035
Demands (mgd)						
Retail System Demand	77.7	80.7	78.9	78.5	79.2	80.9
Supplies (mgd)						
Groundwater	2.2	5.0	5.0	5.0	5.0	5.0
Recycled Water	0.0	0.3	4.0	4.0	4.0	4.0
SFPUC RWS Watersheds[1]	75.5	75.4	69.9	69.5	70.2	71.9
Supply and Demand Comparison						
Demand Totals (mgd)	78	81	79	79	79	81
Supply Totals (mgd)	78	81	79	79	79	81
Difference (mgd)	0	0	0	0	0	0
Difference as % of Demand	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Difference as % of Supply	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

1. Assumes groundwater and recycled water are used before RWS watershed supplies to meet retail demand. However, if these supplies are not available, additional RWS watershed supply could be used up to 81 mgd.

Table 30: Projected Single Dry Year Retail System Supply and Demand Comparison

SUPPLY / DEMAND	2010 (mgd)	2015 (mgd)	2020 (mgd)	2025 (mgd)	2030 (mgd)	2035 (mgd)
Demands (mgd)						
Retail System Demand	77.7	80.7	78.9	78.5	79.2	80.9
Supplies (mgd)						
Groundwater	2.2	5.0	5.0	5.0	5.0	5.0
Recycled Water	0.0	0.3	4.0	4.0	4.0	4.0
SFPUC RWS Watershed[1]	75.5	75.4	69.9	69.5	70.2	71.9
Supply and Demand Comparison						
Demand Totals (mgd)	78	81	79	79	79	81
Supply Totals (mgd)	78	81	79	79	79	81
Difference (mgd)	0	0	0	0	0	0
Difference as % of Demand	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Difference as % of Supply	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

1. Assumes groundwater and recycled water are used before RWS watershed supplies to meet retail demand. However, if these supplies are not available, additional RWS watershed supply could be used up to 85.86 mgd. Due to the Phased WSIP Variant, it is assumed that only 81 mgd would be used.

Multiple Dry Years: **Table 31** illustrates the level of water delivery shortages that would be anticipated

if a three-year dry hydrologic condition occurred, for each year of the 5-year intervals shown. It attempts to illustrate a theoretical application of how the different water supplies may be used in multiple dry years per the UWMP requirements. As described previously, in the event of a multi-year drought, no cutbacks are anticipated in year 1. Therefore, the dry year sequences shown below begin in year 2 of a multi-year drought.

Table 31: Projected Multiple Dry Year Retail System Supply and Demand Comparison [1,2]

YEAR1	SFPUC SUPPLY AND DEMAND [2,3]	MULTIPLE DRY YEAR EVENT (MGD)		
		YEAR 1	YEAR 2	YEAR 3
2010	Total Retail Demand	77.7	77.7	77.7
	Groundwater	2.2	2.2	2.2
	Recycled Water	0.0	0.0	0.0
	RWS Watersheds[3]	75.5	75.5	75.5
	Total Retail Supply	77.7	77.7	77.7
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**
2015	Total Retail Demand	80.7	80.7	80.7
	Groundwater	5.0	5.0	5.0
	Recycled Water	0.3	0.3	0.3
	RWS Watersheds[3]	75.4	75.4	75.4
	Total Retail Supply	80.7	80.7	80.7
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**
2020	Total Retail Demand	78.9	78.9	78.9
	Groundwater	5.0	5.0	5.0
	Recycled Water	4.0	4.0	4.0
	RWS Watersheds[3]	69.9	69.9	69.9
	Total Retail Supply	78.9	78.9	78.9
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**

YEAR1	SFPUC SUPPLY AND DEMAND [2,3]	MULTIPLE DRY YEAR EVENT (MGD)		
		YEAR 1	YEAR 2	YEAR 3
2025	Total Retail Demand	78.5	78.5	78.5
	Groundwater	5.0	5.0	5.0
	Recycled Water	4.0	4.0	4.0
	RWS Watersheds[3]	69.5	69.5	69.5
	Total Retail Supply	78.5	78.5	78.5
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**
2030	Total Retail Demand	79.2	79.2	79.2
	Groundwater	5.0	5.0	5.0
	Recycled Water	4.0	4.0	4.0
	RWS Watersheds[3]	70.2	70.2	70.2
	Total Retail Supply	79.2	79.2	79.2
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**
2035	Total Retail Demand	80.9	80.9	80.9
	Groundwater	5.0	5.0	5.0
	Recycled Water	4.0	4.0	4.0
	RWS Watersheds	71.9	71.9	71.9
	Total Retail Supply	80.9	80.9	80.9
	Difference	**0**	**0**	**0**
	Difference as % of Demand	**0%**	**0%**	**0%**
	Difference as % of Supply	**0%**	**0%**	**0%**

1. The multiple dry years shown in this table reflect years 2-4 of the SFPUC's 8.5-year design drought for 2010, and years 6-8 of the SFPUC's 8.5-year design drought for years 2015 through 2035.
2. Under the WSAP, the SFPUC Retail allocations at a 10% shortage are 85.86 mgd. However, due to the Phased WSIP Variant (see Section 3.1.2, only 81 mgd of RWS watershed supply is shown.
3. Assumes groundwater and recycled water are used before RWS watershed supplies to meet retail demand. However, if these supplies are not available, additional RWS watershed supply could be used up to 79.5 mgd.

5.7 SUPPLY AND DEMAND COMPARISON OF THE WHOLESALE WATER SYSTEM

This section provides an assessment of the reliability of the SFPUC water supply during normal, dry and multiple dry years for the SFPUC's Wholesale Customers. The reliability analysis included in the following tables does not reflect decisions that may be made by 2018 regarding serving the Wholesale Customers additional water supplies in excess of the Supply Assurance or converting San Jose and Santa Clara to permanent customers. In either case, the SFPUC would serve more than 184 mgd to the Wholesale Customers which in combination with the Retail Customers may result in a watershed demand above 265 mgd. If the SFPUC were to take on serving more than 265 mgd within the service area, the SFPUC would need to develop the additional water supplies identified in Section 3.2 to continue meeting the water supply objectives of the adopted WSIP (see **Table 21**). The SFPUC is required by the WSA to consider meeting Wholesale Customer demands beyond the Supply Assurance and converting San Jose and Santa Clara to permanent customers. As those decisions have not yet been made, the SFPUC's reliability analysis carries the current Supply Assurance forward through 2035 and does not factor either the development of additional water supplies beyond those necessary to meet demands through 2018 or meeting demands in excess of the Supply Assurance. Future UWMPs will include additional information and analysis related to decisions regarding post-2018 water supply and demand comparisons.

Normal Years: **Table 32** compares current and projected supply and demand of the SFPUC wholesale system. It indicates that during normal precipitation years, the SFPUC has adequate supplies to meet its projected wholesale water demands.

Table 32: Projected Normal Year Wholesale Water Supply and Demand Comparison

SUPPLY / DEMAND	2010	2015	2020	2025	2030	2035
Demands (mgd)						
SFPUC Wholesale Demand[1]	149.5	175.4	177.6	183.1	184.0	184.0
Supplies						
SFPUC RWS Watershed Supplies to Wholesale Customers	149.5	175.4	177.6	183.1	184.0	184.0
Supply and Demand Comparison						
Demand Totals	149	175	178	183	184	184
Supply Totals	149	175	178	183	184	184
Difference	**0**	**0**	**0**	**0**	**0**	**0**
Difference as % of Supply	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Difference as % of Demand	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

1. Assumes that the 265 mgd supply limitation extends beyond 2018, and projected Wholesale Customer demands are limited to 184 mgd. Prior to 2018, 184 mgd includes the demands of San Jose and Santa Clara. After 2018, San Jose and Santa Clara will be supplied on a temporary and interruptible basis, with their total supply not exceeding 9 mgd assuming supply is available (decision to be made by end of 2018).

Single Dry Year: Given the additional supplies assumed to be available, **Table 33** illustrates the level of first dry year water delivery shortage that could occur with the projected 5-year increments of water demands. As shown in this table, the maximum projected shortage of 17% (calculated as % of demand) would occur in 2035.

Table 33: Projected Single Dry Year Wholesale Water Supply and Demand Comparison

SUPPLY / DEMAND	2010 (mgd)	2015 (mgd)	2020 (mgd)	2025 (mgd)	2030 (mgd)	2035 (mgd)
Demands (mgd)						
SFPUC Wholesale Demands[1]	149.5	175.4	177.6	183.1	184.0	184.0
Supplies (mgd)						
SFPUC RWS Watershed Supplies to Wholesale Customers	149.5	152.6	152.6	152.6	152.6	152.6
Supply and Demand Comparison						
Demand Totals (mgd)	149	175	178	183	184	184
Supply Totals (mgd)	149	153	153	153	153	153
Difference (mgd)	**0**	**23**	**25**	**30**	**31**	**31**
Difference as % of Supply	**0%**	**15%**	**16%**	**20%**	**21%**	**21%**
Difference as % of Demand	**0%**	**13%**	**14%**	**17%**	**17%**	**17%**

1. Assumes that the 265 mgd supply limitation extends beyond 2018, and projected Wholesale Customer demands are limited to 184 mgd. Prior to 2018, 184 mgd includes the demands of San Jose and Santa Clara. After 2018, San Jose and Santa Clara will be supplied on a temporary and interruptible basis, with their total supply not exceeding 9 mgd assuming supply is available (decision to be made by end of 2018).

Multiple Dry Years: Multiple-year drought sequences could subject the SFPUC customers to greater levels of shortage. **Table 34** illustrates the level of water delivery shortages that would be anticipated if a 3-year dry hydrologic condition occurred, for each year of the 5-year intervals shown. It attempts to illustrate a theoretical application of how the different water supplies may be used in multiple dry years per UWMP requirements. As described previously, in the event of a multi-year drought, no cutbacks are anticipated in year 1. Therefore, the dry year sequences shown below begin on year 2 of a multi-year drought.

Table 34: Projected Multiple Dry Year Wholesale Water Supply and Demand Comparison

YEAR	SFPUC SUPPLY AND DEMAND (MGD)	MULTIPLE DRY YEAR EVENT [1]		
		YEAR 1	YEAR 2	YEAR 3
2010	SFPUC Wholesale Demands[2]	149.5	149.5	149.5
	RWS Watershed Supplies to Wholesale Customers	149.5	132.5	132.5
	Difference	**0**	**17**	**17**
	Difference as % of Supply	**0%**	**13%**	**13%**
	Difference as % of Demand	**0%**	**11%**	**11%**
2015	SFPUC Wholesale Demands[2]	175.4	175.4	175.4
	RWS Watershed Supplies to Wholesale Customers	152.6	132.5	132.5
	Difference	**23**	**43**	**43**
	Difference as % of Supply	**15%**	**32%**	**32%**
	Difference as % of Demand	**13%**	**24%**	**24%**
2020	SFPUC Wholesale Demands[2]	177.6	177.6	177.6
	RWS Watershed Supplies to Wholesale Customers	152.6	132.5	132.5
	Difference	**25**	**45**	**45**
	Difference as % of Supply	**16%**	**34%**	**34%**
	Difference as % of Demand	**14%**	**25%**	**25%**
2025	SFPUC Wholesale Demands[2]	183.1	183.1	183.1
	RWS Watershed Supplies to Wholesale Customers	152.6	132.5	132.5
	Difference	**30**	**51**	**51**
	Difference as % of Supply	**20%**	**38%**	**38%**
	Difference as % of Demand	**17%**	**28%**	**28%**
2030	SFPUC Wholesale Demands[2]	184.0	184.0	184.0
	RWS Watershed Supplies to Wholesale Customers	152.6	132.5	132.5
	Difference	**31**	**52**	**52**
	Difference as % of Supply	**21%**	**39%**	**39%**
	Difference as % of Demand	**17%**	**28%**	**28%**
2035	SFPUC Wholesale Demands[2]	184.0	184.0	184.0
	RWS Watershed Supplies to Wholesale Customers	152.6	132.5	132.5
	Difference	**31**	**52**	**52**
	Difference as % of Supply	**21%**	**39%**	**39%**
	Difference as % of Demand	**17%**	**28%**	**28%**

1. The multiple dry years shown in this table reflect years 2-4 of the SFPUC's 8.5-year design drought for year 2010, and years 6-8 of the SFPUC's 8.5-year design drought for years 2015 through 2035.
2. Assumes that the 265 mgd supply limitation extends beyond 2018, and projected Wholesale Customer demands are limited to 184 mgd. Prior to 2018, 184 mgd includes the demands of San Jose and Santa Clara. After 2018, San Jose and Santa Clara will be supplied on a temporary and interruptible basis, with their total supply not exceeding 9 mgd assuming supply is available (decision to be made by end of 2018).

5.8 FUTURE ACTIONS AFFECTING WATER SUPPLY AND DEMAND

The previous supply and demand comparison is based on assumptions that reflect decisions made to date. There are a multitude of upcoming actions that affect the SFPUC's water supply and may increase SFPUC water demands. These actions include:

- **Securing an additional 7.4 mgd annual average in water supply to meet the shortfall in current watershed supplies resulting from instream flow requirements in San Mateo and Alameda Creeks.** The 7.4 mgd shortfall also assumes that the Upper Alameda Creek Filter Gallery Project is able to provide an annual average water supply of approximately 5.4 mgd. Additional supplies will be necessary to resolve this shortfall long-term.

- **Resolving the status of San Jose and Santa Clara as temporary, interruptible customers.** Converting San Jose and Santa Clara to permanent, non-interruptible customers would require the SFPUC to secure 9 mgd of additional water supply. Currently, San Jose and Santa Clara are temporary customers with an interruptible status. The SFPUC will continue to meet the two cities' demands up to 9 mgd through 2018, but may issue a conditional five-year notice of termination or reduction in supply to San Jose and Santa Clara if water use by the Wholesale Customers is projected to exceed 184 mgd before June 30, 2018. Development of additional supplies would be necessary to offer San Jose and Santa Clara permanent status.

- **Resolving the additional unmet needs of the Wholesale Customers beyond 2018.** Demand projections indicate an unmet need of 5 mgd in 2035 beyond the needs of San Jose and Santa Clara. Currently, the SFPUC is obligated to meet the Wholesale Customers' Supply Assurance of 184 mgd. The SFPUC has limited its deliveries from the watersheds to the Wholesale Customers collectively to 184 mgd through 2018. The Wholesale Customers have projected an increased need for water from the SFPUC greater than 184 mgd through 2035. Development of additional supplies would be necessary to meet Wholesale Customer demands beyond 184 mgd.

- **Incorporating the results of SB 375 in demand projections for the retail and wholesale customers.** SB 375 requires ABAG and MTC to develop a Bay Area Sustainable Communities Strategy (SCS) which 1) achieves a greenhouse gas emissions reduction target set by the California Air Resources Board by reducing vehicle travel, and 2) identifies a strategy to meet the Bay Area's entire housing need by income level within the Bay Area. The SCS is scheduled to be adopted by April 2013. Results of the SCS planning effort to-date suggest an increase of 903,000 more housing units and 1,222,000 more jobs in the nine-county Bay Area by 2035 which is 269,000 more housing units and 92,900 more jobs than under ABAG Projections 2009. Of this total increase, the SCS currently proposes that San Francisco would accommodate 19,000 more housing units and 16,000 more jobs than were included in this UWMP's 2035 demand projections. Wholesale Customers in the SFPUC service are expected to absorb much of this additional growth in housing and jobs under the SCS as well. If the adopted SCS places more growth in the SFPUC service area, water demand may increase.

- **Resolving additional potential shortfalls attributed to State and Federal regulatory actions or proceedings that may affect SFPUC water supplies from the Tuolumne River and local watersheds including the following:**
  - Federal Energy Regulatory Commission (FERC) relicensing of the Don Pedro Project
    - State Water Resources Control Board (SWRCB) 401 Certification of FERC relicense
    - Endangered Species Act (ESA) Section 7 consultation for FERC relicense
  - Central Valley Total Maximum Daily Load regulations
  - Bay- Delta proceedings (SWRCB, Legislative actions)
  - ESA Habitat Conservation Plans for SFPUC local watersheds

This section describes the SFPUC's water demand management measures (DMMs). The SFPUC is currently implementing various conservation measures and is meeting the 14 DMMs identified under the Urban Water Management Planning Act, which also correspond to the Best Management Practices (BMPs) developed by the California Urban Water Conservation Council (CUWCC). The SFPUC is preparing its 2008-2009 and 2009-2010 BMP Reports, and expects to be in compliance with the BMP requirements.

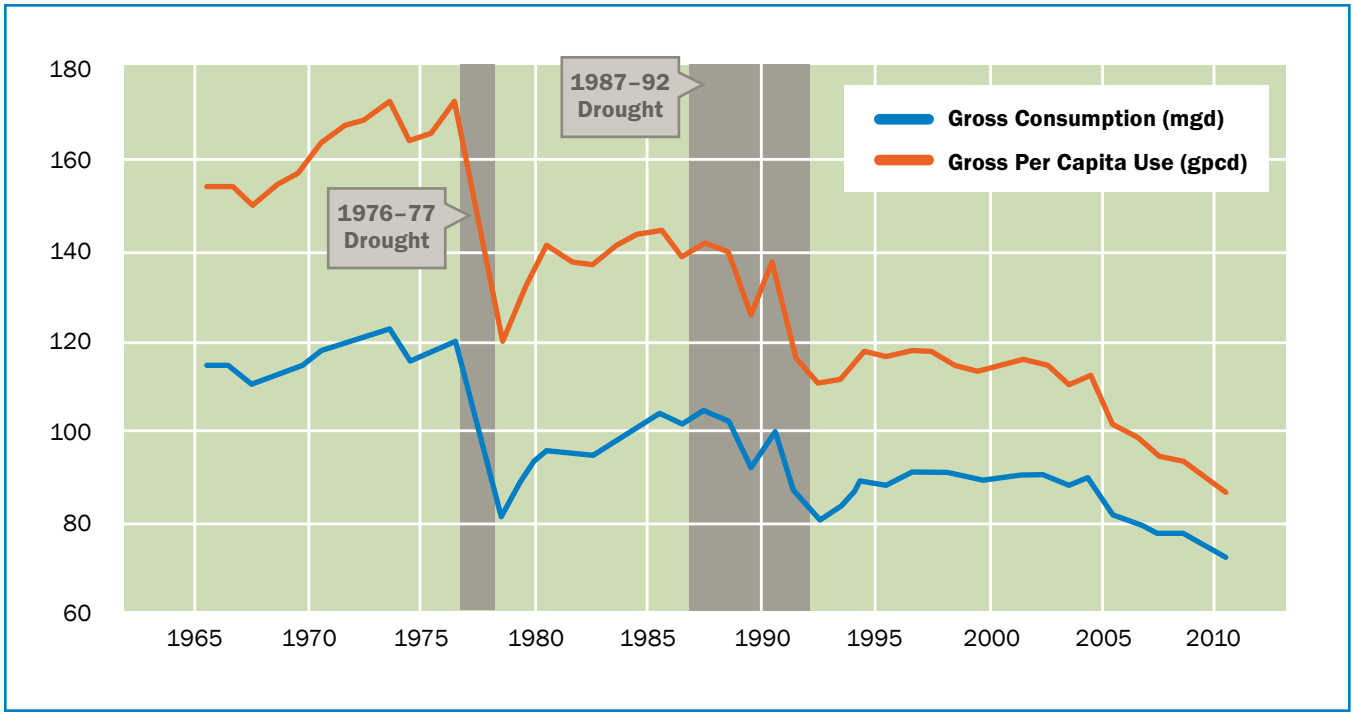
6.1 INTRODUCTION

The SFPUC has been implementing conservation programs for over 20 years. Through its continuous promotion and effort in educating San Franciscans on efficient and appropriate use of water, its conservation efforts have helped to reduce per capita water use by over one-third since 1965.

As illustrated in **Figure 9**, the first substantial decrease occurred after the 1976-77 drought in which gross per capita water use dropped from over 160 to below 120 gpcd. Despite continuous growth in San Francisco since then, total water demand remains lower than the pre-drought levels.

A second substantial decrease in water use occurred as a result of the 1987-92 drought when a new level of conservation activities resulted in a further reduction in water use. Through the continuation and expansion of these programs, per capita water use is anticipated to decrease well into the future. Today, the City's gross per capita water use is about 85.6 gpcd, one of the lowest of major urban areas in the state.

Figure 9: SFPUC Water Use During Historic Drought Periods



6.2 DEMAND MANAGEMENT BMPS

The conservation programs implemented by the SFPUC are based on the 14 BMPs identified by signatories of the CUWCC Memorandum of Understanding Regarding Urban Water Conservation in California (MOU) in 1991. The BMPs describe actions and activities that encourage water conservation and are a result of balanced collaboration between urban water agencies, public interest organizations, and private entities. These 14 BMPs also correspond to the 14 DMMs identified in the Urban Water Management Planning Act. The SFPUC is in process of compiling its 2008-2009 and 2009-2010 BMP reports to the CUWCC and expects to be on track to comply with BMP goals.

Under the MOU, the CUWCC was created and charged with responsibilities and authorities, including but not limited to recommending study methodologies for BMPs, collecting and summarizing information on implementation of BMPs and submitting annual reports to the State Water Resources Control Board. Signatories of the MOU are required to submit bi-annual reports to the CUWCC outlining progress toward implementing the BMPs.

The CUWCC amended the MOU in 2008, re-organizing the 14 BMPs into five categories and offering its signatories more flexible options for meeting the BMP requirements. The new BMP structure and compliance options reflect the evolutionary nature of water conservation measures as new implementation strategies are developed and new plumbing codes and technology advancements take place. **Table 35** summarizes the re-structured BMPs and the corresponding DMMs, and also lists some of the conservation measures implemented by the SFPUC that correspond to each BMP/DMM, as well as the year that each measure was implemented. A more detailed discussion of each BMP/DMM is provided in the subsequent subsections.

Table 35: SFPUC Conservation Programs and BMP/DMM Compliance

DMM[1]	BMP Categories[2]	BMP/DMM DESCRIPTION	SFPUC MEASURES, PROGRAMS, OR ORDINANCES (Implementation Year)[3]
A	P-Residential (3.1)	Residential Assistance Program: Water survey programs for SFR and MFR customers[4]	• Water Wise Evaluations (1920s*) • Water Audits for Direct Install Program (2008*) • Leak Allowance Program (1960s*) • Distribution of free devices (1990s*)
A	P-Residential (3.2)	Landscape Water Survey: Water survey programs for SFR and MFR customers	• Water Wise Evaluations (1920s*) • Water Audits for Direct Install Program (2008*)
B	P-Residential (3.1)	Residential Assistance Program: Residential Plumbing Retrofit	• Ordinance 392-90 (1990) • Ordinance 359-91, 185-91 and 346-91 (1991) • Ordinance 76-09 (2009)

DMM[1]	BMP Categories[2]	BMP/DMM DESCRIPTION	SFPUC MEASURES, PROGRAMS, OR ORDINANCES (Implementation Year)[3]
C	F-Operations (1.2)	Metering with Commodity Rates for All New Connections and Retrofit of Existing Connections	• 2-Tier water and wastewater rate structure (2009)
D	F-Operations (1.3)	Water Loss Control	• Unaccounted for Water Study (2005) • Automated Water Meter Program (2010-2012) • Pipeline Inspection Program (1990s*)
E	P-Landscape (5)	Large Landscape Conservation Programs and Incentives	• Large Landscape Audits (2008*) • Large Landscape Grant Program (2009*) • Ordinance 92-91 (1991), amended by Ordinance 192-00 (2000) • Ordinance 301-10 (2010)
F	P-Residential (3.3)	High-Efficiency Clothes Washing Machine Financial Incentive Programs	• Bay Area Clothes Washer Rebate Program (2006) • PG&E Water and Energy Rebate Program (2008*)[7] • Smart Rebates Program (2008*)
G	F-Education (2.1)	Public Information Programs	• Multiple Ongoing Activities * • "Water Conservation Starts with You" Newsletter (2008) • Garden for the Environment Workshops and Tours (2008*)
H	F-Education (2.2)	School Education Programs	• Conservation Connection Program (2008*) • Garden for the Environment School Field Trips (2009*) • Water Resources Curriculum and Classroom Presentations (2009*)
I	P-CII[5] (4)	Conservation Programs for CII Accounts[5]	• Water Wise Evaluations (1989*) • Water Savers Pilot Program (2005) • Large Municipal Facilities Audits (2009*) • SFUSD[8] Green Team School Audits (2009*) • Leak Allowance Program (1960s*)
J	F-Operations (1.1.3)	Wholesale Agency Assistance Programs	• As-needed staff resource to collaborate on regional efforts through BAWSCA*
K	F-Operations (1.4)	Retail Conservation Pricing	• 2-Tier water and wastewater rate structure (2009)

DMM[1]	BMP Categories[2]	BMP/DMM DESCRIPTION	SFPUC MEASURES, PROGRAMS, OR ORDINANCES (Implementation Year)[3]
L	F-Operations (1.1.1)	Conservation Coordinator	• Full-Time position(s) for Water Conservation Administrators (1986)
M	F-Operations (1.1.2)	Water Waste Prohibition	• SFPUC's Rules and Regulations for Water Service, Section E (original requirement 1960s, amendments made later) • SFPUC's Rules and Regulations for Water Service, Section F (2010, pertains to irrigation) • Ordinance 301-10 (2010)
N	P-Residential (3.4)	WaterSense Specification toilets, Residential ULFT[6] Replacement Programs	• ULFT Rebate Programs (1995-2008) • HET[9] Rebate Programs (2006*) • Direct Install Program (2009*)

1. The Urban Water Management Planning Act identified 14 DMMs that agencies need to evaluate in each UWMP.
2. F = foundational BMPs; P = programmatic BMPs. Foundational BMPs are considered to be essential water conservation activities by any utility and are adopted for implementation by all signatories to the MOU as ongoing practices with no time limits.
3. Many conservation programs listed in this table are ongoing efforts and are active to date. They are marked with an asterisk (*) after the implementation year.
4. SFR = single-family residential; MFR = multi-family residential
5. CII = commercial, industrial, and institutional
6. ULFT = ultra-low-flush toilet
7. PG&E = Pacific Gas and Electric Company
8. SFUSD = San Francisco Unified School District
9. HET = high-efficiency toilet

DMM A (BMP 3.1 & 3.2): Water Survey Programs for Residential Customers

San Francisco has provided water survey programs to its single- and multi-family residential accounts since the 1920s, focusing on the identification and repair of leaks, as well as promoting ongoing rebate programs for water-efficient fixtures. Since approximately 1989, the SFPUC has conducted conservation audits for over 30,000 single-family and 30,000 multi-family residential customers.

On average, SFPUC conducts over 600 residential water survey programs every year. Between 2007 and 2009, SFPUC conservation staff conducted 1,619 and 487 water surveys for single- and multi-family customers respectively, corresponding to an estimated water savings of over 5 acre-feet[15]. In 2008, Section staff also identified and contacted the top 5% of residential water users to encourage them to take advantage of the free water surveys program to help reduce their water use.

The surveys (also referred to as water audits) are conducted by the Section's inspectors and focus on educating customers about leak detection and water-efficient practices. During each audit, an inspector monitors the site's meter, laundry area, water heater, and plumbing fixtures, as well as landscape if applicable. In larger multi-unit buildings, the inspector will then typically inspect

15 SFPUC Water Conservation Report 2007-2010 (SFPUC, 2010). Savings were estimated for single-family water survey programs. SFPUC is currently refining its method for attributing savings to multi-family surveys

25-50% of the building's apartments or flats to identify additional leaks. For each site, the inspector will create a checklist for needed repairs and give a copy of the checklist to the owner or manager. A written summary is then returned to the owner or manager. At the request of the customer, the inspectors will mark the building's water shut-off valve with a plastic tag to improve its visibility in case of an emergency.

Starting in 2010, SFPUC inspectors also conducted thorough water surveys for single family homes that participate in the SFPUC's low-income Community Assistance Program (CAP). Free devices such as showerheads and faucet aerators are provided during the surveys, and customers found to have toilets eligible for replacement are scheduled for free installation of high-efficiency models (more details are available below under DMM N). To date, the SFPUC has conducted over 3,000 water surveys at CAP participant homes under this program and replaced over 2,000 toilets. The program also includes a multi-family component for which over 700 free toilets were provided to 28 buildings in 2010, and starting 2011 is expanding to include free toilets and installations to qualifying low-income multi-family buildings as part of coordination with the Mayor's Office of Housing for properties undergoing energy and water retrofits.

DMM B (BMP 3.1): Residential Plumbing Retrofit

Beginning with the adoption of *Ordinance 392-90*[16] in 1990, the City began efforts to require customers to install water-conserving devices. This ordinance changed the City's plumbing codes to require all new buildings (including any buildings in which the water drainage system is substantially altered, modified or renovated) to retrofit toilets and urinals with fixtures using no more than 1.6 gallons per flush (gpf) and 1 gpf, respectively. *Ordinance 359-91*[17], passed in 1991, requires the same plumbing retrofit requirements for commercial buildings, including hotels and motels.

The City then adopted a series of additional ordinances to address conservation within existing dwellings. In May and September 1991, San Francisco adopted *Ordinance 185-91* and *Ordinance 346-91*[18]. Together, these ordinances require water conservation device retrofits within single- and multi-family residential buildings upon sale, transfer of title, or major improvement to a dwelling. In 2009, an updated Residential Water Conservation Ordinance, *Ordinance 76-09*, was adopted, which requires homeowners to comply with more restrictive requirements before selling a home, including:

- Replace toilets exceeding 1.6 gpf;
- Replace showerheads with flow rate exceeding 2.5 gallons per minute (gpm);
- Replace faucets and faucet aerators having a flow rate exceeding 2.2 gpm; and
- Locate and repair all leaks.

16 San Francisco Plumbing Code sections 905 and 1001.1
17 San Francisco Building Code, Chapter 53B, Sections 53B01-53B15
18 San Francisco Housing Code, Chapter 12A, Section 12A01-12A14

DMM C (BMP 1.2): Metering with Commodity Rates for All New Connections and Retrofit of Existing Connections

All of San Francisco's Retail Customers have been metered since 1916, and are billed by volume for both water and sewer use. There are approximately 178,000 existing water meters in San Francisco. A vast majority (close to 90%) of these meters are small meters (2-inch or less) used for residential and some small commercial accounts. The remaining are large meters (3-inch or greater) used for commercial, industrial or irrigation accounts.

Since 2009, the SFPUC has implemented a 2-tier water and wastewater rate structure and a 5-year rate increase[19] for its residential accounts that promotes conservation practices by sending appropriate price signals. The rate structures are summarized in **Table 36** and **Table 37**. Non-residential sewer rates vary by the type and concentration of pollutants discharged, with more polluted the sewage being assessed a greater sewer service charge per hundred cubic foot (CCF).

Table 36: Residential 2-Tier Water Rate Structure ($/CCF)

ACCOUNT TYPE	WATER USE	EFFECTIVE 7/1/2009	EFFECTIVE 7/1/2010	EFFECTIVE 7/1/2011	EFFECTIVE 7/1/2012	EFFECTIVE 7/1/2013
Single Family Residential	≤ 3 CCF	$2.61	$3.09	$3.50	$3.90	$4.20
	>3 CCF	$3.48	$4.12	$4.60	$5.20	$5.50
Multi-Family Residential	≤ 3 CCF	$2.87	$3.28	$3.70	$4.20	$4.50
	>3 CCF	$3.82	$4.37	$4.90	$5.50	$5.90

Table 37: Residential 2-Tier Wastewater Rate Structure ($/CCF)

ACCOUNT TYPE	WATER USE	EFFECTIVE 7/1/2009	EFFECTIVE 7/1/2010	EFFECTIVE 7/1/2011	EFFECTIVE 7/1/2012	EFFECTIVE 7/1/2013
Single Family Residential	≤ 3 CCF	$6.05	$6.91	$7.16	$7.52	$7.90
	>3 CCF	$8.35	$9.21	$9.55	$10.03	$10.53
Multi-Family Residential	≤ 3 CCF	$5.66	$6.51	$7.49	$7.86	$8.25
	>3 CCF	$7.45	$8.68	$9.99	$10.49	$11.01

DMM D (BMP 1.3): Water Loss Control

An efficient distribution system is a key factor in ensuring efficient water use. The difference between the amount of water produced or purchased by an agency and the amount recorded as sold at customers' meters is referred to as "unaccounted for water. Some amount of loss in distribution is unavoidable due to necessary but un-metered uses such as fire fighting, main flushing, and storage facility cleaning. However, a portion of a system's losses can be controlled.

19 The SFPUC was previously bound by Proposition H, passed in 1998, which restricted the SFPUC's ability to increase or restructure water rates. Proposition H expired in 2006.

Retail Service Area: The SFPUC has an ongoing program to minimize the loss of water within its distribution system. Measures include regular investments in repair and replacement of old, leak-prone mains, systematic leak detection programs and regular meter calibration and repair programs. Since the 1970s, the SFPUC has implemented system-wide leak inspection and repair programs to reduce distribution system losses. From the use of advanced pitometer measurements and system zone analysis in the 1990s to the use of Permaloggers in 2005, the SFPUC has continuously enhanced its practices to identify leaks and reduce the unaccounted for water. In 2005, the SFPUC also completed an independent Unaccounted for Water Study to identify and quantify water losses. The study results indicate that the SFPUC leak management program is one of the most effective out of a nationwide sample. The SFPUC's system water loss is estimated to be less than 9% of total in-City demand (7% from unbilled authorized and unauthorized consumption, 2% from meter under-registration).

In Spring 2010, the SFPUC began deployment of the Automated Water Meter Program (AWMP), which will upgrade all of San Francisco's approximately 178,000 retail water meters with wireless advanced metering technology. Full deployment is anticipated by the end of 2012. The new system will measure, collect and analyze water usage more accurately and more frequently (on an hourly basis), which allows the SFPUC and customers to monitor water use and detect leaks faster and without the need for physical field visits and manual meter readings.

Wholesale Customer Service Area: The SFPUC initiated a Pipeline Inspection Program in the early 1990s on its RWS's 350 miles of water transmission lines. Routine inspections are considered preventive maintenance measures, but they also provide information on pipeline leaks. These inspections are usually conducted year-round with no more than one section of a major pipeline out of service at any time. The Pipeline Inspection Program covers the entire water transmission system over a 20-year period and then repeats. The SFPUC has a goal to inspect one section per quarter (4 inspections per year), with each section averaging 4-6 miles. Technically, the regional system does not have any distribution system components, only transmission system components. SFPUC staff perform meter calculations that estimate the leakage rate by comparing customer usage, plant production and water crossing the San Francisco County line.

DMM E (BMP 5): Large Landscape Conservation Programs and Incentives

In 2007, the SFPUC teamed with the City Department of Recreation and Parks to conduct a study that provided detailed audits and improvement recommendations to 12 of the highest water using parks in the City.

Recognizing that irrigation of large landscapes contributes significantly to the City's water use, the SFPUC initiated a Large Landscape Grant Program in 2009. This program provides large water users the financial incentives to implement retrofits and install fixtures to maximize the use of non-potable water or to reduce irrigation water use through conservation measures and innovative practices. The program was open to all SFPUC Retail Customers with landscape size greater than or equal to 2.5 acres. The SFPUC posted notice of the grant program on its website and mailed letters to notify a number of Retail Customers with large landscapes. In response, the SFPUC received a total of eight proposals from five

organizations. The proposals were evaluated based on a number of factors such as funding availability, estimated water savings, and community use and benefits. In FY 2009/10 and 2011/12, the program provided a total of over $4 million in funding for six projects. Upon completion of these projects, the SFPUC expects to achieve a water savings of over 20 million gallons per year.

To promote efficient irrigation water use and to comply with the State's Water Conservation in Landscaping Act (Assembly Bill 1881), the SFPUC replaced the existing irrigation ordinance (*Ordinance 92-91* Chapter 63 of the San Francisco Administration Code) with a new Water Efficient Irrigation Ordinance, adopted in 2010, *Ordinance 301-10*. Beginning in January 2011, new landscape projects or landscape modification projects between 1,000 and 2,500 square feet are required to increase their water-efficient plantings and limit turf plantings. Landscape projects greater than 2,500 square feet must demonstrate that their irrigation water use will stay within their assigned water budget, and must also obtain approval from the SFPUC Conservation Administrator of their landscape, irrigation, and soil management plans prior to any landscape installation. Owners of large landscaped areas greater than 10 acres must work with SFPUC staff to develop a compliance plan that lays out an implementation strategy and schedule for improving landscape water use efficiency.

DMM F (BMP 3.3): HECW Financial Incentive Programs

The SFPUC has offered a clothes washer rebate program for residential customers since 1999, and expanded the program to commercial customers in 2004.

In 2006 and 2007, the SFPUC partnered with six water agencies to implement the Bay Area Clothes Washer Rebate Program, which offered rebates of up to $150 per residential clothes washer depending on the efficiency level. The program was co-funded by a grant from the State of California, and was featured in San Francisco's local retail appliance stores and in larger regional stores through store visits, direct mailings, and bill inserts.

Starting in 2008, the SFPUC and over 20 local water agencies have partnered with Pacific Gas and Electric Company (PG&E) to provide a combined water and energy rebate for high-efficiency clothes washing (HECW) machines. Rebate amounts for qualifying machines have ranged from $200 for the first year ($125 from the SFPUC and $75 from PG&E) to $125 as of 2011 ($75 from the SFPUC and $50 from PG&E).

To date, the SFPUC has provided almost 15,000 residential HECW rebates through both programs. Total water savings from these rebates is estimated to be more than 7,000 acre-feet over the lifetime of the machines.

The SFPUC also provides HECW rebate programs to non-residential customers. In 2008, the SFPUC partnered with the CUWCC and 36 California water agencies in the Smart Rebates Program, which received grant funding from the State to provide commercial, industrial, and institutional (CII) customers with financial incentives for fixture upgrades, including HECWs. CII customers purchasing HECWs for common area laundry facilities (such as laundromats) are eligible. To date, approximately

280 commercial HECW rebates have been provided, corresponding to an estimated lifetime savings of 1,354 acre-feet. The SFPUC also extended the rebate program in 2010 to business owners with leased washers.

DMM G (BMP 2.1): Public Information Programs

Retail Service Area: The SFPUC works hard to promote conservation initiatives and educate the public about efficient and appropriate use of water. Ongoing activities include:

- Newspaper advertisements;
- Direct mailings;
- Distribution of educational materials and brochures to libraries and community centers,
- Participation in community events (the SFPUC staffed more than 115 events between 2007 and 2009); and
- SFPUC websites and newsletters.

In 2008, the SFPUC also created a series of direct-mailed newsletters entitled "Water Conservation Starts with You." These newsletter series addressed the need to implement voluntary cutbacks in response to historic dry winter conditions. A total of more than 350,000 newsletters were mailed to residential and commercial accounts, informing them of dry year conditions, simple conservation practices and SFPUC conservation program incentives.

Since 2008, the SFPUC has provided funding and is working with the Garden for the Environment, a public demonstration garden in San Francisco, to offer environmental education programs to interested San Francisco residents on organic gardening, urban compost systems and sustainable food systems. The partnership includes free workshops focused on climate appropriate plant selection, efficient watering practices, and pollution prevention strategies, and compliance with local irrigation ordinance requirements.

The SFPUC has also been reaching out to customers and the public directly through its billing process. On each bill, the account's current average daily water use is shown in comparison to its water use during the same period of the previous year. The bill also provides water-saving tips for home and business owners. This information helps customers recognize their water use trends and alerts them to any significant leakage issues. Conservation-related articles and tips are also included in most of the SFPUC's bi-monthly *Currents* newsletters that are mailed to customers with their bills, e-mailed, and posted on the SFPUC's web site.

In addition, the SFPUC maintains a close relationship with high-efficiency toilet and clothes washer vendors. The SFPUC staff routinely visits plumbing and appliance retail outlets to educate vendors about the SFPUC's rebate programs. A close relationship with vendors assures that the most efficient models are available to customers and that rebate program information is accurate.

Wholesale Customer Service Area: The SFPUC provides technical and administrative assistance for public information to its Wholesale Customer agencies, as requested. In addition, the SFPUC completed a series of comprehensive water demand and conservation potential studies with its Wholesale Customers in 2004. These conservation studies evaluated the cost-effectiveness of 32 conservation measures and the resulting water savings potential for each individual Wholesale Customer. These studies provided informative and educational data for the Wholesale Customers about water conservation measures and associated water savings.

The SFPUC has also been active in many regional activities to promote water conservation in the Bay Area. Recently, the SFPUC along with BAWSCA and several other Bay Area water agencies submitted a proposal for implementation grant funding through Proposition 84 for regional water conservation activities, including public information and outreach in the Bay Area.

DMM H (BMP 2.2): School Education Programs

Retail Service Area: The SFPUC's water conservation education program enriches the knowledge of students to encourage protection and preservation of our water resources. To assist with this learning, the SFPUC offers a variety of education resources developed in partnership with the San Francisco Unified School District (SFUSD), municipal departments, community gardens and non-profit education organizations.

The SFPUC provides annual funding to the SFUSD's Conservation Connection Program for the design and implementation of a comprehensive environmental education program for underserved communities. This program provides environmentally-themed workshops for educators and field trips for students.

The SFPUC also provides funding to the Garden for the Environment, an organic community garden, to offer field trips to San Francisco schools. Each field trip includes a pre-trip classroom visits in which students are introduced to water conservation and pollution prevention concepts that they can practice at the garden.

The SFPUC's education programs also bring water conservation to San Francisco classrooms. In 2009, the SFPUC partnered with the San Francisco Department of Environment (SFE) to develop a water resources curriculum for San Francisco's 4th and 5th grade students that covers the history of San Francisco's water supply, the water cycle, drought, alternative water resources, and the importance of water conservation. The curriculum includes fact sheets, lesson plans, and activity sheets that meet State of California curriculum standards. Each year the curriculum is marketed to a wide network of educators and the SFPUC and SFE also provide classroom presentations. In 2011, the SFPUC established a partnership with the Tuolumne River Trust to conduct annual presentations on source water and conservation to City elementary schools.

Together, the SFPUC's school education programs are expected to reach over 4,000 educators and students each year throughout San Francisco's public and private schools.

Wholesale Customer Service Area: The SFPUC is available to provide technical and administrative assistance for school education to its Wholesale Customer agencies, as requested. In several instances, the SFPUC has provided information packets on the SFPUC water system, such as the two-piece map series of the Hetch Hetchy/Peninsula Water Supply System and San Francisco's Water Distribution System to Wholesale Customers for inclusion in their school education programs.

DMM I (BMP 4): Conservation Programs for CII Accounts

Similar to the residential water survey program, San Francisco offers a commercial and industrial audit program to identify and repair leaks for its non-residential customers. Since 1989, the SFPUC has conducted conservation audits on over 15,000 CII accounts.

From 2007 to 2009, the SFPUC conducted 429 water audits in large commercial buildings, corresponding to an estimated lifetime savings of over 560 acre-feet. The audits are tailored to specific business operations and provide recommendations for increasing efficiency of processes on site, including cooling towers; meter(s); laundry facilities; restrooms; boilers; landscapes; and food service equipment such as ice machines, food steamers, and pre-rinse spray valves. The SFPUC inspector also reviews water consumption history, assesses fixture efficiencies, and informs the customers of possible financial incentives for which the property may qualify. Free water-saving devices and materials are provided as needed.

The SFPUC also launched a Water Savers Pilot Program in 2005 to pursue long-term, verifiable savings for large CII customers through incentives based on the volume of water saved. Participants included hotels, hospitals, colleges, and urban food harvesters. The potential lifetime water savings from the 2-year pilot were estimated at 566 acre-feet.

In response to Mayor Gavin Newsom's Executive Directive in 2009 to reduce municipal water use by 10%, San Francisco's municipal departments have implemented measures and sought assistance from the SFPUC to reduce water use. Comparison of FY 2008/2009 water consumption data to 2007/2008 data reveals that City departments met the savings goal, achieving a total savings of over 700 acre-feet for the City.

In addition, the SFPUC provided technical support and conducted detailed audits on a number of large municipal facilities, including:

- City Hall
- War Memorial and Performing Arts Center (War Memorial Opera House, Louise M. Davies Symphony Hall, War Memorial Veteran's Building)
- Main Library
- San Francisco Zoo

- Police Department (10 police stations, stables, shooting range, police academy)
- Fire Department (42 fire stations, headquarters, arson unit)
- Combined Emergency Communications Center
- 25 Van Ness (Department of Public Health, Office of Housing, and others)
- 30 Van Ness (Departments of Public Health, Public Works, Parks and Recreation, etc.)
- 1650 Mission (San Francisco Planning Department, Code Enforcement Section, etc.)
- 1660 Mission (Department of Building Inspection)

The SFPUC also partnered with the SFUSD to conduct water audits at San Francisco's Green Team schools. Audits were conducted at nine schools in 2009. The program continued in 2010 with audits for additional four schools. The SFPUC inspectors were also able to perform on-site fixture retrofits such as installing 0.5 gpm aerators on lavatory faucets and 1.5 gpm aerators on classrooms and break room faucets, helping the schools realize significant instant water savings. Together, these audits represent a potential savings of over 15 acre-feet of water annually.

DMM J (BMP 1.1.3): Wholesale Agency Assistance Programs

Under the terms of the long-term WSA with its Wholesale Customers, the SFPUC cannot provide direct financial assistance for conservation programs to a Wholesale Customer and subsequently add this expense to the suburban wholesale rate base for that year. The SFPUC can provide staff to assist Wholesale Customer conservation efforts and through agreement with BAWSCA can develop service area-wide conservation programs that can be funded as a joint expense by its Retail and Wholesale Customers.

DMM K (BMP 1.4): Conservation Pricing

Retail Service Area: For many years, the SFPUC has used conservation pricing as an incentive to conserve water. To promote the installation of efficient plumbing fixtures, the SFPUC implemented an incentive rate structure for its Retail Customers.

Water and wastewater rates were last revised in 2009 with the introduction of the 2-tier rate structure and a 5-year rate increase schedule for single- and multi-family residential accounts. The rate structures are summarized previously in **Table 2** and **Table 3**. Non-residential sewer rates vary by the quantity and type of pollutants in the wastewater discharged, with more polluted wastewater assessed a greater sewer service charge per CCF.

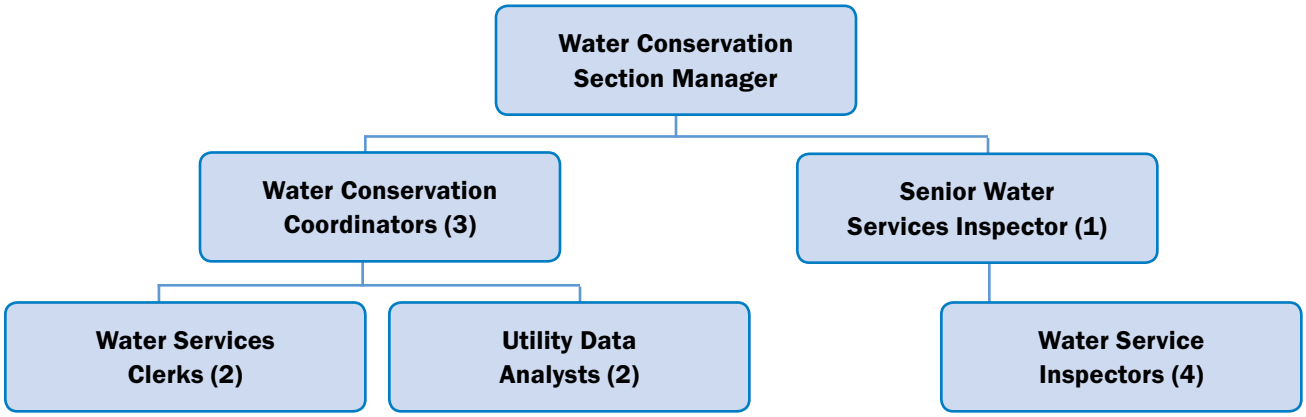
The SFPUC also addresses water use violations through its rate schedule. Violations of any water use restriction may result in the discontinuance of water service or the installation of flow restricting devices. The costs of these actions are borne by the customer.

Wholesale Customer Service Area: The SFPUC's wholesale rate structure complies with conservation pricing principles and is designed to recover the cost of providing service. Billing is based on meter readings, and utilizes an uniform rate structure. In addition, the SFPUC assesses excess use surcharges during drought periods.

DMM L (BMP 1.1.1): Water Conservation Coordinator

Retail Service Area: The SFPUC Water Conservation Section currently has 3 full-time Water Conservation Coordinators and 2 Utility Analysts. Under the direction of the Water Conservation Section Manager, these staff positions conduct implementation of various residential, landscape, and CII conservation programs. The Section also has its own inspection team and 2 water services clerks. **Figure 10** presents the current organizational chart of the SFPUC Water Conservation Section.

Figure 10: SFPUC Water Conservation Section Organization Chart (2010)



DMM M (BMP 1.1.2): Water Waste Prohibition

Section E of the SFPUC's Rules and Regulations for Water Service includes a provision regarding water waste prohibition. During the 1987-92 drought, the SFPUC enacted numerous water use restrictions and prohibitions in response to the severe water shortage. These measures are discussed in the Water Shortage Contingency Planning section of this report. With the end of the drought in 1993, the SFPUC elected to continue certain water use restrictions to further long-term conservation program. These measures are listed below and included in Section E of the SFPUC's Rules and Regulations for Water Service:

- Water waste shall be avoided, including (but not limited to) flooding or runoff into the sewers or gutters.
- Hoses used for any purpose must have positive shutoff valves.
- Restaurants shall serve water to customers only upon request.
- Decorative fountains must recycle water.

- Use of potable water for consolidation of backfill, dust control or other non-essential construction purposes is prohibited if other sources such as groundwater or reclaimed water are available and approved by the Department of Health.
- Water used for all cooling purposes and commercial car washes must be recycled.

Violation of any water use restriction may result in the installation of a flow-restricting device in the service line of the customer. Continued violation could result in termination of service. The customer bears the cost of any enforcement action.

Effective 2010, Section F of the SFPUC's Rules and Regulations for Water Service includes additional water waste prevention measures specific to irrigation, these measures are also now in the City's Water Efficient Irrigation Ordinance, *Ordinance 301-1* and include prohibition of water runoff from landscapes of all size in caused by low head drainage, overspray, broken irrigation hardware, or other conditions where water flows onto adjacent property, walks, roadways, parking lots or other structures.

DMM N (BMP 3.4): WaterSense Specification Toilets & ULFT Replacement Program

Between 2005 and 2008 the SFPUC conducted a highly visible ultralow-flush toilet (ULFT) residential rebate program providing rebates for replacement of inefficient toilets with that flush at 3.5 gpf or higher with toilets that flush at 1.6 gpf. Starting in 2006 and continuing, San Francisco has been offering rebates for replacement of 3.5 gpf or higher model toilets with High Efficient Toilets (HETs) that flush as 1.28 gpf or lower. The goal is to catalyze a market transformation toward HETs, which, unlike ULFTs, until July 2011 were not captured in the plumbing codes. Since ULFT and HET rebate program inception, San Francisco has replaced over 30,000 inefficient toilets.

Also, under the 2009 Residential Water Conservation Ordinance, residential buildings are required to install water conservation devices upon sale, transfer of title, or major improvement. This is expected to accelerate the replacement of inefficient devices (The Commercial Water Conservation Ordinance requires the same installation of efficient fixtures in all commercial properties by 2017).

San Francisco's water use patterns reveal that the highest household density and water consumption occur in the lower-income residential population. To assist these residential customers in overcoming the financial burden of initial fixture and installation costs, the SFPUC launched a high-efficiency toilet direct installation and water survey program in 2008. In this program, the SFPUC originally partnered with a local nonprofit organization to conduct water efficiency surveys, provide free high-efficiency devices, and identify potential households for the direct toilet install program. In 2010, the program was shifted mainly to recipients of the SFPUC's low-income CAP, which provides discounted water and wastewater to single family homes. Customers found to have toilets eligible for replacement are scheduled for free installation of high-efficiency models. Under the program, the SFPUC also delivered free HETs to more than 30 multi-family properties and starting in 2011 will be expanding free toilets and installations to low-income multi-family buildings. These toilet replacements represent a lifetime savings of over 3,000 acre-feet of water.

6.3 BEYOND BMPS AND DMMS

In addition to the 14 BMPs/DMMs, the SFPUC also seeks water savings through innovative programs that encourage the use of graywater and rainwater.

The SFPUC Water Enterprise teamed with the SFPUC Wastewater Enterprise in 2009 to develop a framework to promote safe use of graywater in the City. This effort included development of a guidance manual for customers on how to design simple graywater systems and launched a small laundry-to-landscape pilot program in 2011 for residential customers.

The Wastewater Enterprise also administers a rain barrel and cistern discount program and provides technical assistance related to rain barrel installation. The program also developed stormwater design guidelines and provided technical assistance on swales, rainwater gardens, stormwater planters, green roofs, and permeable pavement that captures rainwater for irrigation and recharge purposes.

Like many other water utilities, the SFPUC provides free conservation fixtures and devices to its residents during water audits and for pick up at its customer service office, such as 1.5-gpm showerheads, 0.5-gpm faucet aerators, garden spray nozzles, and toilet replacement parts (e.g. flappers and fill valves). Conservation device giveaways are a simple and cost-effective way to help customers reduce their water use. From July 2007 to June 2010, the SFPUC estimated that it distributed nearly 100,000 water-efficient devices to both residential and commercial customers.

6.4 REGIONAL COORDINATION

The SFPUC seeks opportunities to work with BAWSCA and its member agencies and other water agencies, including the SCVWD, to leverage available resources on an ongoing basis. The SFPUC's commitment to regional coordination is evident in many of its conservation programs, such as the Bay Area Clothes Washer Rebate Program in 2006 and the PG&E HECW Water and Energy Rebate Program in 2008 (both programs are discussed in previous subsections).

In 2007, the SFPUC, BAWSCA, and five other Bay Area water agencies secured $1 million in grant funding for a regional "Water Saving Hero" public education campaign. This campaign provided a consistent message about water supply conditions and long-term challenges, and informed customers across the region via simple and effective water conservation examples. The integrated advertising and marketing program included regional print, transit and radio ads, marketing materials, and a new website. Throughout the campaign, the SFPUC reduced systemwide water usage by more than 13% compared to historic consumption under similar hydrologic conditions.

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The issue of climate change has become an important factor in water resources planning in the State, and it is being considered during planning for the RWS. There is evidence that increasing concentrations of greenhouse gases have caused and will continue to cause a rise in temperatures around the world, which will result in a wide range of changes in climate patterns. These changes will have a direct effect on water resources in California, and numerous studies on climate change have been conducted to determine the potential impacts on water resources. Based on these studies, climate change could result in the following types of water resource impacts, including impacts on the RWS and associated watersheds:

- Reductions in the average annual snowpack due to a rise in the snowline and a shallower snowpack in the low- and medium-elevation zones, such as in the Tuolumne River basin, and a shift in snowmelt runoff to earlier in the year,
- Changes in the timing, intensity, and variability of precipitation, and an increased amount of precipitation falling as rain instead of as snow,
- Long-term changes in watershed vegetation and increased incidence of wildfires that could affect water quality,
- Sea level rise and an increase in saltwater intrusion,
- Increased water temperatures with accompanying potential adverse effects on some fisheries and water quality,
- Increases in evaporation and concomitant increased irrigation need, and
- Changes in urban and agricultural water demand.

However, other than the general trends listed above, there is no clear scientific consensus on exactly how global warming will quantitatively affect the state's water supplies, and current models of State water systems generally do not reflect the potential effects of global warming.

The SFPUC performed an initial assessment of the potential effects of climate change on the RWS. This initial assessment evaluated a temperature rise of 1.5-degrees Celsius (°C) between 2000 and 2025 with no change in precipitation. The temperature rise of 1.5°C is based on a consensus among many climatologists that current global climate modeling suggests a 3°C rise may occur between 2000 and 2050. The evaluation predicts that an increase in temperature of 1.5°C will raise the snowline approximately 500 feet. The elevation of the watershed draining into Hetch Hetchy Reservoir ranges from 3,800 to 12,000 feet above mean sea level, with about 87% of the watershed area above 6,000 feet. In 2000 (a normal hydrologic year in the 82-year period of historical record), the average snowline in this watershed was approximately 6,000 feet during the winter months. Therefore, the SFPUC evaluation indicates that a rise in temperature of 1.5°C between 2000 and 2025 will result in less or no snowpack between 6,000 and 6,500 feet and faster melting of the snowpack above 6,500 feet. Statistical modeling of a 1.5°C increase indicates that about 7% of the runoff currently draining into Hetch Hetchy Reservoir will shift from the spring/ summer seasons to the fall/winter seasons in the Hetch Hetchy basin by 2025. This percentage is within the current interannual variation in runoff and is within the range accounted for during normal runoff forecasting and existing reservoir management practices. The predicted shift in

runoff timing is similar to the results found by other researchers modeling water resource impacts in the Sierra Nevada due to warming trends associated with climate change.

The SFPUC is currently planning two additional assessment analyses. The first will utilize a newly calibrated hydrologic model of the Hetch Hetchy watershed to explore sensitivities to different climate change scenarios involving changes in air temperature and precipitation. The hydrologic model, HFAM II, simulates hydrologic processes using hourly input meteorological data to produce runoff into Hetch Hetchy Reservoir under varying conditions. Climate change parameters will be fed into the model to gauge sensitivity of runoff to those changing parameters. Because 85% of the SFPUC's supply derives from the Hetch Hetchy basin, this is an important part of understanding the potential effects of climate change on our system.

In addition, the SFPUC is project manager of a national pilot project under the auspices of the Water Utility Climate Alliance, a national coalition of drinking water providers chaired by the SFPUC general manager since its founding in 2007. The project, Piloting Utility Modeling Applications for Climate Change (PUMA) is a partnership between five water utilities, four Regional Integrated Sciences and Assessment (RISA) programs, and selected climate science experts. The project has five primary objectives:

1. Identify state-of-the-art climate modeling tools and techniques for use in assessment;
2. Articulate the uncertainties embedded in modeling results, as well as how to best use down-scaled and other climate modeling data in planning;
3. Acquire climate projection data utilizing the identified modeling tools and translate that data into a form and scale that can be used by utility hydrologic models to generate watershed and/or urban runoff information;
4. Build a national collaboration with the RISA program by engaging RISA experts from the north-west, California-Nevada, southeast, and northeast regional RISA enterprises;
5. Inform developing conversations between climate science users and providers regarding how existing research meets or does not meet the needs of the adaptation community, how future investment in research might better serve society, and the nature of climate services needed on the ground in communities facing adaptation challenges.

Three utilities – the SFPUC, Seattle Public Utilities, and Tampa Bay Water – are committed to conducting pilot project assessment in conjunction with the PUMA project. Two others, Portland Water Bureau and New York City Department of Environmental Protection, are active with the project and are currently considering participating at the pilot level. Given the level of collaboration between utilities facing adaptation challenges, RISA leaders, and other climate science experts in the PUMA project, the SFPUC expects both enhancement of the collective understanding of best practices in this arena, as well as a more detailed and robust assessment of the SFPUC's potential vulnerability to climate change, to emerge from the project. Thus, the SFPUC will be better equipped to make risk-based decisions in the future. A team of top climate scientists and the California RISA program, under the management of SFPUC staff, is currently developing a workplan for the SFPUC's assessment, which will encompass both Hetch Hetchy and local watersheds.

This section provides the UWMP checklist to facilitate DWR's review of the completeness of this document. The tables are organized according to subject matter.

Contingency

#[20]	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
35	Provide an urban water shortage contingency analysis that specifies stages of action, including up to a 50-% water supply reduction, and an outline of specific water supply conditions at each stage.	10632 (a)	Table 27 (p.61)
36	Provide an estimate of the minimum water supply available during each of the next three water years based on the driest three-year historic sequence for the agency's water supply.	10632 (b)	Table 31 (p.68), Table 34 (p.72)
37	Identify actions to be undertaken by the urban water supplier to prepare for, and implement during, a catastrophic interruption of water supplies including, but not limited to, a regional power outage, an earthquake, or other disaster.	10632 (c)	Section 5.5 (p.63)
38	Identify additional, mandatory prohibitions against specific water use practices during water shortages, including, but not limited to, prohibiting the use of potable water for street cleaning.	10632 (d)	Table 28 (p.62)
39	Specify consumption reduction methods in the most restrictive stages. Each urban water supplier may use any type of consumption reduction methods in its water shortage contingency analysis that would reduce water use, are appropriate for its area, and have the ability to achieve a water use reduction consistent with up to a 50% reduction in water supply.	10632 (e)	Section 5.4.2 (p.58), Table 27 (p.61)
40	Indicated penalties or charges for excessive use, where applicable.	10632 (f)	Table 28 (p.62)
41	Provide an analysis of the impacts of each of the actions and conditions described in subdivisions (a) to (f), inclusive, on the revenues and expenditures of the urban water supplier, and proposed measures to overcome those impacts, such as the development of reserves and rate adjustments.	10632 (g)	Section 5.4.4 (p.63)
42	Provide a draft water shortage contingency resolution or ordinance.	10632 (h)	Appendix H
43	Indicate a mechanism for determining actual reductions in water use pursuant to the urban water shortage contingency analysis.	10632 (i)	Section 4.2.4 (p.45)

20 Numbers are according to Table I-2 of the 2010 UWMP Draft Guidebook

Demand Management Measures (DMMs)

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
26	Describe how each water demand management measures is being implemented or scheduled for implementation. Use the list provided.	10631 (f) (1)	Table 35, Section 6.2 (p.76)
27	Describe the methods the supplier uses to evaluate the effectiveness of DMMs implemented or described in the UWMP.	10631 (f) (3)	Section 6.2 (p.76)
28	Provide an estimate, if available, of existing conservation savings on water use within the supplier's service area, and the effect of the savings on the ability to further reduce demand.	10631 (f) (4)	Section 6.2 (p.76)
29	Evaluate each water demand management measure that is not currently being implemented or scheduled for implementation. The evaluation should include economic and non-economic factors, cost-benefit analysis, available funding, and the water suppliers' legal authority to implement the work.	10631 (g)	N/A All 14 DMMs are being implemented (see Section 6.2, p.76)
30	Include the annual reports submitted to meet the Section 6.2 requirements, if a member of the CUWCC and signer of the December 10, 2008 MOU.	10631 (j)	N/A - Section completed in lieu of attaching BMP Report (currently under development)

Reliability

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
22	Describe the reliability of the water supply and vulnerability to seasonal or climatic shortage and provide data for (A) an average water year, (B) a single dry water year, and (C) multiple dry water years.	10631 (c) (1)	Section 5 (p.49)
23	For any water source that may not be available at a consistent level of use - given specific legal, environmental, water quality, or climatic factors - describe plans to supplement or replace that source with alternative sources or water demand management measures, to the extent practicable.	10631 (c) (2)	Table 19 (p.49)
53	Assess the water supply reliability during normal, dry, and multiple dry water years by comparing the total water supply sources available to the water supplier with the total projected water use over the next 20 years, in five-year increments, for a normal water year, a single dry water year, and multiple dry water years. Base the assessment on the information compiled under Section 10631, including available data from state, regional, or local agency population projections within the service area of the urban water supplier.	10635 (a)	Section 5.7 (p.70), Section 5.6 (p.66)

External Coordination and Outreach

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
4	Coordinate the preparation of its plan with other appropriate agencies in the area, including other water suppliers that share a common source, water management agencies, and relevant public agencies, to the extent practicable.	10620 (d) (2)	Section 1.1 (p.3)
6	Notify, at least 60 days prior to the public hearing on the plan required by Section 10642, any city or county within which the supplier provides water that the urban water supplier will be reviewing the plan and considering amendments or changes to the plan. Any city or county receiving the notice may be consulted and provide comments.	10621 (b)	Section 1.2 (p.4)
7	Provide supporting documentation that the UWMP or any amendments to, or changes in, have been adopted as described in Section 10640 et seq.	10621 (c)	Appendix B
54	Provide supporting documentation that the urban water management plan has been or will be provided to any city or county within which it provides water, no later than 60 days after the submission of this urban water management plan.	10635 (b)	Appendix B
55	Provide supporting documentation that the water supplier has encouraged active involvement of diverse social, cultural, and economic elements of the population within the service area prior to and during the preparation of the plan.	10642	Appendix B
56	Provide supporting documentation that the urban water supplier made the plan available for public inspection and held a public hearing about the plan. For public agencies, the hearing notice is to be provided pursuant to Section 6066 of the Government Code. The water supplier is to provide the time and place of the hearing to any city or county within which the supplier provides water. Privately-owned water suppliers shall provide an equivalent notice within its service area.	10642	Appendix B
57	Provide supporting documentation that the plan has been adopted as prepared or modified.	10642	Section 1.3 (p.5), Appendix C
58	Provide supporting documentation as to how the water supplier plans to implement its plan.	10643	Section 1.3 (p.5)
59	Provide supporting documentation that, in addition to submittal to DWR, the urban water supplier has submitted this UWMP to the California State Library and any city or county within which the supplier provides water supplies a copy of its plan no later than 30 days after adoption. This also includes amendments or changes.	10644 (a)	Section 1.3 (p.5), Appendix B
60	Provide supporting documentation that, not later than 30 days after filing a copy of its plan with the department, the urban water supplier has or will make the plan available for public review during normal business hours	10645	Section 1.3 (p.5), Appendix B

Service Area

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
8	Describe the water supplier service area.	10631 (a)	Section 2.1 (p.7)
9	Describe the climate and other demographic factors of the service area of the supplier	10631 (a)	Section 2.3 (p.14), Section 2.4 (p.14)
10	Indicate the current population of the service area	10631 (a)	Section 2.4 (p.14), Section 2.5 (p.18), Table 3 (p.16), Table 5 (p.18)
11	Provide population projections for 2015, 2020, 2025, and 2030, based on data from State, regional, or local service area population projections.	10631 (a)	Section 2.4 (p.14), Section 2.5 (p.18), Table 3 (p.16), Table 5 (p.18)
12	Describe other demographic factors affecting the supplier's water management planning.	10631 (a)	Section 2.4 (p.14), Section 2.5 (p.18)

Water Conservation

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
1	Provide baseline daily per capita water use, urban water use target, interim urban water use target, and compliance daily per capita water use, along with the bases for determining those estimates, including references to supporting data.	10608.20 (e)	Section 4.2 (p.40)
-	Include an assessment of present and proposed future measures, programs, and policies to help achieve the water use reductions.	10608.36	Section 4.2.4 (p.45)
3	Report progress in meeting urban water use targets using the standardized form.	10608.40	N/A. Does not apply until 2015 UWMP

Water Demands

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
25	Quantify past, current, and projected water use, identifying the uses among water use sectors, for the following: (A) single-family residential, (B) multifamily, (C) commercial, (D) industrial, (E) institutional and governmental, (F) landscape, (G) sales to other agencies, (H) saline water intrusion barriers, groundwater recharge, conjunctive use, and (I) agriculture.	10631 (e)(1)	Table 12 (p.36), Table 13 (p.37), Table 17 (p.47)
34	Include projected water use for single-family and multifamily residential housing needed for lower income households, as identified in the housing element of any city, county, or city and county in the service area of the supplier.	10631.1(a)	Section 4.1.4 (pg.37)

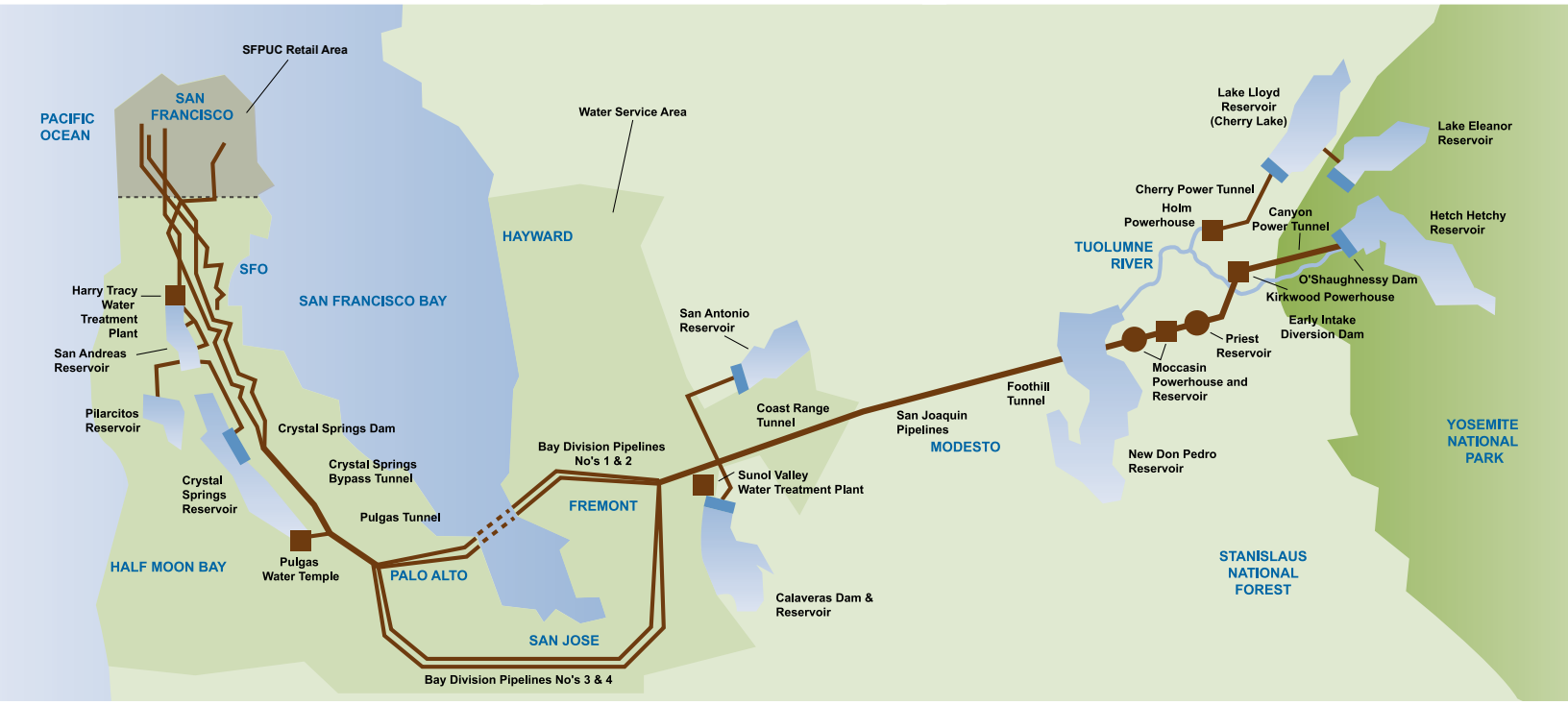
Recycled Water

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
44	Provide information on recycled water and its potential for use as a water source in the service area of the urban water supplier. Coordinate with local water, wastewater, groundwater, and planning agencies that operate within the supplier's service area.	10633	Section 3.3.2 (p.27)
45	Describe the wastewater collection and treatment systems in the supplier's service area, including a quantification of the amount of wastewater collected and treated and the methods of wastewater disposal.	10633 (a)	Section 3.2.2 (p.25), Table 9 (p.26)
46	Describe the quantity of treated wastewater that meets recycled water standards, is being discharged, and is otherwise available for use in a recycled water project.	10633 (b)	Table 8 (p.26)
47	Describe the recycled water currently being used in the supplier's service area, including, but not limited to, the type, place, and quantity of use.	10633 (c)	Section 3.2.2 (p.25)
48	Describe and quantify the potential uses of recycled water, including, but not limited to, agricultural irrigation, landscape irrigation, wildlife habitat enhancement, wetlands, industrial reuse, groundwater recharge, indirect potable reuse, and other appropriate uses, and a determination with regard to the technical and economic feasibility of serving those uses.	10633 (d)	Table 10 (p.30)
49	The projected use of recycled water within the supplier's service area at the end of 5, 10, 15, and 20 years, and a description of the actual use of recycled water in comparison to uses previously projected.	10633 (e)	Table 10 (p.30)
50	Describe the actions, including financial incentives, which may be taken to encourage the use of recycled water, and the projected results of these actions in terms of acre-feet of recycled water used per year.	10633 (f)	Section 3.3.3 (p.29)
51	Provide a plan for optimizing the use of recycled water in the supplier's service area, including actions to facilitate the installation of dual distribution systems, to promote re-circulating uses, to facilitate the increased use of treated wastewater that meets recycled water standards, and to overcome any obstacles to achieving that increased use.	10633 (g)	Section 3.3.4 (p.29)

Water Supply

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
5	Describe water management tools and options to maximize resources and minimize the need to import water from other regions.	10620 (f)	Section 3.3 (p.27)
13	Identify and quantify the existing and planned sources of water available for 2015, 2020, 2025, and 2030.	10631 (b)	Sections 3.1, 3.2 (p.19-26)
14	Indicate whether groundwater is an existing or planned source of water available to the supplier. If yes, then complete 15 through 21 of the UWMP Checklist. If no, then indicate "not applicable" in lines 15 through 21 under the UWMP location column.	10631 (b)	Yes
15	Indicate whether a groundwater management plan been adopted by the water supplier or if there is any other specific authorization for groundwater management. Include a copy of the plan or authorization.	10631 (b) (1)	Section 3.2 (p.24)
16	Describe the groundwater basin.	10631(b) (2)	Section 3.2 (p.24)
17	Indicate whether the groundwater basin is adjudicated? Include a copy of the court order or decree.	10631 (b) (2)	Section 3.2 (p.24)
18	Describe the amount of groundwater the urban water supplier has the legal right to pump under the order or decree. If the basin is not adjudicated, indicate "not applicable" in the UWMP location column.	10631 (b) (2)	Not Applicable
19	For groundwater basins that are not adjudicated, provide information as to whether DWR has identified the basin or basins as overdrafted or has projected that the basin will become overdrafted if present management conditions continue, in the most current official departmental bulletin that characterizes the condition of the groundwater basin, and a detailed description of the efforts being undertaken by the urban water supplier to eliminate the long-term overdraft condition. If the basin is adjudicated, indicate "not applicable" in the UWMP location column.	10631 (b) (2)	Section 3.2 (p.24)
20	Provide a detailed description and analysis of the location, amount, and sufficiency of groundwater pumped by the urban water supplier for the past five years.	10631 (b) (3)	Section 3.2 (p.24)
21	Provide a detailed description and analysis of the amount and location of groundwater that is projected to be pumped.	10631 (b) (4)	Section 3.2 (p.24), Section 3.3.1 (p.27)
24	Describe the opportunities for exchanges or transfers of water on a short-term or long-term basis.	10631 (d)	Section 5.2.4 (p.53)
30	Include a detailed description of all water supply projects and programs that may be undertaken by the water supplier to address water supply reliability in average, single-dry, and multiple-dry years, excluding demand management programs addressed in (f)(1). Include specific projects, describe water supply impacts, and provide a timeline for each project.	10631 (h)	Section 5.2 (p.51)
31	Describe desalinated water project opportunities for long-term supply, including, but not limited to, ocean water, brackish water, and GW.	10631 (i)	Section 5.3.1 (p.56)

#	UWMP REQUIREMENT	CA WATER CODE	2010 UWMP LOCATION
33	Provide documentation that either the retail agency provided the wholesale agency with water use projections for at least 20 years, if the UWMP agency is a retail agency, OR, if a wholesale agency, it provided its urban Retail Customers with future planned and existing water source available to it from the wholesale agency during the required water-year types.	10631 (k)	Appendix G
52	Provide information, to the extent practicable, relating to the quality of existing sources of water available to the supplier over the same five-year increments, and the manner in which water quality affects water management strategies and supply reliability.	10634	Section 3.4 (p.31)



2010 Urban Water Management Plan

for the City and County of San Francisco

Prepared by: The San Francisco Public Utilities Commission

San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

East Bay Municipal Utility District
Home Water Report Pilot Study
Preliminary Water Saving Data Summary
January 2013

A summary of water consumption data from the experimental and control groups receiving Home Water Reports beginning in June and July of 2012 shows a 4.5% savings from September and October 2012 meter reads, and a 6.6% savings from November and December meter reads.

September/October 2012 Meter Reads

	# Accounts	Average Change from Prior Year (GPD)	GPD Difference from Prior Year (Percent)	Difference In GPD Change (Percent)	P-Value
All	5,829				
Control	2,614	16.03	4.8%		
Experimental	3,214	1.14	0.3%	**-4.5%**	0.0002

November/December 2012 Meter Reads

	# Accounts	Average Change from Prior Year (GPD)	GPD Difference from Prior Year (Percent)	Difference In GPD Change (Percent)	P-Value
All	4,287				
Control	1,732	-6.16	-2.3%		
Experimental	2,554	-22.17	-8.9%	**-6.6%**	0.0002

EAST BAY MUNICIPAL UTILITY DISTRICT

Home Water Reports:

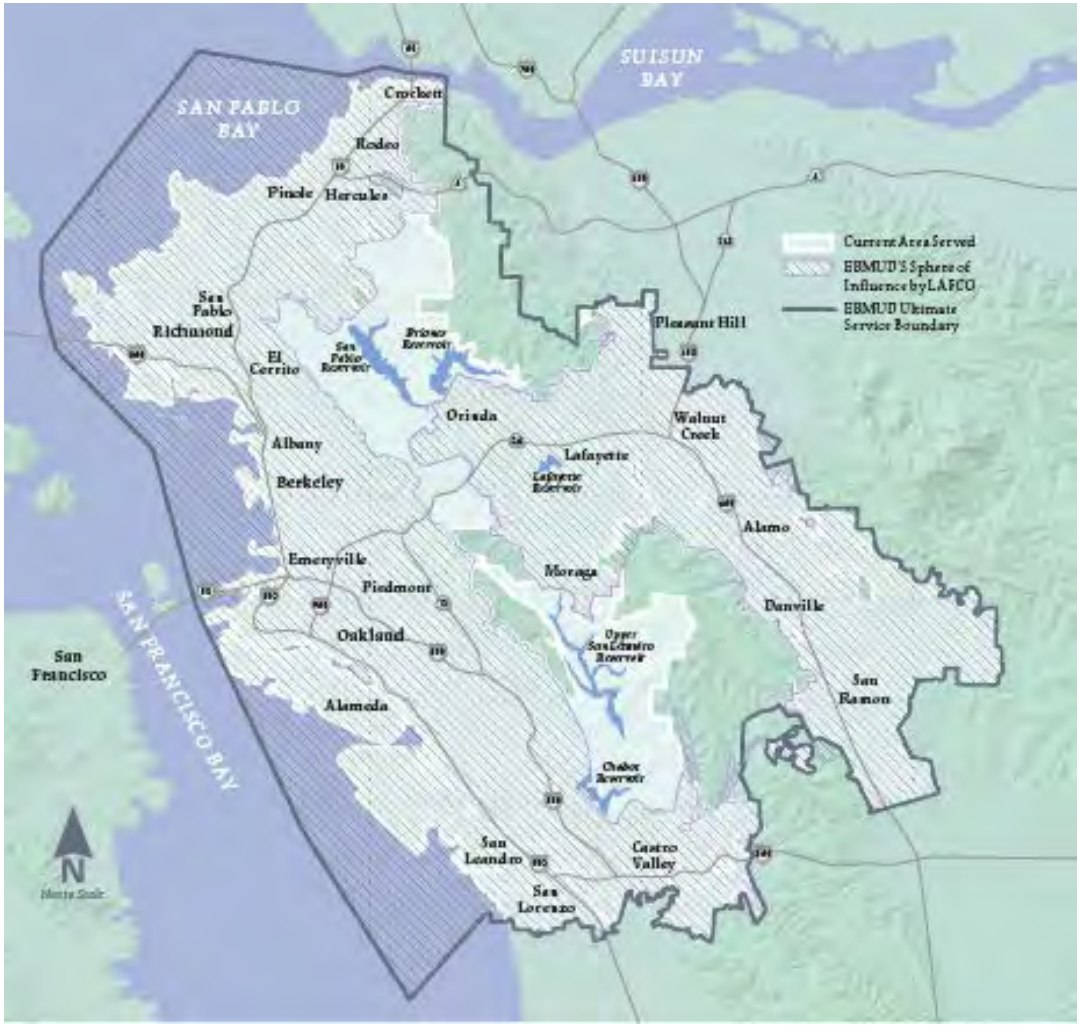
The Brains Behind Water Billing

Richard Harris, EBMUD

Peter Yolles, WaterSmart Software Inc.

WaterSmart Innovations 2012 Conference and Exposition

Water and Wastewater Service Areas



- 1.34 million customers (W)
- 0.65 million customers (WW)
- 85 % residential
- ~ 210 mgd demand
  - 160 mgd
- 35 communities
- Distinct microclimates
- 330 sq.mi service area (W)
- 83 sq.mi service area (WW)
- >4,000 miles of pipe
- 400,000 meters
- 385,000 accounts

Project Drivers

- Energy utilities have pioneered conservation programs that provide customers with information on how their use compares to neighbors, past use, and efficient use.
- Based on research in behavioral sciences these programs have produced measurable direct reductions in energy use and served as entry to other conservation programs.

Project Drivers

- Need for new turnkey solutions for 325,000 residential accounts
- 20+ year outdated water bill format, little room for messaging, no charts
- New billing system launched in Sept. 2011 not yet capable for customization
- Conservation services moving away from standard fixture and appliance rebates toward water management tools/services

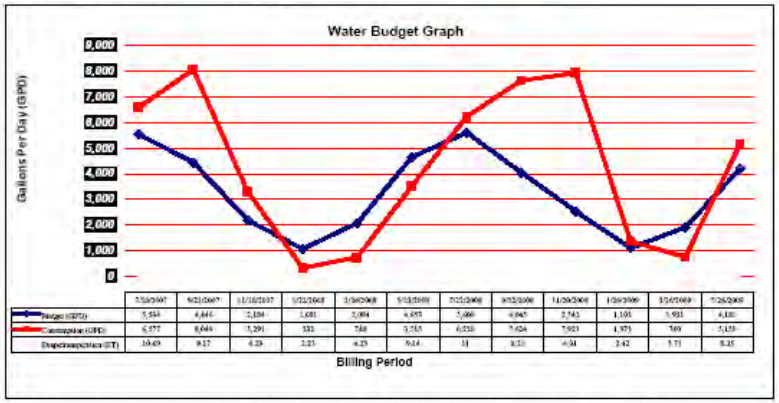
Water Management Services
Landscape Irrigation Water Budgets

East Bay Municipal Utility District
Water Conservation Division
Maximum Allowable Water Budget

Thank you for participating in our Landscape Irrigation Water Budget Program. The following is your customized water usage profiles for the last two years. EBMUD records indicate that this account primarily serves landscape irrigation. The graphical description compares your measured water usage verse your budgeted water usage for each billing period.

Customer Name:	[redacted]
Service Address:	
City:	San Leandro
Account #:	[redacted]
Meter #:	
Est. Irrigated Area (sq. ft.):	49,000

Water Budget Summary	Used	Budgeted
Gallons used last 12 months	1,743,000	1,178,973
Gallons used previous year	1,350,720	1,214,098
Percent of budget last 12 months		148%
Percent of budget for previous year		111%
2 year "irrigation season" estimated savings in dollars		$ 3,342.76
2 year "irrigation season" estimated savings in gallons		969,142



	7/26/2007	9/21/2007	11/16/2007	1/12/2008	3/10/2008	5/12/2008	7/12/2008	9/12/2008	11/10/2008	1/9/2009	3/12/2009	7/26/2009
Budget (GPD)	5,559	4,444	2,184	1,681	2,004	4,955	5,660	4,845	2,743	1,101	1,921	4,130
Consumption (GPD)	6,577	8,049	3,291	332	748	3,215	6,210	7,424	2,923	1,971	769	5,439
Evapotranspiration (ET)	10.49	9.17	4.39	2.23	4.23	9.14	11	8.21	4.34	2.42	3.71	8.45

* ET = Represents the estimated water need of cool season grass (in inches) for each billing period. The Water Budget Calculation does not use rain, typically irrigation sytems can be turned off for the winter months of November, December, January, and February

The Maximum Allowable Water Budget is calculated using 100% of Reference Evapotranspiration (ETo) of the irrigated area for each billing period. If you feel the irrigated area is not accurate or would like more information on this program, contact EBMUD at 510 986-7615.

Water Management Services:
Customized Water Savings Reports

EAST BAY MUNICIPAL UTILITY DISTRICT

water SMART

Success Story – Crow Canyon Heights

Common Interest
315 Diablo Rd. #221
Danville, CA 94526
Kellie Graham, Property Manager
(925) 743-3080
kgraham@commoninterest.com

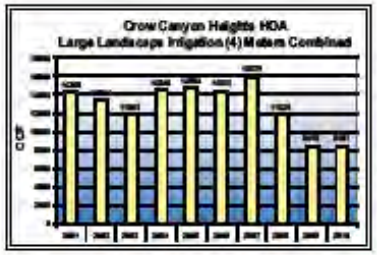
Cleary Brothers Landscaping
P.O. Box 3577
Danville, CA 94526
Martin Cleary, Owner
(925) 838-2551
mcleary@clearybros.com

New high efficiency sprinklers and rotating nozzles

Estimated Water Savings for common area landscaping:
11.9 million gallons used in 2007
6.3 million gallons used in 2010
Total savings compared to 2007 usage:
5.6 million gallons and over $14,000

Crow Canyon Heights contacted the East Bay Municipal Water District (EBMUD) Water Conservation Division to request a free irrigation audit in 2006. The audit was completed and a report submitted to Common Interest Management. Cleary Brothers Landscape then submitted an application for rebates from EBMUD. In 2008, Cleary Brothers submitted proposals to the Crow Canyon Heights Board of Directors to install new high efficiency lawn sprinklers equipped with pressure regulation devices, check valves, and rotating nozzles to improve sprinkler uniformity and minimize low head drainage. In addition, self-adjusting irrigation controllers were installed in some areas.

By 2011, Cleary Brothers submitted an upgrade application for the last irrigation only meter. Pending rebates total $6,100 through the end of 2011. For each rebate, water consumption was tracked and checked against a landscape water budget based on local weather and the total irrigated area for a period of one year. The bar chart shows how improved irrigation equipment and management can reduce water consumption and costs.



EBMUD recognizes these businesses and customer for their water conservation effort at this site. However, EBMUD makes no representation regarding these businesses or that similar water savings will be achieved on other sites.

www.ebmud.com/watersmart

We make it easy to conserve. EBMUD

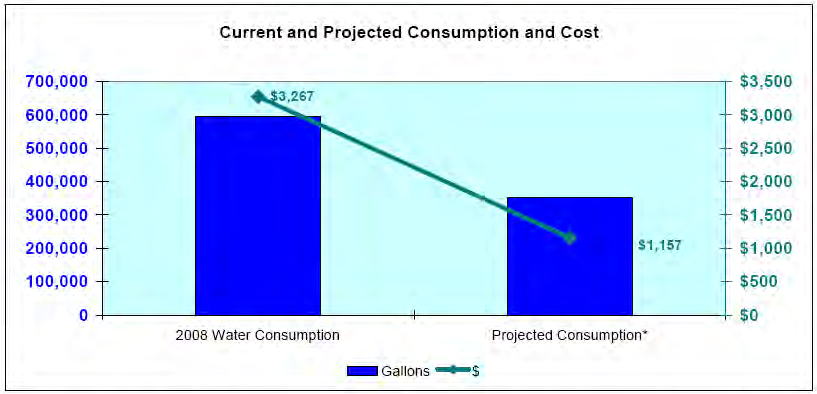
East Bay Municipal Utility District
WaterSmart Worksheets - Executive Summary

Water Savings Summary for Clif Bar & Company

Estimated Annual Savings	
Water Savings (gallons)	241,849
Energy Savings (therms)	481
Total Dollar Savings	**$2,111**

Return on Investment	
Estimated cost for water efficiencies:	$14,100
EBMUD Rebates:	$0
Payback (years):	**6.7**

Identified Water Savings by Device/Area



Graph I notes: The dollar value for the water costs are based on a straight water and wastewater rate calculation and may not reflect actual costs. * Estimated consumption upon implementation of water savings identified.

EBMUD ♦ PO Box 24055, MS 48 ♦ Oakland, CA 94623-1055 ♦ 1-866-403-2683 ♦ www.ebmud.com

water SMART

Pilot Study Objectives

- Test new customer communication tools
- Benchmark water use and behaviors
- Ongoing customer surveys and feedback
- Evaluate water savings and future potential
- Inform future EBMUD bill redesign efforts
- Benefit water utility community in new water management services

Study Partners and Participants

EBMUD

- client
- in-kind services (Call Center, survey data entry)

WaterSmart Software, Inc. (WSS)

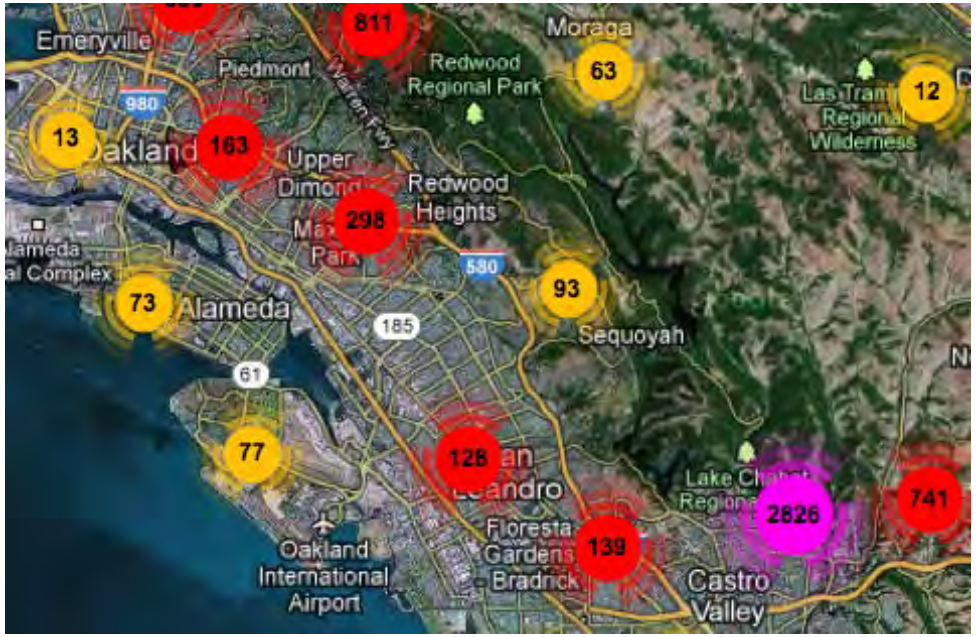
- vendor
- web-hosting

California Water Foundation (CWF)

- co-funder
- Independent evaluation and customer satisfaction

HWR Pilot Study Participants

City	No. of Participants	Control Group	Total
Castro Valley, CA	8,000	-	8,000
Oakland, CA	-	3,500	3,500
Random	1,500	1,500	3,000
Total	**9,500**	**4,000**	**14,500**



Project Schedule

- **Feb 2012** - Residential Water Use Survey
- **Jun 2012** - Home Water Reports mailed
- **Jun 2012** - Customer & utility analytics dashboards launched
- **Jan 2013-14** - CWF/EBMUD 1-year evaluation period
- **2014 onward** – potential on-going deployment under EBMUD Water Conservation Master Plan

WaterSmart Software—How It Works

Consumption and Residence Data

Rebate & Incentive Programs

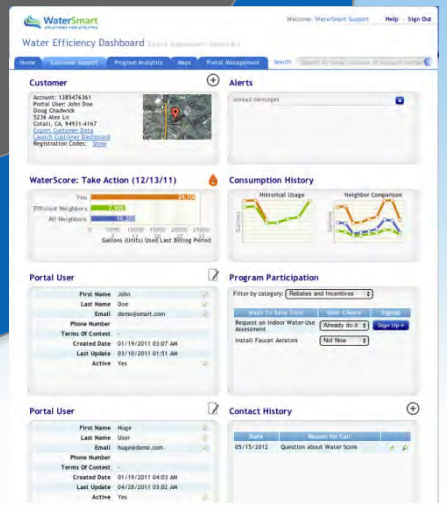
Demographic & Real Estate Data

Survey Responses & User Information

WaterSmart Recommendation Engine

Consumer Web Portal

Home Water Reports

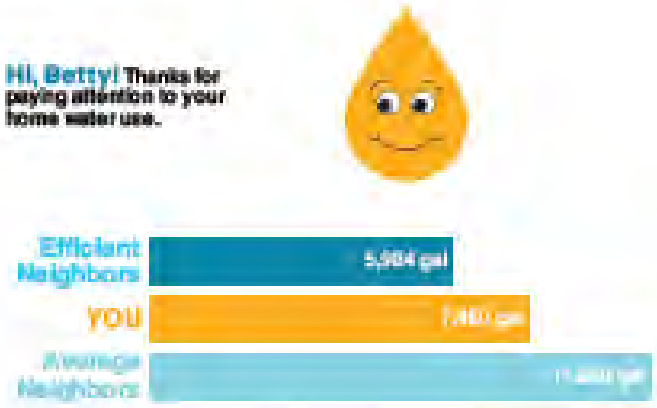


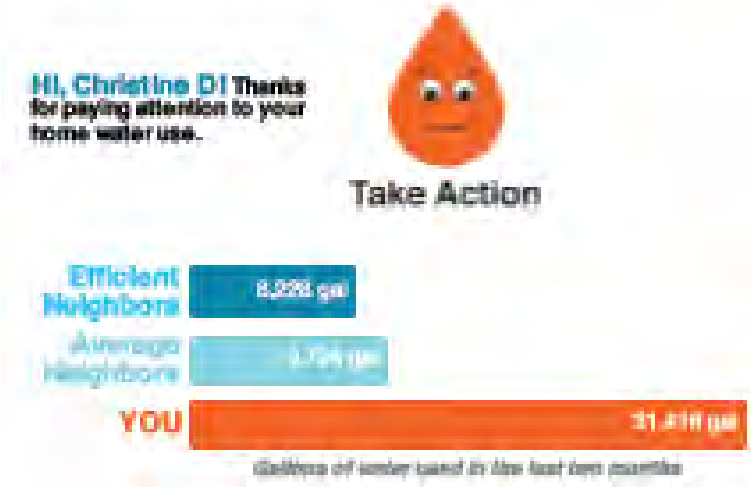
Water Efficiency Dashboard

Survey, Consumption & Real Estate Data → Comparable Residences

- Occupancy Cohorts (1 – 5 pphh)
- Irrigable Area Cohort (sq. ft.<5K, 5k-10k, >10k)
- Cohort Size (# households, 100's – 1,000's)
- Households Used (35 – 187 per cohort)
- Median (Bi-monthly) Household Water Use (3,740 – 14,950 gal)
- Median Daily Per Capita Water Use (34 – 105)

Benchmarking Water Use

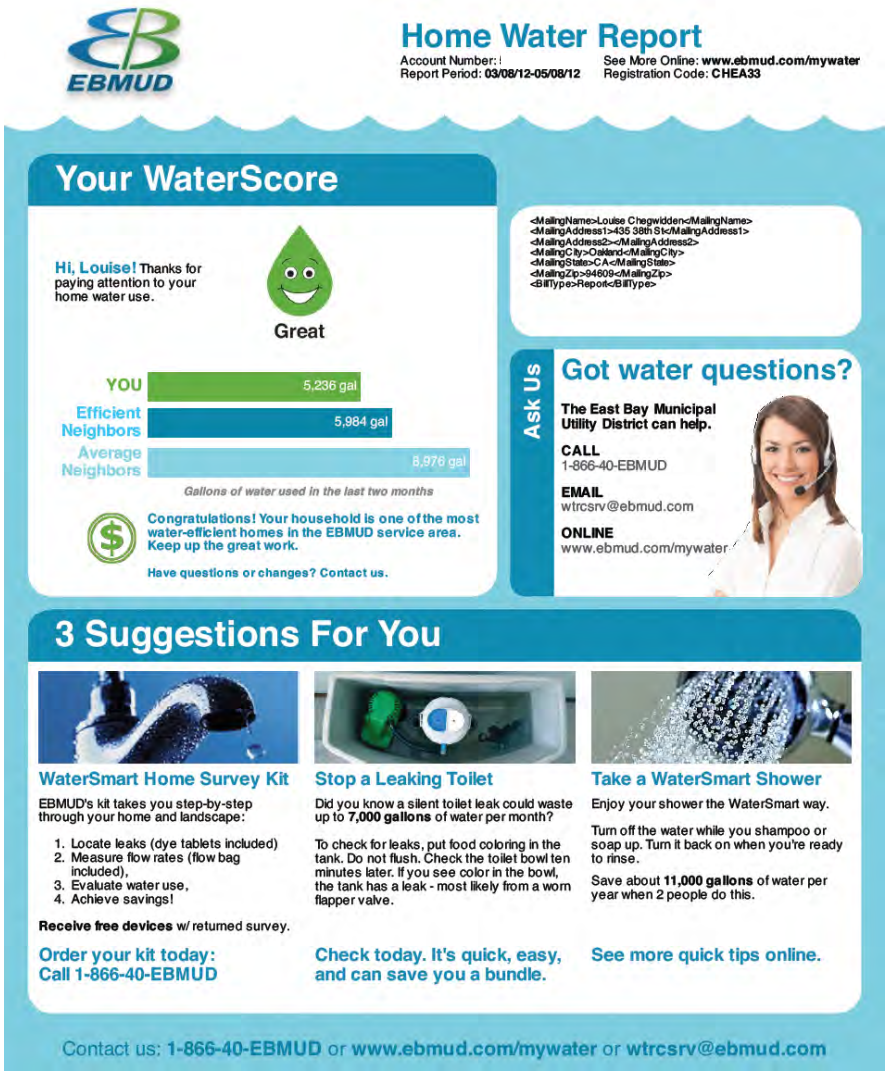




Home Water Report Design
Bi-monthly Mailings

Comparison to similar households

Personalized savings/offers



EBMUD

Home Water Report

Account Number: |
Report Period: **03/08/12-05/08/12**

See More Online: **www.ebmud.com/mywater**
Registration Code: **CHEA33**

Your WaterScore

Hi, Louise! Thanks for paying attention to your home water use.

Great

YOU	5,236 gal
Efficient Neighbors	5,984 gal
Average Neighbors	8,976 gal

Gallons of water used in the last two months

Congratulations! Your household is one of the most water-efficient homes in the EBMUD service area. Keep up the great work.

Have questions or changes? Contact us.

<MailingName>Louise Chegwidden</MailingName>
<MailingAddress1>435 38th St</MailingAddress1>
<MailingAddress2></MailingAddress2>
<MailingCity>Oakland</MailingCity>
<MailingState>CA</MailingState>
<MailingZip>94609</MailingZip>
<BillType>Report</BillType>

Ask Us

Got water questions?

The East Bay Municipal Utility District can help.

CALL
1-866-40-EBMUD

EMAIL
wtrcsrv@ebmud.com

ONLINE
www.ebmud.com/mywater

3 Suggestions For You

WaterSmart Home Survey Kit

EBMUD's kit takes you step-by-step through your home and landscape:

1. Locate leaks (dye tablets included)
2. Measure flow rates (flow bag included),
3. Evaluate water use,
4. Achieve savings!

Receive free devices w/ returned survey.

Order your kit today: Call 1-866-40-EBMUD

Stop a Leaking Toilet

Did you know a silent toilet leak could waste up to **7,000 gallons** of water per month?

To check for leaks, put food coloring in the tank. Do not flush. Check the toilet bowl ten minutes later. If you see color in the bowl, the tank has a leak - most likely from a worn flapper valve.

Check today. It's quick, easy, and can save you a bundle.

Take a WaterSmart Shower

Enjoy your shower the WaterSmart way.

Turn off the water while you shampoo or soap up. Turn it back on when you're ready to rinse.

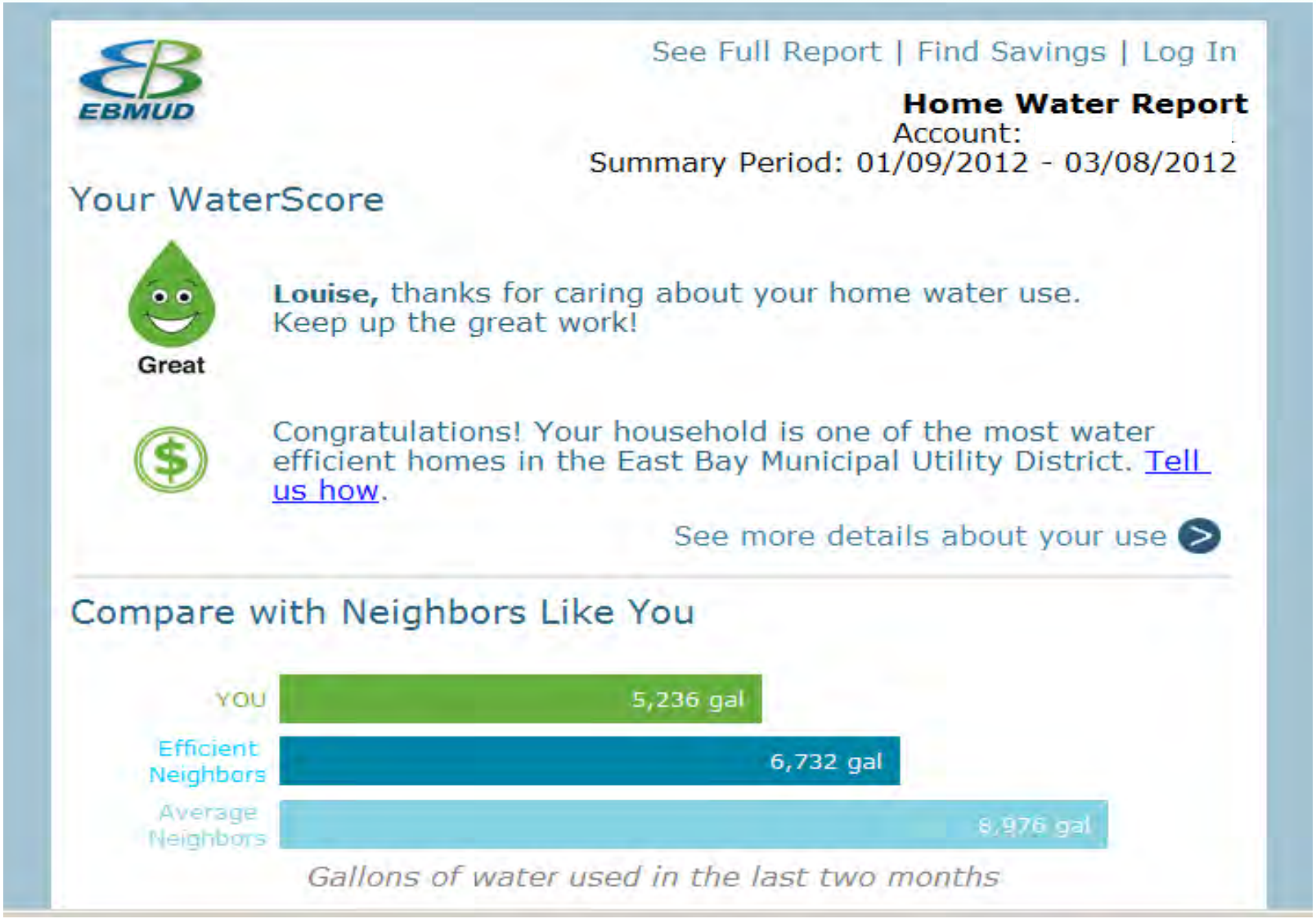
Save about **11,000 gallons** of water per year when 2 people do this.

See more quick tips online.

Contact us: **1-866-40-EBMUD** or **www.ebmud.com/mywater** or **wtrcsrv@ebmud.com**

Modified messaging and raffle prizes

Email Home Water Report (eHWR)

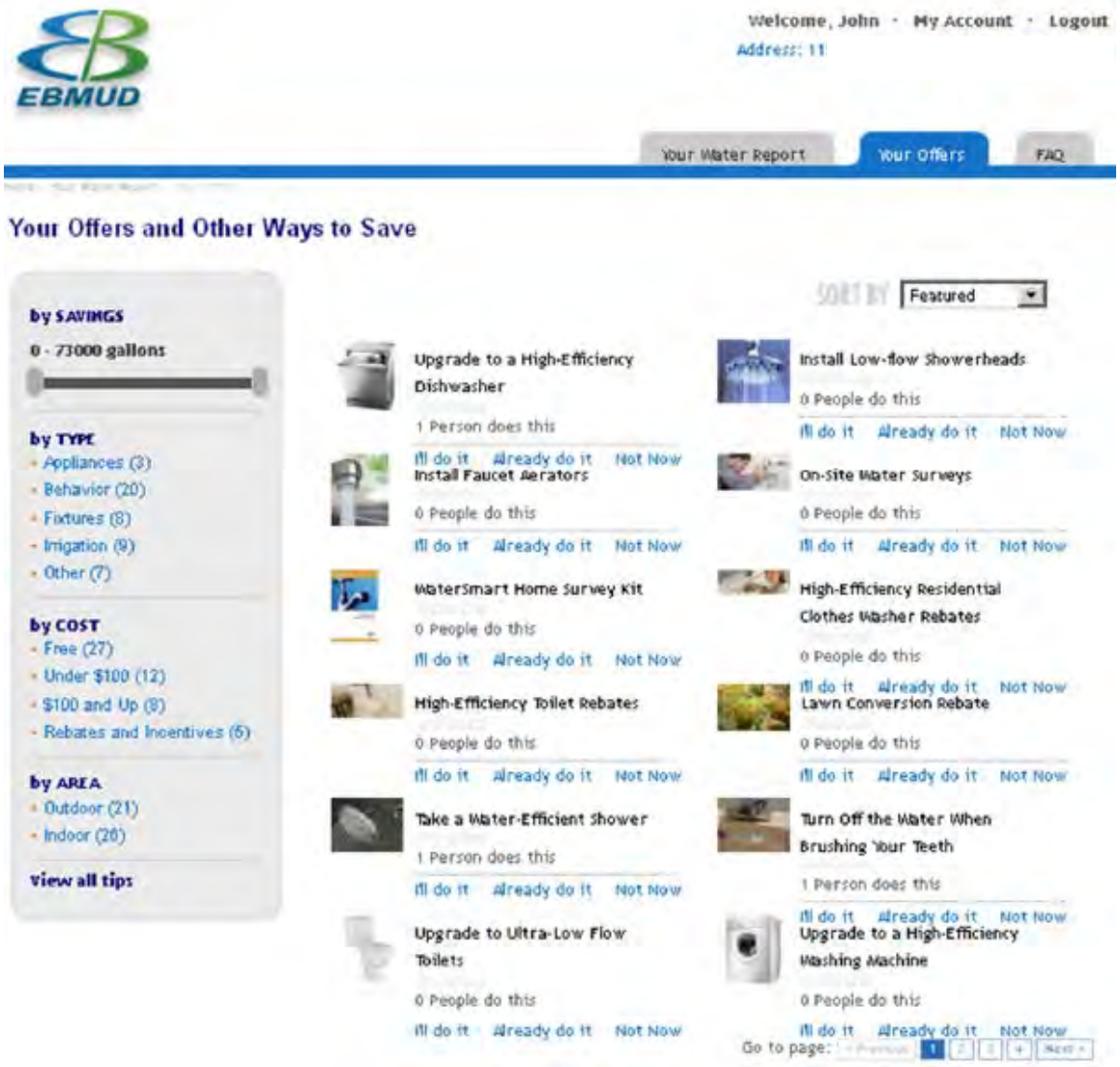


Online Customer Portal

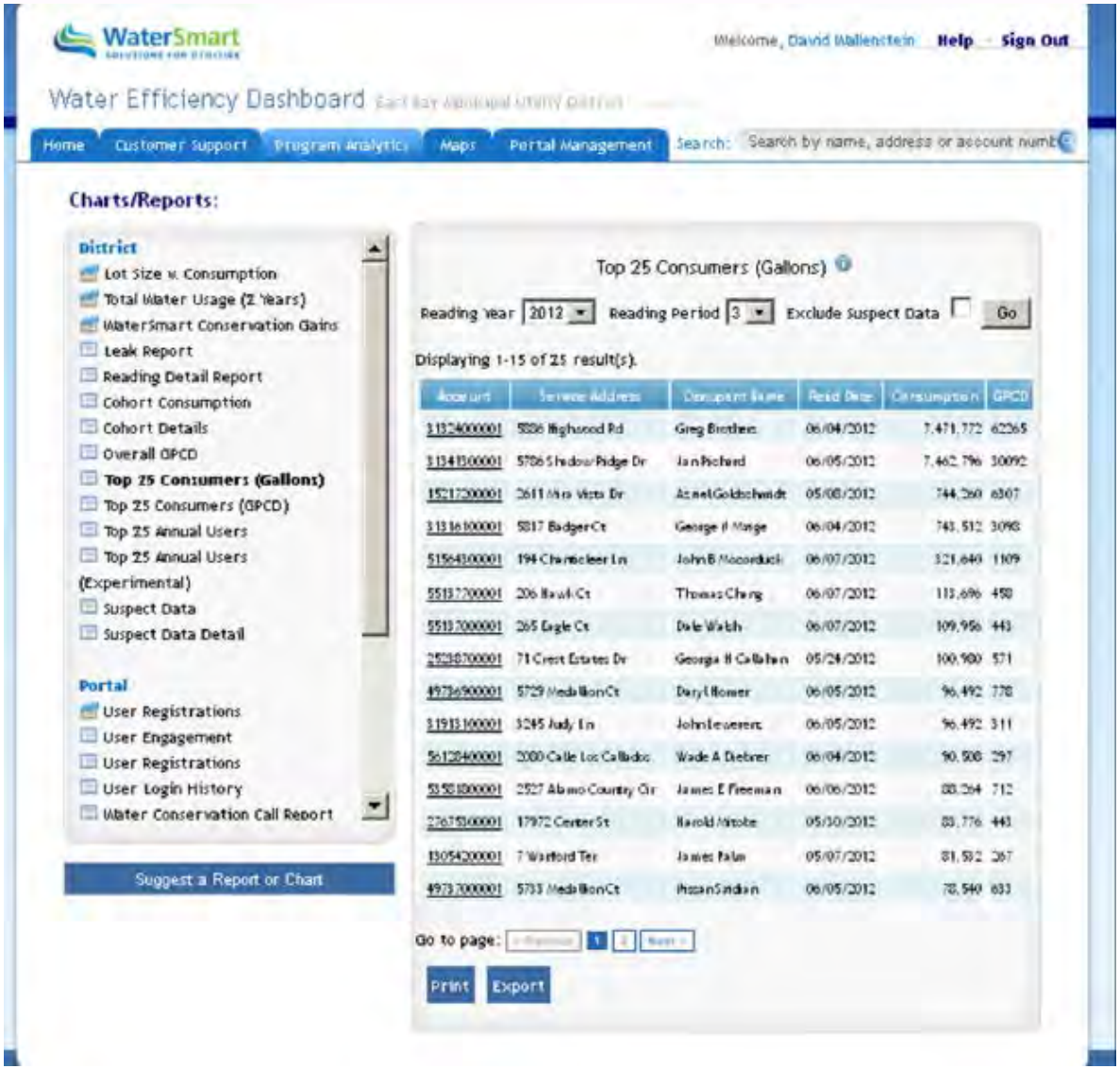
- Historical Water Consumption
- Neighbor Water Use Comparisons
- Customer FAQ
- Ability to Change Residence Information
- Possible Integration with AMR

Online Customer Portal

- Conservation rebate offers
- Water savings tips
- Educational materials



Utility-Facing Water Efficiency Dashboard

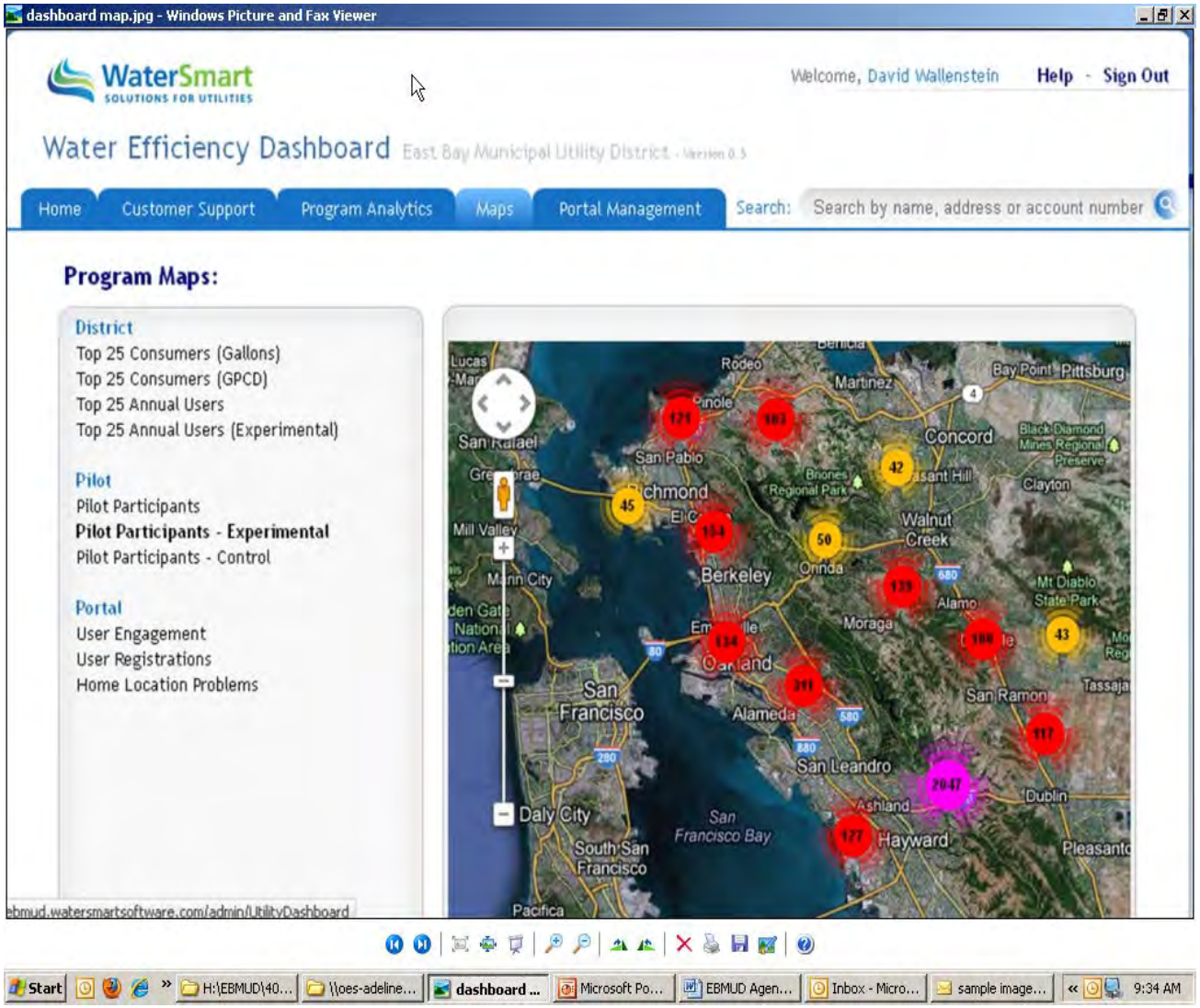


- Program Management
- Utility-Level and User-Level Data
- Water Use Analyses

Utility-Facing Water Efficiency Dashboard

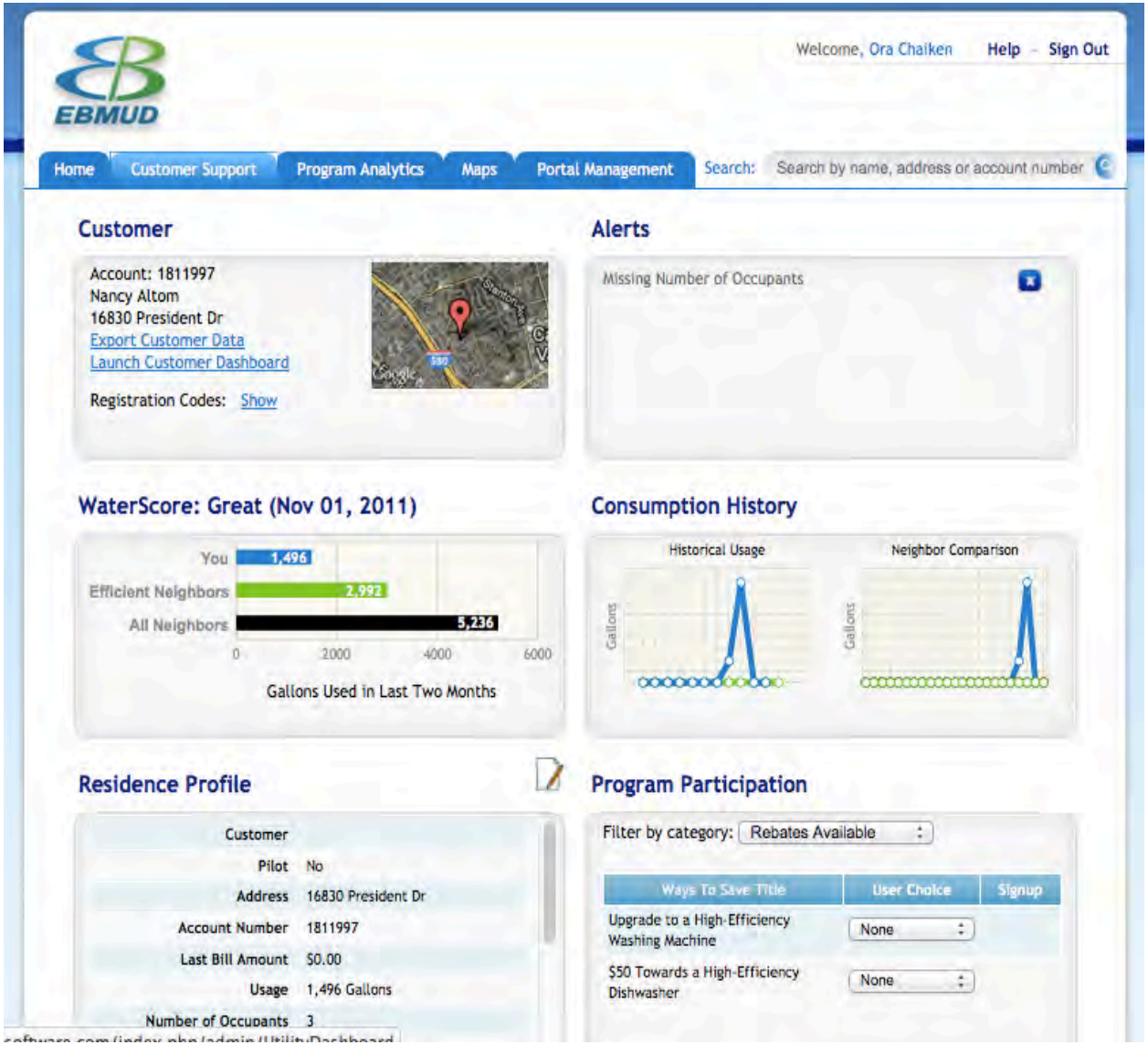
- Water Use Analyses
- Feedback & Tracking

Utility Dashboards: Training and Tools



- Mapping & Data Visualization

Utility Dashboards: Training and Tools



- Administrative Tools
- Call Center Training
- Customer Call Logging

Lessons and Results: Survey

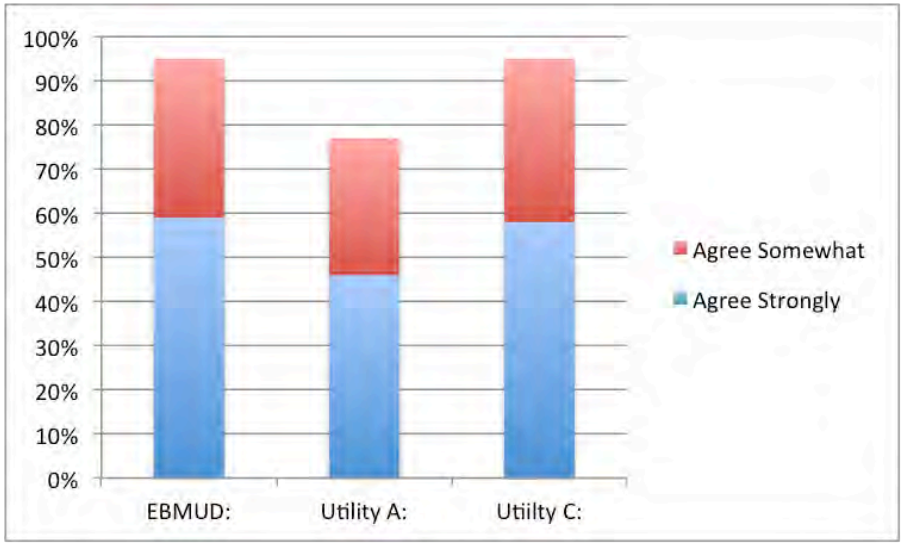
- >13,000 distributed online and via mail
- Responses: >2,600 (~21%) ($100 cash prize a motivator)
- Confirmed how little people know about their water use

Do you agree or disagree with the following statements?

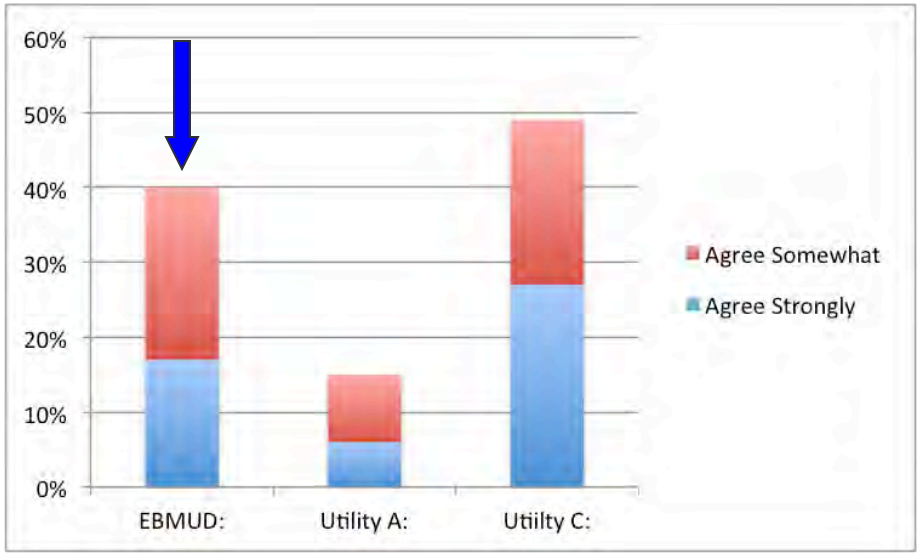
	Agree Strongly	Agree Somewhat
I make an active commitment to use water efficiently indoors and outdoors.	☐	☐
It is important to me to reduce my water bill.	☐	☐
I believe that using water efficiently helps the environment.	☐	☐
I talk with others in my household about reducing our water use.	☐	☐
I talk with friends and/or neighbors about ways to use water more efficiently.	☐	☐

Survey Results: Attitudes and Awareness

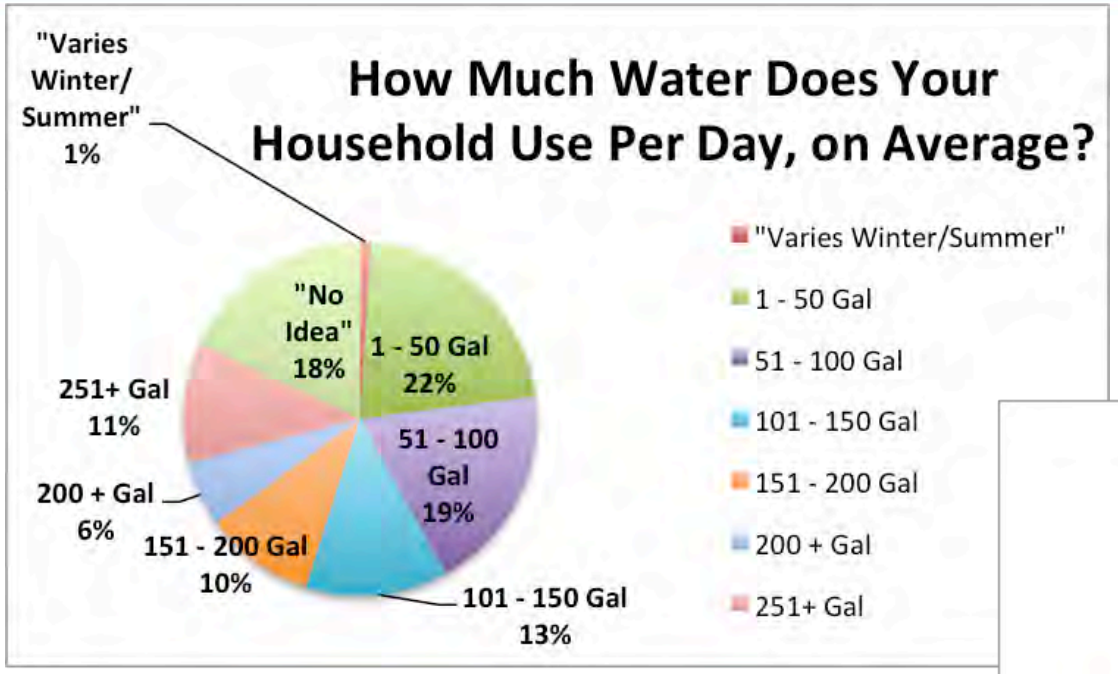
I make an active commitment to use water efficiently indoors and outdoors.

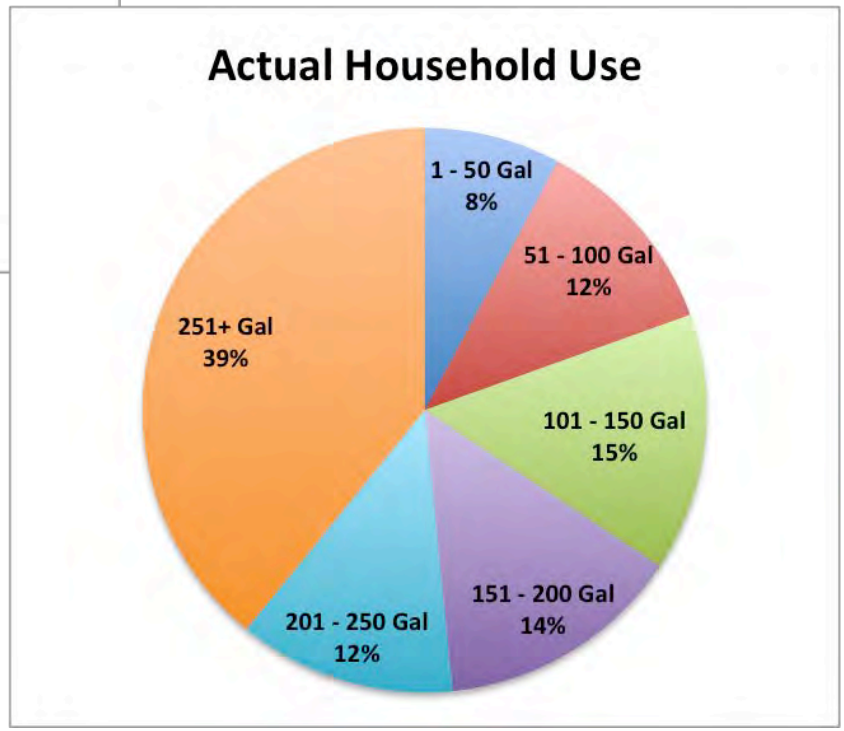


I talk with friends and neighbors about ways to use water more efficiently.



Survey Results: Attitudes and Awareness





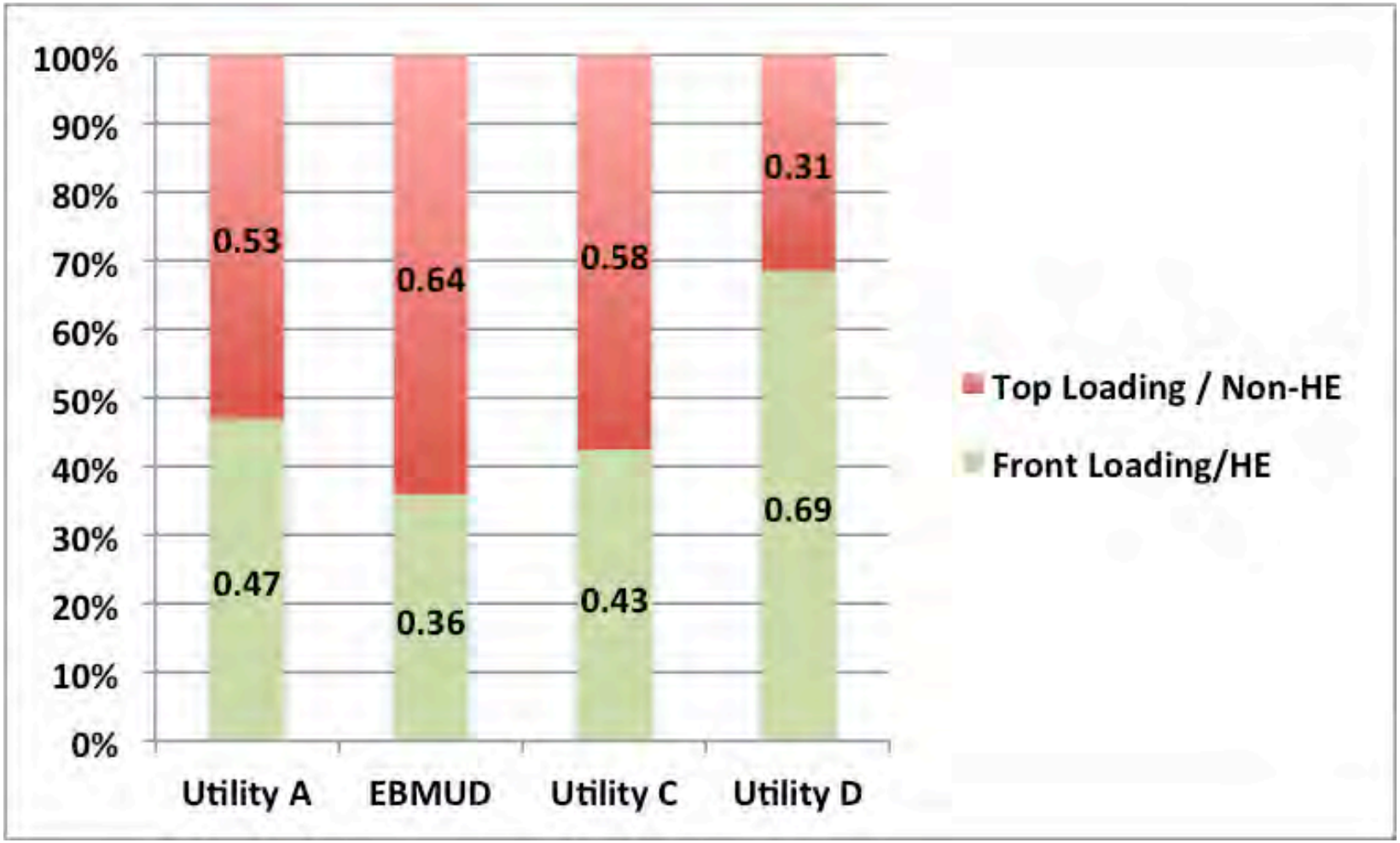
Survey Results: Fixtures, Appliances, Behaviors

Toilets

		Number of High Efficiency Toilets							
# of Toilets	# / % of Responses	Don't Know	0	1	2	3	4	5	6+
1	51 / 4%	14%	24%	61%					
2	371 / 26%	9%	17%	14%	60%				
3	562 / 40%	5%	8%	9%	14%	63%			
4	241 / 17%	6%	5%	4%	10%	10%	64%		
5	112 / 8%	7%	5%	2%	7%	7%	7%	64%	
6+	69 / 5%	10%	6%	3%	1%	1%	8%	1%	71%

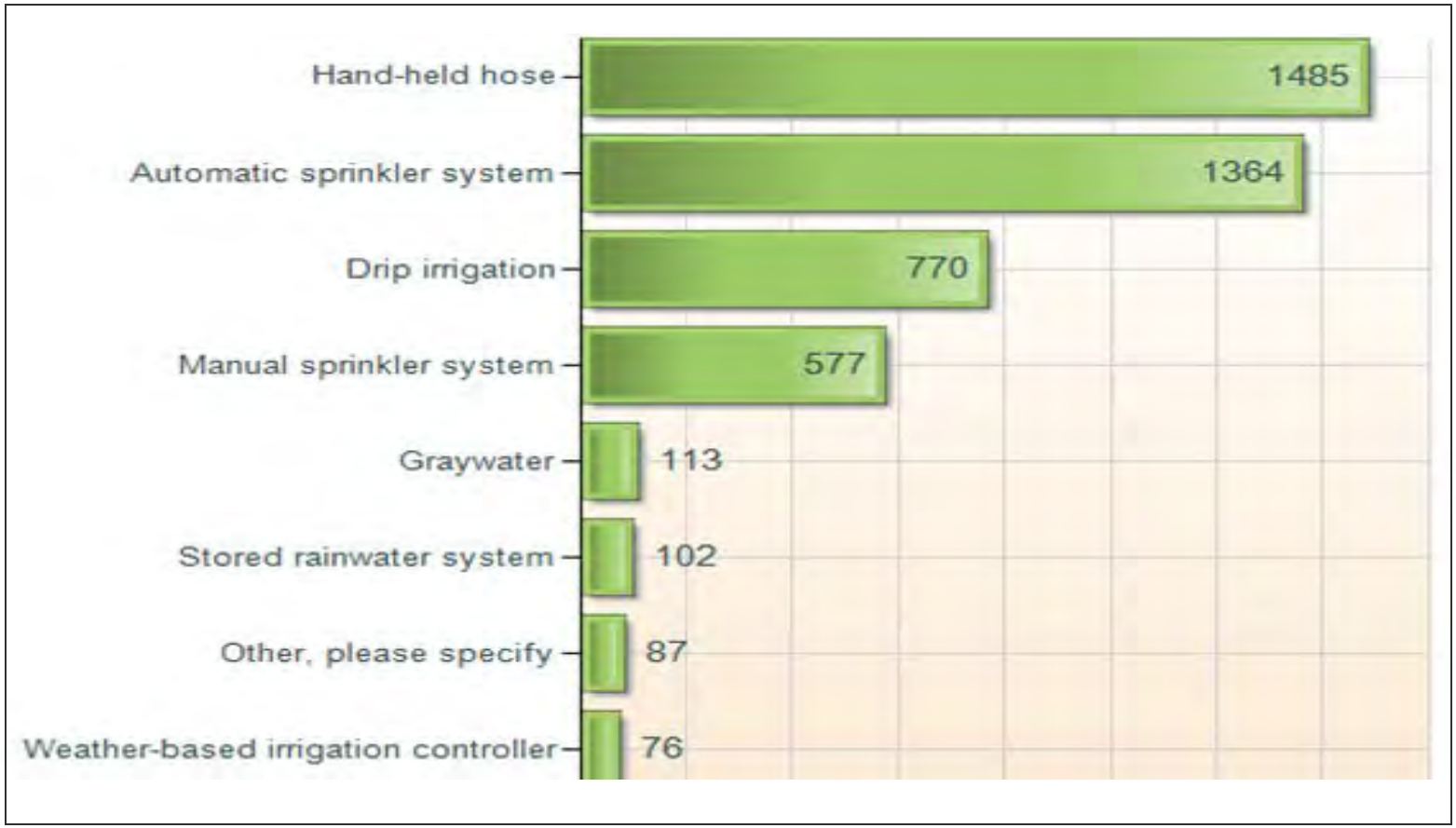
Survey Results: Fixtures, Appliances, Behaviors

Washing Machine



Survey Results: Fixtures, Appliances, Behaviors

Irrigation



Survey (& Consumption & Real Estate) Data → Personalization

Individual Results → Personalized Recommendations

Aggregate Results → Awareness, Saturation, Program Priorities

OUTDOOR INVESTMENTS

	Replace sprinkler heads	Upgrade to a weather-based controller	Use Drip Irrigation for Shrubs	Replace Lawn with Drought-Tolerant plants
Definitely Would	23%	18%	16%	16%
Might Do It	30%	29%	28%	25%
Probably Would Not	10%	18%	18%	24%
Definitely Would N				
Already Did It				

21. If you do not regularly adjust your timer-based irrigation controller, what are the reasons why?

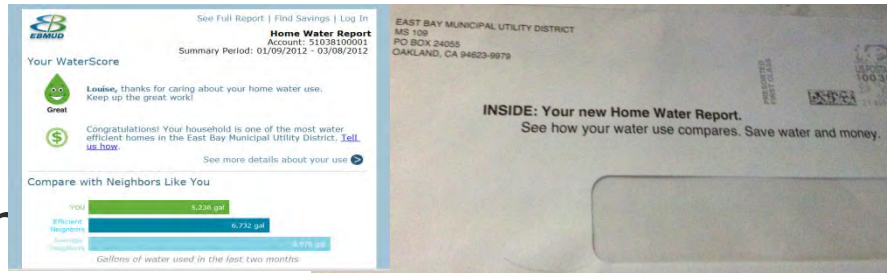
Too complicated / don't know how	
Don't have the time	
Not sure of how much or how often to water	

Lessons and Results: Home Water Reports

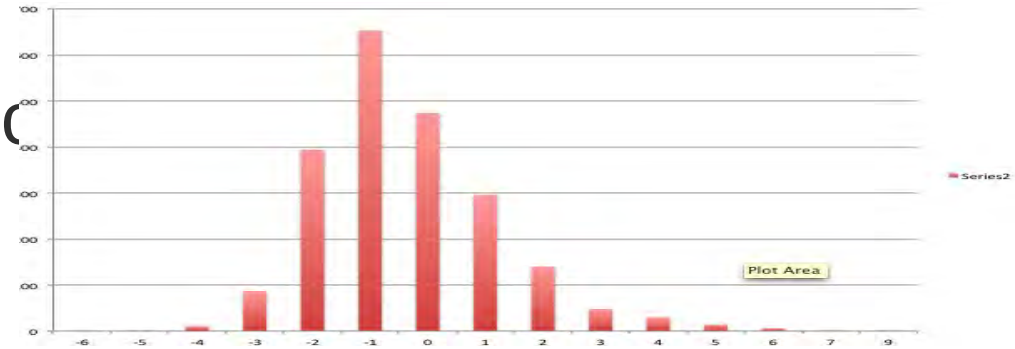
- Overall customers happy, liked the neighborhood comparison
- 4.6% of customers have called or gone online
- Increase in requests for conservation services (+3 audits/day)
- Power of social norms - water use comparison v. $ on bill
- Effective prompt/nudge for people who were complacent
- Graphics v. text-heavy bill – simple communication effective
- Some people pay close attention – pull out old bills to check use
- *Targeting 2% annual water savings overall*

Lessons and Results: Home Water Reports

- Email as effective as m



- Accuracy of actual occ
(% upgraded)



- iPad trumps cash offer

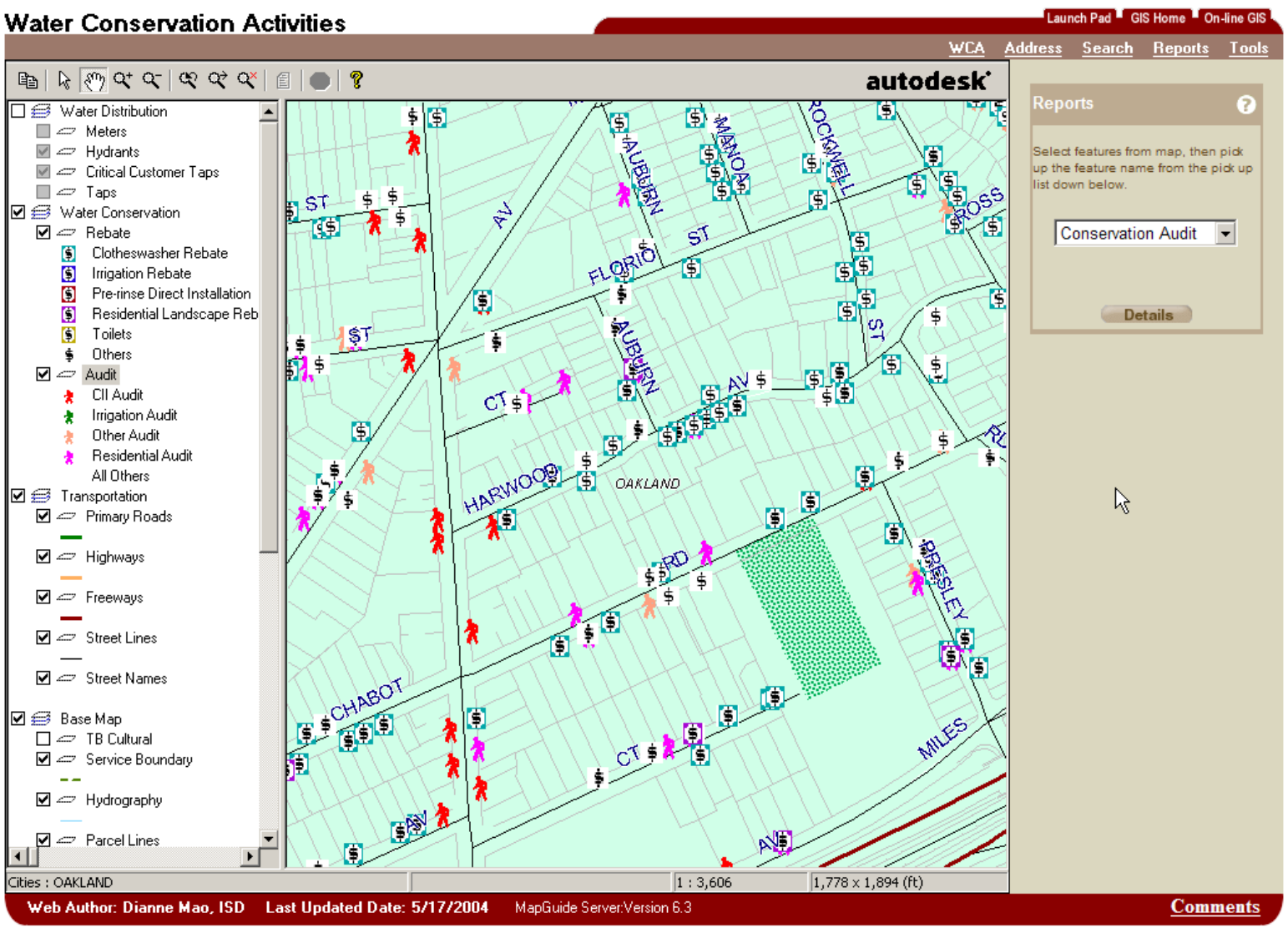
Independent Evaluation:

- Funded/managed by California Water Foundation
- Questions to be addressed:
  - weigh the costs of the program against expected benefits;
  - improve program design to potentially realize greater savings at lower costs; and
  - understand under what conditions the program is likely to be more, or less, effective.

Independent Evaluation: EBMUD-Specific

- How HWRs fit into overall conservation program goals and objectives
- How HWR data may be integrated with existing customer billing and conservation programs and tracking systems
- Potential role HWRs may have in a water shortage

Future Applications: Targeted Conservation Services



Water Usage - Chart View - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Search Favorites

Address https://www.watersmarttoolbox.com/UserWaterUsage?overlay_temp=true Go Links

EBMUD water SMART TOOLBOX

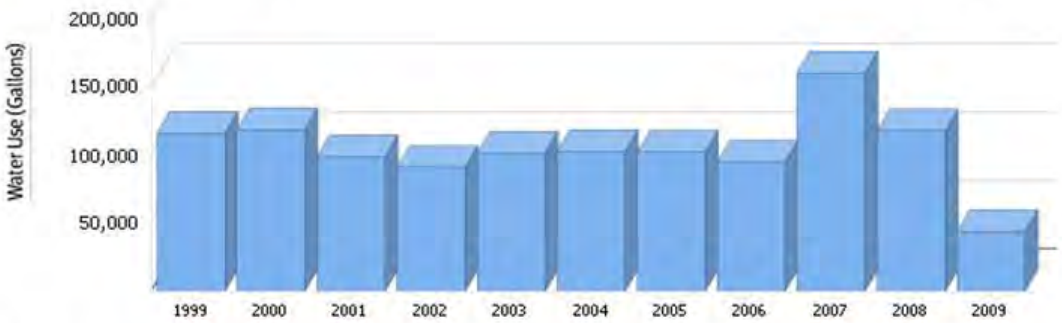
WATER USAGE SETTINGS

Account #123451 Sign Out

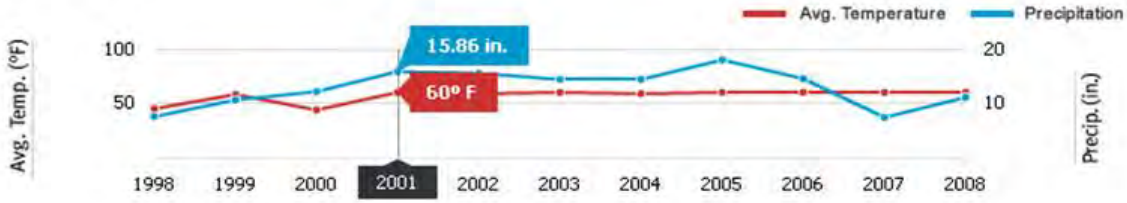
ALERT - Your meter is showing continuous usage which may indicate a leak. More info... Reset Close

Yearly Water Usage

Last 10 years



Climate



Quick View

Yearly Monthly Daily Hourly

Table View

Climate

☑ Temperature

☑ Precipitation

Settings

Edit

Chart Units: **Gallons**

Daily Limit: **ON**

Alert sent at 780 Gallons

Leak Detection: **ON**

Threshold set at 1 Gallons

Download Report

Enter timeframe

Water Use:

Choose ...

DOWNLOAD

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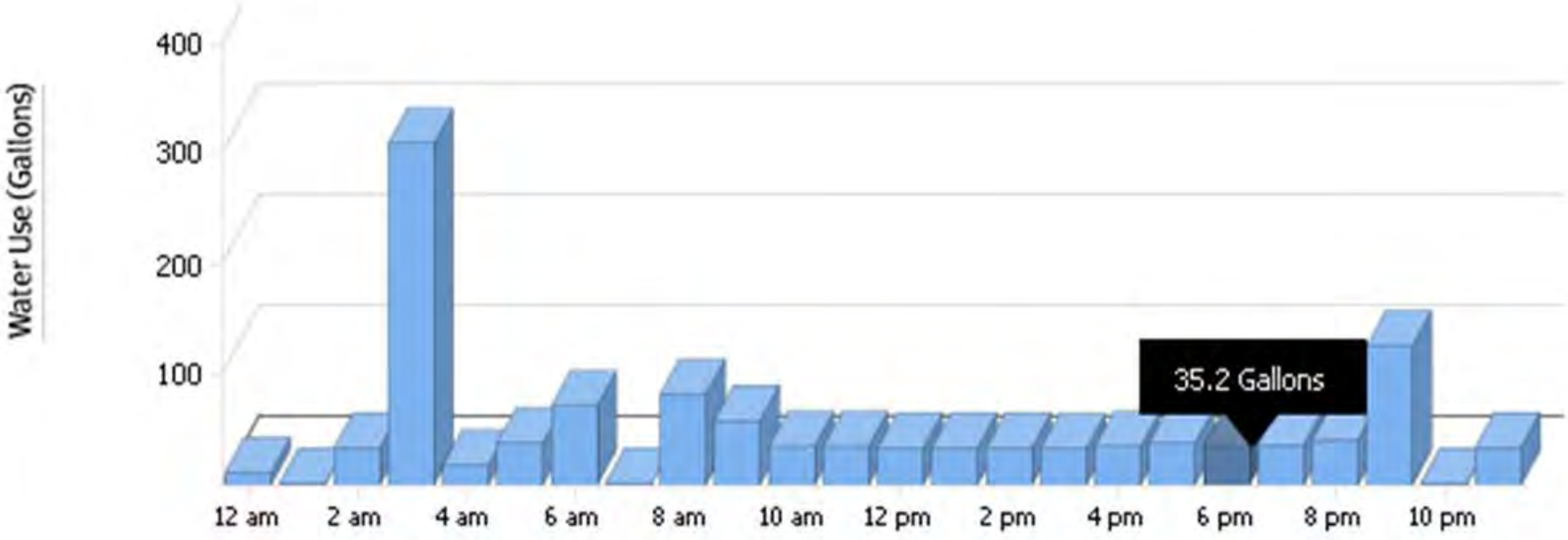
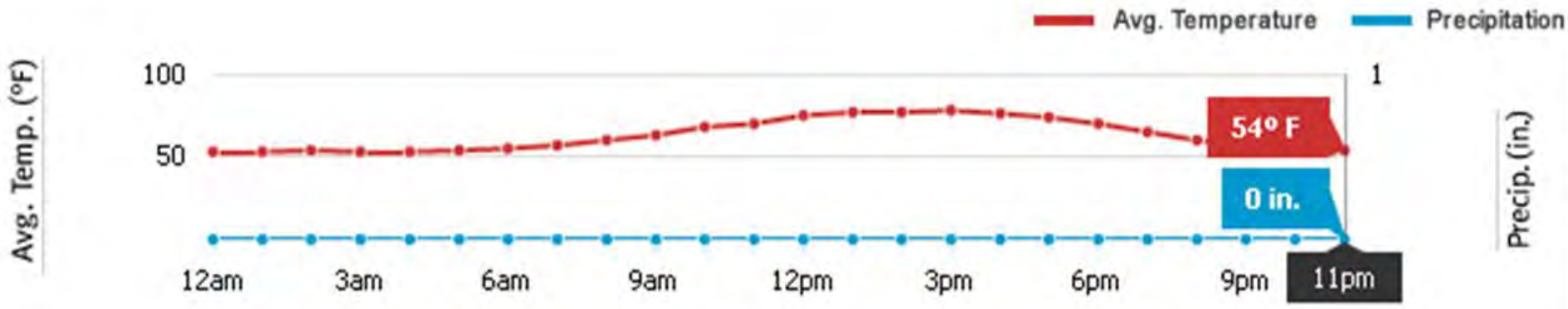
Hourly Water Usage

Hourly usage for 2009-07-06



Climate



Future Applications: Net-Zero Demand Annexations

- 1,400 homes, phased construction
- 4 developers –
  - Shapell, KB, Ponderosa, Lennar
  - Meter sizing 5/8- to 2-inch
  - Lots = 4,000 - 15,000 sq. ft.
- Each of the four developments has its own <u>water budget</u>

Questions

Richard Harris

EBMUD Manager of Water Conservation

rharris@ebmud.com

510-287-1675

Peter Yolles

CEO WaterSmart Software

peter@watersmartsoftware.com

(415) 789-6061

	Forecast to be Online	Total Demand (average annual demand)		Project Costs (3% inflated to midpoint construction period)	SFPUC Demand (average annual demand)		SFPUC Share of Costs (3% inlation to midpoint of construction period)	Grants or Other Funding Offset	Annual Project Cost Payment (5%; 30 years, 13% financing cost)	Annual O&M Cost (2018)	Description of Incremental Annual Costs	Incremental Annual Cost (2018)	Incremental Annual Cost per Acre Foot ($/AF) (2018)	3620	2052
		MGD	Acre-Feet		MGD	Acre-Feet								Comparison to Retail Cost of Water 2018[2]	Comparison to Wholesale Cost of Water 2018[2]
Projects in Implementation*															
RECYCLED WATER															
Harding Park Recycled Water Project [1]	Spring 2012	0.23	258	$10,040,763	0.23	258	$10,040,763	$2,114,000	$582,681	$78,286	Water Purchase	$230,320	$3,460	0.96	1.69
Pacifica Recycled Water Project (serving Sharp Park Golf Course) [2]	Winter 2011	0.10	112	$9,987,422	0.08	90	$7,838,663	$1,859,006	$439,553				$4,906	1.36	2.39
CONSERVATION															
Conservation Program (based on program average) [3]	2005 through 2035	6	6,720										$1,089		
Projects in Planning**															
RECYCLED WATER															
SF Westside Recycled Water Project [4]	Summer 2016	1.6	1,792	$155,141,889	1.6	1,792	$155,141,889		$11,404,189	$2,240,410			$7,614	2.10	3.71
GROUNDWATER															
San Francisco Groundwater Supply [5]	Summer 2015	4	4,480	$61,557,004	4	4,480	$61,557,004		$4,524,940	$ 1,467,407			$1,338	0.37	0.65
Regional Groundwater Storage & Recovery (prev. Conjunctive Use)	Summer 2015	7.2	8,064	$85,291,730	1.44	1,613	$85,291,730		$6,269,635	$ 1,802,461			$5,005	1.38	2.44
RECAPTURE															
Upper Alameda Creek Filter Gallery	Summer 2016	5.4	6,048	$46,000,000	5.4	6,048	$46,000,000		$3,381,374	$ 613,000			$660	0.18	0.32
Projects Undergoing Feasibility Analysis**															
RECYCLED WATER															
SF Eastside Recycled Water Project [6]	Projected, 2020	2	2,240		2	2,240									
One Centralized Treatment Facility				$131,641,425			$131,641,425		$9,676,714	$2,240,410			$5,320	1.47	2.59
Two Decentralized Treatment Facilities				$216,444,987			$216,444,987		$15,910,464	$2,240,410			$8,103	2.24	3.95
South San Francisco Recycled Water Project [7]	Projected, 2014	0.4	448	$22,400,904	0.3	336	$16,845,479		$1,238,280	*To Be Determined*			*To Be Determined*	TBD	TBD
Menlo Country Club Recycled Water Project [8]	Projected, 2016	0.22	246	$11,480,190	0.18	207	$11,480,190		$843,887				$4,077	1.13	1.99
Daly City Recycled Water Expansion Project [9]	*To Be Determined*	1.3	1,456	$74,296,680	1.3	1,456	$74,296,680		$5,461,409	$228,466			$3,908	1.08	1.90
Presidio - Marina Corridor Pipeline [10]	*To Be Determined*	0.03	33.6	$3,640,101	0.03	33.6	$3,640,101		$267,577	$ 19,002	Water Purchase	$37,447	$9,644	2.66	4.70
DESALINATION															
Bay Area Regional Desalination Project [11]	Projected, 2020	20	22,400	$191,176,063	9	10,080	$84,820,914	$1,199,056	$6,235,026	$13,061,059			$1,914	0.53	0.93
Cost of Water (2018)															
	mgd	***A/F***	***ccf***	***gallons***											
265 mgd (wholesale rate)	$1,700,000	$1,518	$3.48	$0.0047											
225 mgd (wholesale rate)	$2,002,228	$1,788	$4.10	$0.0055											
Retail rate	$4,054,802	$3,620	$8.31	$0.0111											

Footnotes:

* Cost estimates based contractor's bid estimates, subject to change based on actual costs incurred. Because these projects are under construction, costs have not been inflated to 2018 dollars.

** Planning level costs, subject to change. Costs are inflated to construction-midpoint based on the projected construction dates.

*** Costs are based on preliminary feasibililty analysis. Subject to change as the project develops. Costs are inflated to projected construction midpoint.

1) Estimate for Harding is based on awarded construction contract (per March 2011 Monthly Report). O&M is stimated based on $40K (about 0.25 FTE) for pump station maintenance, and $20K for power and expendables (for pump station only) inflated to 2018 dollars. "Purchased Water" is the cost of buying recycled water from Daly City with contract costs of $1.62 Ccf in FY 10-11 inflated to 2018 costs by an estimate of 3% per year. Revenue is expected to be received from Harding Park to offset this purchase cost. Currently, revenue for recycled water is anticipated to be the same as the revenue for potable water. Non-WSIP costs are also included in the total Project Costs.

2) Costs for Pacifica Recycled Water Project are based on the SFPUC's 78% share of project planning and construction costs and 100% of retrofit and water service connection costs for Sharp Park Golf Course. Project costs are paid through an escrow account funded upfront, but financing charges over 30 years are assumed for comparison purposes. Grant funding is adjusted to account for costs that are anticipated to be ineligible. Per Agreement with NCCWD, the SFPUC will not be responsible for O&M costs associated with the project; those costs will be recovered from Recycled Water Customers, including SFRPD. SFRPD will not be charged for any project capital costs as part of their water rate. SFRPD will pay NCCWD directly for its irrigation use and the SFPUC will continue to provide potable water, wheeled through NCCWD, for both potable demand as well as for back-up to irrigation needs.

3) Individual Conservation Projects are listed separately. This row represents a programmatic average between 2005 and 2035 for comparative purposes only. The average cost of conservation on a per acre-foot basis is estimated in 2018 dollar terms.

4) Estimates for SF Westside Project are for revised project scope (Richmond-Sunset site), and include pipeline up to Presidio point-of-connection. Costs are consistent with the March 2011 WSIP Quarterly Report. O&M is an estimate from Draft CER (SFPUC, October 2010).

5) Online date and costs for San Francisco Groundwater Supply Project are based on awarding 1 construction contract for six well facilities and 1 construction contract for all pipeline segments. Estimated completion date for both construction contracts is summer 2015. Two well facilities and 2 pipeline segments are subject to the approval of the Westside Recycled Water Project.

6) Costs for SF Eastside Recycled water provide a range based on two alternatives - 1 centralized treatment facility or 2 decentralized treatment facilities. Both alternatives are shown to provide a cost range. Costs are estimated to be $22,900,000 for planning and $120,000,000 for project construction costs. It is assumed that O&M costs area will be similar to Westside.

7) Based on the memo "Recommended Recycled Water Project for South San Francisco and the SFPUC (Carollo, Jan 2011)". Project costs include planning, environmental review, design and construction of treatment and storage facilities, and transmission mains to serve an annual average demand of 0.4 mgd (Phase 1A). Costs were estimated in 2009 and have been inflated to 2018 dollars. O&M costs are not included. If the project is expanded in the future to include the California Golf Club (Phase 1B), additional treatment costs would be added to serve an annual average demand on 0.6 mgd.

8) Estimates based on Feasibility Study for Developing an Alternative Water Supply for Golf Course Irrigation (K/J, Dec 2010) and additional planning estimates resulting from discussions with MCC and Redwood City. Like the Pacifica RW Project, it is assumed that the SFPUC will not pay for O&M Costs.

9) Based on Combined Results of Recycled Water Treatment and Delivery System Expansion Feasibility Studies (Carollo, October 2009) and Table 2.2 of Recycled Water Facility Plan for SSF, CalWater, SFPUC and San Bruno (Carollo, Aug 2009)

10) Preliminary project cost estimate based on serving Marina Green only (0.03 MGD), and installing limited pipeline. Project costs include construction costs escalated to 2012, along with estimating contingency, and project delivery/soft costs. Cost of purchased water is based on $2.70/1000 gallons estimate provided by the Trust in conference call on June 7, 2010. Annual O&M is a preliminary estimate.

11) Costs refined through Institutional Feasibility analysis conducted by project staff in 2010, and based on Feasibility Study (2007) and Pilot Study costs (2009) developed by independent consultants. Annual O&M costs include costs to purchase water (from water rights' holders), cost to wheel water through EBMUD's system, and costs to operate the Hayward Intertie, in addition to the costs of operating and maintaining the project facilities. Assumptions were compared to and cross-checked with projects that have been recently built or are planned in California including the Huntington Beach Seawater Desalination Project (Orange County), Alameda County Brackish Water Desalination Project, and Marin Municipal Water District Desalination Project.

Annual Inflation Assumption	3%
Inflating to year	2018
Inflating to year	2017
Inflating to year	2016
Inflating to year	2015
Inflating to year	2014
Inflating to year	2013

Project Name	Total Project Cost Estimate	Year Estimate Based On	Inflated Total Project Cost	SFPUC Project Cost Estimate	Year estimate is based on	Inflated SFPUC Project Costs	
SF Westside Recycled Water Project	$155,141,889	2016	$155,141,889	155,141,889	2016	155,141,889	2016
SF Eastside Recycled Water Project							
Centralized Treatment	$131,641,425	2016	131,641,425	131,641,425	2016	131,641,425	2016
Decentralized Treatment	$216,444,987	2016	216,444,987	216,444,987	2016	216,444,987	2016
South San Francisco Recycle Water Project	$20,500,000	2010	22,400,904	15,416,000	2010	16,845,479	2013
Menlo County Club Recycled Water Project	$10,200,000	2010	11,480,190	10,200,000	2010	11,480,190	2014
Daly City Recycled Water Expansion	$60,410,000	2009	74,296,680	60,410,000	2009	74,296,680	2016
Presidio-Marina Corridor Pipeline	$3,048,528	2010	3,640,101	3,048,528	2010	3,640,101	2016
Bay Area Regional Desalination Project	$155,443,634	2009	191,176,063	68,967,165	2009	84,820,914	2016
San Francisco Goundwater Supply	$61,557,004	2014	$61,557,004	61,557,004	2014	61,557,004	2014
Regional Groundwater Storage & Recovery	$85,291,730	2014	$85,291,730	85,291,730	2014	85,291,730	2014
Conservation Program				860	2010	1,089	2018

Note:
Projects are inflated at 3% at the midpoint of the construction period (counted from the date the project will be online)

SFPUC Regional Groundwater Storage and Recovery Project																	
Spending Plan by phase by year																	
Project Phase		**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Period Total**
Project Milestones	Actual Total																0
	Remaining Total																0
	At Completion Total																0
Project Management	Actual Total				49,388	99,174	122,800	248,109	196,256	116,160	960,138	630,146	50,045				2,472,214
	Remaining Total												1,067,188	476,490	472,274	162,759	2,178,711
	At Completion Total				49,388	99,174	122,800	248,109	196,256	116,160	960,138	630,146	1,117,233	476,490	472,274	162,759	4,650,925
Project Planning	Actual Total		335,521	548,513	267,106	442,444	412,491	25,806									2,031,881
	Remaining Total																0
	At Completion Total		335,521	548,513	267,106	442,444	412,491	25,806									2,031,881
Environmental Review	Actual Total						31,538	152,232	504,455	575,519	697,080	836,849	72,205				2,869,878
	Remaining Total												692,886	550,467			1,243,352
	At Completion Total						31,538	152,232	504,455	575,519	697,080	836,849	765,091	550,467			4,113,231
Right of Way	Actual Total							32,045	43,304	43,131	87,155	123,292	10,850				339,778
	Remaining Total							30,198	40,808	40,644	20,407		513,064	473,602			1,118,722
	At Completion Total							62,243	84,112	83,775	107,562	123,292	523,913	473,602			1,458,500
Design	Actual Total							499,735	763,812	1,310,619	2,064,590	1,271,293	71,556				5,981,607
	Remaining Total								19	47	64,815	78,099	3,094,668	19,486			3,257,134
	At Completion Total							499,735	763,831	1,310,666	2,129,405	1,349,392	3,166,224	19,486			9,238,740
Bid and Award	Actual Total								10,866								10,866
	Remaining Total												155,226	274,880			430,106
	At Completion Total								10,866				155,226	274,880			440,972
Construction Management	Actual Total							159,080	217,735			119,408	1,863				498,086
	Remaining Total												8,367	2,917,140	3,364,062	309,494	6,599,063
	At Completion Total							159,080	217,735			119,408	10,230	2,917,140	3,364,062	309,494	7,097,149
Construction	Actual Total		132,941	197,792	108,430		90,553	429,620	339,510			2,970,500	-2,687				4,266,660
	Remaining Total											96,364	796,822	18,227,267	27,605,611	7,260,365	53,986,429
	At Completion Total		132,941	197,792	108,430		90,553	429,620	339,510			3,066,865	794,135	18,227,267	27,605,611	7,260,365	58,253,090
Close-Out	Actual Total																0
	Remaining Total															316,242	316,242
	At Completion Total															316,242	316,242
Total	**Actual Total**		**468,463**	**746,305**	**424,923**	**541,617**	**657,383**	**1,546,628**	**2,075,939**	**2,045,430**	**3,808,963**	**5,951,489**	**203,831**				**18,470,971**
	Remaining Total							**30,198**	**40,827**	**40,691**	**85,221**	**174,464**	**6,328,220**	**22,939,332**	**31,441,948**	**8,048,859**	**69,129,759**
	At Completion Total		**468,463**	**746,305**	**424,923**	**541,617**	**657,383**	**1,576,826**	**2,116,766**	**2,086,121**	**3,894,184**	**6,125,952**	**6,532,051**	**22,939,332**	**31,441,948**	**8,048,859**	**87,600,730**

Project Cost Estimate		
	Total	
Project Management	$	450,000
Planning	$	200,000
Environmental Review	$	565,000
Design	$	800,000
Bid & Award	$	40,000
Construction		$6,775,000
Construction Management		$1,355,000
Closeout	$	15,000
Total	**$**	**10,200,000**

Capital Cost Breakdown (FS Estimate)	Cost/Unit	Alt 1a (1M Tank Above Ground)	
Tank Size: 1,000,000 gallons			
a) Above-ground	1.25	$1,250,000	
b) Below-ground	2		$2,000,000
Standby Potable Connection		$200,000	
RW Pump Station		$200,000	
Offsite Pipelines		$4,000,000	
Onsite Pipeline		$75,000	
Special Crossings by Bore & Jack		$450,000	
Land		$350,000	
Irrigation System Upgrade		$250,000	
Planning, Legal, Engineering, CM, Admin		$1,543,750	
Contingency		$1,852,500	
Total FS Estimate		$10,171,250	

Projected Water Rate Comparisons

FY	SFPUC Potable Rate	RWC Potable Rate	RWC Recycled Rate
2010-2011	3.89	3.92	2.94
2011-2012	4.52	4.27	3.2
2012-2013	5.10	4.78	3.59
2013-2014	5.40	5.35	4.02
2014-2015	N/A	5.78	4.33
2015-2016	N/A	6.13	4.6
2016-2017	N/A	6.5	4.87
2017-2018	N/A	6.76	5.07
2018-2019	N/A	7.03	5.27

Project Cost (2014)	Annualized Project Cost Payment	Dry Year Yield (1 in 5)	Dry Year O&M (inflated to 2018)	Dry Year O & M (inflated to 2012)	Wet Year Yield (4 in 5)	Wet Year O&M (inflated to 2018)	Dry Year O&M (inflated to 2012)	Weighted Average O&M (2018)
$ 85,291,730	$ 6,012,964	8064	$ 4,615,009	$ 5,194,233	$ -	$ 1,099,324	$ 1,237,299	$ 1,341,200
reduce from 2018 to 2012 (6 years * 3% per year)			$ 3,784,307.38			$ 901,445.68		

Cost During Wet Years	$ 6,914,410
Cost During Dry Years	*$ 6,012,964*
Cost / af During Dry Years	$ 746
Average Cost a/f	$ 835
Based on annualized O&M (average)	$ 4,846
Assuming the value of 1,613 af on an annual basis:	
Cost During Wet Years	$ 4,287
Cost During Dry Years	$ 3,728
Average Cost	$ 4,175
Assuming an 18.5 year project cycle (7.5 years of continuous take, and 11 year to recharge):	
Put year cost (total = 11 yrs)	$ 76,058,506
Take year cost (total =7.5)	$ 45,097,230.0
Total cost (18.5 yrs)	$ 121,155,736.5
Take yield (over 7.5 years)	60480
Cost / af	$ 2,003.24

Total Project Cost (2010 dollars)	Total Project Cost (2012)
$10,200,000	$10,821,180

Project Cost Estimate

	Total	SFPUC Share
Project Management	450000	360000
Planning	200000	160000
Environmental Review	565000	452000
Design	800000	640000
Bid & Award	40000	32000
Construction	6775000	5420000
Construction Management	1355000	1084000
Closeout	15000	12000
Total	**10200000**	**8160000**

FEATURES

Valuing Properties with Wetland Potential

by Michael Cragg, PhD, Christine Polek, PhD, and Stephen Polasky, PhD

ABSTRACT

The Clean Water Act and federal policy of "no net loss of wetlands" prohibit the destruction of wetland acreage in the United States. However, these policies allow for wetland destruction to be offset by developing and converting suitable land into qualifying wetlands, which can then be sold as credits to developers. Land with a highest and best use for wetland mitigation credits typically requires environmental analysis, engineering expertise, landscape design, and approval by authorities before it can be resold for that purpose. This article offers information, examples, and suggestions for the valuation of property readily converted to qualifying wetlands.

Wetlands, generally speaking, are swamps, bogs, and marshy areas. The US Army Corps of Engineers (COE) and the US Environmental Protection Agency (EPA) define *wetlands* as

> those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.[1]

When wetlands are adversely impacted, mitigation or compensation for the impact is typically required. Mitigation banking is one method that has emerged by which to mitigate wetland impacts; *mitigation banking* is defined as

> wetland restoration, creation, enhancement, and in exceptional circumstances, preservation undertaken expressly for the purpose of compensating for unavoidable wetland losses in advance of development actions, when such compensation cannot be achieved at the development site or would not be as environmentally beneficial. It typically involves the consolidation of small, fragmented wetland mitigation projects into one large contiguous site. Units of restored, created, enhanced or preserved wetlands are expressed as "credits" which may subsequently be withdrawn to offset "debits" incurred at a project development site.[2]

Regulations issued in 2008 mandated mitigation banking as the preferred method for wetland restoration or creation as compensation for unavoidable wetland losses in advance of actions that adversely impact wetlands.[3] The recent regulations are expected to stimulate the mitigation banking industry and make mitigation banking more commonplace.

However, the current mitigation market itself is fragmented and characterized by a lack of readily available information about transactions. It is rare that anyone can observe the relationship between land purchased for mitigation

1. US Army Corps of Engineers Virginia, *Recognizing Wetlands: An Informational Pamphlet*, available at http://www.nao.usace.army.mil/technical%20services/Regulatory%20branch/RBwetlands.asp.
2. "Federal Guidance for the Establishment, Use and Operation of Mitigation Banks," *Federal Register* 60, no. 228 (November 1995): 58605–58614.
3. US Army Corps of Engineers and US Environmental Protection Agency, "Final Compensatory Mitigation Rule Factsheet: Improving, Restoring, and Protecting the Nation's Wetlands and Streams," available at http://www.epa.gov/owow/wetlands/pdf/Mit_rule_QA.pdf.

and the amount of mitigation allowed. Furthermore, mitigation transaction prices are usually only known to the direct participants, and regional policies and geography have a strong influence on market forces. Consequently, the valuation of lands whose highest and best use is for saleable wetland credits is not a straightforward task.

This article expands on previous research addressing the complexity and unique challenges associated with wetland valuation. This analysis differs from related research, such as research by Keating, Edmonds, and Stanwick,[4] which reflects an environment where on-site mitigation (wetland compensation undertaken on or adjacent to the development site) is preferred. The current article addresses the impact of regulations adopted in 2008 that prioritize mitigation banking as the preferred option for offsetting adverse impacts and are expected to strengthen the market for wetland creation. The discussion here also provides suggestions for valuing wetlands given the data limitations for suitable comparable sales, and therefore is complementary to the discussion in Keating's book, *The Valuation of Wetlands*, which emphasizes the use of sales comparables in valuing wetlands.[5]

This article proposes two valuation methodologies that address the complexities associated with valuing potential mitigation lands: one that focuses on the income-generating potential for property with wetland mitigation potential; and another that uses sales comparables. A case study of these valuation techniques is presented with an application to property that can be readily converted to wetlands and is located in the San Francisco Bay region of California. This region has a high level of political commitment to wetland restoration and exhibits characteristics that are useful for demonstrating the challenges of valuing properties with mitigation potential.

The discussion is organized as follows. The first section provides background on the mitigation banking industry. The second section presents an overview of the income capitalization approach to valuation as applied to lands with mitigation potential, and a number of research issues are identified that need to be addressed in implementation. In particular, suggestions are offered for defining the underlying assumptions that are required for the income capitalization approach as well as ways to overcome data limitations. The third section describes the underlying assumptions for the sales comparison approach. The fourth section applies the two approaches to convertible lands that are located in the San Francisco Bay Area. The last section offers conclusion and some final remarks.

The US Mitigation Banking Industry

Wetlands, like forests, are natural habitats that have been adversely impacted by the growth and demands of modern society. In the early to mid-part of the twentieth century in the United States, wetlands were converted for other uses at a rapid pace, and the supply of wetlands decreased severely. Over time, public attitudes and public policy shifted and began to encourage wetland conversion and restoration. The shift in public preference for conversion to wetland, instead of conversion from wetland, became clear with the Clean Water Act (CWA), which established the wetlands regulatory program in 1972[6] and provides the primary federal law governing wetland use in the United States, thereby creating a market for developed wetland credits. In accordance with the CWA, land developers whose projects impact wetlands are required to compensate for or offset wetland loss or degradation. In 1987, the National Wetland Policy Forum was convened, recommending the national goal of no net loss of wetlands. The "no net loss" policy explicitly recognized that any loss of wetlands due to public or private initiatives must be more than offset by the restoration and recovery of wetlands, and this policy has become the guiding principle for much of the federal wetlands program.[7]

Mitigation banks are large tracts of land intended for the establishment or restoration of wetland habitat. Mitigation banks emerged as a market-based response to the CWA requirements and the "no net loss" policies. Mitigation banks sell recovered parcels as wetland "credits" to offset impacts in delineated regions. Lands with mitigation-banking potential

4. David Michael Keating, Charles P. Edmonds, and Sarah Stanwick, "A Conceptual Framework for Appraising Wetland Mitigation Banks," *The Appraisal Journal* (April 1997): 165–170.
5. David Michael Keating, *The Valuation of Wetlands*, 2nd ed. (Chicago: Appraisal Institute, 2002).
6. The Federal Water Pollution Control Amendments (FWPCA) of 1972 included the enactment of section 404. In 1977, the FWPCA was renamed the Clean Water Act (CWA) and an executive order to minimize the destruction, loss, or degradation of wetlands was passed.
7. Richard Ambrose, "Wetlands Mitigation in the United States: Assessing the Success of Mitigation Policies," *Wetlands* (Australia) 19, no. 1 (August 2000): 1–27.

include those that are adjacent to rivers, streams, forested areas, and drained agricultural areas, as these are most likely to provide a natural landscape that provides recognized wetland functions.[8]

More recently, federal initiatives designed to protect and restore wetland have evolved and become more explicit in guiding the implementation of mitigation and recovery of wetlands. In 1990, the Department of the Army and the EPA entered into a Memorandum of Agreement (MOA) that legitimized the creation of mitigation banks. Then in 1995, the COE, EPA, US Fish and Wildlife Service, National Resource Conservation Service, and National Oceanic and Atmospheric Administration published "The Federal Guidance for the Establishment, Use and Operation of Mitigation Banks" (1995 Guidance). Together, the 1990 MOA and 1995 Guidance offer specific interagency coordination and policy guidance. The impact of the 1995 Guidance has been favorable in terms of wetland acreage measurements and development of the mitigation banking industry. Between 1998 and 2004, an average annual net increase of 32,000 wetland acres was achieved.[9] Additionally, the number of active mitigation banks in the United States more than tripled between 1992 and 2001.[10]

Mitigation banking is expected to develop further as a result of the revised regulations governing compensatory mitigation issued in 2008 by the COE and the EPA "Final Compensatory Mitigation Rule".[11] The rule establishes a hierarchy for mitigation options, and while it allows for substitution between permittee-responsible, third-party, and in-lieu fee mitigation, the rule indicates a clear preference for mitigation through use of mitigation banks. These regulations reflect regulator and permittee initiatives to develop mitigation credit markets in light of the historical limited availability of private-seller credits.[12]

Consideration of these major policy initiatives impacting wetland mitigation should be explicit in any wetland mitigation market analysis, as demonstrated in the valuations provided next.

Valuing Convertible Land Using the Income Capitalization Approach

If the highest and best use of the property is for compensatory mitigation for wetland losses, the property is valued for its use in a mitigation bank using the willing buyer and willing seller fair market value standard. As such, the property is projected to generate income through the establishment and sale of mitigation credits, where mitigation credits are units of restored wetland acreage. It is important to note that the market forces that drive the land values for a mitigation bank are identical to those that drive land values for permittee-responsible mitigation. The mitigation credits supported by any of these sources are economic substitutes. One cannot, however, simply compare the prices of mitigation credits and in-lieu fees because in-lieu fees are often subsidized with alternative funding sources thereby distorting their measure as the full cost of mitigation.[13] The value of discussing mitigation credits is that credits are standardized units that are comparable.

The income capitalization approach determines land values as the present value of any profits from sales of mitigation credits that remain after paying the costs of creating and maintaining the mitigation bank. These costs include (1) payments to the financiers for the time value of money and risk bearing, (2) construction costs, (3) management, (4) selling and marketing costs, and (5) payments to the entrepreneur for undertaking the project. The underlying economic principle behind the income capitalization approach is that in a setting with equally informed buyers and sellers, the market process will function so that the seller will extract all profits remaining once the buyer and its financiers

8. "Federal Guidance for the Establishment, Use and Operation of Mitigation Banks."
9. T. E. Dahl, *Status and Trends of Wetlands in the Conterminous United States 1998 to 2004* (Washington, DC: US Fish and Wildlife Service, December 2005).
10. Jessica Wilkinson and Jared Thompson, *2005 Status Report on Compensatory Mitigation in the United States* (Washington, DC: Environmental Law Institute, April 2006).
11. Department of Defense, Department of the Army Corp of Engineers, 33 CFR Parts 325 and 332; Environmental Protection Agency 40 CFR 230, "Compensatory Mitigation for Losses of Aquatic Resources" (Final Rule: April 10, 2008).
12. Leonard A. Shabman and Paul Scodari, *Past, Present, and Future of Wetland Credit Sales*, discussion paper 04-48 (Washington, DC: Resources for the Future, December 2004), 7, 10, 16.
13. See for example, GAO, *Wetlands Protection: Assessments Needed to Determine Effectiveness of In-Lieu Fee Mitigation*, GAO-01-325 (Washington, DC: US General Accounting Office, May 2001), 10–12; and Environmental Law Institute, *The Status and Character of In-Lieu Fee Mitigation in the United States* (Washington, DC: Environmental Law Institute, June 2006), 4–5.

have earned their competitive rate of return.[14] This means that if the highest and best use of a property is mitigation, a mitigation banker will be purchasing land at the same price as someone seeking to do their own off-site mitigation. This will also be the price paid in an arm's-length sale between a knowledgeable profit-maximizing seller and an environmentally motivated buyer seeking to recover wetlands.

Data Required to Apply the Income Capitalization Approach

To apply the income capitalization approach in measuring the value of land used for a mitigation bank, data is needed to measure over time the flow of revenues from the mitigation bank and the costs of creating and maintaining the bank. Mitigation revenues are dependent on regional forces of supply and demand, as well as both federal and local government regulation. Mitigation costs are dependent on the physical and biological requirements that are specific to the bank site. The number of mitigation credits that the property can supply, and the region in which they can be sold, is dictated by a complicated negotiation process with government agencies, which determine how much restoration can be done and the environmental value of the restoration. Thus, the estimation of the revenues and costs of a mitigation-bank venture requires specific study by practitioners in the mitigation market in the area in which the property is located. It requires an understanding of the physical features of the property, the property's importance to a regional development plan, and experience navigating the regulatory process and agency requirements. Analysis is further complicated because industry knowledge, and in particular information about wetland credit prices, is closely held. Economic factors that drive revenues for mitigation banks in the United States are discussed next, and considerations that vary by region are identified.

Mitigation Banking Revenue: Estimating Mitigation Credit Sales

Estimating Demand Relative to Supply. In order to verify there is a market for privately developed mitigation credits in a region, the demand for mitigation credits must be compared to the available supply of mitigation credits. As discussed later, to analyze the supply and demand for wetland acreage, the availability of restorable former wetlands is compared to the historic volume and rate of credits used. Consideration should be given to not only private demand for restoration, but also government agency and nonprofit restoration of sites. It is also useful to consider the impact of expected infrastructure construction when estimating demand.

Estimating the Supply of Convertible Land. If the required information is not directly available to measure the supply of convertible land, it may be possible to estimate the potential mitigation supply by establishing a historical reference point and tracking conversion projects that reduce supply over time. The approach to identifying potential mitigation supply begins with the measurement of the amount of land that lies within the historic boundaries of the region, is no longer wetlands, and can be readily recovered. The land may no longer be wetlands for a variety reasons, including draining by dikes, landfills, or levees, or creation of ponds for salt production.

Estimates of Demand. If not already identified, an estimate of future mitigation demand requires measures of historical wetland conversion rates, as well as historical rates of planned mitigation projects. Historic demand figures that are based on completed restoration projects alone tend to underestimate future demand. Typically it takes years to complete a wetland recovery project. Therefore, if the conversion rate is rising, the annual completion rate will be lower than the annual project-planning rate. For example, a measure of demand that is based on completed projects alone may not adequately measure changes in project-planning rates that are triggered by regulatory changes. Consideration of both completed and planned conversion rates is therefore preferable and should be considered in light of the evolving regulatory environment for wetlands.

Wetland impacts are driven by market development. Market development typically manifests a direct impact on wetlands through infrastructure requirements that accompany it. Therefore, it is useful to consider expected infrastructure requirements in estimating future mitigation need; these needs historically have been a significant and consistent

14. See for example, C. F. Sirmans, *Real Estate Finance*, 2nd ed. (New York: McGraw-Hill Book Company, 1988), 320–323; and James B. Kau and C. F. Sirmans, *Real Estate* (New York: McGraw-Hill Book Company, 1985), 255–256, 191–192.

source of mitigation demand.[15] This approach recognizes, for example, regional urban demand for mass transit development, and considers what a for-profit mitigation banker would prudently anticipate in planning for infrastructure demand over a two-decade period. Incorporating future infrastructure projects into the demand analysis can validate historic estimates, as well as add greater confidence in projections of the magnitude of long-term demand.

At least five broad infrastructure projects typically require mitigation: airport expansion, port expansion, surface transportation projects, sewer projects, and levees.[16] The first four categories are conditional on growth in the region and their significance depends on the following: (1) the extent that the region is identified with a major or minor airport; (2) the role of the area as a regional, intermodal hub for imports and exports; and (3) requirements of ongoing transportation and sewage treatment facility upgrades designed to address economic growth and density constraints. The fifth category, the necessity of levee enhancement and construction, arises from two sources: rising sea and storm levels, and earthquakes. To the extent these infrastructure issues are applicable to the region, they will require mitigation in the future.

Impact of Government Regulation. In addition to supply and demand, the market forces of wetland mitigation are influenced by governmental policy. Government regulators are charged with protecting the public interest and ensuring that mitigation is consistent with regional environmental goals. The primary agency involved in approving wetland mitigation is the COE, although other agencies may be involved depending on where the wetland impact is made. The regulatory agencies decide whether proposed mitigation is adequate or suitable and use scoring criteria to establish the amount of mitigation required for wetland impact. This scoring results in the assignment of *wetland credits*, which are the standard unit of measurement for quantifying the net gain in wetland acreage or function that results from wetland restoration, creation, enhancement, or preservation.

Policy at the national, regional, and local levels all play a role in determining how many mitigation credits can be derived from mitigation supply sites, and how many mitigation credits are required by demand impacts. *Mitigation replacement ratios* (also referred to as *compensation ratios*) are the "proportional requirements for replacing wetlands that are permitted for fill."[17] Across the nation, the large majority of replacement ratios fall between 1:1 and 3:1.[18] The ability of a site to meet demand depends on the specific ratios required. For example, consider a 100-acre salt pond that supports 50 credits (i.e., every two acres restored is worth one mitigation credit), and a developer who would like to fill 25 acres of wetland. The 100 acre salt pond mitigation can be used to fully mitigate for 25 acres of impact if the replacement ratio is 2:1 or lower (i.e., the impact that requires 50 credits or less).

Mitigation Banking Revenue: Identifying Future Mitigation Prices

Mitigation Land as an Exhaustible Resource. In order to measure the value of a tract of land with wetland potential, one must determine how many mitigation units the land can generate, the value of a mitigation unit, and the cost to generate a standard mitigation unit. Given the presence of a mitigation credit market, the natural choice for the standard unit is a mitigation credit, and therefore estimates of area wetland credit prices are needed. Generally speaking, however, data on mitigation credit prices is not readily available because of the fragmented nature of the market and the proprietary nature of the data. However, economic theory and econometric analysis can be used to derive reasonable estimates of mitigation credit prices.

Economic theory dictates that convertible land prices rise as land for mitigation becomes scarce, and the rate of price increase, as well as the rate at which the mitigation bank will sell out, is a function of expected demand and competition in meeting this demand. Land that is suitable for wetland mitigation is a nonrenewable and exhaustible resource, consequently there is limited supply relative to

15. Environmental Law Institute, *Banks and Fees: The Status of Off-Site Wetland Mitigation in the United States* (Washington DC: Environmental Law Institute, September 2002), 15. This report notes that the majority of the nation's early wetland banks were single-user banks established by state departments of transportation. See also, "Infrastructure, Local Development, and Housing Programs," chapter 5 in *The Impact of Federal Programs on Wetlands, Volume II*, a report to Congress by the Secretary of the Interior, available at http://www.doi.gov/oepc/wetlands2/v2ch5.html#foot1.
16. Sewer projects may be considered a fifth type of infrastructure project requiring mitigation.
17. National Research Council, *Compensating for Wetland Losses Under the Clean Water Act* (Washington, DC: National Academy Press, 2001), 108.
18. Environmental Law Institute, *Banks and Fees*, 63.

demand. The economics of this type of scarcity have been extensively studied by economists starting with Hotelling.[19] The Hotelling model predicts that for any nonrenewable resource, prices will rise as the resource is used up since informed sellers are determining the best price and time to sell in order to maximize their profits based on the dynamics of the market. The knowledgeable owner of mitigation land will compare the price increase of the land to the return on capital invested in alternative investments. If prices increase faster than the rate of interest, sellers will enter the market, supply will increase and price increases will slow to the long-term trend. If prices rise slower than the rate of interest, then sellers will withhold supply, and the price will rise back to the long-term trend.[20] Therefore, an economically rational seller of mitigation credits developed from convertible properties will not lower the price of credits so that the bank is sold out in a single year. Instead, the seller will sell credits at a rate that supports the growth of past mitigation prices.

Similarly, in a competitive market the difference in the price of land suitable for mitigation and the price of mitigation credits reflects the costs of creating mitigation credits and the competitive profits being earned by the various parties who create the mitigation credits. This is the basic competitive markets assumption where the suppliers of services (i.e., construction, financing, selling, general and administrative functions for creating the bank, environmental engineering, and agency relations and lobbying) necessary for the creation of a mitigation bank are compensated at the competitive rate of return.

Estimating Mitigation Prices. In some cases, it may be possible to conduct a regression analysis to create a reasonable forecast of what market participants would expect for future prices. The results can be validated through interviews, research, and surveys conducted by others. In developing a model for regression analysis, consideration is given to the market for mitigation credits and factors that are believed by market participants to drive credit prices. In the research presented here, three readily available variables are identified that are linked to mitigation credit prices and therefore are suitable regressors: median home sale prices, population density, and wetland acreage. Home sale prices indicate the price paid for development and reflect the local economic conditions. Therefore, home sale prices are expected to be strongly linked to mitigation credit prices. Similarly, population density influences the demand for development and is expected to be linked to the demand for mitigation and credit prices. Wetland acreage is a proxy for the variations in supply and demand constraints dictated by the environment where the property is located.

Mitigation Banking Costs

Industry and site-specific knowledge is also necessary to estimate the direct costs of creating and maintaining the mitigation bank, and the indirect costs of marketing, administering, and selling the credits. The estimation of the direct costs of creating a mitigation bank requires environmental engineering knowledge that allows the development and costing of a restoration program tailored to the physical and biological requirements specific to the site. Additionally, costs related to marketing, selling, and developer profits are simply not readily available in this industry. Often the approach is to estimate these costs from a similar industry (the typical approach for transfer pricing), to use company data, or to rely on the expertise of a practitioner.

The determination of financing costs is a standard problem for economists, and much of the field of finance is dedicated to providing models and data to estimate these costs. Industry interviews and theory can determine the capital structure (i.e., the mix of debt and equity) required for the project. It is possible to estimate the costs that providers of debt will charge through a mixture of interviews and analysis of the debt costs to real estate developers. The cost of equity is estimated several ways–through the capital asset pricing model (CAPM), interviews with developers and mitigation bankers, and analysis of survey data. The correct method for using these financing costs is to derive a discount rate (i.e., weighted average cost of capital or WACC) that ignores idiosyncratic risk[21] and apply it to expected cash flows from the mitigation banking project. Thus, the discount rate reflects the risk that is rewarded by the market, the systematic risk. Therefore, the central focus of the analysis is

19. See for example, Shantayanan Devarajan and Anthony C. Fisher, "Hotelling's 'Economics of Exhaustible Resources': Fifty Years Later," *Journal of Economic Literature* 19, no. 1 (March 1981): 65–73.

20. Robert S. Pindyck and Daniel L. Rubinfeld, *Microeconomics*, 2nd ed. (New York: Macmillan Publishing Company, 1992), 559.

21. *Idiosyncratic risks* are risks that can be diversified away and therefore not incorporated into the valuation.

the measurement of expected cash flow. Ideally, the sensitivity of the valuation and potential variation in outcomes around expected cash flow is tested through scenario analysis.[22]

Valuing Convertible Land Using the Sales Comparison Approach

In addition to the income capitalization approach, it is possible to examine the value of convertible land through the sales comparison approach. The sales comparison approach is based on the principle of substitution: the property's value is no more than what the market will pay for an equally desirable substitute.[23]

Identifying Comparable Sales

In principle, land sales that are economically comparable are excellent indicators of value. Ideal economic comparables in the present context would include former wetland acreage that was sold for conversion to a mitigation bank, with direct information about how the number of mitigation credits was determined. However, determining the attributes that make the subject property more or less expensive to turn into a mitigation bank is a complicated task and involves scientific and market knowledge about specific conversion costs. The following three criteria are considered in comparable sales analysis related to mitigation bank transactions:

1. **Arm's-length sales between knowledgeable buyers motivated by the creation of mitigation credits, and knowledgeable sellers who did not provide a bargain sale.** The first criterion is the typical requirement for a valid market transaction, the involvement of knowledgeable buyers and sellers. Therefore, evidence is necessary that both parties have an understanding of the mitigation market and recognize that the highest and best use is for mitigation and that the sale was at arm's length. Many transactions involve government and not-for-profit agencies with motivations that can differ substantially from arm's length transactions that enable mitigation. Such sales often involve sellers who receive compensation through knowing that the land is being set aside for purely environmental reasons. Unlike for-profit agencies, the sellers' motivation is not to extract highest level of profits from the sale of the land.[24] Such utility-maximizing sales generally need to be excluded from a comparable sales analysis because they involve nonpecuniary compensation that cannot be readily identified.
2. **Sales that occur contemporaneously with the hypothetical sale.** The second criterion, contemporaneous sale, is necessary to control for government agency changes that made the mitigation market function more efficiently. Thus, any sale needs to be reasonably contemporaneous with the hypothetical sale. The reason for this is that the mitigation market is a rapidly growing and evolving market. For example, to consider transactions from before 1995 would require taking into account the impact that the 1995 Guidance had in changing the market.
3. **Properties with no potential development.** Many of the existing sales of tracts with land where the highest and best use is mitigation also include a substantial portion of land with development potential. This third criterion, lack of development potential, is very important due to the enormous differentials between developable land and mitigation land. Developable land can be ten to twenty times more expensive than land suitable for mitigation. However, when such land is located in the proximity of wetlands, litigation and environmental scrutiny makes it highly uncertain whether development can occur.[25] Ascertaining the value of developable land and the likelihood of development is necessary to value the associated wetlands. However, there are great uncertainties in this analysis that undermine its usefulness for determining wetland prices. Thus, mixed-use land as a comparable yields results that are very sensitive to the underlying assumptions; therefore, these sales are excluded.

22. See for example, Stephen Ross, Randolph Westerfield, and Jeffrey Jaffe, *Corporate Finance*, 4th ed. (New York: Irwin McGraw-Hill, 1996), 206–209, 293–294.
23. Sirmans, *Real Estate Finance*, 2nd ed., 132–134.
24. There is significant economic research regarding the theory of nonprofit organization. The motivation of not-for-profit organizations is considered different from for-profit, in that they are modeled as "utility maximizers" rather than "profit maximizers." See J. A. Hewitt and D. K. Brown, "Agency Costs in Environmental Not-for-Profits," *Public Choice* 103, no. 1–2 (January 2000): 163–183.
25. Mixed-use properties with development and habitat preservation potential have a history of extensive litigation. See Felicity Barringer, "Reach of Clean Water Act Is at Issue in 2 Supreme Court Cases," *The New York Times* (February 20, 2006); Shaun Bishop, "Initiative Renews Bayfront Fight," *The San Mateo Daily Journal* (March 7, 2008); David Blackwell and Allen Matkins, "Wetlands 'Protection' Threatens Property Owners," *The East Bay Business Times* (March 28, 2003); and Jonathan H. Adler, "Swamp Rules: The End of Federal Wetland Regulation?" *Regulation* 22, no. 2 (Summer 1999): 11–16.

Because of the factors discussed, it is preferable to consider only those sales that satisfy all three criteria in order to best utilize standard economic tools.

Adjusting the Comparables

This article presents a method of adjusting sales to make them comparable that relies on the properties having a pure mitigation use and not involving a bargain sale. This method also relies on comparable sales being drawn contemporaneously from the same geographic market and knowledge of how much mitigation can be derived from the site.

While two general categories of wetlands are recognized—coastal or tidal wetlands and inland or nontidal wetlands—there is a wide variation in wetland functionality due to regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors. Thus, the determination of the number of mitigation credits that can be created from each site requires consideration of an environmental premium that reflects how the Corps of Engineers and other agencies assess the properties' mitigation value. Three significant criteria drive the regulator and agency decisions about mitigation value in properties: size, degradation, and location. Regulator and agency preferences are not static and can vary by location. Furthermore, the category of wetlands is considered: coastal or tidal wetlands and inland or nontidal wetlands. The current regulatory and agency preferences are described briefly below.

Size. Currently regulators and agencies see great value in creating large wetland tracts, and they therefore provide more credits per unit of land for a larger site. The 1995 Guidance in particular favors consolidating compensatory mitigation into a larger parcel because it improves the likelihood of achieving functional equivalency with the impact site.[26] Thus, larger properties are more valuable than smaller properties because of size. However, economic analysis of the regulatory environment indicates that a size adjustment is not warranted, as the environmental premium for larger sites offsets the typical circumstance where smaller sites tend to have more value.

Degradation. Another relevant factor which determines the amount of mitigation credits that agencies and regulators assign to a property is contingent on the degree to which a piece of land is degraded. For example, lands that are no longer exposed to water—or exposed to water with salinity so high that native vegetation or animal species cannot be supported—are given a much higher credit ratio than lands that have experienced mild degradation (for instance, from the dumping of dredge spoils).

Location. Location is also an important criterion to the agencies. Within their jurisdiction, agencies may provide more credits per unit of land for properties that complete the continuity of existing wetland tracks or those that are in areas that are deemed important for restoration.

In sum, the comparable sales analysis adjusts for market conditions and the quality of the land sale as it pertains to its mitigation potential. Direct adjustments are made for (1) the agency's desire for the property as wetland mitigation, i.e., how many credits can be derived from the comparable; and (2) market conditions, i.e., how has the value of mitigation credits changed since the comparable sale date and how does it differ from properties at issue.

In the next section, a case study of a hypothetical property in the San Francisco area is used to illustrate the application of the income capitalization and sales comparison approaches as described. The method presented controls directly for the difference in the amount of mitigation that can be created from each of the sites discussed. To simplify the presentation, it is assumed that the cost of converting the lands to wetlands has the same unit cost across all the comparable sites. Furthermore, adjustments are made for differences in the timing and location using a model of mitigation credit prices that directly allows adjustments to site prices for location and date of sale.

Case Study Application of Income Capitalization and Sales Comparison Approaches

This case study demonstrates analysis of mitigation transactions using the income capitalization and sales comparison approaches. The case study uses a San Francisco Bay Area land sale known as Pond A18. Pond A18 was purchased by the City of San Jose from a private seller for potential mitigation in 2003. Pond A18 is an 856-acre, low-salinity pond surrounded by

26. Environmental Law Institute, *Banks and Fees*, 35.

levees in Santa Clara County, and it supports 385.2 mitigation credits.[27] The approaches as described below result in an appraised value of approximately $34,000 per acre, or approximately $29 million for the entire property.

Application of the Income Capitalization Approach to Pond A18

As described earlier, the application of the income capitalization approach requires an understanding of the flow of revenue and costs associated with a mitigation bank. To understand the flow of revenue, the supply and demand for mitigation credits in the region first must be considered. A comprehensive description of the historical supply and demand for mitigation in the San Francisco Bay Area and predictions about the market dynamics that are likely to play out have been developed for a related research project.[28] This research provides adequate evidence that there is significant demand for mitigation credits and limitations in supply for mitigation credits in the Bay Area. For the purposes of this study, it is assumed that wetland credits are the only revenue-generating items associated with Pond A18 and that all the land is valued at its highest and best use as saleable mitigation credits. Note that in application, however, a complete valuation should consider all possible revenue-generating items associated with the property. For example, often property with acreage suitable for wetland conversion may also include portions suitable for flood conveyance, endangered species mitigation, or dredge disposal. All of these considerations may impact the valuation.

Estimating Bay Area Wetland Mitigation Prices

As previously noted, there is a shortcoming of publicly available data on wetland mitigation transactions. In order to develop estimates of Bay Area wetland mitigation price, it would be ideal to have data on regional prices. In the absence of regional data, mitigation transaction data in a wider geographical area is considered. Such data allows for a regression analysis to the predict mitigation credit prices in the future while controlling for underlying differences in market conditions.

For purposes of this study, data is incorporated from a wetland mitigation bank on the universe of wetland mitigation transactions it has conducted. Since the bulk of the transactions have not been in the Bay Area, a regression analysis is developed that allows the prediction of credit prices in the future, controlling for differences in market conditions.

The regression results, shown in Table 1, provide coefficients on the explanatory variables that are both significant in terms of statistical power and reasonable in light of what economic theory and market experience predicts. As presented, estimates for prices are based on home sale prices and population estimates. The growth of these variables explains the growth in mitigation prices. Home sale price and population figures are known and currently available up through 2005.[29] On average, the estimates for Santa Clara mitigation prices (where Pond A18 is located) grew at 9% per year between 1997 and 2005, and were approximately $186,000 per acre in 2003. This high growth rate is consistent with the theoretical predictions of the Hotelling model.

Research also provided additional information about the value of mitigation credits in the San Francisco Bay Area, which validates the results. These include the US Army Corps of Engineers' estimates of South Pacific/San Francisco area prices of $400,000 per acre as of 2005,[30] and Stratus Consulting estimates of $250,000 per acre price in 2003 for

27. City of San Jose, Office of the City Clerk, *Memo 7.6* (May 20, 2003), available at http://www.sanjoseca.gov/clerk/agenda/5_20_03docs/05_20_03_7.6.htm; and Wetland Tracker, "Bay Area Project List," available at http://www.californiawetlands.net/tracker/ba/view/1018.

28. See the authors' working paper "Wetland Policy and Urban Growth in the San Francisco Bay Area: Constraints, Conflicts and Consequences," which provides a comprehensive description of the supply and demand conditions for mitigation credits in the San Francisco Bay region; the working paper is available by request from the authors.

29. Wetland area data provided by the California Department of Housing and Community Development, Division of Housing Policy Development, available at http://www.hcd.ca.gov/hpd/hrc/rtr/ex12.pdf; home sale pricing data by county provided by DataQuick Information Systems; county population estimates for 2000–2007 provided by the State of California, Department of Finance, "Population Estimates and Components of Change by County, July 1, 2000–2007" (California, December 2007), available at http://www.dof.ca.gov/html/DEMOGRAP/ReportsPapers/Estimates/E2/E-2_2000-07.php; county population estimates for 1996–1999 provided by the State of California, Department of Finance, "E-4 Historical Population Estimates for City, County and the State, 1991–2000, with 1990 and 2000 Census Counts" (California, August 2007) available at http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Estimates/E4/E4-91-00/E-4text2.php; land area data provided by the United States Census Bureau, "Land Area, Population, and Density for States and Counties: 1990," and for Puerto Rico, "GCT-PH1 Population, Housing Units, Area, and Density: 2000," available at http://www.census.gov/population/censusdata/90den_stco.txt.

30. US Army Corps of Engineers, "Compensatory Mitigation Practices" (working paper, US Army Corp of Engineers, March 2006), 10. We obtained the underlying data in our communications with the authors.

Table 1 Regression Results

Variable	Coefficient	Standard Error	*t*-Statistic	*P*>|*t*|	95% Confidence Interval (lower/upper bounds)	
Home sale price	0.311	0.037	8.42	0.000	0.238	0.384
Population density	29.397	9.857	2.98	0.003	9.935	48.859
Wetland acreage	0.205	0.151	1.36	0.177	-0.093	0.504
Constant	-1147.45	12801.70	-0.09	0.929	-26,422.58	24,127.68

Dependent variable = price per credit

the Springtown Natural Communities Reserve.[31] (Springtown Natural is located in Alameda County.)

Additional Data Required for the Income Capitalization Approach

The case study used publically available mitigation cost research for assumptions regarding the number of credits generated by Pond A18 and their associated costs. Ideally, this data would be confirmed and refined through industry interviews and local research.[32] This study addresses three previously identified general categories of project costing: preconstruction, construction, and post-construction. Preconstruction costs include permitting and designing costs. Post-construction costs reflect the present value of the ongoing maintenance costs as well as reflect legal and monitoring requirements which are associated with wetland properties.[33] Based on the research findings, it is assumed that it takes approximately two years to develop saleable mitigation credits.[34] Because of this lag in wetland sales from the valuation standpoint, the analysis requires the determination of an appropriate discount rate.

A variety of methods are used for developing discount rates for use in net present value calculations. For the purposes of this analysis, standard economic and finance theory is followed, and the determination of the discount rate is based on the weighted average cost of capital (WACC) method. The key inputs into the WACC calculation are the cost of debt, cost of equity, percent of debt/equity in the capital structure, and the tax rate. Here the capital asset pricing model (CAPM) is used to estimate the costs of debt and equity. This approach yields a discount rate of 8% as shown in Table 2. This finding is in line with research reporting a discount rate for wetland value of 7%.[35]

Results of Income Capitalization Approach to Value Pond A18

The income capitalization approach produces a valuation for Pond A18 in the range of $29 million or $34,122 per acre. Table 3 shows the discounted cash flow calculations used to determine the value for Pond A18. The valuation calculations assume that demand for wetland mitigation exhausts the mitigation credits attributable to Pond A18. A discount rate of 8% is applied, and estimates for the price of wetland mitigation credits are incorporated. Note that prices were estimated to increase approximately 9% per year where Pond A18 is located. Given that the rate of price increase is estimated to be greater than the estimated discount rate, it is assumed that the owner of Pond A18 would not hold back mitigation credits. Furthermore, related research has established that there is sufficient demand for mitigation credits to justify a simplifying assumption that all the wetlands credits are sold upon their introduction to the market. However, an analysis that allows for credits to be sold over time would not significantly alter the results.

31. *A Nationwide Survey of Conservation Prices* (Boulder, CO: Stratus Consulting, December 2003), 30, available at http://www.st.nmfs.noaa.gov/st5/documents/Stratus%20Consulting_Conservation%20Banking_Final.pdf.

32. P. L. Wilkey, R. C. Sundell, K. A. Bailey, and D. C. Hayes, *Wetland Mitigation Banking for the Oil and Gas Industry: Assessment, Conclusions and Recommendations* (Illinois: Argonne National Laboratory, 1994); D. M. King and C. C. Bohlen, *The Cost of Wetland Creation and Restoration*, Technical Report DOE/MT/92006-9 (DE95000174) (Washington, D.C.: US Department of Energy, 1995).

33. See for example, Environmental Law Institute, *Banks and Fees*, 30, for discussion of monitoring costs. Costs of mitigating banks have also been grouped into six stages, including regulatory approval and permitting site design, engineering, land acquisition, construction, operations, and retirement. For example, see Wilkey, Sundell, Bailey, and Hayes, *Wetland Mitigation Banking*. This study attempts to account for all mitigation banking costs, and presents the cash flows as closely to a pro forma statement as feasible.

34. Celia Lamb, "Mitigation Banks Prepare for Construction to Rebound in 2010," *Sacramento Business Journal* (March 6, 2009), available at http://www.bizjournals.com/sacramento/stories/2009/03/09/story12.html.

35. King and Bohlen, *The Cost of Wetland Creation*.

Table 2 Weighted Average Cost of Capital Calculation Using Capital Asset Pricing Model

	Valuation Date 03/06/2003		
	2-Year Beta	**5-Year Beta**	**Source**
Unlevered beta	0.334	0.288	Real estate and developer betas as identified by Bloomberg; see Comparable Companies Table
Debt/Total cap	50.00%	50.00%	Industry interviews/Assumed
Relevered beta	0.667	0.575	
Risk free rate—10 yr	3.67%	3.67%	The Federal Reserve Statistical Release, H.15 (519) Selected Interest Rates (March 10, 2003), http://www.federalreserve.gov/releases/h15/20030310/, March 6, 2003 values
Equity risk premium–long horizon	7.40%	7.40%	*Stocks, Bonds, Bills and Inflation (SBBI) Valuation Edition 2007 Yearbook*, Morningstar, Inc, Chicago, Illinois, Table A-1 gives the equity risk premia (long-horizon, based on the arithmetic mean returns from 1926–2001. This is the same as reported in *Stocks, Bonds, Bills and Inflation (SBBI) Valuation Edition 2002 Yearbook*, Ibbotson Associates, Chicago, Illinois, Table C-1)
Size premium	3.30%	3.30%	SBBI 2002, micro-cap size premium for cap below $269 million
Cost of equity	11.91%	11.23%	Cost of equity = risk free rate + beta*market risk premium
Pre-tax cost of debt	6.91%	6.91%	Federal Reserve Statistical Release, H.15 (519) Selected Interest Rates, (March 10, 2003), http://www.federalreserve.gov/releases/h15/20030310/, March 6, 2003 value
Tax rate	35.0%	35.0%	
Equity/Total cap	50.0%	50.0%	
Debt/Total cap	50.0%	50.0%	
WACC	8.2%	7.9%	***WACC*** = % debt * after tax cost of debt + % equity * cost of equity

Next, the sales comparison approach will be used to value Pond A18, and the results will be compared to the results of the income capitalization approach.

Application of the Sales Comparison Approach to Pond A18

The challenge to finding arm's-length sales is well illustrated by the Bay Area mitigation market where political forces have played an important role in the execution of sales at agreed on prices.

Three economically comparable transactions were identified that satisfactorily match all the criteria discussed and at the same time have sufficient information available to make necessary adjustments. These transactions include the 2000, sale of Plummer Creek by Cargill, Inc., a privately held multinational corporation, to Wildlands, a mitigation bank; Port of Redwood City's 1998 sale of Deepwater Slough to developers of the office park Pacific Shores Center; and Cargill, Inc.'s 2000 sale of Pond A4 to Santa Clara Water District, a government agency.

The list of comparables is narrow because the analysis is using a restrictive set of selection criteria, which is necessary to make reliable adjustments using standard economic tools. The restriction to lands that have little or no development potential and those that were purchased for the purpose of mitigation eliminates a large number of the available properties.

Table 3 Income Approach Calculations *Discount rate 8.0%* *Tax rate 40.0%* *NPV $29,209*

	Year/Period			Total	Assumptions
	2003	**2004**	**2005**		
Sales–Credits					
Total Wetland Credits	0.00	0.00	385.20	385.20	
Price (predicted for Santa" Clara County)	186.00	207.00	239.00		Estimated
Total Revenues	$0.00	$0.00	$92,218.00	$92,218.00	
Cost of Sales					
Marketing Expense	0.00	0.00	9,222.00	9,222.00	Assumes 10% of sales revenue
Reserve Account	0.00	0.00	2,043.00	2,043.00	A non-wasting reserve for long-term maintenance and operations. Costs are assumed to be $5,000 per credit with 3% growth per year. Estimate based on industry interviews and published research.
Total Cost of Sales	0.00	0.00	11,625.00	11,625.00	
Total Net Sales	$0.00	$0.00	$80,953.00	$80,953.00	
Cost of Goods Sold					
Pre-construction Mgmt Cost	0.00	1,873.00	0.00	1,873.00	Follows King and Bolen (1994), where total cost estimate is derived for Salt Marsh properties, San Francisco region with 16% of total cost estimate attributable to preconstruction. Current dollar figures assuming annual 3% inflation.
Construction Cost–Habitat	0.00	0.00	8,801.00	8,801.00	Follows King and Bolen (1994), where total cost estimate is derived for Salt Marsh properties, San Francisco region with 73% cftotal cost estimate attributable to construction. Current dollar figures assuming annual 3% inflation.
Construction Cost—Post-Construction Maintenance	0.00	0.00	1,366.00	1,366.00	Follows King and Bolen (1994), where total cost estimate is derived for Salt Marsh properties, San Francisco region with 11% of total cost estimate attributable to post-construction. Current dollar figures assuming annual 3% inflation.
Total Cost of Goods Sold	$0.00	$1,873.00	$10,167.00	$12,040.00	
Gross Profit	$0.00	($1,873.00)	$70,785.00	$68,913.00	
G & A Expenses					
Accounting & Administration	75.00	77.00	180.00	332.00	Assumed $75,000 per year, growing at 3% per year. Additional $100,000 assumed on year of sale.
Legal	50.00	63.00	78.00	191.00	$50,000 per year up to first sale, growing at 25% per year. Growth rate reflects risks associated with processing and permitting.
Insurance	3.00	3.00	3.00	10.00	Assume $8 per acre, growing at 3% per year.
Design/Permitting	300.00	375.00	469.00	1,144.00	Assume first expense two years before first sale ($300K), growing at 25%. Growth rate reflects risk associated with permitting process.
Monitoring	0.00	0.00	1,323.00	1,323.00	$100,000 per year starting the first year credits are sold, growing at 3% per year. Assuming that a 20-year monitoring period is required
Total G & A Expenses	$428.00	$518.00	$2,053.00	$2,999.00	
NET REVENUE BEFORE ENT. COSTS	($428.00)	($2,391.00)	$68,733.00	$65,914.00	
Entrepreneurial Costs–25%	(107.00)	(598.00)	(5,871.00)	(6,756.00)	Assumed market profit requirement
NET REVENUE BEFORE TAXES	($535.00)	($2,989.00)	$62,861.00	$59,338.00	
Taxes	214.00	1,195.00	(25,145.00)	(23,735.00)	
NET REVENUE AFTER TAXES	($321.00)	($1,793.00)	$37,717.00	$35,603.00	
Discount Factor	0.962	0.891	0.825		
Discounted Cash Flow to 6/30/2003—**$29,209**	($309.00)	($1,598.00)	$31,115.00		

*all dollars in thousands

Plummer Creek. Plummer Creek is one of the few mitigation banks in the Bay Area. Prior to the transaction, this 25.97-acre property was primarily used for grazing and as a flying field for model airplane enthusiasts. The land was acquired in 2000 at a sale price of $30,000 per acre. Both the buyer and seller knew that the land would be used for a mitigation bank. At sale, the property was converted to a tidal marshland by Wildlands. The conversion yielded 15.71 mitigation credits.

Deepwater Slough Island. Deepwater Slough Island was purchased in 1998 by Pacific Shores Center for the purpose of mitigating the development of a neighboring office park. This 140-acre property was owned by the Port of Redwood City and contained 33 acres of tidal marsh degraded by upland vegetation. The mitigation plan was to restore 20 of the 33 acres of filled uplands to wetlands and to improve all of the remaining 120 acres. The sale was accomplished through an exchange of a 9.167-acre property, owned by Pacific Shores Center, for the entirety of Deepwater Slough Island, which is a 136-acre island bordered by Deepwater Slough and Redwood Creek.

The appraised value of property offered by Pacific Shore Center was $4,800,000. Thus, the implied price of the mitigation property is $34,285 per acre (i.e., $4,800,000/140 acres). Both the buyer and seller knew that the land would be used for mitigation purposes. The compensatory mitigation of Deepwater Slough Island allowed Pacific Shore Center to fill 15.75 acres of wetlands, 1.9 acres of other waters, and 1 acre of tidal wetlands. Deepwater Slough Island provided Pacific Shores Center with 57.815 mitigation credits, as for each acre of habitat lost, Pacific Shore Center was required to replace 3.10 acres (i.e., 3.1 * (15.75 + 1.9 + 1) = 57.815).

Pond A4. Pond A4 was purchased by the Santa Clara Water District for mitigation in 2000. Pond A4 is a low-salinity pond surrounded by levees. The average sale price was $18,884 per acre, which was derived from a negotiation that assigned $21,000 per acre for the 257.221 acres that were owned free and clear and $10,400 per acre for the 64.195 acres with easements.

Adjusting the Comparables

Adjustments to the comparable properties are straightforward because the environmental studies and market conditions for the three properties are available. The adjustments include the following:

- A quality adjustment for the economic differences in land quality that arise from their ability to generate mitigation credits. The adjustment is calculated by multiplying the sale price per acre by the ratio of Pond A18 credits per acre to comparable credits per acre. (See Line 10 in Table 4 and the accompanying notes.)
- A location adjustment for the differences in location. The adjustment is calculated by multiplying the comparable 2003 sale price by the ratio of the predicted Santa Clara County (Pond A18) average credit sale. The credit price at different locations at a point in time captures geographic differences in prices. Land cost and urban density differentials generate variation in the value of commercial mitigation. By adjusting for location, these factors can be incorporated, and an appropriate price for the market can be determined. (See Line 11 in Table 4 and the accompanying notes.)
- A time adjustment for the difference in the timing of the comparable sale. This adjustment is calculated by multiplying the comparable sale price by the ratio of the 2003 credit price to the credit price at the date of sale. This captures the rate at which mitigation land prices would be changing from the date of sale. (See Line 12 in Table 4 and the accompanying notes.)

Application of the Sales Comparison Approach

Table 4 summarizes the results of the sales comparison application. The three properties identified as comparables—Plummer Creek, Deepwater Slough Island, and Pond A4—are listed in columns A through C. Table 4 also lists the defining features of the properties comparables, including: (1) the size of the property (in acres); (2) the number of mitigation credits supported by the property; (3) the price of the sale; (4) the county where the property is located; (5) the date of the sale; (6) the estimated nominal price per credit generated through the sale; (7) the price per credit adjusted to reflect 2003 dollars; and (8) the number of credits per acre supported by the property. Column D provides this same information for the Pond A18 property.

As shown in Table 4, the comparable properties were nominally priced between $18,883 and $30,000

Table 4 Sales Comparison Approach Applied to Pond A18

	A	B	C	D	
	Plummer	**Deepwater**	**Pond A4**	**Pond A18**	
Size	25.97	140.00	321.42	856.00	[1]
Credits	15.71	57.82	144.45	385.20	[2]
Price	$779,100	$3,225,000	$6,069,500		[3]
Location (county)	Alameda	San Mateo	Santa Clara	Santa Clara	[4]
Sale date	2000	1998	2000	2003	[5]
Price/Credit (sale date)	$157,697	$148,089	$174, 820		[6]
Price/Credit (2003)	$187,575	$219,271	$185,981	$185,981	[7]
Credits/Acre	0.60	0.41	0.45	0.45	[8] = [1] / [2]
Sale price (sale/acre)	$30,000	$23,036	$18,883		[9] = [3] / [1]
Quality adjustment	0.74	1.09	1.00		[10] = [D8] / [8]
Location adjustment	0.99	0.85	1.00		[11] = [D7] /[7]
Time adjustment	1.19	1.48	1.06		[12] = [7] / [6]
Adjusted price (per acre)	$26,319	$31,522	$20,115	$23,722	[13] = [9] x [10] x [11] x [12]
Value of Pond A18	$22,529,339	$26,982,593	$17,218,650	$20,306,261	[14] = [13] x [D1]

Data Sources:

[1] Size (in acres) is as reported.

[2] Credits reflect the number of mitigation credits supported by the acres.

[3] Price is as reported.

[4] County of sale is as reported.

[5] Year of sale is as reported.

[6] Price per credit is as estiimated through the regression model. Differences in prices reflect different county of sale and different year of sale.

[7] Price per credit in 2003 is as estimated through the regression model.

per acre and sold in three different counties over the course of three years (1998–2000). Each property is adjusted, as discussed earlier, to make it comparable to the Pond A18 property. Quality (Line 10), location (Line 11), and time (Line 12) adjustments are each applied to the sale price per acre (Line 9). Once the comparable sales are adjusted for these differences, the results indicate that the price per acre in 2003 prices ranges between $20,115 and $31,522. To determine the implied value of the Pond A18 property, the adjusted price per acre (Line 13) is multiplied by the total Pond A18 acreage (Line D1).

The results are complementary to the analysis using the income capitalization approach. The three comparables provide a range of estimates:

- $23 million for the Plummer Creek sale in 2000
- $27 million for the Deepwater sale in 1998
- $17 million for the Pond A4 sale in 2000

Using the calculated weighted average of these properties, the comparable sales approach indicates that the Pond A18 property value is approximately $20 million ($23,723 per acre x 856 acres). The valuation of the comparable properties adds support to the value indicated by the income capitalization approach ($29 million).

Typically, in a deeply competitive market with many transactions, the consideration of a small sale is a standard appraisal problem that simply requires observing and adjusting prices from comparables. The mitigation market is inactive relative to the residential real estate market where there are a large number of buyers, sellers, and frequent transactions with readily available information. Thus, while the standard market method appraisal technique of using comparable sales is appropriate in the real estate market, the income capitalization approach is a better indicator of value for land with mitigation potential.[36] However, it is useful to apply the sales comparison approach and verify that the two methodologies support valuations that are not contradictory, as has been done here.

36. See for example, Appraisal Institute, *The Appraisal of Real Estate*, 12th ed. (Chicago: Appraisal Institute, 2001), 63, 419–421; and Thomas J. Lueck, "Raising the Standards for Appraisers," *New York Times* (October 1990).

Conclusions

The policy initiatives that promote the restoration and protection of wetlands have led to an increase in the supply of wetlands. There also has been a concomitant decrease in the supply of convertible land as historic wetlands are restored and converted back to their original state. Seventy-five percent of the remaining US wetlands are on private lands.[37] As long as federal and local governments maintain a commitment to wetland mitigation, the valuation of large tracts of land intended for the establishment or restoration of wetland habitat will be a relevant task. As discussed in this article, the valuation of land with wetland potential requires a thorough analysis of the influences on wetland supply and demand for the region in which the land is located. More specifically, the valuation of lands with wetland potential must explicitly incorporate the influence of federal and regional policy, paying particular consideration to how mitigation credits are determined within the region.

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37. "Wetlands: History and Restoration Issues," *Environmental Policy Issues* (September 2003), available at http://www.csa.com/discoveryguides/ern/03sep/overview.php.

Appendix

Comparables for Weighted Average Cost of Capital

Name	Stewart Enterprises	Bresler & Reiner	Blue Ridge Real Estate	Orleans Homebuilders	Gyrodyne	California Coastal Comm	BF Enterprises	Heartland Partners	Oak Ridge Capital Group
Ticker	STEI	BRER	BLRGZ	OHB	GYRO	CALC	BFET	HTLLQ	ORCG
10-K/Q date	1/31/03	12/31/02	1/31/03	12/31/02	1/31/03	12/31/02	12/31/02	12/31/02	12/31/02
Shares outstanding date	3/6/03	3/14/03	1/31/03	2/5/03	2/25/03	2/27/03	3/14/03	3/24/03	3/17/03
Valuation date closing stock price	$2.89	$21.50	$12.49	$7.00	$16.67	$6.26	$8.96	$6.87	$0.18
Shares outstanding	108,352,123	2,738,351	1,916,130	12,627,565	1,117,062	10,058,589	3,521,346	2,092,438	2,096,641
Book equity	$822,138,000	$118,514,000	$10,572,782	$73,537,000	$6,614,253	$159,900,000	$27,321,000	$18,962,000	$11,980,000
Value of debt (millions)	$552,195,000	$100,586,000	$8,750,692	$125,880,000	$688,802	$9,800,000	$0	$8,282,000	$15,477,000
Value of equity (millions)	$313,137,635	$58,874,547	$23,932,464	$88,392,955	$18,621,424	$62,966,767	$31,551,260	$14,375,049	$377,395
Total cap	$865,332,635	$159,460,547	$32,683,156	$214,272,955	$19,310,226	$72,766,767	$31,551,260	$22,657,049	$15,854,395
Adjusted beta, 2yr weekly	0.981	0.412	0.167	1.097	0.58	0.397	0.654	0.558	0.381
Adjusted beta, 5yr monthly	0.848	0.372	0.402	0.884	0.389	0.396	0.403	0.521	1.461
Cash (excl: restricted cash)			$393,086	$6,833,000	$2,370,705	$9,200,000	$11,214,000	$709,000	$395,000
Debt									
Current maturities of long-term debt	$6,645,000		$5,416,497						
Long-term debt, less current maturities	$545,550,000		$3,334,195						
Real estate loans payable		$100,586,000							
Mortgages and other notes				$122,290,000					
Loans/Notes payable				$3,590,000	$688,802			$8,282,000	
Project debt						$9,800,000			
Mortgages related to waste tech products									$173,000
Development loans									$4,077,000
Loan payable-credit agreement									$4,197,000
Lines of credit									$7,030,000
Unlevered beta, 2 year	0.355	0.152	0.122	0.453	0.559	0.344	0.654	0.354	0.009
Unlevered beta, 5 year	0.307	0.137	0.294	0.365	0.375	0.343	0.403	0.331	0.035

The sample of comparable companies is the result of Bloomberg equity screening for Land Subdividers and Developers (SIC code 6552) which were actively traded (public) as of March 6, 2003.

Bloomberg provides a description of each company, stock price (on or around March 6, 2003) as well as the 2-year and 5-year average beta (on or around March 6, 2003).

Additional data used for the beta calculation from the sample companies' 10-K or 10-Q reports.

Specifically this includes: The Stewart Enterprises' 10-Q from January 2003; Bresler & Reiner Blue Ridge Real Estate's 10-K from December 2002; Orleans Homebuilders 10-K from December 2002;

Gyrodyne's 10-Q from January 2003; California Coastal Communities' 10-K from December 2002; BF Enterprises' 10-K from December 2002; Heartland Partners' 10-K from December 2002; and Oak Ridge Capital Group's 10-K from December 2002.

Web Connections

Internet resources suggested by the Y. T. and Louise Lee Lum Library

Association of State Wetlands Managers, Inc.
http://www.aswm.org/

Environmental Law Institute
http://www.eli.org/

—National Wetlands Newsletter
http://www.wetlandsnewsletter.org/welcome/index.cfm

National Mitigation Banking Association
http://www.mitigationbanking.org/index.html

—Wetland and Stream Mitigation Banks
http://www.mitigationbanking.org/mitigationbanks/index.html

US Army Corp of Engineers
—Wetlands Research Technology Center
http://el.erdc.usace.army.mil/wetlands/

—Corps of Engineers Wetland Delineation Manual
http://www.fedcenter.gov/Bookmarks/index.cfm?id=6403

US Environmental Protection Agency
—Wetlands, Mitigation Banking Factsheet
http://www.epa.gov/owow/wetlands/facts/fact16.html

—EPA Wetlands Regulatory Summary
http://www.epa.gov/owow/wetlands/pdf/reg_authority_pr.pdf

World Wildlife Fund—Global Lakes and Wetlands Database
http://www.worldwildlife.org/science/data/item1877.html

United States
Department of
Agriculture

Forest Service

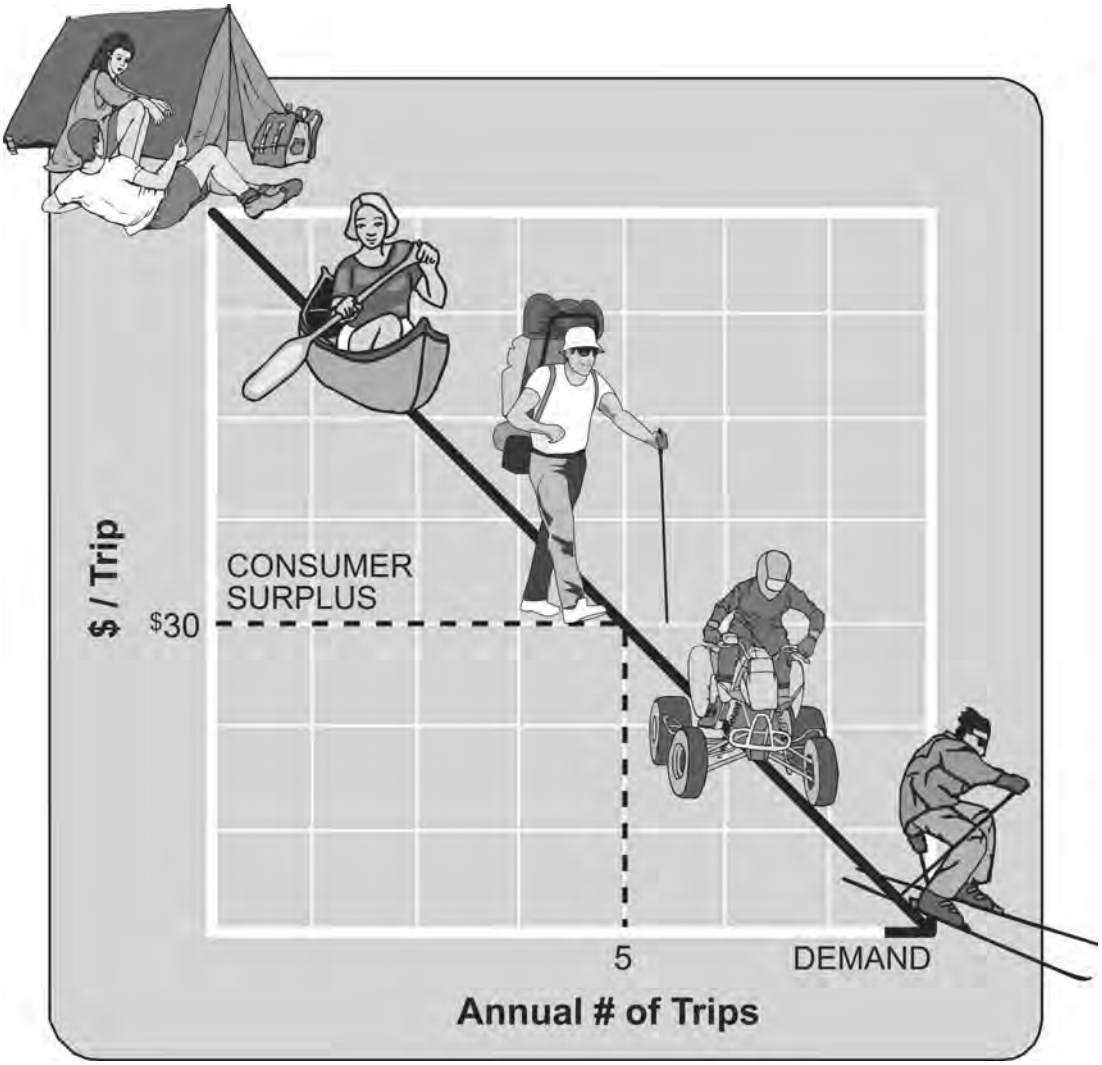
Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-658

October 2005

Updated Outdoor Recreation Use Values on National Forests and Other Public Lands

John Loomis



The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Abstract

Loomis, John. 2005. Updated outdoor recreation use values on national forests and other public lands. Gen. Tech. Rep. PNW-GTR-658. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

This report summarizes more than 30 years of the literature on net economic value of outdoor recreation on public lands. The report provides average net willingness to pay or consumer surplus per day for 30 recreation activities at the national level. Values per day by recreation activity are also presented by census region of the United States. Detailed tables provide the average value per day as well as the standard error for calculating confidence intervals. Guidance for using these values in performing benefit transfer to unstudied sites is also provided. The report provides a link to a Web site where the spreadsheet that underlies the averages calculated in this report is available.

Keywords: Benefit transfer, consumer surplus, recreation use values, willingness to pay.

Executive Summary

This report presents updated average values per visitor-day of outdoor recreation opportunities commonly found at national forests, with emphasis on the Pacific Northwest region. The use of past valuation information for current policy analysis is called benefit transfer (Brookshire and Neill 1992). In this report, the term "value" is used to mean net willingness to pay or consumer surplus, a measure commonly used for benefit-cost analysis or economic efficiency analysis by federal agencies such as the U.S. Army Corps of Engineers, Bureau of Reclamation (U.S. Water Resources Council 1979, 1983) and U.S. Environmental Protection Agency.

This report updates past USDA Forest Service-sponsored reviews of the literature on outdoor recreation use valuation by including recent analyses and estimates through the year 2003. Adding studies from this period to past reviews results in a database on outdoor recreation use valuation that spans 1967 to 2003; 1,239 estimates obtained from the literature provide values for 30 outdoor recreation activities. This update includes new recreation activities such as snorkeling, scuba diving, and birdwatching that were not part of the Rosenberger and Loomis (2001) report. The values presented in this report are averages of values per day from original or primary Contingent Valuation Method or Travel Cost Method studies (see Loomis and Walsh 1997 for more details on these two valuation methods). To standardize the units of recreation use, average values are reported per visitor-day. The average visitor-day value is reported for each activity by census region when available, and specifically broken out into greater detail for the Pacific Northwest. The complete spreadsheet providing the results of the individual studies is available at: http://www.fs.fed.us/pnw/data/RecValues.htm.

Although the report provides average values for all regions of the United States, the values for the Pacific Northwest are separated out. Based on the existing literature, hunting on public lands in the Pacific Northwest has an average value of $35 per day, fishing averages $42 per day, and wildlife viewing is $35 per day. Hiking has a value of $24 per day in the Pacific Northwest.

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Introduction

The USDA Forest Service and other federal land management agencies including the National Park Service, U.S. Fish and Wildlife Service, and USDI Bureau of Land Management require information on values of recreation. Whether for land management planning or Government Performance and Results Act (GPRA) of 1993, these requirements feed directly into a need for credible measures of benefits. In this case, we are interested in developing credible measures of benefits for outdoor recreation.

This report is intended to serve two functions. First, it provides information from a literature review of economic studies conducted in the United States, spanning 1967 to 2003, that estimated outdoor recreation use values. Second, this report provides some basic guidelines on performing benefit transfers in the context of recreation use valuation. This report is not a cookbook for benefit transfers, but instead it is to be used as a guide to the empirical estimates available (a more complete discussion of benefit transfer protocols can be found in Rosenberger and Loomis 2001). Per federal government benefit-cost guidelines (U.S. Water Resources Council 1979, 1983), economic value is defined as visitor's net willingness to pay or consumer surplus (Freeman 1993). The values summarized in this report are averages of original or primary Contingent Valuation Method (CVM) or Travel Cost Method (TCM) studies (see Loomis and Walsh 1997 for more details on these two valuation methods). The values reported in this publication are unweighted or simple averages where each study and each estimate from each study is given equal weight. This is the same approach used by Rosenberger and Loomis (2001). However, by using the spreadsheet, an analyst could construct a weighted average by using any reasonable criteria such as study sample size or survey response rate, etc. To standardize the units of recreation use, average values are reported per visitor-day.

Data

Literature Review Efforts, Past and Present

We provide data on outdoor recreation use values based on empirical research conducted from 1967 to 2003 in the United States. This data is the compilation of five literature reviews conducted over the last 20 years. The first review covered the literature on outdoor recreation and forest amenity use value estimation from the mid-1960s to 1982, collecting 93 benefit estimates in all (Sorg and Loomis 1984). The second review covered outdoor recreation use valuation studies from 1968 to 1988, building on the first review, but focusing primarily on the 1983–88 period (Walsh et al. 1988, 1992). That second review increased the number of benefit

estimates to 287 estimates. A third literature review on the subject covered the period 1968–93 (MacNair 1993). A fourth literature review on outdoor recreation use valuation, focusing on studies reported from 1988 to 1998 (Loomis et al. 1999). Rosenberger and Loomis (2001) then merged the results of the fourth review with the MacNair (1993) database. The main emphasis was to improve on coding procedures used in the past review efforts to focus on use value estimates for all recreation activity categories identified by USDA Forest Service documents. Fishing benefit studies were not emphasized, as this was the focus of a separate review sponsored by the U.S. Fish and Wildlife Service, and published by Industrial Economics, Inc. (Markowski et al. 1997). Fishing studies coded in the MacNair (1993) database that were from the Walsh et al. (1988) review were sufficient in number and coverage for valuation of fishing for statistical purposes. This report represents the fifth literature review, adding new studies from 1998 through 2003. In this new review, we were able to obtain 479 new observations.

Data Sources and Coding Procedures

Coding fields include reference citation to the research, benefit measure(s) reported, methodology used, recreation activity investigated, recreation site characteristics, and user or sample population characteristics.

A concerted effort was made to locate studies on activities that were not previously investigated and recreation activities of particular interest to the USDA Forest Service, especially the Pacific Northwest Region. Computerized databases, such as American Economic Association's ECONLIT and Thomson's ISI Web of Science were searched for published literature along with the University of Michigan's dissertation and master's thesis abstracts. Gray literature was located by using conference proceedings, bibliographies on valuation studies (Carson et al. 1994), and access to working papers. Details of studies conducted from 1967 to 1988 were obtained primarily from MacNair's (1993) database that coded the Walsh et al. (1988, 1992) literature review. A few study details were obtained directly from the Walsh et al. (1988) review that were not included in the MacNair (1993) database.

For consistency and to allow merging of the new studies with studies compiled by Rosenberger and Loomis (2001), the same master coding sheet was used for the base. The spreadsheet dataset and code sheet contains 126 fields. The main coding fields include reference citation to the research, benefit measure(s) reported, methodology used, recreation activity investigated, recreation site characteristics, and user or sample population characteristics. Study reference citation details include, in part, author, year of study, and source of study results. Benefit measure(s) details include, in part, the monetary estimate provided by the study (converted to activity-day units by using information provided in the study report), the units in which the estimate is reported (e.g., day, trip, season, or year), and benefit measures temporally adjusted for inflationary trends to 2004 dollars. An activity-day represents

the typical amount of time a person pursues an activity within a 24-hour period. This unit was chosen because of its ease in being converted to other visitation/participation units (e.g., recreation visitor-days, trips, seasons).

Value-Per-Day Tables by Activity and Region

New data were combined with old data to create a database of 1,239 observations spanning 1967 through 2003. This table (table 1) presents data for the 30 activities. Information that can be observed includes the number of studies, number of estimates, mean/average, standard error, and range of values. In brief, the activities most commonly found include hunting, fishing, wildlife viewing, and camping. The average estimate of consumer surplus is $47.64 per person per day across all 1,239 observations.

Table 1—Summary statistics on average consumer surplus values per person per day by activity from original recreation benefit studies, 1967–2003

Activity	Studies	Estimates	Mean	Standard error	Range of estimates	
	- - - Number - - -		*- - - - - - - - - - - 2004 dollars - - - - - - - - - - -*			
Backpacking	1	6	52.10	9.29	26.82	80.34
Birdwatching	4	8	29.60	8.35	5.80	78.46
Camping	29	48	37.19	5.77	2.03	224.53
Cross-country skiing	8	12	31.38	3.41	14.05	48.38
Downhill skiing	5	5	33.49	8.48	15.05	63.11
Fishing	129	177	47.16	4.81	2.08	556.82
Floatboating/rafting/canoeing	20	81	100.91	9.56	2.70	394.82
General recreation	15	39	35.10	8.69	1.42	257.51
Going to the beach	5	33	39.43	5.06	3.78	117.82
Hiking	21	68	30.84	4.33	0.40	262.04
Horseback riding	1	1	18.12		18.12	18.12
Hunting	192	277	46.92	2.20	2.60	250.90
Motorboating	15	32	46.27	7.43	3.78	203.62
Mountain biking	7	32	73.78	12.11	20.86	295.69
Off-road vehicle driving	4	10	22.92	3.95	5.24	40.86
Other recreation	15	16	48.70	11.57	5.71	206.82
Picnicking	8	13	41.46	10.69	8.94	142.74
Pleasure driving (which may include sightseeing)	4	11	59.23	18.84	3.02	167.74
Rock climbing	4	27	56.26	6.86	26.62	135.82
Scuba diving	2	24	32.36	11.21	2.81	250.04
Sightseeing	15	28	36.84	8.80	.65	209.77
Snorkeling	1	9	30.31	15.36	5.23	135.29
Snowmobiling	3	8	36.29	13.24	10.79	124.44
Swimming	11	26	42.68	6.14	2.20	134.34
Visiting environmental education centers	1	1	6.01		6.01	6.01
Visiting arboretums	1	1	13.54		13.54	13.54
Visiting aquariums	1	1	28.31		28.31	28.31
Waterskiing	1	4	49.02	12.72	15.13	70.07
Wildlife viewing	69	240	42.36	2.64	2.40	347.88
Windsurfing	1	1	395.47		395.47	395.47

Table 2 breaks down the information further by subdividing the activities by region. Six regions are used that roughly follow U.S. Census Regions: Alaska, Intermountain, Northeast, Pacific Coast (USDA Pacific Southwest and Pacific Northwest Regions [R5 and R6]), Southeast, and our own construct, Multiple Area. Multiple Area was included, as several of the studies spanned more than one region. Figure 1 illustrates the geographic regions used for this analysis. This update provides 354 observations in the Intermountain area, 306 in the Northeast, 281 in the Southeast, 186 in the Pacific Coast, 26 in Alaska, and only 86 in the Multiple Area studies. Deciding upon the best degree of geographic aggregation is a tradeoff between greater geographic specificity, which enhances accuracy in benefit transfer, and smaller sample sizes within each region, which reduces accuracy. Considering this tradeoff, it was desirable to use regions broader than Forest Service administrative regions. This increased the sample size in each cell. Second, for some recreation activities, if smaller administrative regions were used it would lead to numerous blank cells, indicating no values for that activity in that region. Finally, the larger censuslike regions correspond to the Resources Planning Act (RPA) assessment regions, so there is some connection to Government Performance and Results Act and RPA regions.

Table 2 also presents average recreation values of empirical studies conducted in wilderness areas by region. Of the 1,239 total studies, 108 were found to be in wilderness areas.

Table 3 provides more detail about each activity in each region, including standard error and minimum and maximum values for each activity. The region with the least amount of activity values was Alaska, with eight recreation activities having values. None of the regions had values for all 30 recreation activities.

Table 4 presents averages specific to the Pacific Northwest Region (R6), Oregon and Washington. As can be seen, there are relatively few studies, although they produce a large number of benefit estimates for the different sites and variants of valuation techniques used in each study. There are quite a few fishing, hiking, hunting, and wildlife viewing studies and estimates.

Many of the estimates in table 4 (specifically, camping, off-road vehicles, picknicking, sightseeing, and swimming) are from a USDA Forest Service-commissioned study by Bergstrom et al. (1996). Many of the hunting and fishing studies are from Brown and Hay (1987) from the USFWS hunting and fishing survey, and from Rowe et al. (1985). Most of the hiking value estimates came from Hilger's (1998) master's thesis on wilderness day hikers, and Englin and Shonkwiler (1995).

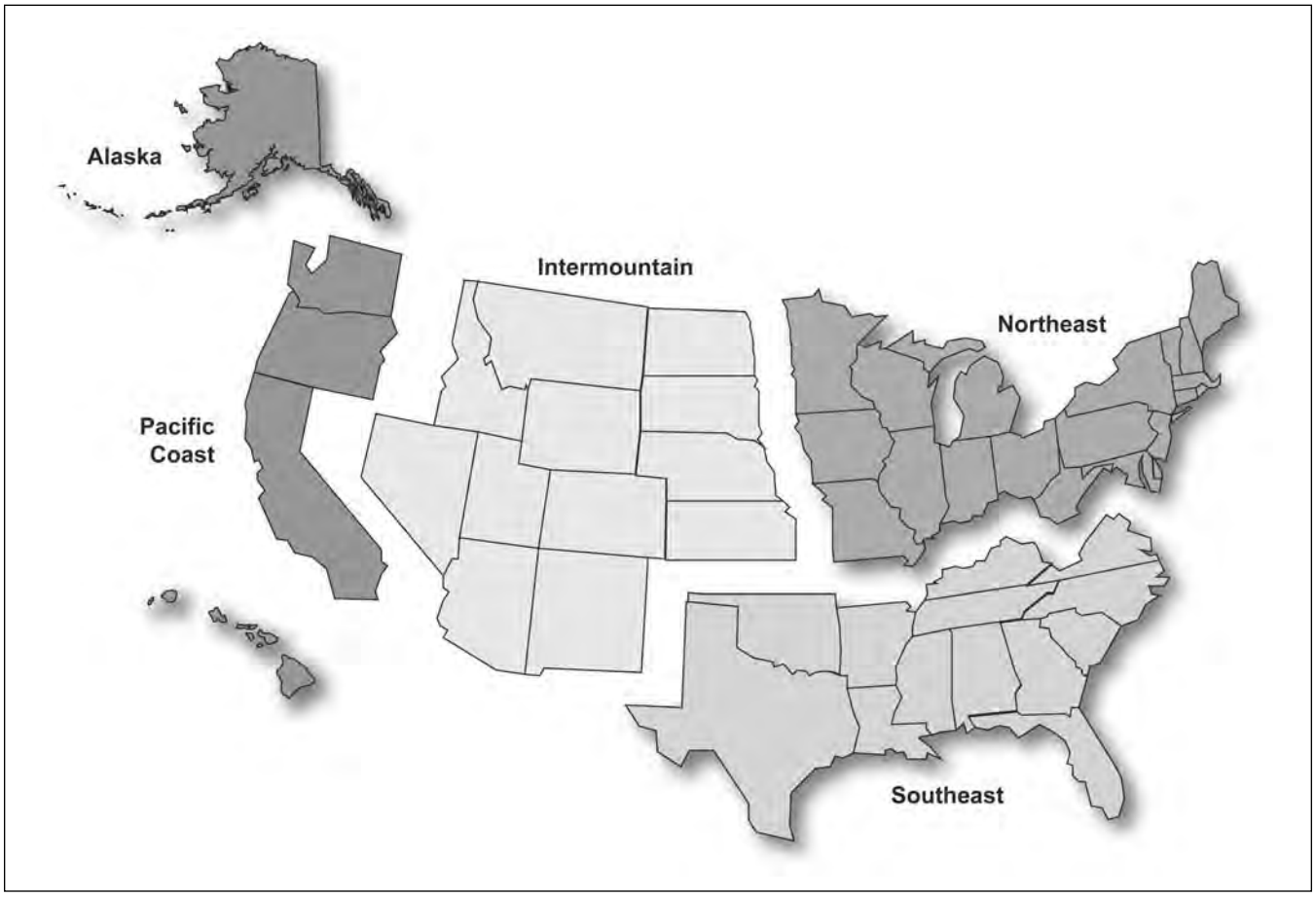

Figure 1—Study regions.

Tables 1, 3, and 4 present the standard error of the mean. This statistic is calculated from the standard deviation and the square root of sample size. The standard error of the mean is used to construct the confidence interval around the population mean. For example, a 95-percent confidence interval around the population mean is formed by adding and subtracting 1.96 standard errors from the mean. Thus in table 1 for camping, the mean is $37.19, and the standard error is $5.77. The 95-percent confidence interval is $25.88 to $48.50. We expect that there is only a 5 percent chance, given the data we have, that the true population mean for camping lies outside of this range.

Tables 1 and 3 contain maximum and minimum values for each activity and region. Although some of these maximum values may appear quite large or minimum values appear quite small, these study values were checked against the original study as were our calculations. Thus, all the values included in the report were used in calculating the averages. The user can access the spreadsheet data to calculate averages with what they consider to be outliers removed if they wish.

Table 2—Summary statistics on average consumer surplus values per person per day by activity and region, 1967 to 2003

	Alaska		Inter-mountain		Multiple area studies		Northeast		Pacific Coast		Southeast		Total	
Activity	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
		2004 dollars		*2004 dollars*		*2004 dollars*		*2004 dollars*		*2004 dollars*		*2004 dollars*		*2004 dollars*
Backpacking									6	52.10				
Birdwatching							3	34.86			5	26.46		
Camping			21	34.72	2	11.82	10	33.11	4	104.35	11	25.79		
Cross-country skiing			7	29.88	1	15.20	3	34.60	1	48.38				
Downhill skiing			3	39.62	1	23.53			1	25.08				
Fishing	4	61.99	48	49.57	14	47.53	69	32.60	15	44.36	27	79.21		
Floatboating/rafting/canoeing	1	18.16	22	67.70	1	34.01	6	88.32	4	27.84	47	127.46		
General recreation	1	14.84	12	48.46	3	4.00	5	16.87	9	32.35	9	42.77		
Going to the beach							22	42.60			11	33.12		
Hiking	1	15.52	7	38.53	1	25.04	3	75.18	49	23.24	7	60.38		
Horseback riding					1	18.12								
Hunting	7	65.68	109	48.55	12	61.69	87	47.45	18	45.49	44	35.36		
Motorboating			7	53.68	1	34.36	3	29.68	8	26.94	13	58.92		
Mountain biking			6	184.48	1	21.13	1	40.93	16	49.68	8	49.62		
Off-road vehicle driving			7	22.81	1	23.93			1	40.37	1	5.24		
Other recreation			10	56.35	1	20.83			1	74.47	4	30.07		
Picnicking			5	28.27	1	18.83	2	56.45	3	64.22	2	36.62		
Pleasure driving	3	8.41	4	69.74	1	36.46	1	21.35			2	144.78		
Rock climbing			3	50.45	12	26.82	1	102.89			11	85.70		
Scuba diving							14	17.92	10	52.60				
Sightseeing	1	15.84	11	23.58	1	17.83	2	121.43	4	20.27	9	46.06		
Snorkeling									9	30.31				
Snowmobiling			8	36.29										
Swimming			1	29.54	1	23.56	7	22.21	4	27.29	13	60.92		
Visiting environmental education centers							1	6.01						
Visiting arboretums											1	13.54		
Visiting aquariums											1	28.31		
Waterskiing			2	56.96	1	67.00	1	15.13						
Wildlife viewing	8	49.33	61	37.24	29	56.36	65	31.30	23	72.48	54	40.10		
Windsurfing											1	395.47		
All activities in wilderness			32	41.68	17	28.46	8	25.48	46	26.22	5	118.67	108	35.38

Table 3—Detailed descriptive statistics on average consumer surplus values per person per day by activity and region, 1967 to 2003

Area and activity	N	Mean	Standard error	Minimum	Maximum
			2004 dollars		
Alaska region:					
Fishing	4	61.99	9.22	45.60	81.94
Floatboating/rafting/canoeing	1	18.16		18.16	18.16
General recreation	1	14.84		14.84	14.84
Hiking	1	15.52		15.52	15.52
Hunting	7	65.68	4.81	47.06	85.45
Pleasure driving	3	8.41	3.67	3.02	15.43
Sightseeing	1	15.84		15.84	15.84
Wildlife viewing	8	49.33	9.49	10.69	84.40
Intermountain area studies:					
Camping	21	34.72	6.64	2.03	116.66
Cross-country skiing	7	29.88	4.58	14.05	46.49
Downhill skiing	3	39.62	13.88	15.05	63.11
Fishing	48	49.57	6.96	8.96	227.28
Floatboating/rafting/canoeing	22	67.70	14.33	2.70	316.42
General recreation	12	48.46	20.92	7.91	257.51
Hiking	7	38.53	7.84	12.85	75.76
Hunting	109	48.55	3.35	2.60	169.31
Motorboating	7	53.68	25.93	5.29	203.62
Mountain biking	6	184.48	41.05	65.88	295.69
Off-road vehicle driving	7	22.81	4.31	7.96	40.86
Other recreation	10	56.35	17.36	12.17	206.82
Picnicking	5	28.27	4.09	13.61	38.76
Pleasure driving	4	69.74	33.23	26.41	167.74
Rock climbing	3	50.45	7.58	35.78	61.14
Sightseeing	11	23.58	8.65	.65	100.73
Snowmobiling	8	36.29	13.24	10.79	124.44
Swimming	1	29.54		29.54	29.54
Waterskiing	2	56.96	13.09	43.87	70.07
Wildlife viewing	61	37.24	3.30	5.26	193.91
Multiple area studies:					
Camping	2	11.82	2.00	9.82	13.82
Cross-country skiing	1	15.20		15.20	15.20
Downhill skiing	1	23.53		23.53	23.53
Fishing	14	47.53	10.49	2.40	126.00
Floatboating/rafting/canoeing	1	34.01		34.01	34.01
General recreation	3	4.00	2.03	1.97	8.05
Hiking	1	25.04		25.04	25.04
Horseback riding	1	18.12		18.12	18.12
Hunting	12	61.69	23.05	6.00	232.58
Motorboating	1	34.36		34.36	34.36
Mountain biking	1	21.13		21.13	21.13
Off-road vehicle driving	1	23.93		23.93	23.93
Other recreation	1	20.83		20.83	20.83
Picnicking	1	18.83		18.83	18.83
Pleasure driving	1	36.46		36.46	36.46

Table 3—Detailed descriptive statistics on average consumer surplus values per person per day by activity and region, 1967 to 2003 (continued)

Area and activity	N	Mean	Standard error	Minimum	Maximum
			2004 dollars		
Rock climbing	12	26.82	.04	26.62	26.92
Sightseeing	1	17.83		17.83	17.83
Swimming	1	23.56		23.56	23.56
Waterskiing	1	67.00		67.00	67.00
Wildlife viewing	29	56.36	12.38	3.00	313.99
Northeast area:					
Birdwatching	3	34.86	22.20	5.80	78.46
Camping	10	33.11	6.32	6.73	66.44
Cross-country skiing	3	34.60	2.82	29.70	39.49
Fishing	69	32.60	5.46	2.08	253.13
Floatboating/rafting/canoeing	6	88.32	22.93	20.08	143.50
General recreation	5	16.87	8.08	1.97	46.69
Going to the beach	22	42.60	7.03	3.78	117.82
Hiking	3	75.18	12.83	49.80	91.10
Hunting	87	47.45	4.03	4.16	250.90
Motorboating	3	29.68	25.21	3.78	80.10
Mountain biking	1	40.93		40.93	40.93
Picnicking	2	56.45	47.51	8.94	103.96
Pleasure driving	1	21.35		21.35	21.35
Rock climbing	1	102.89		102.89	102.89
Scuba diving	14	17.92	3.43	2.81	45.00
Sightseeing	2	121.43	88.36	33.07	209.77
Swimming	7	22.21	6.14	2.20	50.10
Visiting environmental education centers	1	6.01		6.01	6.01
Waterskiing	1	15.13		15.13	15.13
Wildlife viewing	65	31.30	2.18	2.40	96.30
Pacific coast area studies:					
Backpacking	6	52.10	9.29	26.82	80.34
Camping	4	104.35	45.38	7.45	224.53
Cross-country skiing	1	48.38		48.38	48.38
Downhill skiing	1	25.08		25.08	25.08
Fishing	15	44.36	8.68	4.43	103.50
Floatboating/rafting/canoeing	4	27.84	1.01	25.21	29.58
General recreation	9	32.35	14.38	1.42	125.57
Hiking	49	23.24	2.65	.40	129.62
Hunting	18	45.49	7.73	6.25	111.36
Motorboating	8	26.94	5.90	12.48	64.08
Mountain biking	16	49.68	2.74	31.70	78.74
Off-road vehicle driving	1	40.37		40.37	40.37
Other recreation	1	74.47		74.47	74.47
Picnicking	3	64.22	39.66	15.19	142.74
Scuba diving	10	52.60	25.86	5.23	250.04
Sightseeing	4	20.27	13.51	5.23	60.77
Snorkeling	9	30.31	15.36	5.23	135.29
Swimming	4	27.29	11.35	6.06	58.90
Wildlife viewing	23	72.48	16.90	7.09	347.88

Table 3—Detailed descriptive statistics on average consumer surplus values per person per day by activity and region, 1967 to 2003 (continued)

Area and activity	N	Mean	Standard error	Minimum	Maximum
			2004 dollars		
Southeast area studies:					
Birdwatching	5	26.46	6.41	9.44	43.27
Camping	11	25.79	8.09	3.30	65.02
Fishing	27	79.21	23.65	3.60	556.82
Floatboating/rafting/canoeing	47	127.46	13.45	18.05	394.82
General recreation	9	42.77	20.51	5.02	189.46
Going to the beach	11	33.12	5.76	6.79	53.83
Hiking	7	60.38	34.46	1.87	262.04
Hunting	44	35.36	2.86	5.69	82.80
Motorboating	13	58.92	9.59	6.91	134.34
Mountain biking	8	49.62	5.39	20.86	67.52
Off-road vehicle driving	1	5.24		5.24	5.24
Other recreation	4	30.07	11.33	5.71	57.19
Picnicking	2	36.62	8.06	28.56	44.69
Pleasure driving	2	144.78	21.72	123.06	166.49
Rock climbing	11	85.70	9.78	39.28	135.82
Sightseeing	9	46.06	13.70	7.92	112.70
Swimming	13	60.92	9.00	13.64	134.34
Visiting arboretums	1	13.54		13.54	13.54
Visiting aquariums	1	28.31		28.31	28.31
Wildlife viewing	54	40.10	3.20	2.86	134.34
Windsurfing	1	395.47		395.47	395.47

Table 4—Pacific Northwest (Oregon and Washington) consumer surplus per person per day

Activity	Average value	Number of estimates	Number of studies	Standard error
	2004 dollars			
Camping	92.72	2	2	17.44
Downhill skiing	25.08	1	1	
Fishing	41.98	11	5	9.42
Hiking	23.98	40	5	3.14
Hunting	35.27	8	5	9.22
Motorboating	12.48	1	1	
Mountain biking	49.68	16	1	2.73
Off-road vehicle driving	40.37	1	1	
Picknicking	34.74	1	1	
Sightseeing	60.77	1	1	
Swimming	6.06	1	1	
Wildlife viewing	35.00	6	3	2.40

Using Value Tables and Database for Benefit Transfer to Unstudied Recreation Sites on National Forests

Benefit transfer is a term referring to the application of existing valuation information to new sites or unstudied national forests. The two simplest types of benefit transfer involve either using the simple average consumer surplus or value-per-day information from the previous tables, or selecting from the spreadsheet data to more closely match the available studies to the features of the recreation site or national forest for which values are needed. In the nomenclature of benefit transfer, the site with existing valuation data is typically called the "study" site, and the site to which values are transferred is called the "policy" site. It would be preferable to value recreation at the policy site by using that site's specific data (from campground fee receipts, wilderness permits, trail registers, etc.) to estimate a site-specific Travel Cost Method (TCM) demand model to calculate consumer surplus, but this is often not possible. Therefore, benefit transfer can be used, as a "second-best" strategy, for evaluating management and policy impacts. Including a well-prepared benefit transfer is much better than not including recreation economic values in the economic analysis. Some decisionmakers tend to overlook resources that have been omitted from economic analysis and incorrectly assume that those that have been included are more economically important when it may only mean that those included in the analysis are easier to measure.

Benefit transfer can be used, as a "second-best" strategy, for evaluating management and policy impacts. Including a well-prepared benefit transfer is much better than not including recreation economic values in the economic analysis.

Thus, benefit transfer is a practical way to evaluate management and policy impacts when primary research is not possible or justified because of limited time or budget constraints.

Benefit Transfer Methods

There are two broad approaches to benefit transfer: (1) value transfer, and (2) function transfer (fig. 2). Value transfers encompass the transfer of (1-a) a single (point) benefit estimate from a study site, or (1-b) a measure of central tendency (such as an average value) for several benefit estimates from a study site or sites, or (1-c) administratively approved estimates. Administratively approved value estimates will be discussed in conjunction with the measure of central tendency discussion (hereafter average-value transfer will refer to both (1-b) and (1-c)). Function transfers encompass the transfer of (2-a) a function for benefit, willingness to pay, or demand from a study site, or (2-b) a meta-regression analysis function statistically estimated from several study sites. Benefit function transfers tailor the function to fit the specifics of the policy site by setting the values of independent variables such as socioeconomic characteristics, extent of market and environmental impact, and

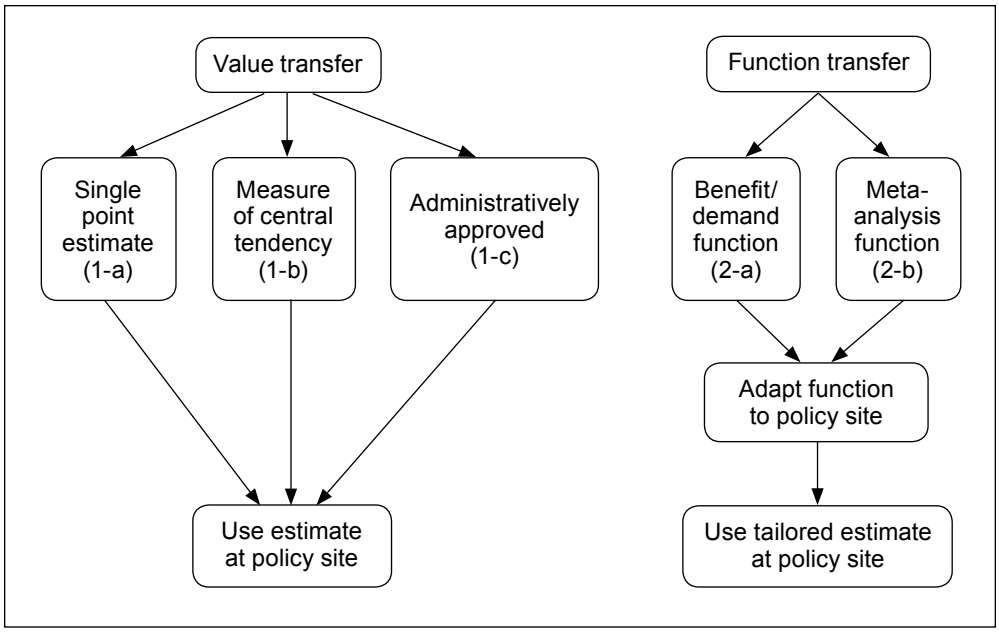

Figure 2—Benefit transfer approaches (from Rosenberger and Loomis 2001).

other measurable characteristics that systematically differ between the study site(s) and the policy site to the values at the policy site. The adapted or tailored benefit function is then used to "forecast" a benefit measure for the policy site.

In this section we define and identify what the benefit measures are, what they mean, and how they were estimated.

Single-Point Estimate Transfer

A single-point estimate benefit transfer is based on using an estimate from a single relevant primary research study (or range of point estimates if more than one study is relevant) obtained from the spreadsheet data. The primary steps to performing a single-point estimate transfer include identifying and quantifying the effect of management- or policy-induced changes on recreation use, and locating and transferring a "unit" consumer surplus measure. The detailed list of the steps involved in single-point estimate transfers were given by Rosenberger and Loomis (2001) as:

1. Identify the resources affected by a proposed action or alternative.
2. Translate resource impacts to changes in recreational use.
3. Estimate recreation use changes.
4. Search the spreadsheet data for relevant study sites.
5. Assess relevance and applicability of study site data.
6. Select a benefit measure from a single relevant study or a range of benefit measures if more than one study is relevant.
7. Multiply benefit measure by total change in recreation use.

We provide information in this report that aids in identifying study site benefit measures from the literature.[1] [2] The spreadsheet includes studies conducted from 1967 through 2003 in the United States and Canada. There are 593 studies and 1,239 benefit measures identified. The spreadsheet includes a full reference, recreation activity, geographic region, methodology used, etc., for each observation.

It is important to note that all "unit" benefit measures provided in this report are in consumer surplus per activity-day per person. Therefore, when translating resource impacts into recreation use changes, these impacts should be expressed in activity days.

The simplicity with which the steps to performing a single-point estimate transfer are presented may be misleading. This will become apparent when the information on the conditions for benefit transfers are taken into account as identified below. See Boyle and Bergstrom (1992) for an example of how to critically filter existing research for applicability to a policy site context. In their example, they located five studies that measured the benefit of white-water rafting. They then filtered the studies by three idealized technical considerations (Boyle and Bergstrom 1992: 659):

> (1) the nonmarket commodity of the site must be identical to the nonmarket commodity to be valued at the policy site; (2) the populations affected by the nonmarket commodity at the study site and the policy site have identical characteristics; and (3) the assignment of property rights at both sites must lead to the same theoretically appropriate welfare measure (e.g., willingness to pay versus willingness to accept compensation).

Their filtering of each study based on these considerations left them with no ideal benefit measures to transfer to their policy site. They stated that this is likely to be the case for many transfer scenarios in which "a small number of potential study sites are available and the value(s) estimate at these study sites may not be applicable to the issue at the policy site" (p. 660). Therefore, when performing critical single-point estimate benefit transfers, the original reporting of the study results must be obtained in order to determine its applicability to the evaluation issue at hand.

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[1] Another database that contains recreation use values in addition to other values for the environment is the Environmental Valuation Reference Inventory™ (EVRI™). This is a subscription database and can be found at http://www.evri.ec.gc.ca/evri/.

[2] Use of trade or firms names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Average-Value Transfer

An average-value transfer is based on using a measure of central tendency of all or subsets of relevant and applicable studies as the transfer measure for a policy site. The primary steps to performing an average-value transfer include identifying and quantifying the management- or policy-induced changes on recreation use, and locating and transferring a "unit" average consumer surplus measure. Rosenberger and Loomis (2001) provided a detailed list of the steps involved in average-value transfers:

1. Identify the resources affected by a proposed action.
2. Translate resource impacts to changes in recreational use.
3. Estimate recreation use changes.
4. Search the spreadsheet for relevant study sites.
5. Assess relevance and applicability of study site data.
6. Use average-value provided in table 2 for that activity in that region or calculate an average of a subset of applicable study values.
7. Multiply benefit value by total change in recreation use.

Guidance for Performing an Accurate Benefit Transfer

There are several conditions required for performing an accurate benefit transfer (Desvousges et al. 1992). This section illustrates the application of these conditions for a hypothetical benefit transfer. For each condition we provide the name of the relevant variables in the spreadsheet. The exact definition of each of these variables is given in table 5.

The purpose of checking the correspondence of variables for the candidate studies to be transferred against the policy site in need of values is to ensure they are reasonably similar in most characteristics that affect the value of recreation (e.g., determinants of demand and supply). Accuracy in benefit transfer would be improved if there is a good match between the natural environment (e.g., forest) at the sites with values and the sites for which you need values (e.g., forest). This point can best be illustrated by an example. If one only had values in the spreadsheet for mountain biking in the high desert of Moab, Utah, and needed values for mountain biking in the evergreen forests of the El Dorado National Forest near Sacramento in northern California, there would be a mismatch between the natural environment (as well as differences between a small rural town of Moab versus a large urban city of Sacramento, on the demand side). The following factors or variables are worth checking in the spreadsheet to determine whether the average value from the table can be transferred or whether the analyst should select a subset of studies from

Table 5—Variable definitions in spreadsheet

Code #	Variable	Coding
General study characteristics		
V000	STUDYID	Study number
V001	ORIGDATA	1,0; 1 = This is the first study to use this data
V002	AUTHOR(s)	Name(s)
V003	STUDY TITLE	Text
V004	SOURCE/VOL/PAGES	Text
V005	PUBDATE	Month (if available) and year of publication
V005A	DATAANAL	Year of publication
V006	PUBLISHER	Text
V007	DOCUMENT TYPE	1 = journal; 2 = book; 3 = proceedings; 4 = report; 5 = thesis or dissertation; 6 = working paper
V008	CTRY NAME	USA, Canada
Benefit measures		
V009	BENMEAS	1 = willingness to pay (WTP); 2 = willingness to accept (WTA)
V010	MEAN/MED	1,0; 1 = mean, 0 = median (mean should be reported where possible)
V011	DOLVALUE	Value converted to per person per day in 2004 dollars
V011org	ORIGVAL	Original value printed in report
V012	YEARVAL	Year of data
V012a	YEARVALUSED	Year that the given values are based on
V013	ORIGVALUNITS	1 = day; 2 = trip; 3 = year; 4 = season
V013a	AVGTRIP	Average days per trip
V013aa	REPESTASK	Reported, estimated, or asked author
V013b	ORIGNUM	Original number of people per group for ORIGVAL
V014	STD ER	Standard error of mean/median WTP for $ value or study average value
V015	CI'S	1,0; 1 = confidence interval included in report
V016	NATIONAL	1,0; 1 = national
V017	MULTI-STATE	1,0; 1 = multistate
V018	STATE	1,0; 1 = state
V019	ST NAMES	Type in two-letter state abbreviation (e.g., CO for Colorado).
V019b	REGION	U.S. Forest Service Regions 1 thru 10 (11 is all regions); 100 for U.S. national, 101 for Canada
V019cc	Region for Tables	1 = NE (Forest Service area R9); 2 = SE (R8); 3 = Intermountain (R1, R2, R3, R4); 4 = Pacific Coast (R5, R6); 5 = Alaska (R10); 6 = Multiple area studies (R11); there is no region 7
V019ccc	Region for Category	1 = Northeast; 2 = Southeast; 3 = Intermountain; 4 = Pacific Coast; 5 = Alaska; 6 = Multiple area studies (R11)
V19b1	CENSUSREG	Census regions of the USA, 1 thru 5 (and 6 is all regions); 100 is U.S. National, 101 is for Canada
V020	ESTSELEC	1 = author recommendation; 0 = other
V021	AVGSITIME	Average onsite time per trip, in hours (convert multiple days by using 12 hours/day)
V022	GROUPSIZE	Average number of people in group
V023	TOTSITEVIS	Number of visits to the area/site per year in total or per person
V023a	TOTSITDES	Description of the units of number of visits data
V024	SEASLNGTH	Season length converted to days (e.g., hunting period allowed)
V025	ALL/NO-SQ	1,0; 1 = Yes, valued for existing condition; 0 = No

Table 5—Variable definitions in spreadsheet (continued)

Code #	Variable	Coding
V026	CHGVAL	1,0; 1 = Yes, valued for change in quality; 0 = No
V026b	DOLVALCHG	$ value of change
V027	CHGDESCRIP	Text description of change
V028	CHGSIZE	% change, absolute change
V029	STDYSPONSOR	0 = industry; 1 = university; 2 = government; 3 = environmental/ conservation; 4 = multiple category of sponsors; 5 = others
V030	NUMSVYSRET	Number of surveys returned
V030a	NUMUSE	Number of usable surveys
V031	RESPRATE	Response rate percentage
V0331a	RESUSE	Response rate of usable surveys
V032	MAILSVY	1,0; 1 = some studies will have more than 1 survey mode; mail survey includes those mailed out to people but also those that were given to people and needed to be mailed back
V033	PHONESVY	1,0; 1 = phone survey used in the study
V034	INPERSON	1,0; 1 = in person used in the study
V035	SAMPFRAME	1 = on-site; 2 = user list; 3 = general population; 4 = others;
V036	VALMETHOD	1 = contingent valuation method, 0 =travel cost method, 2 = both
V037	GEOGAREA	Geographic area of visitor origin (average one-way distance in miles
Details of CVM application		
V038	PAYVEHICLE	1 = trip cost; 2 = entrance fee/license; 3 = annual pass; 4 = others
V039	OECVM	1,0; 1 = open-ended CVM question
V040	ITBID	1,0; 1 = iterative bidding used
V041	CONJOINT	1,0; 1 = conjoint (rating scale approach)
V042	ST&RP	1,0; 1 = combined stated and revealed preference
V043	PAYCARD	1,0; 1 = payment card
V044	MIDPTS	1 = midpoint; 2 = amount circled (refers to payment card)
V045	PCCAMHUPLF	1,0; 1 = Cameron-Huppert likelihood function (refers to payment card)
V046	DCCVM	1,0; 1 = dichotomous choice or referendum
V047	SB	1 = (SB) single bound; 2 = (DB,MB) double bound or multiple bound
V048	DCSTAT	1 = logit; 2 = probit; 3 = nonparametric; 4 = semi-nonparametric
V049	CVWTPEQ	1,0; 1 = WTPEQ, if equation estimate for any CVM, 0 = no; equation (refers to open-ended CVM)
V050	CVEQTYPE	1 = OLS; 2 = 2SLS; 3 = TOBIT; 4 = others (refers to open-ended CVM)
V051	HNNEGMEAN	1 = no neg (log of Bid or 1/B*(ln(1+expBo)); 2 = neg allowed.
V052	CVUPTRUNC	1,0; 1 = upper limit; 0 = no upper limit of integration
V053	CVOUTLIE	1,0; 1 = removed or “trimmed” outliers; 0 = if not or full sample
V054	PROTESTR	1,0; 1 = protest responses removed; 0 = all observations used
Details of TCM application		
V055	TCMTYPE	1 = zonal; 2 = individual; 3 = RUM/MNL
V056	TCMEQTYPE	1 = OLS; 2 = 2SLS or SUR; 3 = TOBIT; 4 = count data (POISSON, neg binomial); 5 = others (includes MNL, NMNL, when TCMTYPE = 3)
V057	TRUNCADJ	1,0; 1 = truncation adjustment
V058	ENDOGSTRT	1,0; 1 = corrected for endogenous stratification
V059	TRAVTIMEVAR	1,0; 1 = separate variable given for travel time
V060	OPCOSTIME	Wage rate in percent

Table 5—Variable definitions in spreadsheet (continued)

Code #	Variable	Coding
V060a	OPCTINC	1,0; 1 = V060 has value coded; 0 otherwise
V061	COSTMILE	$ per mile used in study year
V061a	COSTKM	$ per km used in study year
V062	SUBS	1,0; 1 = price of substitute or availability of substitute variable included in demand function
V063	SITEQUAL	1,0; 1 = site quality or facility (indicated by author)
V064	HEDTCM	1,0; 1 = hedonic TCM
V065	LHSFUNCFRM	1 = linear; 2 = log; Poisson, negative binomial; 3 = other
V066	RHSFUNCFRM	1 = linear; 2 = log; 3 = other
V067	EXPENDAT	1,0; 1 = expenditure data included in the study/report (e.g., lodging, food, equipment, etc.)
V068	TCMWTPTRUNC	1,0; 1 = upper limit of integration truncated, at max observed TC
V069	TCMOUTLIE	1,0; 1 = outliers or multidestination trips explicitly removed
Study location		
V070A	GENDES	General description of area studied
V070	COUNTY	1,0; 1 = county
V071	CTY NAME	County name
V072	SITE NAME	Name of site
V073	LAKE/RESERVOIR	1,0; 1 = lake/reservoir
V074	LAKE NAME	Text
V075	ESTBAY	1,0; 1 = site is estuary or bay
V076	OCEAN	0 if not ocean; 1 = Atlantic; 2 = Pacific; 3 = Gulf of Mexico
V077	RIVER	1,0; 1 = recreation site is river based
V078	RIVNAME	Name of the river
V079	GREAT LAKES	1,0; 1 = great lakes
V080	AREASIZE	Size of recreation area in acres
V081	NAT FOREST	1,0; 1 = national forest
V082	NFNAME	Name of national forest
V083	NATPARK	1,0; 1 = national park
V084	N.P.NAME	Name of national park
V084bbb	NP,NF,Other	Whether in national park, national forest, or other
V085	NRAREA	1,0; 1 = national recreation area
V086	NRANAME	Name of national recreation area
V087	W/L AREA	1,0; (1 = wildlife refuge or game management area)
V088	W/L AREA NAME	Name of refuge or mgmt area
V089	WILDERNESS	1,0; 1 = recreation use is in wilderness area
V090	WILDNAME	Name of wilderness area
V091	STPARKFOR	1,0; 1 = recreation use is in state park or state forest
V092	STPKNAME	Name of state park
V093	PUBLIC	1,0; 1 = public land including federal, state, county/city
V094	PRIVATE	1,0; 1 = private land
V095	W/L SPECIES	1 = BGAME (deer, elk, etc.); 2 = SGAME (rabbit, quail, dove, etc.); 3 = WTRFWL (duck, geese); 4 = threatened and endangered; 5 = songbirds; 6 = raptors, hawks, eagles, etc.; 7 = fish; 8 = general wildlife
V095a	W/L SPECIES 2	
V095b	W/L SPECIES 3	
V095c	W/L SPECIES 4	

Table 5—Variable definitions in spreadsheet (continued)

Code #	Variable	Coding
V096	FOREST	1,0; 1 = recreation area in forest; 0 = otherwise
V097	ENV TYPE	1 = wetland, 2 = riparian; 0 = otherwise
V098	WATERQUAL	1,0; 1 = water quality was valued or focus of study
V099	AIRQUAL	1,0; 1 = air quality was valued or focus of study
V100	DEVELOP	1,0; 1 = site studied had developed recreation facilities (such as arranged tables etc., e.g., camping, boating, etc.)
V101	DISPERSED	1,0; 1 = site studied was dispersed recreation with no formal site or facilities (e.g., hunting, hiking, etc.)
V102	ROSCLASS	1 = primitive; 2 = SPNM (semiprimitive nonmotorized); 3 = SPM (semiprimitive motorized); 4 = RN (roaded natural); 5 = rural; 6 = urban; 7 = various
V103	ACT TYPE 1	1 = camping; 2 = picnicking; 3 = swimming; 4 = sightseeing; 5 = off-road vehicle driving; 6 = motorboating; 7 = floatboating/rafting/canoeing; 8 = hiking; 9 = mountain biking; 10 = downhill skiing; 11 = cross-country skiing; 12 = snowmobiling; 13 = snowplay; 14 = hunting; 15 = fishing; 16 = wildlife viewing; 17 = horseback riding; 18 = resort; 19 = rock climbing; 20 = general recreation; 21 = other recreation; 22 = visiting wilderness; 23 = waterskiing; 24 = pleasure driving (can include sightseeing); 25 = visiting arboretums; 26 = going to the beach; 27 = relaxing outdoors; 28 = visiting aquariums; 29 = scuba diving; 30 = windsurfing; 31 = bird watching; 32 = snorkeling; 33 = backpacking; 34 = visiting environmental education centers
V104	ACT TYPE 2	One of the above categories of ACTTYPE except one already chosen
V105	ACT TYPE 3	One of the above categories of ACTTYPE except one already chosen
V106	ACT TYPE 4	One of the above categories of ACTTYPE except one already chosen
V107	NUMACT	Number of activities site offers or typical visitor could participate in at site
V108	AVGINC	Average income of visitors
V109	AVGED	Average education of visitors
V110	AVGAGE	Average age of visitors
V111	AVGSEX	(% female); 1 = female; 0 = male; or percent female for group
V112	RESIDENTS	1,0; 1 = residents only; 0 = both
V113	USEEXP	1,0; 1 = very experienced (level of user experience with site); 0 = otherwise
V114	SUCESRATE	Percentage of success rate in hunting
V115	BAG	Number of animals (in hunting)
V116	HOUR	1,0; 1 if bag reported is per hour, zero otherwise
V117	DAY	1,0; 1 if bag reported is per day
V118	TRIP	1,0; 1 if bag reported is per trip
V118a	YEAR	1,0; 1 if bag reported is per year
V119	HIQUAL	1,0; 1 = author states site is of high quality (e.g., popular, unique, well-known, only in the region, etc.)
V120	DATAYEAR	Year data collected
V121	SAMPSIZE	Total sample size used in analysis
V122	NUMTCZONES	Number of zones or origins in zonal TCM.
V123	MULTSITE	1,0; 1 = yes
V124	NUMSITES	Number of sites modeled in multisite or RUM models
V125	CHOICEOC	Number of choice occasions (frequency)
V126	COMMENTS (COMMENTS2 and COMMENTS3)	Text field where coder can write anything special or unusual about study or details about recreation site or area where study was performed

the spreadsheet data from which to calculate average value based on studies that more closely match the study site.

1. The activities to be valued should be identical, or at least similar; see spreadsheet variables, ACT TYPE1, ACT TYPE 2, and ACT TYPE 3.
2. The general geographic region of the study sites and the policy site should be identical or at least similar; see spreadsheet variables ST NAMES, REGION (USFS Regions 1 through 10) and CTY NAME (when available).
3. The type of public land at the study sites and the policy site should be identical or at least similar; see spreadsheet variables PUBLIC, PRIVATE, NAT FOREST, NATPARK, NRAREA (national recreation area), W/L AREA (state or federal wildlife area), WILDERNESS, STPARKFOR (state park or state forest).
4. For wildlife recreation, similar species should be valued in both cases. For example, for valuation of big game hunting, one should use existing big game hunting studies, not waterfowl or upland game bird hunting studies; see spreadsheet variables W/L SPECIES, W/L SPECIES 2, W/L SPECIES 3.
5. The type of population and magnitude of the human population at the study site and policy site should be similar (i.e., rural to rural, or urban to urban); see spreadsheet variables AVGED, AVGAGE, RESIDENTS.
6. Level of facility development and recreation opportunity spectrum classification should be similar between the study sites and the policy site; see spreadsheet variables DEVELOP, DISPERSED, ROSCLASS.
7. The environmental resource and the natural setting of the resource at the study site and the resource at the policy site should be similar. As mentioned in the example above, it would be desirable to transfer values of a particular recreation activity that occurred in the same environmental setting or ecosystem type. Thus camping in a forest might yield different values than camping at the beach. See spreadsheet variables FOREST, ENV TYPE, LAKE/RESERVOIR, ESTBAY (estuary/bay), OCEAN, RIVER, GREAT LAKES.
8. The markets or determinants of demand (similarity of demographic profiles between the two populations and their cultural aspects) for the study site and the policy site should be similar. That is, similar levels of income, racial composition, degree of ruralness. Unfortunately, most studies did not report demographics, but check spreadsheet variable AVGINC. If there are no observations for this demographic variable, inspection of spreadsheet variables such as ST NAMES and CTY NAME (when available) may be instructive. For example, a camping study in North Dakota might not yield accurate

values for camping at the Angeles National Forest outside of Los Angeles owing to differences in income levels and racial composition of the two populations.

9. The conditions and quality of the recreation activity experiences (e.g., intensity, duration, and skill requirements) are similar between the study site and the policy site. It is not accurate to transfer the value per day for rafting down the Colorado River in Grand Canyon National Park to rafting down the Colorado River in the White River National Forest paralleling I-70 in Glenwood Canyon.

Keep in mind that most of the original research studies reported in the database were not designed for future benefit-transfer applications. The information requirements expressed in the above conditions are not always met in the reporting of data and results from primary research. In addition to weighing the benefits of more information from expensive primary research, the implicit cost of performing benefit transfers under conditions of incomplete information should be accounted for. Therefore, benefit transfer practitioners need to be pragmatic in their applications of the method when considering the many limitations imposed upon them by the limited availability of existing studies. It is this author's opinion that in many cases, even a rough approximation of the average value per day from a conservative benefit transfer is better than simply ignoring the economic value of recreation in forest plans or environmental impact statements.

Validity and Reliability of Benefit Transfers

There are at least two sources of error in benefit transfer that influence the reliability and validity of the resulting benefit estimates. First is the underlying variability in the original study estimates. If the original study reports the standard error of the estimate, then a confidence interval for transferred point estimates can be calculated. This confidence interval provides the statistical range in which we would expect the original estimate to be some large percentage of the time (e.g., a 95-percent confidence interval means the estimate would be within the calculated range 95 percent of the time). However, this confidence interval does not account for the additional error associated with transferring the estimate from the original study site to the policy site.

Several recent studies have tested the convergent validity and reliability of different benefit-transfer methods (Desvousges et al. 1998, Downing and Ozuna 1996, Kirchhoff et al. 1997, Loomis et al. 1995, Rosenberger and Loomis 2000). The methods tested include single-point estimate, average-value, demand-function, and meta-regression-analysis transfers. Although the above studies show that some of

the methods are relatively more valid and reliable than other methods, the general indication is that benefit transfer cannot replace original research, especially when the costs of being wrong are high. In tests of the benefit-transfer methods within the same geographic region, transferred values were very similar to the "true" values and errors were in the range of 4 to 40 percent when using benefit-function transfer (Loomis 1992). In other cases, the disparity between the "true" value and the "tailored" value was quite large. These errors were typically in the range of 50 to 80 percent when using meta-regression benefit transfer as compared with in-sample study values used to estimate the meta-regression (Rosenberger and Loomis 2000) and a comparison to new out-of-sample study values not used to estimate the original meta-regression (Shrestha and Loomis 2003).

Other Potential Limitations of Benefit Transfers

Several other factors can also influence the accuracy of any particular benefit transfer. Factors that affect the accuracy of any specific benefit transfer include:

- The quality of the original study.
- A limited number of studies investigating an activity's economic value, thus restricting the pool of estimates and studies from which to draw information.
- Different research methods across study sites for a specific recreation activity, including differences in what question(s) was asked, how it was asked, what was affected by the management or policy action, how the environmental impacts were measured, and how these impacts affect recreation use.
- Different statistical methods used for estimating models, which can lead to large differences in values estimated. This also includes issues such as the overall impact of model mis-specification and choice of functional form of the demand function (Adamowicz et al. 1989).
- Unique sites and conditions of existing studies used for valuing recreation activities. See the variables SITE NAME, LAKE NAME, N.P. NAME, W/L AREA NAME, STPKNAME to ensure there is similarity of the study site and policy site.

The above listed factors can lead to bias or error in, and restrict the robustness of, the benefit-transfer process. An overriding objective of the benefit-transfer process is to minimize mean square error between the "true" value and the transferred value of impacts at the policy site. However, the original or "true" values are themselves approximations and are therefore subject to error. As such, any information

transferred from a study site to a policy site is accomplished with varying degrees of confidence in the applicability and precision of the information.

Nonetheless it is our belief that national forest decisionmaking involving tradeoffs between types of recreation (motorized vs. nonmotorized), and other multiple-use tradeoffs can often be improved by inclusion of even approximate estimates of nonmarket recreation values.

A Note on Definition of Benefit Measures and Use in Policy Analyses

All of the benefit estimates provided by this report, either recorded from the literature review or "forecasted" by adapting benefit functions, are average consumer surplus per person per activity-day. In the case of a single study, the estimate is the average consumer surplus of the average individual values reported in the study. In the case of several studies, the estimate is the average of the study samples' average consumer surpluses from all included studies.

Consumer surplus is the value of a recreation activity beyond what must be paid to enjoy it.[3] When the change in recreation supply or days is small and localized, consumer surplus is equivalent to a "virtual" market price for a recreation activity (Rosenthal and Brown 1985). A general assumption when applying the benefit estimates is that the estimates are constant across all levels of resource impacts and perceived changes for an individual. This assumption may be plausible for small changes in visitation, but it may be unrealistic for large changes (Morey 1994). However, this assumption is necessary for some of the simple approaches to benefit transfers such as point-estimate or average-value transfer. If the analyst is evaluating a large-scale ecosystem change, then an original study will often be necessary (and warranted), or a benefit-function transfer approach that incorporates the quality of the resource would be necessary to accurately capture the change in benefits. Such a benefit-function transfer approach would be to apply a demand curve that contains a resource quality variable or apply a contingent valuation method willingness-to-pay equation that contains the relevant resource quality variables for the change being evaluated.

[3] There are two prominent types of consumer surplus estimated by using slightly different definitions of the demand function: Marshallian consumer surplus based on an ordinary demand function, and Hicksian surplus based on either a compensated demand function or elicited directly by using hypothetical market techniques. The difference between these measures is due to the income effect (Willig 1976). Because outdoor recreation expenditures are a relatively small percentage of total expenditures (income), differences between the two measures are expected to be negligible.

Simply stated, the benefit-transfer estimate of a management- or policy-induced change in recreation is the average consumer surplus estimates for the average individual from the literature aggregated for the particular change in use of the natural resource. The change in recreational use of a resource may be induced either through a price change for participating in an activity (e.g., fee change or location of the site) or through a quality change in the recreation site.

Details of Spreadsheet Coding

Often times in performing benefit transfer, it is more appropriate to compute an average value per visitor-day from empirical studies that closely match the policy site, rather than just using an overall average for the region. To facilitate doing this, the spreadsheet contains numerous details about each of the studies.

Details of the recreation site include, in part, its geographic location, whether it was on public or private land, the type of public land (e.g., national park, national forest, state park, state forest), the state, the USDA Forest Service Region, and land type (e.g., lake, forest, wetland, grassland, river). In many cases, specific details about the recreation site were not provided either because of incomplete reporting or because the activity was not linked with a specific site. Details of the user population characteristics include, in part, average age, average income, average education, and proportion female.

Methodology details include survey mode (e.g., mail, telephone, in-person, use of secondary data), response rate for primary data collection studies, and sample frame (e.g., onsite users, general population). Methodology details are further divided between the application of revealed preference (RP) and stated preference (SP) modeling when appropriate. Details of RP modeling include, in part, identifying the model type (e.g., individual travel cost, zonal travel cost, random utility models), use of travel time or substitute sites in the model specification, and functional form (double log, linear, semilog, log-linear). Details of SP modeling include, in part, identifying the model type (e.g., conjoint analysis, contingent valuation models), the elicitation technique for contingent valuation models (e.g., open ended, dichotomous choice, iterative bidding, payment card), and functional form.

The details of each study were coded to the extent that they could be gleaned from the research-reporting venue. However, not every study could be fully coded (table 5). This was either because information was not reported or was not collected for a study. For example, very few of the studies in the literature review reported any details about the user population. This and other factors are indicative of the lack of consistent and complete data reporting that further limits the ability to perform critical benefit transfers.

Summary

This report provides updated average values and a spreadsheet that gives information on outdoor recreation use valuation studies, including study source, benefit measures, recreation activity, valuation methodology, and geographic region. This literature review spans 1967 to 2003 and covers more than 20 recreation activities.

Guidance on performing various benefit-transfer methods is also provided in this report. Benefit transfer is the use of past empirical benefit estimates to assess and analyze current management and policy actions. Two benefit-transfer approaches (single-point estimates, average values) were discussed in detail.

A research effort such as this is really never complete, as new studies appear every year. Some of these studies could fill important gaps in the existing literature or increase the small sample of valuation studies for that activity in that region. Augmenting this database with new studies every 5 years is probably a worthwhile undertaking to keep the database current and of greatest use for field personnel.

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Preface

This report presents a catalog of conservation banks, which are used to mitigate the impacts of habitat modification or habitat loss on threatened and endangered species. The catalog presents information on 22 conservation banks, and provides detailed information on the credit transaction histories of 4 banks. This report is divided into four sections. Section 1 provides some background information on conservation banks, to provide a context for the catalog; Section 2 describes the methods we used to identify and survey banks; Section 3 summarizes results from the catalog of information developed for 22 banks; Section 4 presents the additional credit transaction data developed for 4 banks. The catalog of information for 22 banks is presented in an attachment to the report.

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1. Introduction

A conservation bank is a parcel of habitat that is managed for the protection of sensitive species and used to offset impacts to these species occurring on nonbank lands. Federally certified conservation banks are designed to protect federally listed threatened or endangered species. Conservation banks also may be established when state or local ordinances require mitigation for impacts to sensitive habitats or species that may not be federally listed. The protection of species in conservation banks generates conservation “credits” that can be used to mitigate species impacts, or “debits.”

Conservation banking transferred the concept of wetland mitigation banking into the area of conservation of threatened and endangered species. Officially, wetland mitigation banking focuses on creating, restoring, or enhancing the function and value of wetlands. Establishing wetland mitigation banks allowed larger wetland areas to be restored and simplified the mitigation process for developers. Without mitigation banks, developers needed to mitigate wetland projects case by case, often creating small, isolated wetlands with little long-term habitat value. In contrast to wetland banks, conservation banks usually focus on preserving large areas of existing habitat with long-term value for a specific species, which can effectively mitigate the loss of isolated or fragmented habitat areas (U.S. Fish and Wildlife Service, 2003).

In practice, however, developers of conservation banks can use a variety of strategies to enhance threatened and endangered species, including preserving existing habitat, restoring habitat function in degraded areas, and creating habitat. Banks also can be a hybrid of a mitigation and conservation bank — offering wetland mitigation credits and individual species credits.

Conservation banks have attracted the interest of public agencies, private individuals, and environmental nonprofit organizations because of the possibility that banks can offer a "win-win" solution for tackling issues related to endangered species and development. From a biological point of view, conservation banks can provide large areas of contiguous habitat, which may be critical to species survival. Small, isolated populations of endangered species are vulnerable to demographic and environmental stochasticity. The survival probability of a population depends on birth rate and population size; small populations with low birth rates are especially vulnerable to extinction (Dushoff, 2000). In contrast, larger populations in bigger habitat areas are considered to be more resilient to chance events. Conservation banking agreements also require ongoing habitat management and maintenance, which can be important for species survival. In addition, certain types of habitat management, such as controlled burns, are feasible only in larger habitat areas. At the same time, conservation banks cannot guarantee long-term species survival. Several large banks in Southern California were completely consumed by fire in 2003 (Leslie Beck, The Environmental Trust, personal communication, December 3, 2003). Concentrating species in one area also can make individuals susceptible to disease.

In our review of conservation banking agreements, we found that many agreements did not specify what would happen if the bank were damaged by a natural catastrophe. Management endowment funds appear to be targeted at routine management needs, and are not seen as contingency funds for catastrophic events. We did not find any examples of agreements that specifically required insurance policies to insure against catastrophic events. At the East Plum Creek Conservation Bank in Colorado, established to benefit the Preble's meadow jumping mouse (PMJM), the conservation banking agreement specified that "in the event of damages to the Conservation Bank caused by a natural catastrophe such as a major flood, prolonged drought, disease, or regional pest infestation, CDOT [Colorado Department of Transportation], FHWA [Colorado Division of the Federal Highway Administration], and the USFWS shall confer in a timely manner to determine what actions, if any, should be taken to protect the PMJM. During such time, Conservation Credits still available in the Bank shall be withheld from use."

Another important biological issue to consider is whether conservation banks end up providing a net benefit for endangered species. When the land used for a conservation bank is not in immediate danger of development, the credits provided by the bank essentially result in a net loss of endangered species habitat. In other words, the incidental take of endangered species (usually through habitat destruction or modification) is authorized contingent upon the purchase of conservation credits, but the bank is not actually providing any new or additional habitat beyond

what already existed in the area. The bank would, however, guarantee protection of that habitat in perpetuity. Banks that restore habitat or actively manage habitat types that would otherwise be lost through neglect (for example, long-leaf pine ecosystems require regular fire) more clearly provide a near-term benefit to endangered species that most likely equals or exceed the loss from an incidental take.

From an economics and policy point of view, conservation banks offer the opportunity to reduce the cost of undertaking mitigation and streamline the development permitting process. In areas where development projects have been halted for years while acceptable endangered species mitigation projects are developed and approved, conservation banks provide a streamlined method for developers to meet mitigation requirements by simply writing a check. Landowners who are prevented from developing their land because of the presence of endangered species appreciate the opportunity to realize an economic gain from property where uses would otherwise have been restricted.

In addition, conservation banks offer the possibility of reducing the overall cost to undertake mitigation through increasing efficiencies for mitigation projects and economies of scale. There are two major fixed costs in developing mitigation projects: permitting and equipment mobilization. Additionally, there may be decreasing average costs associated with land acquisition. Individual mitigation projects each face permit and equipment costs, that a larger conservation banking project can allocate to reduce average total costs. This may reduce the amount that individuals would need to pay into a bank relative to the cost of undertaking the mitigation project on their own. Additionally, land acquisition, often a large cost component of mitigation projects, often exhibit decreasing average costs over a large range of parcel sizes. These economies of scale can be captured by a larger bank, and passed on to future bank users, again reducing the costs that an individual bank user would face. Thus, the per-acre cost of habitat preservation or mitigation for endangered species impacts is likely to be greater when projects are mitigated case by case compared to a conservation bank where multiple projects can receive mitigation credits in a single location. Therefore, more habitat is likely to be created or protected when banking is used as the instrument for protection compared to when individual developers or agencies mitigate for each project individually. In our interviews with bank managers, several agencies noted that the high cost of “piecemeal” mitigation had motivated their interest in developing a conservation bank.

Conservation banking offers the possibility of moving endangered species protection from a strictly regulatory realm into the arena of markets. Conservation bank owners can adjust the price of conservation credits to reflect market conditions — discounting credits where demand is low and increasing the price when demand is high and the supply of credits is limited. The banking market, however, is a highly regulated market. The ability to provide credits and the determination of species debits is regulated by the U.S. Fish and Wildlife Service (USFWS) or the appropriate state or local agency. The market size for credits is restricted to the service area

of the bank — banks with a small service area may find little demand for credits within the area. Banks also are subject to shifting regulatory conditions. For example, in areas that adopted fee-based mitigation schemes, parties needing to mitigate for incidental takes of endangered species can pay a fee to the county or agency that has received approval for fee-based mitigation (usually based on approval of a multispecies habitat conservation plan). Fee-based mitigation can therefore eliminate the demand for purchasing credits at a private conservation bank.

1.1 History of Conservation Banks

Carlsbad Highlands, the first conservation bank in the United States, was dedicated in April 1995 in San Diego County, California (Anonymous, 1995). That same month, the State of California issued an official policy on conservation banks that provided formal guidance on using conservation banks to accomplish resource management goals (Wheeler and Strock, 1995). This policy established a set of precepts to guide the development of conservation banks, including the need for permanent protection of all land in the bank after sale of the first credit, approval by a regulatory agency, approval of a resource management plan and guarantees of funding for operation and maintenance, provision for long-term management of the bank after credits have been awarded, assessment of bank credits with reference to baseline conditions at the site, and the need to award bank credits case by case negotiated between the project proponent, bank manager, and regulatory agency (Wheeler and Strock, 1995).

The initial incentive for conservation banking in California was to help implement the state's Natural Community Conservation Planning (NCCP) Program, which was first developed to help protect coastal sage scrub habitat for the threatened California gnatcatcher and other species. The goal of the NCCP process is to identify and conserve threatened habitat at the ecosystem scale, to help avoid conflicts between economic growth and development and habitat preservation (Anonymous, 1995; Environmental Defense, 1999). Under the NCCP, conservation banks were envisioned as a tool for providing long-term protection of habitat and offering landowners economic incentives for habitat protection by being able to sell mitigation credits. In California, mitigation requirements result from the California Environmental Quality Act (CEQA), which requires mitigation if a proposed activity will "substantially diminish habitat for fish, wildlife, or plants," and from requirements of state and federal endangered species acts.

In 1996, the California Department of Fish and Game and the U.S. Fish and Wildlife Service jointly issued a "Supplemental Policy Regarding Conservation Banks Within the NCCP Area of Southern California." This policy reaffirmed the support of the agencies for the creation of conservation banks, and specifically noted that the "the number of conservation banks that are established will be regulated by the 'free market' . . . not by the wildlife agencies." The policy also notes that "[o]nly in-kind mitigation (same habitat and species) will be permitted unless . . . the wildlife agencies determine that the bank achieves regional conservation goals" (U.S. Fish &

Wildlife Service and California Department of Fish and Game, 1996). By 1999, more than 20 conservation banks had been developed in California (Environmental Defense, 1999).

For this report, we identified conservation banks that were focused specifically on species protection. Although many of these banks also sell habitat or wetland credits, we only included the banks that focused on species-specific protection as well as on habitat or wetland protection. We excluded "wetland only" banks, which are more appropriately categorized as "wetland mitigation" banks instead of conservation banks. We were able to identify 48 active conservation banks that met our criteria and 4 banks that are in development. The active banks are located in eight states and the island of Saipan (see Section 2.2).

Ironically, although the NCCP program was the original impetus for establishing conservation banking in California, some of the new plans produced under the NCCP do not include conservation banking as part of a regional conservation strategy. For example, the Western Riverside County Multi-Species Habitat Conservation Plan (MSHCP), which was approved by the Riverside County Board of Supervisors on June 17, 2003, provides for a regional approach for assembling the required conservation area, relying on protection of federal, state, local, and private lands. An applicant wanting to develop property outside of the protected conservation area will receive an incidental take authorization through payment of a mitigation fee or "in-lieu payment" to the relevant city or county. These fees are used to support conservation, but not to purchase credits in a private conservation bank. The MSHCP specifically notes that "because of the . . . fee-based mitigation program, it is not anticipated that any new conservation banks or mitigation areas will be established." Existing conservation banks are "grandfathered" into the plan by allowing the "in-lieu payment" requirement to be met through acquiring acreage in a conservation bank, with a 1:1 ratio for area of project impact and area of acquired land (Dudek & Associates, 2003).

In other areas of the country, however, interest in conservation banks is growing and new banks are under development. For example, in Oregon, the USFWS is working with the Oregon Department of Transportation to pursue the development of a conservation bank for an endangered fish (Oregon chub) that occurs on Department of Transportation lands (Rollie White, Aquatic Endangered Species Division Manager — Oregon Fish and Wildlife Office, e-mail communication, September 16, 2003). In Alabama, the Department of Transportation is working to set up a new bank for gopher tortoises with 600 acres of mitigation credits that would be used internally for Department of Transportation projects (Bruce Porter, USFWS Daphne Field Office, personal communication, October 10, 2003). In Florida, the interest in conservation banking is high, but legal statutes have not yet been developed that authorize the creation and use of banks (Lynn Zenczak, Earthmark Companies, personal communication, September 9, 2003).

1.2 Legal Status of Conservation Banks

Conservation banks approved by the USFWS for mitigation of impacts to endangered species are usually authorized through a formal conservation bank agreement between the bank owner, the USFWS, and possibly a related state agency. The conservation bank agreement specifies the number of conservation credits established for use in the bank, the number of acres or individuals of a species that pertain to each credit, restrictions on land use of the bank, procedures for sales and transfers of conservation credits, requirements for monitoring and annual reports, and provisions for default among any of the parties. Agreements may also include clauses such as a "no discrimination" clause that prohibits the USFWS from establishing more onerous mitigation requirements if a party chooses to purchase conservation credits from the conservation bank versus conducting other types of off-site mitigation (e.g., U.S. Fish and Wildlife Service et al., 1997). Agreements may also specify required land management activities to be undertaken by the bank owner.

Conservation credits in a conservation bank are usually linked to an approved habitat conservation plan for the bank. A habitat conservation plan describes the measures to be undertaken that will mitigate for "incidental takes" of species protected by the federal Endangered Species Act. An "incidental take" is defined as a take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity" (Endangered Species Act Amendments of 1982; P.L. 97-304, Oct. 13, 1982, 96 Stat. 1426). A conservation bank may receive authorization for a "Master Permit," which allows the approved habitat conservation plan to mitigate for incidental takes by third parties (e.g., U.S. Fish and Wildlife Service et al., 1997). When a third party applies for an "Incidental Take" permit under Section 10 of the federal Endangered Species Act, the USFWS may authorize an applicant to fulfill off-site mitigation requirements through purchasing a certain number of conservation credits at an approved conservation bank. The USFWS will often provide a list of a suitable bank or banks that an applicant can use in areas served by conservation banks.

1.3 Location of Banks across the United States

The presence of conservation banks varies greatly across the United States, primarily reflecting different priorities of each of the regions of the USFWS. Figure 1 is a map of USFWS regions, with information on conservation banking activities in each of the regions.

Region 1 — The greatest number of active conservation banks are in California. The CEQA was identified as a significant motivation for the development of conservation banks (R. White, U.S. Fish and Wildlife Service, Aquatic Endangered Species Division Manager for Region 1 — Oregon, personal communication, September 16, 2003). We identified 34 active banks in California, but it is possible that there are other banks. We also identified two banks in

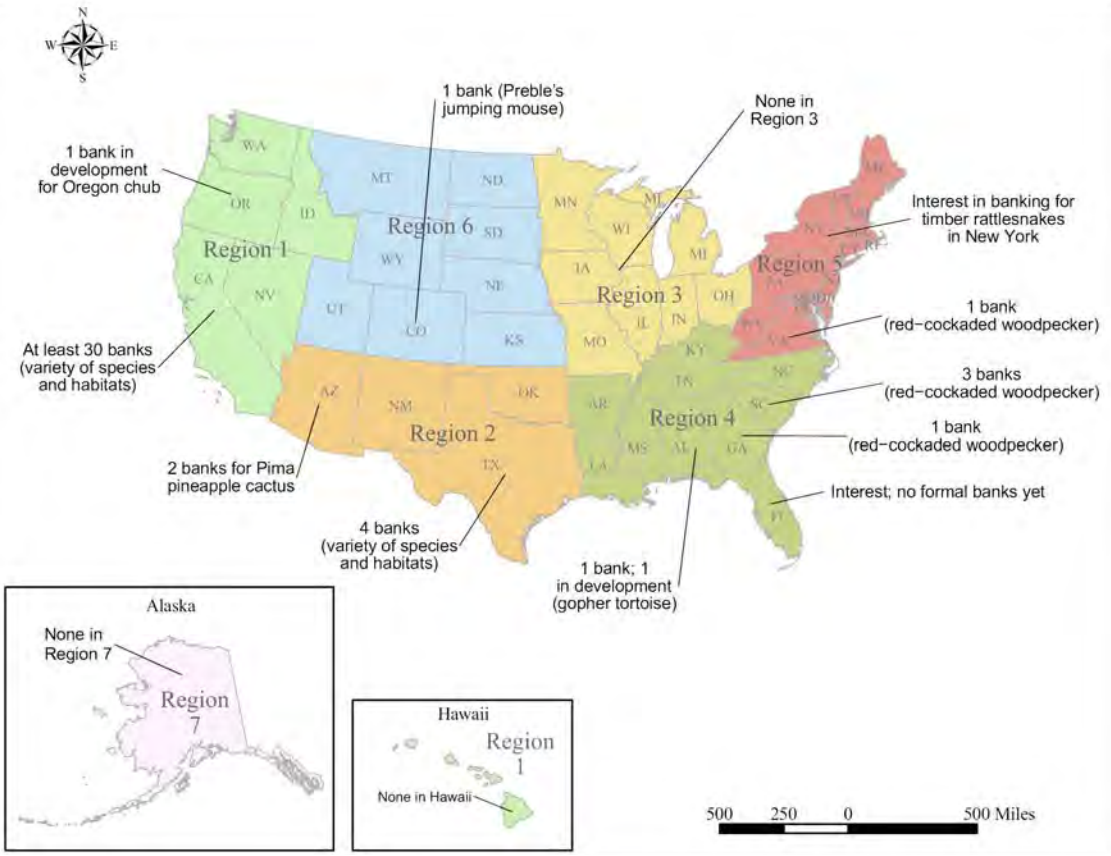

Figure 1. Map of conservation bank activity across the United States.

California that were developed, but the agreements fell through before completion. There are no active conservation banks outside of California in Region 1, according to Larry Salata, Endangered Species Program Region 1 (personal communication, September 15, 2003). The absence of banks outside of California was attributed to a combination of extensive protection for listed species, intervention to preserve listed species when the species are identified, limited population pressures in some areas, and large federal land holdings. In Oregon, an effort is under way with the Oregon Department of Transportation to establish a conservation bank to address the Oregon chub (R. White, U.S. Fish and Wildlife Service, Aquatic Endangered Species Division Manager for Region 1 — Oregon, personal communication, September 16, 2003).

Region 2 — There are four active conservation banks in Texas (Hickory Pass, Brushy Creek, Williamson County Karst, and Balcones) and two banks in Arizona for the Pima pineapple cactus (Swan Road and Palo Alto Ranch). The USFWS expects that conservation banks would eventually be developed in New Mexico and Oklahoma as urban growth and development

pressures increase in those areas (Leslie Dierauf, Region 2 active chief overseeing threatened and endangered species, personal communication, September 16, 2003).

Region 3 — There are no active conservation banks in this region, according to T.J. Miller, Supervisor of Endangered Species Consultation for Region 3. The absence of banks was attributed to hesitation about the concept of conservation banks at the field station level. Also, no conservation banking proposals have been received for review (T.J. Miller, personal communication, September 10, 2003).

Region 4 — The active conservation banks in Region 4 consist of three red-cockaded woodpecker banks in South Carolina and one in Georgia, and one gopher tortoise bank in Mobile, Alabama. An additional gopher tortoise bank is under development in Alabama with the Alabama Department of Transportation. In Florida, conservation banks have not yet been formally approved, but private investors have purchased land with the intention of offering mitigation credits (David Dell, Regional Habitat Conservation Plan Coordinator, personal communication, September 16, 2003).

Region 5 — Piney Grove Preserve in Virginia has sold one credit for red-cockaded woodpeckers. Otherwise, there are no active conservation banks in this region, according to Diane Lynch, regional permits coordinator for Region 5 in the Division of Endangered Species (personal communication, September 10, 2003). EarthMark Companies, which has experience developing wetland mitigation banks, is working on a potential conservation bank location for timber rattlesnakes in upstate New York.

Region 6 — The Preble's jumping mouse bank in Colorado is the only active conservation bank in this region. The absence of additional banks was attributed to a small number of listed species on nonfederal lands. Urban growth and development may result in additional banks in the future (Jill Parker, Chief of Endangered Species for Region 6, personal communication, September 11, 2003).

Region 7 — There are no conservation banks operating in Alaska, according to Steve Klosiewski (Region 7 Endangered Species program, personal communication, September 15, 2003). The absence of conservation banks was attributed to extensive federal holdings, minimal development pressure, and the opportunity to avoid locations with endangered species when development issues arise.

Across the different USFWS regions, the trend seems to be toward increasing interest in conservation banking where development pressures are mounting. In California, the most active area for conservation banking, there is decreasing interest in conservation banking where regional habitat conservation plans are moving toward "in-lieu fee payments" for mitigation and increasing interest in other areas.

2. Methods

2.1 Identifying Banks

We initiated the project by compiling a list of all conservation banks that we could identify (Table 1). We included banks in the initial list only if they either targeted individual species or were designed to conserve upland habitats that included sensitive species. Banks designed specifically for wetland mitigation or preservation credits were excluded from the list. Forty-eight active banks and four "in development" banks were identified through 1) internet searches, including the catalog of conservation and mitigation banks that was developed by the California Department of Fish and Game (http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/catalogue.shtml); 2) telephone calls to relevant personnel in each of the regional USFWS offices to inquire if banks are present in that region; and 3) a search of relevant information databases. Databases searched were Dialog News Room, a database that indexes more than 7,000 publications, including trade journals, scholarly publications, consumer press, newspapers, newsletters, broadcast transcripts, and more; Dialog's "Papers" Category, which indexes over 50 major newspapers from across the United States; NTIS (National Technical Information Service), which indexes government reports; and Biosis, Agricola, Social SciSearch, SciSearch, and Gale Group Magazine Index, which all index technical or scholarly literature. Search terms used were "conservation bank" (and variates — banks, banking, etc.) and the term "mitigation banking" combined with "threatened or endangered species."

Out of the 48 banks identified, we selected 22 banks for inclusion in the catalog. Banks were selected for inclusion if they had evidence of previous credit transactions and a clear focus on species conservation. We also tried to represent different species, habitat types, and geographic areas.

We tried to obtain credit transaction data on each of the banks in the catalog, but found that most of the bank owners were not willing to provide transaction data because of privacy concerns. Specifically, private bank developers and owners did not want future clients to know the price of previous transactions, especially if the price of credits had increased over time. We were able to obtain transaction data for two banks that have maintained fixed pricing for credits over time: Kern Water Bank and Mobile County Gopher Tortoise Conservation Bank. We also obtained credit transaction data, without pricing information, for two banks: Sedco Hills and Springtown Reserve.

Table 1. Summary of identified conservation banks

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Included in catalog							
Agua Fria Multi-Species Mitigation Bank	CA	Merced	3,234 acres	San Joaquin kit fox, burrowing owl	Brian Boroski 559 449 1423	http://sacramento.fws.gov /es/bank_list.htm	
Balcones Canyonlands Preserve	TX	Austin	26,323 acres goal of 30,428	Golden-cheeked warbler, black-capped vireo, Tooth Cave pseudoscorpion, Tooth Cave Spider, Tooth Cave ground beetle, Kretschmarr Cave mold beetle, Bone Cave harvestman	Kevin Connally 512 854 9437	http://www.ci.austin.tx.us /preserves/bcp.htm	http://www.co.travis.tx.us/tnr/bccp/ default.asp
Chiquita Canyon Conservation Bank	CA	Orange	327 acres (1 acre = 1 credit)	California gnatcatcher	Valerie McFall 949 754 3400 ext. 475	http://www.dfg.ca.gov/ hcpb/conplan/mitbank/ catalogue/orange.shtml	
Coles Levee Ecosystem Preserve	CA	Kern	6,059 acres (1 acre = 1 credit)	San Joaquin kit fox, Tipton kangaroo rat, giant kangaroo rat, blunt-nosed leopard lizard, Swainson's hawk	Wes Rhodehamel 661 835 8300 ext. 105	http://www.dfg.ca.gov/ cpb/conplan/mitbank/ atalogue/kern.shtml	http://sacramento. fws.gov/es/bank_ list.htm
East Plum Creek Conservation Bank	CO	Douglas	25 acres	Preble's meadow jumping mouse	F. Yates Opperman 303 757 9497	http://www.epa.gov/fedrgstr/EPA-SPECIES/2002/ December/Day-26/e32464.htm	
Fitzgerald Ranch Conservation Bank	CA	San Joaquin	803 acres; 62 credits	Vernal pool fairy shrimp, *Legenere limosa*, California tiger salamander, western spadefoot toad	Lane Family Partnership Trust #1 (Marden Wilbur) 209 483 0030	http://www.dfg.ca.gov/ hcpb/conplan/mitbank/ catalogue/san_joaquin. shtml	http://sacramento. fws.gov/es/bank_ list.htm

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Hickory Pass Conservation Ranch	TX	Burnett	3,000 acres (500 acres in bank = 500 credits)	Golden-cheeked warbler	David Johnston 512 472 4542	http://news.fws.gov/ewsReleases/R2/BC6C6868-4DDC-4892-BC6B96EDA824DB4A.html	http://www.williamson-county.org/agenda/minutes/m050702.htm
Kern Water Bank (Conservation Bank)	CA	Kern	3,267 acres (1 acre = 1 credit)	San Joaquin kit fox, Tipton kangaroo rat, blunt-nosed leopard lizard, others	Cheryl Harding 661 399 8735	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/kern.shtml	http://sacramento.fws.gov/es/bank_list.htm
Kimball Island Conservation Bank	CA	Sacramento	102-109.6 acres	Delta smelt, Sacramento splittail, chinook salmon, steelhead	Kellie Berry 916 331 8810	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/sacramento.shtml	http://sacramento.fws.gov/es/bank_list.htm
Mobile County Gopher Tortoise Conservation Bank	AL	Mobile	222 acres; 125 tortoises	Gopher tortoise	Bruce Porter 251 441 5864	http://southeast.fws.gov/news/2001/r01-039.html	
Pleasanton Ridge Conservation Bank	CA	Alameda	600-654 acres	California red-legged frog, Alameda whipsnake	Nancy Wenninger 510 544 2607	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/alameda.shtml	http://sacramento.fws.gov/es/bank_list.htm
Pope Ranch Conservation Bank	CA	Yolo, Solano, Sacramento	391 acres	Giant garter snake	Kellie Berry 916 331 8810	http://sacramento.fws.gov/es/bank_list.htm	

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Red-Cockaded Woodpecker — University of South Carolina Development Foundation	SC	Georgetown	1500 acres (25-30 RCW clusters)	Red-cockaded woodpecker	C. Lamar Comalander 803 788 0590	http://www.environmentaldefense.org/article.cfm?contentid = 2664	
Sedco Hills	CA	Riverside	180 acres	California gnatcatcher	Leslie Beck 619 461 8333	http://www.sdcounty.ca.gov/dplu/Resource/5~mitbanks/5~mitbnks-index.html	
Sheridan Conservation Bank	CA	Placer	623 acres	Valley elderberry longhorn beetle	Kellie Berry 916 331 8810	http://sacramento.fws.gov/es/bank_list.htm	
Southlands Forest	GA	Bainbridge	1500 acres (11 breeding clusters of red-cockaded woodpeckers)	Red-cockaded woodpecker	Craig Hedman 229 246 3642 ext. 270	http://www.environmentaldefense.org/article.cfm?contentid = 2664	
Springtown Reserve	CA	Alameda	92.5 acres	California tiger salamander, burrowing owl	Terry Huffman 415 925 2000	http://www.dfg.ca.gov/cpb/conplan/mitbank/atalogue/alameda.shtml	
Stillwater Plains Mitigation Bank	CA	Shasta	834-900 acres	Valley elderberry longhorn beetle, vernal pool fairy shrimp, Orcutt's grass	Glenn Hawes 530 365 4233	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/shasta.shtml	http://sacramento.fws.gov/es/bank_list.htm

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Swan Road Conservation Bank	AZ	Pima	513 acres (1 acre = 1 credit)	Pima pineapple cactus	Linda Closs 520 740 6305	http://www.sahba.org/ regaffairs10.htm	
Williamson County Karst Conservation Foundation	TX	Williamson	220 acres	Bone Cave harvestman spider, potential for Coffin Cave mold beetle, Tooth Cave ground beetle	Steve Paulson 512 347 9000	http://www.wilcokarst. rg/facts.html	
Wilson Creek	CA	Riverside	1850 acres (1 acre = 1 credit)	California gnatcatcher and Quino checkerspot butterfly	Michael McCollum 916 688 2040	http://www.mccollum. com/Mitbanks.htm	
Wilson Valley	CA	Riverside	1280 acres (1 acre = 1 credit)	California gnatcatcher and Quino checkerspot butterfly	Michael McCollum 916 688 2040	http://www.mccollum. com/Mitbanks.htm	
Not included in catalog							
Arroyo Seco Conservation Bank	CA	Sacramento	240 acres	Vernal pool tadpole and fairy shrimp, Orcutt grass	Conservation Resources, LLC 916 974 3383	http://sacramento.fws.gov /es/bank_list.htm	
Barten Ranch	CA	Sacramento	1,440 acres	Vernal pool, wetlands, listed crustaceans	Angelo Tsakopoulos 916 383 2500	http://www.dfg.ca.gov/ hcpb/conplan/mitbank/ catalogue/sacramento. shtml	
Brosnan Forest	SC	Not known	10 breeding clusters of red-cockaded woodpeckers	Red-cockaded woodpecker	C. Lamar Comalander 803 788 0590	http://www.milliken forestry.com/services_ environmentalservices. htm	

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Brushy Creek Conservation Bank	CA	Contra Costa	120 acres	Burrowing owl	Wildlands 877 683 8810	http://www.wildlandsinc.com/banks/mit_wildbanks.htm	
Brushy Creek Forest	TX	East Texas	2,000 acres	Red-cockaded woodpecker	Champion International Corporation	Battelle, 1998	
Bryte Ranch Conservation Bank	CA	Sacramento	573 acres	Vernal pool tadpole and fairy shrimp	Charter Properties 916 489 6600	http://sacramento.fws.gov/es/bank_list.htm	
Cajon Creek	CA	San Bernardino	610 acres (1 acre = 1 credit)	Riversidian alluvial fan sage scrub, 24 associated sensitive species	Douglas W. Sprague 213 258 2777	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_bernardino.shtml	
Carlsbad Highlands	CA	San Diego	180 acres	Upland coastal sage scrub (multispecies credits)	Michael McCollum 916 688 2040	http://www.mccollum.com/Mitbanks.htm	
Chevron Lokern Conservation Bank	CA	Kern	18,000 acres (3 acres = 1 credit for permanent disturbance; 1.1 acres = 1 credit for temporary disturbance)	San Joaquin kit fox, blunt-nosed leopard lizard, Tipton kangaroo rat, and Swainson's hawk	Ron Rempel (USFWS) 916 654 9980	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/kern.shtml	
Dolan Ranch Conservation Bank	CA	Colusa	251 acres	Vernal pool preservation, giant garter snake	Dolan Ranch Conservation Bank 916 331 8810	http://sacramento.fws.gov/es/bank_list.htm	

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Four Seasons	CA	Riverside	99 acres	Not available	Not available	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf	
Friendfield Plantation	SC	Not specified	6 breeding clusters of red-cockaded woodpeckers	Red-cockaded woodpecker	C. Lamar Comalander 803 788 0590	http://www.millikenforestry.com/services_environmentalservices.htm	
Goldrich Conservation Bank	CA	Riverside	445 acres	Not available	Not available	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf	
Haera Wildlife Conservation Bank	CA	Alameda	562 acres	Burrowing owl, San Joaquin kit fox	Kellie Berry 916 331 8810	http://www.wildlandsinc.com/banks/mit_wildbanks.htm	
Laguna Creek Conservation Bank	CA	Sacramento	780 acres	Vernal pool preservation and creation, valley elderberry longhorn beetle	Laguna Creek Conservation Bank 916 974 3383	http://sacramento.fws.gov/es/bank_list.htm	
Madura Mitigation Site	CA	San Diego	35 acres (1 acre = 1 credit)	California gnatcatcher	Mark Madura 619 756 5526	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_diego.shtml#Madura	
Manchester Avenue Conservation Bank	CA	San Diego	150 acres	Coastal sage scrub/multispecies, including state and federally listed plants	Michael McCollum 916 688 2040	http://www.mccollum.com/Mitbanks.htm	
North Peak	CA	Riverside	789.27 acres	Not available	Not available	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf	

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Palo Alto Conservation Bank	AZ	Pima	N/A	Pima pineapple cactus	Ross Humphreys — owner 520 623 9558		
Piney Grove Preserve	VA	Sussex	2695 acres; 1 breeding cluster of red-cockaded woodpeckers	Red-cockaded woodpecker	Brian van Eerden 757 549 4690	http://nature.org/wherewework/northamerica/states/virginia/preserves/art4982.html	
Poway (SANREX) Mitigation Land Bank	CA	San Diego	880 acres (1 acre = 1 credit)	California gnatcatcher	Don Hunsaker 858 573 1835	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_diego.shtml#Poway	
Rancho Jarmul Mitigation Bank	CA	San Diego	250 acres	Least Bell's vireo, freshwater wetlands, riparian habitat	Kellie Berry 916 331 8810	http://www.wildlandsinc.com/banks/mit_wildbanks.htm	
Saipan Upland Mitigation Bank	Saipan, Northern Mariana Islands		814 acres = 97 credits	Endangered birds: Micronesian megapode, nightingale reed-warblers	Arlene Pangelinan (USFWS, Region 1) 808 792 9400		
Silverado Ranch	CA	Riverside	2480 acres	Not available	Not available	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf	
Skunk Hollow	CA	Riverside	150 acres (1 acre = 1 credit)	Fairy shrimp, Orcutt's grass	Jeff Newman (USFWS) 619 431 9440	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/riverside.shtml	

Table 1. Summary of identified conservation banks (cont.)

Conservation bank name	State	County or location	Size (acres and credits)	Species for which credits are available	Contact name and phone	Background information source #1	Background information source #2
Whelan Ranch	CA	San Diego	136 acres	Coastal sage scrub/multispecies	Jim Jackson or Michael McCollum 619 515 5653 or 916 688 2040	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_diego.shtml#Whelan	http://www.mccollum.com/Mitbanks.htm
In development							
Oregon chub — Oregon DOT	OR	Not known	Not known	Oregon chub	Rollie White, USFWS Region 1 503 231 6179	Bank is still in proposal stage with ODOT and FWS	
Big Cypress Mitigation Bank	FL	Collier/ Hendry	2,500 acres	Florida "priority one" panther habitat, but credits developed on a habitat basis and not on a species basis	Lynn Zenczak 239 415 6200	http://www.mitigationbank.com/endangered_species.htm	
Commence-ment Bay	WA	Pierce	Not known	Juvenile chinook salmon, English sole, "Hylebos birds complex"	ATOFINA Chemicals, Inc.	http://www.darcnw.noaa.gov/hylsettl.htm	
Timber Rattlesnake Bank	NY	Not known	Not known	Timber rattlesnake	Lynn Zenczak 239 415 6200		
Developed as banks, but never became active							
Lake Hodges	CA	San Diego	280 acres (1 acre = 1 credit)	California gnatcatcher	Don Hunsaker (SDSU, president of the Environmental Trust) 619 461 8333	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_diego.shtml#Lake	
Lost Hills Utility District Mitigation Bank	CA	Kern	160 acres	San Joaquin kit fox, blunt-nosed leopard lizard, Tipton kangaroo rat, Swainson's hawk, giant kangaroo rat, San Joaquin woolythreads	Wes Rhodehamel 661 835 8300 ext. 105	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/kern.shtml	

2.2 Data Collection

We obtained information about each bank in the catalog through telephone interviews with a bank contact person. We developed a template for information gathering that was used to structure the interviews. Where necessary, interviews were followed with e-mail messages to clarify responses to questions. When available, we also reviewed the conservation banking agreement or other documents associated with a bank.

3. Catalog of banks

The catalog of bank information is presented in the attachment to this report, with banks listed in alphabetical order. Table 2 presents a summary of the size of each bank in the catalog, the number of credits used, and the price per credit. Many of the banks in the catalog include habitat credits (such as wetland creation) as well as species-specific credits. In Table 2, we listed only the number and price of credits that pertain to species-specific credits, because species credits are the focus of this report. The full range of habitat credits available at a bank is included in the catalog so that the full range of a bank's activities could be documented. We also noted the primary motivation for the bank's development: internal use, regional planning, or for profit (see Section 4.1). Not surprisingly, we found a large variation in the price of credits, ranging from $55 per credit for karst habitat at the Balcones Canyonlands Preserve in Texas to $100,000 for a red-cockaded woodpecker breeding pair credit at the red-cockaded woodpecker bank owned by the University of South Carolina Development Foundation. Below, we briefly review some of the results from the catalog of banks, identifying some of the common findings across sites.

We also summarized the banks in the catalog by species grouping (Table 3). Overall, we found that the banks in the catalog encompassed 43 species. We summarized the number of banks that had credits for each species or species group, as well as the maximum banking acreage for each species or species group in the catalog. We used the full acreage in a bank for each of the species covered in the bank, unless the banking agreement specifically allocated acreage in the bank to different species. There were 3 banks that had credits available for amphibians, 12 banks with credits for birds, 1 bank with credits for fish, 8 banks with credits for invertebrates, 4 banks with credits for mammals, 4 banks with credits for plants, and 5 banks with credits for reptiles.

3.1 Motivations for Bank Development

We identified three primary motivations for bank development: internal use, regional planning, and a desire for species protection combined with profit. Banks have been developed for internal use by private companies and by governmental agencies. These banks provide mitigation credits

Table 2. Summary of bank size, credits used, and average prices for banks in catalog

Bank	Type of bank	Acres per credit	Number of acres	Number of credits in bank	Number of credits used	Transaction size	Price per credit
Agua Fria	For profit	1	137 in Phase 1	137	100+	Not available	$7,500-$15,000
Balcones Canyonlands Preserve	Regional planning	1	26,727	26,727	5000-7000	< 10 acres or > 200 acres	$3000 for Zone 1 habitat; $1500 for Zone 2 habitat; $55 for karst habitat
Chiquita Canyon	Internal use	1	327	327	0	0	Internal use — no price
Coles Levee	For profit	1	6059	6059	5500-5800	Not available	$650-$1000
East Plum Creek	Internal use	1	25.3	25.3	Not available	Not available	Internal use — no price
Fitzgerald Ranch	For profit	0.6	37	62	11	Not available	$65,000
Hickory Pass	For profit	1	500	500	400	Not available	$5,000
Kern Water Bank	For profit	1	3267	3267	598	3-5 acres usually	$2,375 per credit plus $5,000 fee per transaction
Kimball Island — endangered fish habitat in shallow water marsh (other wetland habitats also available; see catalog)	For profit	1	75	75	38	< 1 acre	$25,000
Mobile County	Regional planning	1.5	222	128	61	1-13 tortoises	$3,500
Pleasanton Ridge							
Alameda whipsnake	For profit	Not applicable	654.1	9	16	Not available	$2,000-$4,000
Red-legged frogs	For profit			771	26	Not available	$2,000-$4,000
“Dual species” credits for either species	For profit			112-168		Not available	$2,000-4,000

Table 2. Summary of bank size, credits used, and average prices for banks in catalog (cont.)

Bank	Type of bank	Acres per credit	Number of acres	Number of credits in bank	Number of credits used	Transaction size	Price per credit
Pope Ranch	For profit	1	391	310	155	0.05-50 credits	$25,000
Red-cockaded woodpecker USC	For profit	Not applicable	1200	1 breeding cluster of red-cockaded woodpeckers	1	1 cluster	$100,000
Sedco Hills — California gnatcatchers (other habitats available — see catalog)	For profit	1	180	8 pairs	6 pairs	1-2 pairs	$5,300
Sheridan — Valley Elderberry Longhorn Beetle (other habitats available — see catalog)	For profit	1800 sq. feet = 1 credit	616	1400	1,310	Not available	$1800 per elderberry unit plus transplant costs
Southlands Experimental Forest	Internal use and for profit	Not applicable	5300	12 red-cockaded woodpecker clusters	3	1-2 clusters	Internal use — no price
Springtown Reserve — Tiger salamander (wetland creation habitat available — see catalog)	For profit	0.1	52	520	None used	0	No price set
Stillwater Plains	For profit	1800 sq. feet = 1 credit	260	Approx. 100	Not available	Not available	Not available
Swan Road	Internal use	1	592	513	37	37 credits used for 1 project	Internal use — no price
Williamson County	Regional planning	Not defined	220	9 caves	9 caves	9 caves	$11 million total
Wilson Creek	For profit	1	1850	1850	688.3	Not available	$5,000-$12,000
Wilson Valley	For profit	1	1280	1280	991.95	Not available	$5,000-$12,000

Table 3. Summary of banks in catalog by species group

Species group	Species	Bank name	Number of banks	Total acres[a]
Amphibians	California tiger salamander	Fitzgerald Ranch, Springtown Reserve	2	89
	Red-legged frogs	Pleasanton Ridge	1	654.1
	Western spadefoot toad	Fitzgerald Ranch	1	37
Birds	American peregrine falcon, Aleutian Canada goose (delisted as endangered species)	Kern Water Bank	1	3,267
	Black-capped vireo	Balcones Canyonlands Preserve	1	Small area within 26,727 acre preserve
	Burrowing owl	Agua Fria, Springtown Reserve	2	189
	California gnatcatcher	Chiquita Canyon, Sedco Hills, Wilson Creek, Wilson Valley	4	3,637
	Golden-cheeked warbler	Balcones Canyonlands Preserve, Hickory Pass	2	27,227
	Red-cockaded woodpecker	Red-cockaded woodpecker USC, Southlands experimental forest	2	6,200
	Swainson's hawk	Coles Levee	1	6,059
Fish	Delta smelt, Sacramento splittail, chinook salmon, steelhead	Kimball Island	1	75
Invertebrates (with habitat type)				
Karst invertebrates	Bone Cave harvestman, Tooth Cave ground beetle	Balcones Canyonlands Preserve, Williamson County	2	Small area at Balcones + 220 acres at Williamson
Karst invertebrates	Kretschmarr Cave mold beetle, Tooth Cave pseudoscorpion, Tooth Cave spider	Balcones Canyonlands Preserve	1	Small area at Balcones

Table 3. Summary of banks in catalog by species group (cont.)

Species group	Species	Bank name	Number of banks	Total acres[a]
Karst invertebrates	Coffin Cave mold beetle	Williamson County	1	220
Riparian	Valley elderberry longhorn beetle	Kern Water Bank, Sheridan, Stillwater Plains	3	3,585
Sage scrub	Quino checkerspot butterfly	Wilson Creek, Wilson Valley	2	3,130
Vernal pool	Vernal pool fairy shrimp	Fitzgerald Ranch, Kern Water Bank, Stillwater Plains	3	3,564
Vernal pool	Conservancy fairy shrimp, longhorn fairy shrimp, vernal pool tadpole shrimp	Kern Water Bank	1	3,267
Mammals	San Joaquin kit fox	Agua Fria, Coles Levee, Kern Water Bank	3	9,463
	Giant kangaroo rat, Tipton kangaroo rat	Coles Levee, Kern Water Bank	2	9,326
	Preble's meadow jumping mouse	East Plum Creek	1	25.3
Plants	*Legenere limosa*	Fitzgerald Ranch	1	37
	Orcutt's grass	Stillwater Plains	1	260
	Pima pineapple cactus	Swan Road	1	513
	Bakersfield cactus, California jewel flower, Hoover's woolly-star, Kern mallow, San Joaquin wooly-threads	Kern Water Bank	1	3,267
Reptiles	Alameda whipsnake	Pleasanton Ridge	1	654
	Blunt-nosed leopard lizard	Coles Levee, Kern Water Bank	2	9,326
	Giant garter snake	Kern Water Bank, Pope Ranch	2	3,658
	Gopher tortoise	Mobile County	1	222
Total number of species covered by banks		**43**		

for current and planned future impacts to endangered species. For example, the Swan Road bank in Arizona provides internal conservation credits for Pima County, allowing the construction of county facilities and roads. The East Plum Creek and Chiquita Canyon banks were developed by transportation authorities in Colorado and California, respectively, to provide internal credits to mitigate for road construction. The Southlands red-cockaded woodpecker bank in Georgia is designed to provide internal credits for logging activities by International Paper, as well as potentially providing credits for third party use.

Another set of banks was motivated by the need for a regional planning and development strategy. In these areas, development was being restricted because of the need for endangered species mitigation and a local governmental authority or utility recognized the need to create a regional process to protect endangered species and their habitats and facilitate development. The Balcones Canyonland Preserve and the Williamson County Karst Conservation Foundation (both in Texas) are examples of banks that were developed to serve county-wide needs. The Mobile County gopher tortoise bank was developed by the Mobile Area Water and Sewer System to meet the needs of their customers to install septic tanks in areas with gopher burrows.

The largest number of banks appears to be motivated by a combination of a desire to protect endangered species while earning a profit (or covering costs, for nonprofit organizations that sponsor banks). Some bank owners have purchased land or restored habitat solely to create a conservation bank and realize a profit. Examples include the banks developed by Wildlands, Inc. (including Sheridan, Pope Ranch, and Kimball Island) and Springtown Reserve. Other bank owners have found themselves in the position of already owning land that is valuable habitat for endangered species and being unable to develop the land. Conservation banking then becomes a way to realize a profit from existing land holdings, often while maintaining current land uses such as grazing. Examples of this type of bank include the Fitzgerald Ranch, Hickory Pass, and Agua Fria.

3.2 Basis for Credit Development

An issue common to all banking agreements is the need to define and measure the quantity of conservation credits that a bank will be allowed to sell (or use internally). The most common method is to define one credit as equal to one acre of habitat suitable for the species of interest. Either the USFWS or a private contractor employed by the bank owner will survey the property to determine the number of acres of different types of habitat that can be used to generate credits. A similar method bases the number of credits on the number of acres in the bank, but uses a multiplier to adjust the final credit number based on species abundance or perceived habitat quality. At the Fitzgerald Ranch, for example, each acre was equal to 1.7 credits. The least common method for defining credits is to base the number of credits on the number of individuals of endangered species that a bank can support. The Mobile County gopher tortoise

bank defines one credit as equal to one tortoise — the number of tortoises that the bank could support was the basis for defining the total number of credits in the bank.

The most rigorous system for defining credits is the method used at the red-cockaded woodpecker conservation banks. For these banks, one credit is defined as the establishment of a new group of red-cockaded woodpeckers in an area that can support at least 10 breeding clusters. A credit is generated only when a new group of birds is demonstrated to have stayed on a territory for at least six months, including one breeding season. No credits are available for protection of existing breeding clusters.

For incidental takes of federally listed species, the USFWS is responsible for determining the amount of mitigation required for an individual take. This analysis determines the number of credits that a party is required to purchase (or use internally) at a conservation bank. In general, bank owners are not involved at all with the debit determinations. A party wanting to purchase credits at a bank will come to the bank owner already knowing how many credits they are required to purchase. The ratio of credits to debits varies across species and regions, with 1:1 or higher ratios required by USFWS for mitigation.

3.3 Issues Related to Banking Success

The bank owners and operators that we surveyed all viewed their banks as successful from an ecological point of view, with mixed reports regarding economic success. Several bank owners complained that the local USFWS office was not supportive of their bank and limited their access to potential purchasers of credits. The lengthy process to formalize banking agreements also was criticized. Bank owners that enjoyed good relations with the local regulatory agencies and had high demands for their credits were generally very pleased with the overall success of their banking effort. Not surprisingly, banks were especially successful if they held a monopoly for a certain type of credit in an area. The need to protect habitat from vandalism, unauthorized dumping, and other illegal uses was a common concern of bank owners.

4. Credit Transaction Information for Four Banks

In this section, we provide additional information on credit development and transaction data for four banks: the Kern Water Bank, Mobile County Gopher Tortoise Conservation Bank, Sedco Hills, and Springtown Reserve. The Kern Water Bank and Mobile County were able to provide transaction information because they have had fixed credit prices over time. Sedco Hills and Springtown Reserve provided transaction data without pricing information.

4.1 Kern Water Bank

The Kern Water Bank in California includes 19,900 acres, with the primary purpose of storing water in alluvial aquifers for later use ("groundwater banking"). The bank needed to have a habitat conservation plan and incidental take permit approved to be able to conduct groundwater banking — the idea of a conservation bank developed out of the habitat conservation plan negotiations.

Specifically, out of the 19,900 acres at the site, 5,900 acres were designated for basins for recharge activities and 481 acres were designated for permanent water banking facilities. An area of 960 acres was designated to protect existing populations of listed plant species; 5,592 acres between basins were planned to revert to habitat; 530 acres were designated as mitigation for previous California Department of Water Resources projects; and 3,170 acres were designated for farming. The remaining acreage (3,267 acres) was designated for the conservation bank (62 FR 27062 – 27064). The conservation banking agreement established that one credit would be equal to one acre of habitat (U.S. Fish and Wildlife Service et al., 1997). The area and acreage set aside for each of the designations listed above were developed through intensive negotiations and consideration of the value of different habitats at the site.

Between 1998 and July 2003, there have been 38 transactions at the bank for a total of 598 credits purchased (Table 4). Twenty-nine transactions have been with corporations or other private enterprises, two transactions have been with individual landowners, and seven transactions have been with public agencies. The smallest transaction was for one credit (one acre), and the largest transaction was for 151 credits. Prices have remained fixed over this time — each credit costs $2,000. In addition, there is a $5,000 administrative fee per transaction (regardless of number of credits) that goes to the bank. The bank also collects $375 for the California Department of Fish and Game per transaction. The Kern Water Bank authority is considering increasing the price of credits because of a strong demand for credits.

Table 4. Summary of 38 credit transactions at the Kern Water Bank through July 2003

Date	Credit purchaser	Type of party (public agency, corporation, individual)	Credits used	Cost
6/9/1998	Production Specialties	Corporation	3	$11,375
10/28/1998	Royale Energy Inc.	Corporation	5	$15,375
1/5/1999	Production Specialties	Corporation	2	$9,375
11/23/1999	Production Specialties	Corporation	2	$9,375
12/23/1999	Rubinder Jhaj (DJ Holdings Inc.)	Corporation	12	$29,375
2/9/2000	Occidental of Elk Hills	Corporation	1	$7,375
3/10/2000	Williams Communications	Corporation	18	$41,375

Table 4. Summary of 38 credit transactions at the Kern Water Bank through July 2003 (cont).

Date	Credit purchaser	Type of party (public agency, corporation, individual)	Credits used	Cost
4/19/2000	Kiewit Network Services Inc.	Corporation	7	$19,375
5/18/2000	Sempra Energy	Corporation	6	$17,375
6/5/2000	Rio Bravo Tomato Company	Corporation	34	$73,375
6/14/2000	Williams Communications	Corporation	6	$17,375
6/27/2000	Trudy Rogers	Individual	1	$7,375
7/24/2000	Pilot Corporation	Corporation	23	$51,375
8/1/2000	State of California — CalTrans	Public agency	2	$9,375
3/12/2001	EOG Resources	Corporation	20	$45,375
3/20/2001	EOTT Energy LLC	Corporation	24	$53,375
4/10/2001	Production Specialties	Corporation	3	$11,375
4/6/2001	City of Shafter	Public agency	5	$15,375
7/2/2001	GWF Power Systems	Corporation	3	$11,375
5/23/2001	GWF Power Systems	Corporation	7	$19,375
6/6/2001	Berkley (Anadarko Petroleum)	Corporation	17	$39,375
6/8/2001	West Kern Water District	Public agency	1	$7,375
6/21/2001	Auch/Borrego	Corporation	3	$11,375
8/29/2001	Production Specialties	Corporation	1	$7,375
10/19/2001	Pacific Gas & Electric (PG&E)	Public agency	1	$7,375
11/30/2001	Love's Country Stores	Corporation	24	$53,375
12/7/2001	GWF Power Systems	Corporation	10	$25,375
1/29/2002	Fidelity Resources	Corporation	3	$11,375
3/5/2002	Production Specialties	Corporation	1	$7,375
3/19/2002	Three landowners (unnamed)	Individual	5	$15,375
4/24/2002	Kern County	Public agency	20	$45,375
10/3/2002	West Kern Water District	Public agency	31	$67,375
10/7/2002	Highway 58 LLC (Vogle)	Corporation	80	$165,375
10/21/2002	Ennis Homes	Corporation	36	$77,375
10/22/2002	McDonalds & Lawton Powers	Corporation	1	$7,375
11/8/2002	Emerald Trail LLC	Corporation	7	$19,375
5/3/2003	Occidental of Elk Hills, Inc.	Corporation	22	$49,375
7/2/2003	CA Department of Transportation	Public agency	151	$307,375
Total			**598**	**$1,400,250**

4.2 Mobile County Gopher Tortoise Conservation Bank

The Mobile County Gopher Tortoise Conservation Bank was established to provide private landowners in Mobile County, Alabama, with a mechanism for mitigating impacts to gopher tortoises resulting from habitat loss. In Mobile County, housing construction was halted in some areas because of the presence of active gopher tortoise burrows. The Board of Water and Sewer Commissioners of the City of Mobile (the Board), which is responsible for septic tank installation in Mobile, applied for an incidental take permit in order to establish a conservation bank to benefit the federally threatened gopher tortoise. Under the conservation bank plan, the Board could issue "certificates of inclusion" to private landowners who purchase mitigation credits from the Board. This would allow private landowners to proceed with septic tank installation in areas with gopher tortoise burrows.

The Board owned suitable habitat for gopher tortoises, but the longleaf pine habitat had been degraded over time by fire suppression, which had allowed hardwood encroachment into the longleaf pine ecosystem. To establish the bank, management was needed to "restore more open, longleaf-pine canopy conditions, reduce hardwood encroachment, reduce invasive exotic species, and restore more natural fire regimes" (Board of Water and Sewer Commissioners of the City of Mobile, no date).

The number of credits available at the 222-acre conservation bank was based on the number of tortoises that the bank could support and the amount of suitable habitat at the site (205 acres). Each credit represents one tortoise. Parties wanting to purchase credits are required to pay a fee for habitat management and to cover the cost of translocating a tortoise to the site if a tortoise is present on their property (Board of Water and Sewer Commissioners of the City of Mobile, no date).

The habitat conservation plan specified that the stocking rate for the conservation bank would be 80% of the target density of 1.2 acres per tortoise, resulting in a stocking rate of 1.5 acres per tortoise at the bank. The decision to use an 80% stocking rate was based on the need to allow for natural growth and reproduction of the population at the site. The habitat conservation plan authorized the Board to offer 125 credits to the public, which would require 188 acres of land. In addition, the baseline population at the site was estimated to be 15 tortoises — these tortoises were estimated to need 1.2 acres per tortoise, for a total of 18 acres required. The total number of acres required for the translocated tortoises and the baseline population is 205 acres, which equals the amount of available habitat at the bank (Board of Water and Sewer Commissioners of the City of Mobile, no date).

Between 2001 and November 2003, there have been 18 transactions at the bank for a total of 61 credits purchased (Table 5). The Board did not provide us with information about the identity of the parties purchasing credits. The smallest transaction was for one credit, and the largest

Table 5. Eighteen credit transactions at the Mobile County Gopher Tortoise Conservation Bank

Date	Number of tortoises	Mitigation fee
8/2/2001	1	$3,500
8/6/2001	13	$45,500
8/14/2001	2	$7,000
9/26/2001	4	$14,000
9/26/2001	1	$3,500
1/9/2002	5	$17,500
2/20/2002	1	$3,500
4/23/2002	2	$7,000
7/15/2002	5	$17,500
8/6/02	1	$3,500
9/24/02	1	$3,500
5/30/02	2	$7,000
7/3/03	12	$42,000
7/10/03	1	$3,500
10/24/03	1	$3,500
10/28/03	3	$10,500
11/21/03	5	$17,500
Total	**61**	**$213,500**

transaction was for 13 credits. Prices have remained fixed over this time — each credit costs $3,500 per tortoise. The Board has applied for funding to cover the mitigation costs for parties that cannot afford the banking fee.

Bruce Porter, Fish and Wildlife biologist from the local USFWS field office that oversees the bank, noted that one problem the bank has faced is illegal tortoise dumping (personal communication, December 1, 2003). Because the location of the bank was publicized (which the bank managers now realize was a mistake), tortoises have been dumped at the bank site without any payment of the mitigation fee and without testing of the tortoises for upper respiratory disease which could spread to other tortoises at the bank.

4.3 Sedco Hills

The 180 acre Sedco Hills Conservation Bank was started by The Environmental Trust, a nonprofit agency in Riverside County, California, as a means to help conserve habitat and protect the federally threatened California gnatcatcher. Credits were defined on the basis of one credit equals one acre, for the two different habitat types available at the site (148 acres of Riversidian sage scrub and 31.85 acres of Chamise chaparral). In addition, credits are available for eight pairs of gnatcatchers at the site. Purchase of each gnatcatcher credit requires purchasing 20 acres of supporting habitat per pair of birds. Biological surveys conducted over several years were used by the USFWS to determine that eight pairs of California gnatcatchers were supported on the site (Leslie Beck, The Environmental Trust, personal communication, December 2, 2003).

Between 2000 and April 2003, there have been seven transactions at the bank, for a total of 148 credits of sage scrub, 1.2 credits of chaparral, and 6 credits for California gnatcatchers (Table 6). On average, habitat credits sell for $3,950 per credit, while credits with the California Gnatcatcher sell for $5,300 per credit. Transaction data were provided to us by Leslie Beck at The Environmental Trust, but without individual pricing data for each transaction.

Table 6. Seven credit sales at the Sedco Hills Conservation Bank

Date	Buyer	Project name	Riversidian sage scrub	Chamise chaparral	Gnatcatcher pair
6/14/00	Railroad Canyon-Lake Elsinore L.P.	Railroad Canyon Project, portion Tract 20704	20		1
1/25/01	Granite Homes dba Elsinore 98 LLC	Granite Homes Project, Tract 20705	9.7		
3/1/01	Williams Communications Inc.	Fiber Optic Cable Installation-Phoenix, AZ to Riverside County, CA	8.0		
9/7/01	Rancho California Water District	Santa Margarita River Outfall Project No. 98048	1.5		
1/21/02	Barrington Heights LLC	Sun City Project	18.8	1.2	1
2/8/02	AGK Group LLC Temecula Village Dev. LP	Temecula Ridge Apartments and Temecula Village Development	45.0		2
4/9/03	Antelope Road LP	Antelope Road Project	45		2
Total			148	1.2	6

4.4 Springtown Natural Communities Reserve

Three different types of habitat credits are available at the Springtown Natural Communities Reserve: alkali meadow habitat, California tiger salamander breeding and estivation habitat, and freshwater palustrine emergent seasonal wetlands. Credits were defined on an acreage basis, with one credit equaling 0.1 acre. Credits were defined in terms of fractional areas to simplify record-keeping for small transactions. The minimum transaction size is one credit.

The number of credits available for each habitat type was defined based on a combination of preserving existing alkali meadow habitat and creating 31 acres of seasonal wetlands on the site that had existed before subdivision development in the 1950s. The bank protects one listed species (state and federally listed endangered palmate-bracted bird's beak) and a state species of concern, the California tiger salamander. There is no active market for credits for either of these species, however. The bank actively sells credits for wetlands creation, but at the moment there is no active market for credits for California tiger salamander because of the availability of cheaper credits in the area. This bank is able to maintain itself as a conservation bank for endangered species because it also serves as a wetlands mitigation bank, where the market for credits is more active. A summary of the wetland transactions at the bank is given in Table 7. There have been a total of 12 transactions at the bank, ranging in size from 1 credit (0.1 acres) to 156 credits (15.6 acres). The current price for wetland creation credits is $25,000 per credit ($250,000 per acre).

Table 7. Wetland creation credit transactions at Springtown Reserve

Mitigation/project name	Mitigation acres	Mitigation credits
Carr/Baytech+	15.6	156
Kaiser	0.2	2
H.G.C. II/Zelman Kreg-Oc (Koll)	0.7	7
Greystone	0.66	6.6
Alameda County	0.1	1
Ho/Burne	0.87	8.7
Frontier Ti	0.1	1
Greystone II (E)	2	20
URS Greiner/ Caltrans	1.18	11.8
IMO	0.7	7
HPS&S	1.5	15
BART	0.9	9
Total	**24.51**	**245.1**

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Attachment — Catalog of Conservation Banks

The attached tables present a catalog of 22 conservation banks located across the United States. The banks were chosen to represent different regions of the United States and different species. The information provided for each bank includes its location, size, species and habitats covered, the methods used to define credits and debits, transaction history, ownership history and current status, management and operation, performance monitoring, and subjective appraisals. Full citations for the reports and documents referenced in the catalog are provided at the end of this attachment.

Agua Fria Multi-Species Mitigation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	10/6/03
Bank name	Agua Fria Multi-Species Mitigation Bank
Location	
Address	Jasper Sears Road
City	Gustine
State	CA
County/location	Merced
Contact for information	
Name	Brian Boroski (through contacts provided by Donn Campion — bank owner)
Phone	559-449-1423
E-mail	bboroski@harveyecology.com
Organization	H.T. Harvey & Associates
Title/role	Wildlife ecologist — Agua Fria Bank Project Manager
Additional contact, if any	
Name	Donn Campion
Phone	408 867 1593
E-mail	dcampion@aguafria.net
Organization	n/a
Title/role	Owner of Agua Fria Multi-Species Mitigation Bank
URLs with information	
URL#1	http://sacramento.fws.gov/es/bank_list.htm
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	Bank is planned for 3,234 acres which would be implemented in two phases. Phase I consists of 137 acres and has been activated and is near full subscription. Phase II consists of 3,097 acres. The owner is close to activating the second phase, assuming that no major changes occur.
No. of acres of buffer areas, if any	None formalized.
No. of credits in bank	Across both phases there will be 3,200 credits available.
No. of credits used or sold to date	Over 100 credits sold to date through Phase I of the bank.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	Burrowing owl (C)
Fish	
Invertebrates	
Mammals	San Joaquin kit fox (FE)

Agua Fria Multi-Species Mitigation Bank

Information categories	Responses
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits are defined in terms of acreage. Project impacts to San Joaquin kit fox often require mitigation ratios of 1:1 up to 3:1 depending on the habitat affected. Therefore, a project impacting 100 acres may need to purchase from 100 to 300 credits to mitigate for impacts. Mitigation for impacts to burrowing owls is negotiated with the California Department of Fish and Game (CDFG), but the common requirement is to preserve 6.5 acres of habitat for each pair of owls impacted by a project.
What was the method used for defining and measuring credits?	Credits are based on a habitat survey that assessed the acreage of habitat suitable to San Joaquin kit foxes or burrowing owls. Habitat was surveyed to establish value for target species.
How were multiple species issues addressed?	Credits are generally exclusive in that an acre cannot be sold twice to separate parties even if the debits being offset are for different species. The exception to this is when an interested party needs to purchase credits to offset impacts to both San Joaquin kit foxes and burrowing owls. In this case, the number of credits required for purchase is based on the species requiring the largest number of credits, with the debit for the other species assumed to be offset. For example, if impacts to kit fox required 150 acres of compensation and impacts to burrowing owls required 100 acres of compensation, the total amount of compensation required from a single party would be only 150 acres.
What is the service area for the bank?	Kit fox service area includes areas in Stanislaus, Merced, and Fresno counties west of the San Joaquin River. The primary burrowing owl service area includes areas in Stanislaus, Merced, and Fresno counties west of the San Joaquin River, San Benito County, and southern Santa Clara County. Santa Clara County north of Hwy 152 provides a secondary service area. Impacts in this area require a ratio of 2:1 for mitigation at the bank (i.e., 2 acres of credit are required to offset each acre of debit).
Can we get the Conservation Banking Agreement?	Habitat Management Plan included with supplemental materials. See H.T. Harvey & Associates, 2001. Donn Campion has a copy of the Conservation Banking Agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS and CDFG staff.
Can different species be "traded off" for debits vs. credits?	No.

Agua Fria Multi-Species Mitigation Bank

Information categories	Responses
Credit transaction history	
If individual transaction data not available	
Who used credits?	Sales of credits to date have been exclusively to private parties.
Total number of transactions?	Not available.
Average size	Not available.
Average price or change in price over time	Credits have generally been sold for $15,000 each, but to facilitate sales, the owner has the discretion to negotiate on the price with each transaction. As a result, the effective price per credit may have effectively ranged from roughly $7,500 to $15,000.
History/status of bank	
Current status	The bank is in active operation and is nearing full subscription on its planned first phase that encompasses 137 acres. From all indications it sounds as if the second phase, covering 3,097 acres, will be made available to interested parties in the near future.
Who owns bank?	Dr. Donn Campion (this is a private landholding and is not associated with the owner's primary residence).
Has ownership changed – If so, why?	No.
Who can use the bank?	All interested public and private parties who can pay the required fee.
Establishment date	2002
Date first credit used	2002
Management and operation	
Who manages the habitat?	H.T. Harvey & Associates is in charge of the habitat monitoring and management (Brian Boroski is the project manager).
Who markets the credits?	Active marketing has not been required given the need for mitigation credits to the species serviced by the bank.
Who owns the land?	Dr. Donn Campion
What types of management activities take place?	The bank's habitat management plan has invasive species plans to control both plants and predatory wildlife such as red foxes. The plan also contains restoration elements to address degraded areas of habitat, including fencing along selected streams and seasonally wet drainage swales. Grazing practices will be managed to favor habitat conditions for burrowing owls and kit foxes, and their preferred prey species. Overall the plan emphasizes an adaptive management strategy.
Did active management for restoration need to take place to gain credits?	No. Credits are effectively based on preservation of the existing habitat. However, certain management activities did occur before operation of the bank, such as fencing of riparian areas and ending rodent control activities, to allow the prey base for kit foxes and burrowing owls to increase.

Agua Fria Multi-Species Mitigation Bank

Information categories	Responses
What are long-term management arrangements?	Not currently known whether property will be retained by owner or sold or transferred to a resource management agency once the active sale of credits in the bank is completed.
What is planned lifespan of bank?	The period of active credit sales is not currently being forecast. With the sale of any Phase II credits, however, the entire bank acreage will have permanent conservation easements attached to the property. The land will be managed in perpetuity to maintain habitat and conservation values.
What types of monitoring take place to ensure bank "performance"?	Species specific surveys and periodic habitat suitability surveys are currently envisioned for the bank and described in the available habitat management plan for the bank.
Performance monitoring	
How frequently does monitoring occur?	The management plan for the bank states that focal habitat and species surveys will be conducted annually.
Are there provisions for monitoring to trigger remedial actions?	The habitat management plan identifies an "adaptive management process," but does not identify what conditions would trigger additional restoration or management actions.
Can monitoring reports be obtained?	Bank is barely a year old so annual monitoring has not yet taken place.
Subjective appraisals	
Impetus to start bank	Development opportunities for the land were effectively constrained given the nature of surrounding development that has left the land as the last viable habitat corridor for San Joaquin kit foxes and other species in the region. The bank's owner determined that the land's highest value could be realized through development of a conservation bank that would also place only minor restrictions on current activities that occur on the ranch (e.g., modification of grazing practices).
Issues at startup	None apparently.
Difficulty in marketing credits	No.
Issues with current regulations	None.
Is bank a success?	Bank appears to be an economic success given the speed with which the credits in the first phase have been purchased along with the plans to pursue the sale of credits in the second phase of the bank, which will result in a permanent conservation easement on the entire property. Development of the bank has benefited regional habitat and species management programs through improved habitat management. The permanent conservation easements on the bank property protect the land in perpetuity; however, the development potential of the land was apparently already severely constrained, given its function as a habitat corridor in the region.

Agua Fria Multi-Species Mitigation Bank

Information categories	Responses
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	Not available
Review notes	This version reviewed by Brian Boroski and sent to Stratus Consulting 10/17/03.

Balcones Canyonlands Preserve

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	November 25, 2003 (site visit November 21, 2003)
Bank name	Balcones Canyonlands Preserve
Location	
Address	Western Travis County
City	Austin
State	TX
County/location	Travis
Contact for information	
Name	Kevin Connally
Phone	(512) 854-9437
E-mail	kevin.connally@co.travis.tx.us
Organization	Travis County
Title/role	Environmental Specialist and Balcones Canyonlands Conservation Plan Coordinator
Additional contact, if any	
Name	William Conrad
Phone	512 263 6430
E-mail	william.conrad@ci.austin.tx.us
Organization	Water & Wastewater Utility, City of Austin
Title/role	Wildland Conservation Division Manager
URLs with information	
URL#1	http://www.co.travis.tx.us/tnr/bccp/default.asp
URL#2	http://www.ci.austin.tx.us/preserves/bcp.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	26,727 acres assembled as of November 25, 2003 with additional 460 acres close to signed contracts. Target acreage for permit is 30,428 acres.
No. of acres of buffer areas, if any	No buffer areas.
No. of credits in bank	1 acre = 1 credit; Zone 1 = confirmed nesting habitat; Zone 2 = believed to be good habitat, no data on actual bird presence.
No. of credits used or sold to date	Approximately 5,000-7,000 credits have been used up.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	Black-capped vireo (FE), golden-cheeked warbler (FE)
Fish	
Invertebrates	Bone Cave harvestman spider (FE), Bee Cave harvestman spider (FE), Tooth Cave pseudoscorpion (FE), Tooth Cave spider (FE), Tooth Cave ground beetle (FE), Kretschmarr Cave mold beetle (FE)

Balcones Canyonlands Preserve

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	1 credit = 1 acre of habitat in the preserve.
What was the method used for defining and measuring credits?	Biological Advisory Team defined necessary acreage for regional habitat conservation plan based on what is necessary to ensure survival of species in this area. The preserve contains the best remaining golden-cheeked warbler habitat in the center of its range; the preserve also is located on the eastern edge of black-capped vireo habitat.
How were multiple species issues addressed?	Habitat managed for both bird species; karst areas protected for cave invertebrates.
What is the service area for the bank?	Western Travis County — 567,000 acre service area.
Can we get the Conservation Banking Agreement?	The conservation banking provisions are included within the regional habitat conservation plan (HCP), which is a massive document, not available electronically. Excerpts from the HCP are available at http://www.ci.austin.tx.us/preserves/bcp.htm.
Measurement methods for "debit areas"	
How is "debit area" assessed?	USFWS created habitat maps that show areas of Zone 1 and Zone 2 habitat. The number of acres of habitat in each zone determines the required mitigation fee for a private party. For Capital Improvement Projects proposed by the City of Austin or Travis County, 1 acre of Zone 1 habitat is compensated with 1 acre of credit; 1 acre of Zone 2 habitat is compensated for with 1/2 acre of credit.
Can different species be "traded off" for debits vs. credits?	Not an issue here. Mitigation at the preserve is available for impacts to golden-cheeked warbler, black-capped vireo, and karst habitat.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Mostly private parties.
Total number of transactions?	Approximately 400 applications have been received for "participation certificates" that allow private parties to pay a fee to the preserve for mitigation.
Average size	Most transactions are either smaller than 10 acres or larger than 200 acres, reflecting the needs of small versus large developments.

Balcones Canyonlands Preserve

Information categories	Responses
Average price or change in price over time	Fee reduction has been in effect from 1999 to 2004. Current fees are $3,000 per acre for Zone 1 habitat; $1,500 per acre for Zone 2 habitat; and $55 per acre for karst habitat. Original fee structure was $5,500 per acre for Zone 1 habitat; $2,750 per acre for Zone 2 habitat; and $55 per acre for karst habitat. There are additional reduced fee provisions for developing a single-family lot on a larger tract that remains intact ($1,500 one-time fee) or for small agricultural improvements.
History/status of bank	
Current status	Active
Who owns bank?	The incidental take permit, and the associated multi-species habitat conservation plan, which authorizes the conservation bank was issued jointly to Travis County and the City of Austin.
Has ownership changed – If so, why?	No.
Who can use the bank?	Public agencies and private parties.
Establishment date	Permit issued in May 1996.
Date first credit used	Not addressed.
Management and operation	
Who manages the habitat?	Separate tracts managed by three "managing partners:" Travis County, the City of Austin, and the Lower Colorado River Authority. In addition, the Travis Audubon Society and The Nature Conservancy manage land that is part of the preserve.
Who markets the credits?	Travis County administers the public participation program; the City of Austin manages the infrastructure mitigation program.
Who owns the land?	Ownership of separate tracts by Travis County, the City of Austin, the Lower Colorado River Authority, the Travis Audubon Society, and The Nature Conservancy.
What types of management activities take place?	Prescribed fire and brush removal to maintain open shrubland conditions for black-capped vireos; control of harmful species, including brown-headed cowbirds, white-tailed deer, feral hogs, and fire ants. Control of exotic plant species.
Did active management for restoration need to take place to gain credits?	Active management and restoration are needed to create and maintain habitat for black-capped vireos, which require mid-successional habitat in this area. Active ranches in the area had previously maintained habitat in a suitable state for black-capped vireos, but the loss of ranches to development required new management actions to create the necessary habitat. Yellow-cheeked warblers and the six karst invertebrates require protection of existing habitat.
What are long-term management arrangements?	Managing partners expect to manage land in perpetuity.
What is planned lifespan of bank?	The incidental take permit, and the associated multi-species habitat conservation plan, was granted for 30 years.

Balcones Canyonlands Preserve

Information categories	Responses
What types of monitoring take place to ensure bank "performance"?	Population surveys for yellow-cheeked warblers and black-capped vireos, surveys of nesting success, vegetation surveys.
Performance monitoring	
How frequently does monitoring occur?	Annual monitoring occurs and is compiled in an annual report.
Are there provisions for monitoring to trigger remedial actions?	Adaptive management plans are an integral part of the land management plans. There are no specific triggers for remedial actions.
Can monitoring reports be obtained?	We did not obtain any of the monitoring reports.
Subjective appraisals	
Impetus to start bank	In the early 1990s, intense development pressure in the region led to a number of parties coming together for different reasons. Environmental interests were working to ensure survival of endangered species and habitat protection in the area; development and landowner interests were concerned with the lengthy and costly process needed to obtain an incidental take permit; the City of Austin and Travis County had a large economic stake in creating a mechanism that would not slow down economic development. All of these groups (city and local government, developers, nonprofit agencies, USFWS) worked cooperatively to develop the first regional multi-species habitat conservation plan in the nation, which provided for substantial habitat protection and a simple mechanism (fee-based "participation certificates") for mitigating development of endangered-species habitat.
Issues at startup	In Texas, there is a long history of private land ownership and private property rights. At first, there was some public sentiment against the purchase of large tracts of land for the preserve, because it was seen as a "government land grab." Obtaining funding for purchasing the land was an important hurdle to overcome. The City of Austin passed a bond issue that enabled Austin to buy large tracts of land (especially because it occurred at the time when failed Savings and Loan Associations were selling land cheaply). Travis County did not pass a bond-issue, but has been successfully writing grants for federal matching funds, which provide 3 federal dollars for each local dollar.
Difficulty in marketing credits	No — the local USFWS office is supportive of fee-based mitigation through the preserve.
Issues with current regulations	Not addressed.

Balcones Canyonlands Preserve

Information categories	Responses
Is bank a success?	Yes — the preserve has been successful at protecting large tracts of critical habitat for endangered species and also has facilitated development in the region through streamlining the mitigation process. This project is seen as a model for getting interest groups, agencies, and landowners to work together cooperatively to find solutions for protecting endangered species without halting development.
Do they know of any banks that were started and failed – If so, why?	No. The development of a large publicly-funded and managed preserve that functions as a conservation bank (with credits far exceeding demand at the moment) has eliminated any incentive for developing private conservation banks in the region.
Relevant permits	Habitat Conservation Plan Permit No. 788841
Review notes	

Chiquita Canyon

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	12/8/2003
Bank name	Chiquita Canyon
Location	
Address	Near Rancho Mission Viejo
City	
State	CA
County/location	Orange
Contact for information	
Name	Valerie McFall
Phone	949.754.3400 ext. 475
E-mail	mcfall@sjhtca.com
Organization	Orange County Transportation Corridor Agencies
Title/role	
Additional contact, if any	
Name	Jeff Newman
Phone	(619) 431-9440
E-mail	
Organization	U.S. Fish and Wildlife Service
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/orange.shtml
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	327 acres set aside as bank.
No. of acres of buffer areas, if any	Total parcel is 1182 acres.
No. of credits in bank	327; 1 acre = 1 credit.
No. of credits used or sold to date	No credits used so far.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	California gnatcatcher (FT)
Fish	
Invertebrates	
Mammals	
Plants	
Reptiles	

Chiquita Canyon

Information categories	Responses
Habitat types	Coastal sage scrub
Credit definition for bank	
Unit for credits (acres or organisms?)	Acres
What was the method used for defining and measuring credits?	Area for bank based on actual location of gnatcatchers.
How were multiple species issues addressed?	Not applicable.
What is the service area for the bank?	Orange County
Can we get the Conservation Banking Agreement?	The banking agreement is a large, multi-volume document that is not easy to copy or send.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Based on impacts to coastal sage scrub and California gnatcatchers from Transportation Corridor Agency projects.
Can different species be "traded off" for debits vs. credits?	Not applicable.
Credit transaction history	
If individual transaction data not available	
Who used credits?	Credits in bank are being reserved for roadway extension of foothills transportation corridor south.
Total number of transactions?	If the extension occurs, all credits will be used up.
Average size	Not applicable.
Average price or change in price over time	Not applicable.
History/status of bank	
Current status	Waiting to see if roadway extension occurs.
Who owns bank?	Transportation Corridor Agency
Has ownership changed – If so, why?	No.
Who can use the bank?	Designed for internal use; allowed to sell credits for third parties.
Establishment date	Jul-96.
Date first credit used	No credits used yet.

Chiquita Canyon

Information categories	Responses
Management and operation	
Who manages the habitat?	Overall management by Transportation Corridor Agency, with hands-on work done by consultants.
Who markets the credits?	No marketing, unless sales to third parties begin.
Who owns the land?	Transportation Corridor Agency purchased a conservation easement on land owned by the Rancho Mission Viejo company.
What types of management activities take place?	Invasive species management; testing for growth of coastal sage scrub and grassland; oak management; cactus wren surveys; gnatcatcher surveys; small mammal surveys; monitoring of wildlife undercrossings under roadway.
Did active management for restoration need to take place to gain credits?	Yes. Habitat had been heavily grazed by cattle, creating problems with invasive species. After the conservation easement was put in place, the land has required intensive management for invasive species to enhance coastal sage scrub.
What are long-term management arrangements?	Long-term plan is to transfer land to the Orange County Southern Natural Communities Conservation Program (a regional planning effort).
What is planned lifespan of bank?	No set life-span — the Transportation Corridor Agency will utilize the bank until all credits have been used up.
What types of monitoring take place to ensure bank "performance"?	Monitoring of vegetation and wildlife use of site documents habitat quality.
Performance monitoring	
How frequently does monitoring occur?	Monitoring occurs throughout the year and is reported annually.
Are there provisions for monitoring to trigger remedial actions?	Not specifically. The bank is managed according to a management plan agreed to in 1996. The agency is looking at revising the management plan to incorporate new findings and management techniques.
Can monitoring reports be obtained?	Not easy to send.
Subjective appraisals	
Impetus to start bank	The Transportation Corridor Agency knew that the southern extension of the foothills transportation corridor would occur eventually and would require mitigation. It was more cost-effective for the Agency to put the conservation easement in place in advance of building the project.
Issues at startup	Negotiations between landowner and resource agency.
Difficulty in marketing credits	Not applicable.
Issues with current regulations	None identified.

Chiquita Canyon

Information categories	Responses
Is bank a success?	Bank seen as a success because of preserving large area of open space in urban setting. It is still unknown whether all credits will be used internally, or whether some credits will be sold to third parties.
Do they know of any banks that were started and failed – If so, why?	The Agency is aware of banks that were established, but have not had much demand for credits because nearby habitat areas were preserved by the county.
Relevant permits	
Review notes	

Coles Levee Ecosystem Preserve

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	10/16/03
Bank name	Coles Levee Ecosystem Preserve
Location	
Address	The bank itself does not have a real address. For correspondence, the Quad Knopf office address is: 5500 Ming Avenue, Suite 410 Bakersfield, California 93309
City	Bakersfield
State	CA
County/location	Kern
Contact for information	
Name	Wes Rhodehamel
Phone	661 835 8300 (ext 105)
E-mail	wesr@quadknpf.com
Organization	Quad Knopf (engineering firm)
Title/role	Senior Ecologist — manager for implementing habitat management and monitoring programs.
Additional contact, if any	
Name	
Phone	
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/kern.shtml
URL#2	http://sacramento.fws.gov/es/bank_list.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	6,059 acres.
No. of acres of buffer areas, if any	Buffer acres are not explicitly a component of the bank. However this bank is located in a cluster of conservation/mitigation banks that includes Coles Levee, the Kern Water Bank, and banks established by Chevron and Occidental Petroleum.
No. of credits in bank	6,059 credits.
No. of credits used or sold to date	Approximately 5,500 to 5,800 credits of the initial 6,000 have been used or sold to date. Uncertainty in the exact number reflects differences in the accounting of credit sales and use by Quad Knopf, the firm that has been tracking the data since the bank was developed, and the current owner AERA.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened

Coles Levee Ecosystem Preserve

Information categories	Responses
Amphibians	
Birds	Swainson's hawk (C)
Fish	
Invertebrates	
Mammals	San Joaquin kit fox (FE), tipton kangaroo rat (FE), giant kangaroo rat (FE)
Plants	
Reptiles	Blunt-nosed leopard lizard (FE)
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits are based on acres of habitat and are assigned with 1 acre of habitat = 1 credit.
What was the method used for defining and measuring credits?	Credits were assigned on a simple 1:1 approach that evaluated the acreage being designated for the bank. Because this bank was one of the initial, and perhaps the first conservation bank established in the country, it is now recognized that a more sophisticated evaluation of the suitability of the habitat would be a preferred basis for establishing baseline credits if the bank were being established today (e.g., credits based on a combined assessment of species abundance and habitat suitability).
How were multiple species issues addressed?	Multiple species issues are not explicitly addressed as credits are not assigned or allocated to specific species. However, multi-species issues are addressed in practice with credits being mutually exclusive (i.e., once sold, a credit can not be reused to mitigate for impacts to a second species, even if the two can coexist in the same area). There are no rules or guidelines in place to alter the required scale of mitigation if a potential buyer needs to address impacts to several species.
What is the service area for the bank?	Kern, Kings, and Tulare counties.
Can we get the Conservation Banking Agreement?	We did not obtain the agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Not available.
If individual transaction data not available	

Coles Levee Ecosystem Preserve

Information categories	Responses
Who used credits?	A mix of private and public parties have used credits from the banks. Most credit transactions have occurred in large blocks to mitigate for public development impacts and impacts from private oil and gas development projects.
Total number of transactions?	Not available.
Average size	Not available.
Average price or change in price over time	Prices are negotiated between the bank owner and the buyer for each transaction. Prices have varied considerably over time as a function of changes in the level of supply and demand for the credits and as a function of discounts provided to buyers, especially for large blocks of credits. The credit price has roughly moved in the range of $650 to $1,000 but it is expected to rise again perhaps to $1,200 as the remaining credits are sold. The credit price includes three components: a fee, a management endowment, and a fencing endowment. The fee is collected and kept by the owner. The management and fencing endowments have been roughly $375 and $100 per credit over the bank's existence and these are accounted for separately in each transaction and provided to the state. The state is supposed to return the funds to the designated manager for the bank's upkeep and maintenance, but reimbursement has not occurred in the past several years. The owner has continued management activities as prescribed in the management plan.
History/status of bank	
Current status	Bank is currently operating and has available credits for sale. However, these credits may be held for internal mitigation needs by the current owner and may not be available to the public.
Who owns bank?	AERA Energy LLC
Has ownership changed – If so, why?	Bank ownership has changed over time with shifts in the current and anticipated future activities of firms involved with oil and gas exploration and development in the region of the bank and in California in general. Original owner/developer of the bank was ARCO (Atlantic Richfeld Company).
Who can use the bank?	All USFWS approved parties can use the bank.
Establishment date	The conservation easement for the bank was signed in October 1992 but the formal banking agreement was signed in March 1996.
Date first credit used	1996
Management and operation	
Who manages the habitat?	Quad Knopf has managed the habitat for the bank owners since the development of the bank.
Who markets the credits?	Active marketing of the credits has not generally been required given the local knowledge about the bank in the development community combined with the USFWS staff knowledge of the bank.
Who owns the land?	AERA LLC

Coles Levee Ecosystem Preserve

Information categories	Responses
What types of management activities take place?	Active management of the habitat, separate from monitoring, is not a feature of the bank as credits were essentially allocated assuming preservation of habitat at the time.
Did active management for restoration need to take place to gain credits?	No. Initial credit allocation was made assuming habitat preservation instead of restoration.
What are long-term management arrangements?	Currently the bank is structured so that it will be privately managed in perpetuity. California Department of Fish and Game (CDFG) could take control of the land if they determine that the owner is "nonperforming." In this case, however, management would still be undertaken by a subcontractor such as Quad Knopf because CDFG cannot hire staff specifically for management of a designated parcel.
What is planned lifespan of bank?	The conservation easement is established in perpetuity. The recent sale of the bank to AERA and apparent confusion over the number of available credits make it uncertain how much longer the bank will be looking to actively sell credits. After credit sales are closed to the public, there will likely be a number of credits remaining in the bank that will be reserved for internal mitigation requirements of the owners.
What types of monitoring take place to ensure bank "performance"?	Monitoring includes small mammal surveys, San Joaquin kit fox spot lighting for natal dens, and completion of survey transects for leopard lizards among other activities.
Performance monitoring	
How frequently does monitoring occur?	The monitoring described above is conducted yearly.
Are there provisions for monitoring to trigger remedial actions?	No.
Can monitoring reports be obtained?	We did not obtain monitoring reports.
Subjective appraisals	
Impetus to start bank	The bank was developed to resolve legal issues stemming from ARCO's failure to obtain a permit from USFWS for development of an oil well in an area where listed species were present. A compromise was reached that included development of the conservation bank to avoid further legal action against ARCO. The state and USFWS were very interested to implement a test case for conservation banking.

Coles Levee Ecosystem Preserve

Information categories	Responses
Issues at startup	None. This was a fast-tracked project where all the regulators were on board from the beginning. As an example of this it only took 8 months to receive the USFWS approval of the Incidental Take (Secton 10a) permit when submitted in 1996 even though this period coincided with the federal government shutdown. Similarly it took less than a year to receive approval for the corresponding state permit.
Difficulty in marketing credits	No. The bank was developed during a time of active oil and gas exploration and infrastructure development along with a period of significant regional public works projects (e.g., Bakersfield Metro project).
Issues with current regulations	None. Noted in discussion that a similar project developed today would likely have a more elaborate initial consideration of habitat suitability within the bank's acreage along with a more detailed initial assessment of species presence in order to establish initial credit allocation.
Is bank a success?	Yes. Ecologically, an extensive contiguous habitat for a number of listed species has been preserved in perpetuity. Economically, the development of the bank has allowed the owners to realize an income stream from land that would otherwise have probably remained idle as a result of the presence of the listed species and limited interest in further oil and gas development in the immediate area. Economic assessment is somewhat clouded in a straight accounting sense by the failure of the state to return management endowment funds to the owner's designated habitat managers but this has not limited sale of credits or scope of management/monitoring. Perhaps most importantly from the point of view of the bank's original owner/developer (ARCO), the bank was a success as it turned a potential legal and public relations nightmare (see impetus to start bank above) into a project for which the company was roundly applauded for their environmental commitment. In addition, continued out-of-pocket funding of management activities by the current owners generates good relations with the state and federal agencies.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	Incidental Take Permit Number PRT-809228.
Review notes	

East Plum Creek Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	November 5, 2003
Bank name	East Plum Creek Conservation Bank
Location	
Address	
City	
State	CO
County/location	Douglas
Contact for information	
Name	F. Yates Opperman
Phone	303 757-9497
E-mail	Francis.Oppermann@dot.state.co.us
Organization	Colorado Department of Transportation (CDOT)
Title/role	Environmental Planner
Additional contact, if any	
Name	Roland Wostl
Phone	303-757-9788
E-mail	Roland.Wostl@dot.state.co.us
Organization	Colorado Department of Transportation
Title/role	Manager, Environmental Planning and Policy Unit
URLs with information	
URL#1	http://www.epa.gov/fedrgstr/EPA-SPECIES/2002/December/Day-26/e32464.htm
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	25.3 acres.
No. of acres of buffer areas, if any	Working on expanding the size of the bank; hoping to double the size; working with Castle Rock and Douglas County.
No. of credits in bank	25.3 credits potentially available — not all credits have been certified yet.
No. of credits used or sold to date	Bank built around needs of specific projects.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	
Invertebrates	
Mammals	Preble's meadow jumping mouse (FT)
Plants	

East Plum Creek Conservation Bank

Information categories	Responses
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	1 credit = 1 acre.
What was the method used for defining and measuring credits?	Conservation credits for the bank were established for meeting success criteria in different areas. A total of 6.32 credits were certified at bank establishment to reflect the conservation easement and the initial habitat restoration activities that took place. Achieving success criteria for maintaining alluvial groundwater levels will release 12.65 credits. Achieving success criteria for habitat vegetation will release 3.80 credits. Achieving success criteria for the Preble's meadow jumping mouse based on presence and population density will release 2.53 credits. Preble's mouse was found above and below project location, but project location was subject to deep erosion and was not suitable habitat anymore. Restoration proposal was to erect nine check dams to raise the water levels to its original position. Vegetation reestablished on its own in response to the water manipulations. In addition, revegetation programs were undertaken. The mouse has moved into the project location.
How were multiple species issues addressed?	Not applicable.
What is the service area for the bank?	CDOT projects in Douglas County that will impact Preble's meadow jumping mouse.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See Colorado Department of Transportation et al., 2003.
Measurement methods for "debit areas"	
How is "debit area" assessed?	1 acre of permanent impact requires 1.5 credits for compensation. Temporary impacts require 1 encumbered credit for 1 acre of disturbance in the primary service area and 2 encumbered credits for 1 acre of disturbance in the secondary service area. When temporary impacts have been restored appropriately, the encumbered credits will be made available to the bank again.
Can different species be "traded off" for debits vs. credits?	Not applicable — bank is for one species only.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Internal use by CDOT.
Total number of transactions?	Not available.

East Plum Creek Conservation Bank

Information categories	Responses
Average size	Not available.
Average price or change in price over time	No price.
History/status of bank	
Current status	Active
Who owns bank?	Colorado Department of Transportation
Has ownership changed – If so, why?	No.
Who can use the bank?	Colorado Department of Transportation
Establishment date	17-Apr-03
Date first credit used	2003
Management and operation	
Who manages the habitat?	CDOT
Who markets the credits?	No marketing — internal use.
Who owns the land?	CDOT
What types of management activities take place?	Weed control, maintenance of check dams, protection of site from unauthorized uses.
Did active management for restoration need to take place to gain credits?	Yes — Preble's mouse was found above and below project location, but project location was subject to deep erosion and wasn't suitable habitat anymore. Proposal was to erect 9 check dams, to raise water levels and restore hydrology. Vegetation reestablished on its own and in addition, revegetation programs were undertaken. The mouse has moved into the project location.
What are long-term management arrangements?	CDOT agreed to manage land in perpetuity.
What is planned lifespan of bank?	Credits are anticipated to be available to mitigate for 8-20 years of road construction projects.
What types of monitoring take place to ensure bank "performance"?	Annual monitoring reports are required by the USFWS. To receive certification for all conservation credits, the bank must demonstrate that it has achieved very specific success criteria, including depth-to-water, foliar cover, shrub cover, and appropriate population densities of Preble's mice.
Performance monitoring	
How frequently does monitoring occur?	At least annually.
Are there provisions for monitoring to trigger remedial actions?	If monitoring determines that success criteria have not been reached, conservation credits will not be released.

East Plum Creek Conservation Bank

Information categories	Responses
Can monitoring reports be obtained?	Not available.
Subjective appraisals	
Impetus to start bank	Three bridge projects were proposed that would cross East Plum Creek. Establishment of bank was seen as cheaper than case-by-case mitigation, and also would provide an opportunity to create a larger habitat area.
Issues at startup	General criteria were agreed to orally, which allowed bridge construction to proceed. The formal agreement followed later.
Difficulty in marketing credits	Not applicable.
Issues with current regulations	Piecemeal mitigation does not make sense for CDOT. They prefer a banking approach instead of small case-by-case mitigation projects.
Is bank a success?	Yes — this has simplified CDOT's need for mitigation and successfully created habitat for the Preble's mouse.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	Incidental Take Application Permit E TE-017353.
Other notes	In addition to the conservation bank, CDOT undertakes on-site and off-site measures to mitigate impacts to the Preble's meadow jumping mouse, including working during the mouse's hibernation period.

Fitzgerald Ranch Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	Dave Mills
Interview date	10/1/03 with Marden Wilbur
Bank name	Fitzgerald Ranch Conservation Bank
Location	
Address	26115 East Highway 88
City	Clements,
State	CA (95227)
County/location	San Joaquin
Contact for information	
Name	Marden Wilbur
Phone	209 483 0030
E-mail	lnranch@inreach.com
Organization	Lane Family Partnership Trust #1
Title/role	ranch/conservation bank owner and operator
Additional contact, if any	
Name	Susan Hill
Phone	916 414 6494
E-mail	susan_hill@fws.gov
Organization	U.S. Fish and Wildlife Service
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/san_joaquin.shtml
URL#2	http://sacramento.fws.gov/es/bank_list.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	Approximately 37 acres.
No. of acres of buffer areas, if any	Existing ranch property is 803 acres, including the 37 acres in the conservation bank. The remainder of the ranch currently acts as buffer habitat, but these buffers are not protected by conservation easements and may not exist in perpetuity.
No. of credits in bank	62 credits were initially allocated to the bank for sale at the signing of the banking agreement with USFWS.
No. of credits used or sold to date	11 (as of 10/3/03)
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	California tiger salamander (FE), western spadefoot toad (not listed state or federal)
Birds	
Fish	
Invertebrates	Vernal pool fairy shrimp (FT)

Fitzgerald Ranch Conservation Bank

Information categories	Responses
Mammals	
Plants	Legenere (*Legenere limosa*) (not listed)
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Initial credit allocation was based on a combination of species abundance and existing acres of suitable habitat for the listed species. Each credit equals approximately 1.7 acres.
What was the method used for defining and measuring credits?	The bank was initially established with 62 available credits, based on species abundance and acres of suitable habitat. There is an opportunity for more credits to become available if monitoring shows an increase in species abundance within the initial 37 acres of habitat where the species were concentrated. However, a decline in species abundance below initial levels would not result in a reduction in the bank's credit allowance.
How were multiple species issues addressed?	Credits are nonoverlapping because all credits are based on a conversion from acres. For example, if a developer needs to offset 2 acres of California tiger salamander impacts, this would require 3.45 credits purchased at the bank. The credits used up by a purchase cannot be used again for a different species. Effectively, this creates credits that are non-overlapping by species and that are available for a single use only.
What is the service area for the bank?	Credits from the bank are approved for use in a multi-county area (e.g., Amador, El Dorado, Merced, San Joaquin, Stanislaus, Tuolomne) and can, with approval from USFWS, be applied on a case-by-case basis as an offset for impacts out of the originally defined service area.
Can we get the Conservation Banking Agreement?	We did not obtain the agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff. Credit purchase is currently scaled to debits on a per-acre basis after multiplying by an adjustment factor of 1.726. For example if USFWS tells a developer the habitat debit they need to offset for impacts to California tiger salamanders is 2 acres the number of credits that need to be purchased is actually 3.45 from 2 * 1.726.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Not available.
If individual transaction data not available	

Fitzgerald Ranch Conservation Bank

Information categories	Responses
Who used credits?	Credits are available to both public and private parties. Credit transactions that have been completed to date have been primarily with private developers but a significant transaction is in the process of being completed to provide CalTrans with mitigation credits.
Total number of transactions?	Not available.
Average size	Not available.
Average price or change in price over time	Average price of $65,000 per credit was provided.
History/status of bank	
Current status	Active
Who owns bank?	The bank is owned by the Lane Family Partnership Trust #1. The trust was established by the owners of the ranch property which includes the conservation bank.
Has ownership changed – If so, why?	No.
Who can use the bank?	Bank credits are available to any interested party (i.e., no public or private organization restrictions).
Establishment date	December 1999.
Date first credit used	First credits sold early in 2003.
Management and operation	
Who manages the habitat?	Current bank credits are based on the preservation of existing habitat so no direct management actions are being taken. Annual monitoring of the lands for species presence and abundance is subcontracted to a company named LSA Biological that corresponds directly with the USFWS staff overseeing the bank (Susan Hill).
Who markets the credits?	Credits are marketed by the bank owners and indirectly by USFWS if asked about availability of credits in the area.
Who owns the land?	The Lane Family Partnership Trust #1 owns the land for the bank.
What types of management activities take place?	No active management beyond monitoring currently being undertaken.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	Conservation easements are designed to preserve existing habitat. It is unclear if an endowment for long-term management or monitoring exists.
What is planned lifespan of bank?	Will operate until current available credits are completely sold.

Fitzgerald Ranch Conservation Bank

Information categories	Responses
What types of monitoring take place to ensure bank "performance"?	Annual monitoring, at least, to evaluate species abundance in the bank.
Performance monitoring	
How frequently does monitoring occur?	At least annually.
Are there provisions for monitoring to trigger remedial actions?	No specific triggers for remedial action were identified.
Can monitoring reports be obtained?	Monitoring reports were not obtained.
Subjective appraisals	
Impetus to start bank	Bank reflects the most viable option to realize full value of the property. Initial evaluation of land concluded that land had limited development potential beyond use as a conservation bank. Appeal of conservation banking lay in its ability to allow current ranching activities to continue without additional restriction while potentially providing an additional income stream.
Issues at startup	Frustration at interactions with USFWS in establishing the bank expressed by bank owner as "Think in 30 day increments act in 60 day increments."
Difficulty in marketing credits	Delay in sale of credits following bank establishment reflects complications in ability to market credits, given delays in finalizing agreements with USFWS.
Issues with current regulations	None expressed beyond continued frustration in dealing with regulators in general.
Is bank a success?	From an economic standpoint, the delay in sale of credits initially was frustrating and cast doubt on the viability of the bank as an investment mechanism. Recent sales of credits provide additional hope that full value will be realized. Ecologically, bank has preserved high quality habitat for threatened and endangered species so is a success in that regard.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	
Other notes	There is the potential for expansion of the bank to offer additional credits from additional habitat if restoration actions are taken. It has not yet been decided whether this opportunity will be pursued while there are still credits available in the current phase of the bank.

Hickory Pass Ranch Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	10/8/2003
Bank name	Hickory Pass Ranch Conservation Bank
Location	Mailing address: 1803 Brookhaven Drive, Austin, Texas 78704
Address	13001 RR 1174
City	Bertram
State	TX
County/location	Burnet/Travis
Contact for information	
Name	David Johnston
Phone	512 472 4542
E-mail	hickorypass@hotmail.com
Organization	Hickory Pass, L.P.
Title/role	General partner/manager of Hickory Pass Ranch Conservation Bank
Additional contact, if any	
Name	Sybil Vosler (contact for copies of the banking agreement and monitoring reports)
Phone	512 490 0057
E-mail	sybil_vosler@fws.gov
Organization	U.S. Fish and Wildlife Service — Region 2
Title/role	Ecological Services Staff
URLs with information	
URL#1	http://news.fws.gov/NewsReleases/R2/BC6C6868-4DDC-4892-BC6B96EDA824DB4A.html
URL#2	http://www.williamson-county.org/agenda/minutes/m050702.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	Ranch is 3,000 acres, all of which could eventually be incorporated into the bank through development of additional phases. Initial phase of the bank covers 500 acres and it appears that a second phase which would cover an additional 250 acres is highly likely in the near term.
No. of acres of buffer areas, if any	No buffer areas currently. Buffer areas are not required because of the quality of the habitat, the bank's location, and the habitat needs of the golden-cheeked warbler.
No. of credits in bank	500 in Phase I.
No. of credits used or sold to date	400 credits sold to date, a number of additional transactions are pending and likely to occur.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	Golden-cheeked warbler (FE)
Fish	
Invertebrates	

Hickory Pass Ranch Conservation Bank

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits are indirectly related to the organisms but are available on a per acre basis with 1 credit = 1 acre of bank habitat.
What was the method used for defining and measuring credits?	Credits are measured based on the available acres of "high quality" habitat available in the bank for the golden-cheeked warbler. Quality of the land was determined through initial biological surveys at the Ranch. In addition, there was an a priori assumption that the land was of high quality as the ranch is within the USFWS' defined habitat acquisition area for golden-cheeked warbler habitat.
How were multiple species issues addressed?	Not an issue in this bank as credits are available only for mitigation of impacts to golden-cheeked warblers and their habitat.
What is the service area for the bank?	Williamson, Burnet, Blanco, and northern Hays counties, TX. Additional impacts from other areas would presumably be addressed on a case by case basis as the bank provides a unique mitigation opportunity in the area.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See Hickory Pass, L.P. and U.S. Fish and Wildlife Service, 2002.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	
If individual transaction data not available	
Who used credits?	Credits available to all interested parties. Sales to date have been made to a mix of private developers and public agencies (e.g., Williamson County, the Texas Turnpike Authority).
Total number of transactions?	To date, 400 credits have been sold and several transactions are pending. Total number of transactions was not available.
Average size	One transaction for 109.2 acres for $546,000 was sold to Williamson County for road mitigation. Other transaction sizes not available.
Average price or change in price over time	Credits currently sell for $5,000 each.
History/status of bank	
Current status	Active.

Hickory Pass Ranch Conservation Bank

Information categories	Responses
Who owns bank?	Hickory Pass, L.P., a Texas limited partnership
Has ownership changed – If so, why?	No.
Who can use the bank?	Any party requiring mitigation credits within the service area or that has received permission from the USFWS.
Establishment date	May 2002.
Date first credit used	Summer 2002.
Management and operation	
Who manages the habitat?	David Johnston coordinates the actual habitat management but a Technical Advisory Committee has been established to provide input into the management protocols that includes representatives of Environmental Defense, the neighboring National Refuge, Texas A&M staff. Monitoring is overseen by Steve Paulson of the ACI-Group.
Who markets the credits?	David Johnston, general partner.
Who owns the land?	Hickory Pass, L.P.
What types of management activities take place?	Golden-cheeked warblers rely on "mature" habitats so most of the management is geared to a "do no harm" approach. This includes managing existing ranching activities along with other actions such as the capture and removal of invasive/nuisance bird species that prey upon golden-cheeked warblers.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	Owner required to preserve habitat and conservation values in perpetuity, including maintaining fencing to restrict trespassers, managing the deer population, controlling cowbirds, and minimizing fire risks.
What is planned lifespan of bank?	David Johnston will continually evaluate the market for mitigation credits to determine whether to develop additional phases of the bank, as acreage can only be added to the bank in a minimum of 200 acre installments. Ideally, the demand for credits would be sufficient enough to enroll all of the existing ranch acreage into banking agreements.
What types of monitoring take place to ensure bank "performance"?	Seasonal bird abundance monitoring during the March-August period with emphasis on April and May.
Performance monitoring	
How frequently does monitoring occur?	Annually at a minimum, check monitoring reports.

Hickory Pass Ranch Conservation Bank

Information categories	Responses
Are there provisions for monitoring to trigger remedial actions?	Not currently but an adaptive management approach is being used with respect to the habitat so the possibility exists that the TAC could recommend remedial actions based on monitoring results.
Can monitoring reports be obtained?	Did not obtain. Reports may be available from Sybil Vosler of the USFWS.
Subjective appraisals	
Impetus to start bank	David Johnston and his wife desired to keep the ranchlands free of development as the lands have been in Mrs. Johnston's family for some time. Conservation banking was seen as a way to realize an income stream from these lands that satisfied the goal of avoiding development while providing a greater return than would be available through a simple appraisal-based sale of the land to the USFWS.
Issues at startup	No significant issues. Some delay with the agreement taking roughly a year and a half to be realized but the bank was the first of its kind in the region and there was a need to process the monitoring results before reaching a final agreement. In all, Mr. Johnston has been extremely pleased by the support and assistance he has received from USFWS regarding the development and management of the bank.
Difficulty in marketing credits	No. Neighboring Williamson County is one of the fastest growing counties in the nation so the development has created a substantial need for mitigation credits.
Issues with current regulations	None.
Is bank a success?	Yes according to owner. Has achieved their desired land preservation and economic goals while increasing the protected acreage for a listed species within a defined habitat acquisition area for the species.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	
Other notes	This bank should be seen as an example of the classic convergence of interests that can make for a successful conservation and mitigation bank where existing landowners want to preserve their habitat in an area facing development pressure but also would like to or need to realize some sort of market return for that decision. Both of these needs can be realized by a conservation/mitigation bank and, in areas with significant development pressures, the economic returns may prove larger via the sale of mitigation credits than through more traditional means such as market appraisal-based sales to resource agencies.
Review notes	This version reviewed by David Johnston and sent to Stratus Consulting 10/23/03.

Kern Water Bank — Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	Oct. 10, 2003
Bank name	Kern Water Bank — Conservation Bank
Location	
Address	SW of Bakersfield; Taft Highway
City	Bakersfield
State	CA
County/location	Kern
Contact for information	
Name	Cheryl Harding
Phone	Phone: (661) 399-8735; Fax: (661) 399-9751
E-mail	charding@kwb.org
Organization	Kern Water Board Authority
Title/role	Administrator
Additional contact, if any	
Name	
Phone	
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/kern.shtml
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	3,267 acres.
No. of acres of buffer areas, if any	20,000 acres in the total parcel for groundwater recharge.
No. of credits in bank	3,267 credits.
No. of credits used or sold to date	598 credits.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened Incidental take permits covers: 17 listed species (see below); 28 rare but unlisted species; and 116 species which may become rare over the life of the permit.
Amphibians	
Birds	American peregrine falcon; Aleutian Canada goose (both birds have been delisted and are classified as recently recovered).
Fish	

Kern Water Bank — Conservation Bank

Information categories	Responses
Invertebrates	Valley elderberry longhorn beetle (FT); vernal pool fairy shrimp (FT); conservancy fairy shrimp (FE); vernal pool tadpole shrimp (FE); longhorn fairy shrimp (FE)
Mammals	San Joaquin kit fox, Tipton kangaroo rat, giant kangaroo rat (all FE)
Plants	San Joaquin wooly-threads (FE); Hoover's woolly-star (delisted, was FT); California jewel flower (FE); Kern mallow (FE); Bakersfield cactus (FE)
Reptiles	blunt-nosed leopard lizard (FE); giant garter snake (FT, C)
Habitat types	Upland habitats
Credit definition for bank	
Unit for credits (acres or organisms?)	1 acre = 1 credit.
What was the method used for defining and measuring credits?	HCP negotiated over a year of intensive negotiations. The value of the land, the value of the habitat, and how best to use the property all factored into credit assignment of 3,267 acres.
How were multiple species issues addressed?	All species included within habitat credits.
What is the service area for the bank?	http://sacramento.fws.gov/es/Banks/kern_water_bank_service.pdf
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See U.S. Fish & Wildlife Service et al., 1997
Measurement methods for "debit areas"	
How is "debit area" assessed?	
Can different species be "traded off" for debits vs. credits?	Impacts to all species mitigated with the same credits.
Credit transaction history	
If individual transaction data not available	See Table 3 in main body of report.
Who used credits?	Agencies, private parties, corporations.
Total number of transactions?	6-10 per year.
Average size	Most sales — 3-5 acres.
Average price or change in price over time	The price is $2,000 for each credit purchased. In addition, there is a $5,000 administrative fee per transaction (regardless of number of credits) that goes to the bank. The bank also collects $375 for the Department of Fish and Game per transaction.
History/status of bank	
Current status	Active
Who owns bank?	Kern Water Bank Authority

Kern Water Bank — Conservation Bank

Information categories	Responses
Has ownership changed – If so, why?	No.
Who can use the bank?	USFWS would prefer that credits be sold to small developers and private landowners; agency sales and large developer sales have also occurred.
Establishment date	October 1997.
Date first credit used	Early 1998.
Management and operation	
Who manages the habitat?	Kern Water Bank Authority
Who markets the credits?	Kern Water Bank Authority
Who owns the land?	Kern Water Bank Authority
What types of management activities take place?	Monitor exotic species and state highway rights-of-way that traverse property. Cattle grazing is used to control tumbleweed. There are security issues at the bank with poaching and unauthorized used of all-terrain vehicles. The bank maintains fencing and locked gates to deal with security issues.
Did active management for restoration need to take place to gain credits?	Habitat was in good condition when land was purchased. The land had been owned by a few owners and had been heavily used for mineral production but very little farming had occurred. There was little surface disturbance. The oil-field structures still exist at the bank, but are not in use.
What are long-term management arrangements?	Continued management by Kern Water Bank Authority.
What is planned lifespan of bank?	75 year permit.
What types of monitoring take place to ensure bank "performance"?	The bank prepares annual monitoring reports. Monitoring requirements specified in the conservation banking agreement have already been fulfilled. The bank has conducted spot-lighting surveys for kit foxes and surveys for blunt-nosed leopard lizards (none were found). Some live trapping occurs as well.
Performance monitoring	
How frequently does monitoring occur?	Annual monitoring reports include GIS tracking of wildlife sightings.
Are there provisions for monitoring to trigger remedial actions?	Adaptive management — expectation to adapt management if a species was disturbed; no specific remedial actions or triggers were specified in the conservation banking agreement.
Can monitoring reports be obtained?	Monitoring reports can be reviewed in the office. They are very large reports with expensive color copies.

Kern Water Bank — Conservation Bank

Information categories	Responses
Subjective appraisals	
Impetus to start bank	Kern Water Bank Authority gained control of the land from the California Department of Water Resources for groundwater banking and recovery, following the "Monterey Agreement" in 1994. They needed to get a habitat conservation plan (HCP) approved to do the groundwater banking, out of those negotiations came the development of the conservation bank.
Issues at startup	HCP intensely negotiated for 1 year.
Difficulty in marketing credits	No effort to market credits. Kern County was working on a master mitigation project (Valley Floor HCP) which would allow for fee-based mitigation, but this hasn't worked out yet. Currently, the Kern Water Bank credits are the only ones available, so there is a reasonably strong demand for credits especially by small developers, and a limited supply.
Issues with current regulations	The bank is aware that the USFWS offices have to respond to a shifting legislative environment and pressures, which affects how permits (like incidental take permits) are granted.
Is bank a success?	Successful for Kern Water Bank Authority, but it would not be successful if full economic cost of land was dependent on credit sales. The bank is successful for the agencies because the land is being conserved and managed in an appropriate fashion.
Do they know of any banks that were started and failed – If so, why?	(Didn't ask)
Relevant permits	Incidental Take Permit Number 828086.
Review notes	

Kimball Island Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills, Diana Lane
Interview date	26-Nov-03
Bank name	Kimball Island Conservation Bank
Location	
Address	Located near the confluence of the Sacramento and San Joaquin rivers, below lower Sherman island
City	
State	CA
County/location	Sacramento
Contact for information	
Name	Kellie Berry
Phone	916 331 8810
E-mail	kberry@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	
Additional contact, if any	
Name	Steve Morgan
Phone	916 331 8810
E-mail	smorgan@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	CEO/CFO of Wildlands, Inc.
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/sacramento.shtml
URL#2	http://sacramento.fws.gov/es/bank_list.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	109 acres.
No. of acres of buffer areas, if any	Not formally defined as buffer areas.
No. of credits in bank	Separate credits for each habitat type: 35,000 linear feet of shaded riverine aquatic habitat; 12 credits (acres) of riparian habitat; 75 credits (acres) of shallow-water marsh. Note that mitigation for endangered fish species is accomplished with shallow-water marsh habitat.
No. of credits used or sold to date	Shaded riverine aquatic habitat and riparian habitat credits have been sold out; 38 credits of shallow-water marsh habitat have been sold (37 credits are remaining).
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	

Kimball Island Conservation Bank

Information categories	Responses
Fish	Delta smelt (FT), Sacramento splittail (not federally listed), chinook salmon (FE, FT), steelhead (FE, FT).
Invertebrates	
Mammals	
Plants	
Reptiles	
Habitat types	Shaded riverine aquatic, riparian, shallow-water marsh
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits defined in terms of acres or linear feet of habitat.
What was the method used for defining and measuring credits?	Credits were based on habitat creation for three different habitat types (shaded riverine aquatic, riparian, shallow-water marsh). The project design and the credits were defined in advance in coordination with USFWS during the planning stage of the project. There is a chance that the final number of credits could vary if the "as-built" design varied slightly from the plans.
How were multiple species issues addressed?	All of the fish species need the same habitat for refuge (shallow-water marsh), so credits are defined on a habitat basis.
What is the service area for the bank?	Alameda, Contra Costa, San Joaquin, Solano, and Yolo counties — see map included in supplemental materials.
Can we get the Conservation Banking Agreement?	Wildlands prefers not to distribute their Conservation Banking Agreements to the public because they contain information that could be helpful to competitors. They acknowledge that the documents are available from USFWS (through a FOIA request, if necessary).
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments are made by USFWS. In general, parties need to mitigate at a 3:1 ratio for impacts to shallow-water marsh habitat (for example, a 1 acre disturbance requires purchase of 3 credits).
Can different species be "traded off" for debits vs. credits?	No. Debit assessments are made for each of the habitat types available at the bank — a debit for a particular habitat type requires mitigation for that same habitat type.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Public agencies and private individuals.
Total number of transactions?	63 transactions as of November 26, 2003.
Average size	The shaded riverine aquatic and riparian habitat credits were primarily used up by large government projects; most sales of the shallow-water marsh habitat have been less than 1 acre, with a minimum size of 0.02 acres.

Kimball Island Conservation Bank

Information categories	Responses
Average price or change in price over time	Shallow-water marsh habitat is currently $25,000 per credit; shaded riverine aquatic and riparian habitats have been sold out for a long time, so current price data is not available.
History/status of bank	
Current status	Active for shallow-water marsh; sold-out for shaded riverine aquatic and riparian habitat.
Who owns bank?	Wildlands Inc.
Has ownership changed – If so, why?	No.
Who can use the bank?	Public agencies and private individuals (anyone who needs credits and can pay the fee).
Establishment date	1998
Date first credit used	Fall 1998
Management and operation	
Who manages the habitat?	Wildlands Inc.
Who markets the credits?	Wildlands Inc.
Who owns the land?	Wildlands Inc.
What types of management activities take place?	On-going management is focused on preventing vandalism and unauthorized use of property. Illegal "squatting," marijuana cultivation, and construction of drug laboratories have all occurred in nearby locations. Wildlands, Inc. has a local caretaker who is on the property daily to prevent illegal uses. In addition, invasive water hyacinth is removed from the property. Wildlands expects the water hyacinth problem will require more aggressive management in the future as the plant becomes more pervasive in the region.
Did active management for restoration need to take place to gain credits?	All of the habitats on the island are the result of active restoration. Wildlands created channels of various sizes on an existing island, to restore the shallow-water marsh habitat needed by endangered fish species. Shaded riverine aquatic and riparian habitat also were created through construction of berms and revegetation with native species.
What are long-term management arrangements?	After the bank is closed, Wildlands will have the right to turn over management to an approved third party and to request funds from the state endowment fund for monitoring and maintenance. (Each credit that is purchased requires payment of a fee to the endowment fund). Currently, Wildlands retains management control over all the banks that it has developed.
What is planned lifespan of bank?	Agreements require maintaining habitat in perpetuity.

Kimball Island Conservation Bank

Information categories	Responses
What types of monitoring take place to ensure bank "performance"?	Fish monitoring and habitat monitoring.
Performance monitoring	
How frequently does monitoring occur?	Annually.
Are there provisions for monitoring to trigger remedial actions?	Adaptive management plans are included as part of the management agreement. There are no specific triggers for additional remedial work. The USFWS needed to approve the "as-built" plans, however, before credits could be sold.
Can monitoring reports be obtained?	Wildlands prefers not to make the reports public.
Subjective appraisals	
Impetus to start bank	In 1996, the Army Corps of Engineers (ACOE) and the USFWS were looking for another mitigation bank to mitigate different kinds of habitat impacts that were occurring, including levee work, work done by reclamation districts, and impacts from boat-dock construction. The agencies approached Wildlands to see if they were interested in establishing a bank in this area.
Issues at startup	The bank is governed by an ACOE nationwide Section 27 permit for stream and wetland restoration activities (see U.S. ACOE, 2002 in supplemental materials for a description of Section 27 permits). Wildlands had to make sure that the project complied with permit conditions. In addition, there are always different kinds of issues at start-up: land purchase, permitting, design, construction, etc.
Difficulty in marketing credits	No. Wildlands has sold all the credits for two of the habitat types and half the credits for the remaining habitat type within 5 years.
Issues with current regulations	Wildlands is careful to make sure of agency support in advance of creating a bank, and has good relations with relevant agencies. If a regional habitat conservation plan (that provides for fee-based mitigation) is close to adoption for an area, Wildlands would likely choose not to develop a bank because of the risk that the market for credits would disappear.
Is bank a success?	Wildlands considers all of their banks to be successful.
Do they know of any banks that were started and failed – If so, why?	They know of banks that other individuals or companies have tried to establish, but have been unable to find clients.
Relevant permits	

Kimball Island Conservation Bank

Information categories	Responses
Other notes	According to Ellison and Daily (2003), Wildlands invested $2,000,000 to make a small island (formerly covered with fallow hay fields) into habitat hospitable to endangered delta smelt and steelhead trout. The firm dug 5 miles of meandering channels and planted native sycamores and willows. The firm has earned more than $9,000,000 selling credits in the bank. (copy of article is included with supplemental materials).

Mobile County Gopher Tortoise Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Chapman
Interview date	10/10/2003 (site visit with Bruce Porter, USFWS)
Bank name	Mobile County Gopher Tortoise Conservation Bank
Location	
Address	No exact address for bank
City	
State	AL
County/location	Mobile
Contact for information	
Name	Bruce Porter
Phone	251 441 5864
E-mail	bruce_porter@fws.gov
Organization	USFWS, Daphne, AL field office
Title/role	Fish & Wildlife Biologist
Additional contact, if any	
Name	Sally Berry
Phone	(251) 694-3158
E-mail	
Organization	Mobile Area Water and Sewer Board
Title/role	
URLs with information	
URL#1	http://southeast.fws.gov/news/2001/r01-039.html
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	222 acres (205 acres are suitable habitat); 1,200 additional acres are expected to be added to the bank in 2006.
No. of acres of buffer areas, if any	6,000 acres (not formally in bank).
No. of credits in bank	128 total credits: 125 credits are available to public, 3 credits are reserved for potential take of 3 tortoises resulting from mitigation activities on-site.
No. of credits used or sold to date	61 credits, as of November 2003.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	
Invertebrates	
Mammals	
Plants	

Mobile County Gopher Tortoise Conservation Bank

Information categories	Responses
Reptiles	Gopher tortoise (FT).
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Organism (credits defined per tortoise).
What was the method used for defining and measuring credits?	Exact area required for each tortoise credit was based on a study that determined the size of necessary habitat and the home range of tortoises. Area needed is about 1.2 acres for each individual tortoise. Banking agreement used an 80% capacity to allow for some natural increase in population to get to 1.5 acres/individual. In addition, the baseline tortoise population at the site was estimated to be 15 individuals.
How were multiple species issues addressed?	Not formally addressed, however habitat is good also for woodpeckers and if a pair were available for transplant, it is likely that they would put them on the property.
What is the service area for the bank?	Mobile County, AL — but only available to people hooking up septic tanks within the Mobile Area Water and Sewer System service area.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See Board of Water and Sewer commissioners of the City of Mobile, no date.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit is determined on the basis of individual tortoises impacted by septic tank installation. If tortoise burrows are found during a septic tank installation permit request, then mitigation is required. If an actual tortoise is found, it can be relocated to the bank. USFWS does the actual identification and relocation of tortoises.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	See Table 4 in main body of report.
If individual transaction data not available	
Who used credits?	Individuals or developers that need to install septic tanks on property.
Total number of transactions?	18 transactions.
Average size	3-4 tortoises
Average price or change in price over time	$3,500 per individual.
History/status of bank	
Current status	Active.
Who owns bank?	Board of Water and Sewer Commissioners of Mobile, AL.
Has ownership changed – If so, why?	No.

Mobile County Gopher Tortoise Conservation Bank

Information categories	Responses
Who can use the bank?	Individuals in Mobile Area Water and Sewer Service Area who need to install a septic system.
Establishment date	June 2001.
Date first credit used	2001.
Management and operation	
Who manages the habitat?	Habitat is managed by Southeastern Natural Resources, Inc.
Who markets the credits?	Mobile Area Water and Sewer System
Who owns the land?	Mobile Area Water and Sewer System
What types of management activities take place?	Underbrush clearing, timber harvesting, controlled burns, control of exotic species (e.g., cogongrass) to maintain open-canopy longleaf pine forest.
Did active management for restoration need to take place to gain credits?	Before establishing the bank, management was needed to "restore more open, longleaf-pine canopy conditions, reduce hardwood encroachment, reduce invasive exotic species, and restore more natural fire regimes." (Board of Water and Sewer Commissioners of the city of Mobile, no date).
What are long-term management arrangements?	Mobile Area Water and Sewer System contracts with Southeastern Natural Resources, Inc. for all management actions and intends to continue this relationship.
What is planned lifespan of bank?	100 years.
What types of monitoring take place to ensure bank "performance"?	Testing of all tortoises for upper respiratory disease before they are placed in bank, radio-telemetry location tracking for first 25 tortoises placed in bank and for the resident tortoises, burrow surveys with GIS location information every two years, annual habitat management assessment.
Performance monitoring	
How frequently does monitoring occur?	Annual measurements of vegetation characteristics, survey of active and inactive tortoise burrows every two years; intensive radio-telemetry of resident and translocated tortoises during first two years.
Are there provisions for monitoring to trigger remedial actions?	Scientific Advisory Panel of 4-6 scientists was established to oversee implementation of monitoring program. If fewer than 60% of translocations are successful, the Panel will make binding recommendations to improve translocation success. If the success rate is "especially low," the Panel and the Service would consider closing the bank to additional landowners. The Panel also will make recommendations for improvement if recruitment is low or exotic species control is not successful.
Can monitoring reports be obtained?	We did not obtain monitoring reports. Bruce Porter at USFWS may be able to provide them.
Subjective appraisals	

Mobile County Gopher Tortoise Conservation Bank

Information categories	Responses
Impetus to start bank	USFWS approached MAWSS to use land as relocation site for affected tortoises.
Issues at startup	None identified.
Difficulty in marketing credits	No. This bank is the only available gopher tortoise bank and is the easiest method for landowners to obtain an incidental take permit for development of property with active tortoise burrows. There are plans to expand the bank by 1,200 acres adjacent to the current bank.
Issues with current regulations	None identified.
Is bank a success?	Yes. Bank provides active management for tortoise habitat. Tortoises on small tracts of private property are threatened by fragmentation and habitat degradation. The bank and USFWS can issue a "certificate of inclusion" to private landowners to be included within the scope of the Section 10(a) Incidental Take Permit issued to the Board of Water and Sewer Commissioners of the City of Mobile, following tortoise relocation and payment of the required fee. This greatly simplifies the process of receiving an incidental take permit for landowners.
Do they know of any banks that were started and failed – If so, why?	No. The Alabama Department of Transportation is working to set up a 600 acre tortoise bank for internal use for road mitigation.
Relevant permits	Incidental Take Permit Number TEO35340-0.
Other notes	Bruce Porter of USFWS has noted two items that he would do differently if they were starting the bank again. First, they publicized the exact location of the bank, which has led to people "dumping" unauthorized tortoises at the bank, with the potential for spreading upper respiratory disease. Second, they accepted credits and translocated tortoises before the habitat restoration was finished, which limited the types of restoration and management actions they could undertake.

Pleasanton Ridge Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	10/16/03
Bank name	Pleasanton Ridge Conservation Bank
Location	
Address	n/a
City	Pleasanton
State	CA
County/location	Alameda
Contact for information	
Name	Nancy Wenninger
Phone	510 544 2607
E-mail	nwenninger@ebparks.org
Organization	East Bay Regional Parks District
Title/role	Land Acquisition Manager
Additional contact, if any	
Name	Kevin Peters
Phone	925 245 3600
E-mail	
Organization	Shea Homes
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/alameda.shtml
URL#2	http://sacramento.fws.gov/es/bank_list.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	654.1 acres
No. of acres of buffer areas, if any	Bank is surrounded on three sides by an existing East Bay Regional Park.
No. of credits in bank	Banking agreement established 771.165 credits for California red-legged frog, 9.060 credits for Alameda whipsnake, and between 112.130 and 167.859 “dual species” credits (see section below on credit definition). An additional 130.845 red-legged frog credits are possible if restoration work expands the amount and quality of red-legged frog habitat. Additional credits (undetermined number) may also be available for Alameda whipsnake following restoration work.
No. of credits used or sold to date	To date, 16 whipsnake and 26 red-legged frog credits have been used.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	California red-legged frog (FT)
Birds	

Pleasanton Ridge Conservation Bank

Information categories	Responses
Fish	
Invertebrates	
Mammals	
Plants	
Reptiles	Alameda whipsnake (FT)
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Conservation credits are not based on a defined unit. 1 credit does not equal 1 acre or 1 organism — instead the number of credits were defined based on a combination of species abundance, habitat size, and habitat quality.
What was the method used for defining and measuring credits?	Initial credit allocation was made based on a complex formula that accounted for both species abundance and the quality of the habitat for the species in the bank area. For red-legged frogs, the credits were based on a multiplier of 1.497 (1 acre = 1.497 credits). The formula was developed by Wildlands Inc and is described in the Conservation Banking Agreement (California Department of Fish and Game et al., 1999) provided with supplemental materials.
How were multiple species issues addressed?	The bank credits for the red-legged frog and Alameda whipsnake are separate and non-transferable. However, the bank's initial credit allocation includes a number of "dual species" credits that can be used to mitigate for either species. The exact number of available dual species credits depends on whether they were assigned to Alameda whipsnake or red-legged frog.
What is the service area for the bank?	Alameda, Contra Costa, and Santa Clara counties.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See California Department of Fish and Game et al., 1999.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	It was not immediately clear who has used the credits because the East Bay Regional Park District is still working its way through the documentation accompanying their recent acquisition of the bank from Shea Homes. It is likely that both public and private parties have purchased credits.
Total number of transactions?	Not known.

Pleasanton Ridge Conservation Bank

Information categories	Responses
Average size	Not known.
Average price or change in price over time	Indirect information on prices suggests credits may have sold in the neighborhood of $4,000 each, regardless of species. Shea Homes had retained an option to purchase up to 100 credits at $2,000 per credit, which is believed to be about half the market value.
History/status of bank	
Current status	The East Bay Regional Park District is currently evaluating the bank's status with respect to whether they will sell or retire the remaining credits.
Who owns bank?	The East Bay Regional Park District.
Has ownership changed – If so, why?	The East Bay Regional Park District is the third owner of the bank following its creation in 1999 by the American Land Conservancy. The bank was purchased by Shea Homes from the American Land Conservancy in order to mitigate expected impacts from a nearby Shea Homes development. When the development failed to proceed, Shea Homes looked to sell the bank because the property lacked development potential following the enactment of the conservation easement and Shea Homes lacked both the desire and expertise to manage the property or sell the credits. The sale was executed as a bargain sale to maximize the economic benefit to Shea through the combined sale revenue and tax discounts while minimizing the Park District's expense for the property.
Who can use the bank?	If credits are made available it is anticipated that they would be available to any interested and USFWS-approved party (e.g., public and private entities).
Establishment date	1999
Date first credit used	1999
Management and operation	
Who manages the habitat?	Management responsibilities for the habitat currently reside with and are being undertaken by the East Bay Regional Park District. Originally, Wildlands, Inc. was contracted as the bank manager by the American Land Conservancy.
Who markets the credits?	Credits are not currently for sale while the East Bay Regional Park District evaluates the merits of alternative plans of action with respect to their ownership of the credits and the land.
Who owns the land?	The East Bay Regional Park District
What types of management activities take place?	Current management activities on the bank include implementing predator control practices and managing the location and duration of grazing activities.
Did active management for restoration need to take place to gain credits?	Active management and/or restoration was not needed to gain initial credits but additional credits are available if specific restoration actions are undertaken.

Pleasanton Ridge Conservation Bank

Information categories	Responses
What are long-term management arrangements?	Currently the bank is being managed by the East Bay Regional Park District and a land use plan is being developed now that the District owns an effective contiguous habitat unit.
What is planned lifespan of bank?	This is also an issue currently being addressed by the East Bay Regional Park District as part of their overall evaluation of the bank's future direction. However, the conservation easement on the property associated with the bank is in perpetuity.
What types of monitoring take place to ensure bank "performance"?	There is currently species-specific monitoring for the species providing credits as well as monitoring designed to identify the status of predator species.
Performance monitoring	
How frequently does monitoring occur?	Currently there is twice yearly monitoring for the abundance of bullfrogs (which compete with California red-legged frogs) and periodic predator monitoring.
Are there provisions for monitoring to trigger remedial actions?	The banking agreement contains provisions outlining situations that would require remedial action (e.g., in response to overgrazing).
Can monitoring reports be obtained?	Not available.
Subjective appraisals	
Impetus to start bank	Bank was initially developed by the American Land Conservancy to protect important habitat for red-legged frogs and Alameda whipsnake. The subsequent owner, Shea Homes, was motivated to purchase the bank so that it would be adequately prepared to mitigate against expected species impacts in a proposed development project. The failure to initiate the development project motivated the bank's sale to the East Bay Regional Park District which desired the parcel because it was surrounded on three sides by other park property.
Issues at startup	None that the East Bay Park District is aware of.
Difficulty in marketing credits	It is not known how difficult it would be to sell the credits if that option is pursued although the park district has already been contacted by a third party that is potentially interested in buying the bank as an investment opportunity.
Issues with current regulations	None to date.

Pleasanton Ridge Conservation Bank

Information categories	Responses
Is bank a success?	This bank is relatively unusual compared to others in this project as a result of the rapid succession of owners in the four years since the bank was initiated. The varying motivations for the establishment of the bank and the subsequent purchases also complicate evaluating its success. Ecologically, the preservation of the habitat with the conservation easement represents one indication of the bank's success. The limited number of management actions that have been taken (e.g., expanding the extent of cattle exclusion fencing from streambanks) also have likely improved the habitat or prevented declines in its quality both of which can be viewed as ecological successes. Evaluating the economic success of the bank is complicated because of the relatively little effort its current and past owners have devoted to fostering the market for the credits.
Do they know of any banks that were started and failed — If so, why?	No.
Relevant permits	
Review notes	The information in this worksheet is consistent with information sent for review to Nancy Wenninger and the edits that were received from her in a 11/5/03 email.

Pope Ranch Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills, Diana Lane
Interview date	26-Nov-03
Bank name	Pope Ranch Conservation Bank
Location	
Address	Located West of Clarksburg, and South of I-80
City	
State	CA
County/location	Solano
Contact for information	
Name	Kellie Berry
Phone	916 331 8810
E-mail	kberry@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	
Additional contact, if any	
Name	Steve Morgan
Phone	916 331 8810
E-mail	smorgan@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	CEO/CFO of Wildlands, Inc.
URLs with information	
URL#1	http://sacramento.fws.gov/es/bank_list.htm
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	391 acres
No. of acres of buffer areas, if any	81 acres not suitable for habitat
No. of credits in bank	310 credits
No. of credits used or sold to date	155 credits sold
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	
Invertebrates	
Mammals	
Plants	
Reptiles	Giant garter snake (FT)

Pope Ranch Conservation Bank

Information categories	Responses
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	1 credit = 1 acre of suitable habitat.
What was the method used for defining and measuring credits?	Appropriate habitat was created for the giant garter snake on the land purchased for the bank. The project includes 1/3 aquatic habitat and 2/3 upland habitat, because the snake requires both habitat types in close proximity.
How were multiple species issues addressed?	No multiple species issues.
What is the service area for the bank?	Includes parts of Solano, Yolo, and Sacramento Counties — see service area map.
Can we get the Conservation Banking Agreement?	Wildlands prefers not to distribute their Conservation Banking Agreements to the public because they contain information that could be helpful to competitors. They acknowledge that the documents are available from USFWS (through a FOIA request, if necessary).
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments are made by USFWS. In general, parties need to mitigate at a 2:1 to 3:1 ratio for impacts to giant garter snake habitat.
Can different species be "traded off" for debits vs. credits?	Not applicable because bank only applies to giant garter snake.
Credit transaction history	
If individual transaction data not available	
Who used credits?	Public agencies and private individuals; work on levees can impact giant garter snake habitat.
Total number of transactions?	10
Average size	Transaction size has ranged from 0.05 — 50 credits.
Average price or change in price over time	$25,000 per acre
History/status of bank	
Current status	Active.
Who owns bank?	Wildlands, Inc.
Has ownership changed – If so, why?	No.
Who can use the bank?	Public agencies and private individuals (anyone who needs credits and can pay the fee).
Establishment date	2001
Date first credit used	2001

Pope Ranch Conservation Bank

Information categories	Responses
Management and operation	
Who manages the habitat?	Wildlands, Inc.
Who markets the credits?	Wildlands, Inc.
Who owns the land?	Wildlands, Inc.
What types of management activities take place?	Some water management in the late fall to bring water to aquatic habitat areas.
Did active management for restoration need to take place to gain credits?	Restoration work was required to create upland habitat areas (mounds).
What are long-term management arrangements?	After the bank is closed, Wildlands will have the right to turn over management to an approved third party and to request funds from the state endowment fund for monitoring and maintenance. (Each credit that is purchased requires payment of a fee to the endowment fund). Currently, Wildlands retains management control over all the banks that it has developed.
What is planned lifespan of bank?	Agreements require maintaining habitat in perpetuity.
What types of monitoring take place to ensure bank "performance"?	Vegetation monitoring and species-specific surveys; the giant garter snake has not yet been sighted at the bank.
Performance monitoring	
How frequently does monitoring occur?	Annually.
Are there provisions for monitoring to trigger remedial actions?	Adaptive management plans are included as part of the management agreement. There are no specific triggers for additional remedial work.
Can monitoring reports be obtained?	Wildlands prefers not to make the reports public.
Subjective appraisals	
Impetus to start bank	The USFWS approached Wildlands to develop a giant garter snake bank because of the need for mitigation for giant garter snake habitat and the lack of opportunities for mitigation.
Issues at startup	Initially, the local agricultural community was concerned about the development of a conservation bank in the area because of a desire to avoid endangered species issues.
Difficulty in marketing credits	No. This is the only giant garter snake bank in the area.

Pope Ranch Conservation Bank

Information categories	Responses
Issues with current regulations	Wildlands is careful to make sure of agency support in advance of creating a bank, and has good relations with relevant agencies. If a regional habitat conservation plan (that provides for fee-based mitigation) is close to adoption for an area, Wildlands would likely choose not to develop a bank because of the risk that the market for credits would disappear.
Is bank a success?	Wildlands considers all of their banks to be successful.
Do they know of any banks that were started and failed — If so, why?	They know of banks that other individuals or companies have tried to establish, but have been unable to find clients.
Relevant permits	
Review notes	

Red-Cockaded Woodpecker Conservation Bank — Univ. of South Carolina Development Foundation

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills and Diana Lane
Interview date	10/20/03 for interview with Ralph Costa; 11/13/03 for interview with Lamar Comalander
Bank name	Red-Cockaded Woodpecker Conservation Bank — Univ. of South Carolina Development Foundation
Location	
Address	Located 7 miles northeast of Georgetown, South Carolina
City	
State	South Carolina
County/location	Georgetown
Contact for information	
Name	C. Lamar Comalander
Phone	803 788-0590 (office); 803-920-8775 (cell phone)
E-mail	comalander@millikenforestry.com
Organization	Milliken Forestry
Title/role	Vice President
Additional contact, if any	
Name	Ralph Costa
Phone	864 656 2432
E-mail	ralph_costa@fws.gov
Organization	USFWS
Title/role	Recovery coordinator, red-cockaded woodpecker
URLs with information	
URL#1	http://www.environmentaldefense.org/article.cfm?contentid = 2664
URL#2	http://www.millikenforestry.com/services_environmentalservices.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	Approximately 1200 acres preserved.
No. of acres of buffer areas, if any	No formal buffer areas.
No. of credits in bank	1 breeding cluster of red-cockaded woodpeckers above baseline.
No. of credits used or sold to date	1 breeding cluster of red-cockaded woodpeckers.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	Red-cockaded woodpecker (FE)
Fish	
Invertebrates	

Red-Cockaded Woodpecker Conservation Bank — Univ. of South Carolina Development Foundation

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Group of red-cockaded woodpecker ("recruitment cluster") in combination with habitat.
What was the method used for defining and measuring credits?	Need to have one pair of birds stay on their territory for at least one breeding season (minimum 6 months) to receive one credit. To qualify as a bank, the area must support a minimum of 10 groups of woodpeckers with a minimum of 1500 — 2000 acres. Each group needs at least 100 acres. The minimum size of 10 groups was based on demographic models that showed a high probability of woodpecker persistence for 20 years, with a minimum size of 10 groups.
How were multiple species issues addressed?	Not applicable — bank focuses only on red-cockaded woodpecker.
What is the service area for the bank?	For each red-cockaded woodpecker bank authorized by the USFWS, the service area is defined as the recovery unit. There are a total of 12 recovery units, based on ecoregion definitions.
Can we get the Conservation Banking Agreement?	Red-cockaded woodpecker recovery plan available at http://rcwrecovery.fws.gov/finalrecoveryplan.pdf. Excerpt included in supplemental materials, see U.S. Fish and Wildlife Service, 2003.
Measurement methods for "debit areas"	
How is "debit area" assessed?	The USFWS has a 1:1 mitigation policy — an applicant needs to replace a lost group of birds with a new group of birds ("mitigation"). In addition, the birds on impacted habitat are relocated to a new area ("minimization").
Can different species be "traded off" for debits vs. credits?	Not applicable.
Credit transaction history	Only 1 credit sold.
If individual transaction data not available	
Who used credits?	1 credit sold to Litchfield Development Corporation for mitigation of a cluster impacted by a golf course development.
Total number of transactions?	1
Average size	Not applicable.
Average price or change in price over time	$100,000

Red-Cockaded Woodpecker Conservation Bank — Univ. of South Carolina Development Foundation

Information categories	Responses
History/status of bank	
Current status	No additional clusters available for this tract; 6 clusters are available at the Friendfield Plantation and 10 clusters are available at Brosnan Forest (owned by Norfolk Southern Railroad). These properties are all managed by Milliken Forestry. These credits are priced at $250,000 each and none have been sold.
Who owns bank?	University of South Carolina Development Foundation
Has ownership changed — If so, why?	No.
Who can use the bank?	Any private party.
Establishment date	N/A
Date first credit used	Mitigation completed in 2001
Management and operation	
Who manages the habitat?	Milliken Forestry
Who markets the credits?	Milliken Forestry
Who owns the land?	University of South Carolina Development Foundation
What types of management activities take place?	Forest has an approved habitat management plan which includes prescribed burning and cavity management, including removing flying squirrels from cavities.
Did active management for restoration need to take place to gain credits?	Yes — a new breeding cluster had to be established.
What are long-term management arrangements?	Requires long-term protection of birds and habitat management.
What is planned lifespan of bank?	Indefinite.
What types of monitoring take place to ensure bank "performance"?	Population monitoring and habitat management required.
Performance monitoring	
How frequently does monitoring occur?	Not available.
Are there provisions for monitoring to trigger remedial actions?	Monitoring must document success of breeding cluster before credit is approved.

Red-Cockaded Woodpecker Conservation Bank — Univ. of South Carolina Development Foundation

Information categories	Responses
Can monitoring reports be obtained?	Did not address.
Subjective appraisals	
Impetus to start bank	Mitigation banks for red-cockaded woodpeckers are included as part of the recovery plan (USFWS, 2003); requirements for banks are consistent across all properties (individual banking agreements are not issued for each property).
Issues at startup	Did not address
Difficulty in marketing credits	Because of high cost of credits, marketing of additional available credits has been difficult. One potential transaction fell through when an automobile manufacturer chose not to build a new plant in South Carolina. Generally, credits are only sold for large development projects that can afford the mitigation costs.
Issues with current regulations	Did not address.
Is bank a success?	Mitigation banking is a successful method for increasing number of red-cockaded woodpecker breeding cluster. Limited demand for credits makes economic success more difficult.
Do they know of any banks that were started and failed — If so, why?	Did not address.
Relevant permits	
Review notes	

Sedco Hills Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	n/a — template filled out electronically by Leslie Beck of The Environmental Trust
Interview date	Completed template e-mailed to Stratus Consulting (Dave Mills) on 12/2/03.
Bank name	Sedco Hills Conservation Bank
Location	
Address	
City	
State	CA
County/location	Riverside
Contact for information	
Name	Leslie Beck
Phone	619 461 8333
E-mail	lbeck@tet.org
Organization	The Environmental Trust
Title/role	Real Property Coordinator
Additional contact, if any	
Name	California Department of Fish and Game, Bill Tippets
Phone	U.S. Fish and Wildlife Service, Janet Struckrath (619) 431-9440
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.sdcounty.ca.gov/dplu/Resource/5~mitbanks/5~mitbnks-index.html
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	180 acres
No. of acres of buffer areas, if any	No buffer areas are specifically incorporated in the bank.
No. of credits in bank	180 credits (1 acre = 1 credit) for a combination of Riversidian sage scrub (148 acres/credits) and Chamise chaparral (31.85 acres/credits), credits are also available for 8 pairs of California gnatcatchers.
No. of credits used or sold to date	148 credits of Riversidian Sage Scrub used; 1.2 credits of Chamise chaparral used; 6 pairs of gnatcatcher credits used.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	California gnatcatcher (FT)
Fish	
Invertebrates	

Sedco Hills Conservation Bank

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	Riversidian coastal sage scrub, Chamise chaparral
Credit definition for bank	
Unit for credits (acres or organisms?)	Acres only for the Riversidian sage scrub or Chamise chaparral, credits for a pair of Gnatcatchers also require supporting acreage (20 acres support 1 pair).
What was the method used for defining and measuring credits?	USFWS defined credits based on habitat acreage. Biological surveys conducted over a couple of years were used by USFWS to determine that six pairs of California gnatcatchers were supported on the site.
How were multiple species issues addressed?	All species on site noted and periodic brief biological surveys are conducted. Credits are tracked separately for Riversidian sage scrub and Chamise chaparral.
What is the service area for the bank?	Western Riverside county
Can we get the Conservation Banking Agreement?	This Conservation Bank Agreement is in its 4th draft and has never been signed by USFWS representatives.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments for impacts to sage scrub, chaparral, or California gnatcatchers are made by the USFWS.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	See Table 5 in main body of report.
If individual transaction data not available	
Who used credits?	Developers with projects in southwestern Riverside County.
Total number of transactions?	Eight.
Average size	21 acres of Riversidian sage scrub.
Average price or change in price over time	Habitat only (no California Gnatcatcher) avg. $3,950/credit. Credit w/ California Gnatcatcher avg. $5,300/credit.
History/status of bank	
Current status	Active.
Who owns bank?	The Environmental Trust, Inc.
Has ownership changed – If so, why?	No.
Who can use the bank?	Anyone approved by USFWS.
Establishment date	The Environmental Trust gained title in Sept. 1999. As noted above, conservation banking agreement never signed by USFWS.

Sedco Hills Conservation Bank

Information categories	Responses
Date first credit used	First sale June 2000.
Management and operation	
Who manages the habitat?	The Environmental Trust, Inc.
Who markets the credits?	Environmental Land Solutions
Who owns the land?	The Environmental Trust, Inc.
What types of management activities take place?	Management Plan stipulates regular site visits for mapping, signage, access control; perpetual biological corridor maintenance; annual biological monitoring; and adaptive management strategies dependent on conservation and regulatory agency requirements.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	The Environmental Trust is owner and manager in perpetuity.
What is planned lifespan of bank?	Perpetuity.
What types of monitoring take place to ensure bank "performance"?	The Environmental Trust monitors the biological resources and conducts yearly surveys. USFWS may do independent monitoring.
Performance monitoring	
How frequently does monitoring occur?	Four to six times a year.
Are there provisions for monitoring to trigger remedial actions?	Conservation banking agreement and management plan commit The Environmental Trust to monitoring. If changes in habitat or species status occur, The Environmental Trust will obtain advice from USFWS.
Can monitoring reports be obtained?	Not available.
Subjective appraisals	
Impetus to start bank	The Environmental Trust is a nonprofit agency in Riverside County. It was motivated to start the bank to help conserve habitat and protect the California gnatcatcher.
Issues at startup	Protection by use of easements and covenants led to three separate "covenants of conditions and restrictions" to be recorded, two with USFWS, one with Riverside County.

Sedco Hills Conservation Bank

Information categories	Responses
Difficulty in marketing credits	Riverside County, unlike San Diego County, did not have an implemented multiple species habitat conservation plan (MSHCP) until 2003. There are still considerable uncertainties remaining about the implementation of the MSHCP and the role of conservation banks. The USFWS and the County have not always agreed on the implementation and future of mitigation banks.
Issues with current regulations	The Environmental Trust is not aware of current active issues. This is their only bank in Riverside County.
Is bank a success?	In the sense that The Environmental Trust has sold the majority of the resources it is a success. The Tier III habitat remaining will not be selling in the near future which means The Environmental Trust will not be fully endowed for a number of years.
Do they know of any banks that were started and failed – If so, why?	There are other banks in this area which also do not have signed conservation banking agreements. The Environmental Trust would not currently start another bank in Riverside County.
Relevant permits	
Review notes	Template filled out by Leslie Beck of the Environmental Trust, with minor edits by Stratus Consulting.

Sheridan Conservation and Mitigation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills, Diana Lane
Interview date	26-Nov-03
Bank name	Sheridan Conservation and Mitigation Bank
Location	
Address	Southeast of Yuba City
City	
State	CA
County/location	Placer
Contact for information	
Name	Kellie Berry
Phone	916 331 8810
E-mail	kberry@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	
Additional contact, if any	
Name	Steve Morgan
Phone	916 331 8810
E-mail	smorgan@wildlandsinc.com
Organization	Wildlands Inc.
Title/role	CEO/CFO of Wildlands, Inc.
URLs with information	
URL#1	http://sacramento.fws.gov/es/bank_list.htm
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	616 acres
No. of acres of buffer areas, if any	No buffer areas defined as such.
No. of credits in bank	Separate credits for each habitat type: 1,400 units of valley elderberry longhorn beetle credit (1 unit = 1,800 sq. feet of elderberry); 220 credits (acres) of wetlands/marsh; 55 credits (acres) of vernal pools; 30 credits (acres) of riparian habitat.
No. of credits used or sold to date	1,310 elderberry credits sold; 53 vernal pool credits sold; 145 wetland credits sold; 30 riparian credits sold.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	
Invertebrates	Valley elderberry longhorn beetle (FT)

Sheridan Conservation and Mitigation Bank

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	Vernal pool creation; wetland/marsh; riparian
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits defined as "units" for valley elderberry longhorn beetle; credits defined in acres for habitats.
What was the method used for defining and measuring credits?	Credits were based on the value of created habitat on a piece of property with poor habitat values.
How were multiple species issues addressed?	Credits are defined on a habitat basis, with impacts to each habitat type requiring mitigation of that same type.
What is the service area for the bank?	Large service area covering multiple counties.
Can we get the Conservation Banking Agreement?	Wildlands prefers not to distribute their Conservation Banking Agreements to the public because they contain information that could be helpful to competitors. They acknowledge that the documents are available from USFWS (through a FOIA request, if necessary).
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments are made by USFWS. In general, parties need to mitigate at a 1:1 to 1.5:1 ratio for impacts to wetland and riparian habitat. Valley elderberry longhorn beetle debits depend on a complicated formula that includes location (riparian vs. non-riparian), size of impact, and evidence of beetle use.
Can different species be "traded off" for debits vs. credits?	No. Debit assessments are made for each of the habitat types available at the bank — a debit for a particular habitat type requires mitigation for that same habitat type.
Credit transaction history	
If individual transaction data not available	
Who used credits?	Public agencies and private individuals.
Total number of transactions?	360 transactions.
Average size	Transaction size has varied from 0.02 acres up to 5-10 acres.
Average price or change in price over time	$45,000 per acre for seasonal wetlands; $125,000 per acre for vernal pools; $1,800 per elderberry unit plus transplant costs, if transplanting of shrubs from impacted site is required.
History/status of bank	
Current status	Active for elderberry credits, vernal pool credits, and wetland credits. All riparian credits have been sold out.
Who owns bank?	Wildlands, Inc.
Has ownership	No.

Sheridan Conservation and Mitigation Bank

Information categories	Responses
changed – If so, why?	
Who can use the bank?	Public agencies and private individuals (anyone who needs credits and can pay the fee).
Establishment date	1995
Date first credit used	1995
Management and operation	
Who manages the habitat?	Wildlands, Inc.
Who markets the credits?	Wildlands, Inc.
Who owns the land?	Wildlands, Inc.
What types of management activities take place?	Management activities are designed to maintain high-quality habitat. The bank can accept transplants of elderberry from impacted areas.
Did active management for restoration need to take place to gain credits?	Yes. All of the habitat at the bank was created from poor-quality fallow land that was no longer used for agriculture.
What are long-term management arrangements?	After the bank is closed, Wildlands will have the right to turn over management to an approved third party and to request funds from the state endowment fund for monitoring and maintenance. (Each credit that is purchased requires payment of a fee to the endowment fund). Currently, Wildlands retains management control over all the banks that it has developed.
What is planned lifespan of bank?	Agreements require maintaining habitat in perpetuity.
What types of monitoring take place to ensure bank "performance"?	Monitoring of vegetation condition and wildlife surveys take place.
Performance monitoring	
How frequently does monitoring occur?	Annually.
Are there provisions for monitoring to trigger remedial actions?	Adaptive management plans are included as part of the management agreement. There are no specific triggers for additional remedial work.
Can monitoring reports be obtained?	Wildlands prefers not to make the reports public.
Subjective appraisals	

Sheridan Conservation and Mitigation Bank

Information categories	Responses
Impetus to start bank	The founder of Wildlands (Steve Morgan) was aware of mitigation banking in other parts of the country and saw a need for mitigation banking in the Sacramento region. He incorporated the company in 1991. Sheridan was the first mitigation banking project developed by Wildlands.
Issues at startup	This project was the first wetland creation bank in the region and preceded current policy guidance. The USFWS was supportive of the banking idea.
Difficulty in marketing credits	Early marketing efforts were focused on educating the public and agencies about mitigation banking. Currently, Wildlands engages in marketing activities to the development community and to agencies.
Issues with current regulations	Wildlands is careful to make sure of agency support in advance of creating a bank, and has good relations with relevant agencies. If a regional habitat conservation plan (that provides for fee-based mitigation) is close to adoption for an area, Wildlands would likely choose not to develop a bank because of the risk that the market for credits would disappear.
Is bank a success?	Wildlands considers all of their banks to be successful.
Do they know of any banks that were started and failed – If so, why?	They know of banks that other individuals or companies have tried to establish, but have been unable to find clients.
Relevant permits	
Review notes	

Southlands Forest

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	8-Dec-03
Bank name	Southlands Forest
Location	
Address	Southwest Georgia; 35 miles N. of Tallahassee
City	
State	Georgia
County/location	Decatur
Contact for information	
Name	Craig Hedman
Phone	229 246-3642 x 270
E-mail	craig.hedman@ipaper.com
Organization	International Paper, Southlands Forest
Title/role	Manager, Forest Ecology & Water Resources
Additional contact, if any	
Name	Ralph Costa
Phone	864 656 2432
E-mail	ralph_costa@fws.gov
Organization	USFWS
Title/role	Recovery coordinator, red-cockaded woodpecker
URLs with information	
URL#1	http://www.environmentaldefense.org/article.cfm?contentid = 2664
URL#2	http://rcwrecovery.fws.gov/index.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	5300 acres in bank
No. of acres of buffer areas, if any	Forest totals 16,000 acres
No. of credits in bank	12 red-cockaded woodpecker (RCW) groups comprising 47 birds as of December 2003; goal is to establish 25 - 30 RCW groups
No. of credits used or sold to date	3 credits used internally as of December 2003
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	Red-cockaded woodpecker (FE)
Fish	
Invertebrates	
Mammals	
Plants	

Southlands Forest

Information categories	Responses
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	RCW group in combination with habitat
What was the method used for defining and measuring credits?	A credit is gained when a new group is on-site for 6 months plus a breeding season. The number of birds in a group can vary from a single bird to a breeding pair with helper birds. Habitat was surveyed to establish value for target species.
How were multiple species issues addressed?	Not applicable — bank's focus is only on RCW.
What is the service area for the bank?	The service area for 3rd party use of the bank includes the coastal plain of Florida, Georgia, and Alabama. The bank might be eligible to mitigate for takes outside of this area on a case-by-case basis.
Can we get the Conservation Banking Agreement?	We did not obtain the agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	The USFWS has a 1:1 mitigation policy — an applicant needs to replace a lost group of birds with a new group of birds ("mitigation"). In addition, the birds on impacted habitat are relocated to a new area ("minimization"). In addition, mitigation needs to be in-kind. A take of a single bird can be mitigated with establishing a single bird; a take of a pair can be mitigated with establishing a potential breeding pair.
Can different species be "traded off" for debits vs. credits?	Not applicable.
Credit transaction history	
If individual transaction data not available	
Who used credits?	To date, all credits have been used internally by International Paper.
Total number of transactions?	2 locations with takes (= 2 internal transactions).
Average size	1 group at one locations and 2 groups at the other, a total of 3 groups that required mitigation.
Average price or change in price over time	No price set yet for third party sales. The price will likely be in the range of $250,000 per credit.
History/status of bank	
Current status	Active
Who owns bank?	International Paper

Southlands Forest

Information categories	Responses
Has ownership changed – If so, why?	International Paper
Who can use the bank?	Internal use by International Paper and third party use is allowed
Establishment date	Incidental Take Permit issued Jan. 29,1999; kick-off meeting with USFWS, Environmental Defense Fund, and Georgia DNR in March 1996
Date first credit used	2003
Management and operation	
Who manages the habitat?	International Paper
Who markets the credits?	International Paper
Who owns the land?	International Paper
What types of management activities take place?	Prescribed burning; timber management (selection harvests and thinnings); cavity maintenance (most intensive activity); installing artificial cavities; control of some cavity competitors, e.g., rat snakes and flying squirrels
Did active management for restoration need to take place to gain credits?	Yes — new groups need to be established before credits can be earned and subsequently used.
What are long-term management arrangements?	International Paper will actively manage habitat for at least the 30 years of the Habitat Conservation Plan.
What is planned lifespan of bank?	Habitat Conservation Plan is authorized for 30 years.
What types of monitoring take place to ensure bank "performance"?	Intensive monitoring occurs of habitat and bird populations. All red-cockaded woodpeckers on site are banded and marked for monitoring. Other bird species are monitored as well.
Performance monitoring	
How frequently does monitoring occur?	RCWs and cavities are monitored throughout the year.
Are there provisions for monitoring to trigger remedial actions?	Efforts are required to reestablish groups if birds are lost. International Paper intends to maintain RCW groups above baseline as a "cushion" in case groups are lost. The current baseline for International Paper is 18 active clusters; the current inventory of birds is 19-21 groups.
Can monitoring reports be obtained?	Not available.
Subjective appraisals	

Southlands Forest

Information categories	Responses
Impetus to start bank	The idea of banking arose from discussions in an informal setting. International Paper, Environmental Defense Fund, and the USFWS were looking for opportunities for proactive management of endangered species and to promote conservation measures for private landowners. Conservation banking was an idea that all the parties were interested in trying. Since the RCW represented management challenges similar to the northern spotted owl, this species was selected. Having excellent RCW habitat and some birds (3 adult males at the time), Southlands Forest became the most logical place to try implementing a bank.
Issues at startup	Working through the habitat conservation plan and incidental take permit process were the most challenging time-consuming parts of start-up.
Difficulty in marketing credits	No sales to 3rd parties yet, although discussions with 3rd parties have occurred.
Issues with current regulations	Not specifically. International Paper has stayed engaged in the process by being active in regional translocation strategy meetings hosted by USFWS and providing written comments on the recently revised RCW Recovery Plan.
Is bank a success?	Yes — for all parties. USFWS and GA DNR got a positive example of working with private landowners as well as a strategically placed "new" population of RCWs. The habitat and clusters established at Southlands provide an important linkage between two large populations of red-cockaded woodpeckers (Apalachicola National Forest and Red Hills Region of GA/FL). Environmental Defense Fund has seen conservation practices and policies they have championed concretely implemented on-the-ground. For International Paper, the bank increases management flexibility and frees up timber that was encumbered.
Do they know of any banks that were started and failed – If so, why?	Not aware of any.
Relevant permits	Incidental Take Permit Application (PRT-833203)
Review notes	This version reviewed by Craig Hedman, December 9, 2003.

Springtown Natural Communities Reserve

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	12/1/2003
Bank name	Springtown Natural Communities Reserve
Location	
Address	Located near Livermore, CA in an urban area
City	
State	CA
County/location	Alameda
Contact for information	
Name	Terry Huffman
Phone	(415) 925-2000
E-mail	thuffman@h-bgroup.com
Organization	Environmental Mitigation Exchange Company (EMAX) / Huffman-Broadway group
Title/role	Vice-President
Additional contact, if any	
Name	Carl Wilcox
Phone	(707) 944-5525
E-mail	
Organization	California Department of Fish and Game
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/alameda.shtml
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	52 acres in bank; 31 acres of wetland creation credits.
No. of acres of buffer areas, if any	No formal buffer areas.
No. of credits in bank	520 credits for tiger salamander; 310 credits for wetland creation (1 acre = 10 credits).
No. of credits used or sold to date	0 credits used to date for tiger salamander; approximately 155 wetland credits sold (bank has sold half of the available credits).
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	California Tiger Salamander (state species of concern)
Birds	
Fish	
Invertebrates	
Mammals	

Springtown Natural Communities Reserve

Information categories	Responses
Plants	
Reptiles	
Habitat types	Seasonal wetlands — creation.
Credit definition for bank	
Unit for credits (acres or organisms?)	10 credits per acre.
What was the method used for defining and measuring credits?	EMAX coordinated with California Department of Fish and Game (CDFG) for development of credits. Credits were defined on an acreage basis. The use of 10 credits per acre makes it easier to keep track of small credit sales (1 credit = 0.1 acres).
How were multiple species issues addressed?	No multiple species issues. The bank includes breeding and upland habitat for the tiger salamander.
What is the service area for the bank?	40-mile radius service area — only wetland bank in county.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See California Department of Fish and Game and EMAX, no date.
Measurement methods for "debit areas"	
How is "debit area" assessed?	CDFG assesses debit areas and determines the need for mitigation credits. This bank is a "state approved" bank only. It is not a federal conservation bank and cannot be used as mitigation for impacts to federally listed threatened or endangered species.
Can different species be "traded off" for debits vs. credits?	Not applicable.
Credit transaction history	See Table 6 in main body of report.
If individual transaction data not available	
Who used credits?	Private parties and the county transportation authority.
Total number of transactions?	11 transactions.
Average size	Average transaction size is 1/2 acre (5 credits). The largest sale was 14 acres (140 credits).
Average price or change in price over time	Current price for wetland creation credits is 250,000 per acre (25,000 per credit). The price has fluctuated over time in response to changing market conditions. Competitor banks for California tiger salamanders sell salamander credits for 12,000 per acre. Springtown Reserve can't match that price because of high cost of land in an urban area. Therefore, no price has been set for salamander credits at this bank, because there is no current demand for salamander credits from the Springtown Reserve.
History/status of bank	

Springtown Natural Communities Reserve

Information categories	Responses
Current status	Credits available for wetland creation (half of original credits are remaining). All salamander credits are available, but there is no demand for these credits. EMAX also has an option for purchasing two additional parcels of land to expand bank, but funds for purchase are not available yet.
Who owns bank?	EMAX
Has ownership changed – If so, why?	No.
Who can use the bank?	Private parties and public agencies.
Establishment date	1997
Date first credit used	1997
Management and operation	
Who manages the habitat?	EMAX
Who markets the credits?	EMAX
Who owns the land?	EMAX
What types of management activities take place?	General property maintenance — maintain fencing and signs; remove trash and debris, including illegal dumping; keep out trespassers. Some invasive species removal is done, but this work is minor because of high quality of habitat.
Did active management for restoration need to take place to gain credits?	Yes. Wetland habitat was created on site, including creating two additional breeding ponds for tiger salamanders (one breeding pond already existed on site).
What are long-term management arrangements?	CDFG maintains an endowment fund for long-term management of the property (funded by fees from credit sales). If EMAX goes bankrupt or stops fulfilling its obligation to manage the land, CDFG will gain title to the land and will use the endowment fund for long-term management.
What is planned lifespan of bank?	Land needs to be managed in perpetuity.
What types of monitoring take place to ensure bank "performance"?	Monitoring of vegetation, soils, and hydrology annually for 10 years post-wetland creation to certify that wetland species are present and that the wetland areas meet Army Corps of Engineers criteria.
Performance monitoring	
How frequently does monitoring occur?	Annually.
Are there provisions for monitoring to trigger remedial actions?	The banking agreement specifies standards that need to be met. If standards are not met, appropriate remedial actions are required. For example, small-mammal activity damaged a weir structure that then had to be replaced.

Springtown Natural Communities Reserve

Information categories	Responses
Can monitoring reports be obtained?	Not available.
Subjective appraisals	
Impetus to start bank	Impetus to start bank was a discussion between Terry Huffman of EMAX and Carl Wilcox of CDFG. They both had an interest in preserving a federally-listed plant species (bird's beak) in the area. In discussing different ways to try to purchase habitat and conserve it, they decided that a conservation bank would be the best mechanism for protecting existing habitat and creating new wetlands habitat.
Issues at startup	The start-up was challenging because conservation banking was new in the area in 1997, so there were no set documents. Legal issues needed to be overcome. EMAX and CDFG set up a joint escrow account during the wetland construction, until the wetlands were certified by CDFG as successfully built. Also, funding for the bank was difficult. It is difficult to get a loan from a conventional bank for land purchase because conservation banking is seen as having a greater risk than farming or development.
Difficulty in marketing credits	Not too hard to market credits, because this is the only wetland creation bank in the area. At the moment, demand is slow. The bank owner feels that it would be easier to sell credits if the bank were certified as a federal bank, as well as a state bank.
Issues with current regulations	The bank has good relations with local agencies. The bank owner feels that it is helpful to allow advance credit sales, because this helps banks get started where financing is not available. Also, it is important that agencies don't approve competitor banks with large service areas that can take away the market from existing banks.
Is bank a success?	Financially, the bank has been able to break even, but more credit sales will be required to finance the long-term endowment and pay the interest on the land. Ecologically, the bank has been a success for conserving valuable habitat in the area, especially for the federally-listed bird's beak plant.
Do they know of any banks that were started and failed – If so, why?	Not aware of failures. However, the high cost of land in the area prevents people from starting conservation banks.
Relevant permits	

Springtown Natural Communities Reserve

Information categories	Responses
Other notes	Springtown Reserve is an interesting example of how the species credits associated with a bank do not necessarily reflect the full ecological value of a bank. For example, this bank protects a federally-listed plant species (bird's beak), but there are no credits associated with protecting the species because the bank is not federally-certified and because the bank owners felt that there would be no demand for purchasing credits for this species. The bank is certified to provide credits for impacts to California tiger salamanders, but no credits have been sold for this species because of the availability of competitor banks that can sell salamander credits at a lower price.

Stillwater Plains Mitigation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	12/4/03
Bank name	Stillwater Plains Mitigation Bank
Location	
Address	21923 Dersch Road
City	Anderson
State	CA (zip, 96007)
County/location	Shasta
Contact for information	
Name	Glenn Hawes
Phone	530 365 4233 or 530 365 5078
E-mail	Not used
Organization	Stillwater Plains Mitigation Bank
Title/role	Owner and operator of the bank
Additional contact, if any	
Name	
Phone	
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.dfg.ca.gov/hcpb/conplan/mitbank/catalogue/shasta.shtml
URL#2	http://sacramento.fws.gov/es/bank_list.htm
Size of bank	
No. of acres in bank (note if parcel not contiguous)	Bank currently has 260 acres approved and associated with a mix of credits that can be purchased. This 260 acres represents the first of four implementation phases that will be executed (the banking agreement has five phases but the fifth listed phase in the agreement will not be pursued). The second phase should be in place by the fall of 2004 and will cover an additional 400 acres. Ultimately the four phases will encompass roughly 830 acres although there is adjacent land that could be purchased and used to support further extension of the bank.
No. of acres of buffer areas, if any	No buffer acres are specifically defined.
No. of credits in bank	Build out is 100 credits, preservation credits on order 100 for all phases and all species
No. of credits used or sold to date	Exact number of transactions by habitat category not available; also, several transactions are pending (e.g., CalTrans purchase of elderberry unit credits)
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	None
Birds	None

Stillwater Plains Mitigation Bank

Information categories	Responses
Fish	None
Invertebrates	Valley elderberry longhorn beetle (FT) Vernal pool fairy shrimp (FT)
Mammals	None
Plants	Orcutt grass (FE or FT depending on species); Legenere; other species
Reptiles	None
Habitat types	Vernal pool (preservation and creation) Wetlands (have 130 acres enrolled in Federal Wetlands Reserve Program) Emergent marsh, Riparian
Credit definition for bank	
Unit for credits (acres or organisms?)	For habitat, one acre = one credit. For valley elderberry longhorn beetle, one credit = 1,800 square feet (roughly 1/24th of an acre).
What was the method used for defining and measuring credits?	Credits assigned based on areas of different habitat, following restoration work.
How were multiple species issues addressed?	Species specific credits currently available only for mitigating impacts to the valley elderberry longhorn beetle. The only other listed species are mitigated with wetland habitat credits (vernal pool preservation or creation for fairy shrimp). Therefore, there are no overlapping species credit issues.
What is the service area for the bank?	For endangered species credits, the bank's service area is effectively the northern half of California. For the remaining habitat credits (e.g., vernal pools and wetlands) the effective service area is the valley areas of Shasta and Tehama counties. In both cases, the banking team for the bank, composed of staff from USFWS, US ACOE, EPA, and CDFG can evaluate whether a transaction from outside the area should be approved or whether the service area of the bank should be expanded.
Can we get the Conservation Banking Agreement?	We did not receive a copy of the final banking agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments for which credits from this bank could be used to satisfy mitigation requirements are determined by USFWS staff.
Can different species be "traded off" for debits vs. credits?	No, credits are not transferable across species or habitats.
Credit transaction history	
If individual transaction data not available	
Who used credits?	Private parties and public agencies. A transaction is pending for CalTrans to purchase Elderberry credits.

Stillwater Plains Mitigation Bank

Information categories	Responses
Total number of transactions?	Not available. The fact that Phase II of the project will begin in the fall of 2004, and will place a conservation easement on an additional 400 acres of land suggests that the bank has been active.
Average size	Specifics not given.
Average price or change in price over time	Currently credits are priced on a per acre basis with a distinction for whether the credits are based on habitat creation or preservation. Creation-based credits sell for $100,000 per acre. Preservation-based credits sell for $65,000 per acre. Valley elderberry longhorn beetle credits cost approximately $4250 per credit.
History/status of bank	
Current status	Bank is active with credits available and additional phases planned for implementation.
Who owns bank?	Glenn Hawes
Has ownership changed – If so, why?	No.
Who can use the bank?	Any party with a transaction approved by the USFWS.
Establishment date	Late 2000.
Date first credit used	2000, shortly after opening.
Management and operation	
Who manages the habitat?	Glenn Hawes
Who markets the credits?	Glenn Hawes
Who owns the land?	Glenn Hawes
What types of management activities take place?	Cattle are currently used to graze vegetation that would compete with the listed plant species.
Did active management for restoration need to take place to gain credits?	The bank contains a mix of credits that are associated with habitat preservation and some that are associated with habitat creation (e.g., riparian, vernal pool). The valley elderberry credits are associated with designated parcels suitable for the valley elderberry where bushes that would be lost in development can be transplanted and mixed in with other appropriate native vegetation.
What are long-term management arrangements?	Not available.
What is planned lifespan of bank?	Sale of credits is desired as rapidly as possible. Bank property is in middle of a larger parcel owned by the bank operator and there are no plans to sell the bank or surrounding property.
What types of monitoring take place to ensure bank "performance"?	Details of monitoring not available.

Stillwater Plains Mitigation Bank

Information categories	Responses
Performance monitoring	
How frequently does monitoring occur?	Details of monitoring not available.
Are there provisions for monitoring to trigger remedial actions?	Details of monitoring not available.
Can monitoring reports be obtained?	Details of monitoring not available.
Subjective appraisals	
Impetus to start bank	Owner was initially approached by CDFG following a survey of the local area by researchers from Cal State-Chico that identified the planned bank area as the most suitable area for development of a local habitat conservation and mitigation bank. In addition, the abundance of listed species on the property effectively precluded any alternative development. In this case the conservation-mitigation bank option was viewed as a win-win by the owner as it allowed the character of the ranching land to be retained while allowing for development of an income stream from the property.
Issues at startup	Apparently the process to formalize the bank began in 1995. Despite being approached by CDFG the approval process took five years. However, some of this extended time period can be attributed to the number of species on the property and the need to account for a mix of credits to be provided by preservation and restoration actions.
Difficulty in marketing credits	No difficulties noted.
Issues with current regulations	None mentioned.
Is bank a success?	Bank owner seems enthusiastic about the potential for the bank to be beneficial from a species and habitat management point of view while providing an economic opportunity for a nondestructive development of the property.
Do they know of any banks that were started and failed – If so, why?	Not asked.
Relevant permits	
Review notes	

Swan Road Conservation Bank

Information categories	Responses
Background	
Stratus Consulting interviewer	Diana Lane
Interview date	12-Nov-03
Bank name	Swan Road Conservation Bank
Location	
Address	Section 15 of Township 16 South, Range 14 East; Gila and Salt River Base and Meridian
City	Pima
State	AZ
County/location	Pima County
Contact for information	
Name	Linda Closs
Phone	520-740-6305
E-mail	
Organization	Pima County Public Works Center
Title/role	Manager
Additional contact, if any	
Name	Steve Anderson
Phone	520-877-6000
E-mail	steve.anderson@parks.pima.gov
Organization	Pima County Parks and Recreation
Title/role	
URLs with information	
URL#1	http://www.sahba.org/regaffairs10.htm
URL#2	http://www.pima.gov/pksrec/home2/home2.html
Size of bank	
No. of acres in bank (note if parcel not contiguous)	592 acres.
No. of acres of buffer areas, if any	77 acres not suitable for cactus.
No. of credits in bank	513 credits.
No. of credits used or sold to date	37 credits used by Pima County for a governmental complex.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	
Invertebrates	
Mammals	
Plants	Pima pineapple cactus (FE)

Swan Road Conservation Bank

Information categories	Responses
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	Credits are based on acres of habitat and are assigned with 1 acre of habitat = 1 credit.
What was the method used for defining and measuring credits?	Habitat acreage suitable for cactus was assigned 1 credit per acre. Transplant of additional cacti onto property would not increase number of available credits. Habitat suitability evaluation was conducted by a contractor for the USFWS. 390 acres of "high suitability" habitat plus 170 acres of "medium suitability" habitat were found, for a total of 560 acres. Subsequently, Pima County chose to reserve a 100 foot corridor along each side of the section for a future road right-of-way, reducing the total suitable acreage to 513 acres.
How were multiple species issues addressed?	Not applicable — Pima pineapple cactus is the only species for this bank.
What is the service area for the bank?	Pima County.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See Pima County and U.S. Fish and Wildlife Service, 2002.
Measurement methods for "debit areas"	
How is "debit area" assessed?	USFWS assesses value of impacted habitat for the Pima pineapple cactus and determines the amount of off-site mitigation credits required. The conservation banking agreement specifies the maximum ratio of replacement habitat to lost habitat will be 3:1.
Can different species be "traded off" for debits vs. credits?	Not applicable.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Pima County.
Total number of transactions?	1 transaction to date.
Average size	37 credits used.
Average price or change in price over time	No price — credits are used internally by Pima County.
History/status of bank	
Current status	Active.
Who owns bank?	Pima County.

Swan Road Conservation Bank

Information categories	Responses
Has ownership changed – If so, why?	No.
Who can use the bank?	Only the county can use credits for public works projects.
Establishment date	Jun-02.
Date first credit used	Not available.
Management and operation	
Who manages the habitat?	Pima County.
Who markets the credits?	No marketing — internal use only.
Who owns the land?	Pima County.
What types of management activities take place?	Habitat management specified in conservation banking agreement. Transplant areas are designated to receive Pima pineapple cactus salvaged from other areas. Location of cactus on reserve monitored with GPS coordinates every 3 years. No vehicular access or livestock grazing will be allowed on the property.
Did active management for restoration need to take place to gain credits?	No restoration required — habitat was in good shape without any widespread infestations of non-native invasive grasses.
What are long-term management arrangements?	Agreement to maintain conservation easement on property, maintain biological value of lands, and not engage in any property uses that degrade biological values.
What is planned lifespan of bank?	Indefinite.
What types of monitoring take place to ensure bank "performance"?	Monitoring plan, specifies monitoring of established and transplanted cacti.
Performance monitoring	
How frequently does monitoring occur?	Monitoring of established cacti every three years; monitoring of transplanted cacti quarterly for two years.
Are there provisions for monitoring to trigger remedial actions?	If non-native grass invades the reserve, management actions will be taken to remove the grass.
Can monitoring reports be obtained?	Not available.
Subjective appraisals	
Impetus to start bank	Need for mitigation for county projects — purchasing land for off-site mitigation on a case-by-case basis was costly and time-consuming.

Swan Road Conservation Bank

Information categories	Responses
Issues at startup	The county considered making credits available to the public, but decided to retain all credits for internal use because of the county's needs and because of the perceived difficulty of the legal and financial transactions required to sell credits to the public.
Difficulty in marketing credits	Not applicable.
Issues with current regulations	No.
Is bank a success?	Yes. The county appreciates having mitigation credits available up-front and not needing to buy additional land to mitigate for county projects.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	
Review notes	

Williamson County Karst Conservation Foundation

Information categories	Responses
Background	
Stratus Consulting interviewer	David Mills
Interview date	10/8/2003
Bank name	Williamson County Karst Conservation Foundation
Location	
Address	Southwest Regional Park, near County Road 175 and New Hope Drive
City	
State	TX
County/location	Williamson
Contact for information	
Name	Steve Paulson
Phone	512 347 9000
E-mail	spaulson@aci-group.net
Organization	ACI-Group
Title/role	Preserve biologist and manager
Additional contact, if any	
Name	Sybil Vosler (contact for copies of the banking agreement and monitoring reports)
Phone	512 490 0057
E-mail	sybil_vosler@fws.gov
Organization	U.S. Fish and Wildlife Service — Region 2
Title/role	Ecological Services Staff
URLs with information	
URL#1	http://www.wilcokarst.org/facts.html
URL#2	
Size of bank	
No. of acres in bank (note if parcel not contiguous)	220 acres that encompassed 9 karst caves were in the original banking area.
No. of acres of buffer areas, if any	Buffers around cave openings are included in the 220 acres.
No. of credits in bank	A formal number of credits was never defined for the bank. The basis for evaluating debits from impacts to caves and credits from cave preservation is still being established.
No. of credits used or sold to date	The mitigation potential for the 9 karst caves in the original banking area (purchased by the Karst Conservation Foundation) has been completely claimed.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	
Fish	

Williamson County Karst Conservation Foundation

Information categories	Responses
Invertebrates	Bone Cave harvestman (FE), potential for Coffin Cave mold beetle (FE), Tooth Cave ground beetle (FE)
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	The USFWS considers the size of a cave and its known or potential suitability for the listed species when determining the mitigation potential of a cave considered for purchase. Credits are not formally defined.
What was the method used for defining and measuring credits?	There still is no formal basis for evaluating the credit potential of a cave that may be purchased for mitigation with the issue still being addressed on a case-by-case basis, with discussions between developers, the USFWS, and the Williamson County Karst Conservation Foundation.
How were multiple species issues addressed?	Multiple species issues have been dealt with to date by avoiding looking at impact debits and credits on a species specific basis. This in part reflects the lack of available data on the species in the impacted and mitigation caves and relies on an assessment of the potential of the habitats to support these species.
What is the service area for the bank?	21 individual service areas are being defined for Williamson County, because of different micro-environments for the karst species.
Can we get the Conservation Banking Agreement?	Included with supplemental materials. See U.S. Fish and Wildlife Service and Williamson County Karst Conservation Foundation, 2002.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Only 1 transaction (see below).
If individual transaction data not available	
Who used credits?	All of the credits pertaining to the initial group of nine caves (220 acres) were purchased by the Texas Turnpike Authority to mitigate impacts associated with the construction of Texas Road 45. Plans exist to purchase additional karst-fauna areas of 40-70 acres to allow all interested public and private parties to purchase mitigation credits.
Total number of transactions?	Only 1 transaction (to the Texas Turnpike Authority) to date.
Average size	9 caves (220 acres).

Williamson County Karst Conservation Foundation

Information categories	Responses
Average price or change in price over time	No price per credit — parcels needed for mitigation are purchased as funding becomes available.
History/status of bank	
Current status	Credits from protecting the initial group of caves have been fully claimed. Currently, the Williamson County Karst Conservation Foundation is raising money to support "conservation actions" that would help protect or manage karst caves that occur in the area. According to the banking agreement, these conservation actions would then generate conservation credits that could be sold to third parties for impacts to karst areas. The current goal is to finance the purchase of 6 or 7 karst faunal areas that would be roughly 40-70 acres in size. These areas would include karst caves and buffer areas intended to protect the caves' hydrology which drives the suitability for the listed species.
Who owns bank?	Williamson County Karst Conservation Foundation (a nonprofit organization established by Williamson County).
Has ownership changed – If so, why?	No.
Who can use the bank?	Payments currently collected from private and public parties.
Establishment date	Initial agreement finished in December 2002.
Date first credit used	December 2002.
Management and operation	
Who manages the habitat?	ACI-Group under the direction of Steve Paulson.
Who markets the credits?	Credits are not specifically marketed given the awareness in the developer community of the existence of the bank with its recognition by USFWS.
Who owns the land?	Williamson County.
What types of management activities take place?	Current management activities involve restricting access to the caves once they are identified and purchased, combined with incorporation of buffer areas intended to maintain the hydrology that is essential to the caves providing suitable habitat to the listed species.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	Purchased lands are owned by the county and incorporated into its planning with regard to open space.
What is planned lifespan of bank?	Unclear. However, goal is to establish 6-7 karst-faunal preserve areas. Active development and growth in the county will likely continue the demand for mitigation areas.

Williamson County Karst Conservation Foundation

Information categories	Responses
What types of monitoring take place to ensure bank "performance"?	Monitoring protocols for the caves are currently being developed and implemented at various levels of intensity to identify the types of data and level of effort that are needed to evaluate the quality of the habitat and to provide indications that additional actions may be required.
Performance monitoring	
How frequently does monitoring occur?	Not known.
Are there provisions for monitoring to trigger remedial actions?	The monitoring and management plans for the caves are not finalized. Given the relative lack of knowledge about the caves and their listed species, initial monitoring results will be used to help establish baseline conditions. Over time, monitoring results that indicate a decline in invertebrate populations may trigger remedial actions. Specific remedial action thresholds have not yet been defined.
Can monitoring reports be obtained?	Did not receive. Reports may be available from Sybil Vosler of the U.S. Fish and Wildlife Service.
Subjective appraisals	
Impetus to start bank	County advisors and staff recognized that significant future development in the county would require a coordinated plan for mitigating impacts to endangered karst cave species. Funding from a bond issue was used to purchase the initial set of 9 caves and associated lands which were intended for a county park. The immediate driver for creating the mitigation bank came when the USFWS needed to spend $3.2 million that it had accepted for mitigation to impacts in karst caves resulting from the Texas Turnpike Authority's construction of Texas Road 45. The $3.2 million payment was intended to fund the purchase of a cave parcel from a private landholder but the deal collapsed when the landowner raised the effective price of the mitigation parcel from $3.2 million to $11 million because of frustration with USFWS. Instead, the USFWS paid Williamson County to preserve 220 acres of cave habitat in a regional park. This payment was the start of the revolving fund administered by the Williamson County Karst Conservation Foundation for the purchase of additional karst faunal areas in the county.
Issues at startup	Initial issues were significant skepticism within the county with regard to the development of a mitigation plan for "bugs" (i.e., cave invertebrates). Allocating funds from the bond issue to environmental projects also was seen as controversial. In general, county officials like conservation banking because the funding burden for endangered species management is placed on developers. In addition, private individuals who were facing restrictions on land-use because of the presence of caves on their land are able to earn money from protecting their land.

Williamson County Karst Conservation Foundation

Information categories	Responses
Difficulty in marketing credits	No. While credits have not formally existed, with impacts and mitigation being addressed on a case by case basis, there is active growth in the county so the need for mitigation is significant and anticipated to remain steady or grow in the near term.
Issues with current regulations	None to date.
Is bank a success?	Success in that it has enabled the preservation of a number of critical habitats that support the listed species. Ecological success is somewhat clouded by the overall uncertainty regarding the requirements of the listed species and concern over whether existing protective measures (e.g., setbacks incorporated into the purchase agreements) will prove adequate over time.
Do they know of any banks that were started and failed – If so, why?	No.
Relevant permits	
Other notes	This bank differs from other banks because credits and debits have not been clearly defined yet. The credit and debit issues for listed species that depend on karst cave habitats are clearly still being dealt with on a case by case basis in the county. Proposed impacts are evaluated against proposals from the Williamson County Karst Conservation Foundation to undertake future purchases of identified karst-faunal habitats. At the moment, this bank is essentially functioning like a fee-based mitigation system. The county is not concerned that land prices could outstrip fees collected by the Foundation because there is still an abundance of undeveloped areas in the county.

Wilson Creek/Joe A. Gonzalez

Information categories	Responses
Background	
Stratus Consulting interviewer	David Chapman, Diana Lane, David Mills
Interview date	10/3/2001 with Michael McCollum. Note that Michael McCollum provided the same information for the Wilson Creek and Wilson Valley Conservation Banks. The bank descriptions differ only in the owner, the size, and the number of credits available and sold.
Bank name	Wilson Creek/Joe A. Gonzalez
Location	
Address	
City	
State	CA
County/location	Riverside
Contact for information	
Name	Michael McCollum
Phone	916 688 2040
E-mail	mccollum@mccollum.com
Organization	McCollum Associates
Title/role	Helped develop the currently unsigned banking agreements for the respective bank owners and is active in the marketing of available credits.
Additional contact, if any	
Name	
Phone	
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.mccollum.com/Mitbanks.htm
URL#2	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf
Size of bank	
No. of acres in bank (note if parcel not contiguous)	1,850 acres.
No. of acres of buffer areas, if any	No formal buffer areas.
No. of credits in bank	1,850 credits.
No. of credits used or sold to date	688.3 credits used.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	California gnatcatcher (FT)
Fish	
Invertebrates	Quino checkerspot butterfly (FE)

Wilson Creek/Joe A. Gonzalez

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	1 acre = 1 credit for high quality habitat.
What was the method used for defining and measuring credits?	The credits in both banks are for high quality habitat of the respective species for which credits are available (gnatcatcher and the Quino checkerspot butterfly).
How were multiple species issues addressed?	Credits can be used for either gnatcatcher or checkerspot butterfly impacts — the same credit cannot be sold twice for different species.
What is the service area for the bank?	Credits in the bank are available only for projects incurring losses in Riverside County.
Can we get the Conservation Banking Agreement?	We did not obtain the agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Credits have been purchased exclusively by private parties.
Total number of transactions?	Not available.
Average size	Not available.
Average price or change in price over time	Credits initially sold for between $5,000-$7,000 and currently are typically selling for between $10,000 and $12,000.
History/status of bank	
Current status	Active, but in final phase of operation following the approval of a multiple species habitat conservation plan (MSHCP) in Riverside County. Under this plan, Riverside County will adopt a fee-based system for species mitigation. The county will collect fees directly from those proposing incidental takes and will use the funds to purchase lands in accordance with the goals of the county's habitat conservation plan.
Who owns bank?	Private individual (Joseph A. Gonzalez).

Wilson Creek/Joe A. Gonzalez

Information categories	Responses
Has ownership changed – If so, why?	No.
Who can use the bank?	Open to any individual/organization that USFWS will approve. History of credit purchases to date is that credits have been purchased by private parties (i.e., not public institutions).
Establishment date	1997/98.
Date first credit used	Not available.
Management and operation	
Who manages the habitat?	Bank lands are managed by the owners.
Who markets the credits?	McCollum Associates
Who owns the land?	The bank is privately owned by Joseph Gonzalez.
What types of management activities take place?	Bank credits are based on the preservation of existing habitat and are not conditional upon improvements from restoration actions.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	Specified in conservation agreement which we did not obtain.
What is planned lifespan of bank?	Banks have a short term time horizon for sale of existing credits and are not going to expand given move on the part of Riverside County to adopt a fee-based mitigation system.
What types of monitoring take place to ensure bank "performance"?	Information not available.
Performance monitoring	
How frequently does monitoring occur?	Information not available.
Are there provisions for monitoring to trigger remedial actions?	Information not available
Can monitoring reports be obtained?	Information not available.
Subjective appraisals	
Impetus to start bank	Banks were developed for investment purposes following the successful creation of other conservation/mitigation banks in Southern California (e.g., Wheeler and Carlsbad banks).

Wilson Creek/Joe A. Gonzalez

Information categories	Responses
Issues at startup	Process for establishing the banking agreements took longer than anticipated based on experience of Michael McCollum in establishing other similar agreements.
Difficulty in marketing credits	Credit marketing has been complicated by either the refusal or the reluctance of the USFWS to formally sign the banking agreements. The pool of potential credit purchasers is limited to those who are directed to the banks by the USFWS staff (which does not always occur), or who are already aware of the banks and receive approval from USFWS to use credits from the bank for mitigation.
Issues with current regulations	Current move to a fee-based system for species mitigation in Riverside County has effectively ended the opportunities for the development of additional private mitigation banks in the county. The County has agreed that existing banks will have the opportunity to sell remaining credits.
Is bank a success?	The bank can be viewed as ecologically successful in terms of preserving significant acreage of high quality habitat for the Quino checkerspot butterfly and California gnatcatcher. However, from an ecological assessment, the banks could potentially have had a much larger positive impact for the species had the banking agreements been signed. If more transactions had occurred, the banks would likely have purchased additional land and expanded. Economically, the failure to sign the banking agreements and the move in Riverside County to a fee-based system of species mitigation have introduced delays and constraints that have minimized the potential returns to the bank owners.
Do they know of any banks that were started and failed – If so, why?	Michael McCollum noted that there is effectively no future for private conservation/mitigation banks in Riverside County because of the implementation of the fee-based species mitigation program. He also noted that a general agency commitment to conservation banking is a necessary but not sufficient condition to ensure their development and success. Local USFWS agency staff have significant control in determining local mitigation options and can severely constrain the conditions in which any approved bank can effectively provide mitigation credits.
Relevant permits	
Other notes	Michael McCollum observed that the history of the development banks in So. California can be characterized by significant initial cooperation on the part of interested parties (e.g., landowners, developers, regulators) to establish model banks followed by increasing skepticism by regulators regarding their benefits and reluctance to use them. This reluctance is demonstrated through refusing to sign agreements or through incorporating operational constraints that limit their effective viability.

Wilson Valley/Won Yoo

Information categories	Responses
Background	
Stratus Consulting interviewer	David Chapman, Diana Lane, David Mills
Interview date	10/3/2001 with Michael McCollum. Note that Michael McCollum provided the same information for the Wilson Creek and Wilson Valley Conservation Banks. The bank descriptions differ only in the owner, the size, and the number of credits available and sold.
Bank name	Wilson Valley/Won Yoo
Location	
Address	
City	
State	CA
County/location	Riverside
Contact for information	
Name	Michael McCollum
Phone	916 688 2040
E-mail	mccollum@mccollum.com
Organization	McCollum Associates
Title/role	Helped develop the currently unsigned banking agreements for the respective bank owners and is active in the marketing of available credits.
Additional contact, if any	
Name	
Phone	
E-mail	
Organization	
Title/role	
URLs with information	
URL#1	http://www.mccollum.com/Mitbanks.htm
URL#2	http://www.rcip.org/mshcpdocs/vol1/4_6_1.pdf
Size of bank	
No. of acres in bank (note if parcel not contiguous)	1280 acres.
No. of acres of buffer areas, if any	No formal buffer area.
No. of credits in bank	1,280 credits.
No. of credits used or sold to date	991.95 credits used.
Species/habitats/credits available	C = California threatened species; FE = federally endangered; FT = federally threatened
Amphibians	
Birds	California gnatcatcher (FT)
Fish	
Invertebrates	Quino checkerspot butterfly (FE)

Wilson Valley/Won Yoo

Information categories	Responses
Mammals	
Plants	
Reptiles	
Habitat types	
Credit definition for bank	
Unit for credits (acres or organisms?)	1 acre = 1 credit for high quality habitat.
What was the method used for defining and measuring credits?	The credits in both banks are for high quality habitat of the respective species for which credits are available (gnatcatcher and the Quino checkerspot butterfly).
How were multiple species issues addressed?	Credits can be used for either gnatcatcher or checkerspot butterfly impacts — the same credit cannot be sold twice for different species.
What is the service area for the bank?	Credits in the bank are available only for projects incurring losses in Riverside County.
Can we get the Conservation Banking Agreement?	We did not obtain the agreement.
Measurement methods for "debit areas"	
How is "debit area" assessed?	Debit assessments that could use credits from this bank are made with USFWS staff.
Can different species be "traded off" for debits vs. credits?	No.
Credit transaction history	Not available.
If individual transaction data not available	
Who used credits?	Credits have been purchased exclusively by private parties.
Total number of transactions?	Not available.
Average size	Not available.
Average price or change in price over time	Credits initially sold for between $5,000 and $7,000 and currently are typically selling for between $10,000 and $12,000.
History/status of bank	
Current status	Active, but in final phase of operation following the approval of a multiple species habitat conservation plan (MSHCP) in Riverside County. Under this plan, Riverside County will adopt a fee-based system for species mitigation. The county will collect fees directly from those proposing incidental takes and will use the funds to purchase lands in accordance with the goals of the county's habitat conservation plan.
Who owns bank?	Private individual (Won Yoo).
Has ownership	No.

Wilson Valley/Won Yoo

Information categories	Responses
changed – If so, why?	
Who can use the bank?	Open to any individual/organization that USFWS will approve. History of credit purchases to date is that credits have been purchased by private parties (i.e., not public institutions).
Establishment date	1997/1998.
Date first credit used	Not available.
Management and operation	
Who manages the habitat?	Bank lands are managed by the owners.
Who markets the credits?	McCollum Associates
Who owns the land?	The bank is privately owned by Won Yoo.
What types of management activities take place?	Bank credits are based on the preservation of existing habitat and are not conditional upon improvements from restoration actions.
Did active management for restoration need to take place to gain credits?	No.
What are long-term management arrangements?	Specified in conservation agreement which we did not obtain.
What is planned lifespan of bank?	Banks have a short term time horizon for sale of existing credits and are not going to expand given move on the part of Riverside County to adopt a fee-based mitigation system.
What types of monitoring take place to ensure bank "performance"?	Information not available.
Performance monitoring	
How frequently does monitoring occur?	Information not available.
Are there provisions for monitoring to trigger remedial actions?	Information not available
Can monitoring reports be obtained?	Information not available.
Subjective appraisals	
Impetus to start bank	Banks were developed for investment purposes following the successful creation of other conservation/mitigation banks in Southern California (e.g., Wheeler and Carlsbad banks).

Wilson Valley/Won Yoo

Information categories	Responses
Issues at startup	Process for establishing the banking agreements took longer than anticipated based on experience of Michael McCollum in establishing other similar agreements.
Difficulty in marketing credits	Credit marketing has been complicated by either the refusal or the reluctance of the USFWS to formally sign the banking agreements. The pool of potential credit purchasers is limited to those who are directed to the banks by the USFWS staff (which does not always occur), or who are already aware of the banks and receive approval from USFWS to use credits from the bank for mitigation.
Issues with current regulations	Current move to a fee-based system for species mitigation in Riverside County has effectively ended the opportunities for the development of additional private mitigation banks in the county. The County has agreed that existing banks will have the opportunity to sell remaining credits.
Is bank a success?	The bank can be viewed as ecologically successful in terms of preserving significant acreage of high quality habitat for the Quino checkerspot butterfly and California gnatcatcher. However, from an ecological assessment, the banks could potentially have had a much larger positive impact for the species had the banking agreements been signed. If more transactions had occurred, the banks would likely have purchased additional land and expanded. Economically, the failure to sign the banking agreements and the move in Riverside County to a fee-based system of species mitigation have introduced delays and constraints that have minimized the potential returns to the bank owners.
Do they know of any banks that were started and failed – If so, why?	Michael McCollum noted that there is effectively no future for private conservation/mitigation banks in Riverside County because of the implementation of the fee-based species mitigation program. He also noted that a general agency commitment to conservation banking is a necessary but not sufficient condition to ensure their development and success. Local USFWS agency staff have significant control in determining local mitigation options and can severely constrain the conditions in which any approved bank can effectively provide mitigation credits.
Relevant permits	
Review notes	Michael McCollum observed that the history of the development banks in Southern California can be characterized by significant initial cooperation on the part of interested parties (e.g., landowners, developers, regulators) to establish model banks followed by increasing skepticism by regulators regarding their benefits and reluctance to use them. This reluctance is demonstrated through a refusal to sign agreements or through incorporating operational constraints that limit their effective viability.

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US Army Corps of Engineers

Compensatory Mitigation Practices in the U.S. Army Corps of Engineers
U.S. Army Corps of Engineers Working Paper, March 2006

Steve Martin* Bob Brumbaugh** Paul Scodari** and David Olson***

This paper reports on the current practice and status of compensatory mitigation authorized by the Corps of Engineers regulatory program. There is no existing comprehensive accounting or description of practices. The National Research Council (NRC) report on mitigation success, or lack thereof and described mitigation types several years ago (NRC, 2002). A year earlier, the Draft Report of the Nationwide Permit Programmatic EIS described mitigation decisions as of 2001, but focused primarily on nationwide permits. The Environmental Law Institute (ELI) proved a detailed description and status of two types of compensatory mitigation, mitigation banks and in-lieu fees as of 2001 (ELI 2002), but did not delve into the extent to which those mitigation services were used. This paper is intended to make available more recent data on compensatory mitigation practices authorized by the Corps of Engineers under permits issued under the auspices of Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. This paper summarizes much of the data collected in a Corps of Engineers Institute for Water Resources (IWR) survey, hereafter referred to as the *2005 Corps Survey of District Mitigation Practices*.

BACKGROUND

The goal of compensatory mitigation is to replace affected aquatic resource functions that will be lost or impaired by permitted activities, or to otherwise maintain or improve the overall aquatic environment. Compensatory mitigation may be provided through the restoration, establishment, enhancement, or preservation of aquatic habitats.

Types of Compensatory Mitigation

Compensatory mitigation can be undertaken by the permittee (or authorized agent) to offset impacts associated with a specific project (i.e., a permittee-responsible mitigation project). Individual mitigation projects may be constructed to provide compensatory mitigation for specific activities authorized by Department of the Army permits. The permittee is responsible for the completion and success of the required compensatory mitigation project.

Mitigation banks and in-lieu fee programs are types of consolidated compensatory mitigation that can also be used to offset losses of waters of the United States authorized by Department of the Army permits.

A mitigation bank is a site or suite of sites where aquatic resources such as wetlands or streams are restored, established, enhanced, and/or preserved for the purpose of providing compensatory mitigation in advance of authorized impacts to similar resources (Federal Register 1995). The mitigation bank, not the permittee, is responsible for the completion and success of the compensatory mitigation associated with permits that use the mitigation bank.

In-lieu fee programs involve the restoration, establishment, enhancement, or preservation of aquatic resources through funds paid to a governmental or non-governmental natural resource management entity (Scodari and Shabman 2000). An in-lieu fee program may consist of a single project or a group of projects. In-lieu fee programs do not typically provide mitigation in advance of permitted impacts. There is often a delay between payments into an in-lieu fee program fund and initiation of a mitigation project to offset permitted impacts. The in-lieu fee program is responsible for the completion and success of the mitigation associated with permits that provide funds to that program.

* Norfolk District Regulatory Branch ** Institute for Water Resources *** Headquarters Regulatory Branch

CORPS 2005 SURVEY ON DISTRICT MITIGATION PRACTICES

Regulatory data on numbers of permit decisions and affected acreage are collected, summarized, and reported regularly by Corps Headquarters. However, detailed information on compensatory mitigation practices, such as the share of permits requiring compensatory mitigation and the type and location of compensatory mitigation (e.g., on-site versus off-site) are not readily available at this time. In 2005, IWR surveyed Corps District regulatory offices using a questionnaire, which is provided in Appendix A, to gather such information. Each District was asked to provide estimates based on best professional judgment when specific data were not already tabulated and readily available. Accordingly, the data on compensatory mitigation practices reported here should be interpreted as estimates that are broadly suggestive of the current compensatory mitigation profile, rather than hard data.

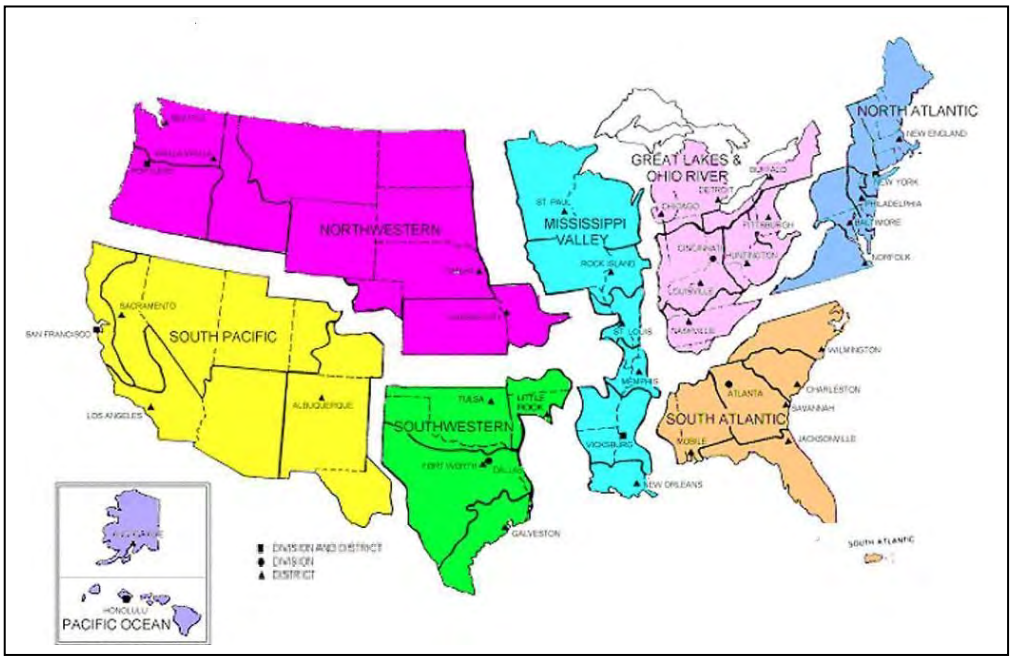

Figure 1. Corps Division and District Regulatory Boundaries.

The data are presented nationally and by geographic regions (i.e., Corps Divisions, see Figure 1). District data were weighted to estimate Division (e.g. regional) shares. For example, estimates of the share of total required compensatory mitigation supplied by different mitigation types (permittee-responsible, mitigation banks, and in-lieu fee programs) are calculated by weighting the reported shares for each District in a Division by the share of total required compensatory mitigation acreage in that Division. Division estimates were weighted in the same manner to calculate national averages. Five of 38 Corps Districts did not respond to the survey and were excluded from weighted averages.

For questions on mitigation shares (e.g., the share of permits for which compensatory mitigation is required), Districts were asked to provide a single estimate for the three-year period of 2002 to 2004. In this paper, reported shares for 2002-2004 were interpreted as Fiscal Year (FY). 2003 estimates so that they could be combined with data on permit authorizations in that year. FY 2003 is the most recent year for which complete records on Department of the Army permits and authorized impacts are available nationally at the time the data compilation was undertaken.

RESULTS

FY 2003 Permits and Impacts

In Fiscal Year 2003, there were 85,878 permit authorizations issued, resulting in impacts to approximately 21,413 acres of wetlands (Table 1). General permits (i.e., nationwide permits and regional general permits) comprised nearly 92 percent of all permits issued, while accounting for only about one-half of the wetland acreage filled (53 percent). Impacts to tidal wetlands represented almost 8 percent of all authorized impacts. Individual permits accounted for nearly 76 percent of those tidal wetland impacts.

Table 1. Permit Authorizations and Aquatic Impacts in FY 2003. Source: Corps Quarterly Permit Data System (QPDS).

Permit Type	Number of Permit Authorizations Issued	Non-Tidal Wetland Impacts Authorized (Acres)	Tidal Wetland Impacts Authorized (Acres)
Individual	7,075	8,767	1,282
General	78,803	10,955	409
Total	**85,878**	**19,722**	**1,691**

Permits Requiring Compensatory Mitigation

In FY 2003, 43,550 acres of wetland compensatory mitigation was required for authorized impacts, including 3,407 acres of tidal wetland mitigation and 40,143 acres of non-tidal wetland mitigation. Nationally, 21 percent of all permits issued in FY 2003 required compensatory mitigation. The share of general permits that required compensatory mitigation was 19 percent; 51 percent of individual permits required compensatory mitigation. See Table 2 for estimates of the share of permits for which some form of compensatory mitigation was required.

The low estimated proportion of permits entailing compensatory mitigation in FY 2003 reflects the fact that many activities authorized by general permits do not typically require compensatory mitigation, because of the nature of those activities or the types of waters of the United States impacted. Examples of activities authorized by general permits that may not require compensatory mitigation include maintenance of existing permitted facilities, pier construction, shoreline stabilization, installation of underwater utilities, minor dredging, temporary access, and cleanup of hazardous wastes.

Similarly, many activities authorized by individual permit may involve only minor or transitory impacts to waters of the United States, and often do not require compensatory mitigation. Individual permits that may not require compensatory mitigation include activities such as dredging projects, ocean disposal of dredged material, commercial or industrial piers and wharves, and shoreline stabilization projects.

Table 2. Estimated Share of Permits Requiring Compensatory Mitigation in FY 2003. Source: *2005 Corps Survey of District Mitigation Practices* and Corps QPDS data.

Corps Division	Number of Permits Issued (FY 2003)	Percentage of Individual Permits Requiring Compensatory Mitigation	Percentage of General Permits Requiring Compensatory Mitigation	Percentage of All Permits Requiring Compensatory Mitigation
Lakes and Rivers	12,924	24	28	21
Mississippi Valley	14,576	86	25	31
North Atlantic	15,829	30	6	6
Northwestern	8,397	91	30	30
Pacific Ocean	1,267	14	8	9
South Atlantic	23,478	72	20	24
South Pacific	4,500	79	69	36
Southwestern	4,907	33	7	10
National Average		**51**	**19**	**21**

Types of Compensatory Mitigation

Permittee-responsible mitigation is estimated to account for 60 percent of all compensatory mitigation acreage in FY 2003, with mitigation banks and in-lieu fee programs providing 33 percent and 7 percent respectively. These national averages mask considerable variation in the estimated use of each mitigation type across Corps Divisions. Table 3 presents estimates of the shares of required compensatory mitigation in FY 2003 that were supplied by different mitigation types (permittee-responsible mitigation, mitigation banks, and in-lieu fee programs).

Nationally, the estimated share of mitigation supplied by mitigation banks is much higher (and the reported share for permittee-responsible mitigation is much lower), than many observers of the permit program have surmised. It is not clear what accounts for this. Since estimates reported in Table 3 are based on the best professional judgment of District staffs, the discrepancy may reflect imprecision in these judgments. Alternatively, the seemingly high estimate of mitigation bank use may reflect an increase in bank use in recent years that has not been fully appreciated by observers of the Corps permit program. Specific data on mitigation shares accounted for by the different mitigation types will not become available until the new Corps automated information system is fully developed and deployed in all Corps Districts. Readers should note that the data reported in Table 3 incorporate estimates of the use of different mitigation types in each District and the acreage of compensatory mitigation provided in that District. Many permits are authorized based on compensatory mitigation decisions that call for use of more than one type of compensatory mitigation for the respective permit. The extent that this would affect mitigation bank share is not estimated in this paper.

Table 3. Estimated Use of Different Compensatory Mitigation Types in FY 2003.
Source: *2005 Corps Survey of District Mitigation Practices* and Corps QPDS data.

Corps Division	Permittee-Responsible Mitigation (percent)	Mitigation Banks (percent)	In-Lieu Fee Programs (percent)
Lakes and Rivers	62	32	5
Mississippi Valley	28	64	8
North Atlantic	69	23	9
Northwestern	90	4	6
Pacific Ocean	20	0	80
South Atlantic	70	24	6
South Pacific	80	16	4
Southwestern	58	38	4
National Average	**60**	**33**	**7**

Impacts Compensated Through Mitigation Banks and In-Lieu Fee Programs

Each District estimated the share of total mitigation acreage provided by mitigation banks and in-lieu fee programs as compensation for impacts to three types of aquatic resources: tidal wetlands, non-tidal wetlands, and streams. These estimates are presented in Tables 4 and 5.

The data show that mitigation banks have been used almost entirely to compensate for impacts to non-tidal wetlands. Nationally, only 3 percent of the compensatory mitigation supplied by mitigation banks in FY 2003 was for impacts to tidal wetlands, and only 4 percent was for stream impacts. This contrasts sharply with the distribution provided by in-lieu fee programs in FY 2003. Roughly 14 percent of the compensatory mitigation supplied by in-lieu fee programs was for impacts to tidal wetlands, and 27 percent was compensation for stream impacts.

Table 4. Estimated Use of Mitigation Banks in FY 2003, by Type of Impacted Waters.
Source: *2005 Corps Survey of District Mitigation Practices.*

Corps Division	Tidal Wetlands (percent)	Non-Tidal Wetlands (percent)	Streams (percent)
Lakes and Rivers	0	99	1
Mississippi Valley	4	96	0
North Atlantic	0	91	9
Northwestern	0	91	9
Pacific Ocean	0	0	0
South Atlantic	6	87	8
South Pacific	0	98	2
Southwestern	0	84	16
National Average	**3**	**92**	**4**

Table 5. Estimated Use of In-Lieu Fee Programs in FY 2003, by Type of Impacted Waters.
Source: *2005 Corps Survey of District Mitigation Practices.*

Corps Division	Tidal Wetlands (percent)	Non-Tidal Wetlands (percent)	Streams (percent)
Lakes and Rivers	0	2	98
Mississippi Valley	29	57	14
North Atlantic	4	77	19
Northwestern	0	10	90
Pacific Ocean	10	53	37
South Atlantic	9	80	11
South Pacific	0	50	50
Southwestern	14	71	15
National Average	**14**	**58**	**27**

Location of Permittee-Responsible Mitigation

Mitigation banks and in-lieu fee programs provide compensatory mitigation for permitted impacts at some distance from the impact sites. Permittee-responsible mitigation, however, can take place on or off the impact site, or consist of a combination of compensatory mitigation activities located both on- and off-site. Permittee-responsible mitigation based on a combination of on-and off-site components is a common practice, and often represents an effort to compensate for specific functions provided by the impacted aquatic resource. For instance, impacts to wildlife habitat are often compensated most effectively off-site than in an area adjacent to the permitted development activity, while impacted resource functions such as flood storage and or maintenance of water quality, may be effectively compensated for on-site.

Corps District estimates suggest that nationally 55 percent of all compensatory mitigation acreage supplied by permittee-responsible mitigation was provided entirely on-site. An estimated eighteen percent was provided entirely off-site and 27 percent was provided by a combination of on-site and off-site compensatory mitigation activities. Table 6 reports these estimates on the location of permittee-responsible mitigation in FY 2003.

Table 6. Location of Permittee-Responsible Mitigation in FY 2003. Source: *2005 Corps Survey of District Mitigation Practices*.

Corps Division	Permittee-Responsible Mitigation On-Site (percent)	Permittee-Responsible Mitigation Off-Site (percent)	Permittee-Responsible Mitigation Combining On-Site and Off-Site (percent)
Lakes and Rivers	56	26	18
Mississippi Valley	49	34	17
North Atlantic	50	18	32
Northwestern	60	19	20
Pacific Ocean	18	18	63
South Atlantic	60	9	31
South Pacific	40	26	34
Southwestern	38	38	24
National Average	**55**	**18**	**27**

Ecological Performance Standards

Ecological performance standards are used to determine whether a compensatory mitigation project is developing into the desired aquatic habitat type and providing the expected functions. As per the Corps of Engineers Regulatory Guidance Letter 02-02, all compensatory mitigation types, including permittee-responsible mitigation, mitigation banks, and in-lieu fee programs, are normally held to some type of performance standards, which would be documented in the specific permit special conditions.

Ecological performance standards are typically based on aquatic resource function and/or structure. For example, ecological performance standards may utilize functional assessment criteria for streams, wetlands, and other aquatic resources. They may also be defined in terms of the physical characteristics of the mitigation projects, such as the criteria in the Corps of Engineers Wetland Delineation Manual (1987 Manual) (Environmental Laboratory 1987), relating to wetland hydrology, soils, and vegetation.

In the *2005 Corps Survey of District Mitigation Practices*, each District was asked to report on the use of performance standards for different mitigation types. Table 7 summarizes the use of different types of performance standards, by Corps Division.

The survey results indicate that ecological performance standards are required for most compensatory mitigation projects regardless of mitigation type. The 1987 Manual criteria are commonly used as performance standards, although more so for certain mitigation types. Nationally, an average of 92 percent of mitigation banks were held to performance standards based at least in part on the 1987 Manual criteria. By contrast, roughly 60 percent of permittee-responsible mitigation and in-lieu fee programs used 1987 Manual criteria to evaluate compensatory mitigation site performance. This difference may reflect that permittee-responsible mitigation and in-lieu fee programs are the primary compensatory mitigation types used to provide compensation for impacts to streams, for which the 1987 Manual criteria are not applicable.

Table 7. Estimated Use of Performance Standards, by Mitigation Type. Source: *2005 Corps Survey of District Mitigation Practices*.

Corps Division	Permittee-Responsible Mitigation			Mitigation Banks			In-Lieu Fee Programs		
	1987 Manual criteria (percent)	Functional/ ecological standards (percent)	Other standards (percent)	1987 Manual criteria (percent)	Functional/ ecological standards (percent)	Other standards (percent)	1987 Manual criteria (percent)	Functional/ ecological standards (percent)	Other standards (percent)
Lakes and Rivers	83	83	17	100	83	17	50	75	25
Mississippi Valley	100	100	33	100	100	17	33	67	67
North Atlantic	50	75	25	100	100	0	100	100	0
Northwestern	100	100	0	100	75	0	100	100	0
Pacific Ocean	0	100	0	100	100	100	0	100	0
South Atlantic	60	80	60	60	100	60	50	50	100
South Pacific	50	100	50	100	100	0	100	100	0
Southwestern	50	100	50	75	100	25	67	100	33
National Average	**62**	**92**	**29**	**92**	**95**	**27**	**63**	**86**	**28**

Trends in Commercial and Single User Mitigation Banks

Numbers of commercial banks are increasing more rapidly than the population of single-user banks. Commercial mitigation banks produce compensatory mitigation credits for sale to permit recipients in need of compensatory mitigation. Single user mitigation banks are developed and used by a single entity, such as a state department of transportation, to provide compensatory mitigation exclusively for its own impacts.

Reporting of the number of banks across the country is complicated by what are known as "umbrella banks." Umbrella mitigation banks can have multiple mitigation sites, but are governed by a single mitigation bank instrument. Umbrella mitigation banks have been used primarily in the single-user mitigation bank mode. However, there are a number of commercial umbrella mitigation banks now in operation, such as the statewide mitigation program operated by the Minnesota Bureau of Water and Soil Resources. Under that program, many individual landowners have restored wetlands for credit production and sale. In the discussion below, however, the Minnesota program as well as any other umbrella mitigation bank is tabulated as a single bank.

Commercial Mitigation Banks

Commercial mitigation bank development increased more than twelve-fold between 1995 and 2001. Although the rate of increase has slowed in more recent years, the number of commercial mitigation banks nearly doubled between 2001 and 2005. Table 8 shows the number of Federally approved commercial mitigation banks at three points in time: 1995, 2001, and 2005.

By 2005, at least 305 commercial mitigation banks had received Federal approval. The greatest increase in commercial mitigation banks from 1995 to 2005 occurred in the Mississippi Valley and South Atlantic Divisions. About 20 percent of all approved commercial mitigation banks had sold out their credit capacity by 2005; more than half of the sold-out mitigation banks were located in the Mississippi Valley Division. Another 149 commercial mitigation banks with a high likelihood of approval are in the proposal stage; roughly 36 percent of these proposed mitigation banks are located in the South Atlantic Division.

Table 8 Trends in the Development of Commercial Mitigation Banks. Source: Estimates for 1995 are from Scodari and Brumbaugh (1996); 2001 estimates are from Environmental Law Institute (2002); 2005 estimates are from the *2005 Corps Survey of District Mitigation Practices*, and District web sites.

Corps Division	1995	2001	2005	Proposed (as of 2005)	Sold Out (as of 2005)
Lakes and Rivers	2	39	43	15	10
Mississippi Valley	1	22	87	36	30
North Atlantic	2	18	40	12	5
Northwestern	0	18	23	10	2
Pacific Ocean	0	0	1	0	0
South Atlantic	5	57	83	54	6
South Pacific	3	16	14	15	5
Southwestern	0	6	14	7	1
Total	**13**	**176**	**305**	**149**	**59**

Single-User Mitigation Banks

Single user banks were by far the predominant type of bank developed prior to the issuance of the Federal Mitigation Banking Guidance in 1995. The rate at which new single user banks have been developed has far been outstripped by the rate of increase and numbers of commercial banks. Table 9 presents estimates of the number of established single-user mitigation banks by Corps Division and nationally at three points in time: 1992, 2001, and 2005. Several factors complicate the interpretation of these estimates as trends, however. First, the data for these years were derived from different sources that may not have defined mitigation banks in the same way. The *2005 Corps Survey of District Mitigation Practices*, which was the source for the year 2005 estimate, sought information on the number of Federally-approved single-user mitigation banks in each District. Some Districts reported only those mitigation banks that had received Federal approval in accordance with the 1995 Federal banking guidance. The estimates for 1992 represent single-user mitigation banks developed prior to issuance of the 1995 Federal banking guidance, and the reported estimates for 2001 include a mix of mitigation banks that were and were not certified in accordance with Federal guidelines. Second, it is not clear whether any of the reported data exclude single-user mitigation banks that had been fully debited as of the reporting year. For these reasons, the reported 2005 inventory of single-user mitigation banks likely understates the number of single-user mitigation banks that have been used to provide compensatory mitigation for permits as of that year.

Table 9 Trends in the Development of Single-User Mitigation Banks. Source: Year 1992 and 2001 data are from Environmental Law Institute (1994, 2002) and Brumbaugh and Reppert (1994); Data for 2005 are from the *2005 Corps Survey of District Mitigation Practices.*

Corps Division	1992	2001	2005	Proposed(as of 2005)
Lakes and Rivers	3	6	18	10
Mississippi Valley	9	15	10	8
North Atlantic	4	10	12	5
Northwestern	5	11	5	9
Pacific Ocean	0	0	0	0
South Atlantic	11	24	33	17
South Pacific	11	4	0	0
Southwestern	0	6	8	0
National Total	**43**	**76**	**86**	**49**

In-Lieu Fee Mitigation Programs

The number of operational in-lieu fee programs grew ten-fold between 1995 and 2001, but then declined by about one-third between 2001 and 2005. Table 10 presents the number of operating in-lieu fee programs in selected years from 1995 to 2005 and the number of discontinued and proposed in-lieu fee programs as of 2005. The decline appears to be due to the discontinuation of many programs in recent years; indeed, the number of in-lieu fee programs that had been discontinued as of 2005 is nearly as great as the number of operational programs in that year. The decline in numbers of in-lieu fee programs over the last several years may be due largely issuance of Federal guidance for the development and use of in-lieu fee mitigation programs in 2000. That guidance established a hierarchy for the use of different mitigation options that favored approved mitigation banks over in-lieu fee mitigation and also called for in-lieu fee mitigation programs to tighten up standards.

Table 10 Trends in the Development of In-Lieu Fee Programs. Source: Year 1995 data are from Scodari and Brumbaugh (1996); year 1999 data are from Scodari and Shabman (2000); year 2001 data are from ELI (2002); year 2005 data are from the *2005 Corps Survey of District Mitigation Practices* and State agency web sites.

	Operational In-Lieu Fee Programs				Discontinued In-Lieu Fee Programs	Proposed In-Lieu Fee Programs
Corps Division	**1995**	**1999**	**2001**	**2005**	**As of 2005**	**As of 2005**
Lakes and Rivers	2	26	34	8	29	1
Mississippi Valley	2	6	20	5	15	1
North Atlantic	2	4	3	5	0	0
Northwestern	1	2	5	5	1	2
Pacific Ocean	0	4	4	4	0	0
South Atlantic	1	7	8	2	7	0
South Pacific	0	3	8	18	0	0
Southwestern	0	1	5	11	0	3
National Average	**8**	**53**	**87**	**58**	**52**	**7**

Compensatory Mitigation Costs to Permittees

The options potentially available to permittees for providing compensatory mitigation include permittee-responsible mitigation, mitigation banks, and in-lieu fee programs. Costs to permittees for these different mitigation types are reviewed briefly below.

Costs of Permittee-Responsible Mitigation

Costs for permittee-responsible mitigation include compliance, time, and risk costs. Compliance costs include costs for identifying and securing compensatory mitigation sites, and preparing mitigation project plans for Corps review and approval. After the District Engineer approves a permittee-responsible compensatory mitigation plan, the permittee incurs compliance costs for the construction, monitoring, and maintenance of the compensatory mitigation project. The time costs of permittee-responsible mitigation include potential opportunity costs of any delay in permit issuance associated with the development and approval of mitigation plans. Risk costs include potential remediation costs if the compensatory mitigation project fails to fulfill its objectives.

Nationwide data on the costs of permittee-responsible mitigation are not available, in part because these costs are not fully observable. Such costs are likely highly variable, however, and driven largely by the nature and size of the permitted impacts, the difficulty of project implementation, and land costs.

Wetland Credit Prices

When a permittee is authorized to provide compensatory mitigation through use of a commercial mitigation bank or in-lieu fee program, the cost to the permittee is the credit price (fee rate) charged for the amount of credits deemed necessary by the District Engineer. When a commercial mitigation bank is used, the permittee pays the mitigation bank a credit price negotiated by the permittee and the bank. When an in-lieu fee program is used, the permittee typically pays a standard fee rate per unit of permitted impact.

There is a considerable variation in wetland credit prices within and across the country. Prices well in excess of $100,000 per acre or per credit have been reported for some commercial bank and in-lieu fee transactions in rapidly urbanizing regions of the country, such as in the Chicago, Norfolk, Portland, and Wilmington Districts. The range of credit prices charged for wetland compensatory mitigation by commercial mitigation banks and in-lieu fee programs by Corps Division is presented in Table 11. These prices were reported by one or more Districts within each Corps Division in the Corps Survey in 2005. These data are based on a limited set of Corps Districts that responded to the survey questions on wetland credit prices, and may not be fully indicative of the range of wetland credit prices across the country. Nevertheless, these limited data indicate that there is considerable variation in wetland credit prices within and across Corps Divisions.

Table 11 Wetland Credit Prices Charged by Commercial Mitigation Banks and In-Lieu Fee Programs. (Prices are on a per-credit or per-acre basis). Source: *2005 Corps Survey of District Mitigation Practices*.

Corps Division	Wetland Credit Prices Charged by Commercial Mitigation Banks	Wetland Credit Prices Charged by In-Lieu Fee Programs
Lakes and Rivers	$7,000 - $145,000	$12,000
Mississippi Valley	$1,500 - $100,000	$18,000
North Atlantic	$16,000 - $350,000	$16,500 - $350,000
Northwestern	$40,000 - $120,000	$30,000
Pacific Ocean		$500 - $30,000
South Atlantic	$4,000 - $65,000	$12,000 - $122,000
South Pacific	$400,000	$125,000
Southwestern	$2,200 - $25,000	$3,000 - $30,000

Stream Credit Prices

The *2005 Corps Survey of District Mitigation Practices* also requested data on credit prices for stream mitigation charged by commercial mitigation banks and in-lieu fee programs in each Corps District. However, only four Districts provided data on the prices of stream credits charged by mitigation banks, and only 11 Districts provided data on stream credit prices charged by in-lieu fee programs. Moreover, while most of the responding Districts reported stream credit prices in terms of linear feet, some Districts reported prices based on other units of measure (e.g., square feet) that are not readily comparable. For those Districts that reported stream credit prices per linear foot, the reported prices charged by commercial mitigation banks ranged from $45 to $400, and the reported range of prices charged by in-lieu fee programs was $15 to $400.

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AN ECONOMIC EVALUATION OF A MULTI-AREA RECREATION SYSTEM

Michael E. Wetzstein

Researchers as well as planners have been concerned with the impact of augmenting an existing recreation system with new recreational areas. That is, they are concerned with the substitution or duplication of services stemming from additional numbers of recreational areas. The increase in benefits from a recreational system resulting from the introduction of new recreational areas are not the benefits accrued to new areas. This results from a substitution or duplication of services that leads to individuals shifting away from existing areas to the new areas. Thus, when measuring the net benefits resulting from introducing new areas, a loss in benefits accruing to the existing areas should be accounted for. This problem confronting both researchers and planners is addressed by determining the demand for individual recreational areas given a multi-area system.

A methodology for modeling a multi-area recreation system has been developed by Burt and Brewer; and Cicchetti et al. In both cases, the prices of recreational areas are employed as independent variables in the models. The problem of multi-areas addressed by these authors involved only six recreational areas each, and, thus, their models contained six independent price variables. As indicated by the authors, incorporating the recreational area prices separately into a demand equation does not pose an estimation problem when the number of recreational areas under consideration are relatively small. However, when there exists a relatively large number of recreational areas, problems with multicollinearity and possible degrees of freedom emerge. Thus, when researchers are confronted with a relatively large number of areas, some alternative model is required to circumvent this estimation problem.

But this problem of multi-area analysis is not unique to the field of recreation. Other fields, in particular international trade, are faced with the same evaluation problem. That is, the demand for both recreation activities and commodities traded in international markets are distinguished by their place of supply. Commodities traded in the world market are distinguished not only by the type of commodities, but also by their region of supply. Likewise, commodities or activities in recreation such as boating, fishing, and hiking are distinguished by the type of activities and also by their region of supply.

This paper develops a multi-area recreational model that systematically simplifies the demand functions so that they are relevant to the practical purposes of estimation. Specifically, a model is developed that circumvents the problems encountered by a relatively larger number of recreational areas. The procedure followed in developing the model is based on an international trade model by Armington. As an application for policy implications, the model is employed to measure the substitution of services, which results in individuals shifting away from existing recreation areas to new areas based on the price of this activity.

THEORY OF RECREATIONAL DEMAND

Recreation demand models are generally based on the idea that consumers and recreation activities are distinguished by their place of residence or origin. Consumer origins may be represented by a vector, $C = (C_1, C_2, \ldots C_n)$, and the different types of recreation activities can also be represented as a vector of activities, $A = (A_1, A_2, \ldots A_m)$. In addition, each activity is differentiated according to where it is supplied by a different recreational area, that is, $A_i = (A_{i1}, \ldots A_{ir})$, where r is the number of recreational areas. The vector of activities can then be represented as

$$(1) \quad A = (A_{11}, A_{12}, \ldots, A_{1r}, A_{21}, \ldots, A_{2r}, \ldots, A_{m1}, A_{m2}, \ldots, A_{mr}).$$

Thus, there are n demands for each activity and m•r activities, thus there exists n•m•r activity demands.

The general approach to deriving outdoor recreation demand functions identified above, is to express a separable utility function of all m•r activities, $U = U(A)$, subject to a budget constraint. Clawson and Knetsch (1966) define outdoor recreation activities as those typically carried on outdoors and thus requiring space. Given this definition, it is assumed that preference

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structures for outdoor recreation generally fit the definition of weak separability. For a discussion of this assumption refer to Wetzstein. Thus, the demand functions for the i_{th} origin would have the following general form

$$(2) \quad A_{itj} = A_{itj}(I_i, P_{i11}, P_{i12}, \ldots, P_{i1r}, P_{i21}, \ldots, P_{i2r}, P_{im1}, P_{im2}, \ldots, P_{imr}), (i = 1, 2, \ldots, n)\ (t = 1, 2, \ldots, m)\ (j = 1, 2, \ldots, r).$$

Where I_i is the aggregation of individual income in origin "i" allocated to outdoor recreation and P_{itj} is the price of activity "t" from recreational area "j" for origin "i." The close association of similar recreation activities available at different recreational areas is not implied in (2). For example, the recreation activity skiing may be obtained at a number of recreational areas. Thus, a utility function may be specified that incorporates this close association. In this regard, a utility function must be specified in such a manner that the utility U_t can be distinguished. That is, under what conditions can a utility function be specified as

$$(3) \quad U = U(U_1, U_2, \ldots, U_m), \text{ where}$$

$$U_t = U_t(A_{t1}, A_{t2}, \ldots, A_{tr})$$

Equation (3) states that all combinations of A_{t1}, A_{t2}, . . . , A_{tr}) which result in the same value of U_t are equally preferred. The necessary and sufficient condition for (3) is that marginal rates of substitution between any two activities of the same characteristics must be independent of the quantities of the activities composed of all other characteristic sets. Specifically, this means independence among activities. That is, individuals' preference for different activities cannot be influenced by their consumption of other activities.[1] For example, individuals' preference for hiking are not influenced by their consumption of swimming. The resulting demand functions are

$$(4) \quad A_{itj} = A_{itj}(I_{it}, P_{it1}, P_{it2}, \ldots, P_{itr}),$$

where I_{it} is the aggregation of individual income in origin i allocated to activity t.

Burt and Brewer applied (4) in their estimation of six recreational areas. If there exists many more alternative recreational areas (4) becomes too complicated for applied use, and, thus, further simplifying assumptions must be imposed for estimation. Researchers in international trade confronted with this same problem assume that consumers in a country consider all the alternative origins of supply for a given commodity imported from a particular country as a single alternative (Armington). Applying this assumption to recreation, it is assumed a consumer who engages in activity t at area j considers all the alternative areas for acquiring activity t as a single alternative to acquiring t at area j. For example, an individual skiing at a certain ski resort considers all the alternative ski resorts as a single alternative to skiing at this resort. Thus, the utility function is represented as

$$(5) \quad U_t = U_t(A_{tj}, Q_{tj}),$$

$$Q_{tj} = Q_{tj}(A_{t1}, A_{t2}, \ldots, A_{tj-1}, \ldots, A_{tj+1} \ldots, A_{tr}),$$

for a consumer who engages in activity t at area j. Note that Q_{tj} is a function of all the recreational areas associated with the tth activity, excluding A_{tj}. Therefore (5) will result in the following demand function for each n origins

$$(6) \quad A_{tj} = A_{tj}(I_t, P_{tj}, W_{tj}),$$

where W_{tj} is a function of the tth activity prices from their recreational areas, excluding P_{tj}.

In order to estimate the degree of substitution between recreation activities at various areas, assume that the elasticities of substitution between A_{tj} and Q_{tj}, for individuals who engage in activity t at area j, are constant. An additional assumption for estimation is that an individual's elasticity of substitution between any two alternative activities competing in a market is the same as that between any other pair of alternative activities competing in the same market. That is, given four ski resorts, an individual's elasticity of substitution between resort a and b is the same as between resort c and d. These assumptions are equivalent to the specification that U_ts are constant-elasticity-of substitution (CES) functions having the general form

$$(7) \quad U_t = [\delta A_{tj}^{\rho t} + (1-\delta)\ Q_{tj}^{\rho t}]^{1/\rho_t},$$

$$Q_{tj} = \sum_{k \neq j}^{r} (A_{tk}).$$

The price index associated with Q_{tj}, W_{tj} must not be specified as any function of alternative activity prices. The prices of alternative activities must correspond with the optimum allocation of the alternative activities. This condition is fulfilled if

$$(8) \quad W_{tj} = P_{tk}/(\partial Q_{tj}/\partial A_{tk}) \text{ for all } k \neq j$$

which corresponds to the first order equimarginal conditions for optimum mix of the alternative activities (Solow). Equation (7) implies

$$(9) \quad \partial Q_{tj}/\partial A_{tk} = 1.$$

Substituting (9) into (8) results in

$$(10) \quad W_{tj} = P_{tk} \text{ for all } k \neq j.$$

From (7) it can be shown that the optimal value

[1] For a general discussion of independence among commodities, refer to Green; Gorman; Strotz. For applications of independence to recreation activities, refer to Cicchetti et al.; Rausser and Oliveira; Wilson 1970, 1972.

of C_{tj}, given P_{tj} and W_{tj} as prices for C_{tj} and Q_{tj}, respectively, is

$$(11) \qquad A_{tj} = b_{tj}^{-\sigma t} Q_{tj} (P_{tj}/W_{tj})^{\sigma t},$$

where σ_t is the elasticity of substitution in the tth market for consumers engaged in activity t at area j, and b_{tj} is a constant.[2] For estimation purposes (11) can be written in a number of forms. For example, as a market share equation, V

$$(12) \qquad V = A_{tj}/Q_{tj} = b_{tj}^{-\sigma t} (P_{tj}/W_{tj})^{\sigma t}.$$

For empirical estimation, a random disturbance term μ is introduced in (12) to account for measurement and stochastic errors. Assuming that the terms can be entered multiplicatively, equation (12) can be estimated from the following loglinear stochastic specification

$$(13) \qquad \ln(V) = -\sigma_t \ln(b_{tj}) + \sigma_t \ln(P_{tj}/W_{tj}) + \ln(\mu).$$

VALUATION OF ACTIVITIES

For illustration purposes, an empirical application of the above theoretical model is presented. The multi-area recreation system considered is the 24 wilderness, primitive, and wilderness back country areas in California, where the recreation activity C_t considered is wilderness area recreation. Thus, the market share for a wilderness area is defined as

$$(14) \qquad V = A_{ij}/\Sigma_{k \neq j} A_{ik},$$

where A_{ij} is the number of visits incurred by origin "i" to wilderness area "j".

With regard to the price variable, a number of authors have expressed this variable in terms of travel costs, while others have it in terms of highway miles (Burt and Brewer; Sinden). In this paper, no attempt was made to convert distance into travel cost.

An additional problem in identifying an appropriate price variable, is the heterogeneous nature of the activities. Wilderness areas in California are not homogeneous; therefore, distances are weighted by an attractiveness variable, S, to account for this heterogeneous nature. The attractiveness variable is a principal component index that accounts for wilderness area variations in miles of streams and trails; forest; and number of peaks, lakes, entry and exit nodes, and campground unit characteristics (Wetzstein and Green). Thus the price of a wilderness activity is expressed as distance, D, weighted by attractiveness. The independent variable is then expressed as

$$(15) \qquad (P_{ij}/W_{ij}) = (D_{ij}/S_{.j}) \,/\, \Sigma_{k \neq j}(D_{ij}/S_{.k}).$$

This variable measures the alternative opportunities to the jth area from origin "i." The denominator expresses the hypothesis that the farther area "k" is away from origin "i," the less of a competing factor it becomes, regardless of its attractive features. However, this competitive factor is relative to the area's attractiveness. The more attractive an alternative wilderness area is, as measured by the principal component index $S_{.k}$, the more competition it poses for the jth area. Thus, distance is divided by $S_{.k}$ with the result then summed over all of the alternative areas. The attractiveness and distance of alternative areas are relative to the given area; hence the denominator of equation (15) is divided into $D_{ij}/S_{.j}$ to account for this property.

Similar proxies have been employed previously. For example, Grubb and Goodwin employed.

$$(16) \qquad \sum_{j=1}^{N} \ln S_j/D_{ij}$$

to account for the alternative areas' substitution effect for water recreational activities, where S_j is the area of the jth lake and D_{ij} is distance.

AN APPLICATION AND RESULTS

All 58 origins (California counties) for 22 existing wilderness areas were combined from cross-sectional data for years 1972–75.[3] Ordinary least squares was the estimation technique applied independently to each separate wilderness area. The results of estimating the market share equations are presented in Table 1. As expected, the price coefficients exhibit negative signs. That is, the further a recreation area is from an origin and the less attractive the area is relative to alternative areas, the lower is the level of use at that area. The t-values indicate that all of the coefficients are significant at the .001 level, except the price coefficient associated with Hoover, which is significant at the .005 level. Furthermore, no serial correlation or structural changes over time are apparent in the wilderness data (Wetzstein et al.).[4] The overall goodness of fit R^{-2} ranges from a low of 0.035 for Hoover wilderness area to a high of 0.733 for High Sierra wilderness area.

[2] Derivation of this result can be found in the mathematical appendix to Armington's paper.

[3] A number of wilderness areas were aggregated due to the inability of separating their representative permit use. These adjacent wilderness areas are Lassen and Caribou, John Muir and Sequoia-Kings.

[4] A possibility of heteroskedasticity exists in the model specification because of aggregation of the data, as mentioned by an anonymous reviewer. Therefore, the estimated coefficients, although unbiased, may not be efficient. Generally, past research in recreation has not been concerned with this problem. One exception is Wetzstein and McNeely, who applied weighted least-squares to aggregated data in order to obtain unbiased and efficient estimators.

TABLE 1. Estimated Recreation Market Share Functions and Elasticity of Substitutions for Wilderness Areas in California

Wilderness Area	Dependent Variable (A_{ij}/Q_{ij})	Constant	Price (P_{ij}/W_{ij})	Price t-ratio	Degrees of Freedom	$\bar{R}^2$ [a]
Cucamonga		- 9.422	-1.308	6.880	43	0.513
Desolation		- 8.224	-2.000	10.041	204	0.328
Dome Land		-10.498	-2.826	4.955	47	0.329
Hoover		- 7.653	-0.516	2.771	183	0.035
Marble Mountain		- 9.415	-2.009	15.583	179	0.573
Minarets		- 7.194	-0.756	3.600	182	0.057
Mokelumne		- 9.126	-2.287	13.111	147	0.536
San Gabriel		-10.838	-1.479	6.512	39	0.509
San Gorgonio		- 8.670	-2.069	14.326	104	0.660
San Jacinto		- 8.307	-2.116	6.916	86	0.350
San Rafael		- 9.710	-2.809	9.237	86	0.492
South Warner		- 8.594	-1.321	6.079	166	0.177
Thousand Lakes		- 8.345	-1.807	10.827	137	0.457
Ventana		- 8.107	-1.543	9.961	182	0.349
Yolla Bolly		- 8.522	-1.854	10.283	129	0.446
Agua Tibia		- 9.332	-2.464	7.087	42	0.534
Emigrant Basin		- 9.575	-1.935	12.980	180	0.481
High Sierra		- 8.043	-2.685	11.282	45	0.733
Salmon-Trinity		- 8.719	-1.502	7.808	196	0.233
Yosemite		- 7.991	-1.920	13.519	216	0.456
Lassen and Caribou		- 8.382	-1.556	9.211	136	0.380
John Muir and Sequoia-Kings		- 9.681	-1.907	12.497	216	0.417

[a] $\bar{R}^2$ is the adjusted R^2 value.

TABLE 2. Percentage Change in Proportion of Visitor Days in Existing Wilderness Areas Resulting From Introducing All the New Wilderness Study Areas (WSA)

Wilderness Area	County: Los Angeles	Sacramento	San Diego	San Francisco	Shasta
Cucamonga and WSA	- 1.3%	- 4.0%	- 1.7%	- 3.4%	1.1%
Desolation	- 18.1	- 25.9	- 13.1	- 23.4	- 19.2
Dome Land	- 25.1	- 29.7	- 17.6	- 28.1	- 21.3
Hoover and Hoover Extension	25.1	27.2	27.1	26.6	27.3
Marble Mountain and WSA	110.4	90.4	122.4	105.0	102.4
Minarets and WSA	19.8	16.6	22.6	17.3	20.0
Mokelumne and WSA	1.6	13.6	5.3	11.0	5.1
San Gabriel	- 15.4	- 16.5	- 10.9	- 15.7	- 11.7
San Gorgonio	- 20.2	- 20.8	- 14.9	- 19.9	- 14.4
San Jacinto	- 20.2	19.8	- 15.4	- 18.9	- 12.9
San Rafael and Madulce	158.0	69.9	126.4	56.5	80.9
South Warner	- 9.2	- 15.9	- 5.9	- 14.5	- 13.0
Thousand Lakes	- 8.0	- 20.9	- 3.2	- 19.0	- 17.7
Ventana	- 14.4	- 19.2	- 10.1	- 18.6	- 14.6
Yolla Bolly	- 15.9	- 23.1	- 11.1	- 21.8	- 18.5
Agua Tibia	- 22.4	- 19.3	- 17.9	- 18.6	- 11.0
Emigrant Basin	- 17.8	- 24.1	- 12.9	- 22.7	- 18.3
High Sierra and WSA	164.8	139.2	186.2	142.8	162.0
Salmon-Trinity Alps and Salmon-Trinity Alps Addition	56.4	50.4	63.1	50.1	75.6
Yosemite	- 19.6	- 24.4	- 14.8	- 23.2	- 19.1
Lassen and Caribou	- 14.0	- 19.9	- 10.0	- 18.6	- 15.9
John Muir and Sequoia-Kings	- 19.7	- 24.3	- 15.0	- 23.1	- 19.1

POLICY IMPLICATIONS

The estimated market share functions provide important policy implications related to the introduction of additional recreational areas. That is, the coefficient associated with the price variable is a measure of the elasticity of substitution between a particular recreational area and all the alternative recreational areas available. If an additional area is added to the system, the relative prices of existing areas may be altered, which would directly affect the proportion of use to existing areas.

As an illustration, Forest and National Park Service have a number of land tracts that are considered as possible additions to the California wilderness area system. These possible additions are called new wilderness study areas (WSA). If all of the new wilderness study areas are introduced into the system, the percentage change in the proportion of visitor days from a county to a wilderness area can be determined given the results of estimating (13). Table 2 presents a number of examples in which the introduction of new wilderness study areas produces a change in the proportion of use. Five out of the 58 counties are presented in the table, representing different regions in the state (Los Angeles and San Diego counties, the southern; Sacramento and San Francisco counties, the central; and Shasta county, the northern part of the state). The recreational areas are listed in the first column. In a number of cases, the addition of a new wilderness study area is adjacent to an existing wilderness area and merely an enlargement of the area. Therefore, the introduction of the new wilderness study area results in an increase in the proportion of use at the existing wilderness area. For example, incorporating Salmon-Trinity Alps Addition into the wilderness system increases the size of the existing wilderness area, Salmon-Trinity Alps. The additional land area will increase the atrractiveness of the destination and thus increase the proportion of use at the wilderness area. The proportion of visitor days from Shasta County to Salmon-Trinity with respect to all other wilderness areas will increase by more than 75 percent, given the introduction of all the new wilderness study areas.

A number of interesting results from the introduction of new wilderness study areas are apparent from Table 2. For example, even with the enlargement at the Cucamonga wilderness area, the proportion of use to that wilderness area declines for four out of five of the counties. This is the result of new wilderness study areas in close proximity to Cucamonga, such as Madulce and Upper Kern, becoming substitutes for Cucamonga. The proportion of visitor days from Los Angeles to San Rafael and Madulce wilderness areas would increase by more than 158 percent. In addition, most of the new wilderness study areas are located in the northern central regions of the state; therefore, the proportional change in price has a greater effect on central and northern counties than on southern counties. This results from the fact that the closer an origin is to a wilderness area, the greater the effect will be when a new wilderness study area is introduced in close proximity to the existing wilder-

ness area. For example, assume that the distance between a county and a wilderness is 100 miles, and that a new wilderness study area is introduced 10 miles from the existing area in line with the county. The percentage decrease in distance is then 10 percent. However, if the distance between the county and wilderness area is 200 miles, the percentage decrease in distance is only 5 percent. Sacramento and San Francisco in most cases exhibit a higher percentage decrease than Los Angeles and San Diego.

These results represent the maximum effects because it is assumed that little, if any, use currently exists at the wilderness study areas. Therefore, the actual effects probably are somewhat lower than the estimated effects, depending upon the present level of use at the new study areas. However, data are not available to measure the current level of use at these areas.

CONCLUSIONS

As an aid to planners in considering additions to an existing recreation system, researchers have developed demand-functions accounting for alternative recreational areas. However, these demand functions tend to become too complicated for estimation when the number of areas in a system are relatively large. This paper suggests an alternative model, borrowed from international trade theory, which further simplifies demand functions for estimating a relatively large number of areas. The alternative recreational areas are aggregated into one explanatory variable based on separability and constant elasticity of substitution. An application of this model is applied to California wilderness areas. The elasticity of substitution for each wilderness area is estimated in order to evaluate the effects of creating additional wilderness areas in California. The results indicate that additions to this recreation system either greatly reduce or increase use at the existing areas. Thus, in order to obtain a true reflection of the benefits that will flow from a new recreational area, planners should account for the degree of substitution resulting from augmenting the recreation system.

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Estimating Business and Residential Water Supply Interruption Losses From Catastrophic Events

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Abstract

Following man-made or natural catastrophes, widespread and long-lasting disruption of lifelines can lead to economic impacts for both business and residential lifeline users. As a result, the total economic losses caused by infrastructure damage may be much higher than the value of damage to infrastructure itself. In this paper, we consider the estimation of economic impacts to businesses and residential consumers resulting from water supply disruption. The methodology we present for estimating business interruption losses assumes that marginal losses are increasing in the severity of disruption, and that there may be a critical water availability cutoff below which business activity ceases. To estimate residential losses from water supply interruption we integrate consumers' demand curves, calibrated to water agency price and quantity data. Our methodologies are spatially disaggregated and explicitly account for the time profile of infrastructure repair and restoration. As an illustration, we estimate the economic losses to business and residential water users of one of the major water supply systems of the San Francisco Bay Area of California resulting from two potential earthquake scenarios, a magnitude 7.9 event on the San Andreas Fault, and a magnitude 7.1 event on the Hayward Fault. For the business loss estimation, our modelling framework is general enough to calculate and compare losses using loss functions from several previous studies. For the residential loss estimation, we also calculate and compare willingness to pay estimates based on previous contingent valuation studies of water supply reliability. Our preferred models estimate business and residential losses for the San Andreas event as $14.4 billion and $279 million, respectively. For the Hayward event, estimated business and residential losses are $9.3 billion and $37 million, respectively.

1 Introduction

Lifeline interruption as a result of natural or man-made disasters can lead to widespread disruption of the daily activities of business and residential consumers. The total economic losses caused by infrastructure damage may be much higher than the value of damage to infrastructure itself. In recent years, a growing literature on methodologies to estimate the economic impacts of lifeline disruption has emerged. In particular, studies have focused on water supply, electric power, and transportation infrastructure [7, 9, 21, 22, 28]. Due to its age and spatial extent, water supply infrastructure in many urban areas is particularly vulnerable to interruption in disasters. A variety of methods – from extremely data-intensive I-O and computable general equilibrium approaches [10, 23] to simpler partial equilibrium approaches [7, 9, 19] and surveys [25, 26, 27] – have been used to analyze regional impacts on business productivity as a result of water supply disruption.

In this paper, we consider the estimation of economic impacts to businesses and residential consumers resulting from water supply interruption or disruption. The methodology we present for estimating business interruption losses is quite general and allows implementation of several existing methods that analyze business resilience to unexpected shocks. However, we improve on existing studies in two ways. First, we assume that marginal losses are increasing in disruption severity. Second, we assume that there is a critical water availability cutoff below which business activity ceases. We argue that each of these changes conforms better than existing models to both economic theory and limited empirical evidence. For residential loss estimation, we derive inverse demand curves that may be calibrated to local data and integrated to give willingness to pay to avoid water supply disruption. Our business interruption loss and residential welfare loss methodologies are consistent and directly comparable, consider the time profile of infrastructure repair and water supply restoration, and are spatially disaggregated so that damage estimates can be compared across regions with different patterns of business and

residential water users and disruptions. Using spatial data on water outages resulting from two large potential earthquakes in the San Francisco Bay Area of California, we estimate business and residential water supply interruption losses. Our results suggest that, at least in large urban areas, the loss of welfare to residential users from lifeline interruption in some catastrophic events may approach the magnitude of business interruption losses, and thus should be included in disaster mitigation planning. Although we use earthquake-induced water supply disruption for our example, the technique presented is widely applicable to other lifeline utilities, such as transport networks and electrical systems, and to other shocks, such as hurricanes, tornados, or terrorist attacks.

Section 2 of this paper presents a methodology for the estimation of business interruption losses due to water supply interruptions, and compares this methodology to existing research on post-catastrophe business resilience. In Section 3, we discuss previous efforts to estimate consumers' willingness to pay to avoid water supply interruption and present a methodology for residential loss estimation. Using spatial data on water outages resulting from two large potential earthquakes in the San Francisco Bay Area of California, business and residential water supply interruption losses are estimated in Section 4. Section 5 is the conclusion.

2 Estimating Business Losses From Water Supply Interruptions

What is the potential magnitude of the impact of water shortages and outages on businesses? Khater *et al.* [19] estimated that normal water service would take up to ninety days to resume following a large San Francisco Bay Area earthquake. Following Hurricane Katrina in 2005, portions of New Orleans were without water service for over two months. Following catastrophes such as this, businesses would be unable to provide running water in sinks, toilets and drains, and adequate water or pressure for fire sprinkling

systems. Similarly, many large commercial and industrial businesses use rooftop cooling towers that run water through fan-powered chillers, routing water to building subsystems for drinking and sanitation, for filtration and use in industrial processes, and into closed fire protection and cooling system loops. Even closed-loop cooling systems lose some water through evaporation and need replenishing in order to prevent chiller overheating and shutdown, which in turn would shut down air conditioning, laboratory temperature-controlled environments, computer server clusters, and any other water cooled equipment such as electrical generators and vacuum pumps. Moreover, many research and manufacturing facilities also need to pre- and post-treat water in order to maintain required water quality standards for production and discharge. Even if alternative supplies of water, such as groundwater, are available to these industries in case of shortages, the cost and difficulty of recalibrating equipment to the change in water quality may be large.

In 2002, the Silicon Valley Manufacturing Group undertook a survey of twenty-eight corporate members on the importance of water supply reliability; more than half of the companies surveyed were involved in manufacturing, and a similar proportion were in the high-technology sector [25]. Two-thirds of the companies surveyed suggested that a thirty day interruption in water supply water service interruption would force them to shut down completely. Additionally, many of the companies surveyed stated that they had no backup plans for the event of unexpected, severe rationing or complete water outages. Similar interviews with commercial and industrial water users in the San Francisco Bay Area of California also suggest that longer water supply interruptions would have serious operational impacts on businesses [3].

In recent years, a focus of disaster preparedness and management has been the measurement of disaster resilience in communities, where resilience has been broadly defined as the extent to which communities can absorb extreme events without large losses [6, 8]. In a business setting, resilience to unexpected interruption of input supply has been defined in several studies as the proportion of normal production that would occur in the

event of a complete outage of that production input [1, 7, 9]. Thus, a business with a resilience of 1 would be able to continue indefinitely at full capacity in the event of unexpected loss of a production input (this scenario is not consistent with the assumption of profit maximization by the business). Conversely, a business with a resilience of 0 would be forced to shut down following complete loss of the production input of interest. For levels of outage less than a complete outage, previous studies have assumed that there is a linear relationship between total production loss and shortage level, and that the first 5 percent of any outage can be absorbed by businesses with no loss of economic activity [1, 9, 19].

For a water supply interruption in region i at time t, the severity of the water shortage may be defined as $z_{it} \in [0, 1]$, where $z_{it} = 0$ corresponds to a complete outage and $z_{it} = 1$ corresponds to normal service. We can account for some portion of water suply being unaffected by supply interruption (for example, through groundwater pumping or interconnectedness and mutual help agreements with other service providers) by defining α_i as the proportion of water supply potentially affected by catastrophic outage in region i. Then, for industry sector j in region i with a resilience at time t of r_{ijt} facing rationing of z_{it}, the proportional loss of daily economic output, $\lambda_{ijt}(z_{it})$, is given by

$$\lambda_{ijt}(z_{it}) = \begin{cases} 0 & \text{if } \alpha_i(1 - z_{it}) \leq 0.05 \\ \frac{1-r_{ijt}}{0.95}\left[\alpha_i(1 - z_{it}) - 0.05\right] & \text{if } \alpha_i(1 - z_{it}) > 0.05 \end{cases} \tag{1}$$

Note that this definition of loss can apply to both industry sectors and individual businesses [9]. Published empirical estimates of business resilience vary significantly. In a study of earthquake-induced outages in the San Francisco region, Khater *et al.* [19] (abbreviated as KSR) report tables of predicted productivity losses by industry sector and rationing level, implying a resilience of 0.1 (the ability to operate at 10 percent of normal output with no water) for the electronics manufacturing industry, but of 0.8 for wholesale and retail trade. KSR assumed that productivity losses were time-invariant, so

that longer water supply interruptions would not reduce output more per day than short interruptions, and thus $\partial r_{ijt}/\partial t = 0$. Chang *et al.* [9] (abbreviated as CSS) developed business resilience factors based on surveys of businesses following the 1994 Northridge, California earthquake [26], and from Memphis, Tennessee [27]. Nearly all outages following the Northridge earthquake were limited to less than one week, and CSS suggested that for this interval, a complete outage would result in a wide range of business effects [9]. Data for mining, a high resilience sector, produced an estimated resilience of 0.73, whereas health services, a low resilience sector, had an estimated resilience of 0.27; both durable and nondurable manufacturing facilities had estimated resiliences of 0.42, and wholesale and retail trade had resiliences of around one half. Estimation for outages of more than two weeks suggested that $\partial r_{ijt}/\partial t < 0$, and that after two weeks resilience in all sectors would be in the range of 0.19 to 0.44 (specific sectors as follows [9]: mining (0.44); health services (0.19); durable and nondurable manufacturing (0.28); wholesale trade (0.30); retail trade (0.28)). Although they did not calculate industry resilience, Woo and Lo also found evidence that $\partial r_{ijt}/\partial t < 0$ for non-residential users experiencing water shortages in Hong Kong [30].

From an economic perspective, the loss estimation equation in (1) has several shortcomings. First, firms' behavior at small levels of shortage is inconsistent with profit maximization. From Equation 1, $\lambda_{ijt} = 0$ if total water availability is greater than or equal to 95 percent of normal. Assuming a positive price on water as a production input, this implies that all firms could make higher profits by voluntarily reducing their water use by 5 percent rather than operating at current levels. Second, a value of $r_{ijt} > 0$ over time implies that firms can continue production indefinitely with zero water availability. As will be discussed below, although this may be a valid approximation for short-lived outages, it is more unreasonable for service outages that may last weeks or months. Third, for shortages greater than 5 percent, the marginal loss as shortages increase in severity is constant, namely $\partial \lambda_{ijt}/\partial z_{it} = \alpha_i r_{ijt}/0.95$. A constant marginal loss implies

that a business can adapt to all levels of shortage with the same ease. An alternative approach would be to assume that marginal loss function is increasing in the level of shortage, implying that businesses find it increasingly difficult to adjust to water supply shortfall. In this paper, we propose a different loss estimation equation that deals with each of these inconsistencies: we use an increasing marginal loss as shortage severity increases, allow complete shutdown of the firm to occur, and assume that profit-maximizing behavior implies that losses are positive (though potentially very small) for all levels of water supply shortage. As the severity of rationing increases, we assume that marginal losses increase until a critical water availability cutoff is reached and business activity ceases. Water supply rationing beyond the cutoff level incurs no further damages, as output is zero.

We assume that each industry sector has a minimum proportion of its normal water availability below which continuing operation is impossible, defined for sector j at time t as γ_{jt}. Thus, $\gamma_{jt} \in [0, 1)$, where $\gamma_{jt} = 0$ implies that sector j can operate at full capacity even if $z_{it} = 0$ and the sector has no water available to it. As γ_{jt} increases, sector j becomes less and less resilient to water supply disruption and shuts down at smaller and smaller water supply shortfalls relative to normal supply. Between the cutoff level γ_{jt} and the normal daily water use defined by $z_{it} = 1$, we assume that the marginal lost value of production is linear in the level of water supply cutback. The proportional daily loss of output value for industry sector j at time t in geographic region i is then given by:

$$\lambda_{ijt}(z_{it}) = \begin{cases} \frac{(1-r_{ijt})\alpha_i^2(1-z_{it})^2}{(1-\gamma_{jt})^2} & \text{if } \alpha_i(1-z_{it}) < (1-\gamma_{jt}) \\ 1 - r_{ijt} & \text{if } \alpha_i(1-z_{it}) \geq (1-\gamma_{jt}) \end{cases} \tag{2}$$

The loss functions represented by Equations 1 and 2 are compared in Figure 1, which shows values of $\lambda_{ijt}(z_{it})$ for the retail trade sector calculated for different levels of water shortage. Figure 1 shows how the assumption of a constant marginal loss function (as used by KSR and CSS) versus a linear marginal loss function (Equation 2) determines

the proportional loss of output for any given water shortage. All three methodologies have similar and very small losses for small decreases in available water. For more severe outages, which methodology yields the largest loss estimate depends on the duration and severity of the outage, as well as the particular value of resilience.

If $f_{it}(z_{it})$ is the probability density function of water disruptions z_{it} in region i at time t then considering a time period of T days until the complete reinstatement of normal water service, with J business sectors in each of I regions with normal daily value of production equal to V_{ij}, gives the following economic loss estimate for business interruption:

$$L_{IT}^{bus} = \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{J} \int_{0}^{1} V_{ij} \lambda_{ijt}(x) f_{it}(x) \, dx \tag{3}$$

If the probability distribution of loss profiles $f_{it}(z_{it})$ over time is not available, a simple approximation is to use a two part distribution for z_{it} that divides business water users into those with complete outages and those with some amount of water rationing, assumed constant across sectors in a region but allowed to vary across regions and time, given by z_{it}. If θ_{it} is the proportion of businesses within region i that are experiencing complete outages at time t, the economic loss estimate then simplifies to:

$$L_{IT}^{bus} = \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{J} V_{ij} \left(\theta_{it} + (1 - \theta_{it}) \lambda_{ijt}(z_{it}) \right) \tag{4}$$

Note that if $\theta_{it} = 0$ and $z_{it} = 1$ for any region, normal water service exists and the business interruption loss estimate will be zero for water users in region i at time t. Based on the resolution of available information, Equation 4 can easily be extended using any discrete distribution of region-specific rationing levels.

The loss estimate in (4) using either Equation 1 or Equation 2 represents a partial equilibrium model such as that applied by Khater *et al.* [19] or Chang *et al.* [9]. Alternative approaches to hazard loss estimation that explicitly include the interlinkages between

industries include I-O and computable general equilibrium (CGE) models [10, 23]. As Rose [23] discusses, I-O models are linear and rigid and do not allow input substitution by industries. As a result, I-O models represent upper bounds on direct and indirect loss estimates. Conversely, CGE modeling does allow the analysis of the potential role of price signals or input substitutability across linked industries and the labor market in determining the potential economic impacts resulting from catastrophic water supply shortages [23]. However, in a catastrophe-loss estimation setting, CGE models have two serious shortcomings. First, such models were developed to analyze long-run equilibrium resulting from changes in the price or availability of inputs, and the resulting behavioral adjustments across the economy. Arguably, catastrophic lifeline interruption is an extremely short-term, disequilibrium phenomenon during which policy-makers care most about immediate costs. Second, because of the underlying CES production functions used, CGE modeling cannot analyze the impacts resulting from complete outage of any production input. Thus, such models must either assume that complete outages cannot occur or that every industry has costless, indefinite availability of backup supplies. Moreover, in a detailed CGE study of water supply shortages in the Portland Metropolitan Area, Rose [23] found that estimated indirect impacts were only about 22 percent of estimated direct impacts (equivalent to a multiplier effect of 1.22), and that both positive and negative indirect effects were observed. Thus, given that the data requirements for a well-executed I-O or CGE model are large and that previous studies suggest that differences in estimated impacts may be relatively small overall and of ambiguous sign by industry, we argue that a simple business loss estimation methodology such as that presented in Equations 2 to 4 is both extremely useful for decisionmakers and easy to implement and interpret.

There are several important issues in the estimation of the economic impacts of water supply interruption that are outside of the scope of analysis of this paper (Rose [21] provides a detailed discussion of many of these issues). These include irreversible damages

related to water supply interruptions, double-counting of damages, and the role of water supply outages in exacerbating fire following earthquakes. We discuss each of these concerns briefly below.

The methodology presented in this paper assumes that the only economic impacts to businesses from water rationing and outages are from lost revenue, and that the scale of economic output can be changed instantaneously and costlessly. However, extended business closures due to water supply interruption may entail irreversibility (at a local scale) if businesses relocate permanently to a different region. Thus, the long-term damage from a reduced economic base and lower employment could be considerable, even after the region as a whole has recovered from the immediate effects of a catastrophe and attendant lifeline disruption.

We focus on the estimation of economic impacts specifically related to water supply interruption. Of course, total economic damages resulting from loss of life or property in a catastrophe such as a major earthquake would be enormous. However, analyzing those impacts is beyond the scope of this paper. Here, we do not consider damages to life, property, or other lifelines resulting from the catastrophic event that caused water supply interruption. One way to view this is as an implicit assumption that there is no overlap between catastrophe-related damages to the water supply infrastructure and other damages. This may be correct for some kinds of catastrophes such as targeted terrorist attacks or natural hazards that affect lifelines at a distance from the populations they serve. However, it is quite clear that businesses and residences that are destroyed by ground shaking in an earthquake are unable to experience losses due to water supply shortages in the post-earthquake period. We argue that, at least for many potential catastrophes in the developed world, our methodology is relatively insensitive to the effects of such double-counting. This is because even earthquakes in major urban areas are predicted to kill only a small proportion of the population and destroy a relatively small proportion of the stock of buildings. As a result, economic losses from water supply

interruption to businesses and residences that are relatively undamaged in a catastrophe will generally far outweigh the double-counting of damages to destroyed property. Note that for some natural catastrophes, double-counting may be an issue. For example, if large areas of a city are inundated by a storm surge, as was the case with Hurricane Katrina in New Orleans, water supply interruption to these areas will not lead to any further incremental damage.

Finally, one of the major potential impacts of water supply shortages is that the operation of emergency services may be compromised [24]. In particular, if water is not available for firefighting purposes, fires may spread further or burn uncontrolled. Fire-related losses to property will thus almost certainly increase. The differential increase in fire damage is an indirect economic loss attributable to water shortages. Estimates of incremental fire damage as a result of water supply interruption will depend on both the nature of the catastrophe and the availability of secondary water supplies and other technology in the region of interest.

3 Estimating Residential Losses From Water Supply Interruptions

Using the concept of resilience to define economic losses is not as useful in a residential setting as in a business setting, as residential water users do not produce an output with monetary value. However, it is clear that water supply interruptions can impose a significant hardship on residential users. Losses can be measured by consumers' willingness to pay to avoid water service interruptions, defined as the amount of money that residential customers would pay in order to avoid a break in water service of some duration.

Residential water use falls into several broad categories, such as drinking and basic sanitation, bathing and cooking, laundry use, and outdoor irrigation. The willingness to pay for water by residential customers will also depend on the intended use of water.

Thus, residential consumers will be willing to pay a large amount of money for water for drinking and basic sanitation, less for water to wash clothes, and a much smaller amount for water for washing cars, filling swimming pools, and outdoor irrigation. In order to analyze indirect economic losses to residential customers from water supply interruption, it is necessary to estimate willingness to pay for any potential shortfall in available water. Because reliable empirical data on consumer demand under significant water shortages are unavailable, alternative approaches must be taken to estimate demand. Three separate approaches have been used to generate estimates of willingness to pay to avoid water supply interruption: contingent valuation, mathematical programming, and integration of estimated demand curves. Below, we discuss each of these methodologies and their advantages and limitations.

Stated preference techniques may be used for the direct elicitation of willingness to pay. In this case, an appropriate survey instrument is administered to a representative sample of residential water users, and econometric analysis is used to estimate a willingness to pay function. Contingent valuation has been applied in the estimation of residential willingness to pay for increased water supply reliability by several previous studies [2, 15, 16, 17]. In general, these studies consider consumers' choices between alternative probabilistic shortage scenarios, and thus provide estimates of value for changes in water supply reliability. Moreover, existing studies consider relatively small water supply shortfalls (Barakat and Chamberlin consider shortages of 10 to 50 percent, Griffin and Mjelde consider the range 10 to 30 percent, and Howe and Smith and Howe *et al.* consider a "standard annual shortage event" where residential outdoor use is restricted to 3 hours a day, but indoor use is unrestricted), and no existing study attempts to value residential welfare loss from complete water supply outages.

Taken together, contingent valuation studies suggest that consumers are fairly insensitive in their valuation of the severity, duration, and frequency of water supply shortfall. Several studies have found threshold effects, with a high willingness to pay to avoid any

shortage, and then decreasing average willingness to pay to avoid shortages of increased duration, severity, or frequency [2, 15]. For example, data from northern Colorado reported in Griffin and Mjelde [15] suggest a total household willingness to pay to avoid immediate, known shortfalls of $WTP = \$18.41 + \$0.212 \times (\%\ water\ shortage) + \$0.344 \times (days\ of\ shortage)$. Griffin and Mjelde also find inconsistencies in their results: consumers stated higher *monthly* willingness to pay to avoid future, probabilistic water supply shortages than *total* willingness to pay to avoid immediate shortages of the same duration and severity. In a comprehensive survey covering all California water agencies, Barakat and Chamberlin Inc. [2] found mean monthly household willingness to pay ranging from $11.63 to avoid a year-long 10 percent reduction service with an expected frequency of one in ten years, to a monthly value of $16.92 to avoid a year-long 50 percent reduction in service with an expected frequency of one in twenty years. Additionally, the Barakat and Chamberlin study found that consumers were more likely to pay higher amounts to avoid larger, infrequent shortages than small, frequent shortages.

In an alternative approach to stated preference studies, Lund [20] assumes that consumers exhibit cost-minimizing behavior and uses a mathematical programming approach to analyze the costs of alternative short- and long-term conservation measures that consumers could implement to avoid the impacts of water shortage. Although he does not provide durations of expected shortfall, he considers shortages of between 50 and 200 gallons per household per day, yielding estimates of willingness to pay of between $51.03 per household per year and $144.10 per household per year for the shortage scenarios considered.

Finally, construction of residential demand functions for water allows direct estimation of willingness to pay. This approach was used by Jenkins *et al.* [18] to estimate the costs of urban water scarcity under current institutional and hydrological conditions and predicted California population and industrial water demand for 2020. Because adequate empirical data to characterize the demand function for all levels of water shortage do not

exist, Jenkins *et al.* assumed a constant elasticity demand function, calibrated using regional observed prices and quantities consumed and estimates of the price elasticity of demand. Using these calibrated demand functions, Jenkins *et al.* estimate monthly loss functions for shortages of up to 50 percent rationing levels, and suggest that by 2020, the average annual cost of urban water scarcity in California could be as high as $1.6 billion.

In this study, we adapt the approach of Jenkins *et al.* [18] so that residential welfare losses from water supply interruption can be analyzed in a framework analogous to that developed for businesses in Section 2. In order to compare estimates of losses derived from calibrated demand functions to estimates obtained from contingent valuation, we also apply the methodologies and coefficients reported by Barakat and Chamberlin Inc. [2] and Griffin and Mjelde [15]. Below, we derive equations for the estimation of consumer willingness to pay to avoid water supply interruptions, modified from Jenkins *et al.*. By definition, the price elasticity of demand for water at any price P and quantity consumed Q is given by $\eta = (dQ/dP)(P/Q)$. This definition may be rearranged and integrated to give an inverse demand function for water, namely $P(Q) = e^{(ln\,Q)/\eta + C}$, where C is a constant of integration. Integrating this expression for $P(Q)$ will give a consumer's willingness to pay to avoid water shortages, where the willingness to pay to avoid a shortage equivalent to any restricted quantity of water consumed is given by the area under the demand curve between the unrestricted consumption quantity and that restricted quantity. Define the water price and quantity consumed when there are no shortages as $P_{baseline}$ and $Q_{baseline}$ respectively. Then the daily loss of welfare $W_i(z_{it})$ for a consumer in region i experiencing a water shortage at time t of z_{it}, leading to a reduced water availability given by $Q_r(z_{it}) \leq Q_{baseline}$, is

$$
\begin{aligned}
W_i(z_{it}) &= \int_{Q_r(z_{it})}^{Q_{baseline}} P(Q)\, dQ = \int_{Q_r(z_{it})}^{Q_{baseline}} e^{(ln\, Q)/\eta + C}\, dQ \\
&= \frac{\eta}{1+\eta} P_{baseline} Q_{baseline} \left[1 - \left(\frac{Q_r(z_{it})}{Q_{baseline}} \right)^{\frac{1+\eta}{\eta}} \right] \qquad (5)
\end{aligned}
$$

where the second line is valid when $-1 < \eta < 0$, implying an inelastic residential demand for water. This assumption is not unduly restrictive, as a meta-analysis by Espey *et al.* [13] found that 90 percent of reported residential price elasticities of demand for water were in the range (-0.75, 0), and meta-analysis by Dalhuisen *et al.* [11] reported a mean price elasticity of demand of -0.41, a median price elasticity of -0.35, and suggested that in general residential demand for water is price inelastic.

Note that with a constant elasticity demand function, the willingness to pay to avoid a complete water supply outage ($Q_r = 0$) is not defined. Here, we assume that the government would be able to provide a minimum amount of water to maintain basic health and sanitation throughout the period of complete outages (for example, by trucking water to distribution points), and that consumers in affected areas would not generally face a price for access to this water. Provision and distribution of water for basic health and sanitation in large urban areas would be extremely costly to the government, but we assume that these costs would be paid for by all taxpayers rather than consumers in the area of the outage. Thus, equation 5 does not attempt to value how much consumers would pay to stay alive, but how much they value water above their basic requirements.

The United Nations defines a "Basic Water Requirement" of 6.6 gallons per capita per day as the minimum required for drinking and basic sanitation, and a minimum requirement of 13.2 gallons per capita per day (gpcpd) when bathing and cooking are included [14]. These amounts may be thought of as the minimum needed to survive for an extended period of time, such as would be encountered following a major earthquake. Thus, we constrain the water availability $Q_r(z_{it})$ to be in the interval $[BWR, Q_{baseline}]$.

We report results from assuming BWR takes values of 6.6 gallons per capita per day, 10 gallons per capita per day, and 13.2 gallons per capita per day to capture the possible sensitivity of cutoff choice as a result of using a constant elasticity demand function. Average per capita daily demands for residential users can be used for the value of $Q_{baseline}$ in Equation 5. If $Q_r(z_{it})$ is calculated using the assumption that basic water requirements for health and sanitation are met, then $Q_r(z_{it}) = BWR + (1 - \alpha_i(1 - z_{it}))(Q_{baseline} - BWR)$, where as in the business loss estimation, α_i represents the proportion of region i's water supply affected by interruption. Note also that from Equation 5 we have assumed that willingness to pay to avoid water shortages does not change over time. This is a conservative assumption; it is likely that willingness to pay for any quantity of water will increase with the length of the disruption, particularly as the possibility of irreversible damage to investments such as landscaping increases.

In order to obtain an estimate of the overall indirect losses from water supply interruption, the individual daily welfare losses W_i need to be aggregated across consumers in each region and across regions. Define N_i as the number of residential consumers in region i and $f_{it}(z_{it})$ as the probability density function of water disruption in region i at time t. Then, considering I regions and a time period of T days until the complete reinstatement of normal water service gives the following residential economic loss estimate:

$$L_{IT}^{res} = \sum_{t=1}^{T} \sum_{i=1}^{I} \int_0^1 N_i W_i(x) f_{it}(x)\, dx \tag{6}$$

If detailed information on the probability distribution of loss profiles $f_{it}(z_{it})$ over time is not available, a simple discrete approximation dividing consumers into two groups, those with complete outages and those with some rationing, may be used instead. If θ_{it} is the proportion of residential consumers within region i that are experiencing complete

outages, the residential economic loss estimate (Equation 6) simplifies to:

$$\begin{aligned} L_{IT}^{res} &= \sum_{t=1}^{T}\sum_{i=1}^{I} N_i \left(\theta_{it} W_i(0) + (1-\theta_{it}) W_i(z_{it})\right) \\ &= \sum_{t=1}^{T}\sum_{i=1}^{I} N_i W_i(0) \left(\theta_{it} + (1-\theta_{it})\frac{W_i(z_{it})}{W_i(0)}\right) \end{aligned} \tag{7}$$

The second line of Equation 7 is directly analogous to the simple equation for business interruption losses, Equation 4. In the residential context, $N_i W_i(0)$ is the total consumer surplus of residential water users in region i during a period of normal water service, and $W_i(z_{it})/W_i(0)$ is the proportion of consumer surplus remaining at rationing level z_{it}. Note that for regions where $\alpha_i < 1$, a rationing level of $z_{it} = 0$ corresponds to some availability of water from alternative sources, such as groundwater or interlinkages and mutual help agreeements with other service providers. Note also that Equation 7 assumes that residential consumers' willingnesses to pay to avoid water supply interruptions are homogeneous within any region. If there are large intra-regional variations in willingness to pay, as may be the case if there are significantly different residential types such as apartments and large single-family houses, then Equation 7 may be easily extended to include this heterogeneity as well.

4 Example: Earthquake-induced Water Supply Interruption in the San Francisco Bay Area, California

As an example of our methodology, we estimate the economic losses to businesses and residential water users resulting from earthquake-induced disruption of one of the major water supply systems of the San Francisco Bay Area of California. We consider two potential earthquake scenarios: a magnitude 7.9 earthquake on the San Andreas Fault,

and a magnitude 7.1 earthquake on the Hayward Fault.

San Francisco's water system captures rain and snowmelt runoff in the Hetch Hetchy reservoir in the Sierra Nevada mountains near Yosemite National Park, and moves it through a 167-mile series of tunnels, aqueducts, treatment plants and pipelines, to reservoirs and turnouts along its route through the southern portion of the Bay Area and into the city of San Francisco. The Hetch Hetchy system is managed and run by the San Francisco Public Utility Commission (SFPUC). Hetch Hetchy facilities cross at least five active earthquake fault zones: the San Andreas, Hayward, Calaveras, Greenville, and Great Valley fault zones. A probability of around 60 percent is assigned to the occurrence of a major, damaging earthquake in the greater San Francisco Bay Region by 2031 [31]. All of the major Hetch Hetchy facility components are at least fifty years old [3]. Some, including the Crystal Springs and San Andreas dams and reservoirs, predate the Hetch Hetchy system and were constructed in the nineteenth century. Key sections of the Hetch Hetchy delivery system have not been seismically retrofitted and braced, and most facilities have little or no redundancy built into them, so that even relatively small system failures can cut off service while repairs are undertaken.

The Hetch Hetchy system routes 260 million gallons per day (mgd) of water to 2.4 million customers in four counties [3]. The city of San Francisco, with a population of 800,000, uses approximately one-third of Hetch Hetchy water. The remainder is supplied to twenty-eight suburban water authorities and other large wholesale customers represented in negotiations with SFPUC by the Bay Area Water Supply and Conservation Agency (BAWSCA; previously known as the Bay Area Water Users Association, or BAWUA). Although several large water agencies (Alameda County Water District, Santa Clara, Milpitas, Sunnyvale, and Daly City) have diversified supplies, seventeen of the suburban customers are completely dependent on Hetch Hetchy for their water and another six are more than 75 percent dependent on it (Table 1 and Figure 2).

Water Supply Interruption and Restoration Profiles

Existing geotechnical reports prepared for BAWUA and the SFPUC Facilities Reliability Program (Phase II) outline the spatial distribution of water supply outages and system recovery following major earthquakes [12, 29]. Earthquake-induced damage to the Hetch Hetchy water supply system will produce two kinds of impacts on water users. First, following a major earthquake, some proportion of water users will experience a complete loss of SFPUC water supply (θ in Equations 4 and 7). Note that a complete outage of SFPUC water only corresponds to zero water availability for those users for which $\alpha_i = 1$ (Table 1). Second, those users that still receive water via the piped system (a proportion of users given by $1 - \theta$) may nonetheless have water rationing during the system repair and recovery period, with the proportion of normal water service available to these users in region i at time t given by $1 - \alpha_i(1 - z_{it})$. Based on information in Eidinger [12], we define six geographic regions for the San Andreas M 7.9 earthquake event and four geographic regions for the Hayward M 7.1 earthquake event. Within each of these regions, Hetch Hetchy water users will experience similar time profiles of water supply outages and rationing until normal service is restored. The pattern of water supply interruption and rationing following a major earthquake is shown for each group in Figures 3 and 4. For those users that have interlinkages with other service providers, or alternative sources of water such as groundwater (see the values of α_i in Table 1), we make the conservative assumption that in any earthquake event, these alternative sources will be able to continue operating at normal service levels, so that the range of possible rationing levels for service provider i at time t is given by $[1 - \alpha_i(1 - z_{it}), 1]$.

Business Loss Estimates

Business and institutional users account for 30 percent of San Francisco water demand (26 mgd) and 25 percent of demand throughout the BAWSCA service territory (65 mgd). Important users of Hetch Hetchy water include the computer, semiconductor, biotechnol-

ogy, automotive, aerospace, tourism, and telecommunications industries, electric utilities, as well as schools and hospitals and smaller water-dependent businesses such as restaurants, glass and metal fabricators, beverage plants and food processors.

As functional relationships between water use and value of output for individual industries are presently unavailable, we use county-level data from the 2002 U.S. Economic Census (available at *http://www.census.gov/econ/census02*), and focus on five sectors of activity: Manufacturing; Wholesale Trade; Retail Trade; Professional, Technical and Scientific services; and Accommodation and Foodservices. Together, these five sectors account for the majority of economic activity within the Bay Area. The relevant four counties for the analysis are San Mateo County, San Francisco County, Alameda County and Santa Clara County. In 2002, the total annual value for the five sectors used in the production loss analysis for these four counties was $334 billion, with county- and sector-specific values shown in Table 2. We assume that the SFPUC water supply system provides water to the whole of San Mateo and San Francisco Counties, and to businesses that account for 50 percent and 80 percent of economic activity in Alameda County and Santa Clara County, respectively. County-level economic activity data can then be decomposed into the same geographic groups as the water supply impacts in Figures 3 and 4 (Table 3). For each group, we assume that the reliance of businesses on SFPUC water as a proportion of their total water use is given by the mean of α_i values for water agencies within that particular group. For the group definitions used in the analysis and shown in Figures 3 and 4, the group-mean values of α_i are between 0.44 and 1.

Using Equations 1, 2, and 4, the data in Tables 1, 2, and 3, and the water supply interruption and restoration profiles in Figures 3 and 4, business losses from water supply interruption were estimated for the two water supply interruption and restoration scenarios (Tables 4 to 8). We estimate four different business loss models:

1. Equation 2 (linear marginal loss), assuming that shutdown is possible, so that $r_{ijt} = 0$, that $\gamma_{jt} = 0.5$ for the manufacturing and accommodation and food sectors,

and that $\gamma_{jt} = 0.2$ for the other sectors analyzed

2. Equation 2 (linear marginal loss), assuming that shutdown is not possible so that $r_{ijt} > 0$, that $\partial r_{ijt}/\partial t < 0$, using industry sector-specific data on r_{ijt} in Chang *et al.* [9], that $\gamma_{jt} = 0.5$ for the manufacturing and accommodation and food sectors, and that $\gamma_{jt} = 0.2$ for the other sectors analyzed

3. Equation 1 (constant marginal loss), assuming that shutdown is not possible so that $r_{ijt} > 0$ and that $\partial r_{ijt}/\partial t < 0$, using industry sector-specific data on r_{ijt} in Chang *et al.* [9]

4. Equation 1 (constant marginal loss), assuming that shutdown is not possible so that $r_{ijt} > 0$ and that $\partial r_{ijt}/\partial t = 0$, using industry sector-specific data on r_{ijt} in Khater *et al.* [19]

For Model 1, Table 4 shows the group- and sector-specific damages for the M 7.9 San Andreas earthquake scenario, and Table 5 shows the group- and sector-specific damages for the M 7.1 Hayward earthquake scenario. The total business interruption loss estimates using Model 1 are $14.4 billion for the San Andreas earthquake scenario over the sixty day period before the full resumption of normal water service. By sector, the total loss estimates are as follows: Manufacturing ($3.9 billion); Wholesale trade ($4.9 billion); Retail trade ($2.4 billion); Professional, Scientific and Technical services ($2.6 billion); and Accommodation and Foodservices ($0.7 billion). Unsurprisingly, the largest group losses occur in groups 1, 3, and 6, which are predicted to have the most severe water disruptions. Losses in group 4, which includes a large portion of economic activity in Santa Clara county, are reduced by the availability of alternative water sources (compare Tables 1, 2, and 3).

Total business interruption losses are estimated as $9.3 billion for the Hayward earthquake scenario using Model 1 (Table 5). By sector, the total loss estimates are as follows: Manufacturing ($3.3 billion); Wholesale trade ($3.4 billion); Retail trade ($1.3 billion);

Professional, Scientific and Technical services ($1.0 billion); and Accommodation and Foodservices ($0.3 billion). In this scenario, losses by geographic group are greatest in groups 1 and 2, which are closest to the Hayward fault and are predicted to have the most severe shortages (Figure 4). Note that in this scenario, losses in San Francisco and areas adjacent on the San Francisco peninsula (groups 3 and 4) are estimated to have relatively small losses, even though there is significant economic activity, because shortages are predicted to be quite limited in nature.

Total business loss estimates for the two earthquake scenarios and each of the four models described above are presented in Table 6. All four models produce loss estimates of the same order of magnitude, with the San Andreas earthquake scenario producing losses approximately 50 percent higher than the Hayward earthquake scenario. Model 4, which assumes that shutdown does not occur as a result of water supply interruption and that resilience is constant over time, and uses industry-specific resilience estimates from KSR, yields the lowest estimates for both earthquake scenarios. Model 1, using a linear marginal loss (Equation 2) and allowing shutdown in the case of severe shortages, yields the highest estimates of business losses. All of these business loss estimates are enormous: many billions of dollars for water supply interruption without considering any other damages. However, the region impacted by our earthquake scenarios includes the high-technology hub of Silicon Valley, as well as many other high-value businesses. As a further comparison, Chang *et al.* [9] analyzed the consequences of water supply disruption from an M 7.5 earthquake close to Memphis, Tennessee. They estimated that during extended water supply disruption, mean monthly losses would be 20.5 percent of monthly gross output. Using the Model 1 results (Table 6), this study finds that mean monthly losses during the San Andreas earthquake scenario would be 25.9 percent of monthly gross output (calculated as 14.41/(334/6)), and mean monthly losses during the Hayward earthquake scenario would be 16.8 percent of monthly gross output. Thus, our loss estimates are quite consistent with the study of Chang *et al.*, particularly given that

the earthquake magnitude scale is logarithmic.

Residential Loss Estimates

The SFPUC water supply system provides service to a residential customer base of 2.4 million people. Data available from the FY 1999-00 BAWUA annual survey provide residential per-capita water use (Table 1 and [5]). In the Hetch Hetchy service area, residential water consumption varies from a low of 50.9 gallons per capita per day in the East Palo Alto Water District to a high of 321.2 gallons per capita per day in the Purissima Hills Water District (Table 1 and Figure 2). The differences in average residential water use across SFPUC customers in large part reflect differences in amount of outdoor irrigation. Average per capita daily demands for residential users from each water provider were used for the value of $Q_{baseline}$ in Equation 5 (Table 1), and $Q_r(z_{it})$ was calculated using the assumption that basic water requirements for health and sanitation were met, so that $Q_r(z_{it}) = BWR + (1 - \alpha_i(1 - z_{it}))(Q_{baseline} - BWR)$. Similarly, values of $P_{baseline}$ were calculated from reported water provider average consumer costs per unit of water, exclusive of service charges (Table 1 and [4]).

Losses to residential consumers following our two scenario earthquakes were calculated using equations 5 and 7, the data in Table 1, and water supply interruption and restoration profiles in Figures 3 and 4, a price elasticity of demand for residential water, η of -0.41, and a Basic Water requirement of 10 gpcpd. Following a magnitude 7.9 earthquake on the San Andreas Fault, our methodology estimates residential losses of \$279.20 million, with the largest losses closest to the fault, namely in the San Francisco peninsula (Table 7). Losses outside of the peninsula region are predicted to be quite small, totalling less than \$2.5 million, as water interruption is limited to relatively small, short outages. Similarly, even though group 2 (Daly City and San Bruno) is located close to the San Andreas fault, residential welfare losses are estimated to be small as there is a limited reliance on Hetch Hetchy water, and our analysis assumes that alternative

sources of water are unaffected by the disruption scenario. Conversely, in the M 7.1 Hayward fault scenario, residential welfare losses are estimated to total $36.94 million, with almost all welfare losses occurring in the East Bay and only relatively small losses on the San Francisco Peninsula (Table 8).

In order to determine how residential welfare losses as determined by Equation 5 vary with the choice of price elasticity of demand and Basic Water Requirement, we calculated losses using alternative values of η and BWR (Table 9). Alternative values of η chosen were -0.35 and -0.51, following the median and mean values reported in the meta-analyses of Dalhuisen *et al.* [11] and Espey *et al.* [13], respectively. As expected from Equation 5, estimates of welfare loss increase as residential water use becomes more price-inelastic, or as Basic Water Requirement (the lower cutoff for welfare measurement in Equation 5) decreases. In particular, a more price-inelastic residential water demand increases the loss estimates more for the San Andreas earthquake scenario than for the Hayward scenario. This is because a larger proportion of residential consumers experience severe outages in the former scenario than the latter (compare Figures 3 and 4), and this translates into much higher willingness to pay estimates with a more inelastic demand. In the context of the model presented here, a lower Basic Water Requirement may be interpreted as corresponding to a situation where the government is able to distribute less emergency water to residential consumers on a daily basis. Note that Equation 5 and our residential loss estimation methodology only calculate willingness to pay for water in excess of the chosen Basic Water Requirement. It is assumed that the government will not allow residential consumers to experience complete loss of water for health and sanititation. However, it is clear that supplying water for residential consumers' health and sanitation purposes for extended periods would be extremely expensive (current charges for tanker-transported water in the Bay Area are around 1 cent per gallon per mile). Moreover, some consumers would certainly be willing to pay extremely large amounts for their first few gallons of water. Thus, because our analysis allows businesses to experience complete

outages, there is an asymmetry in comparing business and residential losses from water supply shortfall and the residential estimates based on Equation 5 should be viewed as lower bounds.

How do residential loss estimates calculated using Equations 5 to 7 compare with estimates that might be obtained through contingent valuation? As a comparison, we calculate residential loss estimates using the methodologies of Barakat and Chamberlin Inc. [2] and Griffin and Mjelde [15]. Barakat and Chamberlin developed a double-bounded bid model to estimate monthly willingness to pay to avoid year-long probabilistic shortages. We adapt their reported data for the San Francisco region, by using their estimated regression constant and coefficients on severity of shortfall and bid (Barakat and Chamberlin Inc., Appendix N [2]), assuming 2.5 individuals per household, and inflating from 1994 dollars to 2002 dollars using a factor of 1.21. Additionally, we define the mean rationing level in region i as $\overline{z}_i = (1/T_i)\sum_{t=1}^{T_i}[\theta_{it}(1-\alpha_i)+(1-\theta_{it})(1-\alpha_i(1-z_{it}))]$, where T_i is the last day for which $z_{it} < 1$. Finally, following Barakat and Chamberlin's regression results, we assume that willingness to pay is insensitive to frequency of shortage, consider a one-month shortage rather than a year-long shortage, and calculate net present value accordingly using a discount rate $r = 5\%$. For region i, this gives an individual willingness to pay of:

$$WTP_i^{BC} = \frac{1.21}{2.5}\left[\frac{\ln(1+\exp(3.115378-2.233299\overline{z}_i))}{0.1100911r}\right] \tag{8}$$

To compare our results to those of Griffin and Mjelde [15], we use the following individual loss estimation equation for region i:

$$WTP_i^{GM} = \frac{1.04}{2.5}\left[18.41+21.2(1-\overline{z}_i)+0.344T_i\right] \tag{9}$$

In equation 9, we have assumed 2.5 individuals per household, and inflated from 2000 dollars to 2002 dollars using a factor of 1.04. Loss estimates for each region under the

two earthquake scenarios using the adapted Barakat and Chamberlin (BC) and Griffin and Mjelde (GM) methodologies are reported in Tables 7 and 8. Several features of the alternative residential loss estimates are noteworthy. First, there is much less regional variation in the contingent valuation-based estimates than in the integrated demand curve estimates. This result is not surprising, as contingent valuation studies report threshold effects with consumers willing to pay to avoid any shortage, but suggest that consumers are not particularly sensitive to duration and severity [2, 15]. However, the magnitude of the estimates varies enormously between the three methodologies and two earthquake scenarios. For the San Andreas earthquake scenario, the BC methodology estimates residential losses to be nearly twice as large as the constant elasticity of demand methodology, and an order of magnitude larger than the GM methodology (Table 7). While the BC methodology and the constant elasticity of demand methodology have comparable loss predictions for groups that suffer extended, severe shortages (groups 1, 3, and 6), both contingent valuation methodologies predict losses much higher than those estimated from the constant elasticity of demand methodology in areas with shorter, less severe rationing. For the Hetch Hetchy earthquake scenario, both contingent valuation methodologies predict total residential losses larger than those predicted by the constant elasticity of demand methodology (Table 8). Once again, the mismatch between contingent valuation constant elasticity of demand methodologies is greatest for groups with limited water supply interruptions.

In terms of risk-preparedness policy, the contingent valuation methods and the constant elasticity of demand methodology have quite different implications for residential water use. Using a constant elasticity of demand to calculate residential losses produces large heterogeneity in impacts as a function of location of water demand relative to the earthquake epicenter, and of the availability of alternative, unaffected water supplies. In the two earthquake scenarios we considered, the smaller M 7.1 Hayward earthquake resulted in relatively small residential losses, as most residential water users only suffered

small water supply shortfalls. The relatively large M 7.9 San Andreas earthquake is predicted to result in large residential losses (although still not of the same magnitude as business losses). From a planning perspective, this suggests that post-earthquake residential water supply restoration efforts that aim to reduce welfare losses should initially target very specific regions; this will be particularly true if some areas have complete outages and the government must provide water for health and sanitation. For small earthquakes that do not lead to severe water shortages to residential users, water supply restoration efforts should focus on business users. Conversely, contingent valuation studies suggest that residential welfare losses following water supply interruption are much more homogenously distributed across the affected region, implying a decreased value of targeting restoration efforts to reduce residential welfare losses.

5 Conclusion

This paper has presented simple methodologies for the estimation of the impacts of water supply interruption and disruption on businesses and residential welfare. Both methodologies use time profiles of water service interruption, rationing, and restoration combined with flexible loss equations that are calibrated to local economic data. For business interruption losses due to water supply disruption, the marginal value of water may be parameterized using the value of normal output and business resilience. In this paper, we assume that the marginal loss due to water supply disruption is increasing in the severity of the disruption, and that extremely severe disruptions or complete outages will lead to businesses shutting down. Residential loss estimation uses constant elasticity demand functions that are calibrated to local price and quantity data and integrated to estimate willingness to pay to avoid water shortages of any given severity and duration.

As an example of our methodology, we estimate the economic losses to businesses and residential water users of one of the major water supply systems of the San Francisco

Bay Area of California resulting from two potential earthquake scenarios. A magnitude 7.9 earthquake on the San Andreas Fault is estimated to lead to $14.4 billion in business interruption losses and $279 million in residential welfare losses over the sixty day period before the resumption of normal service. A magnitude 7.1 earthquake on the Hayward Fault is estimated to lead to $9.3 billion in business interruption losses and $37 million in residential welfare losses over the sixty day period before the resumption of normal service. The large difference between the business and residential loss estimates is partly due to a lack of data from extreme shortages with which to calibrate our residential loss estimation function. We assume that the government will be able to provide water for health and sanitation purposes to residential consumers during the most severe disruptions. Thus, the residential estimates should be viewed as lower bounds.

As a comparison to our business loss estimates, we also calculate losses using several previously published business loss functions and industry-specific data. These include functional forms with constant marginal loss as water supply disruption increases, and forms that allow business resilience to decrease as the duration of water supply interruption increases. For the water supply interruption and restoration profiles considered, we obtain similar results with all methodologies, although modeling industry shutdown under large outages increases loss estimates. As a comparison to our residential loss estimates, we also calculate losses using parameters and loss functions from contingent valuation studies of water supply reliability, calibrated to our two earthquake scenarios. For each scenario, estimates obtained from the contingent valuation studies vary by an order of magnitude. For the San Andreas earthquake scenario, we find that our demand function-based estimate falls between estimates obtained from the contingent valuation studies; for the Hayward earthquake scenario, both contingent valuation estimates of willingness to pay are larger than the demand function-based estimate. These differences in ranking of residential welfare loss are a result of the threshold effects observed in survey data on water supply reliability, where respondents express a high willingness

to pay to avoid any shortage, but are fairly insensitive to duration and severity of that shortage. For large earthquakes such as the M 7.9 San Andreas Fault scenario considered, residential losses from water supply interruption may be large. However, assuming that the government can provide water to meet basic health and sanitation requirements, residential losses will be much less than business interruption losses. Our results imply that business and residential losses following earthquakes may be highly variable over space and time, and by industry type, suggesting that adaptable mitigation strategies are needed to account for such variability.

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Table 1: Data for residential and business welfare loss calculations

Water Agency	**Supply fraction** (α_i)	**Residential consumers** (N_i)	**ADD, gpcpd** ($Q_{baseline}$)	**Ave. cost, $ per gallon** ($P_{baseline}$)
Alameda	0.25	318,250	98.84	0.00281
Belmont	1	25,500	98.93	0.00414
Brisbane	1	4,063	50.97	0.00579
Burlingame	1	30,000	97.33	0.00320
Coastside	0.616	17,990	69.42	0.00405
Cordilleras	1	40	159.08	0.00365
CWS-Bear Gulch	0.905	65,830	158.74	0.00328
CWS-Mid Pen	1	120,820	96.97	0.00289
CWS-SSF	0.859	54,060	67.75	0.00235
Daly City	0.555	104,571	63.76	0.00271
East Palo Alto	1	27,300	50.92	0.00241
Estero	0.98	34,252	97.86	0.00199
Hayward	1	128,000	82.79	0.00273
Hillsborough	1	11,760	292.17	0.00578
Los Trancos	1	1,230	86.73	0.00365
Menlo Park	1	10,200	149.49	0.00182
Millbrae	1	21,394	90.36	0.00341
Milpitas	0.601	65,000	74.43	0.00234
Mountain View	0.793	76,025	86.36	0.00286
N. San Jose	0.926	7,000	115.00	0.00201
N. Santa Clara	0.169	102,500	112.83	0.00242
North Coast	1	39,667	66.37	0.00497
Palo Alto	0.991	61,200	128.08	0.00517
Purissima Hills	1	5,800	321.19	0.00324
Redwood City	1	83,000	89.13	0.00223
San Bruno	0.581	41,750	70.32	0.00368
San Francisco	1	800,000	95.50	0.00242
Skyline	1	1,631	84.27	0.00876
Stanford	0.72	24,700	49.05	0.00517
Sunnyvale	0.437	131,200	95.20	0.00207
Westborough	1	9,990	67.29	0.00286

Notes: Data adapted from BAWUA [5], BAWSCA [4], and Eidinger [12]. The supply fraction α_i represents the proportion of water consumed in water agency i delivered from the Hetch Hetchy system. The value of $P_{baseline}$ for Stanford was taken to be the same as that for Palo Alto, and prices for Cordilleras and Los Trancos were taken as the average cost for special districts (BAWSCA [4]). The city of San Francisco operates tiered pricing based on conservation affidavits on file, but in 2002 total commodity charges per residential user were equal to those of San Jose; accordingly we adjust for the difference in average daily use to estimate $P_{baseline}$.

Table 2: Business activity by county and sector

Sector	**San Francisco**	**San Mateo**	**Santa Clara**	**Alameda**
Manufacturing	3,589	8,305	47,110	29,632
Wholesale trade	8,897	16,798	68,095	41,553
Retail trade	8,883	9,017	20,035	16,512
Prof., sci. & tech.	14,142	6,513	17,494	7,487
Acc. & food	3,547	1,471	3,037	2,051

Notes: Data are given in millions of dollars and are taken from the 2002 U.S. Economic Census, representing annual values for each sector in each county. No county value for wholesale trade is reported for Santa Clara county for 2002; the value reported here is taken from the 1997 U.S. Economic Census. Values reported represent total sales, shipments, receipts, revenue, or business done, as described in the 2002 U.S. Economic Census.

Table 3: Business activity by county and group water supply regions for earthquake scenarios

County	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
San Andreas M 7.9						
San Francisco	0	0	0	0	0	1
San Mateo	0.33	0.33	0.33	0	0	0
Santa Clara	0	0	0.4	0.4	0	0
Alameda	0	0	0	0	0.5	0
Hayward M 7.1						
San Francisco	0	0	1	0	-	-
San Mateo	0.33	0	0	0.67	-	-
Santa Clara	0.264	0.264	0	0.264	-	-
Alameda	0.25	0.25	0	0	-	-

Notes: The table shows the proportion of each county's business activity that is located in each group with similar water supply interruption and restoration profiles (see Figures 3 and 4). For example, we assume that 50 percent of business activity in Alameda county is potentially impacted, and 80 percent of business activity in Santa Clara County is potentially impacted, by interruption of Hetch Hetchy service.

Table 4: Business interruption losses for users of Hetch Hetchy water resulting from a San Andreas Fault M 7.9 earthquake

Group	**Manuf.**	**Wholesale**	**Retail**	**Prof/Tech**	**Acc/Food**	**Total**
1	336	633	340	245	59	1,613
2	247	241	129	93	44	754
3	2,013	2,538	851	708	159	6,269
4	874	567	167	146	56	1,810
5	45	31	12	6	3	97
6	408	852	851	1,355	404	3,870
Sector	3,923	4,862	2,350	2,553	725	14,414

Notes: Group definitions and time paths of water supply interruptions and rationing follow Figure 3. Damage figures are reported in millions of dollars. The estimates in this table assume that $r_{ijt} = 0$ and that $\gamma_{jt} = 0.5$ for the manufacturing and accommodation and food sectors, and that $\gamma_{jt} = 0.2$ for the other sectors analyzed.

Table 5: Business interruption losses for users of Hetch Hetchy water resulting from a Hayward Fault M 7.1 earthquake

Group	**Manuf.**	**Wholesale**	**Retail**	**Prof/Tech**	**Acc/Food**	**Total**
1	2,108	2,644	967	674	168	6,561
2	835	466	155	107	55	1,618
3	78	90	90	144	77	479
4	305	206	80	63	30	684
Sector	3,326	3,406	1,292	988	330	9,341

Notes: Group definitions and time paths of water supply interruptions and rationing follow Figure 4. Damage figures are reported in millions of dollars. The estimates in this table assume that $r_{ijt} = 0$ and that $\gamma_{jt} = 0.5$ for the manufacturing and accommodation and food sectors, and that $\gamma_{jt} = 0.2$ for the other sectors analyzed.

Table 6: Comparing estimates of business interruption losses for San Andreas Fault M 7.9 and Hayward Fault M 7.1 earthquakes

Model	**Equation 2, shutdown possible**	**Equation 2, no shutdown,** $\partial r_{ijt}/\partial t < 0$	**Equation 1, no shutdown,** $\partial r_{ijt}/\partial t < 0$	**Equation 1, no shutdown**
San Andreas M 7.9	\$14,414	\$9,453	\$9,641	\$5,236
Hayward M 7.0	\$9,341	\$6,022	\$6,631	\$3,876

Notes: Time paths of water supply interruptions and rationing by group follow Figures 3 and 4. Estimated business interruption losses are reported in millions of dollars.

Table 7: Residential welfare losses for users of Hetch Hetchy water resulting from a San Andreas Fault M 7.9 earthquake

Group number	**Constant elasticity demand**	**BC contingent valuation parameters**	**GM contingent valuation parameters**
1	\$116.11	\$74.01	\$7.34
2	\$1.04	\$23.79	\$2.82
3	\$61.99	\$55.83	\$6.02
4	\$1.95	\$54.40	\$7.10
5	\$0.36	\$51.67	\$5.48
6	\$97.76	\$170.40	\$17.45
Total	\$279.20	\$430.10	\$46.21

Notes: Time paths of water supply interruptions and rationing by group follow Figure 3. Welfare losses are reported in millions of dollars. The estimates for constant price elasticity of demand assume that BWR = 10 gpcpd and that η = -0.41.

Table 8: Residential welfare losses for users of Hetch Hetchy water resulting from a Hayward Fault M 7.1 earthquake

Group number	**Constant elasticity demand**	**BC contingent valuation parameters**	**GM contingent valuation parameters**
1	\$27.55	\$57.94	\$6.23
2	\$1.62	\$81.16	\$10.93
3	\$5.03	\$105.64	\$14.04
4	\$2.76	\$88.32	\$11.98
Total	\$36.94	\$333.05	\$43.18

Notes: Time paths of water supply interruptions and rationing by group follow Figure 4. Welfare losses are reported in millions of dollars. The estimates for constant price elasticity of demand assume that BWR = 10 gpcpd and that η = -0.41.

Table 9: Sensitivity of residential welfare losses to price elasticity of demand for water and Basic Water Requirement

San Andreas	BWR **= 13.2 gpcpd**	BWR **= 10 gpcpd**	BWR **= 6.6 gpcpd**
$\eta = -0.35$	\$400.76	\$662.03	\$1403.40
$\eta = -0.41$	\$188.86	**\$279.20**	\$499.18
$\eta = -0.51$	\$90.33	\$119.02	\$177.76

Hayward	BWR **= 13.2 gpcpd**	BWR **= 10 gpcpd**	BWR **= 6.6 gpcpd**
$\eta = -0.35$	\$45.60	\$67.37	\$124.10
$\eta = -0.41$	\$27.69	**\$36.94**	\$57.67
$\eta = -0.51$	\$17.23	\$20.85	\$27.65

Notes: Welfare losses are reported in millions of dollars. Estimates reported in detail in Table 8 are shown in bold, and assume that $BWR = 10$ gpcpd, and that $\eta = -0.41$ (following the mean reported in the meta-analysis of Dalhuisen *et al.* [11]). Dalhuisen *et al.* report a median residential price elasticity of demand for water of -0.35, while the meta-analysis of Espey *et al.* [13] reports a value of -0.51.

Figure 1: **Business productivity loss curves**

Figure 2: **Water agencies served by the Hetch Hetchy system**

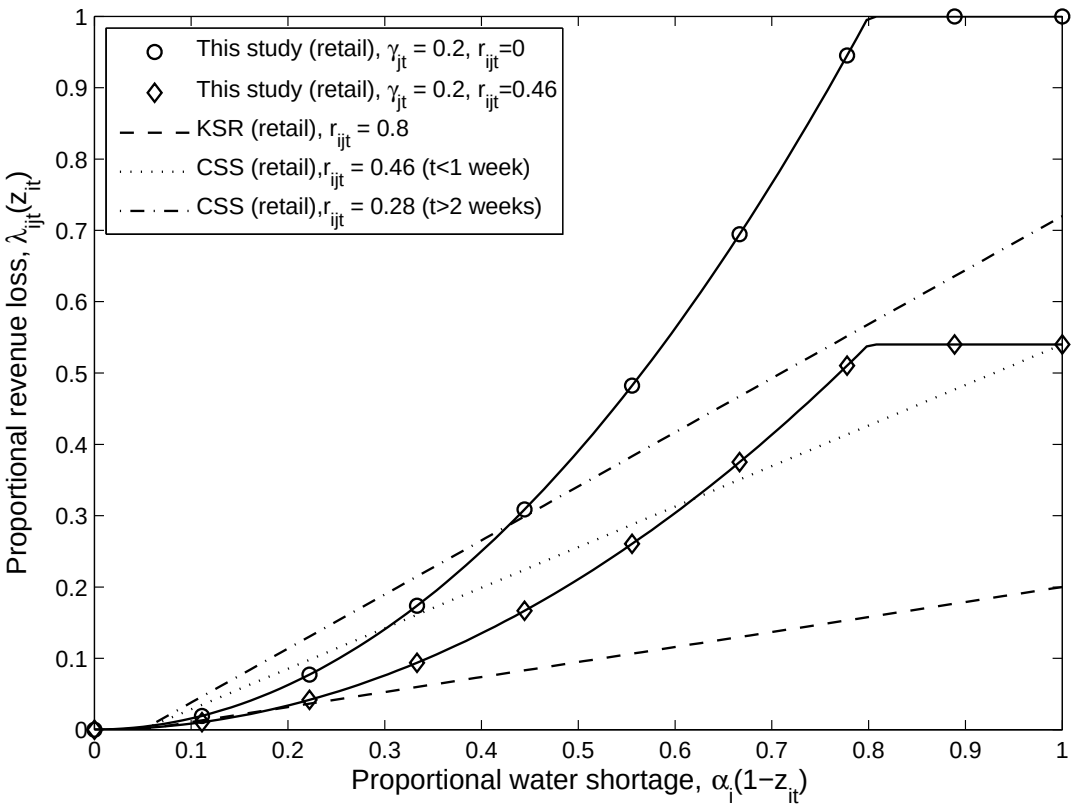
Number	Agency Name	Number	Agency Name
1	Alameda County WD	14	Los Trancos County WD
2	Mid-Peninsula WD	15	City of Menlo Park
3	City of Brisbane	16	City of Millbrae
4	City of Burlingame	17	City of Milpitas
5a	Bear Gulch – CWS	18	City of Mountain View
5b	City of San Carlos – CWS	19	North Coast County WD
5c	City of San Mateo – CWS	20	City of Palo Alto
5d	City of South San Francisco – CWS	21	Purissima Hills WD
6	Coastside County WD	22	City of Redwood City
7	Cordilleras Mutual Water Association	23	City of San Bruno
8	City of Daly City	24	City of San Jose
9	City of East Palo Alto	25	City of Santa Clara
10	Estero Municipal Improvement District	26	Skyline County WD
11	Guadalupe Valley Municipal	27	Stanford University
	Improvement District	28	City of Sunnyvale
12	City of Hayward	29	Westborough WD
13	Town of Hillsborough		

Notes: Data from SFPUC and BAWSCA; WD (Water District), CWS (Cal Water Service Co.). In this analysis, CWS-San Carlos and CWS-San Mateo are joined as CWS-Mid Peninsula. In 2003, CWS-Mid Peninsula and CWS-S. San Francisco consolidated into the current Bayshore District. Note also that Guadalupe Valley is excluded from our analysis due to insufficient data.

Figure 3: **Water supply interruptions and rationing to Hetch Hetchy customers resulting from a San Andreas Fault M 7.9 earthquake**

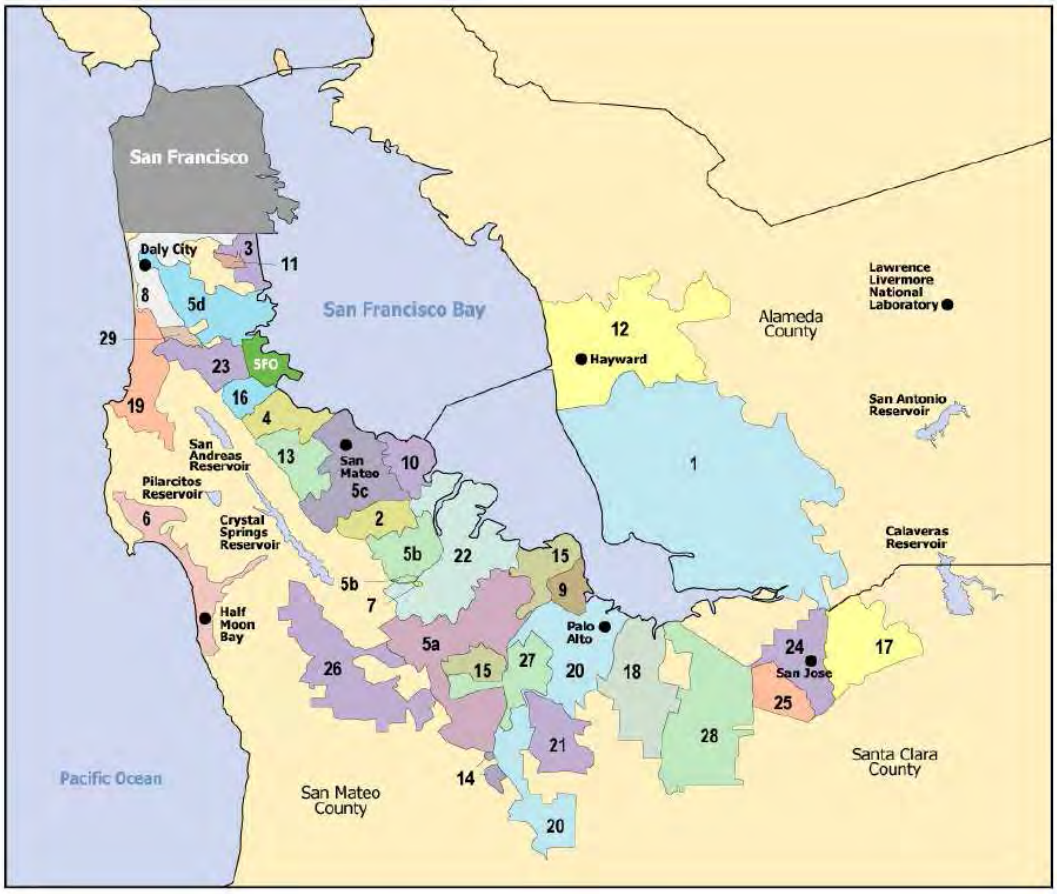
Figure 4: **Water supply interruptions and rationing to Hetch Hetchy customers resulting from a Hayward Fault M 7.1 earthquake**

Figure 1: Business productivity loss curves



Notes: Comparison of representative business loss curves for this study, Chang *et al.* [9] (abbreviated as CSS), and Khater *et al.* [19] (abbreviated as KSR). This figure assumes that $\alpha_i = 1$, and uses Equations 1 and 2, together with retail trade resilience estimates.

Figure 2: Water agencies served by the Hetch Hetchy system



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1	Alameda County WD	14	Los Trancos County WD
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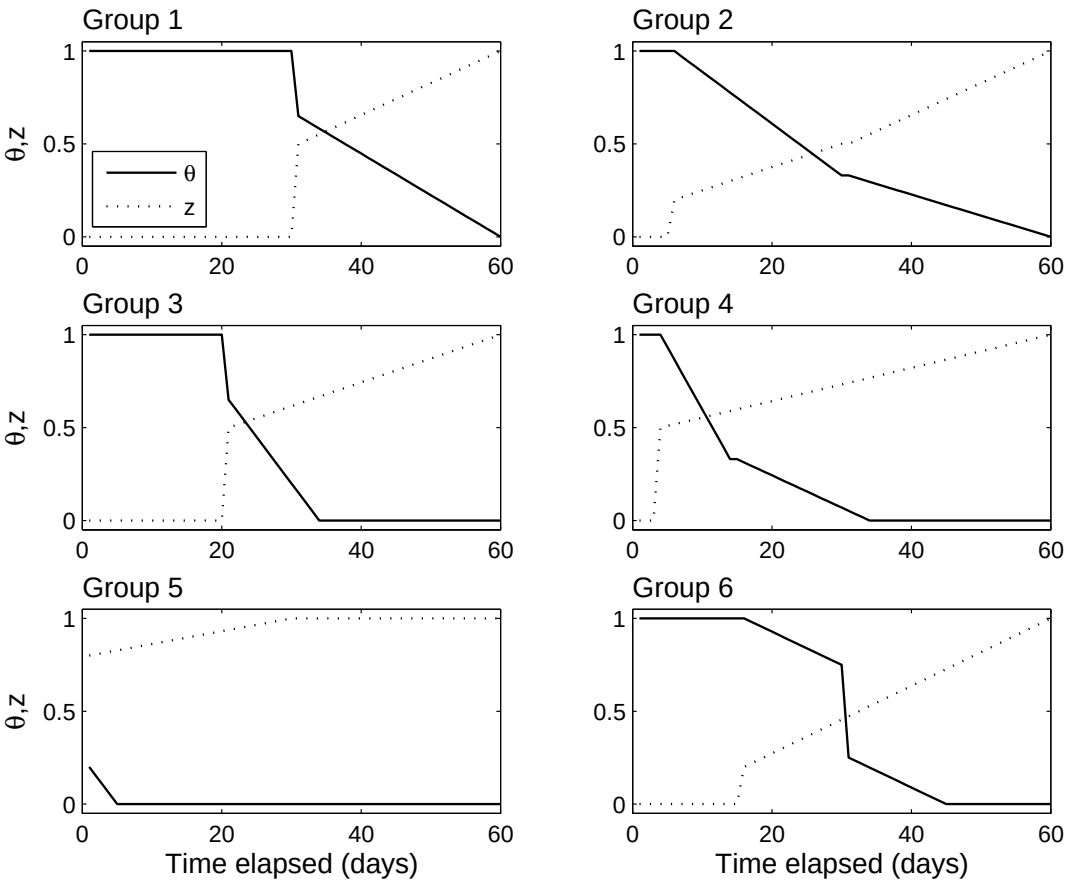
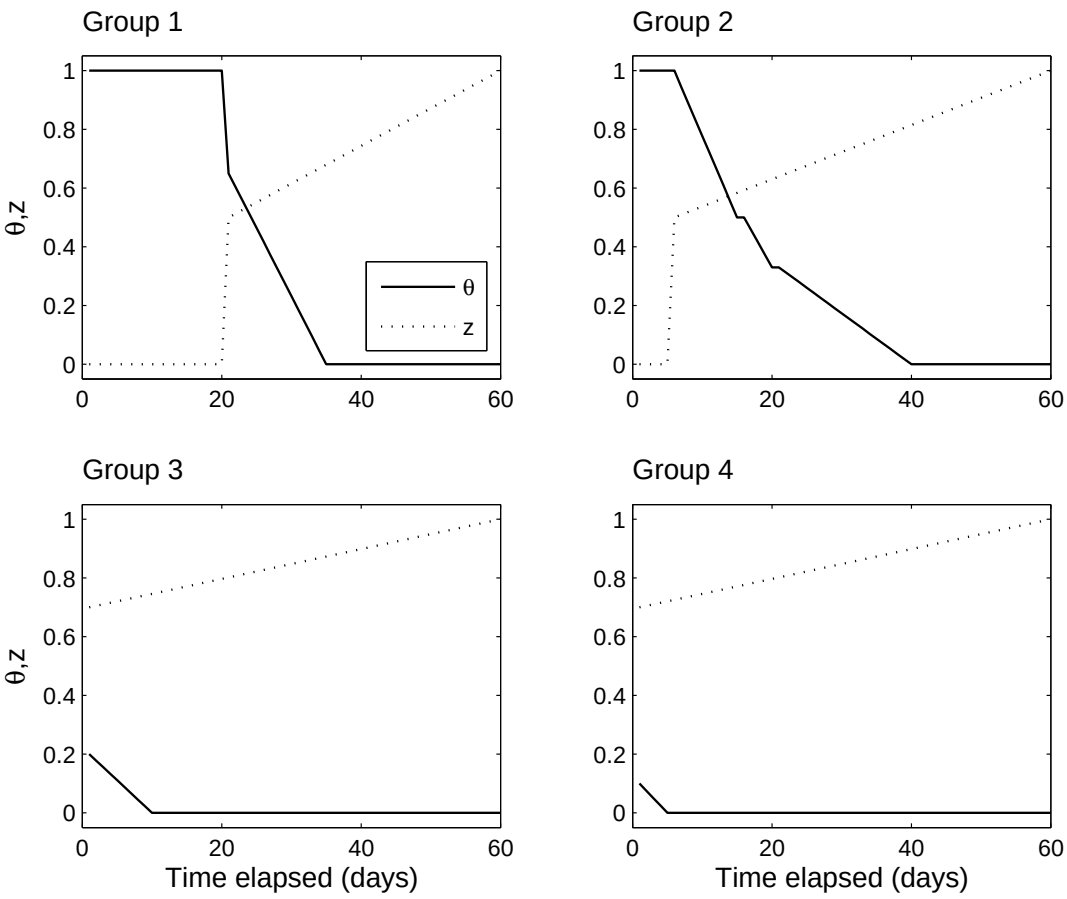
Notes: Data from SFPUC and BAWSCA; WD (Water District), CWS (Cal Water Service Co.). In this analysis, CWS-San Carlos and CWS-San Mateo are joined as CWS-Mid Peninsula. In 2003, CWS-Mid Peninsula and CWS-S. San Francisco consolidated into the current Bayshore District. Note also that Guadalupe Valley is excluded from our analysis due to insufficient data.

Figure 3: Water supply interruptions and rationing to Hetch Hetchy customers resulting from a San Andreas Fault M 7.9 earthquake



Notes: The variable θ represents the proportion of customers in each group that are without Hetch Hetchy water. For those customers receiving Hetch Hetchy water, the variable z represents the rationing level (where $z = 1$ corresponds to no rationing). Note that both θ and z are bounded in the interval $[0, 1]$, and that water agencies for which $\alpha_i < 1$ will have higher levels of overall available water in the range $[1-\alpha_i(1-z_{it}), 1]$. Group membership by BAWSCA and other agencies is defined as follows: Group 1 (Brisbane, Burlingame, CWS - Mid Peninsula, CWS - South San Francisco, Estero, Hillsborough, Millbrae, North Coast, Westborough), Group 2 (Daly City, San Bruno), Group 3 (Belmont, CWS - Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto (City), Purissima Hills, Redwood City, San Jose, Skyline), Group 4 (Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale), Group 5 (Alameda, Hayward), Group 6 (San Francisco). Information in this figure is adapted from Eidinger [12].

Figure 4: Water supply interruptions and rationing to Hetch Hetchy customers resulting from a Hayward Fault M 7.1 earthquake



Notes: Variables used are as defined in Figure 3. Group membership by BAWSCA and other agencies is defined as follows: Group 1 (CWS - Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto (City)*, *Redwood City*, *San Jose*, Skyline), Group 2 (Alameda, Milpitas, Santa Clara, *Stanford*, Sunnyvale), Group 3 (San Francisco), Group 4 (Belmont, Brisbane, Burlingame, CWS - Mid Peninsula, CWS - South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto (City)*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough). Italics denote cities with partial shortages within the group; it is assumed that half of the daily water demand for these water providers is unaffected by an M 7.1 earthquake on the Hayward Fault, and the remainder follows the graphs above. Information in this figure is adapted from Eidinger [12].

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NEWS RELEASE

WEST INFORMATION OFFICE
San Francisco, Calif.

For release Friday, March 1, 2013 **13-397-SAN**

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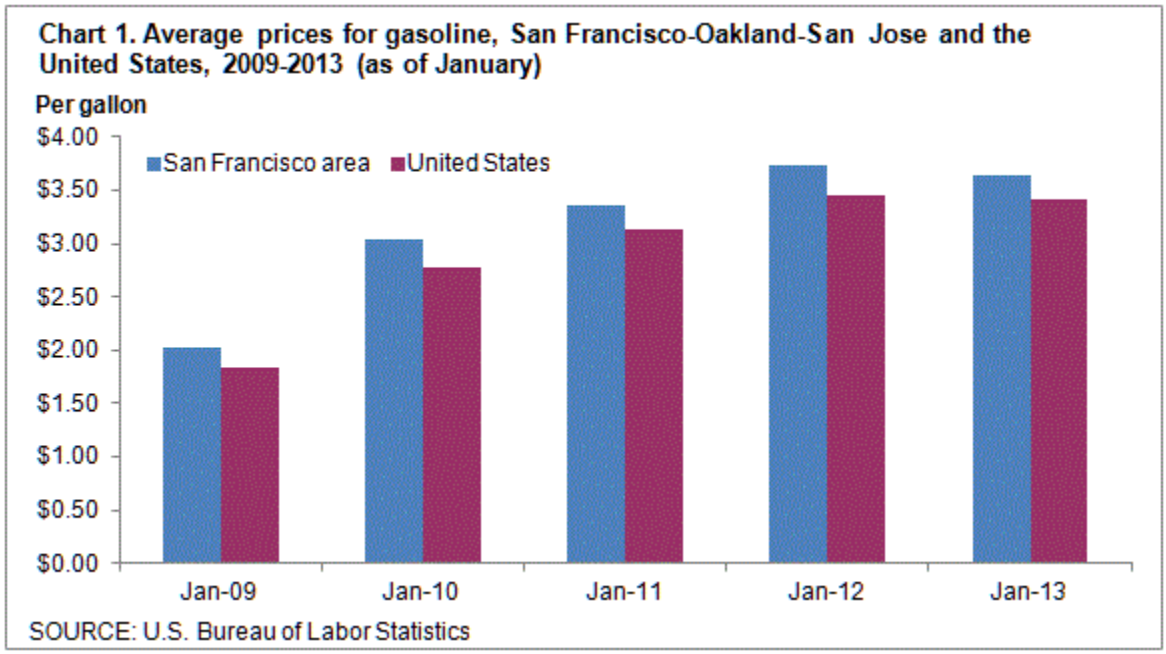
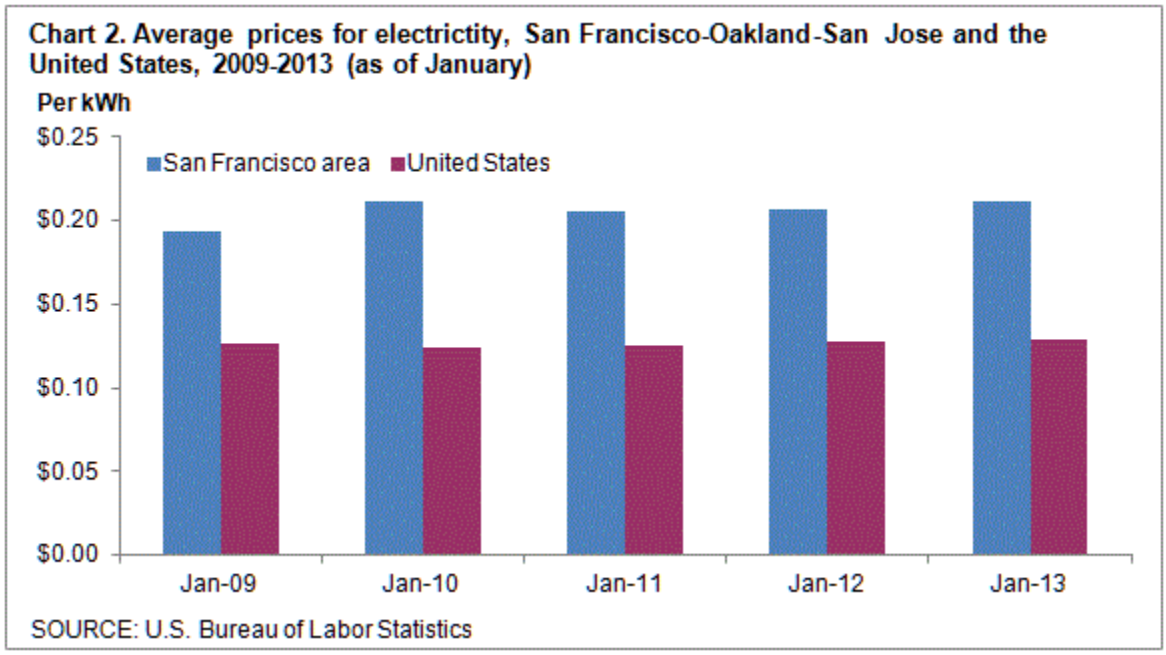
AVERAGE ENERGY PRICES, SAN FRANCISCO AREA–JANUARY 2013

Gasoline prices averaged $3.646 a gallon in the San Francisco area in January 2013, the U.S. Bureau of Labor Statistics reported today. Regional Commissioner Richard J. Holden noted that area gasoline prices were down 9.0 cents compared to last January when they averaged $3.736 per gallon. San Francisco area households paid an average of 21.2 cents per kilowatt hour (kWh) of electricity in January 2013, up from 20.7 cents per kWh in January 2012. The average cost of utility (piped) gas at $1.079 per therm in January was less than the $1.148 per therm spent last year. (Data in this release are not seasonally adjusted; accordingly, over-the-year-analysis is used throughout.)

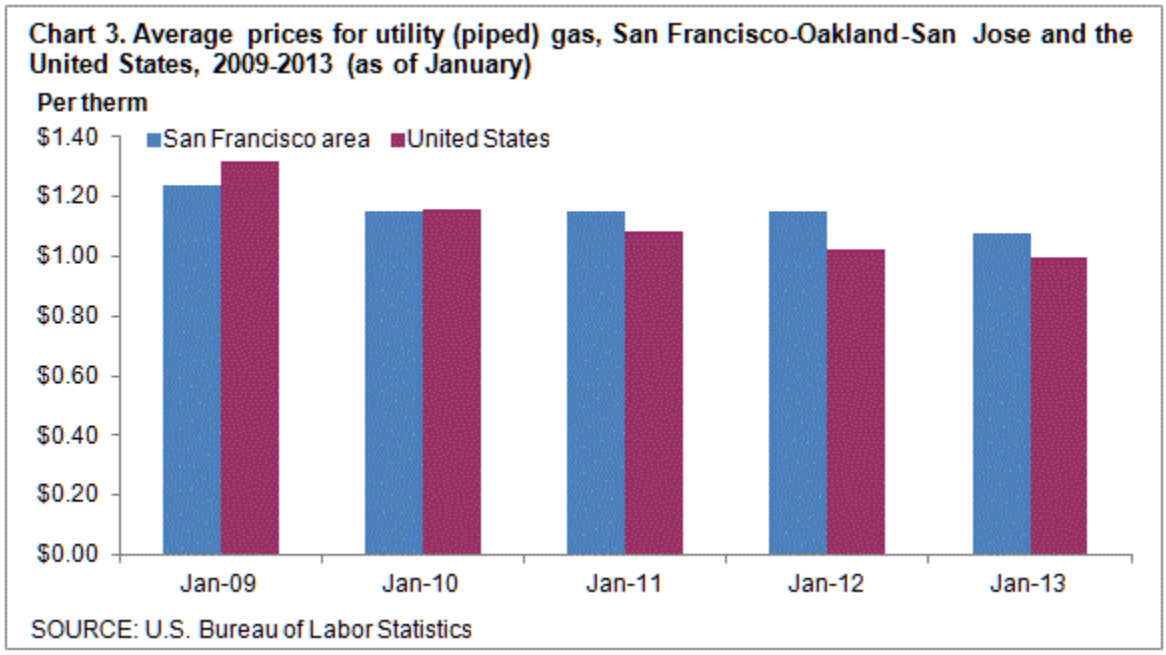
At $3.646 a gallon, San Francisco area consumers paid 7.0 percent more than the $3.407 national average in January 2013. A year earlier, consumers in the San Francisco area paid 8.4 percent more than the national average for a gallon of gasoline. The local price of a gallon of gasoline has exceeded the national average by more than six percent in the month of January in each of the past five years. (See chart 1.)



The 21.2 cents per kWh San Francisco households paid for electricity in January 2013 was 64.3 percent more than the nationwide average of 12.9 cents per kWh. Last January, electricity costs were 61.7 percent higher in San Francisco compared to the nation. In each of the past five years, prices paid by San Francisco area consumers for electricity exceeded the U.S. average by at least 53 percent in the month of January. (See chart 2.)



Prices paid by San Francisco area consumers for utility (piped) gas, commonly referred to as natural gas, were $1.079 per therm, or 8.3 percent above the national average in January 2013 ($0.996 per therm). A year earlier, area consumers paid 12.4 percent more price per therm for natural gas compared to the nation. In the past three years, the per therm cost for natural gas in January in the San Francisco area has been above the U.S. average. (See chart 3.)



The San Francisco-Oakland-San Jose, Calif. metropolitan area consists of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties in California.

Technical Note

Average prices are estimated from Consumer Price Index (CPI) data for selected commodity series to support the research and analytic needs of CPI data users. Average prices for electricity, utility (piped) gas, and gasoline are published monthly for the U.S. city average, the 4 regions, the 3 population size classes, 10 region/size-class cross-classifications, and the 14 largest local index areas. For electricity, average prices per kilowatt-hour (kWh) and per 500 kWh are published. For utility (piped) gas, average prices per therm, per 40 therms, and per 100 therms are published. For gasoline, the average price per gallon is published. Average prices for commonly available grades of gasoline are published as well as the average price across all grades.

Price quotes for 40 therms and 100 therms of utility (piped) gas and for 500 kWh of electricity are collected in sample outlets for use in the average price programs only. Since they are for specified consumption amounts, they are not used in the CPI. All other price quotes used for average price estimation are regular CPI data.

With the exception of the 40 therms, 100 therms, and 500 kWh price quotes, all eligible prices are converted to a price per normalized quantity. These prices are then used to estimate a price for a defined fixed quantity.

The average price per kilowatt-hour represents the total bill divided by the kilowatt-hour usage. The total bill is the sum of all items applicable to all consumers appearing on an electricity bill including, but not limited to, variable rates per kWh, fixed costs, taxes, surcharges, and credits. This calculation also applies to the average price per therm for utility (piped) gas.

Information from this release will be made available to sensory impaired individuals upon request. Voice phone: 202-691-5200, Federal Relay Services: 800-877-8339.

Table 1. Average prices for gasoline, electricty, and utility (piped) gas, San Francisco-Oakland-San Jose and the United States, January 2012-January 2013, not seasonally adjusted

Year and month	Gasoline per gallon		Electricity per kWh		Utillity (piped) gas per therm	
	San Francisco area	United States	San Francisco area	United States	San Francisco area	United States
2012						
January	$3.736	$3.447	$0.207	$0.128	$1.148	$1.021
February	4.040	3.622	0.207	0.128	1.187	0.986
March	4.375	3.918	0.209	0.127	1.055	0.978
April	4.230	3.976	0.209	0.127	1.197	0.951
May	4.331	3.839	0.220	0.129	1.224	0.907
June	4.012	3.602	0.220	0.135	1.345	0.927
July	3.804	3.502	0.218	0.133	1.385	0.943
August	4.136	3.759	0.218	0.133	1.369	0.960
September	4.201	3.908	0.218	0.133	1.320	0.953
October	4.476	3.839	0.218	0.128	1.273	0.962
November	3.832	3.542	0.207	0.127	1.190	0.994
December	3.563	3.386	0.207	0.127	1.140	1.004
2013						
January	3.646	3.407	0.212	0.129	1.079	0.996

Basic Water Requirements for Human Activities: Meeting Basic Needs

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INTRODUCTION

The last few years have seen a remarkable change in the nature of the global discussion of issues of environment and development. In the work of the Brundtland Commission [1], the extensive lead-up to the 1992 Earth Summit in Brazil, and in subsequent discussions and work, the intimate connections between environment and development have been accepted as a given. The questions now being discussed and researched are how to define and achieve development in a "sustainable" way. This is a much needed and welcome change.

Unfortunately, considerable debate and confusion surround both the terms "sustainable" and "development" and only modest forward progress has been made. This lack of progress is particularly disturbing in the area of water resources, which are vitally important for producing food, maintaining aquatic ecosystems, and protecting human health.

Among the concepts raised nearly 20 years ago during the 1977 Mar del Plata conference — one of the earliest international efforts to address global water problems — was that of "basic needs" [2]:

> ... all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs.

This concept was strongly reaffirmed during the 1992 Earth Summit in Rio de Janeiro and expanded to include ecological water needs [3]:

> In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems.

Implicit in this phrase is the idea of minimum resource requirements for certain human and ecological functions, and the allocation of sufficient resources to meet those needs. This article defines and quantifies "basic water requirements" (BWRs) in terms of quantity and quality for four basic human needs: drinking water for survival, water for human hygiene, water for sanitation services, and modest household needs for preparing food. The concept of identifying water needs for growing food and protecting natural ecosystems is also briefly discussed. These minimal needs are also discussed in the context of international water law and two regions with a long history of water disputes: the Middle East and California. Finally, data are presented showing the current failure of many nations to provide even this basic level of clean water to their citizens.

Based on the analysis here, I recommend that international organizations, national and local governments, and water providers adopt a basic water requirement standard for human needs of 50 liters per person per day (l/p/d) and guarantee access to it independently of an individual's economic, social, or political status. Unless this basic need is met, large-scale human misery and suffering will continue and grow in the future, contributing to the risk of social and military conflict. Ultimately, decisions about defining and applying a basic water requirement will depend on political and institutional factors, but the concept may prove useful in meeting basic water needs for the next century.

DEFINING BASIC WATER REQUIREMENTS

Different sectors of society use water for different purposes: drinking, removing, or diluting wastes, producing manufactured goods, growing food, producing and using energy, and so on. The water required for each of these activities varies with climatic conditions, lifestyle, culture, tradition, diet, technology, and wealth, as shown over 20 years ago in the groundbreaking work of White, Bradley, and White [4]. The type of access to water alone is an important determinant in total water use. Tables 1 and 2 show that the level of domestic water use varies with distance from the water source and with the climate.

The term "water use" encompasses many different ideas

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Table 1. Domestic water use by distance to source

Source of Water	Water Use (liters per person per day)
Public Standpipe, farther than 1 kilometer	less than 10
Public Standpipe, closer than 1 kilometer	20
House Connection, simple plumbing, pour, flush toilet	60 to 100
House Connection, urban, with gardens	150 to 400

and is often misleading and confusing. Among other things it has been used to mean the withdrawal (intake) of water, gross water use (intake plus recirculation plus reuse), and the consumptive use of water. In this article, I use the term "withdrawal" to refer to the act of taking water from a source to convey it elsewhere for storage or use. Not all water withdrawn is necessarily consumed, however. Indeed, for many processes, water is often withdrawn and then returned directly to the original source after use, as in water used for cooling thermoelectric power plants. Gross water use is distinguished from water withdrawal by the inclusion of recirculated water. Thus for many industrial processes, far more water is required than is actually withdrawn for use. Water "consumption" or "consumptive use" is taken here to mean the use of water in a manner that prevents its reuse, such as through evaporation, plant transpiration, contamination, or incorporation into a finished product. When the term water "use" is given, it refers to the amount of water required to meet a specific need or to accomplish a particular task.

Minimum Drinking Water Requirement

An absolute "minimum water requirement" for humans, independent of lifestyle and culture, can be defined only for maintaining human survival. To maintain the water balance in a living human, the amount of water lost through normal activities must be regularly restored. While the amount of water required to maintain survival depends on surrounding environmental conditions and personal physiological characteristics, the overall variability of needs is quite small. Routes for water loss include evaporation from the skin, excretion losses, and insensible loss from the respiratory tract. Humans may feel thirst after a fluid loss of only 1 per cent of bodily fluid and be in danger of death when fluid loss nears 10 per cent [7].

Prior physiological studies have generated "reference values" for a daily human water requirement. Table 3 summarizes several estimates of total daily water requirements for a "reference" human. Minimum water requirements for fluid replacement have been estimated at about three liters per day under average temperate climate conditions. When climate and levels of activity are changed, these daily minimum water requirements can increase. In a hot climate, a 70-kilogram human will sweat between four and six liters per day without a comparable change in food intake or activity [7].

Table 2. Rural household water use by climate and source[a]

Climatic Zone	Public Standpost liters/capita/day	House Connection[b] liters/capita/day
Humid	10 to 20	20 to 40
Average	20 to 30	40 to 60
Dry	30 to 40	60 to 80

[a] Data from rural developing countries.
[b] Without flush toilets or gardens.
Source: Reference 5.

The National Research Council of the National Academy of Sciences in the U.S.A. separately estimated minimum human water requirements by correlating them with energy intake in food. They recommend a minimum water intake of between one and one-and-a-half milliliters of water per calorie of food (1 – 1.5 ml/kcal). Note that a food calorie is equivalent to a kcal of energy. In this article, the energy content of food will be represented by kcals. This does not include the water required to *grow* the food consumed, which is discussed later. With recommended daily diets ranging from 2,000 to 3,000 kcals, minimum water requirements are between 2,000 and 4,500 milliliters, or 2 to 4.5 liters per day — comparable with the data presented in Table 3 [14].

Using these data, a minimum water requirement for human survival under typical temperate climates with normal activity can be set at three liters per day. Given that substantial populations live in tropical and subtropical climates, it is necessary to increase this minimum slightly, to about five l/p/d, or just under two cubic meters per person per year. A further fundamental requirement not usually noted in the physiological literature is that this water should be of sufficient quality to prevent water-related diseases.

Basic Requirements for Sanitation

A "minimum" must also be defined for providing sanitation services. There is a direct link between the provision of clean water, adequate sanitation services, and improved health. Extensive research has shown the clear health advantages of access to adequate sanitation facilities

Table 3. Average daily water requirements for survival[a]

Source	Average daily water intake in liters per capita per day
Vinograd [8]; Roth [9]	2.5[b]
World Health Organization [10]	2.5
White et al. [4]	1.8 to 3.0
U.S. Environmental Protection Agency [11]	2.0
National Academy of Sciences [12]	2.0
Saunders and Warford [13]	5

[a] During normal activity and temperate climate.
[b] This value represents the actual fluid requirements measured for early space flights. The recommended intake minimum for Apollo astronauts under routine conditions in the command module was 2.9 liters per day.

and protecting drinking water from pathogenic bacteria and viral and protozoal agents of disease. Effective disposal of human wastes controls the spread of infectious agents and interrupts the transmission of water-related diseases.

Unfortunately, much of the world's population, particularly in developing countries, remains without access to clean drinking water or adequate methods to dispose of human wastes. According to recent estimates, more than 1.7 billion people lacked access to adequate sanitation services in 1990, while over 1.2 billion people lacked adequate clean drinking water [15]. During the decade between 1990 and the year 2000, nearly 900 million more people will be born in these regions [16,17]. It has been estimated that lack of clean drinking water and sanitation services leads to many hundreds of millions of cases of water-related diseases and between five and ten million deaths annually, primarily of small children [18-21].

For the most part, the world health community knows how to prevent these diseases, but lacks the financial and institutional capability needed to take definitive and effective action. While media attention to these problems increases when particularly acute regional crises occur, such as the recent disastrous outbreak of cholera in Latin America or among Rwandan refugees in Zaire, the more widespread chronic problems still beg for attention from the world community.

In recent reviews of epidemiological studies related to water and sanitation, the provision of adequate sanitation services was the most direct determinant of child health after also providing a minimum amount of water for metabolic activity and handwashing [19,20,22-24].

There are many technologies for improving access to adequate sanitation services, with widely varying water requirements. In regions where absolute water quantity is a major problem, alternatives that require no water are available. Table 4 lists those technologies that require no water except for minimal washing. Where historical circumstances led to the use of wasteful, high-volume flush toilets, as much as 75 liters per capita per day, or more, have been used. Table 5 lists the wide range of sanitation technologies that require water. The choice of sanitation technology will ultimately depend on the developmental goals of a country or region, the water available, the economic choice of the alternatives, and powerful regulatory, cultural, and social factors [4,25].

Given these variables, can a recommended basic water requirement for sanitation be identified? Because alternatives are available that require no water, it is technically feasible to set a minimum at zero. Two factors argue against doing this: additional health benefits are identifiable when up to 20 liters per capita per day of clean water are provided [23]; and where economic factors are not a constraint, cultural and social preferences strongly lean toward water-based systems. Access to some water for sanitation, together with concurrent education about water use, decreases the incidence of diseases, increases the frequency of hygienic food preparation and washing, and reduces the consumption of contaminated food products. Accordingly, while effective disposal of human wastes can be accomplished with little or no water when necessary, a minimum of 20 liters per person per day is recommended here to account for the maximum benefits of combining waste disposal and related hygiene, and to permit for cultural and societal preferences. This level can be met with a wide range of technological choices.

Table 4. Sanitation technologies that require no water

Ventilated improved pits (VIP)
Reed Odorless Earth Closets (ROEC)
Ventilated Improved Double-Pit Latrines
Double-Vault Composting Toilets (DVC)
Continuous Composting

Sources: References 25 and 26.

Basic Water Requirement for Bathing

On top of these direct sanitation requirements, additional domestic water is used for showering or bathing. A review of a range of studies in North America and Europe (Table 6) suggests average (not minimum) water use in industrialized nations for bathing to be about 70 liters per person per day, with a range from 45 to 100 l/p/d. Data on water used for bathing in developing countries or in regions with no piped water are not widely available. Some studies suggest that minimum water needed for adequate bathing is on the order of 5 to 15 l/p/d and that required for showering is 15 to 25 l/p/day [25]. A basic level of service of 15 l/p/d for bathing is recommended here.

Basic Requirement for Food Preparation

The final component of a domestic basic water requirement is the water required for the preparation of food. While most detailed surveys of residential water use in industrialized countries do not provide separate estimates of water used for cooking, Brooks and Peters [29] estimate that water use for food preparation in wealthy regions ranges from 10 to 50 liters per person per day, with a mean of 30 liters per person per day. In a study done of the water provided for 1.2 million people in northern California, an average of 11.5 liters per person per day was used for cooking, with an additional 15 liters used for dishwashing [31]. Other studies in both developed and developing countries [4,14,32,33] suggest that an average of 10 to 20 liters per person per day appears to satisfy most regional standards and that 10 l/p/d will meet basic needs.

The Special Case of Food

The four domestic uses described above do not include water required to grow the food necessary for human survival. Minimum caloric requirements, cultural preferences for different kinds of food, regional climatic conditions, irrigation and food processing technologies,

Table 5. Sanitation technologies that require water

Sanitation Technology	Water Requirement	Minimum Water
Pit latrine	Water near toilet	1 to 2 liters/flush
Pour/Flush (PF) toilets	Water near toilet	6 to 10 liters/person/day
Vault toilets and cartage	Water near toilet	3 to 6 liters/person/day
Sewered PF toilets/septic tanks	Water piped to toilet	7.5 liters/person/day
Small-bore sewerage	Water piped to toilet	>50 liters/person/day
Inefficient conventional sewerage	Water piped to toilet	>75 liters/person/day

Sources: References 25 and 26.

and a wide range of social factors all affect total water requirements for producing food. At present, no satisfactory analysis of these factors has been done. Rough calculations, however, offer some insight into how variable these factors can be.

Typical regional diets, compiled from the UN Food and Agriculture Organization [34], are shown in Table 7. Using average evapotranspiration requirements on a regional basis, estimates of rainfed and irrigated acreage, and assumptions about the efficiency of irrigation can give a first-order estimate of the water requirements to produce these regional diets. In fact, however, calculating actual water requirements to grow food is even more complicated. Among the other factors that must be considered are specific regional crop yield information, soil conditions, more precise climatic variations and effects, food processing and waste factors, and so on.

No comprehensive estimates have yet been made, though there have recently been efforts to make some regional estimates. Table 8 shows the estimated water requirements that would be necessary to grow the food needed to meet dietary demands in three arid regions: California, Egypt, and Tunisia [35]. California is a region with heavy meat consumption and heavy irrigation water needs. Tunisia and Egypt have much lower meat consumption, and Tunisia provides a comparatively lower fraction of agricultural water with irrigation. As this table shows, the water required to grow food is far above — by as much as two orders of magnitude — the basic water requirements for domestic human needs. Far more work is required, however, to actually determine "minimum" agricultural water needs to meet specific diets, as opposed to the average values provided in Table 8.

The water required to grow food must be considered a special case for several other reasons. Unlike the BWR for human survival and domestic use described in the previous section, food can be produced in water-rich regions and transported to water-poor regions. In fact, this occurs today on a vast scale and is only constrained by internal political policies that push for domestic food security, by economic problems related to import/export trade balances, and by transportation difficulties. As a result, providing a BWR for food production, however defined and quantified, should be considered independently from the responsibility of governments for providing the BWR for maintaining human survival and health.

Basic Water Requirements for Natural Ecosystems

No attempt is made in this paper to define and quantify precise BWRs to protect natural ecosystems, though the principle that some water be guaranteed to maintain ecosystem health has also been put forward [3,36]. In traditional water planning and management, the water needs of the natural environment are rarely considered or guaranteed. In the United States and Europe, some minimum flow requirements have been set for rivers and some minimum quality or temperature standards have been promulgated to protect environmental assets. In the United States, legislation has protected stretches of certain pristine rivers from development, and some water has been reallocated from major water projects and users to the environment. In California, for example, a combination of federal and state laws has set aside nearly 30,000 million cubic meters (mcm) of annual runoff for environmental purposes, including the protection of wild and scenic rivers, the Sacramento-San Joaquin Delta, and instream and wetlands flow protections for fish and waterfowl [30,36]. This represents nearly 28 per cent of total annual average runoff from the state. Similar legal efforts are under way internationally. In 1994, for example, the International Law Commission (ILC) produced a set of

Table 6. Average residential end-use of water in developed countries (liters per person per day)

End Use	United States [27]	United States [28]	Sweden [27]	The Netherlands [27]	Several North Amer. Cities [29]	Massachusetts [29]	Avge. California [30]	Northern California [31]
Toilets	70	95	40	39	90	84	127	109
Bath/Shower	60	75	70	27	66	73	99	78
Laundry	45	50	30	17	33	29	71	35
Kitchen	45	15	50	17	31	22	56	39
Yard/Other	75	11	25	4	5	4	178	171
Total Use (l/p/d)	295	246	215	104	225	212	531	171

Table 7. Average Regional Diets, 1989 (Calories per person per day)

Region	Maize	Soybean	Millet, Sorghum, Wheat	Rice	Pulses	Roots	Vegetables	Fruits	Vegetable Oils	Animal Fat	Sheep	Beef	Pig	Poultry	Eggs	Milk	Fish	Alcohol	Sweetener	All Other
Africa, South of Sahara	351	237	195	281	81	332	21	90	169	22	14	36	25	15	6	67	25	51	145	25
Centrally Planned Asia	118	43	380	1143	51	144	43	40	59	39	68	45	104	10	17	36	25	52	82	43
Eastern Europe	143	0	1095	32	39	100	74	74	269	274	20	79	202	47	50	250	15	165	381	37
Former USSR	3	16	1043	72	17	180	56	54	248	219	15	205	91	42	59	244	73	133	458	25
Latin America	274	13	438	256	69	124	30	133	220	63	11	89	50	65	20	156	30	78	401	34
Middle East/North Africa	84	28	1103	203	69	68	70	137	339	47	48	41	2	45	24	125	15	12	308	51
OECD-Pacific/Oceania	42	12	492	315	25	326	49	147	209	98	57	90	96	64	28	118	71	80	329	43
South and East Asia	87	41	315	1075	51	62	39	57	190	30	3	23	61	38	18	60	51	43	202	38
Western Europe	37	0	647	43	25	151	70	123	383	243	30	116	307	47	49	342	54	189	413	80
North America	27	2	537	112	28	81	105	146	364	129	21	232	202	136	46	267	48	154	431	68

"All others" includes sugar, nonalcohol stimulants, spices, offals, treenuts, other meats, and other aquatic.
Source: Compiled from Reference 34.

articles setting forth principles to guide the behavior of states. Article 20 explicitly requires "watercourse States" to "protect and preserve the ecosystems of international watercourses" [48].

Despite these efforts, aquatic ecosystems throughout the world are under severe stress and threat of destruction. Globally more than 700 species of fish alone are considered threatened with extinction [37]. In the last couple of years, several have been added to the list, including major anadromous fish species. Basic water requirements to protect these species and, more broadly, whole ecosystems, must be identified and provided.

Ultimately, society will have to make decisions about which ecosystems should be maintained or restored and the indicators by which to measure their health. Then, minimum allocations of environmental water will have to be made on a flexible basis, accounting for climatic variability, seasonal fluctuations, and other factors. Ecosystem management will have to be flexible, with decisions reviewed frequently based on the latest information. Particular care must be taken when human actions might lead to irreversible effects.

Other Water Requirements

There are many other human uses of water, including water for industrial and commercial use, and for power plant cooling and electrical generation. Water requirements to meet these demands depend on what precisely is being produced, on the technology used, and on a host of other characteristics. Detailed analyses are needed to evaluate these demands, but a wide range of requirements is described in Gleick [15]. Because water demands associated with these other sectors reflect human "wants" and not "basic needs," these demands should be provided only after basic human needs are met.

Table 8. Water requirements for growing food, in liters per person per day[1]

	California	Egypt	Tunisia
Total daily water input (l/p/d)	5,908	3,242	2,964
Percentage of water needed to produce meat in diet (%)	64.0	21.4	26.9
Percentage of total daily water input met by irrigation (%)	71.4	69.0	57.3

[1] These data are the water requirements needed to grow the food consumed within a region. Of course, many regions, including these, import and export food, and hence, water embodied in that food. Source: Reference 35.

MEETING BASIC NEEDS: A RECOMMENDATION FOR A GUARANTEED BASIC WATER REQUIREMENT

Table 9 summarizes the water requirements for drinking water, hygiene, sanitation services, and food preparation. Recommended levels are based on fundamental health considerations and on assumptions about technological choices usually made at modest levels of economic development. Considering drinking water and sanitation needs only suggests that the amount of clean water required to maintain adequate human health is between two and 80 liters per person per day, or up to about 30 cubic meters per person per year. The low end of this range is an absolute minimum and reflects survival only. The upper end reflects a more complete satisfaction of basic needs using water piped directly to the house and toilet. This article recommends that a BWR of 25 liters per person per day of clean water for drinking and sanitation be provided by water agencies or governments.

This amount is just above the lower end of the 20 to 40 liters per person per day target set by the U.S. Agency for International Development, the World Bank, and the World Health Organization, each of which also exclude water for cooking and cleaning. It is also in line with the recommended standards of the United Nations International Drinking Water Supply and Sanitation Decade and Agenda 21 of the Earth Summit.

Adding water for bathing and cooking raises the total range to between 27 and 200 liters per capita per day, bracketing the level of 100 liters per capita per day identified by Falkenmark and others [38,39] as typical household demand in water-scarce regions. Falkenmark considers 100 l/p/d to be necessary to provide for some minimum acceptable quality of life [Falkenmark, personal communication, 1996]. The upper end of the range is equal to an annual need of about 75 cubic meters per person (m^3/p/yr). During recent severe drought in California, domestic water use in some of the wealthiest (but

Table 9. Recommended basic water requirements for human needs[a]

Purpose	Recommended Minimum (liters per person per day)	Range (liters per person per day)
Drinking Water[b]	5	2 to 5
Sanitation Services[c]	200 to over 75	
Bathing	15	5 to 70[d]
Cooking and Kitchen	10	10 to 50[d]
Total Recommended Basic Water Requirement	50	

[a] Excluding water required to grow food (see text).
[b] This is a true minimum to sustain life in moderate climatic conditions and with average activity levels.
[c] An average (not minimum) of 40 l/p/d is considered adequate for direct sanitation hookups in industrialized countries. The upper end of the range represents extremely inefficient toilets. In water-short regions, sanitation systems that use no water are available, but rarely embraced socially.
[d] The upper values here represent societal preferences for moderately industrialized countries. Use in some water-rich regions may exceed these amounts. The lowest values reflect minimum uses in developing countries.

water-short) regions was rationed to the equivalent of about 70 m^3/p/yr. These levels were achieved without any severe hardships, even in communities accustomed to far higher levels of household water use [40].

Using minimum levels of 15 l/p/d for bathing and 10 l/p/d for cooking, I recommend here that international organizations and water providers adopt an overall basic water requirement (BWR) of 50 liters per person per day as a new standard for meeting these four domestic basic needs, independent of climate, technology, and culture. While billions of people lack this standard today, it is a desirable goal from both a health perspective and from a broader goal of meeting a minimum quality of life.

To what extent does a state have an obligation to provide its citizens with a basic water requirement? Should the international legal community consider the right to a certain level of fresh water to be a basic human right? McCaffrey [41] has extensively explored international legal frameworks and law and concludes that there are obstacles to the establishment in international law of the human right to water as a binding obligation on states. He goes on to say, however, "it is clear that, at least in some form, the right may be inferred under the basic instruments of international human rights law." He further argues that the devastating consequences of being denied such water should require that relevant provisions of existing human rights instruments "ought to be interpreted broadly, so as to facilitate the implementation of the right to water as quickly and comprehensively as possible." The two international declarations quoted at the beginning of this article also suggest that states have the obligation to develop in such a way as to ensure that their use of fresh water is sustainable and adequate to meet the basic needs of its people. These declarations provide additional support for the conclusion that there is both a basic right to water.

I argue here that the right to water sufficient to meet basic needs should be an obligation of governments, water management institutions, or local communities. While in some regions, governmental intervention may be necessary to provide for basic water needs, many areas will be able to use traditional water providers, municipal systems, or private purveyors within the context of market approaches. Unfortunately, there are many reasons why governments or water providers may be unable to provide this amount of water, including rapid population growth or migration, the economic cost of water-supply infrastructure in regions where capital is scarce, inadequate human resources and training, and even simple political incompetence. Nevertheless, failure to provide this basic need is a major human tragedy. Preventing that tragedy should be a major priority for local, national, and international groups.

How would a proposal for providing a BWR be implemented? Defining and applying this principle might require that the BWR be made available to all inhabitants of a hydrologic region (such as a watershed or the area overlying a groundwater aquifer) prior to resolution of how to distribute remaining water resources. In areas served by municipal systems, subsistence water charges — lifeline rates — for basic levels would ensure provision of a minimum level of service to all users. Such rates have been used for many years by energy utilities and are now beginning to appear in water utility rate design. In regional long-term water planning, providing a BWR to all inhabitants should be set as the highest priority — together with identifying and providing a BWR for the natural environment — before allocations are made for other uses. In international river basins, such allocations will almost certainly require joint basin committees empowered to make binding management decisions for the region [42].

PROGRESS TOWARD MEETING BASIC HUMAN WATER NEEDS

Vast regions of the world and hundreds of millions of people lack the water required to meet the basic human needs proposed above. While the traditional measure of water scarcity has been per-capita water availability [49], it is now possible to begin to use data on actual water use — a measure more representative of actual human well-being. Using the BWR as a benchmark, Table 10 lists those countries whose reported domestic per-capita water withdrawals fail to provide 50 liters per capita per day. According to these data, in 1990 fifty-five countries with a population of nearly a billion people fell below the level recommended in this article. There are actually eight countries whose total reported water use in *all* sectors falls below the recommended BWR for just basic human needs.

In fact, there are strong reasons to believe that the actual number of people failing to receive the recommended BWR is far above the numbers reported here.

The data in Table 10 are country averages, and several large countries, such as India and China, report that their average domestic water use slightly exceeds 50 liters per person per day. We know, however, that average national water-use data hide significant regional variations, with large segments of populations usually falling below the average, while wealthier portions of the population tend to use far more per capita. In addition, the national water use data used in Table 10, while the best available, are known to be inadequate. For example, there are several countries on this list that are relatively water-rich, suggesting the possibility that official data on water withdrawals may miss substantial domestic water use that is self-supplied. Improving the scope, quality, and extent of water use data is vitally important.

Table 10. Countries with total domestic water use below 50 l/p/d

Country	1990 Population (million people)	Total Domestic Water Use in liters/ person/day	Total Domestic Use as a Percentage of the BWR of 50 liters per person per day
Gambia	0.86	4.5	9
Male	9.21	8.0	16
Somalia	7.50	8.9	18
Mozambique	15.66	9.3	19
Uganda	18.79	9.3	19
Cambodia	8.25	9.5	19
Tanzania	27.32	10.1	20
Central Africa Republic	3.04	13.2	26
Ethiopia	49.24	13.3	27
Rwanda	7.24	13.6	27
Chad	5.68	13.9	28
Bhutan	1.52	14.8	30
Albania	3.25	15.5	31
Zaire	35.57	16.7	33
Nepal	19.14	17.0	34
Lesotho	1.77	17.0	34
Sierra Leone	4.15	17.1	34
Bangladesh	115.59	17.3	35
Burundi	5.47	18.0	36
Angola	10.02	18.3	37
Djibouti	0.41	18.7	37
Ghana	15.03	19.1	38
Benin	4.63	19.5	39
Solomon Islands	0.32	19.7	39
Myanmar	41.68	19.8	40
Papua New Guinea	3.87	19.9	40
Cape Verde	0.37	20.0	40
Fiji	0.76	20.3	41
Burkina Faso	9.00	22.2	44
Senegal	7.33	25.4	51
Oman	1.50	26.7	53
Sri Lanka	17.22	27.6	55
Niger	7.73	28.4	57
Nigeria	108.54	28.4	57
Guinea-Bissau	0.96	28.5	57
Vietnam	66.69	28.8	58
Malawi	8.75	29.7	59
Congo	2.27	29.9	60
Jamaica	2.46	30.1	60
Haiti	6.51	30.2	60
Indonesia	184.28	34.2	68
Guatemala	9.20	34.3	69
Guinea	5.76	35.2	70
Cote D'Ivoire	12.00	35.6	71
Swaziland	0.79	36.4	73
Madagascar	12.00	37.2	74
Liberia	2.58	37.3	75
Afghanistan	16.56	39.3	79
Uruguay	3.09	39.6	79
Cameroon	11.83	42.6	85
Togo	3.53	43.5	87
Paraguay	4.28	45.6	91
Kenya	24.03	46.0	92
El Salvador	5.25	46.2	92
Zimbabwe	9.71	48.2	96

Data on domestic water use come from References 15, 43, and 44.

An additional problem is that there are few data to indicate the typical *quality* of the water received. Poor quality of domestic water is a severe and widespread problem, and it is likely that many people who may receive more than the recommended quantity are getting contaminated and unhealthy water. Furthermore, population growth is increasing in most of these regions faster than improvements to water availability.

In contrast to these figures, domestic water use in all industrialized countries far exceeds the BWR, though the quality of this water varies widely. In the countries of western Europe, the recommended BWR is typically less than 25 per cent of total domestic use. In the U.S. and Canada, a BWR of 50 l/p/d is less than 10 per cent of total current domestic use.

What might this BWR concept imply in regions where political conflicts over water resources are prevalent, such as the Middle East? Table 11 shows United Nations medium population projections for the parties of the Jordan Basin [45] and the water required to provide this population with a BWR. Guaranteeing the 1990 population of Israel, Jordan, and the West Bank with just a basic annual water requirement of 50 liters per person per day would require about 180 million cubic meters (mcm) of water annually. By 2025, this amount would rise to over 400 mcm. These quantities also exclude any demands from Syria and Lebanon, portions of whose population rely on water from the Jordan River basin. Estimates of the total annual renewable freshwater availability for all of Israel, Jordan, and the West Bank, are under 3,400 mcm. In the Jordan River basin, a proposal to guarantee the population a basic water requirement could mean allocating 50 l/p/d to all inhabitants of the basin before negotiating shares of remaining water among

Table 11. Populations and basic water requirements in the Jordan Basin

	Population (1,000s)		Total Water Needed to Satisfy BWR of 50 l/p/d	Total Water Needed to Satisfy BWR of 50 l/p/d
	1990	2025	(for 1990 in mcm/yr)	(for 2025 in mcm/yr)
Jordan	4,259	12,039	78	220
Syria	12,348	33,505	225	611
Israel	4,660	7,808	85	142
Lebanon	2,555	4,424	47	81
West Bank[a]	975	2,500	18	46

[a] The UN does not include separate estimates of West Bank population and no recent census has been conducted. Future growth rates are highly dependent on uncertain immigration rates. A population of 2.5 million in the year 2025 was assumed here, but could be substantially higher or lower.
Sources: Population data from Reference 55.

the riparians (Syria, Lebanon, Jordan, Israel, and the Palestinians). In international basins, such a policy would require setting up institutional structures, such as a Joint River Basin Commission, to monitor agreements and allocate water. The recent peace treaty between Israel and Jordan provides the beginnings of such a basin commission.

Shuval [46,47] and Gleick [42] each raised the concept of applying a minimum water requirement in the context of the water disputes in the Middle East. In both approaches, their "minimum" levels included considerable amounts of water required for human uses in addition to the basic needs described above.

Shuval [46] set a minimum at 125 cubic meters per person per year in order to satisfy domestic needs as well as modest industrial and gardening needs. Gleick [42] proposes a lower minimum — 75 cubic meters per person per year — also including some industrial and commercial activities. Using the higher levels proposed by Shuval would increase the total minimum demand in the region to 1,200 mcm/yr in 1990 and about 2,800 mcm/yr by 2025. This latter amount approaches the total for the reliable supply in the entire Jordan Basin. Satisfying this larger "minimum" would require taking almost all the water now used to grow food and applying it to meet domestic and industrial needs. This implies major restructuring for the region's agricultural water policy — a restructuring that has already begun.

In California, like the Middle East, growing populations are coming up against natural water constraints. While California water planners and policymakers have managed to stave off these constraints in the past through massive infrastructure development, the era of building new large dams, reservoirs, and aqueducts is drawing to a close. The current dilemma facing California water managers is how to meet new demands using new approaches. Under traditional water projections, Californians face a shortfall of more than two billion cubic meters per year by 2020, more than one billion cubic meters of permanent groundwater overdraft, declining ecosystem health, and continued inefficient water use in almost all sectors [30]. This kind of traditional forecast, while highlighting the nature of current problems, no longer offers any guidance on how to develop sustainable water policies.

A new approach presents a sustainable vision for California's water resources in the year 2020 [36]. In this analysis, seven criteria for sustainable water use are presented, including providing BWRs for maintaining human health and the health of natural ecosystems. Identifying desirable end results, focusing on demand-side management, and applying the sustainability criteria produces a vision of California's water system that is far more efficient and equitable and that meets basic needs as well as providing water for extensive agricultural production. In this approach, meeting BWRs first coopts only a tiny fraction of total renewable supply, but sets societal priorities in a more equitable way than current management approaches.

CONCLUSIONS

Recent efforts to integrate environmental issues and concerns with sustainable economic and social development have returned to the concept of meeting basic human needs first proposed nearly two decades ago. One of the most fundamental of those needs is access to clean water. This article presents the concept of a basic water requirement (BWR) for human domestic needs and recommends that a BWR for drinking, basic sanitation services, human hygiene, and food preparation be guaranteed to all humans. Specifically, 50 liters per person per day of clean water should now be considered a fundamental human right.

Hundreds of millions of people, especially in developing countries, currently lack access to this BWR, resulting in enormous human suffering and tragedy. Furthermore, rapid population growth and inadequate efforts to improve access to water ensure that this problem will grow worse before it grows better. This problem should be a far higher priority for governments, water providers, and international aid organizations than it appears to be.

In the past, long-term planning for the management and allocation of freshwater resources has relied upon traditional projections of human demand for water, compared projected demand to estimates of available supply, and developed the policies and physical infrastructure necessary to bridge the gap between the two. Absent from traditional water planning has been any voice for natural ecosystems, any thought that the goals, aspirations, and desires of future generations may not be the same as those of the present generation, and any explicit representation of the complex interactions between land-surface processes, atmospheric behavior, the natural biota, and society. It is time for a change. A first step toward sustainable water use would be to guarantee all humans the water needed to satisfy their basic needs.

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Objectives

The principal objectives of the International Water Resources Association are:

- *to advance water resources planning, development, management, administration, science, technology, research, and education on an international level;*
- *to establish an international forum for planners, administrators, managers, scientists, engineers, educators, and others who are concerned with water resources; and*
- *to encourage coordination and support of international programs in the field of water resources, including cooperation with the United Nations and its agencies, and other international and national organizations, in activities of common interest.*

The Value of Residential Land and Structures during the Great Housing Boom and Bust*

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The Value of Residential Land and Structures during the Great Housing Boom and Bust

Abstract

This study examines how the value of residential land and structures evolved during the great housing boom and bust using data on more than a million residential properties that were sold in ten metropolitan areas between 1998 and 2009. We develop a new hedonic estimator that allows us to disentangle the market value of land and structures at a local (census tract) level. Our estimates reveal substantial heterogeneity in the evolution of the market value of land and structures *within* metropolitan areas. Surprisingly, lower value land at the urban fringes of metropolitan areas was the most volatile during the boom-bust.

JEL Codes: R14, R21, R31

Keywords: Land Value, Hedonic Method, Property Values

1. Introduction

Housing is a major source of wealth in the United States. The Federal Reserve's Flow of Funds Report documents that the asset value of owner-occupied housing for the entire U.S. was approximately 23 trillion dollars in 2006—more than the capitalized value of the NYSE, Amex, and Nasdaq exchanges combined. A house's value can be decomposed into two components: the value of the land on which the house is built, and the value of the structures that comprise the house itself. Decomposing property value into the value of land and structures is important for several reasons. First, some cities and counties tax land and structures at different rates (Chapman et al. 2009; Banzhaf and Lavery 2010; Cho, Lambert, and Roberts 2010). Successful implementation of a split-rate tax requires accurate estimates for each component of value. Second, structures depreciate differently from land. Documenting this difference is necessary for calculating tax code allowances for depreciation and for insurance companies to reimburse homeowners for damaged structures. Third, understanding how the value of land has evolved relative to the value of structures may help households, banks, and local governments to manage risk within their financial portfolios. Finally, tracking the evolution of land and structural values within and across metro areas may provide insights into the forces that drive boom-bust cycles in real estate markets.

There are three primary methods for decomposing property values into the value of land and structures. The "teardown" approach derives land value from the sales prices (plus demolition costs) of properties that were purchased with the intention to "tear down" the existing structures. The "replacement cost" approach infers land value from the difference between property values and the depreciated costs of replacing the structures on the property. Finally, the "hedonic" approach (sometimes called the "contribution" approach) estimates land value by regressing the sales prices of properties on the characteristics of the land and structures. Bell et al. (2009) provide an overview of the three methods, describing some of their strengths and weaknesses. The obvious difficulty with the teardown approach is the sparseness of the data. There are too few teardowns in too many markets to successfully apply the methodology at a high level of

spatial resolution in large geographic areas. Bell et al. describe a more nuanced set of tradeoffs between the replacement cost and hedonic approaches, but conclude that "the contribution [hedonic] principle of value seems more consistent with the notion of market value." Despite this conceptual advantage, the replacement cost approach appears to be used more often. This is partly due to the apparent simplicity and relatively low data requirements of the replacement cost approach, but also due to concern that omitted variables may confound hedonic estimates of land value. Indeed, hedonic estimates in the literature at times appear strikingly low.[1]

The objective of this paper is to develop an empirical framework for estimating the market value of land and structures over the recent boom and bust, both within and across major metropolitan areas, using the hedonic approach to land value estimation. The key challenge is to develop a credible research design for mitigating the potential confounding influence of unobserved housing attributes in order to track how land values evolve over time and space following shocks to credit markets, wealth, and expectations about the future asset value of housing.[2] We address this challenge by drawing on an especially rich set of micro data.

Our empirical analysis is based on the sale prices, structural attributes, and physical locations of more than a million houses that were sold in ten metropolitan areas: Boston, Cincinnati, Detroit, Los Angeles, Oakland, Philadelphia, Pittsburg, San Francisco, San Jose, and Tampa. Our study period is the great housing boom and bust of the 2000's. According to the Case-Shiller repeat sales index, residential property values in major metro areas more than doubled between 1998 and 2006 and then declined by approximately 40% between 2006 and the end of 2009 (figure 1). The transactions in our database occurred throughout this period.

The spatial resolution of the data allows us to estimate hedonic price functions for each metro area that are consistent with classic notions of urban spatial structure and residential sort-

[1] For example, hedonic estimates of land value in Glaeser, Gyourko and Saks (2005) suggest that the value of a full acre of land in Boston in 1998 was less than 30k and in San Francisco it was less than 200k.

[2] If nicer houses tend to be built in neighborhoods with higher land values, for example, then the relative values of land and structures may be confounded if the analyst is unable to observe all of the structural attributes of houses that matter to buyers and sellers. In this case, one must develop an econometric strategy to control for the omitted variables.

ing. That is, location matters. The location of each house conveys access to a specific bundle of local public goods and also defines the commuting opportunities that would be faced by a working household. These localized amenities may be in limited supply due to zoning regulations and other forms of development restrictions (Glaeser, Gyourko, and Saks 2005). As a result, it is important to recognize that land values may vary across different neighborhoods in the same metro area at a single point in time.

Equally important is the need to recognize that the market value of land and structures may evolve differently over time. For example, the relative price of land may increase over time as developable land becomes relatively scarce. The magnitude of the increase may vary across metro areas according to their remaining supplies of developable land. Likewise, changes in credit constraints or wealth may alter the relative demands for the public and private attributes of housing in ways that differ across metro areas.

To assess spatiotemporal variation in the market value of land and structures, we estimate annual price functions for housing in each metro area. Previous studies have sought to recover average land values from hedonic estimates for the marginal implicit price per square foot of a lot (e.g. Clapp 1980; Glaeser, Gyourko, and Saks 2005). Our estimator extends this conventional hedonic approach in two ways. First, we use fixed effects for Census tracts to capture spatial variation in localized amenities that contribute to land value through a parcel's location, rather than its size. Second, we add interactions between the fixed effects and square footage of living space to capture spatial variation in latent attributes of structures. We then generate estimates for annual average values of land and structures at the level of an individual Census tract. Our spatially explicit estimates are typically an order of magnitude larger than estimates based on the conventional hedonic approach.

Prior to the boom, our estimates are broadly consistent with metro area averages derived from past studies using the replacement cost method (e.g. Davis and Palumbo 2008). The same is true after the bust. However, the two sets of estimates diverge during the boom-bust period. Our estimates for land values do not rise as fast during the boom or fall as quickly during the

bust. Our estimates imply that the market value of structures exceeded their replacement cost during the height of the boom. The differences can be large—up to 100% for San Francisco. To interpret this finding, it is important to note that our empirical model does not maintain any specific assumption for the nature of competition in local markets for residential property. Markets may be less than perfectly competitive. With a small share of houses on the market at any one time, the bundle of amenities provided by a desirable neighborhood may allow home sellers to command a markup on the structural characteristics of their houses, as Taylor and Smith (2000) first observed. Indeed, we find that neighborhoods with higher pre-boom land values (presumably the higher-amenity neighborhoods) had larger markups on structures during the boom. Over time, we would expect these markups to stimulate new construction, following the general logic of Tobin's q-theory.

We observe that average land values are more volatile in metro areas where the supply of housing is less elastic. Interestingly, we find the opposite pattern *within* metro areas. Neighborhoods at the urban fringe, where we would expect the supply of housing to be most elastic, were the neighborhoods that experienced the most volatility in housing prices and land values during the boom and bust. This general pattern can be seen in the Case-Shiller index. Figure 2 displays indices for the lowest, middle, and highest tier of houses (ranked by 2010 value) for Miami, San Francisco, Boston, and Atlanta. Within each metro area it is the lowest value houses that were the most volatile and the highest value houses that were the least volatile.[3] We find that the higher value houses tend to be located closer to the city where the supply of land is least elastic and the lower value houses tend to be located at the outskirts of the surrounding suburbs where most of the new housing is built. This suggests that factors other than supply elasticity of housing are playing an important role in the evolution of land and structural values. Potential explanations include credit constraints, expectations about future housing values, imperfect competition, and q-theory. These are interesting directions for future research.

Overall, this paper makes three contributions. First, it develops a new approach to de-

[3] One can find the same pattern in the other 16 major metropolitan areas tracked by the Case-Shiller index.

composing housing prices into the implicit value of land and structures in a way that is consistent with the classic theories of urban spatial structure and residential sorting. Second, our empirical analysis provides new estimates for how land values evolved within several metro areas during the great boom-bust cycle of the 2000's. The ability to recover the distribution of land values within a single metro area complements existing work that tracks changes in average land value across metro areas. Finally, we document two interesting phenomena that deserve more attention in future research: (i) the least valuable land at the urban fringes of metro areas was the most volatile during the boom-bust cycle; and (ii) the market value of structures exceeded construction costs during the boom, with the largest markups occurring in the most affluent neighborhoods.

The remainder of the paper proceeds as follows. Section 2 presents a simple conceptual model of the market for housing and uses it to define "land value" and "structure value" in the context of a hedonic price function. Section 3 explains our econometric approach. Section 4 summarizes the data we have assembled for the analysis. Section 5 presents results. Section 6 discusses the implications of our findings and directions for future research, and section 7 concludes.

2. The Market Value of Land and Structures in a Metropolitan Area

We begin from a standard description of residential sorting. Heterogeneous households are assumed to choose from a stock of houses with different lot sizes and structural characteristics (e.g. bedrooms, bathrooms, sqft). Their collective location choices will in turn influence the supply of neighborhood amenities (e.g. public school quality, commute time to the city center, preservation of open space) through a combination of voting, social interactions, and feedback effects.[4] Formally, an individual household's utility maximization problem is

[4] The new empirical literature on Tiebout sorting stresses the need to recognize that neighborhood amenities are typically endogenous to the collective location choices made by the households in a metropolitan area (Kuminoff, Smith, and Timmins, 2010). For example, urban development may provide opportunities for dining and nightlife, while increasing traffic congestion and degrading air and water quality. Homeowners may be asked to vote on assessments to fund open space preservation and public schools. Academic performance among students in those schools may depend on the distribution of income and education among parents in the school district. While we do

$$\max_{j,k} \; U_i\left(g_{kt}, l_{jk}, x_{jkt}, b; \alpha_{it}\right) \;\; subject\ to \;\; y_{it} \;=\; b + P_{jkt}. \tag{1}$$

In period t, household i selects one of $j = 1,...,J_k$ houses located in one of $k = 1,...,K$ neighborhoods. Their utility depends on the lot size of their parcel (l), the structural characteristics of their house (x), the amenities provided by their neighborhood (g), and on the income they have left over to spend on the numeraire good (b) after they pay the annualized after-tax price of housing (P_{jkt}). The household's idiosyncratic preferences are represented by α_{it}.

Sellers in this market may include a mix of developers and individuals selling their houses. There is no need to be more specific about the supply side of the market. Under a pair of weak restrictions on consumer preferences, any market outcome consistent with utility maximizing behavior can be described by a hedonic price function.

ASSUMPTION 1.

a. $U_i\left(g_{kt}, l_{jk}, x_{jkt}, b; \alpha_{it}\right)$ is strictly increasing in b for all $b \in \left(0, y_{it}\right)$.

b. Let $\geq_i$ represent household *i*'s preference ordering over all potential location choices that satisfy their budget constraint. $\geq_i$ is invariant to *i*'s actual location choice.

The first condition is self explanatory. The second condition simply limits the scope for any one household to influence prices or the supply of neighborhood amenities. For example, suppose household *i* has exceptionally bright children. If *i* were to move from their current house in school district R to a new house in school district S, then school quality may increase marginally in S due to peer effects, and decrease marginally in R. These adjustments may be followed by changes in housing prices. Condition *b* implies that these changes must be sufficiently small to leave *i*'s preference ordering over the two houses unchanged.[5] The need for this restriction

not model these mechanisms, our framework is consistent with their presence.

[5] Theorem 1 can also be proven under an alternative assumption that households ignore their own contributions to the supply of neighborhood amenities.

becomes apparent in the proof of theorem 1, which is simply a variation on results derived by Bajari and Benkard (2005).[6]

THEOREM 1. Suppose that assumption 1 holds for every household. Then for any two houses, j,k and r,s, it must be true that $P_{jkt} = P_{rst}$ if $g_{kt} = g_{st}$, $l_{jk} = l_{rs}$, and $x_{jkt} = x_{rst}$.

Proof. Suppose *i* chooses j,k given $P_{jkt} > P_{rst}$. Then $U_i\left(g_{kt}, l_{jk}, x_{jkt}, y_{it} - P_{jkt}; \alpha_{it}\right)$ $< U_i\left(g_{st}, l_{rs}, x_{rst}, y_{it} - P_{rst}; \alpha_{it}\right)$ because utility is strictly increasing in the numeraire. This preference ordering is invariant to whether *i* locates in j,k or r,s. Therefore, j,k cannot be a utility-maximizing location for *i* in period *t*, which is a contradiction. QED

Theorem 1 states that property values will be functionally related to neighborhood amenities, lot sizes, and structural housing characteristics during a single period. Relative to the majority of the empirical literature that maintains the assumptions of Rosen's (1974) hedonic model as a basis for measuring the willingness to pay for urban amenities, theorem 1 is notable for what it does not assume. We do not require households to be free to choose continuous quantities of every housing characteristic in every neighborhood. Nor do we require the market to be perfectly competitive.

The cost of relaxing continuity and perfect competition is that we lose the ability to interpret the gradient of the price function in welfare theoretic terms (Kuminoff, Smith, and Timmins 2010). The benefit is that our model is consistent with the fact that some neighborhoods use zoning regulations to constrain urban development. If a constrained neighborhood provides access to a unique bundle of amenities, then the regulatory process may implicitly convey market

[6] Our theorem recognizes that neighborhood amenities may be determined endogenously through a Tiebout sorting process. In contrast, Bajari and Benkard (2005) characterize markets where product attributes (other than price) are determined exogenously. They also model unobserved product attributes and restrict utility to be Lipschitz continuous in order to guarantee Lipschitz continuity of the price function. While it is straightforward to add these elements to our model, they are unnecessary to guarantee the existence of a price function.

power to property owners in the neighborhood (e.g. see Taylor and Smith, 2000). This is important because local market power offers a potential explanation for some of the patterns in our estimates for land values in section 5.

Our specification for the hedonic price function, $P_{jkt} = P(g_{kt}, l_{jk}, x_{jkt})$, describes a spatial landscape at a single point in time where prices, amenities, and location choices are all defined such that no household would prefer to move, given its income and preferences. This is a single-period snapshot of market outcomes; it may or may not be a long-run steady state. Current period incomes and preferences may reflect temporary macroeconomic factors. Credit may be unusually easy (or difficult) to obtain relative to a long run equilibrium. The average household may be unusually optimistic (or pessimistic) about the future asset value of housing. Budget constraints may reflect other temporary macroeconomic shocks. As all of these factors change over time, households may adjust their behavior in ways that alter the shape of the price function and generate boom-bust cycles.

During a boom-bust cycle, the evolution of the price function can be decomposed into changes in the market value of land and structures. To illustrate this, we first define the market value of a property at a single point in time as its current annualized price.

DEFINITION 1. $P_{jkt} \equiv P(g_{kt}, l_{jk}, x_{jkt})$ is the *market value* of property *j*,*k* in period *t*.

The value of the underlying land is then defined by the thought experiment where we remove all of the structural characteristics from the property.

DEFINITION 2. $LV_{jkt} \equiv P(g_{kt}, l_{jk}, 0)$ is the *land value* of property *j*,*k* in period *t*.

LV_{jkt} measures what a vacant (but otherwise identical) parcel to *j* would sell for in the same neighborhood.[7] This definition of land value captures the spatial tradeoff between commuting

[7] This assumes the undeveloped parcel is also zoned for residential development.

costs and accessibility to the city center (Alonso 1964; Muth 1969; Mills 1967) as well as the value of local public goods and urban amenities conveyed by the neighborhood (Tiebout 1956).[8]

Finally, subtracting land value from total market value yields the value associated with a property's structural characteristics, x_{jkt}.

DEFINITION 3. $SV_{jkt} = P_{jkt} - LV_{jkt}$ is the *structural value* of property *j*,*k* in period *t*.

While it is conceptually straightforward to decompose property value into the value of land and structures, empirical implementation presents several challenges.

3. Estimating the Market Value of Land and Structures

3.1 Background

If life were more like a laboratory experiment, there would be no need to *estimate* land values. Sales of vacant parcels would be randomly distributed throughout metropolitan areas and we would simply measure their transaction prices. The problem, of course, is that vacant land sales typically occur at the fringes of urban areas. We rarely observe such transactions occurring in built-up neighborhoods. In an established neighborhood, the closest substitute for a vacant land sale is likely to be a "teardown."

When an existing structure is purchased with a plan to demolish it and build new housing, the value of the underlying land should equal the sale price of the developed parcel less demolition costs. Rosenthal and Helsley (1994) were the first to apply this idea to infer land values from teardown properties in Vancouver, B.C. In subsequent work, Dye and McMillen (2007) and McMillen (2008) refined the econometrics to control for the non-random selection of which parcels are torn down and provided new evidence on land values in Chicago. While teardowns can support a convincing quasi-experimental approach to measuring land value, the active markets are too few and too thin to apply the method broadly across the United States or at a high

[8] Cheshire and Sheppard (1995) distinguish between these two components of land value. While we could certainly do the same, it is not essential to our analysis.

level of spatial resolution throughout a single metro area.

Since the lack of data make it difficult to measure the market value of land directly, analysts have sought to estimate it indirectly from hedonic regressions or replacement cost equations. Both strategies begin by rearranging the decomposition in definition 3,

$$P_{jkt} = LV_{jkt} + SV_{jkt}. \tag{2}$$

Given data on the structural characteristics of houses and their transaction prices, equation (2) can be used to estimate land values. In the replacement cost framework, two maintained assumptions are sufficient to guarantee the estimator will be consistent. First, the market for housing is assumed to be sufficiently competitive that the market value of a structure will equal the cost of rebuilding that structure in its current condition: $\textit{replacement cost}_{\text{jkt}} \equiv RC_t\left(x_{jkt}\right) = SV_{jkt}$. Second, the replacement cost function is assumed to be known. Under these assumptions, one can obtain a consistent estimate for land value as the residual obtained by subtracting replacement cost from the price of housing,

$$\overline{LV}_{jkt} = P_{jkt} - RC_t\left(x_{jkt}\right). \tag{3}$$

Davis and Heathcoat (2007) applied this logic at the national level to develop the first macroeconomic index of residential land value in the United States. Davis and Palumbo (2008) refined their methodology to control for variation in property values and construction costs across major metropolitan areas. They developed a database describing the value of land in 46 major metropolitan areas between 1984 and present.[9]

During boom-bust cycles, the replacement cost framework tends to attribute most of the changes in property values to speculation on land. This follows from the mechanics of (2)-(3). If residential construction costs are relatively stable during a period when property values are

[9] While the published version of Davis and Palumbo's paper presents estimates for 1984 to 2004, the Lincoln Institute of Land Policy maintains a webpage where their estimates are updated as new data become available: http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp

rising rapidly, then observed changes in property values will be interpreted as changes in land value. This was exactly what happened during the recent boom. The replacement cost model indicates that the ratio of land value to property value on the West Coast increased from 61% in 1998 to 74% in 2004, for example (Davis and Palumbo, 2008). We have no doubt that the market value of land did increase during the boom. However, the replacement cost estimates for the magnitude of the change may be too high if housing markets are less than perfectly competitive or if zoning restrictions and permitting requirements drive a wedge between construction costs and effective replacement costs in the short run.

The hedonic approach to estimating land values avoids the need to specify replacement costs or assume that markets are perfectly competitive. Instead, the key maintained assumption is a parametric specification for the relationship between the sale price of a house and its characteristics. Equation (4) presents a linear example reflecting the spatiotemporal structure of past hedonic land value estimators.

$$P_{jkt} = \xi + \delta \cdot l_{jk} + x_{jkt}\beta + \varepsilon_{jkt} . \tag{4}$$

In this case, $\hat{\delta}$ provides an estimate of the implicit marginal price of land and $\hat{\delta} \cdot l_{jk}$ provides an estimate for the property's land value. Efforts to estimate δ from data on individual housing sales date back at least to Clapp's (1980) study of land values in Chicago.[10] Over the years, the methodology has been refined to allow more flexible parametric specifications for the hedonic price surface (Cheshire and Sheppard, 1995) and extended to compare estimates across 21 metropolitan areas (Glaeser, Gyourko, and Saks, 2005).

There are two key challenges to developing credible hedonic estimates for land values. The first challenge—omitted variable bias—is widely recognized. For example, one might expect that houses built on larger lots will also tend to be built using higher quality materials. Because data on building materials are typically unavailable, their effect on sale prices will be

[10] In earlier work, Jackson (1979) used aggregate census tract data to estimate a coarse approximation to a hedonic price surface in Milwaukee. In principle, his results could also be used to develop an approximation to the value of land.

confounded with the value of land (McMillen, 2008). Another concern is that an estimate for the depreciation of structures (from the coefficient on age) may be confounded with unobserved neighborhood amenities because all of the houses in a subdivision tend to be built at about the same time (Davis and Palumbo, 2008). More generally, there is always likely to be some degree of spatial correlation between observed parcel characteristics and unobserved neighborhood amenities that will ultimately bias the estimator (Kuminoff, Parmeter, and Pope, 2010).

The second challenge is to choose a specification for the price function that is sufficiently flexible to capture the key features of spatial variation in land values. Past studies have focused on allowing the per unit price of land (δ) to vary flexibly within a metropolitan area (for example, see Cheshire and Sheppard, 1995). While this is an important dimension of heterogeneity, we hypothesize that it is equally important to distinguish between the variable (i.e. quantity-based) and fixed (i.e. access-based) components of land value.

Access matters. This is a central theme of urban economics. Commuters value access to the central business district (CBD). Homeowners value access to local public goods and amenities that contribute to their quality of life. These values are fundamental to the models of urban spatial structure and neighborhood formation that build on the work of Tiebout (1956), Alonso (1964), Mills (1967), and Muth (1969). Within a neighborhood, the value of access will be approximately fixed, independent of parcel size. As one moves to a different neighborhood with higher crime rates, lower quality schools, and/or a longer commute to the CBD, the value of access may drop sharply. To identify spatial variation in access value separately from spatial variation in the per/unit price of land, the analyst must observe several housing transactions within each neighborhood during an interval over which land values are relatively stable.[11] Our econometric model is specially designed to accomplish this task using data on the universe of housing sales within a metropolitan area together with controls for omitted variables.

[11] Abbott and Klaiber (forthcoming) make a similar point in the context of identifying what occupants are willing to pay for a particular amenity.

3.2 Refining the Hedonic Approach to Estimation

Our approach to estimating land values relies on micro data that are sufficiently rich to allow us to estimate annual price functions for metro areas, while simultaneously using spatial fixed effects to capture the market value of latent attributes of land and structures. In the case of land, the issue is that no existing database provides comprehensive coverage of spatial variation in access-based amenities below the level of a county. This is important because amenities often vary significantly within a county. To measure this variation we use spatial fixed effects for neighborhoods, which we define to be Census tracts.[12] Within a tract, access to amenities will be approximately fixed. Children will be assigned to public schools in the same school district, their parents will face the same commuting opportunities, and there will be little or no variation in crime rates or air quality. Thus, we would expect tract fixed effects to absorb the composite value of access to these and other neighborhood amenities.

In the case of structures, micro-level data are typically limited to the attributes recorded by the county assessor. Some houses have hardwood floors, granite countertops, skylights, solar panels, and spas. Unfortunately, these improvements are rarely noted in the county records. If the quality of building materials varies systematically across neighborhoods in ways we do not observe, then their average effect on property values may be confounded with our estimates for the fixed component of neighborhood land value. To mitigate this potential source of confounding, we add a set of interactions between the fixed effects for neighborhoods and the square footage of the house. The resulting terms are intended to capture systematic variation across neighborhoods in the average value of a square foot of structural improvements.

We adopt a semi-log form for the estimation, regressing the log of transaction prices for all of the single-family residential properties sold in a metro area during year t on their lot sizes, their structural characteristics, and two sets of fixed effects,

[12] The U.S. Census Bureau defines census tracts to be "relatively homogenous units with respect to population characteristics, economic status, and living conditions."

$$\ln(P_{jkt}) = \underbrace{\xi_{kt} + \delta_{kt} l_{jkt}}_{LV_{jkt}} + \underbrace{\gamma_{kt} sqft_{jkt} + x_{jkt}\beta_t}_{SV_{jkt}} + \varepsilon_{jkt} \,. \tag{5}$$

The first two terms after the equality correspond to the property's land value. ξ_{kt} denotes the neighborhood fixed effects. They will measure the component of land value that is constant across all the houses sold within tract *k* during year *t*, regardless of lot size. The neighborhood amenities that enter ξ_{kt} may also interact with the size of the lot to influence the variable component of land value. For example, the marginal value of yard size may be larger in quieter neighborhoods with lower crime rates. Therefore, we allow the coefficient on lot size, δ_{kt}, to vary over neighborhoods as well.

The third and fourth terms after the equality correspond to the value of structural improvements. $x_{jkt}\beta_t$ measures the component of property value that can be explained by the housing characteristics that are observed. While we allow the implicit prices of characteristics to change over time, we restrict them to be fixed within a metropolitan area during the course of a year. $\gamma_{kt} sqft_{jkt}$ measures systematic variation in the average value of a square foot of living space that varies across neighborhoods due to unobserved structural improvements.

Finally, we interpret the error term ε_{jkt} as the composite of three effects. It will reflect: (i) unobserved idiosyncratic structural improvements that differ from the tract average; (ii) idiosyncratic access to amenities within a neighborhood;[13] and (iii) misspecification in the shape of the price function. To mitigate the first two effects, we aggregate our micro-level estimates for the value of land and structures to report averages for Census tracts, counties, and metropolitan areas. This also allows us to compare our results to estimates from the prior literature. While the resulting estimates surely contain some error, we expect the magnitude of the bias to be smaller

[13] For example, all of the houses in a Census tract may be located near public open space but the handful of lots that are adjacent to the public lands may sell at an additional premium.

than in previous hedonic studies because of the ways in which our model enhances spatial and temporal resolution and controls for omitted variables. To evaluate the impact of these refinements, we use the fact that our model nests the conventional hedonic specification as a special case. Equation (5) reduces to (4) if we omit spatial fixed effects ($\gamma_{kt} = \xi_{kt} = 0$) and restrict the implicit price per acre of land to be constant within a metropolitan area ($\delta_{kt} = \delta$).

4. Data and Summary Statistics

Our analysis is based on more than one million observations on the sales of single-family residential properties across the United States. We purchased the data from a commercial vendor who had assembled them from assessor's offices in individual towns and counties. The data include the transaction price of each house, the sale date, and a consistent set of structural characteristics, including square feet of living area, number of bathrooms, number of bedrooms, year built, and lot size. Using these characteristics, we performed some standard cleaning of the data, removing outlying observations, removing houses built prior to 1900, and removing houses built on lots larger than 5 acres.

The data also include the physical address of each house, which we translated into latitude and longitude coordinates using GIS street maps and a geocoding routine. The lat-long coordinates were then used to assign each house to its corresponding census tract. The tract-level assignment provides the needed spatial resolution to analyze trends in land values within and across metro areas during the boom-bust cycle. Furthermore, it allows us to use spatial fixed effects to control for the average effect of latent variables within each tract.

While we conducted the econometric analysis for ten metro areas, we focus on four of them in greater detail in order to illustrate our main results: Miami, FL; San Francisco, CA; Boston, MA; and Charlotte, NC.[14] We selected these four because each has complete data between 1998 and 2008, they provide geographic variation on populous areas in the United States,

[14] The other six are Cincinnati, Detroit, Los Angeles, Philadelphia, Pittsburg, and Tampa.

they provide variation in the supply elasticity of land, and they differ in the intensity of their boom-bust cycles. Figure 2 illustrates the differences in the sizes of their booms and busts using the Case-Shiller Home Price Index. Each panel also reports Saiz's (2010) estimates for the supply elasticity of housing.[15]

Table 1 provides summary statistics for the housing transactions that we observe in Miami, San Francisco, Boston, and Charlotte. The first two rows of each panel illustrate that the average sale price rose in all four areas between 1998 and 2006. The size of the increase was most striking in Miami ($162k to $410k) and San Francisco ($343k to $809k) where prices more than doubled in nominal terms. These increases do not reflect any obvious changes in the composition of houses on the market. The structural characteristics of the average sale property are essentially constant over the study period. In each area, the median transaction was a single-family house with 3 bedrooms, 2 baths, and between 1600 and 1900 square feet of living area. Naturally, Charlotte and Miami have newer housing stocks than San Francisco and Boston. Lot sizes also tended to be larger in Charlotte and Boston than in Miami and San Francisco, reflecting variation in the balance between sales from the cities and suburbs.

5. Results

5.1 Comparison to Pre-Boom Estimates from the Existing Literature (1998-1999)

We begin by comparing our estimates for land values to previous figures generated by the conventional hedonic estimator in Glaeser, Gyourko and Saks (2005) [henceforth GGS] and the replacement cost estimator developed by Davis and Palumbo (2008) [henceforth DP]. Neither study had the benefit of our spatially delineated micro data on actual housing sales. Instead, they combined data from the American Housing Survey with other sources to generate estimates for average land values within several metropolitan areas. Fortunately, some of their estimates overlap with the spatial and temporal dimensions of our data, providing a baseline for compari-

[15] His estimates are generated using information on geographic constraints, regulatory constraints, and predetermined population levels in each metro area.

son. The purpose of the comparison is to investigate how our refinements to the hedonic land value estimator influence our results.

The task of estimating land values is a relatively small component of the overall analysis in GGS. Their main objective is to test the hypothesis that land use regulations impose an effective tax that explains the rise in housing prices in major metropolitan areas. To illustrate their point and to compare housing prices to construction costs, GGS estimate the "free-market cost of land" using a conventional hedonic model (similar to equation 4 above) for 21 metro areas based on data from the 1998 and 1999 installments of the American Housing Survey (AHS).[16] We have the requisite information to develop comparable estimates for 10 of their 21 metro areas. Conveniently, DP also report estimates for all 10 areas.

To provide the best possible comparison, we focus on the subset of our data that overlap with the information used by GGS. Specifically, we limit our data to the year that matches the year in which each metro area was covered by the AHS (either 1998 or 1999). Then we subdivide metropolitan areas to match the disaggregate definitions used in the AHS. This means subdividing the San Francisco Consolidated metropolitan statistical area into the San Francisco, Oakland, and San Jose primary metro areas, for example. While our micro data still differ from the AHS in terms of the number of observations and the richness of information on structural characteristics, their spatial and temporal dimensions are the same.

The first column in Table 2 simply reproduces the estimates of land value (on a per-acre basis) from table 4 of GGS. In column [2], we report the results from our attempt to come as close as possible to replicating their estimating equation, given the differences between the variables in our data and the AHS micro data.[17] A quick comparison between columns [1] and [2] confirms that the two sets of estimates are quite similar (with Tampa as the exception). Overall, the estimates line up with our general intuition for which metro areas ought to have more expen-

[16] The results (reported in their Table 4) support their hypothesis that the areas that we would expect to be more highly regulated have larger differences between construction costs and housing prices.

[17] Our results are generated using a simple linear model estimated according to equation (4), using the combination of control variables that comes as close as possible to the specification from GGS. Complete results will be provided upon request.

sive land. San Francisco, San Jose, Oakland, and Los Angeles have the highest measures of land value whereas Detroit and Tampa have the lowest. However, all of the estimates seem implausibly low for the late 1990s. Could you really buy an acre of land in San Francisco for under $200,000 or in Boston for under $30,000? A likely explanation is that the conventional hedonic estimator does not fully capture the fixed component of land value associated with access to the local public goods and amenities (ξ_{kt}).

Column [3] reports the corresponding replacement cost estimates for land value from DP. They used information published by R.S. Means Company (2004) to develop metro-level estimates for replacement cost. Their measures for housing prices were developed by combining data on price levels in each metro area during AHS survey years with time-series data on the percentage change in housing prices from Freddie Mac's Conventional Mortgage Housing Price Index (CMHPI). The rank order in column [3] is similar to the first two columns, but the replacement cost estimates are typically an order of magnitude larger! While there are some slight variations in the data sets used to develop the estimates in columns [1] and [3], none seem capable of generating order of magnitude differences.[18] It seems more likely that the differences are due to estimation procedures. In particular, the access-based component of land value associated with local public goods would be included in the replacement cost estimates and excluded from the estimates generated by conventional hedonic regressions.

Column [4] reports the estimates from our refinement to the hedonic estimator, using the specification in equation (5).[19] Generalizing the conventional hedonic model to allow for access-based amenities and latent housing characteristics increases our estimates by an order of magnitude (moving from column [2] to column [4]). The resulting estimates align much more closely with the estimates from DP's replacement-cost model.

[18] For example, the CMHPI uses a slightly different definition for metro areas than the AHS. Also, since DP do not report average lot size, we use the average lot size in our data to convert the DP estimates to a $/acre measure. So, there are certainly some differences in the estimates that are caused by differences in spatial-temporal components of the underlying datasets but we think that it is highly unlikely that these drive the large differences we document between GGS and DP.

[19] We dropped tracts with fewer than 15 observations per year out of concern for our ability to obtain accurate estimates of tract-specific land values.

Finally, it is important to point out that the similarity between our estimates and DP's occurs during a two-year period prior to the boom. As we track the two sets of estimates over the course of the boom-bust cycle, we see some interesting differences.

5.2 The Evolution of Average Land Values during the Boom-Bust Cycle (1998-2009)

We estimated equation (5) for each (metro area, year) combination from 1998 and 2009. Table 3 summarizes results for the four metro areas where we have a complete set of data: Miami, San Francisco, Boston, and Charlotte. It reports our measures for the evolution of land values and the share of property value attributed to land ("land share"), alongside the replacement cost estimates from DP.[20] The hedonic measures were generated by averaging our parcel-specific estimates for land values and improved values over all of the housing transactions in each metro area. There are some obvious differences between the two sets of estimates at the market's peak.

Figure 3 illustrates the differences graphically. Focusing on the first column in the figure, it is clear that land values estimated by both methods rise and fall during the boom and bust. Prior to the boom, the two sets of estimates are similar. The same is true following the bust. However, the peak amplitude is much larger in the replacement cost estimates.

The second column of Figure 3 illustrates how estimates for the value of structures evolved over the same period. The hedonic model suggests that the market value of structures rose and fell in tandem with the market value of land during the boom-bust cycle. The replacement cost measures rose steadily, following a similar trend in every metro area. Once again, the differences between the hedonic estimates and the replacement cost measures are largest at the height of the boom.

Does the difference between the two sets of estimates reveal something interesting about the behavior of housing markets during the boom-bust cycle? Or does it merely reflect differences in the underlying data? While our comparisons were made along a consistent set of spa-

[20] The replacement cost results are the Davis and Palumbo (2008) estimates that have been updated and provided at http://www.lincolninst.edu/subcenters/land-values/. Also note that we were unable to obtain assessor data for the year 2009 in Boston. Therefore all results reported for Boston are for the 1998 to 2008 time frame.

tial and temporal dimensions, the underlying micro data are not the same. DP's replacement cost estimates are based on integrating the AHS data with Freddie Mac's Conventional Mortgage Housing Price Index (CMHPI), whereas our hedonic estimates come from assessor data. In principle, the assessor data describe the universe of housing transactions, whereas the CMHPI is limited to transactions where: (a) the transaction was a repeated sale; and (b) the buyer took out a conventional mortgage that was purchased or insured by Freddie Mac or Fannie May.

Figure 4 compares the evolution of average property values in the two datasets. The assessor data suggest slightly smaller increases in property values during the boom. One possible explanation is that less expensive transactions were more likely to be associated with unconventional mortgages. Another explanation is that new houses built over this period tended to be located near the urban fringe where land values (and property values) were lower. In any case, the differences between the two measures of average property value in Figure 4 are dwarfed by the differences in estimated land values in Figure 3. Thus, the differences between the hedonic and replacement cost estimates for land value appear to be tied to methodology, not the underlying data.

Data differences aside, the main economic implication of our comparison between the hedonic and replacement cost estimates is that, during the boom, the market value of structures may have exceeded their replacement costs. To further investigate this possibility, we examine the spatial variation in the evolution of land values within each metro area.

5.3 Within-Metro Heterogeneity in the Evolution of Land Values (1998-2009)

Figure 5 illustrates the spatial heterogeneity in land values across counties in the greater San Francisco and Boston metropolitan areas.[21] The left-most maps display the land value of the average residential property sold in 1998, the change in average land value during the boom (1998-2006), and the change in average land value during the bust (2006-2009). In the San Francisco metro area the counties with the highest land values in 1998 are San Francisco and San

[21] Charlotte and Miami have only 1 or 2 counties with available assessor data, so their maps are less interesting.

Mateo followed by Marin and Santa Clara. These same counties experienced the largest increases in land value during the boom and the smallest decreases during the bust. Looking at the left-most maps in Figure 5 for the Boston metro area reveals a similar pattern.

The right-most maps in Figure 5 focus on the ratio of land value to total property value. The three maps display the average land share in 1998 and the subsequent changes during the boom and bust periods. Focusing first on the greater San Francisco metro area, we see that areas with higher land shares in 1998 (e.g. San Francisco and San Mateo) tended to see drops in land share during the boom and increases during the bust. Again, a similar pattern emerges in the Boston metropolitan area.

Overall, the spatial heterogeneity in the evolution of land values within the Boston and San Francisco areas seems counterintuitive. The counties that experienced the least volatility in land values during the boom-bust cycle are the same counties that we would expect to have the most inelastic supply of housing!

To further investigate the relationship between land value and housing supply, Table 4 summarizes trends in land values and permits issued for the construction of new housing units in the San Francisco Bay Area. Column [1] reports the baseline number of owner occupied housing units by county from the 2000 Census and column [2] reports the number of new permits for construction of single-family residential (SRF) housing units. The counties are ranked by column [3], which reports the ratio of column [2] to column [1]. The ratios are smallest for San Francisco and its adjacent coastal counties (Marin and San Mateo). The same is true if we look at the ratio of all new permits to all housing units in column [4]. This ratio is much higher for San Francisco because it includes permits to build apartment units. It also includes all housing units in the denominator, regardless of occupancy status. In the absence of county-level estimates for the supply elasticity of housing, columns [3]-[4] provide a crude proxy for the responsiveness of housing supply during the boom.

Comparing the ratios in columns [3]-[4] with the values of land and property in columns

[5]-[12] highlights five interesting trends.[22] First, at the start of the boom period, property values and land values were higher in counties where the supply of housing was less responsive. This is true whether we look at the median self-reported property values in column [5], the mean of actual transaction prices in column [6], or our estimates for mean land values in column [7]. Second, land tends to represent a smaller share of total property value in counties where the housing supply is more responsive (comparing columns [6] and [7]). Third, while the counties with the least responsive housing supply experienced the largest nominal increases in land values during the boom (column [8]), these increases were relatively small in percentage terms (column [9]). Fourth, during the bust, the counties with the least responsive housing supply experienced the smallest decreases in land values in both nominal and percentage terms (columns [10]-[11]). Finally, and perhaps most strikingly, the counties with the least responsive housing supply had large net gains in land value between 1998 and 2009 whereas the fastest growing counties (Contra Costa, Napa, and Solano) lost most of the land value that had accumulated during the boom. Overall, these trends support our initial hypothesis that the Bay Area counties with the most volatile property values and land values during the boom-bust cycle also had the most elastic housing supplies.

Finally, we report an intriguing pattern in our estimates for the ratio of land value to total property value. We further disaggregate our results to the level of a Census tract and regress the change in the land value share of each tract between 1998 and 2006 on its baseline land value share in 1998. We find that census tracts with high initial land shares in 1998 tended to see smaller increases in land shares during the boom. Table 5 summarizes the results, by metro area. For example, the coefficient for the San Francisco metro area indicates that a 1 percentage point increase in a census tract's 1998 land value share was associated with a 0.574 percentage point decrease in the size of the change in the tract's land share between 1998 and 2006. The net effect is an increase (decrease) in the land share for tracts with initial land shares below (above)

[22] All five trends are also present in the Boston area. For brevity, we provide a table with results in the supplemental appendix.

62.5%.[23] This negative correlation holds for all of the metro areas and ranges from -0.393 in Pittsburg to -0.754 in San Jose. Furthermore, the R-squared values between 0.24 and 0.59 suggest that the initial land share in 1998 explains much of the variation in land shares during the boom.

One explanation for this pattern is that areas with high land shares in 1998 (presumably high amenity areas) saw both land values and structural values increase during the boom, but structural values went up relatively more due to markups arising from spatial market power associated with the inelastic supply of access to amenities. Another explanation is that areas with low land shares in 1998 (presumably low amenity areas) saw large increases in land values relative to structural values because (a) the relatively elastic supply of land in low amenity areas kept the implicit price of structures pinned to construction costs; and/or (b) the general relaxation of credit constraints during the boom had the largest impact on demand in these areas. Without imposing additional structure on the data, we cannot disentangle the relative importance of these explanations. We discuss them briefly in the hope of motivating future research.

6. Discussion

Conventional wisdom suggests that variation in the volatility of housing prices *across* metro areas is primarily due to heterogeneity in the supply elasticity of land. In areas with physical and legislated constraints to urban development, the market price of housing will be relatively sensitive to demand shocks fueled by speculation and relaxation of credit constraints. These demand shocks will be translated into higher land values. Our results do not contradict this hypothesis. However, the land supply hypothesis is not sufficient to explain the variation we observe in the amplitude of the boom and bust *within* metro areas.

Within the metro areas that we studied, housing prices were relatively volatile in neighborhoods at the urban fringe, where the supply of land for housing is relatively elastic. Decom-

[23] 62.5% is the value for the 1998 land share that would correspond to a prediction of no change in the land share over the boom. It is calculated by dividing the regression intercept by the slope coefficient (=0.359/0.574). The regression predicts decreases for larger baseline land shares and increases for smaller baseline land shares.

posing this price volatility into the market value of land and structures revealed two other interesting trends. First, we saw that the average market value of land and structures tended to rise and fall in tandem. Since construction costs rose steadily during 1998-2009, our results suggest the presence of a wedge between construction costs and the market value of structures. Second, we saw that the size of the wedge tended to be larger in neighborhoods with higher land shares prior to the boom. We consider two market forces that may help to explain these trends: imperfect competition and q-theory. Both present interesting opportunities for future research.

6.1 Imperfect Competition

If markets were perfectly competitive with no barriers to entry, we would expect the market value of structures to be pinned to construction costs. Our results indicate this is not the case. One explanation is that barriers to entry convey some degree of market power to homeowners in exclusive neighborhoods. The construction industry may be close to perfectly competitive. However, builders cannot simply build more houses in established neighborhoods. Furthermore, development restrictions and zoning regulations often limit the ability of homeowners to expand their houses. With a small proportion of houses on the market at any one time, the unique bundle of amenities provided by a desirable neighborhood may allow home sellers to charge a markup on the structural characteristics of their houses. If there are only a few large houses on the market in the best school district, for example, the implicit market value of square footage may be bid far above construction costs due, in part, to the demand for access to high quality schools. This hypothesis is consistent with our observation that the neighborhoods experiencing the largest increase in market values of structural characteristics were the neighborhoods with the largest pre-boom land values (presumably the highest amenity neighborhoods).

To illustrate the comparative statics of the market power hypothesis, we use Kuminoff and Jarrah's (2010) iterative bidding algorithm (IBA) to simulate hedonic equilibria with heterogeneous households and houses. The IBA uses a numerical procedure to solve for an assignment

of people to houses and a vector of prices that jointly support a hedonic equilibrium, given an initial stock of housing and a set of draws from the joint distribution of income and preferences.

We use the IBA to simulate market outcomes in a stylized metropolitan area containing two built-up neighborhoods, A and B. Each neighborhood is defined to have 100 lots of identical size ($l_i = 7000\,\text{sqft}$). In neighborhood A, half of the lots contain "small" houses, uniformly drawn from $x_i \sim [1000,2000]$ sqft. The remaining lots contain "large" houses, uniformly drawn from $x_i \sim [2000,3000]$ sqft. In neighborhood B, the large and small houses are drawn from the same uniform distributions, but only 20% of the houses are large. The only other difference between the two neighborhoods is that B has more desirable amenities: $g_B = 75 > 50 = g_A$. Utility is specified as a Cobb-Douglas function of housing and neighborhood attributes:

$$V_{ijk} = \ln\left(y_i - p_{jk}\right) + \alpha_{i1} \ln l_{jk} + \alpha_{i2} \ln x_{jk} + \alpha_{i3} \ln g_{jk} + \alpha_{i4} \ln x_{jk} g_{jk} .$$

Finally, the joint distribution of preferences is drawn from a gamma distribution, and income is drawn from the same empirical distribution used by Kuminoff and Jarrah (2010).[24]

In the resulting equilibrium, large houses and small houses are both more expensive in neighborhood B, because it provides access to higher quality amenities. Our main point is that the large houses in B also command larger price premiums because they are in limited supply. To isolate the price premium, we begin by calculating the difference between the average price of large and small houses in each neighborhood. For example, $\left(\overline{p}_j \mid j \in A \;\&\; 2000 < x_j < 3000\right)$ $-\left(\overline{p}_j \mid j \in A \;\&\; 1000 < x_j < 2000\right)$ measures the difference between the average prices of large and small houses in neighborhood A. Differencing removes the market value of land. This follows because all houses in A have identical lots and they provide access to same amenity. The same is true for all houses in B. Therefore, the percentage markup on square footage in neighborhood B can be defined as,

[24] Matlab code to reproduce the simulation results is available as a supplemental online appendix.

$$100 * \left[\frac{\left(\overline{p}_j \mid j \in B \ \& \ 2000 < x_j < 3000\right) - \left(\overline{p}_j \mid j \in B \ \& \ 1000 < x_j < 2000\right)}{\left(\overline{p}_j \mid j \in A \ \& \ 2000 < x_j < 3000\right) - \left(\overline{p}_j \mid j \in A \ \& \ 1000 < x_j < 2000\right)} - 1 \right]. \qquad (6)$$

Figure 6A graphs the relationship between the markup and the difference in amenities provided by the two neighborhoods. In the baseline equilibrium (i.e. $g_B - g_A = 75 - 50 = 25$) there is a 63% premium on the market value of structures in the high amenity neighborhood. As $(g_A - g_B) \to 0$, spatial market power diminishes and the equilibrium markup approaches zero.

It is important to reiterate that our hedonic estimates in section 5 are consistent with the possibility of market power. While Rosen's (1974) welfare interpretation of the hedonic gradient relies on the maintained assumption of perfect competition, we did not maintain that assumption in order to prove that market outcomes can be described by a hedonic price function in theorem 1. As Feenstra (1995) demonstrated, introducing imperfect competition into a hedonic equilibrium simply changes the interpretation of the price function coefficients. They describe the implicit market prices of product characteristics, which reflect marginal costs plus markups.

Taylor and Smith (2000) provided the first hedonic evidence of market power in the market for beach rental properties in North Carolina. In particular, they found access to the beach gave owners the ability to charge markups on structural features of the house that were difficult to modify, such as the number of bedrooms. In our model, markups can enter through variation in the tract-specific coefficients on square feet of living space. It would be interesting to investigate the extent to which this variation can be explained by spatial variation in the quality of local public goods and urban amenities, perhaps using a higher-resolution version of the quality-of-life indices that have been constructed at the county level (e.g. Blomquist, Berger, and Hoehn 1988). One could also consider generalizing our model to allow for more spatial variation in the implicit prices (and markups) for other structural characteristics.

6.2 Q-theory

A second explanation for the wedge between construction costs and the market value of structures is that new houses take time to build. In a long-run equilibrium we would expect the mar-

ket value of an additional unit of each structural characteristic to equal its marginal construction cost. In the short run, however, a positive demand shock may lead market values to exceed construction costs. As the ratio of market value to construction cost increases, so does the incentive for new development. This is the basic idea behind Tobin's "q-theory" of capital investment. Figure 6B illustrates his logic in the context of our hedonic simulation. It graphs the difference ratio that enters the markup formula in (6) against the share of "large" houses in the high amenity neighborhood. Holding the amenity differential fixed, we simulate the transition path to a long-run equilibrium by incrementally "remodeling" the small houses in the high amenity neighborhood as large houses. Each time we remodel an additional 10% of houses, we solve for a new set of equilibrium prices and location choices. While the total number of houses is constant throughout this exercise, there is an increase in the total square footage of living space. As living space increases, the market-clearing difference ratio moves closer to 1, consistent with Tobin's description of the transition to a long-run equilibrium.[25]

While Tobin (1978) noted the potential for his model to explain the evolution of housing prices, there have been few applications. Part of the difficulty is that the logic of q-theory applies to structures, not to land, since we usually think of the supply of land as being fixed.[26] Thus, to evaluate the testable implications of q-theory we need credible estimates for the market value of structures.[27] Given credible estimates for the value of structures and construction costs, the interpretation of q-ratios is still complicated by several factors, including the presence of taxes, search costs, lender fees, and the aggregation over individual housing characteristics, each of which would be expected to have a separate marginal q.[28] These factors may lead to q-ratios that differ from 1 in a long-run equilibrium.

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[25] Since the difference ratios are based on average prices, rather than marginal prices, we would not necessarily expect them to be exactly equal to 1 in a long-run equilibrium.

[26] A rare exception is residential communities that are built on swamps that have been drained or wetlands that have been filled.

[27] Jud and Winkler (2003) apply q-theory to housing values without decomposing them into the value of land and structures.

[28] For a discussion of aggregation issues in a setting with multiple capital goods and citations to the broader literature on the empirical measurement of q-ratios, see Wildasin (1984).

As a first pass at assessing the predictions of q-theory in the housing market, we approximate q by dividing our annual estimates for the market value of structures by the replacement cost estimates for the cost of rebuilding the average home in Miami, San Francisco, Boston, and Charlotte. The results appear to be broadly consistent with the implications of q-theory.[29] Figure 7 illustrates that our pre-boom and post-bust estimates for structural value would imply q-ratios close to 1 in some areas. During the boom we generally see q-ratios increase and then decrease, consistent with lagged construction. In Miami, for example, our estimate for the q-ratio increases from 0.92 in 1998 to 1.5 in 2007, and then decreases back to approximately 0.92 by 2009. The decrease in the q-ratio is likely due to decreased demand as well as increased supply. Boston and Charlotte show similar patterns although their q-ratio is more elevated at the beginning of the time frame. San Francisco however begins with a q ratio of 1.68, peaks at over 3 in 2005 and then drops back to 1.69 in 2009. Modeling the dynamics of housing supply and demand as they relate to q-theory is an important direction for future research.

7. Conclusion

The boom-bust cycle of the 2000's was staggering in its size and its impact on the world economy. Thus, it is of great importance to characterize the dimensions of volatility in housing values and understand why they arise. We have sought to contribute to the process by developing a sharper hedonic approach to decomposing property value changes into variation in the implicit market values of land and structures. Our results indicate that the market value of structures was far more volatile during the boom and bust than has been assumed in previous studies. Two possible explanations are imperfect competition and q-theory. Formal tests of these hypotheses await future research.

Our results also have implications for the literature on land value taxation. Over the years there has been considerable interest in the possible efficiency gains from replacing the

[29] We are grateful to David Wildasin for first bringing this to our attention.

property tax with a tax on the market value of land or a split tax with separate rates on land and structures (e.g. Banzhaf and Lavery 2008; Cho, Lambert and Roberts 2010). One of the stylized facts about land value taxation is that, if implemented, it would lead to more variable revenue streams than the current property tax because land values are more susceptible to speculation (Bourassa 2009). At a practical level, part of the challenge with implementing a tax on land is determining its market value. Our findings have three implications for this literature. First, the replacement cost approach may overstate the value of land during a boom-bust cycle. Second, the bias may not be neutral. Our results suggest it would be largest in the highest-amenity neighborhoods. To the extent that homeowners in these neighborhoods collect markups on structures, they would have a disincentive to invest in structural improvements if they were effectively taxed on these improvements by a replacement cost scheme for determining land value. Finally, our estimates suggest that moving from a property tax to a land tax may actually help to stabilize revenue streams for some municipalities.

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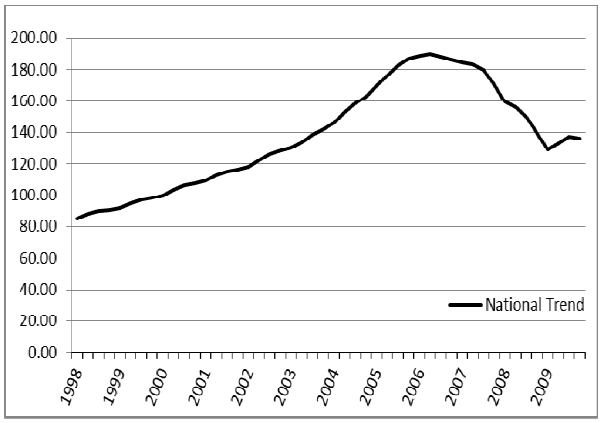
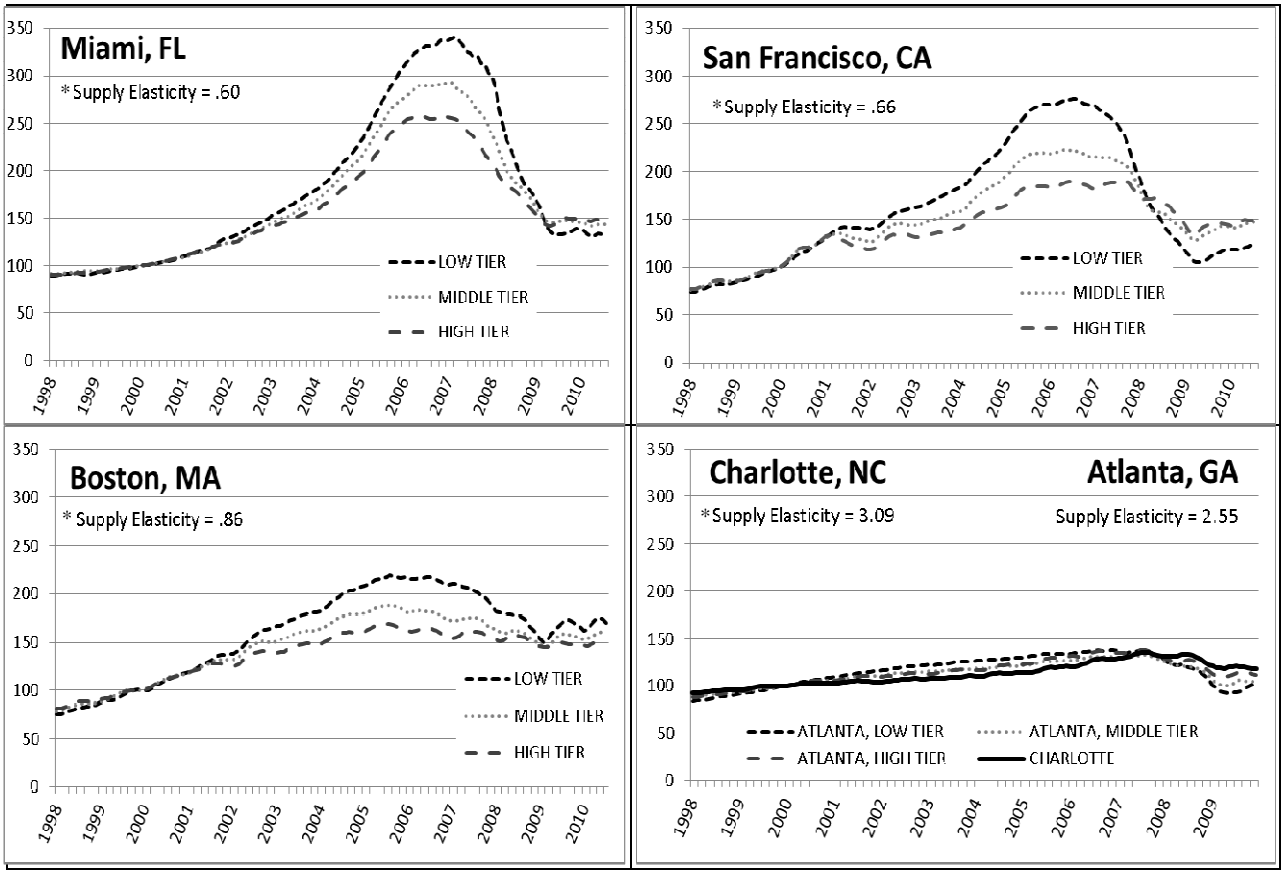
Figure 1: Standard & Poor's Case-Shiller National Housing Price Index



Note: This figure shows that housing prices more than doubled from 1998 to 2006, but then declined substantially from 2006 to 2009 for 20 metro areas included in the index. The data for this figure comes from the the S&P / Case-Shiller U.S. National Values Home Price Index. For documentation, see: http://www.standardandpoors.com.

Figure 2: Hetergogeneity in the Evolution of Housing Prices across & within Metro Areas



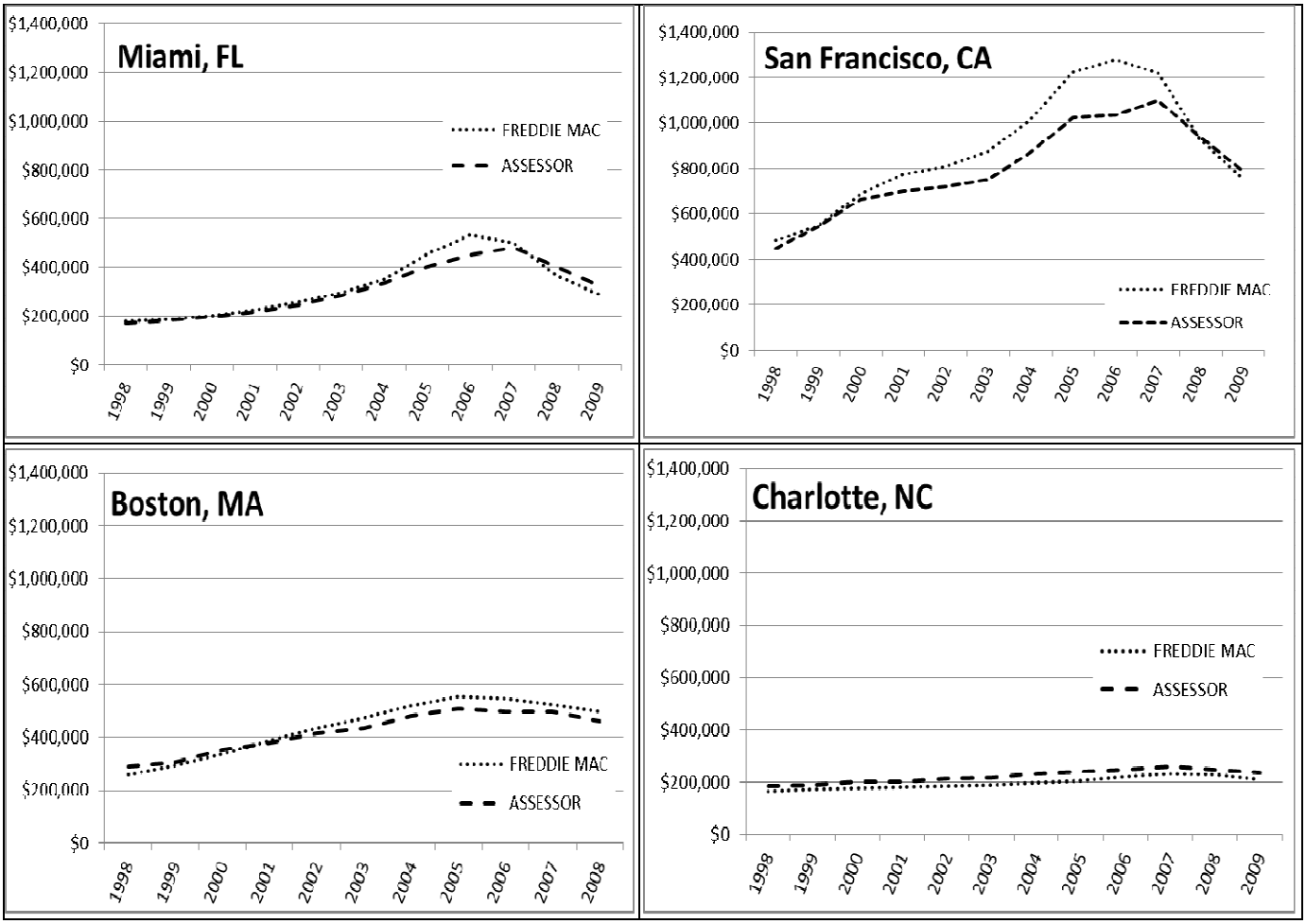
Note: This figure shows the substantial heterogeneity in price changes both across and within metro areas. The three lines show the evolution of prices for a metro's bottom "tier", middle "tier", and top "tier"of the price distribution. Breakpoints are defined by metro area as of August 2010. The data for this figure also comes from the the S&P / Case-Shiller Home Price Index. *Supply elasticities are based on Saiz (2010)

Figure 3: Evolution of Total Land Value and Structural Value for Four Metro Areas

Column 1: Total Land Value *Column 2: Total Structural Value*

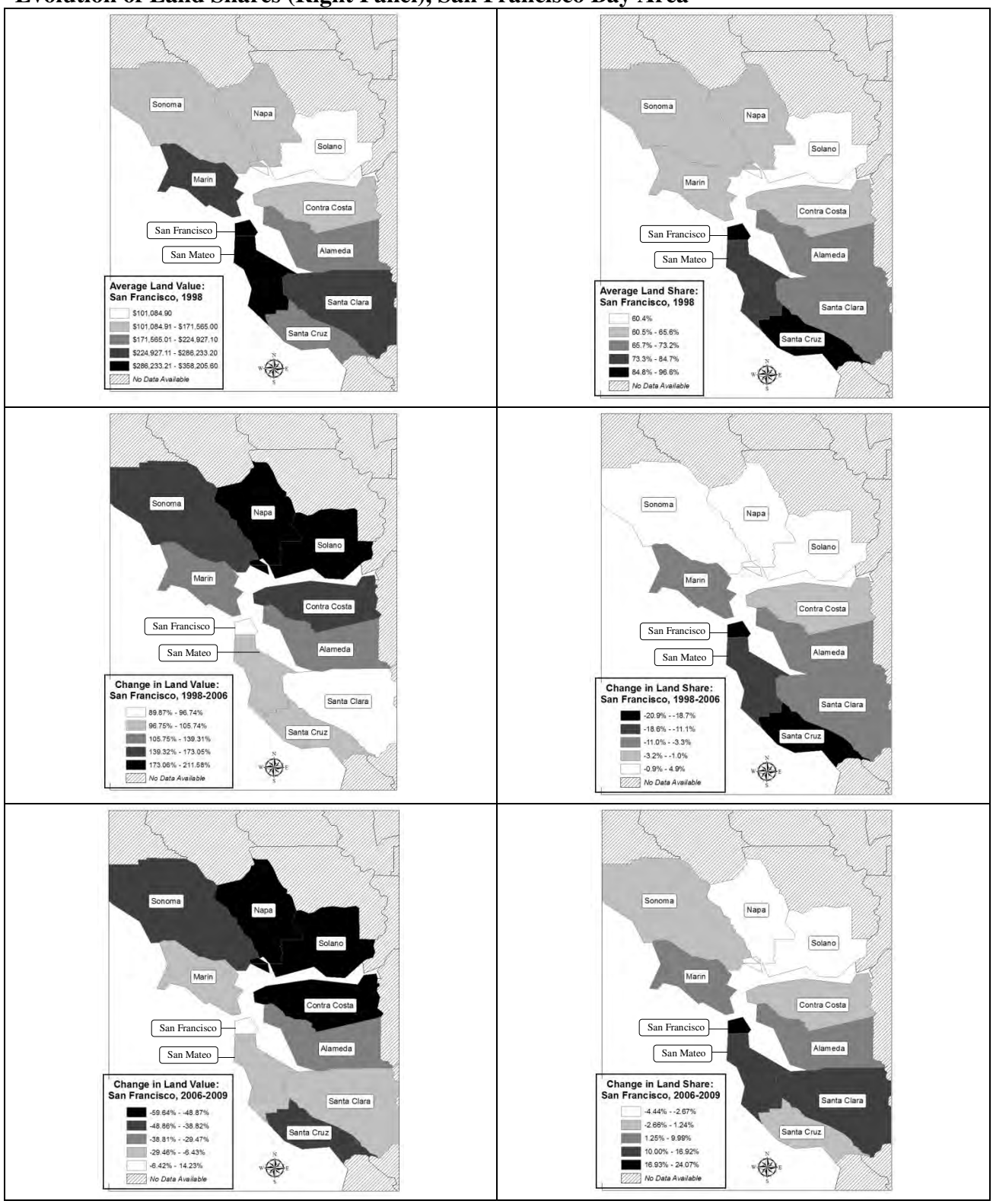
Note: Column 1 shows the evolution of total land value and Column 2 shows the evolution of total structural value by PMSA. Both columns show estimates derived using the hedonic method and the replacement cost method.

Figure 4: Comparing Our Assessor Data to Freddie Mac's Conventional Mortgage Home Price Index (CMHPI)



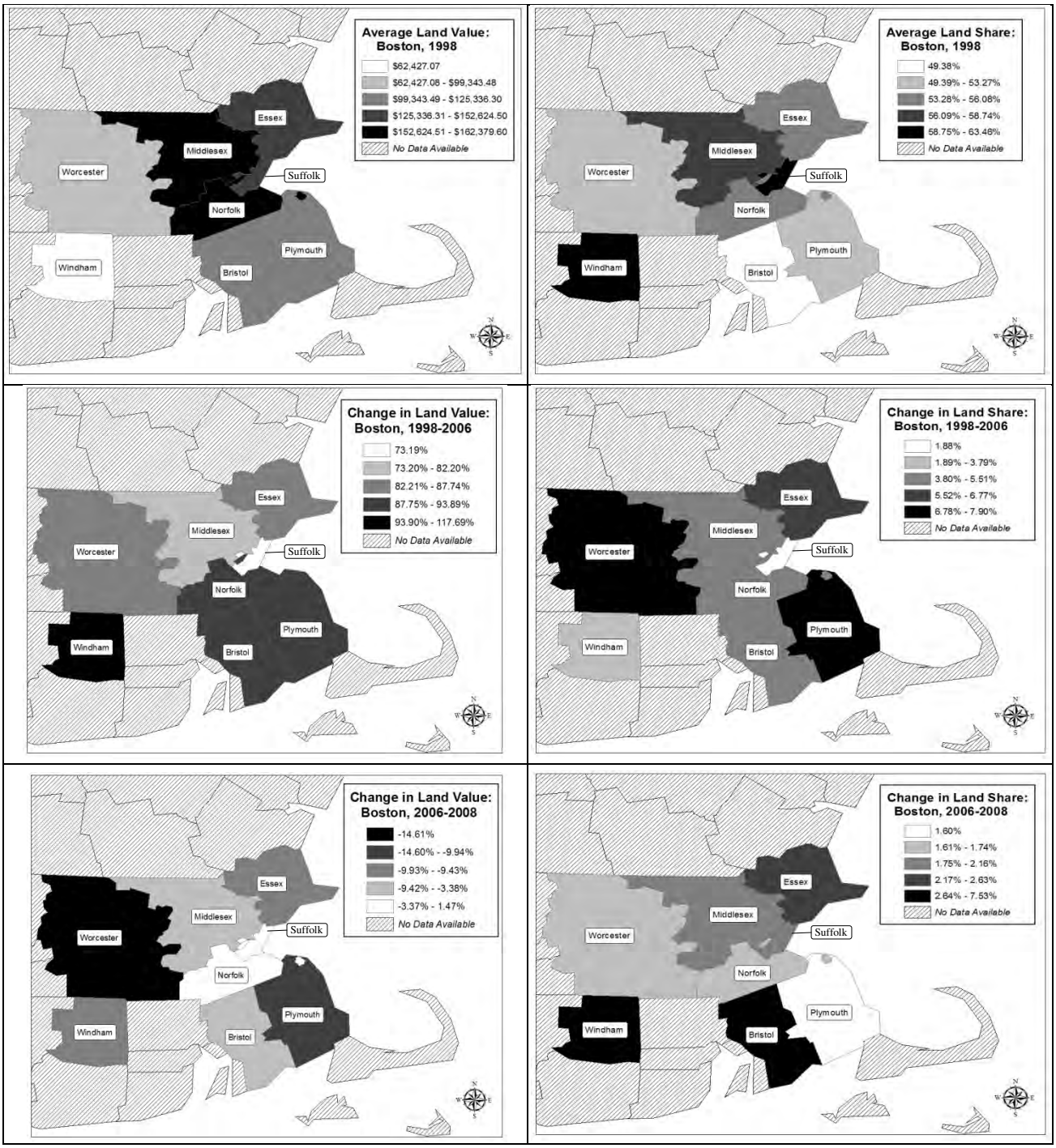
Note: Figures are produced using our assessor data and data from Freddie Mac's "Conventional Mortgage Home Price Index" as documented in Davis and Palumbo (2008).

Figure 5: Within Metro Land Value Heterogeneity (Left Panel) and Heterogeneity in the Evolution of Land Shares (Right Panel), San Francisco Bay Area



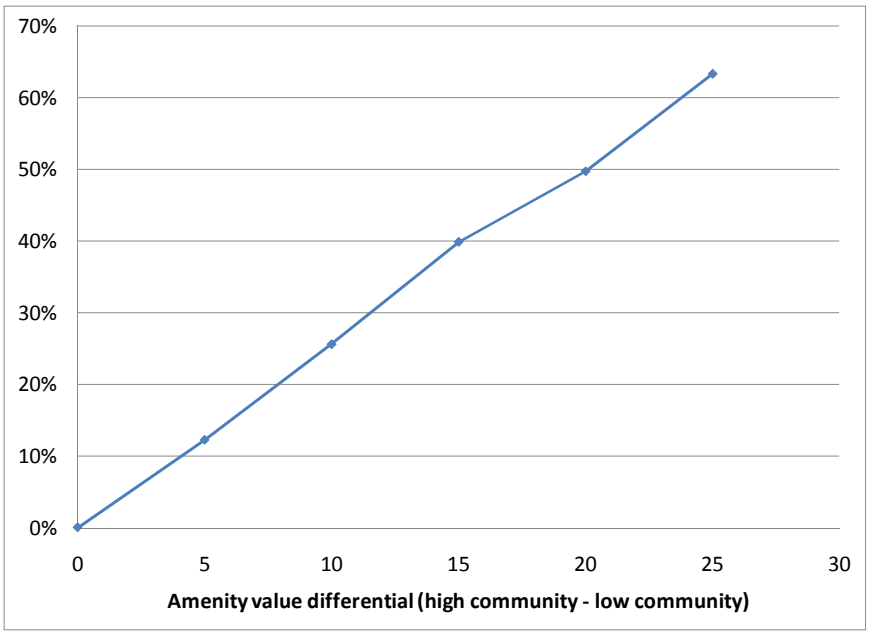
Note: These figures were produced using our hedonic approach to estimating land value. Black represents greatest absolute change, positive or negative.

Figure 5 (Continued): Within Metro Land Value Heterogeneity (Left Panel) and Heterogeneity in the Evolution of Land Shares (Right Panel), Boston Area



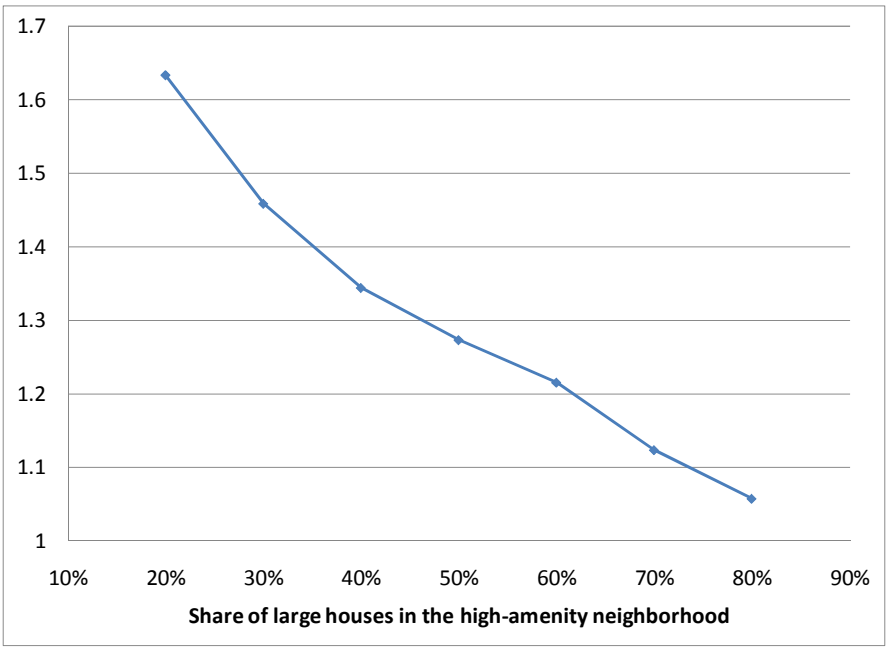
Note: These figures were produced using our hedonic approach to estimating land value. Black represents greatest absolute change, positive or negative.

Figure 6A: Markup on $/SQFT of Large Houses in the High Amenity Neighborhood



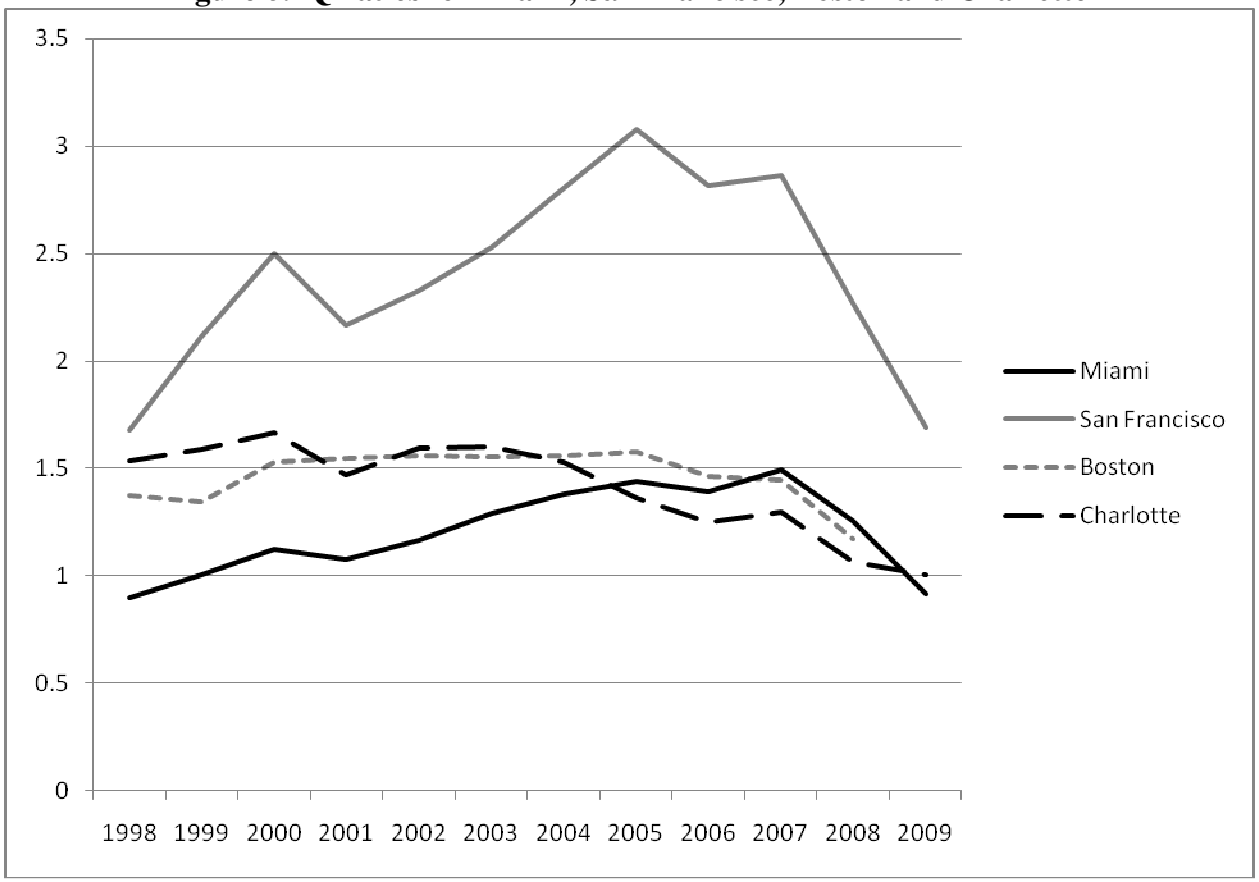
Note: Markups are based on the hedonic simulation described in section 6. The percentage markups on the price of square footage are calculated using equation (6). In the low amenity neighborhood, 50% of houses are large and 50% are small. In the high amenity neighborhood, 20% of houses are large and 80% are small.

Figure 6B: Q-Ratio and the Share of Large Houses in High Amenity Neighborhood



Note: Q-ratios are based on the hedonic simulation described in section 6. Ratios are calculated using the difference ratio in the markup formula (6). The share of large houses in the low amenity neighborhood are held constant at 50%. The level of the amenity in the low (high) amenity community is held constant at 50 (75).

Figure 6: Q-ratios for Miami, San Francisco, Boston and Charlotte



Note: the q-ratios illustrated above are the ratio between the average market value of structures within the metro area and the structural costs of the average house within the metro area as given by the updated estimates of Davis and Palumbo (2008) that can be found at: http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp .

Table 1: Summary Statistics for Miami, San Francisco, Boston and Charlotte

	Variable	Mean	Median	St. Dev.	Min.	Max.	Obs.
Miami	Housing Price (1998)	161,679	129,000	144,276	17,500	3,500,000	9,799
	Housing Price (2006)	409,931	335,000	333,682	23,000	5,000,000	21,730
	Square Feet	1,948.49	1740	861.07	251	9997	194,242
	Bathrooms	2.11	2	0.80	0.5	10	194,242
	Bedrooms	3.18	3	0.83	1	10	194,242
	Year Built	1977	1983	20	1901	2008	194,242
	Lot Size (acres)	0.21	0.17	0.26	0.00	5	194,242
San Francisco	Housing Price (1998)	343,034	285,000	235,225	10,000	4,772,727	31,656
	Housing Price (2006)	809,485	710,000	430,730	15,000	4,900,000	42,193
	Square Feet	1,820.24	1640	769.58	260	9984	517,295
	Bathrooms	2.19	2	0.80	0.5	10	517,295
	Bedrooms	3.34	3	0.88	1	10	517,295
	Year Built	1968	1968	25	1900	2008	517,295
	Lot Size (acres)	0.21	0.14	0.31	0.00	5	517,295
Boston	Housing Price (1998)	275,770	234,000	177,842	16,321	4,150,000	14,399
	Housing Price (2006)	445,970	367,900	302,919	50,000	4,750,000	29,369
	Square Feet	1,875.02	1662	880.97	252	9989	281,920
	Bathrooms	1.93	2	0.83	0.5	9.5	281,920
	Bedrooms	3.25	3	0.82	1	10	281,920
	Year Built	1960	1960	30	1900	2008	281,920
	Lot Size (acres)	0.58	0.34	0.66	0.00	5	281,920
Charlotte	Housing Price (1998)	176,186	137,000	143,959	13,000	2,500,000	4,909
	Housing Price (2006)	231,841	175,000	205,418	7,900	3,700,000	22,552
	Square Feet	2090.49	1876	937.11	412	9968	129,596
	Bathrooms	2.44	2	0.86	0.5	10	129,596
	Bedrooms	3.31	3	0.70	1	10	129,596
	Year Built	1986	1994	21	1900	2009	129,596
	Lot Size (acres)	0.36	0.28	0.36	0.01	5	129,596

Note: Summary statistics for housing characteristics and lot size using the micro-level assessor data for single-family residential properties in Miami, San Francisco, Boston, and Charlotte.

Table 2: Comparing Traditional Hedonic Estimates with Estimates Generated by the Replacement-Cost Method and our New Hedonic Method

		[1]	[2]	[3]	[4]
Metropolitan Area	**Year**	**GGS Hedonic Land Values ($/Acre)**	**Our Approximation to GGS ($/Acre)**	**DP Replacement Cost Land Values ($/Acre)**	**Our New Hedonic Land Values ($/Acre)**
Boston	1998	29,621	20,038	237,063	212,523
Cincinnati	1999	17,424	25,700	131,220	217,927
Detroit	1999	16,117	5,227	96,927	238,939
LosAngeles	1999	112,820	67,954	804,555	857,309
Oakland	1998	101,930	94,525	976,995	908,507
Philadelphia	1999	35,284	16,988	104,087	198,530
Pittsburgh	1998	30,492	21,780	42,007	212,020
SanFrancisco	1998	178,596	192,971	2,421,461	1,716,395
SanJose	1998	170,755	125,017	1,533,329	1,337,703
Tampa	1998	16,117	871	122,822	176,039

Note: Column [1] reports selected land values from Table 4 of Glaeser, Gyourko & Saks (2005) or "GGS" converted to a per/acre basis. Col. [2] reports our replication of the GGS estimates, using a similar (but not identical) set of housing characteristics from assessor data. Col. [3] reports replacement-cost estimates from Davis and Palumbo (2008) or "DP." Finally, Col. [4] reports results from our new hedonic fixed effects estimator.

Table 3: Evolution of Land Values and Land Shares between 1998 and 2009

	Miami, FL				San Francisco, CA			
	Hedonic Land Value	Replace. Cost Land Value	Hedonic Land Share	Replace. Cost Land Share	Hedonic Land Value	Replace. Cost Land Value	Hedonic Land Share	Replace. Cost Land Share
1998	100,833	100,192	0.67	0.57	286,638	384,895	0.73	0.80
1999	100,837	106,185	0.64	0.57	332,605	439,445	0.72	0.82
2000	105,339	116,585	0.62	0.59	401,393	577,058	0.72	0.85
2001	122,341	134,653	0.65	0.61	444,133	675,404	0.73	0.85
2002	138,410	159,482	0.64	0.64	438,264	685,531	0.69	0.85
2003	157,891	193,003	0.64	0.67	440,785	740,952	0.66	0.86
2004	187,726	234,739	0.64	0.69	505,022	868,277	0.67	0.87
2005	231,533	321,360	0.65	0.74	587,105	1,078,102	0.65	0.89
2006	267,107	407,144	0.68	0.76	607,558	1,143,481	0.66	0.88
2007	276,173	383,478	0.67	0.73	623,958	1,085,304	0.64	0.86
2008	218,320	230,180	0.67	0.60	517,277	781,603	0.65	0.80
2009	184,441	129,071	0.68	0.48	469,692	527,940	0.68	0.75

	Boston, MA				Charlotte, NC			
	Hedonic Land Value	Replace. Cost Land Value	Hedonic Land Share	Replace. Cost Land Share	Hedonic Land Value	Replace. Cost Land Value	Hedonic Land Share	Replace. Cost Land Share
1998	144,156	150,676	0.56	0.59	79,700	97,249	0.52	0.59
1999	158,979	178,134	0.59	0.63	77,395	102,112	0.50	0.59
2000	179,920	216,678	0.59	0.67	82,127	106,457	0.49	0.59
2001	196,329	264,326	0.60	0.69	88,791	105,246	0.53	0.58
2002	221,005	300,307	0.61	0.71	83,115	105,388	0.48	0.57
2003	237,622	344,810	0.62	0.73	84,361	106,634	0.47	0.56
2004	264,144	381,594	0.63	0.74	89,847	104,239	0.47	0.53
2005	272,830	413,243	0.62	0.74	89,869	98,610	0.46	0.48
2006	263,627	395,675	0.62	0.71	95,748	100,060	0.47	0.45
2007	253,552	363,197	0.60	0.68	97,479	106,024	0.46	0.46
2008	250,611	320,873	0.64	0.64	102,243	92,201	0.50	0.40
2009		277,680		0.61	97,778	70,959	0.50	0.34

Note: This table shows the evolution of total land value and the share of property values accounted for by land, by PMSA. For each metro-area, estimates are shown for both the hedonic method for deriving land values and the replacement cost method.

Table 4: Housing Units, Property Values, and Land Values in the San Francisco Bay Area, 1998-2009

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
county	Owner occuped units: 2000 (thousand)	Single-family residential permits: 2000-2007 (thousand)	New S.R.F. permits 2000-2007 / baseline owner occ units: 2000	All new permits 2000-2007 / baseline housing units: 2000	Median perceived housing value: 2000 (thousand)	Mean sale price: 1998 (thousand)	Mean land value: 1998 (thousand)	Mean land value change: 1998 to 2006 (thousand)	Mean land value change: 1998 to 2006	Mean land value change: 2006 to 2009 (thousand)	Mean land value change: 2006 to 2009	Mean land value change: 1998 to 2009 (thousand)
San Francisco Metro Area												
San Francisco	79.55	0.58	0.01	0.05	396	408	358	322	90%	97	-14%	419
San Mateo	135.61	5.67	0.04	0.04	469	430	328	332	101%	-42	6%	289
Marin	55.12	3.27	0.06	0.04	515	498	264	324	123%	-102	17%	222
Santa Clara	291.77	18.08	0.06	0.08	446	446	286	277	97%	-82	15%	195
Alameda	251.17	16.29	0.06	0.06	303	316	200	279	139%	-141	29%	138
Santa Cruz	43.43	4.17	0.10	0.06	378	273	225	238	106%	-200	43%	38
Sonoma	91.61	11.79	0.13	0.10	273	250	148	255	173%	-156	39%	99
Contra Costa	210.34	34.41	0.16	0.12	268	303	172	269	157%	-226	51%	43
Napa	23.49	4.30	0.18	0.12	251	231	137	291	212%	-209	49%	82
Solano	75.97	13.94	0.18	0.13	178	188	101	201	199%	-180	60%	21

Note: Col. [1] is based on the 2000 Census. Col. [2] is based on annual counts of permits for single-family residential construction reported by the SOCDS building permits database provided by huduser.org. Col. [3] is the ratio of col. [2] to col. [1]. Col. [4] divides the total number of permits for new housing units (all types) between 2000 and 2007 by the year 2000 stock of housing units (all types). The numerator is reported by the California Statistical Abstract. The denominator is reported by the 2000 Census. Col. [5] is the median self-reported housing value by county, from the 2000 Census. Col. [6] is the average transaction price from our county assessor data. Col. [7]-[12] are based on our estimates for land value of the average single-family residential property in each county.

Table 5: Correlation between Increase in Land Share (1998-2006) and Baseline Land Share (1998)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Dep. Variable = (land share in 2006 - land share in 1998)	**San Francisco**	**Boston**	**Miami**	**Charlotte**	**Los Angeles**	**Detroit**	**Oakland**	**Pittsburg**	**San Jose**	**Tampa**
1998 Land Share	-0.574***	-0.448***	-0.540***	-0.520***	-0.732***	-0.646***	-0.710***	-0.393***	-0.754***	-0.639***
	(-0.062)	(-0.041)	(-0.060)	(-0.081)	(-0.026)	(-0.051)	(-0.038)	(-0.086)	(-0.068)	(-0.095)
Constant	0.359***	0.306***	0.383***	0.235***	0.528***	0.375***	0.483***	0.237***	0.519***	0.386***
	(-0.048)	(-0.024)	(-0.044)	(-0.045)	(-0.020)	(-0.037)	(-0.029)	(-0.057)	(-0.052)	(-0.058)
# of Census Tracts	103	359	141	70	650	180	247	48	142	143
# housing transactions	47,687	181,617	132,498	82,291	312,059	88,570	172,735	24,592	75,863	100,526
R-squared	0.458	0.255	0.365	0.375	0.554	0.479	0.591	0.312	0.467	0.242

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

SUPPLEMENTAL APPENDIX: NOT FOR PUBLICATION

Table A1: Housing Units, Property Values, and Land Values in the Boston Area, 1998-2008

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
county	Owner occuped units: 2000 (thousand)	Single-family residential permits: 2000-2007 (thousand)	New S.R.F. permits 2000-2007 / baseline owner occ units: 2000	All new permits 2000-2007 / baseline housing units: 2000	Median perceived housing value: 2000 (thousand)	Mean sale price: 1998 (thousand)	Mean land value: 1998 (thousand)	Mean land value change: 1998 to 2006 (thousand)	Mean land value change: 1998 to 2006	Mean land value change: 2006 to 2008 (thousand)	Mean land value change: 2006 to 2008	Mean land value change: 1998 to 2008 (thousand)
Boston Metro Area												
Suffolk	39.36	0.81	0.02	N/A	187	249	153	112	73%	4	-1%	116
Norfolk	144.18	7.10	0.05	N/A	230	330	157	143	91%	-4	1%	138
Essex	139.93	8.38	0.06	N/A	220	296	145	127	88%	-26	10%	101
Middlesex	268.54	16.20	0.06	N/A	248	312	162	133	82%	-10	3%	123
Bristol	99.92	10.56	0.11	N/A	152	255	115	108	94%	-14	6%	93
Plymouth	110.22	12.14	0.11	N/A	179	267	125	116	92%	-24	10%	92
Worcester	149.39	21.78	0.15	N/A	146	211	99	85	86%	-27	15%	58

Note: Col. [1] is based on the 2000 Census. Col. [2] is based on annual counts of permits for single-family residential construction reported by the SOCDS building permits database provided by huduser.org. Col. [3] is the ratio of col. [2] to col. [1]. In col. [4] we were unable to obtain data on the total number of permits for new housing units in a format that would be comparable to the data on San Francisco in table 4. Col. [5] is the median self-reported housing value by county, from the 2000 Census. Col. [6] is the average transaction price from our county assessor data. Col. [7]-[12] are based on our estimates for land value of the average single-family residential property in each county.

The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2)

By 2007 Working Group on California Earthquake Probabilities*

USGS Open File Report 2007-1437
CGS Special Report 203
SCEC Contribution #1138
Version 1.0

2008

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U.S. Geological Survey

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The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2)

2007 Working Group on California Earthquake Probabilities (WGCEP) and the USGS National Seismic Hazard Mapping Program (NSHMP)

Executive Summary

California's 35 million people live among some of the most active earthquake faults in the United States. Public safety demands credible assessments of the earthquake hazard to maintain appropriate building codes for safe construction and earthquake insurance for loss protection. Seismic hazard analysis begins with an earthquake rupture forecast—a model of probabilities that earthquakes of specified magnitudes, locations, and faulting types will occur during a specified time interval. This report describes a new earthquake rupture forecast for California developed by the 2007 Working Group on California Earthquake Probabilities (WGCEP 2007).

2007 Working Group on California Earthquake Probabilities

WGCEP 2007 was organized in September, 2005, by the U. S. Geological Survey (USGS), the California Geological Survey (CGS), and the Southern California Earthquake Center (SCEC). It was charged with two tasks: (1) collaborate with the National Seismic Hazard Mapping Program (NSHMP) in producing a revised, *time-independent* forecast for California as input to the 2007 revisions of the national seismic hazard maps, and (2) create a uniform, statewide, *time-dependent* model that, among other purposes, could be used by the California Earthquake Authority (CEA) in setting earthquake insurance rates.

The national seismic hazard maps utilize a time-independent forecast in which the probability of each earthquake rupture is completely independent of the timing of all others. Time-dependent models are based on the concept of stress renewal: the probability of a fault rupture drops immediately after a large earthquake releases tectonic stress on the fault and rises again as the stress is regenerated by continuous tectonic loading. However, observations in California and elsewhere show that the earthquake cycle associated with this elastic rebound theory can be highly irregular, owing, for example, to stress interactions among neighboring faults. We do not understand these interactions well enough to model them explicitly; therefore, variations in the earthquake cycle must be calibrated empirically using historical observations of seismicity and geologic data on the dates and sizes of prehistoric earthquakes (paleoseismology).

Time-dependent earthquake rupture forecasts, in which the probabilities of future events are conditioned on the dates of previous earthquakes, have been the focus of five previous Working Groups on California Earthquake Probabilities (WGCEP 1988, 1990, 1995 & 2003). Each of

these working groups has expanded on its predecessors, improving the data and forecasting methodology, and each has drawn on input from broad cross-sections of the earth science community. Building on this experience, we calculate time-dependent probabilities of large earthquakes on major faults (generally those with the highest rates of slip) where the requisite information is available: the expected mean frequency of earthquakes and the elapsed time since the last earthquake. Where such information is lacking, we use time-independent probabilities, which require only an estimate of earthquake frequency.

The WGCEP 2007 study differs from previous WGCEP efforts by:

- reporting earthquake probability for the entire state of California instead of subregions;
- using uniform methodology across all regions;
- using the same earthquake rate model as the 2007 National Seismic Hazard Map Program;
- compiling and using updated, uniform, and publicly accessible statewide data;
- developing new methods to make models more rigorously adherent to observational data, particularly fault slip rates (moment balanced);
- making analysis tools and data available through a readily accessible web-based interface.

In general, we have adopted the results from previous working groups where justified and have updated the model only when compelled to by new information or understanding, or by necessity to conform the analysis to a uniform statewide approach and with the NSHMP assessment.

Review and Consensus-Building Processes

All UCERF 2 model elements and WGCEP 2007 documents were reviewed by an internal Scientific Review Panel (SRP) comprising experts who were not WGCEP 2007 members. The SRP reported to the Management Oversight Committee (MOC), which coordinated the review and oversaw consensus-building processes. External oversight and review was provided by the National Earthquake Prediction Evaluation Council (NEPEC) and the California Earthquake Prediction Evaluation Council (CEPEC), as well as CEA's Multidisciplinary Research Team. CEPEC and NEPEC tracked model development throughout the WGCEP 2007 process and reviewed the final report.

Advice and comment from the scientific and engineering communities was sought regularly through open meetings and workshops during the several phases of UCERF development. Participants included experts from academia, private and corporate providers of hazard assessments, consulting companies, and government agencies. WGCEP progress was reported at major scientific gatherings such as annual meetings of the American Geophysical Union, the Seismological Society of America, and the Southern California Earthquake Center.

Model Framework

We have built on previous WGCEP and NSHMP efforts to quantify regional earthquake probabilities in California, using the best available science to develop a new framework for a Uniform California Earthquake Rupture Forecast (UCERF). The UCERF framework comprises a sequence of four model types: a *fault model* that gives the physical geometry of the larger, known faults; a *deformation model* that gives slip rates and

aseismicity factors to each fault section; an *earthquake rate model* that gives the long-term rate of all earthquakes of magnitude five or greater ($M \geq 5$) throughout the region; and a *probability model* that gives a probability of occurrence for each earthquake during a specified (future) time interval. This report presents the latest versions of each of these models, including the statewide time-independent earthquake rate model incorporated into the 2007 revisions to the national seismic hazard map (ERM 2.3) and the time-dependent earthquake probability model derived from ERM 2.3 (UCERF 2). The results are intended for use in forecasting the intensity of ground shaking throughout California.

The model incorporates both aleatory uncertainties (arising from natural variability) and epistemic uncertainties (resulting from lack of knowledge). The latter were included by constructing a logic tree with branches representing viable alternative hypotheses. We restricted our consideration to data and methods that have been published, or accepted for publication, in peer-reviewed scientific journals or as U.S. Geological Survey Open File Reports. If relevant published models differed significantly, we applied logic-tree weighting to represent the alternatives. Generally, two alternatives were given equal weight in the absence of any clear evidence to favor one over the other. When there was evidence to favor a given branch, the assignment of relative weights was made though a consensus-building process, which we describe for each case.

Earthquake Rate Model

The WGCEP 2007 earthquake rate model features a new fault geometry with more accurate values of dip and seismogenic depth, and new compilations of fault slip rates and paleoseismic events. The final version, ERM 2.3, includes two alternative fault models for southern California thrust-fault geometry and three alternatives representing the uncertain slip distribution between the southern San Andreas and San Jacinto faults. A significant logic-tree branching involves the choice of the magnitude-area relationship, which is used to translate from fault slip rates to earthquake rates; the global database of rupture areas and magnitude determinations has significant spread, leaving room for alternative interpretations.

Another important model branching incorporates alternative representations of the earthquake rates on major faults. We compiled an *a priori* earthquake rate model derived by a community consensus of paleoseismic and other geologic observations. We also calculated a moment-balanced version of the model, which modifies the earthquake rate to match the observed long-term slip-rate data; the resulting rates were constrained to fall within the ranges derived from paleoseismic observations. These two models balance a consensus of geologic and seismologic expert opinion with strict adherence to specific observational data.

We tested ERM 2.3 in three different ways: by comparing the predicted magnitude-frequency distributions of earthquakes with a unified historic and instrumental earthquake catalog for California and surrounding regions, by comparing integrating measures of deformation across the plate-boundary zone with the plate rate, and by comparing the distribution of source types in the model with historical data. A major issue was overprediction of the rate of $M \geq 6.5$ earthquakes, known informally as “the bulge”, a problem common to previous WGCEP and NSHMP studies. ERM 2.3 predicts an annual rate for $M \geq 6.5$ earthquakes of 0.32 events/yr, which exceeds the historically observed rate of 0.24 events/yr by about a third, though it lies within the

95% confidence bounds on the observed rate (0.13-0.35 events/yr). In comparison, the NSHMP 2002 model for California exceeded the observed rate by a factor of two.

Time-Dependent Earthquake Probability Model

We tightly coordinated the development of the earthquake rate models for California with NSHMP, so that both the 2007 revisions of the national seismic hazard maps and UCERF 2 are based on ERM 2.3. Constructing an earthquake rupture forecast from ERM 2.3 required a probability model that specifies how events are distributed in time, and here we departed from the NSHMP 2007 conventions by considering, along with a time-independent (Poisson) forecast, time-dependent forecasts that use stress-renewal assumptions to condition the event probabilities for the most active faults on the date of their last major rupture.

Our choice of UCERF 2 model branches was based on a careful review of all available probability models. A particularly influential branching is the "empirical" probability model, which includes a geographically variable estimate of California earthquake rate changes observed during the last 150 years. We lack consensus on the underlying physics that causes broad earthquake rate changes, though there is much promising research involving fault interactions. Rather than applying complex physical models to adjust probability, WGCEP 2007 relies on the simpler empirically-based correction.

An important seismic hazard for California is the Cascadia subduction zone, which extends

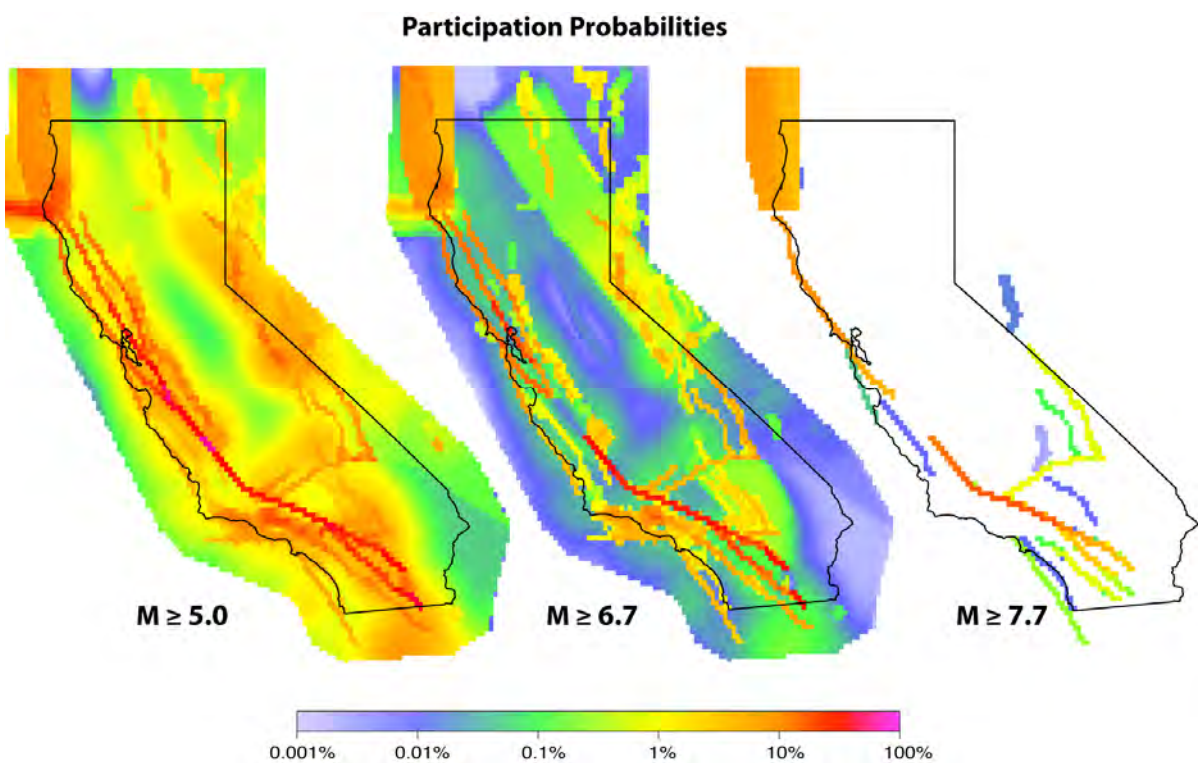

Figure A. Participation probability maps, displaying the mean UCERF 2 probabilities that an individual $0.1^{o} \times 0.1^{o}$ cell in the statewide grid will be involved in a fault rupture of any source type above the specified magnitude threshold during the next 30 years. The magnitude thresholds shown here are M • 5.0, 6.7, and 7.7. Probability color scale is logarithmic; i.e. each decrement unit represents a 10-fold decrease in probability.

about 1200 km from Vancouver Island in British Columbia to Cape Mendocino in California and is capable of generating an earthquake of M 9 or larger. Because this fault lies mostly outside the state, we treated it as a special case with its own logic tree, which included two rupture scenarios: (1) M 8.8-9.2 events that rupture the entire Cascadia subduction zone every 500 years on average, and (2) M 8.0-8.7 events whose ruptures cover the entire zone over a period of about 500 years. A time-independent model was applied to the M 8.0-8.7 scenario, and a time-dependent model to the M 8.8-9.2 scenario.

In computing event probabilities, the branches were weighted by expert opinion gathered in open workshops. The UCERF 2 model has been implemented in a modular (object-oriented), extensible framework using the OpenSHA platform, so that experiments with alternative branch weights can be easily investigated and future updates can be quickly accommodated as new data and methods emerge. The final UCERF 2 logic tree incorporated 480 branches that received nonzero weight, each of which produces a separate set of probabilities for all earthquakes in California. We take the mean and spread of these results to represent the best estimate of earthquake probability and its sensitivity to parameter uncertainty.

Results of Probability Calculations

According to UCERF 2, a $M \geq 6.7$ earthquake is virtually assured in California during the next 30 years (99.7% probability of occurrence). Larger events are less likely: the mean 30-year UCERF 2 estimate gives a 94% chance of a $M \geq 7.0$ earthquake, a 46% chance of a $M \geq 7.5$ shock, and 4.5% chance of a $M \geq 8.0$ event. The UCERF 2 range for these latter probabilities is 85-99%, 29-65%, and 0-11%, respectively. In addition, we estimate a 10% probability of a $M \geq 8.0$ earthquake somewhere along the Cascadia subduction zone (perhaps far from California) in the next 30 years. We emphasize that the probabilities calculated for the largest magnitude events should be used with caution, because they depend critically on rupture scenarios that involve fault lengths longer than historically observed ruptures, as well as an extrapolation of scaling relationships, such as the magnitude-area relationships, beyond the limits of the empirical data.

Dividing the state into two approximately equal areas, we find the 30-year probability of a large earthquake to be higher in the southern half: a $M \geq 6.7$ earthquake has a 97% chance of occurring in southern California in 30-years, compared to a 93% probability in northern California, and the odds for a $M \geq 7.5$ event are doubled (37% vs. 15%). In addition to state-wide and regional estimates, our report gives probabilities for individual faults and fault segments throughout the state, as well as a geographically variable background rate.

The UCERF 2 earthquake rupture forecast can be visualized by mapping the mean probability that an element of area on a statewide grid will include a fault rupture of any source type above a specified magnitude threshold during the next 30 years. Figure A presents these “participation probability” maps for three magnitude thresholds. For events with $M \geq 5.0$, the areas where the participation probabilities exceed 1% (yellow or warmer in color) include over half the state, reflecting the widespread distribution of California seismicity, much of which is represented in the model as “background.” At $M \geq 6.7$, this same probability level is confined to the major faults, and at $M \geq 7.7$, it is generally restricted to the longer strike-slip strands of the San Andreas fault system.

Table A. 30-year probability of M • 6.7 events on the Type-A faults, rounded to the nearest percent.

Fault	WGCEP (2007) Mean [Min-Max]	WGCEP (2003) Mean [2.5% and 97.5%]	WGCEP (1995) Mean
S. San Andreas	59% [22-94]		53%
Hayward-Rodgers Creek	31% [12-67]	27% [10-58]	
San Jacinto	31% [14-54]		61%
N. San Andreas	21% [6-39]	23% [3-52]	
Elsinore	11% [5-25]		24%
Calaveras	7% [1-22]	11% [3-27]	
Garlock	6% [3-12]		

Table A summarizes the mean probabilities for $M \geq 6.7$ events on the principal strike-slip faults of California, which accommodate most of the motion between the North America and Pacific plates, and it compares our results with those of WGCEP 1995 for southern California and WGCEP 2003 for the Bay Area.

The most dangerous fault is the southern part of the San Andreas, which has a 59% probability of generating a $M \geq 6.7$ earthquake in the next 30 years. This compares with 21% for the northern San Andreas fault.

We have enough data to calculate time-dependent earthquake probability on the principal strike-slip faults in Table A. These faults exist within a web of faults with lower slip rates that we know less about, which are consequently treated as time-independent sources. In southern California, the contribution to overall regional probability from these lower slip-rate faults, which include the reverse faults of the Transverse Ranges, exceeds that of the principal strike-slip faults.

Reliability of Results

The larger the area considered and the longer the time considered generally makes a probability calculation more reliable. Thus the statewide 30-year probability values are more reliable estimates than those for individual faults. However, even the most reliable of our calculations are subject to considerable sensitivity to parameters. For example, across the 480 branches of the logic tree we find a minimum 30-year probability of 29% for a $M \geq 7.5$ earthquake, and a maximum of 65%. Calculations are quite sensitive to parameter choices on individual faults; while the mean calculated probability on the southern San Andreas fault is 59%, we find that the value could reasonably be anywhere between 22% and 94% (see Table A).

There are known limitations with the WGCEP 2007 model, which are discussed in detail in the main report. More research time will bring improvements in key topical areas. For example, new earthquake faults will continue to be discovered. Improvements in our methods for determining maximum magnitudes associated with poorly understood faults are needed. A related major research challenge involves improving our ability to forecast more complex earthquake ruptures that include fault jumps, branching, and segment-breaking ruptures.

Comparisons with Previous Studies

The 30-year probability of a $M \geq 6.7$ earthquake striking the San Francisco Bay Area is 63% for UCERF 2, which is indistinguishable from the 62% value reported by WGCEP 2003

(see Table A). Moreover, the extrema calculated from all of the UCERF 2 branches [0.41-0.84] approximate the 95% confidence interval of WGCEP 2003 results for the aggregate Bay Area probabilities [0.38-0.85]. This agreement indicates that we succeeded in capturing the most important epistemic uncertainties (in part because we were guided by the comprehensive uncertainty analysis of the WGCEP 2003 report).

As shown in the table, there are differences between WGCEP 2007 and WGCEP 2003 calculations for individual fault probabilities in the Bay Area. However, none exceed the uncertainty ranges reported by either working group. The differences resulted primarily from inclusion of paleoseismic observations in UCERF 2 and the restricted inventory of probability models that could be used for our statewide analysis.

The differences in the mean 30-year probabilities for $M \geq 6.7$ events between the 1995 and 2007 studies are more significant. The most important arise from new paleoseismic data and analysis, new geodetic data, and an earthquake rate model that allows a greater variety of rupture sizes on faults. One important change is to the San Jacinto fault, where the probability has been halved from 61%, reported by WGCEP 1995, to 31% [14%-54%] calculated by WGCEP 2007 (see table). Similarly, Elsinore fault probability is halved from 24% to 11% [5%-25%] because of the increased array of possible earthquake magnitudes allowed in the model.

Recommendations

The comprehensive nature of the UCERF 2 analysis has identified many opportunities for future model improvements, and we outline in the report specific recommendations for further research. Examples include the relaxation of fault segmentation and the inclusion of fault-to-fault ruptures, which may be in part responsible for the "bulge" problem; the inclusion of earthquake triggering and clustering, as manifested in aftershock sequences; and improved magnitude-area relationships.

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Table 11 Capital Cost for Proposed Levels of Treatment

Item	Level 1	Level 2	Level 3	Level 4
Estimated Capital Costs	$3,410,000	$36,262,000	$48,857,000	$53,328,000
lbs NH3-N removed/day	1,558	6,660	6,660	6,660
lbs-TN removed/day	2,665	1,336	5,610	6,946
$/lb- NH3-N removed (Normalized Cost)	$2,189	$5,444	$7,336	$8,007
$/lb-TN removed (Normalized Cost)	$1,279	$27,146	$8,708	$7,677

Operations costs increase with the level of chemical treatment, volume of recycle flow in the aeration basins, and additional equipment. Table 12 provides an estimate of the annual O & M costs for each level of nutrient removal. As with the capital costs, Level 1 treatment is the least expensive while Level 4 is the most expensive alternative. In terms of O &M costs, Level 1 treatment is also the most cost effective alternative for removing total nitrogen because it does not have a large aeration demand, or intensive recycle pumping.

Table 12 Operations Costs for Proposed Levels of Treatment

Item	Level 1	Level 2	Level 3	Level 4
CEPT	--	$272,800	$272,800	$272,800
Activated Sludge	$289,200	$1,563,700	$1,665,000	$1,688,600
Anammox	$449,700	--	--	--
Tertiary Filters	--	--	$71,000	$227,900
Total Annual Operations Cost	$738,900	$1,836,500	$2,008,800	$2,189,300
lbs NH3-N removed/day	1,359	6,660	6,660	6,660
lbs-TN removed/day	3,281	1,406	5,624	7,031
$/lb-Nh3-N removed (Normalized Cost)	$0.51	$0.12	$0.12	$0.12
$/lb-TN removed (Normalized Cost)	$0.76	$3.77	$0.98	$0.86

Water Supply and Demand: Planning for the Future

July 10, 2012

Steven R. Ritchie
Assistant General Manager, Water Enterprise

Today's Water Supply Agenda

- Background
  - Performance Objectives and 2018 Decisions
- Ongoing Water Conservation Efforts
- Discussion
- Water Supply Projects
  - Status
- Discussion
- Triple Bottom Line Approach
  - Consistent with SSIP
- Discussion and Conclusion

Questions to Consider Today

- Are we proceeding appropriately to develop Regional Water System dry year supplies?
- Should we accelerate planning and design for the recycled water projects?
- Would it be useful to explore a rate structure that is based in part on Individual Supply Guarantees or allocations, or accounts for other Water Supply Agreement considerations?
- Are we on the right track regarding Triple Bottom Line analysis?
- Should we continue to work on all of the projects?

Water Supply Performance Objectives

- Meet average annual water demand of 265 million gallons per day (mgd) from the SFPUC watersheds during non-drought years through 2018.
- Limit rationing to a maximum 20 percent system-wide reduction during extended droughts.
- Diversify water supply options during non-drought and drought periods.
- Improve use of new water sources and drought management, including groundwater, recycled water, conservation, and transfers.

Decisions by December 2018 (including CEQA review)

- Whether or not to make San Jose and Santa Clara permanent customers
- How much water, if any, in excess of the Supply Assurance the SFPUC will supply to Wholesale Customers
- Whether to offer a corresponding increase in the Supply Assurance

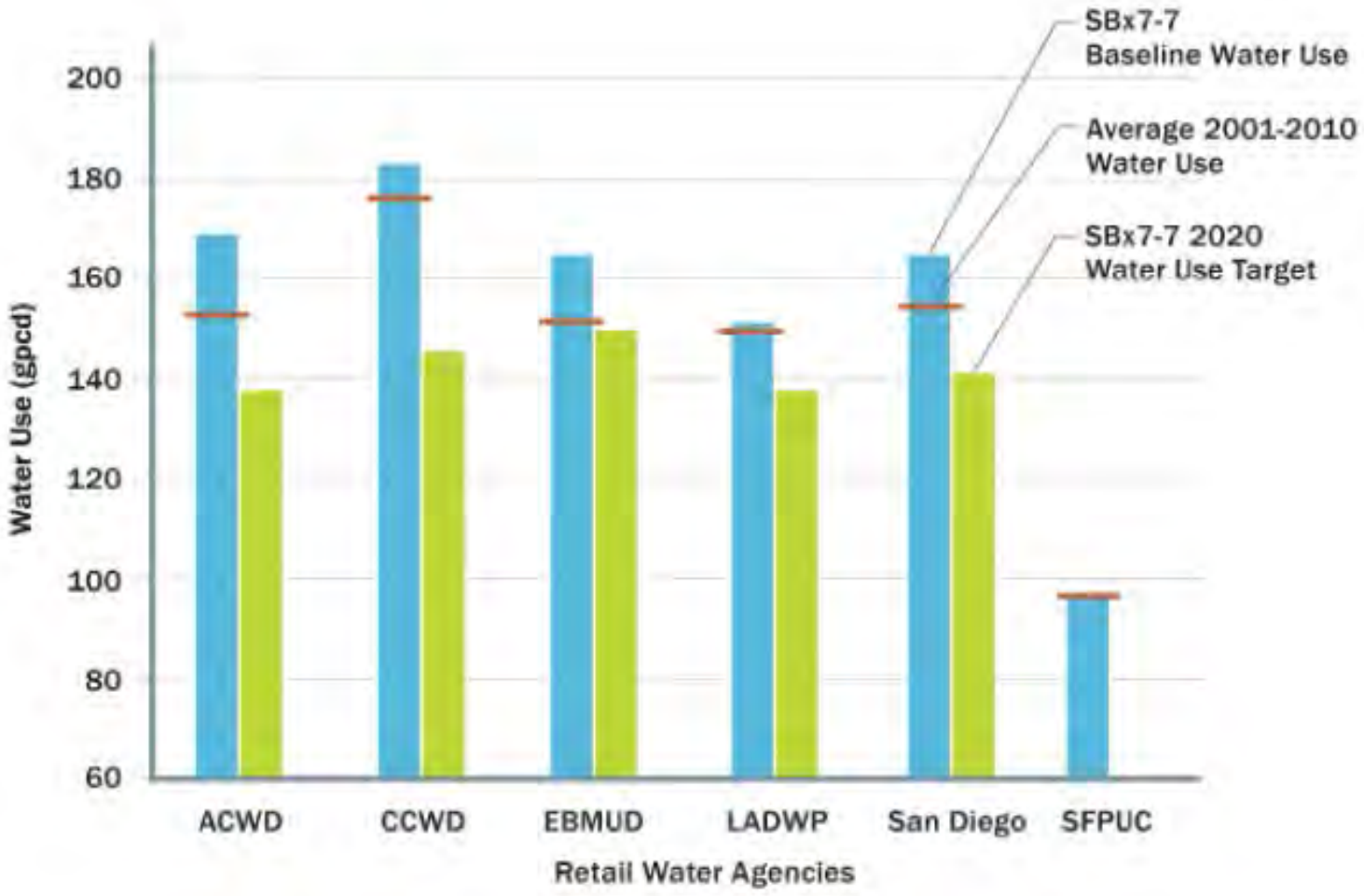
Potential Supply Shortfall - Total

• Regulatory	7.4 mgd
• Future Wholesale Customer demands	4.3 mgd
• San Jose and Santa Clara guarantee	9 mgd
• Reducing drought supply restrictions	???
• TOTAL	20.7 mgd +

Discussion

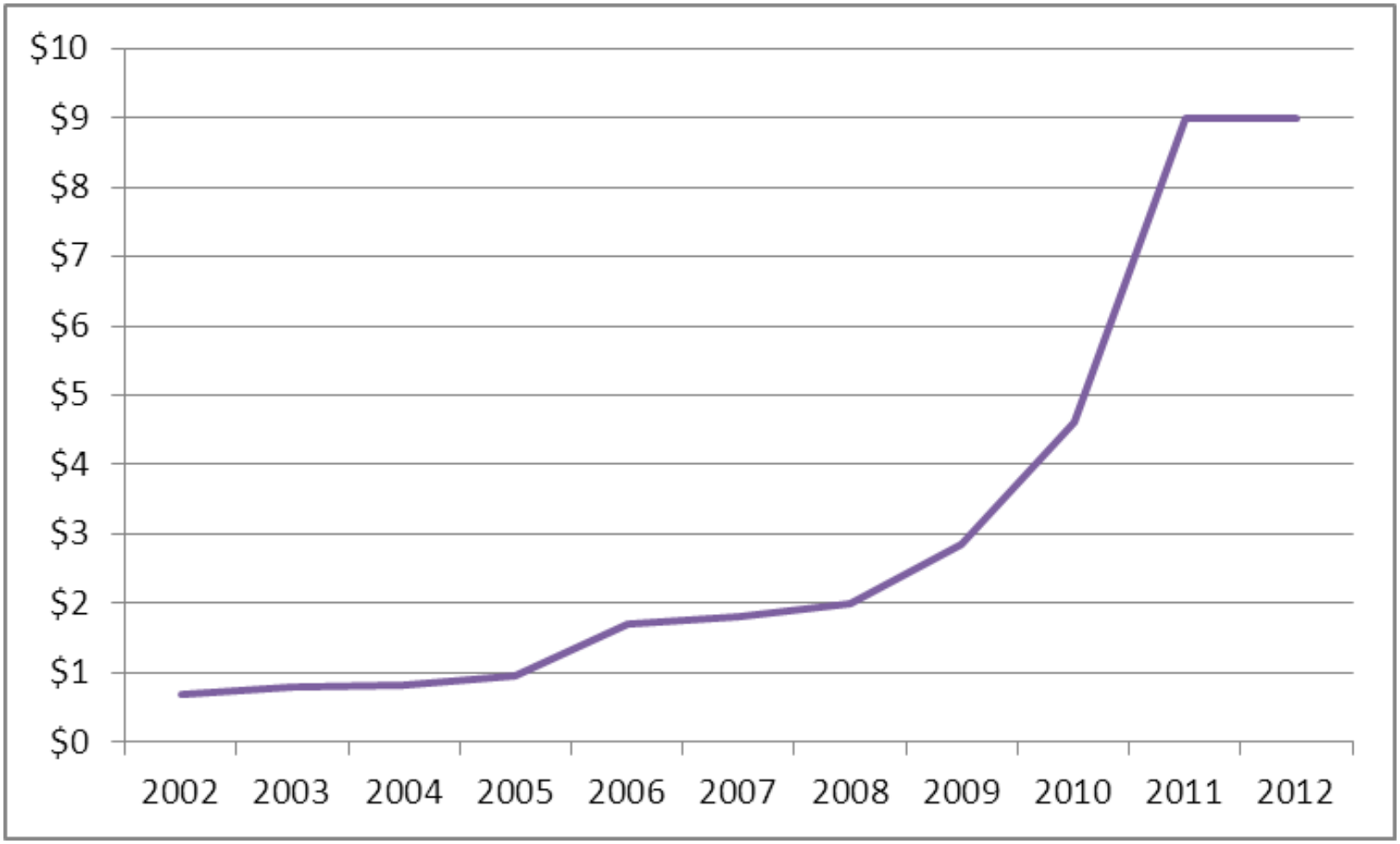
Ongoing Water Conservation Efforts

Current SFPUC per capita use is low compared to peers



**Source of figure: CUWA Water Supply Reliability Report*

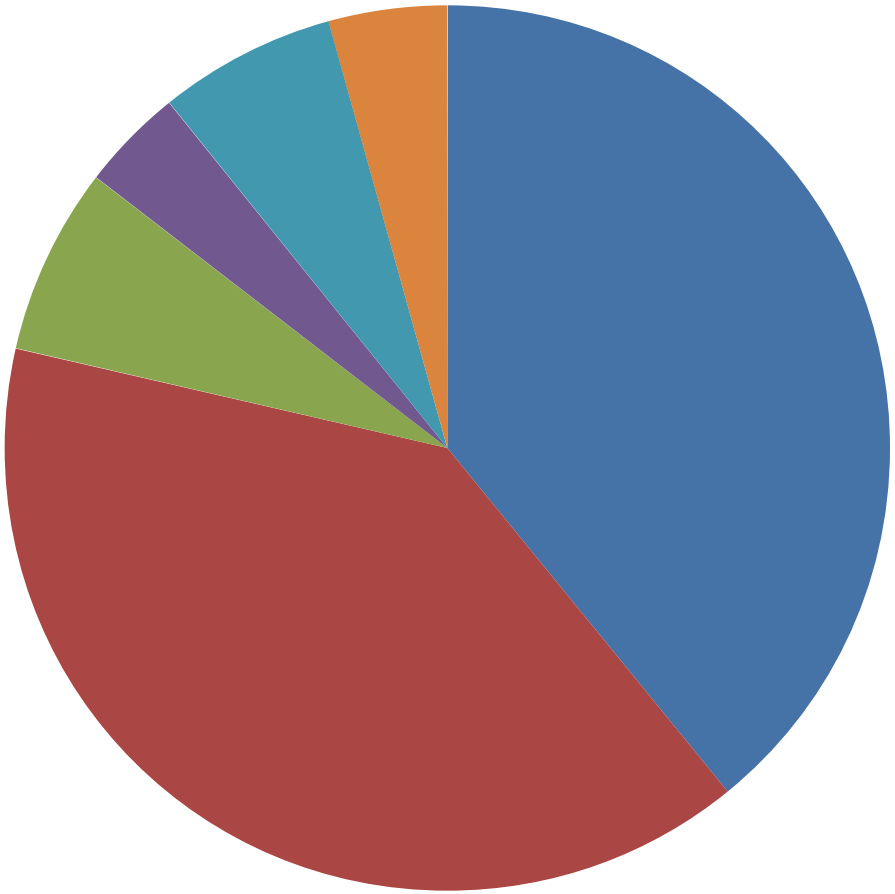
Conservation Budget Since 2002 (in $M)



Cumulative Budget Spent since 1990: Approximately $40 M

How will SFPUC achieve active conservation savings?

- Clothes Washer Incentives
- Toilet Incentives
- Other Fixtures (showerheads, urinals, pre-rinse spray valves)
- Large Nonresidential Indoor Retrofits
- Water Audits (Indoor and outdoor for all customer types)
- Large Landscape Retrofits



% of Conservation Savings by Program

Conservation Success By-the-Numbers

- SFPUC achieved ≈1.8 mgd in savings from active conservation from 2005 to 2011
- Between FY 07-08 to FY 10-11:
  - Distributed over 145,000 water-saving devices
  - Provided incentives to replace over 18,000 clothes washers, 17,000 toilets and 400 urinals
  - Conducted over 8,000 water-wise evaluations
  - Provided over 200 presentations and field trips to local schools
  - Audited and/or provided grant assistance to 15 large landscapes
  - Launched 9 new programs and added 9 staff
  - Implemented three local conservation ordinances

What else could we be doing, and why aren't we doing it?

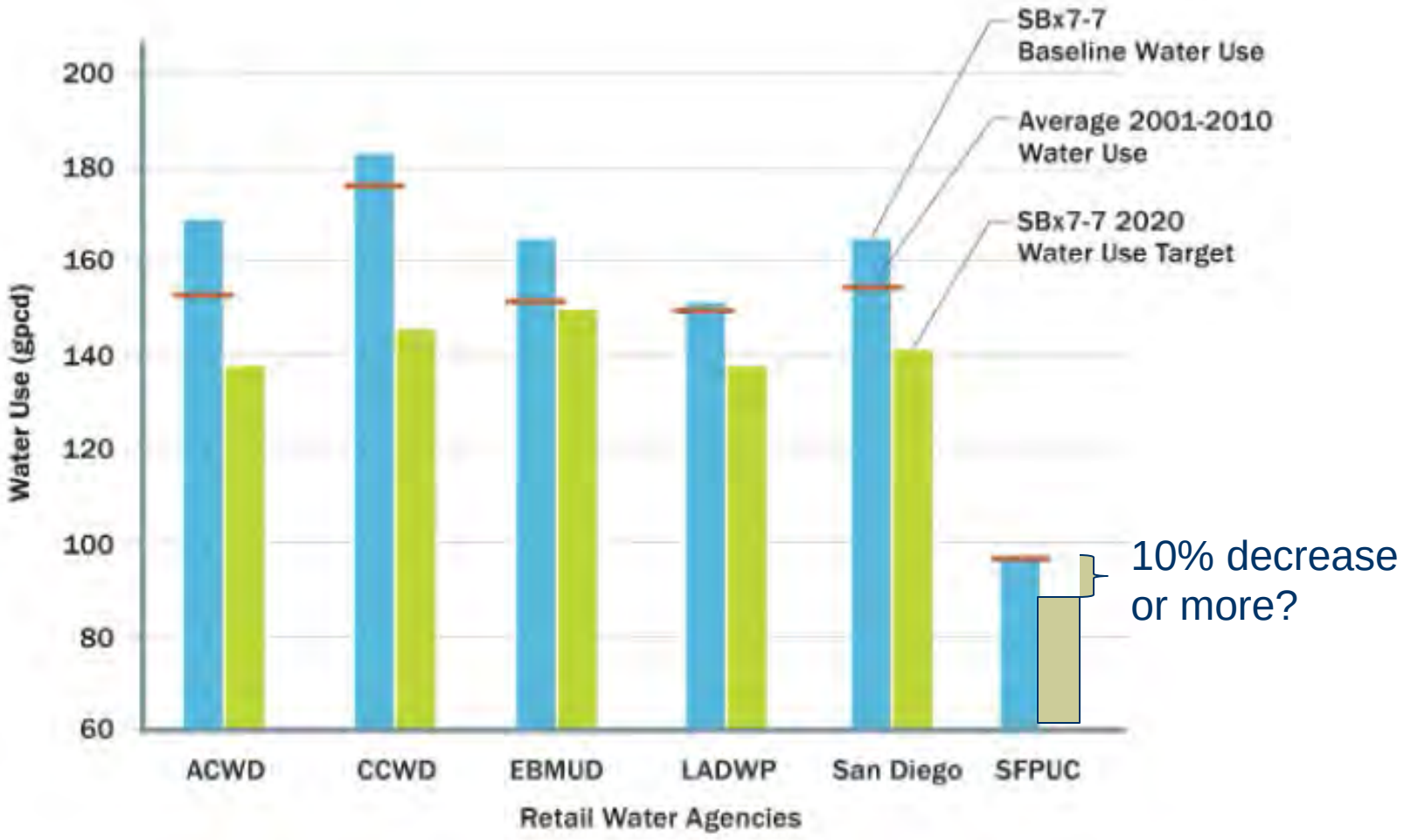
Possible Conservation Action	Reason for not implementing
Toilet retrofit kits	We recommend the entire toilet be replaced
Rebates for replacing dishwashers	Low water savings potential
Rebates for replacing toilets with toilets that flush at 1.6 gpf.	Now we only incentivize replacement with 1.28 gpf. (complies with state code)
Artificial turf incentives	Being implemented by Rec & Park
Water broom incentives	Low interest by City departments and low functionality for cleaning SF streets
Further incentivizing leak repair	May be possible with improved data from AMI, but difficult to know
Small landscape retrofit incentives	Not cost effective
Future technology	As yet unknown; still in future

Focus of Conservation Programs

- We've evaluated over 50 conservation programs covering the spectrum of available technologies
- We've evaluated & ruled out a number of possible measures due to low water savings, high cost or ineffectiveness in our market
- Our current mix captures the bulk of feasible, cost-effective water savings opportunities in San Francisco

FIXTURES

Additional Savings from Conservation through 2020?

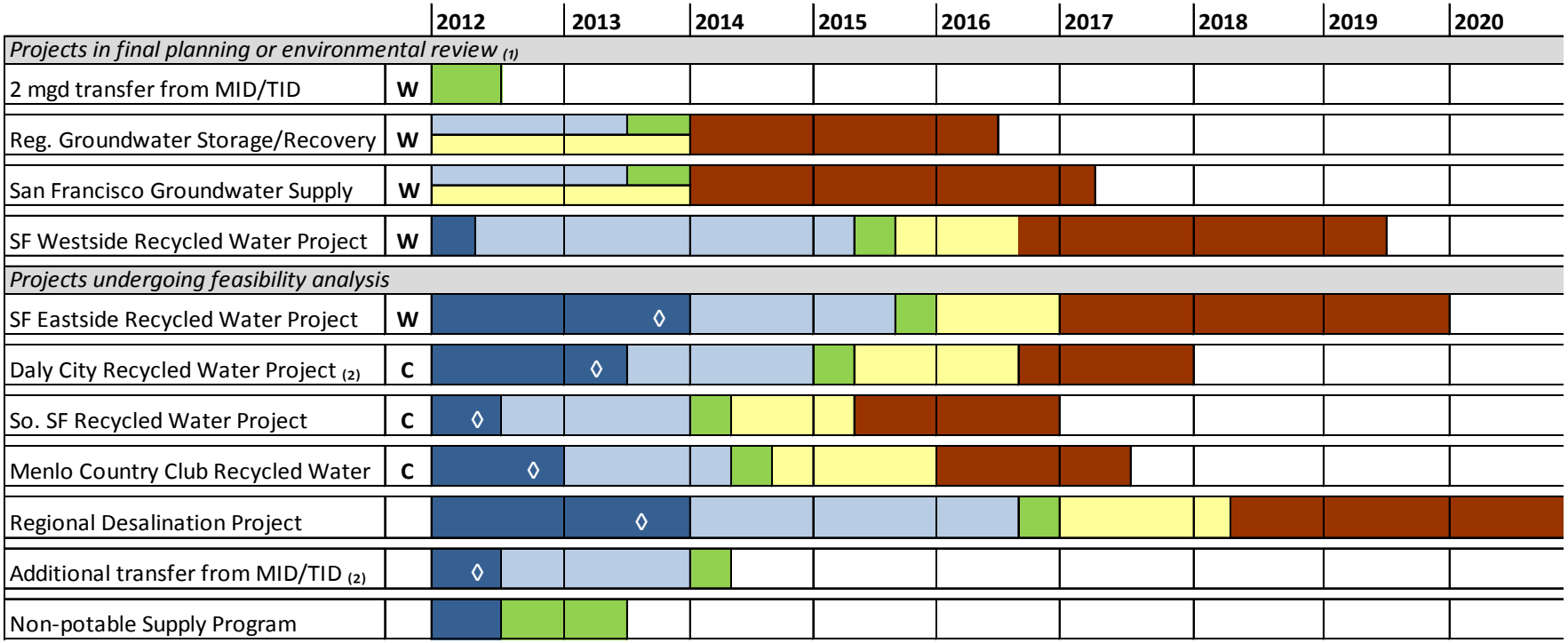


**Source of figure: CUWA Water Supply Reliability Report*

Discussion

Water Supply Projects

Water Supply Project Timeline



(1) The decision to begin environmental review has already been made for the four projects in this category.

(2) Schedules for a potential transfer from MID/TID and the proposed Daly City Recycled Water Project are not finalized and depend on funding, Commission and partner approval, and other factors.

Key:

◊ = Approval to commence environmental review, including sufficient design work to complete environmental review

W = Included in WSIP/PEIR

C = Included in the FY2012/13 Water CIP Budget

Feasibility analysis / Preliminary planning

Environmental review

Project approval

Design

Construction

MGD Supplied Per Project

Water Supply Projects in Implementation	
Sharp Park Recycled Water	0.08 mgd
Harding Park Recycled Water	0.23 mgd
Water conservation	5 mgd by 2018
Water Supply Projects in Planning and Environmental Review	
2 mgd Transfer from MID/TID	2 mgd
Regional Groundwater Storage & Recovery	7.2 mgd
San Francisco Groundwater Supply	4 mgd
SF Westside Recycled Water Project	2 mgd
Water Supply Projects Undergoing Feasibility Analysis	
SF Eastside Recycled Water Project	2 mgd
Daly City Recycled Water Project	1.3 mgd
So. SF Recycled Water Project	0.6 mgd
Menlo Country Club Recycled Water	0.22 mgd
Regional Desalination Project	9 mgd
Additional transfer from MID/TID	Up to 21 mgd

WSIP Water Supply Projects

- Regional Water System Dry Year Supply
  - 2 MGD transfer from Modesto Irrigation District
    - MID Board to consider on July 24
  - Regional Groundwater Storage and Recovery Project
    - Draft EIR expected February 2013
- Retail Supply
  - San Francisco Groundwater Supply
    - Draft EIR expected December 2012
  - Westside Recycled Water Project
    - Proposal to accelerate design
  - Eastside Recycled Water Project
    - Evaluating alternative plant sites

2 MGD Transfer From MID

- Element of the WSIP Phased Variant
- Window of opportunity with MID
- Need exists and will continue to exist
- Best opportunity currently available

Recycled Water Projects

- Westside
  - Advantages of accelerating design
    - Cost savings because “Time is money”
    - Siting is nailed down
- Eastside
  - Advantages of accelerating planning
    - Dual plumbing ordinance
    - Synergies with SSIP and other efforts

Additional Water Supply Options

- More Conservation
- Daly City Recycled Water
- South San Francisco Recycled Water (retail)
  - MOU approved in May
- Menlo Country Club Recycled Water (retail)
- Regional Desalination
  - Conducting outreach and additional studies
- Additional Transfer from MID
  - Based on improved irrigation system efficiency
  - MID Board to consider authorization of analysis on July 24
- Nonpotable Supply Program (retail)
- Utilization of San Francisco's retail allocation

Rate Structure Based in Part on ISGs/Allocations: Worth Exploring?

- Could improve revenue stability
- Could provide basis for valuing ISGs
- Could promote inter-Customer water market, including San Francisco
- Could have unintended consequences, but is worth exploring with BAWSCA and the Wholesale Customers

Discussion

Pool of Project TBL Evaluation Criteria

Financial
Life Cycle Costs
Initial Costs

Environmental
Climate
Habitat
Water Recovery
Natural Resource Use for Construction Materials

Social
System Resilience
Ratepayer Costs
Agency Coordination
Odor
Public Safety
Recreation/ Community Facilities
Jobs
Archaeological and Historic Resources
Noise

Overlay Factor: Public Support for the Project

Criteria Considered for Water Supply Projects

Financial	Environmental	Social
Life Cycle Costs	Climate	System Resilience
Initial Costs	Habitat	Ratepayer Costs
	Water Recovery	Agency Coordination
	Natural Resource Use for Construction Materials	Odor
		Public Safety
		Recreation/ Community Facilities
		Jobs
		Archaeological and Historic Resources
		Noise

Overlay Factor: Public Support for the Project

Scoring Levels

++ More Favorable

+ Moderately Favorable

Neutral

— Less Favorable

Life Cycle Costs

	SF Westside Recycled Water Project	Regional Groundwater Storage & Recovery	San Francisco Groundwater Supply	2 mgd transfer from MID/TID	SF Eastside Recycled Water Project	Daly City Recycled Water Project	So. SF Recycled Water Project	Menlo Country Club Recycled Water	Regional Desalination Project
Life Cycle Costs	—	+	++	++	Not yet known	+	Not yet known	+	++

Life cycle costs translated to cost per acre foot (based on 2018 dollars):

- More favorable: $0 - $3000 (less than current retail price)
- Moderately favorable: $3001 - $4500 (up to 125% of current retail price)
- Neutral: $4501 - $6000
- Less favorable: $6001 and up

Climate / Energy

	SF Westside Recycled Water Project	Regional Groundwater Storage & Recovery	San Francisco Groundwater Supply	2 mgd transfer from MID/TID	SF Eastside Recycled Water Project	Daly City Recycled Water Project	So. SF Recycled Water Project	Menlo Country Club Recycled Water	Regional Desalination Project
Energy	○	+	○	++	Not yet known	Not yet known	Not yet known	Not yet known	−

For purposes of comparison of the water supply projects, the primary climate concern is energy use.

- More favorable: Uses the same energy as SFPUC's RWS
- Moderately favorable: Uses between 0.5 and 1.75 MWh/MG
- Neutral: Uses between 1.75 and 3.75 MWh/MG
- Less favorable: Uses more than 3.75 MWh/MG

Energy Consumption

Project	Energy (MWh/MG)
Westside recycled Water Project (raw water delivery & treatment) [1]	3.6
San Francisco Groundwater Supply Project[2]	3.4
Bay Area Regional Desalination (raw water delivery and treatment) [3]	4.7
State Water Project (raw water delivery and treatment) [4]	9.8 – 12.2
SFPUC Regional Water System (raw water delivery and treatment)	0.5
Net hydroelectric energy production from current water deliveries (for second half of 2011)	(15)
Net State Water Project energy use (for average year)	12

Further Triple Bottom Line Analysis

- Coordination with SSIP has been productive
- As projects come forward for consideration, more complete analyses will be available

Questions to Consider Today

- Are we proceeding appropriately to develop Regional Water System dry year supplies?
- Should we accelerate planning and design for the recycled water projects?
- Would it be useful to explore a rate structure that is based in part on Individual Supply Guarantees or allocations , or accounts for other Water Supply Agreement considerations?
- Are we on the right track regarding Triple Bottom Line analysis?
- Should we continue to work on all of the projects?

2005-23

Final Report

THE COST AND EFFECTIVENESS OF STORMWATER MANAGEMENT PRACTICES

Research

Technical Report Documentation Page

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16. Abstract (Limit: 200 words)

Stormwater management practices for treating urban rainwater runoff were evaluated for cost and effectiveness in removing suspended sediments and phosphorus. Construction and annual operating and maintenance cost data was collected and analyzed for dry detention basins, wet basins, sand filters, constructed wetlands, bioretention filters, infiltration trenches, and swales using literature that reported on existing SMP sites across the United States. After statistical analysis on historical values of inflation and bond yields, the annual operating and maintenance costs were converted to a present worth based on a 20-year life and added to the construction cost. The total present cost of each SMP with the 67% confidence interval was reported as a function of the water quality design volume or, in the case of swales as a function of the swale top width, again with a 67% confidence interval. Finally, the mass of total suspended solids and total phosphorus removed over the 20-year life was estimated as a function of the water quality volume. The results can be used by planners and designers to estimate both the total cost of installing a stormwater management practice at a given site and the corresponding total suspended solids and phosphorus removal.

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THE COST AND EFFECTIVENESS OF STORMWATER MANAGEMENT PRACTICES

Final Report

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Executive Summary

Historical data has been used to compare the cost and effectiveness of several common stormwater management practices (SMP) including dry detention basins, wet detention basins, constructed wetlands, infiltration trenches, bioinfiltration filters, and sand filters. Data on construction costs and annual operating and maintenance costs have been combined to estimate the total present cost (TPC) of the SMPs in 2005 dollars as a function of water quality volume (WQV) or, in the case of swales, the swale top width. The TPC is based on 20 years of annual O&M costs which have been converted to a present value based on historical values of inflation and municipal bond yield rates.

The effectiveness of the SMPs as a function of WQV have been assessed by estimating the total amount of total suspended solids (TSS) and phosphorus (P) removed over a 20-year time period. Both the cost (*i.e.* TPC) and effectiveness (*i.e.* amount of TSS and P removed) estimates are presented with 67% confidence intervals. Also, in order to help the user incorporate land costs, typical land-area requirements for each SMP as a function of watershed area are presented.

For the six SMPs investigated, results show that, ignoring land costs, constructed wetlands are the least expensive to construct and maintain. However, since wetlands typically require more land area to be effective, land acquisition costs may result in wetlands being significantly more expensive then other SMPs that require less area. Also, the long-term capability of wetlands to remove phosphorus has been questioned by other authors.

The results presented in this report can be used by decision makers as a preliminary tool to compare SMPs in the categories of cost and impact on water quality. However, due to the wide

scatter in the original data, the confidence intervals associated with the estimates of TPC and amount of TSS and P removed also exhibit a relatively wide range.

Even with the scatter, the results can be used as a preliminary tool to compare SMPs which are under consideration for a given project.

For a more complete estimate of SMP cost and effectiveness, a more rigorous and detailed comparison which involves, as a minimum, a preliminary SMP design, should be performed.

Introduction

With the implementation of the United States Environmental Protection Agency's (USEPA) National Pollution Discharge Elimination Systems (NPDES) Phase I and II programs, strong interest has developed in the area of water quality treatment of stormwater runoff. While little is known about the cost effectiveness of available stormwater treatment technologies, called Stormwater Management Practices (SMPs) in this report, municipal agencies are now, or soon will be, required to meet certain pollutant removal criteria based on the Phase I and II regulations.

Of primary concern are nutrients such as phosphorus (P) and nitrogen (N), which are just one of the pollutant categories being targeted for removal from stormwater runoff. Excess nutrients can initiate large algae blooms that generate negative aesthetic and eutrophic conditions in receiving lakes and rivers (USEPA, 1999a). In inland water bodies phosphorus is typically the limiting nutrient (Schindler, 1977) and can be contributed to stormwater from various sources such as fertilizers, leaves, grass clippings, etc. (USEPA, 1999a). Another pollutant of primary concern in stormwater is dirt, sand, and other solid particles which are commonly quantified by measuring the Total Suspended Solids (TSS) of a water sample. TSS can severely and negatively impact an aquatic environment. The solids increase turbidity, inhibit plant growth and diversity, affect river biota and reduce the number of aquatic species (Shammaa *et al*., 2002). Also, organic suspended solids can be biologically degraded by microorganisms in a process which consumes oxygen, which is important to the aquatic biota.

With total suspended solids and phosphorus a primary concern of most stormwater management plans, and with little known about the cost effectiveness of available stormwater treatment options, this report seeks to fill a need by developing both a cost-comparison tool

(based on total construction cost not including land acquisition) and an effectiveness comparison tool (based on pounds of total suspended solids and phosphorus removed) for common SMPs. The method is based on published, credible information of existing SMPs relating to their construction and annual operating and maintenance (O&M) costs and their ability to remove TSS and P from stormwater runoff. The goal of the report is to provide planners and engineers with a pre-feasibility tool that can be used to compare the costs and impact on water quality of available SMPs.

Literature Review

Phosphorus can occur in both dissolved and particulate form in stormwater runoff. The dissolved fraction is often in the form of phosphates (PO_4^{3-}) (Jenkins *et al*., 1971) which undergo hydrolysis in water to form H_3PO_4 (pH<2.16), $H_2PO_4^-$ (2.16 < pH < 7.20), HPO_4^{-2} (7.20 < pH < 12.35), or PO_4^{-3} (12.35 < pH). Dissolved phosphorus is usually and somewhat arbitrarily defined as that portion which can pass through a 0.45 micron filter. Solid or particulate phosphorus, defined as that portion which is retained by a 0.45 micron filter, can originate from grass clippings, leaves, animal waste or any other solid organic matter and may also be included as part of the TSS.

The Water Environment Federation in conjunction with the American Society of Civil Engineers (WEF and ASCE, 1998) site a USEPA (1983) publication that reports the expected event mean concentrations for total and dissolved phosphorus in urban runoff as 0.33 mg/L and 0.12 mg/L, respectively. A more recent report (Brown *et al.*, 2003) based upon three different studies that incorporated data from approximately 500, 107, and more than 3,783 storm events, respectively, claims that a total phosphorus concentration of 0.3 mg/L is adequate to describe

both new and old urban development stormwater runoff. Brezonik and Stadelmann (2002) investigated urban runoff in the Twin Cities Metropolitan Area (Minneapolis and St. Paul, MN) and found that event mean concentrations for total and dissolved phosphorus varied as a function of climatic season as follows: 1.37 and 0.37 mg/L for winter, 0.85 and 0.53 mg/L for spring, 0.59 and 0.21 mg/L for summer, and 0.55 and 0.21 mg/L for fall. It must be noted that the values used to calculate average values often varied widely. Based on the wide scatter of data it can be concluded that phosphorus concentrations may vary widely both from site to site and at one location from one storm event to another.

The literature contains little information regarding typical size distributions of solids in stormwater runoff. However, one report published by California State University Sacramento (2002) reported size distributions recorded over a two-year span for highway runoff in the Lake Tahoe basin. The runoff analyzed upstream of any treatment system was reported to have the grain size distribution shown in Table 1 and Figure 1 (Note: Mass finer should decrease with decreasing grain size thus there appears to be a mistake in the values reported for grain sizes of 0.0328 and 0.0196 mm).

Ghani *et al.* (2000) also report grain size distributions of sediment in urban runoff for five cities in Malaysia with average d_{50} values (mm) of 0.6, 0.9, 0.8, 0.6, and 0.7. These values are similar to the d_{50} observed in the Lake Tahoe basin which, by interpolating values in Table 1, can be estimated to be 0.67 mm.

Grain Size (mm)	Mass Finer (%)	Grain Size (mm)	Mass Finer (%)
12.7	97.70	0.15	10.22
9.525	97.33	0.075	5.16
4.75	95.49	0.0716	0.80
2.36	91.25	0.051	0.73
2	84.12	0.0328	1.23
1.18	74.23	0.0196	1.06
0.85	56.84	0.0141	0.53
0.6	47.58	0.0102	0.45
0.425	30.78	0.0055	0.33
0.3	21.24	0.0024	0.20

Table 1. Grain size distribution of highway stormwater runoff in Lake Tahoe Basin.

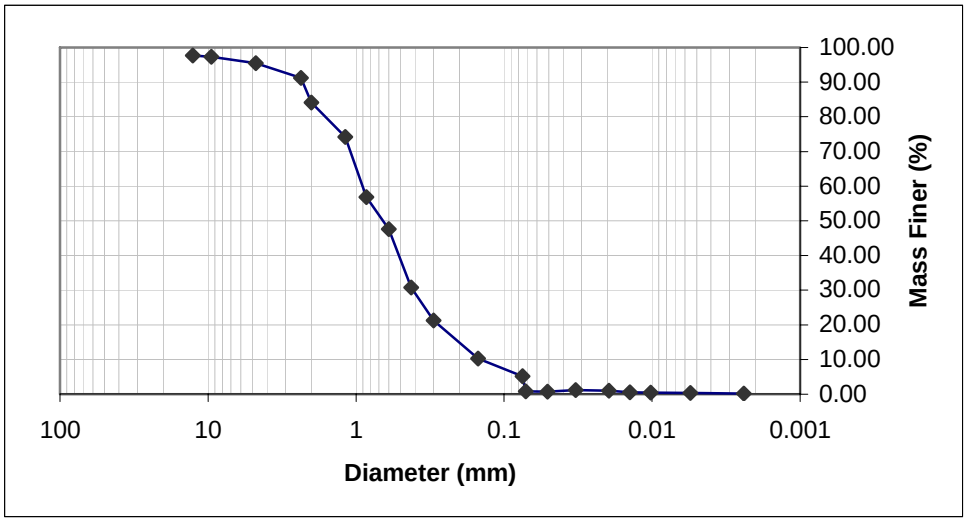

Figure 1. Grain size distribution of highway stormwater runoff in Lake Tahoe basin.

Removal of TSS and phosphorus from water may be achieved by a handful of different mechanisms. Much of the particulate or solid phosphorus can be removed via settling or mechanical filtration such as that which occurs in sand filters and when stormwater flows through adequately spaced and selected vegetation. As with particulate phosphorus, TSS levels may be reduced by settling and/or filtration.

To remove dissolved phosphorus from stormwater, the phosphorus must be converted, by means of a chemical reaction or adsorption, to a solid phase and removed as particulate (Jenkins *et al*., 1971). In wastewater treatment applications, where ambient conditions can be more readily controlled, bacteria have been employed to convert dissolved phosphorus to the

particulate phase. While the use of bacteria in stormwater treatment may be difficult, the use of wetland plants has rapidly become a commonly used process to remove both particulate and dissolved phosphorus. The plants filter TSS and particulate phosphorus out of the water while their roots absorb dissolved phosphorus. Both forms of phosphorus eventually end up in the sediments or plant matter. Once the plants have reached their capacity with regards to phosphorus, the wetland needs to be rehabilitated (typically dredged) in order to prevent the system from becoming a phosphorus source.

In an attempt to keep costs low, current SMPs typically do not include the construction of a treatment facility or a mechanical treatment process such as is commonly found in wastewater treatment plants. For example, some of today's most common SMPs include dry detention basins, wet/retention basins, constructed wetlands, infiltration practices, sand filters, grassed/vegetative swales, and filter strips, all of which will be defined and discussed below. Alternative options for low-cost solutions to pollutant removal may involve slight alterations to these common techniques to improve water quality treatment without significantly increasing construction or maintenance costs. For example, additional media such as limestone or steel wool has been added to sand filters to enhance dissolved phosphorus removal by precipitation and/or adsorption.

A report by Schueler *et al*. (1992) which summarizes studies that have determined removal efficiencies for several stormwater management practices and pollutants of concern is included in Appendix A. This collection illustrates the wide variability in pollutant removal effectiveness typically observed with SMPs.

The USEPA (1999) reported phosphorus removal efficiencies for several stormwater management practices as shown in Table 2. Also included are the minima and maxima data

related to each median value, illustrating the range with which phosphorus removal efficiencies have been reported. In fact, every median reported came from a data set that included negative removal efficiencies indicative of phosphorus contributions to the effluent. Some of the most common SMPs, including those of Table 2, are explained in more detail below.

TYPE	Typical Phosphorus Removal (%)[1]	Median Removal Efficiency (%)			No. of Observations (respectively)
		Total	Dissolved	Ortho-	
Dry Detention Basin	15 - 45				
Wet/Retention Basins	30 - 65	46[3]	34[3]		44, 20
Constructed Wetlands	15 - 45	46[2]	23[2]	28[2]	37, 12, 7
Infiltration Basins	50 - 80	65[3]			5
Infiltration Trenches/Dry Wells	15 - 45				
Porous Pavements	30 - 65				
Grassed Swales	15 - 45				
Vegetated Filter Strips	50 - 80	15[3]	11[3]		18, 8
Surface Sand Filters	50 - 80	45[3]	-31[3]		15, 2
Other Media Filters	< 30				

Table 2. Expected phosphorus removal.

Sources: [1]modified from USEPA (1993), [2]Strecker (1992), [3]Brown and Schueler (1997)

To aid in evaluating the efficiency of stormwater management practices, the American Society of Civil Engineers (ASCE) and the USEPA have developed a website, www.bmpdatabase.org, which contains data regarding SMPs throughout the country. A team of stormwater experts have evaluated over 800 bibliographic sources and posted credible information from full and pilot scale and monitoring studies regarding the efficiency of scores of SMPs. They continue to review submissions and recent studies for incorporation into the database to provide the most accurate, relevant, and current information.

To better understand the cost-effectiveness of today's SMPs and to enable planners and engineers to make wise choices with limited resources, these SMPs must be reviewed for both

their cost and contaminant removal potential and then compared amongst each other. While the final objective of this report is to provide such a comparison, a review and discussion of some common SMPs is presented below.

Dry Detention Basins

Definition: "Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems do not retain a significant permanent pool of water between rainfall events." (USEPA, 1999a)

The primary function of dry detention basins is to reduce the risk of flooding by attenuating the peak storm flow rate by temporarily storing the runoff and releasing it through outlet structures. Compared to other SMPs, dry detention basins typically provide less water quality treatment. While properly designed detention basins can remove large solid particles via settling they often do not detain runoff long enough to allow finer particles to be removed. As the detention time of the basin is increased, however, the amount of solids removed will also increase. Also, dry detention basins may require frequent cleaning to reduce re-suspension during subsequent rainfall events (USEPA, 1999a). Of the phosphorus removed by a dry detention pond, most occurs by means of gravity settling of particulate phosphorus in the pond. Thus dry ponds usually remove little, if any, dissolved phosphorus.

Wet/Retention Basins

Definition: "Retention systems capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems therefore maintain a significant permanent pool volume of water between runoff events." (USEPA, 1999a)

Also termed wet ponds in some contexts, these basins are similar to dry detention ponds except the outlet structure is set at a higher elevation to create a permanent pool within the pond. Retention basins utilize gravity settling as the major removal mechanism but nutrient and organic removal can be achieved through aquatic vegetation and microorganism uptake. Figure 2 below shows a cross section of a retention pond illustrating this type of outlet structure.

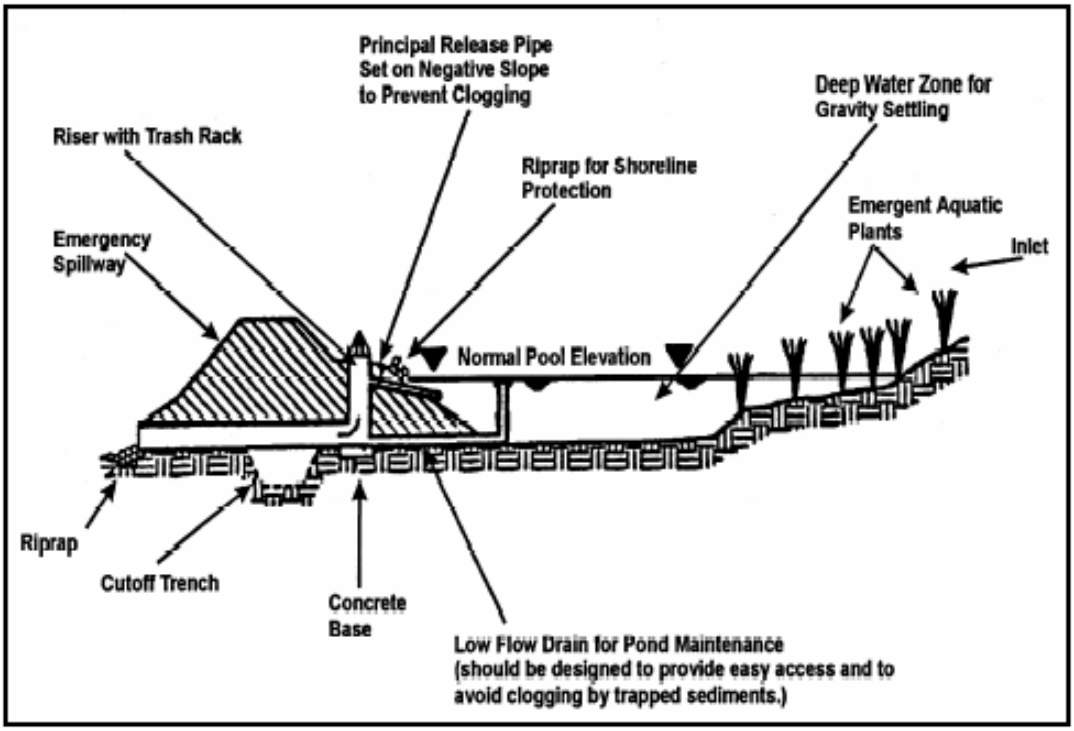

Figure 2. Retention basin cross section.

Source: Barr Engineering Company, 2001.

Limitations of these systems are typically related to retention time. During high flows, or freezing weather (when the permanent pool is frozen or covered with ice) influent runoff can short-circuit through the retention system and reduce the effectiveness of the sedimentation mechanism. Pond characteristics can also affect the removal efficiency. Changes in pH or hardness can alter the solubility of many contaminants and thus release them to the effluent (USEPA, 1999a). Another possible limitation of retention systems is high temperature effluent.

The water in the pond may absorb enough solar energy to significantly increase the temperature of the effluent which may adversely impact fish and other aquatic species in the receiving waters.

Constructed Wetlands

Definition: "Constructed wetland systems are similar to retention and detention systems, except that a major portion of the SMP water surface area (in pond systems) or bottom (in meadow-type systems) contains wetland vegetation. This group also includes wetland channels." (USEPA, 1999a)

Constructed wetlands are similar to dry basins in that they release inflow much more slowly as effluent. They also resemble wet/retention basins in that, although they are shallower, they typically hold a permanent pool of water to maintain wetland vegetation. Whereas dry detention basins are typically designed to release the entire stormwater inflow within 24 to 48 hours, constructed wetlands can take several days or more to release runoff events. Figure 3 shows one potential design of a constructed wetland system, although several configurations and systems are identified as constructed wetlands.

Constructed wetlands allow for more removal mechanisms than detention basins and longer contact times than retention basins; therefore they are capable of removing more pollutants such as nutrients and organics. Unlike dry detention basins, constructed wetlands, if designed properly, do not allow for re-suspension of particles and contaminants. However, a major drawback of constructed wetlands is the large space they require. Constructed wetlands typically require large areas to allow for adequate storage volumes and long flow paths. As a result wetlands are often impractical in urban and suburban areas where land costs are high. Another limitation of constructed wetlands (perhaps retention systems also) is nuisance fowl and insects as wetlands can provide breeding grounds for mosquitoes and other pests.

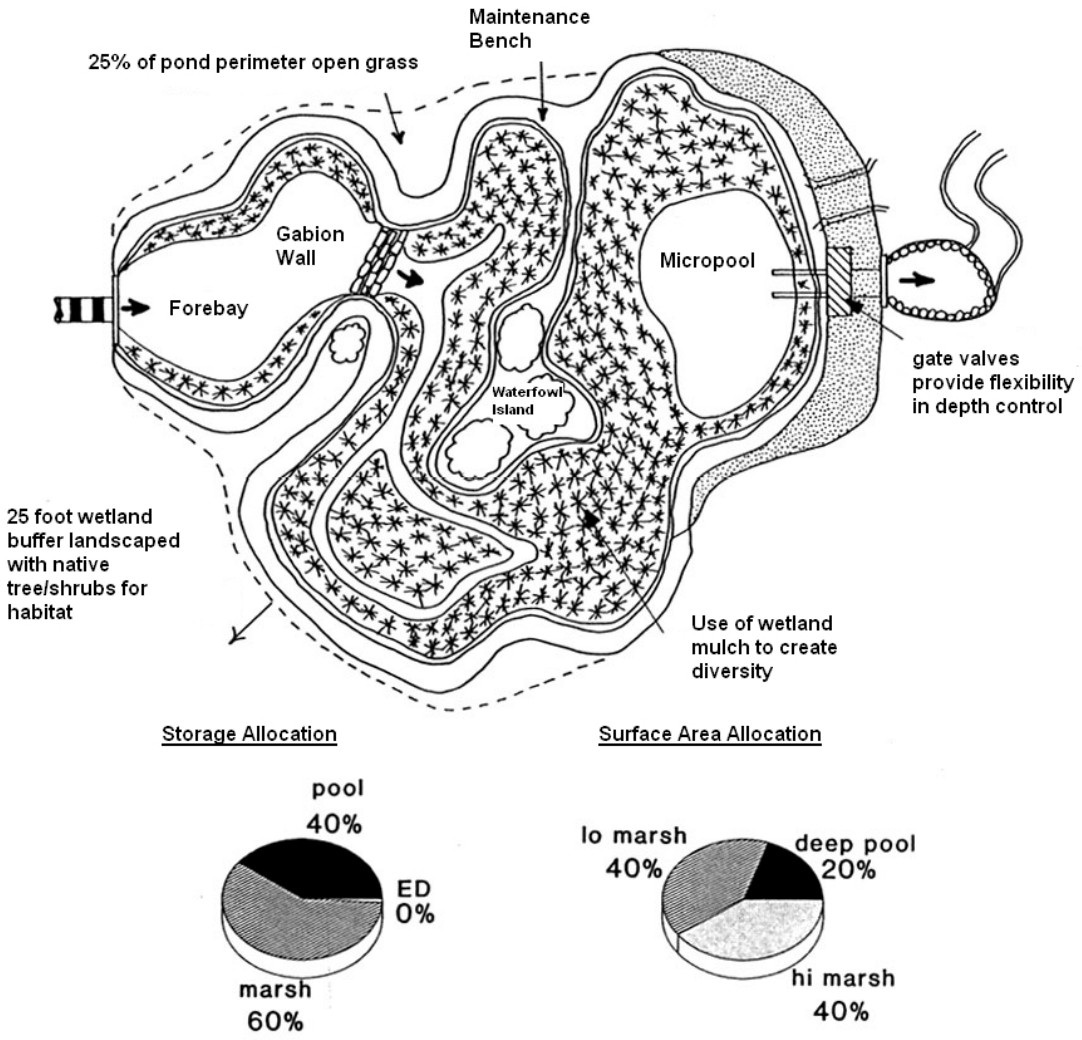

Figure 3. One example of a constructed wetland system.

Source: Barr Engineering Company, 2001.

As with any SMP, constructed wetlands require regular maintenance to remain effective. Faulkner and Richardson (1991) attributed a significant reduction in nutrient removal to the wetland vegetation reaching maximum density. Thus, wetlands plants may have to be harvested to remove overabundant vegetation. Furthermore, overabundant and decaying vegetation can deposit large amounts of soluble and particulate phosphorus into the wetlands system; typically more than the living vegetation can uptake. This can result in an addition of phosphorus to the system. However it is questionable if harvesting plants will adequately remove phosphorus

because in studies where vegetation has been harvested in an attempt to remove phosphorus, only minimal amounts of phosphorus have been recovered (Kadlec and Knight, 1996). These factors may make it difficult for constructed wetlands to be a long-term cost-effective quality control technique.

As with other SMPs, removal efficiencies of TSS and P for constructed wetlands vary widely among monitoring studies. This may be partly attributed to the fact that constructed wetlands can lose their capacity to remove phosphorus over time (Oberts, 1999). Even when phosphorus removal occurs, wetlands usually remove a significantly higher fraction of TSS than phosphorus.

Infiltration Practices

Definition: "Infiltration systems capture a volume of runoff and infiltrate it into the ground" (USEPA, 1999a). Any technique that does not discharge effluent to surface waters, or reduces total discharge, can be categorized as an infiltration practice. Infiltration practices encompass a number of techniques utilized for the treatment of stormwater runoff. Most infiltration practices require some form of pretreatment along with frequent maintenance to prevent blockage and ensure proper operation of the system.

The removal performance of infiltration practices has not been thoroughly reported. The difficulty in determining the quality of the effluent is most likely the chief reason for this lack of information. The data regarding infiltration practices that is available varies drastically due to many factors such as varying soil conditions, influent water quality, depth to water table, degree of pretreatment, maintenance protocols, etc. In areas with highly permeable soil, poor quality effluent may not receive adequate contact time and may be released to aquifers with little or no treatment (USEPA 1999a). It is also very difficult to monitor the effluent of infiltration practices

and confidently report that the findings are solely attributed to the infiltration system itself. Four common infiltration practices are discussed below.

Infiltration Basins

Infiltration basins are similar to detention or retention basins in design and appearance, but do not use an outlet structure to convey effluent, except when the runoff volume is too large and cannot be stored in the basin. These basins release treated water directly to the groundwater after filtration through the basin media which may be comprised of the existing soil and/or a specified filtration media introduced during construction. As mentioned previously, an overflow outlet to a receiving water body is usually installed to discharge the excess water volume of large storms.

Infiltration Trenches

Infiltration trenches can be thought of as constructed channels filled with filtration media or soil which allows for the infiltration of stormwater. These trenches are often placed around the perimeter of parking lots or other structures to treat the runoff generated by the site. With sufficient sizing and properly designed flow regulators (typically check dams), infiltration trenches can infiltrate a large portion of the runoff. Figure 4 shows an example of a typical infiltration trench design.

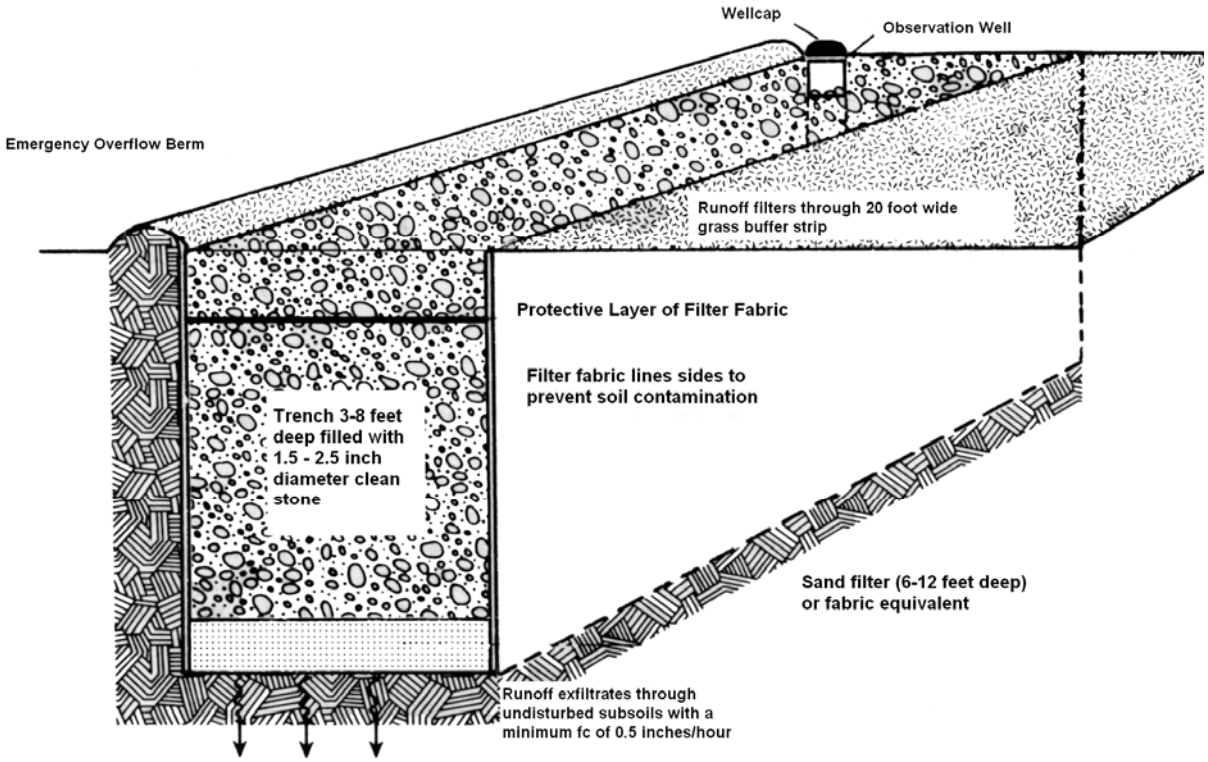

Figure 4. Infiltration trench design.

Source: Barr Engineering Company, 2001.

Bioretention

While not specifically defined by the USEPA, bioretention systems are essentially landscaped depressions to which stormwater runoff is diverted and stored. Once in the depression, the landscaped trees, shrubs, and other vegetation help to remove the water through uptake, while the runoff infiltrates into the soil below. The underlying soil may consist of the original soil or it may be non-native soil such as sand that is installed during construction. Also, depending on the permeability of the underlying soil, a bioretention system may include a perforated underdrain which collects and removes infiltrated water.

Bioretention systems are rapidly gaining in popularity because it is assumed they incorporate the best of vegetative systems and filtration systems. However, their impact on water quality is neither well known nor documented.

Porous Pavements

Definition: "Porous pavement systems consist of permeable pavements or other stabilized surfaces that allow stormwater runoff to infiltrate through the surface and into the groundwater." (USEPA, 1999a)

Porous pavement comes in many forms, some of which are commercially available. Unlike typical asphalt or concrete pavements, porous pavements allow runoff to seep through the pavement surface which reduces the amount of runoff. Porous pavements are categorized as an infiltration practice because they allow runoff to infiltrate into the underlying soil.

Limitations of porous pavements are similar to other infiltration practices and usually involve maintenance and clogging issues. Porous pavements typically contain small voids (or seams between bricks) that can become clogged with sediments. Frequent surface vacuuming or flushing is usually required to keep porous pavements free of sediments and other debris, allowing prompt infiltration of surface runoff.

Water quality treatment of runoff by porous pavements is similar to that of other infiltration practices. The porous pavement itself provides little actual removal while the infiltration of the runoff to receiving groundwater can remove significant amounts of contaminants.

Sand Filtration

Definition: Sand filtration systems utilize granular media to filter stormwater runoff that is collected and discharged as effluent to other treatment systems or directly to receiving waters. Those called "Austin" sand filters appear much like a dry detention basin but include built-in sand filled areas that filter the water and release it to an underdrain. The "Delaware" sand filters are usually smaller, low retention filters that can be placed underground in concrete chambers and are typically designed to capture and treat only the first portion (often called the "first flush") of most runoff events.

Herrera Environmental Consultants (1995) performed a study which showed that sand filters provide little (*i.e.* 20 - 50 % total, 5 - 30 % soluble) capacity for phosphorus removal compared to other SMPs. Anderson *et al*. (1985) monitored several water-quality parameters of more than a dozen intermittent sand filters for the USEPA. Their results also concur that a pure sand-filter media provides "only limited removal of phosphorus" (Anderson, 1985).

Harper and Herr (1993) performed pilot-scale and full-scale monitoring studies in Florida for the removal of several water quality contaminants. It was estimated that typical sand filters remove approximately 40 to 50 percent particulate and total phosphorus, but at most only five percent soluble phosphorus. Another sand filter utilizing a silica sand media exhibited better results for soluble and total phosphorus (35 and 55 percent, respectively) but also contributed particulate phosphorus to the effluent. Harper and Herr acknowledged that the silica sand was considerably coarser than the typical sand media used in their other experiments. Harper and Herr (1993) also conducted experiments comparing sod coverings placed on top of sand filters. Four types of sod were tested in a fashion similar to their previous study. It was determined that

all but one sod covering contributed dissolved phosphorus to the effluent, and removal rates for particulate or total phosphorus were at most 54 percent.

The full scale monitoring performed by Harper and Herr (1993) encompassed many water quality and quantity characteristics of a basin that incorporated both infiltration and filtration practices in what the authors deemed a "Wet detention basin." By performing a mass balance on the pond it was determined that the pond removed roughly 30 to 40 percent of the ortho-phosphorus, 80 percent of the particulate phosphorus, and 60 percent of the total phosphorus over the six month monitoring period. However, the configuration of the pond created a permanent pool of water which allowed for algae growth. Harper and Herr (1993) attribute the high removal rates of ortho-phosphorus to algae uptake by the biomass that developed within the pond and the particulate phosphorus removal to filtration processes.

Bell *et al*. (undated) conducted an assessment of Delaware (also referred to as intermittent) sand filters for their removal efficiencies of several pollutants found in urban stormwater runoff. The study was based on the monitoring of an existing sand filter constructed in Northern Virginia (pg. 5-1) over the course of 20 storm events during the summer of 1994. Among many other pollutants, Bell *et al*. reported removal rates of up to 90 percent for phosphorus (pg. 5-20) and suggested that their results "may not reflect the true potential of intermittent sand filter BMPs." Even though average removals of 60 to 70 percent were reported, an analysis of the filter media revealed constituents of iron (3000 mg/kg), calcium (4-6 mg/kg), and aluminum (2900 mg/kg). Based on evidence provided by Baker *et al*. (1997) and Anderson *et al*. (1985), it can be postulated that these "involuntary" additives affected the removal efficiencies of the sand filters assessed by Bell *et al.* (undated).

Other additives such as peat or compost have been studied for their effectiveness at removing contaminants from stormwater runoff. Farnham and Noonan (1988) conducted a study of peat-sand combination filter efficiencies and reported a direct relationship between phosphorus removal efficiency as percent removal and input phosphorus concentration. Galli (1990) also suggested the use of a peat-sand filter for urbanized runoff treatment and predicted 70 percent removal of total phosphorus for peat species that contain minimal, if any, phosphorus content. The USEPA monitored a filter built to Galli's design specifications and reported instances of both phosphorus removal and phosphorus addition through leaching of the media into the water (USEPA, 1999a, pg. 5-80, 5-81). Other sources (Koerlsman *et al*., 1993) have also reported peat as a source of phosphorus when used as filter media. Stewart (1992) reported that a leaf compost filter can also leach phosphorus into stormwater effluent (Section 3, Table 12).

Vegetated Systems

Definition: "Vegetated systems such as grassed swales and filter strips are designed to convey and treat either shallow flow (swales) or sheet flow (filter strips) runoff." (USEPA, 1999a)

Vegetated systems are a special application of infiltration practices that utilize vegetated cover for two purposes. Vegetated cover on sloped applications slow the overland flow to allow greater opportunity for infiltration into the soil while also providing an opportunity for nutrient uptake through the root system. Vegetated systems suffer the same monitoring difficulties as other infiltration practices, and can be more difficult to maintain. As with infiltration trenches and basins, vegetated systems can become clogged with particles and debris in the absence of proper pretreatment and maintenance. In some cases the sediment deposits can begin to choke

out the vegetated cover and create an erodible surface capable of contributing sediment and other pollutants directly downstream.

Commercial Products

Commercially available products include, but are not limited to, DrainPac™, HydroKleen™, StormTreat™ System, BaySaver™, Stormceptor®, Vortechs ™, Downstream Defender®, Continuous Deflective Separation (CDS®), and StormFilter™. Other commercially available products are available and new products will almost certainly be introduced in the future. Brueske (2000) performed a review of several commercial products, however an unbiased review of the performance of these products can be difficult to obtain and reported removal rates must be used with caution. The relatively small size of the commercial products (as compared to wet basins, wetlands, detention ponds, etc.) may result in their long-term effectiveness being much lower than reported. For example, one product with a reported TSS removal rate of over 80% was field tested and found to remove only about one-third of the sediment load and 19 percent of total phosphorus (Waschbusch, 1999).

Review Summary

The ability of SMPs to remove TSS and phosphorus effectively is dependant on many factors and can occur by various mechanisms. Many researchers have studied SMPs for their capability to remove TSS and phosphorus and some have investigated the mechanisms by which removal occurs. Designers, planners, and other decision makers have little guidance that incorporates this information in combination with SMP costs to aid them in the selection of a SMP. Comparisons of the cost-effectiveness of SMPs are, at best, rare and yet decision makers are continually forced to spend limited resources on technologies whose costs and benefits are

not well understood. A comparison of this nature would enable decision makers to better appropriate limited resources as they strive to meet federal regulations by improving the water quality of stormwater effluent.

This report helps fill a critical knowledge gap by quantitatively comparing the cost and effectiveness of several of the most common SMPs for which reliable data was available. More direct comparisons, however, are needed, including comparisons with and between commercial products.

Cost Estimation

Based on published cost data of actual SMPs a method, which is described below, was developed that will enable designers and planners to make estimates of the Total Present Cost (TPC) of various SMPs if the size of the SMP is known. In this report, the TPC is defined as the present worth of the total construction cost of the project plus the present worth of 20 years of annual operating and maintenance (O&M) costs. The values reported do not include costs of pretreatment units (which may be required), design or engineering fees, permit fees, land costs, or contingencies, etc.

Water Quality Volume

The costs of SMP projects are usually reported along with the corresponding watershed size (usually in acres or square feet) and/or the water quality volume (WQV) for which the SMP was designed. The water quality volume is often defined as the volume (typically in acre-feet or cubic feet) of runoff that the SMP is designed to store and treat.

Claytor and Schueler (1996) calculate the WQV (ft^3) for a particular precipitation amount as:

$$WQV = \left(\frac{43560}{12}\right) * P * R_V * A \quad (1)$$

where: P = Precipitation depth (inches)

R_V = Ratio of runoff to rainfall in the watershed

A = Watershed area (acres), and the constants are conversion factors.

The ratio of runoff to rainfall, R_V, has the most uncertainty of the parameters in Equation 1. For this analysis, a relatively simple relationship was used (Claytor and Schueler, 1996; Young et al., 1996)

$$R_V = 0.05 + 0.009 * (I) \quad (2)$$

where I is the percent (0-100) of the watershed that is impervious. Equation 2 indicates that, for a 100% impervious watershed, 95% of the rainfall becomes runoff.

Total Construction Costs

Values of total construction costs of SMPs throughout the United States were collected from published literature. Although data was collected on many SMP technologies, sufficient data to perform a cost analysis could be found for only dry detention basins, wet/retention basins, constructed wetlands, infiltration trenches, bioinfiltration filters, sand filters, and swales. All data were adjusted to reflect costs in Minnesota by means of 'Regional Cost Adjustment Factors' as reported by the United States Environmental Protection Agency (USEPA, 1999a) and were also adjusted to year 2005 dollars using an annual inflation rate of 3 percent. A value of 3 percent was chosen after an analysis of building cost indexes for the past 11 years (Turner Construction, 2004) revealed that the average annual inflation was 3.26 percent with a range from 0.3 to 5.4 percent.

The cost data which was collected was usually reported in conjunction with the watershed area and/or the water quality volume (WQV) for which the particular SMP was designed. When the cost data was converted to unit construction costs, defined as the total construction cost per acre of watershed or per cubic foot of WQV, the data, in all cases except for bioinfiltration filters, exhibited an Economy of Scale. In other words, when the unit construction cost was plotted versus the size (*i.e.* watershed area or WQV), the unit cost tended to decrease as the size increased. As mentioned, the only exception to this trend was bioinfiltration filters which exhibited a slight increase in unit cost with increasing size.

When comparing unit-cost data based on watershed area and WQV, the data based on WQV was, in most cases, observed to have less scatter as quantified by the standard error of the y-estimate. Thus, in order to provide for as much consistency as possible while minimizing scatter overall, WQV-based unit construction costs were selected for use over watershed area based unit construction costs. However, there was insufficient data to allow for a WQV-based approach when considering grassed/vegetative swales. Furthermore, basing a cost analysis of a swale, which is usually designed for a peak flow rate and could have a wide variety of lengths, on watershed area or WQV does not make intuitive sense. Instead, projected cost estimates per linear foot of swale as a function of geometry were collected and analyzed. Using these data, the cost per linear foot of a grassed/vegetative swale was found to be a function of the top width of the swale. Thus, a second method, used only to estimate the construction costs of swales, was developed and is based on construction cost per linear foot as a function of swale top width.

Figures 5 through 11 below show the unit construction cost data analyzed in graphical form. Also shown is the dashed, best-fit line through the data and the 67% confidence interval as shown by solid lines on either side of the best-fit line. The 67% confidence interval shows the

bounds that will, on average, contain 67% of the data. In other words, one-third of the data could fall outside of the 67% confidence interval. If there is sufficient data (~20) and the distribution is, in this case, truly log-normal, then one-third of the data will fall outside of the 67% confidence interval. The data originating from Brown and Schueler (1997) were read graphically whereas the values from SWRPC (1991), Caltrans (2004), and ASCE (2004) were given in tabular form. The data from Caltrans (2004) was collected by means of a survey distributed by Caltrans to other agencies throughout the country. It should be noted that the total construction costs of SMPs installed by Caltrans were also available but these values were omitted from this

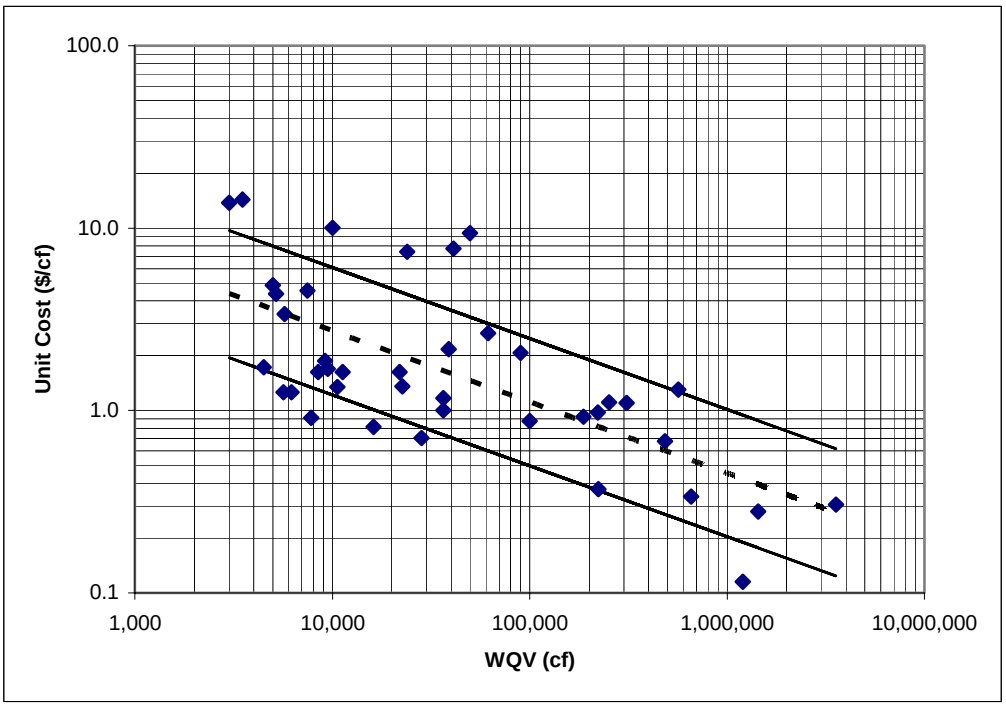

Figure 5. Unit construction costs of dry detention basins.

(Data from Brown and Schueler, 1997; ASCE, 2004; Caltrans, 2004)

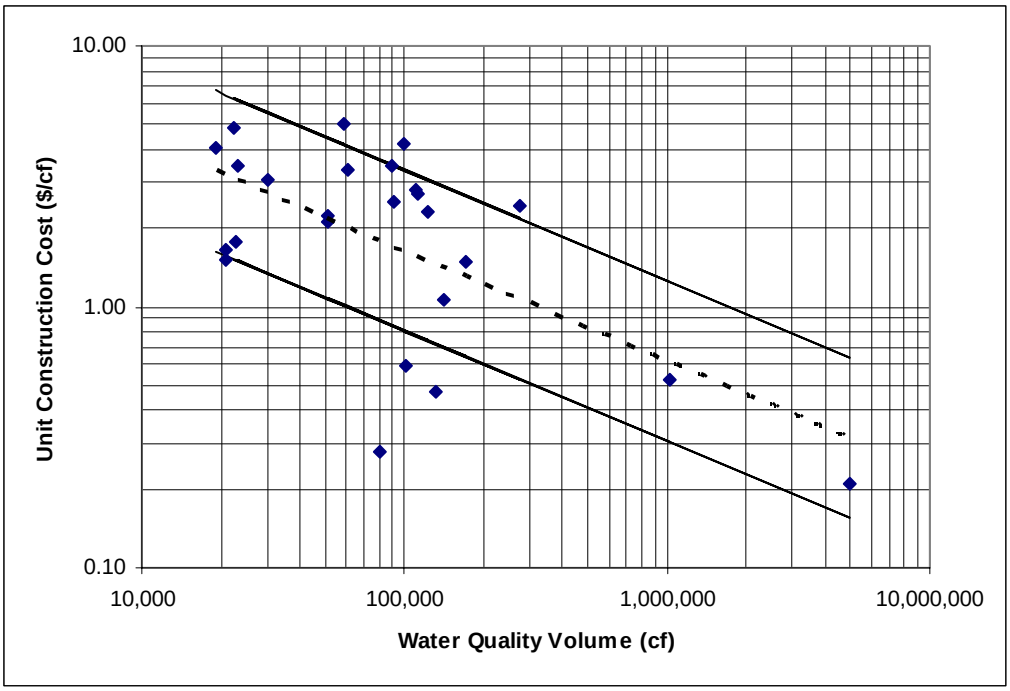

Figure 6. Unit construction costs of wet basins.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

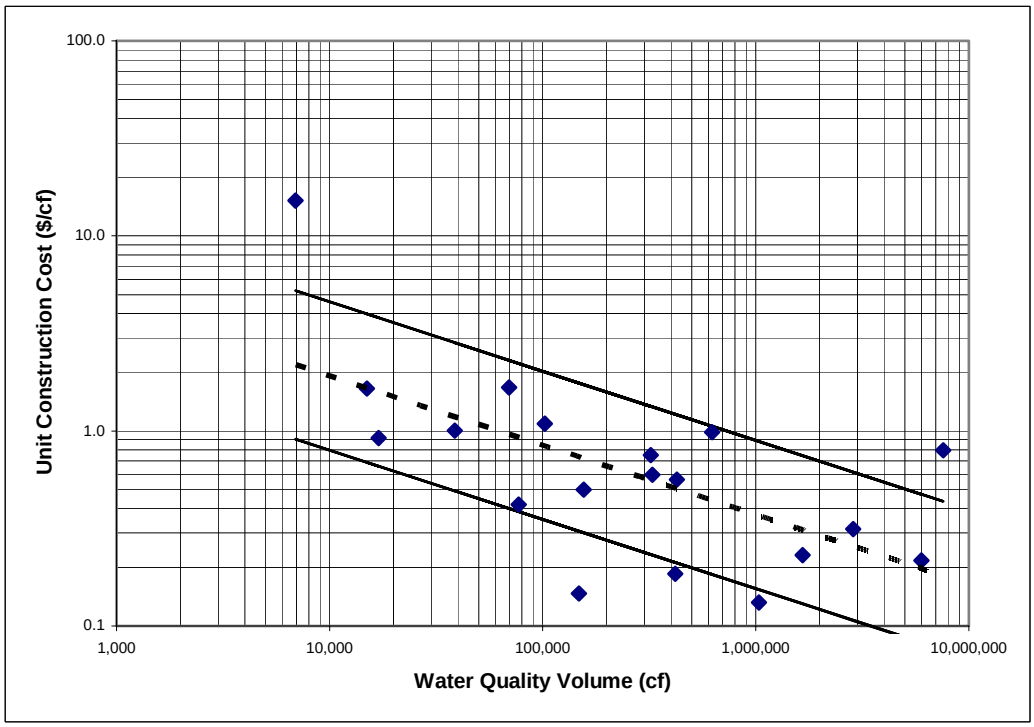

Figure 7. Unit construction costs of constructed wetlands.

(Data from Brown and Schueler, 1997, Caltrans, 2004; ASCE, 2004)

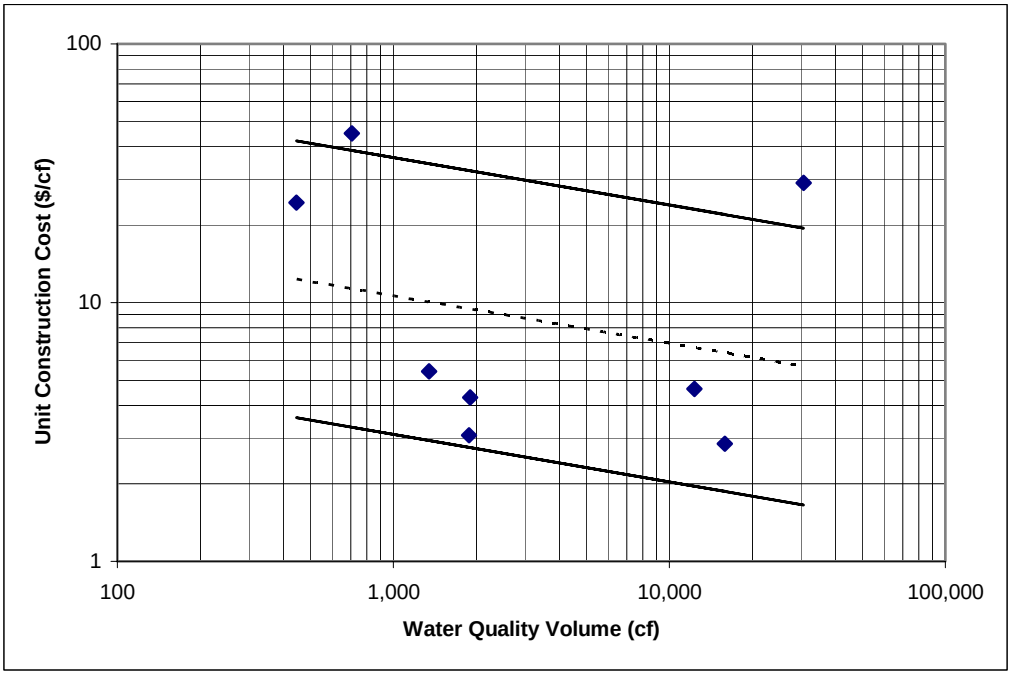

Figure 8. Unit construction costs of infiltration trenches.

(Data from Caltrans, 2004)

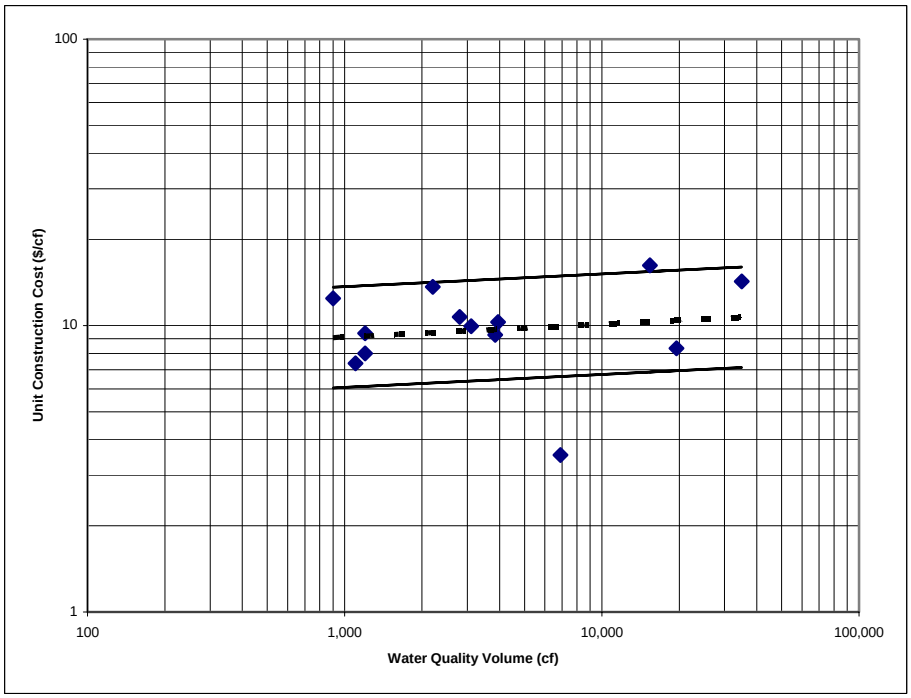

Figure 9. Unit construction costs of bioinfiltration filters.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

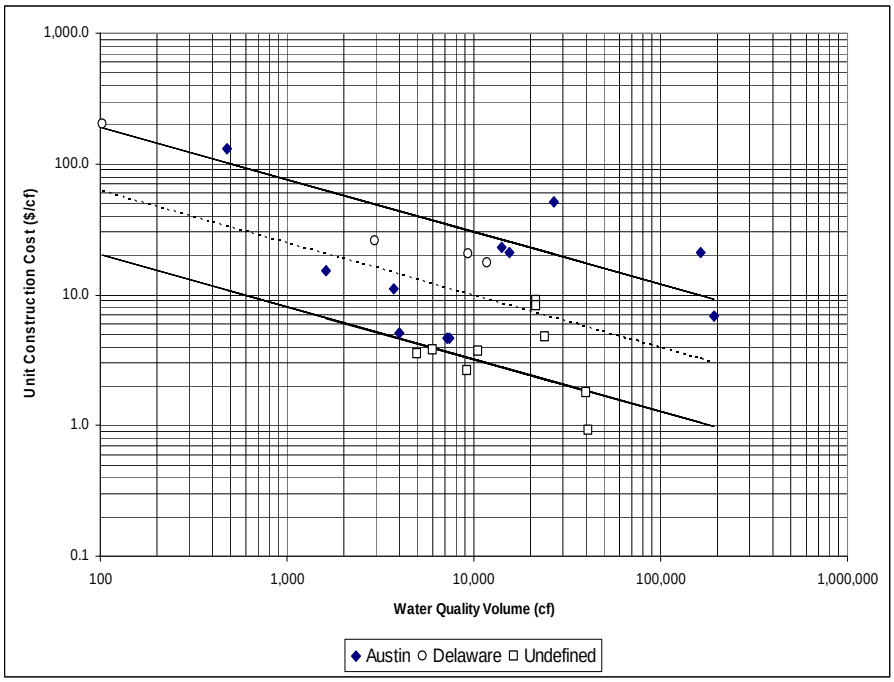

Figure 10. Unit construction costs of sand filters.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

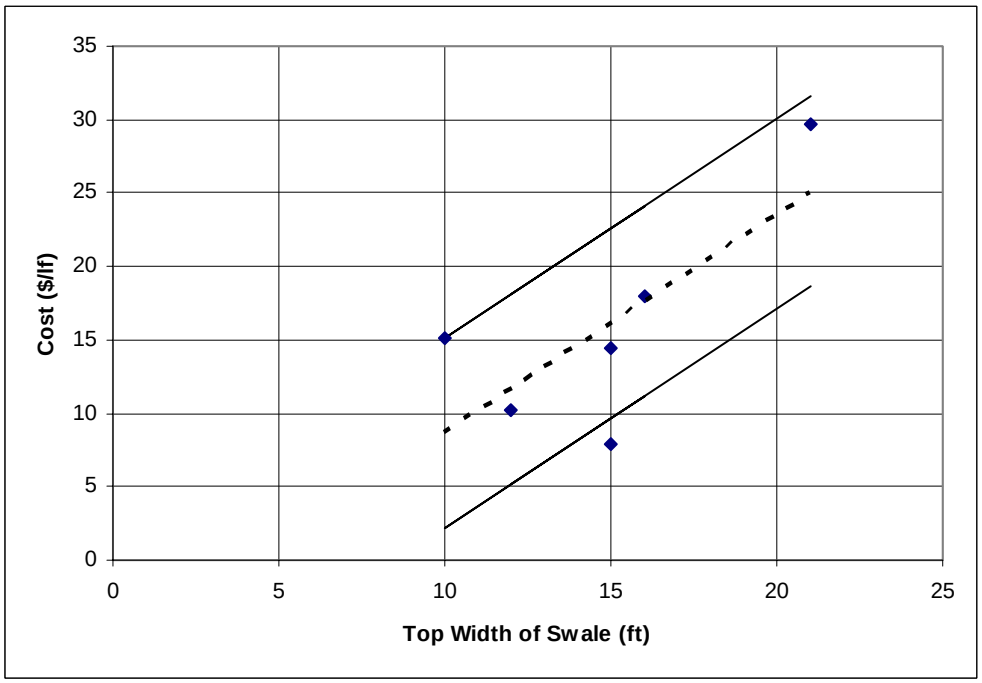

Figure 11. Unit construction costs of grassed/vegetative swales.

(Data from SWRPC, 1991)

analysis because their costs were typically about ten times higher than similarly sized projects constructed by other agencies. Caltrans attributed these high costs to the fact that their projects were retrofits and were not installed as part of larger construction projects.

Of the data collected for sand filters, some contained information on the type of sand filter (*e.g.* Austin or Delaware) while other data included no such description. Interestingly, when analyzing the sand-filter data for unit costs, there was essentially the same amount of scatter when the data of each sand-filter type was analyzed alone as there was when all sand-filter data was combined and analyzed together. This suggests that sand-filter unit-construction costs are independent of the type of filter and, as a result, cost estimates developed herein do not differentiate between sand-filter types. Figure 10 does differentiate between the Austin, Delaware, and undefined data by the data marker but, since no trend was observed for individual filter types, the best-fit line is drawn through the combined data.

The uncertainty observed in the data for all SMPs is most likely due to several factors such as design parameters, regulation requirements, soil conditions, site specifics, etc. For example, variable design parameters that would affect the total construction cost include pond side slopes, depth and free board on ponds, total wet pond volume, outlet structures, the need for retaining walls, etc. Site specific variables include clearing and grubbing costs, fencing around the SMP, etc. Due to the wide number of undocumented variables that affect the data, this scatter would be extremely difficult, if not impossible, to minimize.

Later in this report the data shown in Figures 5 through 11 will be combined with annual O&M cost data to estimate the TPC of each SMP as a function of size. After a discussion of typical land-area requirements, the methods and data used to incorporate O&M costs into this analysis are described.

Land-Area Requirements

An important cost of any SMP is that of the land area on which the SMP will be located. For urban areas, in which land is typically at a premium, this cost can be relatively large. On the contrary, in more open, rural areas, land costs might be a very small percentage of the total project costs. Due to the extreme range of land costs and variability from site to site, no attempt was made to incorporate this cost into the Total Present Cost analysis. However, the land area requirements, and therefore the associated land costs, of each SMP technology can vary dramatically and would, in many scenarios, have a significant impact on the total cost of a project. For example, a sand filter placed underground, below a parking lot would, in effect, require no additional land area. However, a constructed wetland designed to treat the same volume of runoff as the underground sand filter would require significant additional land area that may preclude the use of wetlands. Given the variability of land costs and the variety of potential SMPs that could be used, the impact of land costs must be done on an individual, case-by-case basis. Table 3, which lists typical SMP land-area requirements for effective treatment, is presented to assist designers and planners in making such a comparison. Values reported in Table 3 by Claytor and Schueler (1996) are for the general category of SMP system and may include more than one specific type of SMP. For example, their pond category may include both wet and dry ponds. Table 4 lists wet pond areas required for control of particles that are 5 and 20 microns in size as reported by Pitt and Voorhees (1997). If the land costs in the locale of a particular project are known, these costs can be combined with the information presented in the tables to estimate a range of possible land area costs associated with each SMP under consideration. This information is intended to give only a possible range of land area costs. For more accurate land area cost estimates, a preliminary SMP design should be performed.

SMP System	SMP Area (% of Impervious Watershed) From USEPA, 1999.	SMP Area (% of Watershed) From Claytor and Schueler (1996) Except as noted.
Bioretention	5	--
Wetland	3 - 5	3 - 5
Wet/Retention Basin	2 - 3	--
Sand Filter	0 - 3	--
Dry Det Basin	--	0.5 - 2.0 (UDFCD, 1992)
Infiltration Trench	2 - 3	--
Filter Strips	100	--
Swales	10 - 20	--
Pond	--	2 - 3
Infiltration	--	2 - 3
Filter	--	2 - 7

Table 3. Reported SMP land area requirements for effective treatment.

Land Use	5 micron control	20 micron control
100% Paved	3.0	1.1
Freeways	2.8	1.0
Industrial	2.0	0.8
Commercial	1.7	0.6
Institutional	1.7	0.6
Residential	0.8	0.3
Open Space	0.6	0.2
Construction	1.5	0.5

Table 4. Typical land area requirements (% of total watershed) for wet ponds (i.e. basins).

(Pitt and Voorhees, 1997)

Operating and Maintenance Costs

Over the lifetime of a SMP, the operating and maintenance costs can be a significant expense that must be considered when selecting a treatment method. However, no data was found that documented actual O&M costs of existing SMPs. At best, available data consisted only of expected or predicted O&M costs of recently constructed SMP projects. Often times, general guidelines of estimated annual O&M costs were presented as a percentage of the total

construction cost. For example, the USEPA (1999a) gives a summary of typical SMP annual O&M costs as shown in the middle column of Table 5. Also included in the right column of Table 5 is the range of the authors' collection of predicted O&M costs as a percent of the construction cost.

Ideally the estimate of TPC would be based on actual O&M costs of existing SMPs but, as mentioned above, estimated annual O&M costs were the only available data. When this data was evaluated to determine how the estimated O&M costs compared to those summarized by the USEPA, a trend was observed for all SMPs except infiltration trenches in which the annual O&M cost as a percentage of the construction cost decreased with increasing construction cost. The collected annual O&M cost data are shown as log-log plots in Figures 12 through 18. As with the construction cost data, the best-fit line through the data and the 67% confidence interval are shown.

SMP	Summary of Typical AOM Costs (% of Construction Cost) (USEPA, 1999A)	Collected Cost Data: Estimated Annual O&M Costs (% of Construction Costs)
Retention Basins and Constructed Wetlands	3%-6%	--
Detention Basins	<1%	1.8%-2.7%
Constructed Wetlands	2%	4%-14.1%
Infiltration Trench	5%-20%	5.1%-126%
Infiltration Basin	1%-3% 5%-10%	2.8%-4.9%
Sand Filters	11%-13%	0.9%-9.5%
Swales	5%-7%	4.0%-178%
Bioretention	5%-7%	0.7%-10.9%
Filter Strips	$320/Acre (maintained)	--
Wet Basins	Not Reported	1.9%-10.2%

Table 5. Typical annual O&M costs of SMPs.

In the following section the annual O&M costs will be combined with the unit construction costs to develop an estimate for the Total Present Cost of each SMP as a function of WQV or, in the case of swales, as a cost per linear foot as a function of swale top width.

Total Present Cost

If an estimate of the total construction cost of a SMP were desired, the data presented in Figures 5 through 10 could be used in a stand-alone manner simply by multiplying the unit construction cost ($/ft^3) by WQV (ft^3). The construction cost of swales could also be easily estimated by multiplying the unit cost ($/ft) by the swale length (ft). However, a more practical estimate is that of the total costs needed to not only construct but also to maintain and operate the SMP. Rather than provide one estimate for total construction cost and another estimate for annual O&M expenditures, the data presented in the previous two sections will be combined in

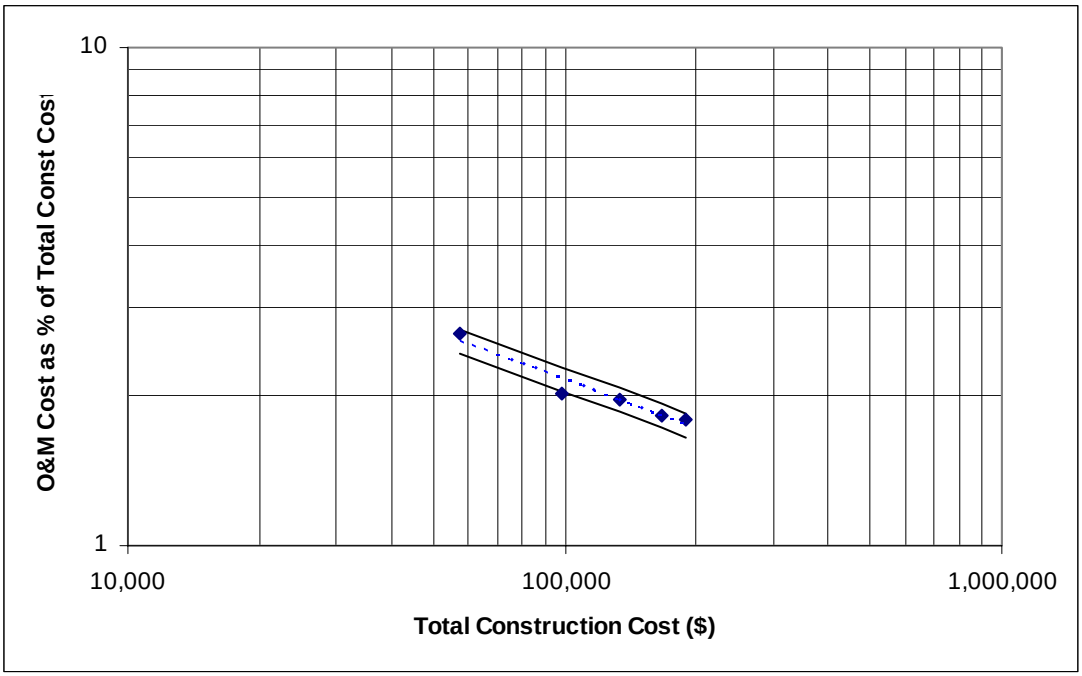

Figure 12. Annual O&M costs of dry detention basins.

(Data from Landphair, *et al*, 2000)

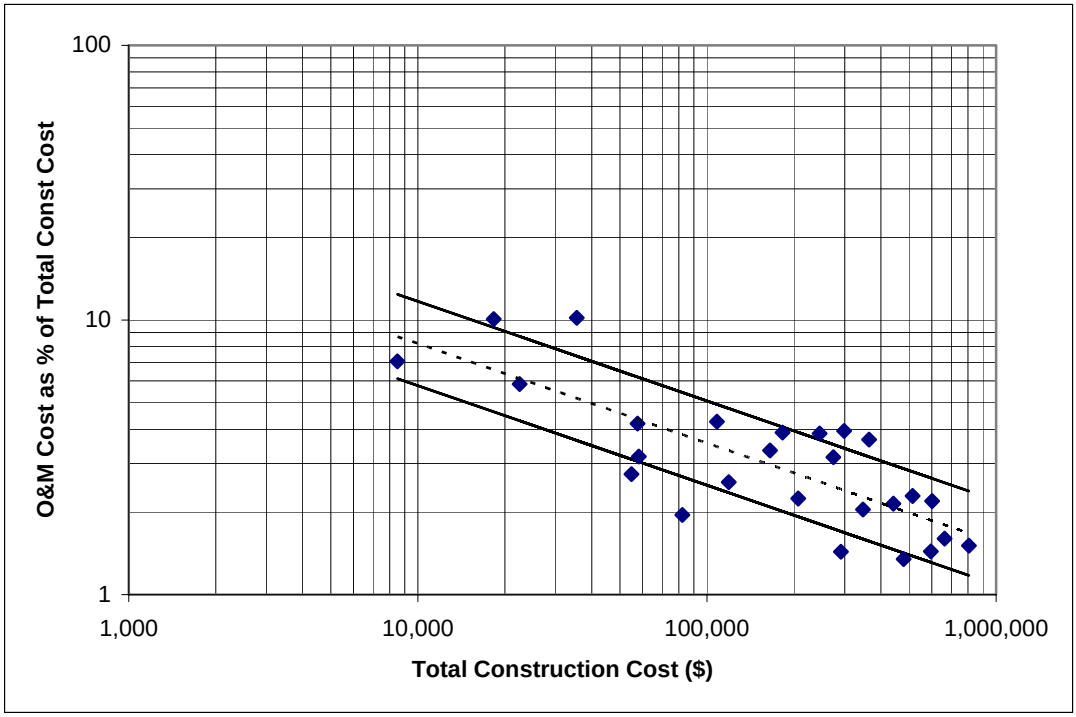

Figure 13. Annual O&M costs of wet basins.

(Data from SWRPC, 1991; Wossink and Hunt, 2003)

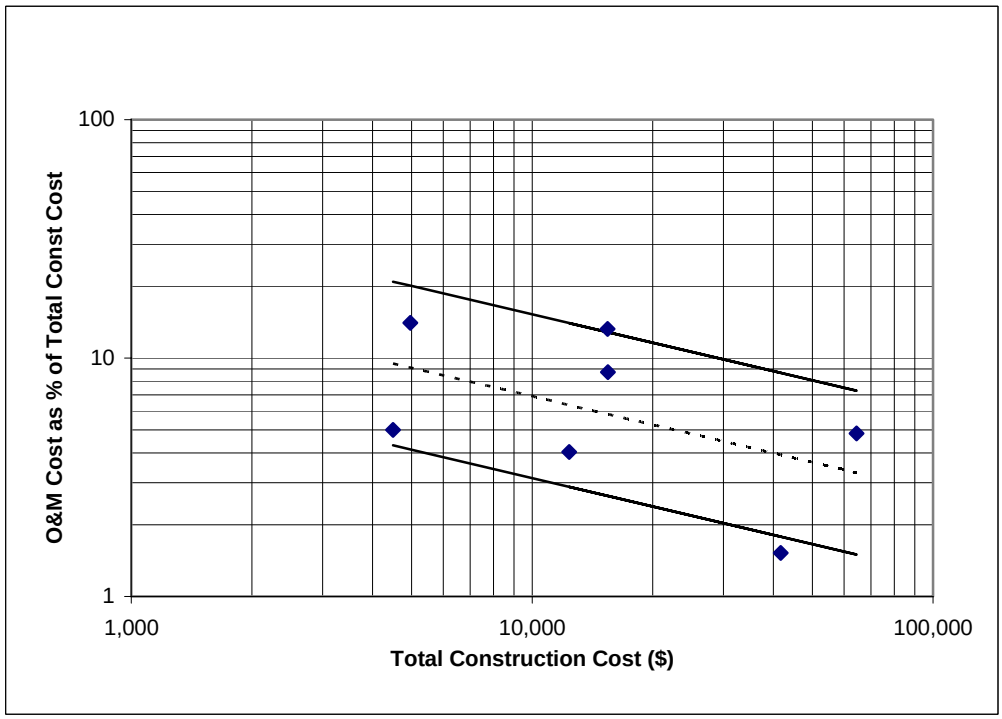

Figure 14. Annual O&M costs of constructed wetlands.

(Data from Wossink and Hunt, 2003)

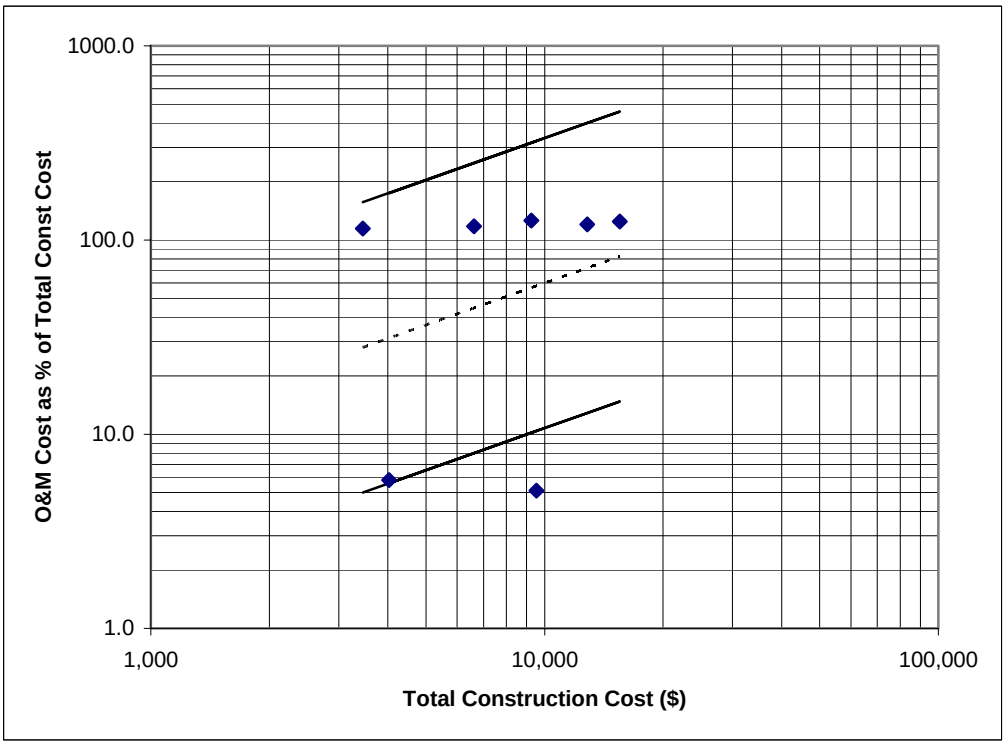

Figure 15. Annual O&M costs of infiltration trenches.

(Data from SWRPC, 1991; Landphair, *et al*, 2000)

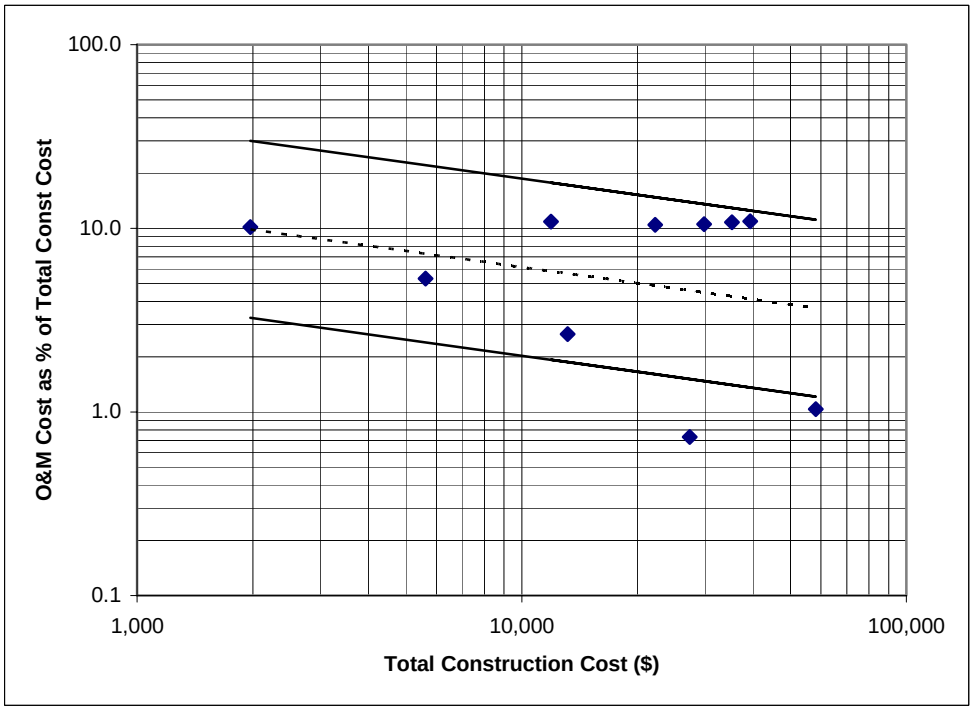

Figure 16. Annual O&M costs of bioinfiltration filters.

(Data from Landphair, *et al*, 2000; Wossink and Hunt, 2003)

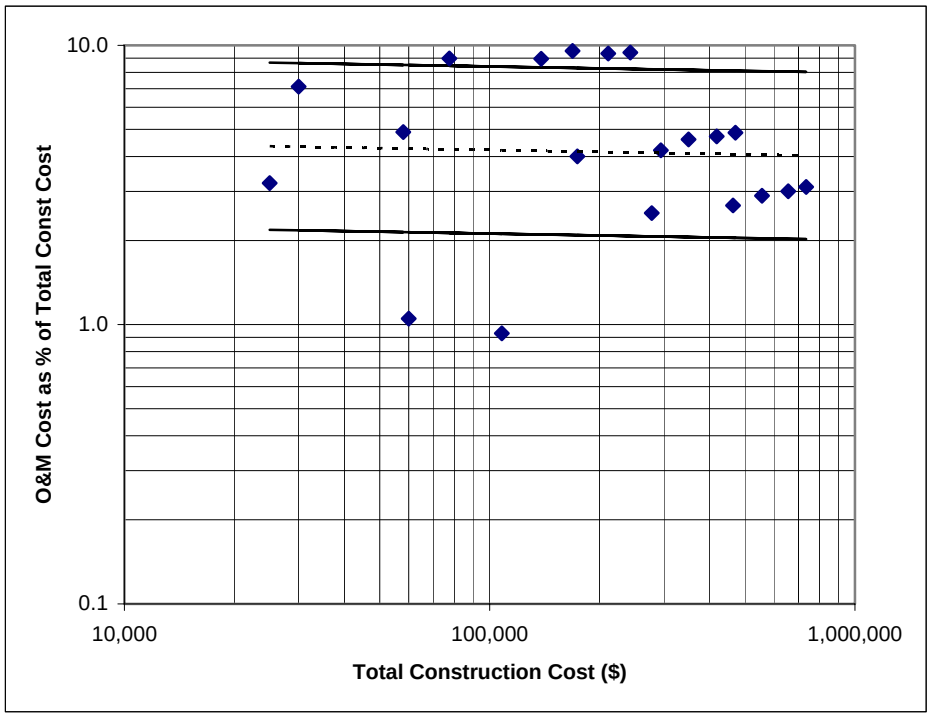

Figure 17. Annual O&M costs of sand filters.

(Data from Landphair, *et al*, 2000; Wossink and Hunt, 2003)

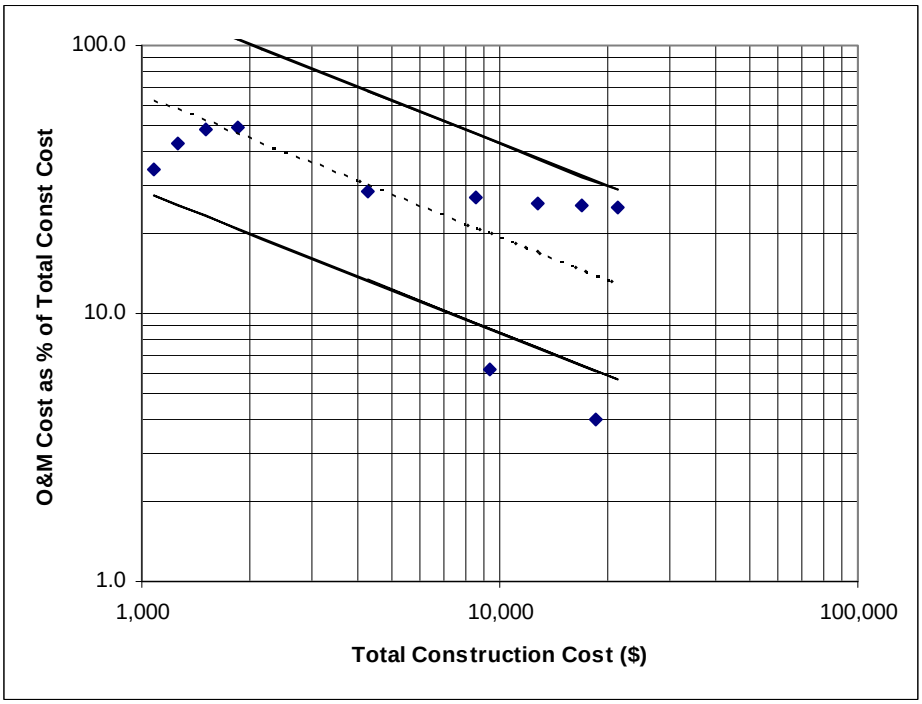

Figure 18. Annual O&M costs of grassed/vegetative swales.

(Data from Landphair, *et al*, 2000; SWRPC, 1991)

order to estimate the Total Present Cost (TPC) of each SMP as a function of size. As previously defined, the TPC is the sum of the total construction cost and the equivalent present cost of 20 years of annual O&M expenses. For each SMP, the TPC is estimated as a function of size (*i.e.* WQV or swale top width).

The Total Present Cost with a 67% confidence interval for six of the seven SMPs was estimated as a function of water-quality volume (WQV). Also, the total present cost of a 1000' long grassed/vegetative swale was estimated as a function of the swale top width. The TPC estimates incorporate the total construction cost data and annual O&M cost data presented in the previous sections. In this estimate, the annual O&M costs are converted to an equivalent present cost using historical data on the rates of municipal bond yields and inflation. The analysis method and the results for each of the seven SMPs are presented below.

In order to estimate the TPC of each SMP the total construction cost was calculated as a function of size (*i.e.* WQV or swale top width) by multiplying the corresponding unit construction cost by WQV or, in the case of swales, by the swale length. Using these values of total construction cost and the annual O&M cost data best-fit line, the annual O&M cost was estimated for each WQV or swale top width. For example, for a dry detention basin, the unit construction costs for a range of WQVs were calculated from the best-fit line shown in Figure 6. The total construction costs were then estimated by multiplying the unit construction costs by the corresponding WQV. The annual O&M costs (as a percentage of construction cost) were then estimated using the best-fit line of Figure 12. Next, the value of the annual O&M cost estimates were calculated by multiplying each percentage (as found from the best-fit line) by the corresponding total construction cost. Finally, the annual O&M costs for a 20-year period were

converted to an equivalent present cost (based on historical values of interest and inflation rates as described below) and added to the total construction cost.

Before the conversion of the annual O&M costs to an equivalent present cost is described, it must be noted that the annual O&M costs for infiltration trenches and grassed/vegetative swales were estimated in a different manner than described above. All but two of the O&M data points for these two SMPs (shown in Figures 15 and 18) were from Landphair, *et al* (2000) whose estimates ranged from 115 percent to 126 percent for infiltration trenches and 25 percent to 178 percent for grassed/vegetative swales. Since these values comprised most of the data and are high compared to the 5 percent to 20 percent for infiltration trenches and 5 percent to 7 percent for grassed/vegetative swales as summarized by the USEPA (1999a), a different method was applied when estimating these annual O&M costs. For infiltration trenches and grassed/vegetative swales, average values of the annual O&M cost (as a percent of total construction cost) based on the USEPA summary shown in Table 5 were assumed. Thus, annual O&M costs for infiltration trenches and grassed/vegetative swales were not determined from the best-fit line through the data, but rather assumed to be 12 percent (± 7%) and 6 percent (± 1%), respectively. Other than these assumptions, the TPC analysis for these two SMPs was identical to the others.

Returning to the method used to convert the annual O&M costs to an equivalent present cost and having obtained an annual O&M cost estimate, it was assumed that these costs would be incurred for 20 years. Based on this assumption, 20 years of annual O&M costs were converted to an equivalent present O&M cost using the time value of money and historical values of interest and inflation rates. Given an interest rate and inflation rate, the equivalent present cost

of the 20-year annual O&M costs can be computed by an equation modified from Collier and Ledbetter (1988) which is:

$$P = C_{OM}\left[\frac{\left(\frac{1+r}{1+i}\right)^{n} - 1}{r - i}\right] \tag{3}$$

Where: P = Equivalent present cost of 20-years of annual O&M costs

C_{OM} = annual O&M cost

r = inflation rate

i = interest rate

n = number of years (*i.e.* 20)

Equation 3 may be rewritten as:

$$P = C_{OM}[E] \tag{4}$$

where: $$E = \left[\frac{\left(\frac{1+r}{1+i}\right)^{n} - 1}{r - i}\right]$$

Using average annual Aaa municipal bond yield rates (Mergent, Inc., 2003) for interest rate values and historical Consumer Price Index (CPI) based inflation rates (Fintrend.com, 2004), the value of E was calculated for each year from 1944 through 2002. Since this analysis is based on a 20-year time span, the running 20-year average value of E was calculated for each year from 1963 through 2002. The running 20-year average values are shown in Table 6 and resulted in an overall average value of 18.68 +/- 2.29 (67% confidence interval). Returning to the example and using a value of 18.68 for E, the present equivalent cost of 20 years of annual O&M expenses were calculated over the range of WQVs and added to the corresponding total construction cost

to give the Total Present Cost (TPC) in 2005 dollars as a function of WQV. The uncertainties associated with the 67% confidence intervals of the unit construction costs, annual O&M costs as a percent of the construction cost, and inflation and interest rates (*i.e.* E) were incorporated into the TPC as described by Kline (1985).

Year	20-yr running Avg. E	Year	20-yr running Avg. E	Year	20-yr running Avg. E	Year	20-yr running Avg. E
1963	23.94	1973	17.55	1983	20.22	1993	18.23
1964	23.73	1974	18.25	1984	19.98	1994	17.41
1965	23.46	1975	18.68	1985	19.75	1995	16.91
1966	22.28	1976	18.74	1986	19.46	1996	16.74
1967	19.17	1977	18.82	1987	19.27	1997	16.36
1968	18.38	1978	19.02	1988	19.01	1998	15.93
1969	18.55	1979	19.80	1989	18.83	1999	15.12
1970	18.53	1980	20.56	1990	18.73	2000	14.32
1971	17.56	1981	20.66	1991	18.62	2001	14.12
1972	17.35	1982	20.46	1992	18.53	2002	14.27

Table 6. Yearly 20-year running average values of E.

(average of values shown is 18.68±2.29).

This method propagates the uncertainty found in each of the three above-mentioned variables (*i.e.* unit construction costs, annual O&M costs, and E) and determines the resulting uncertainty on the total present cost. Kline (1985) discusses two methods of calculating this uncertainty propagation; the first being a direct analytical solution and the second method being an approximate perturbation method. Since the unit-construction cost data is linear on a log-log plot, the linear regression through the data which gave the best-fit line was performed on the log of the unit construction costs and log of the water quality volume. Therefore, the corresponding uncertainty was also based on the log of the data and the uncertainty of the unit-cost values was estimated from this uncertainty. More specifically, the uncertainty of the unit-construction costs was estimated by raising 10 to the α power where α equals the uncertainty on the log of the data. This estimation dictated that the perturbation method be employed rather than the direct analytical solution.

The Total Present Cost (with 67% confidence interval), excluding land costs, of each SMP is shown on log-log plots as a function of WQV or swale top width in Figures 19 through 25. The range of water quality volumes for each SMP shown in these figures corresponds to the range for which construction cost data was obtained. These figures are based on historical data and are intended to be used for comparative purposes only. They are not intended to estimate costs associated with specific SMPs nor should cost be the only factor considered when selecting a SMP.

Effectiveness of Contaminant Removal

Undoubtedly an estimate of the total cost of a SMP can be a valuable aid during the planning and selection process. However, an inexpensive SMP that has minimal impact on water quality would be of little value. Thus, knowledge of the impact or effectiveness a particular

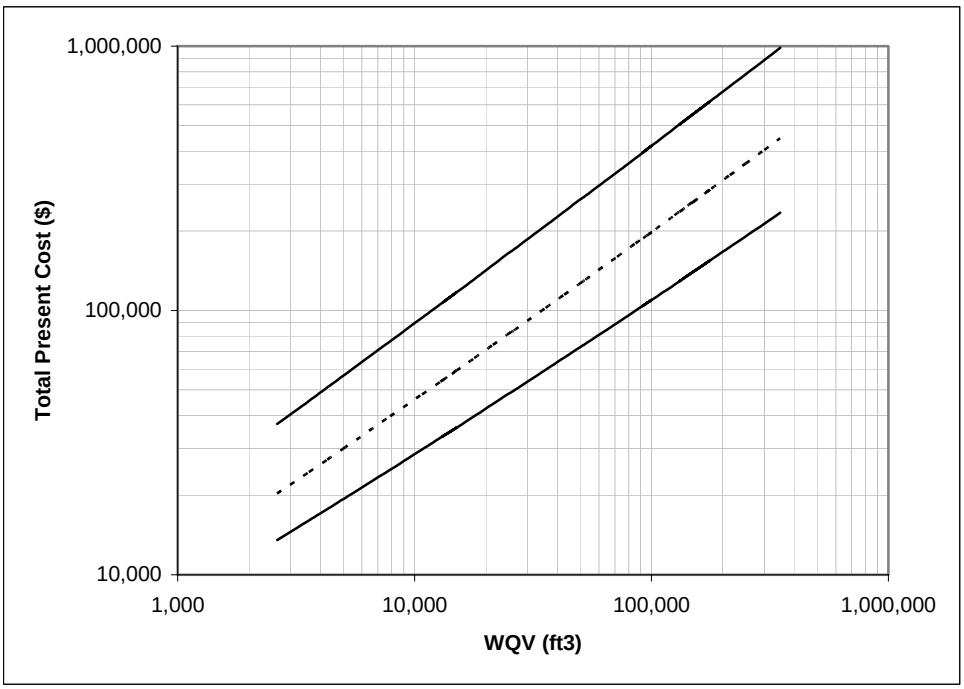

Figure 19. Total Present Cost (TPC) of dry detention basins with 67% CI. Land costs are excluded and need to be determined separately.

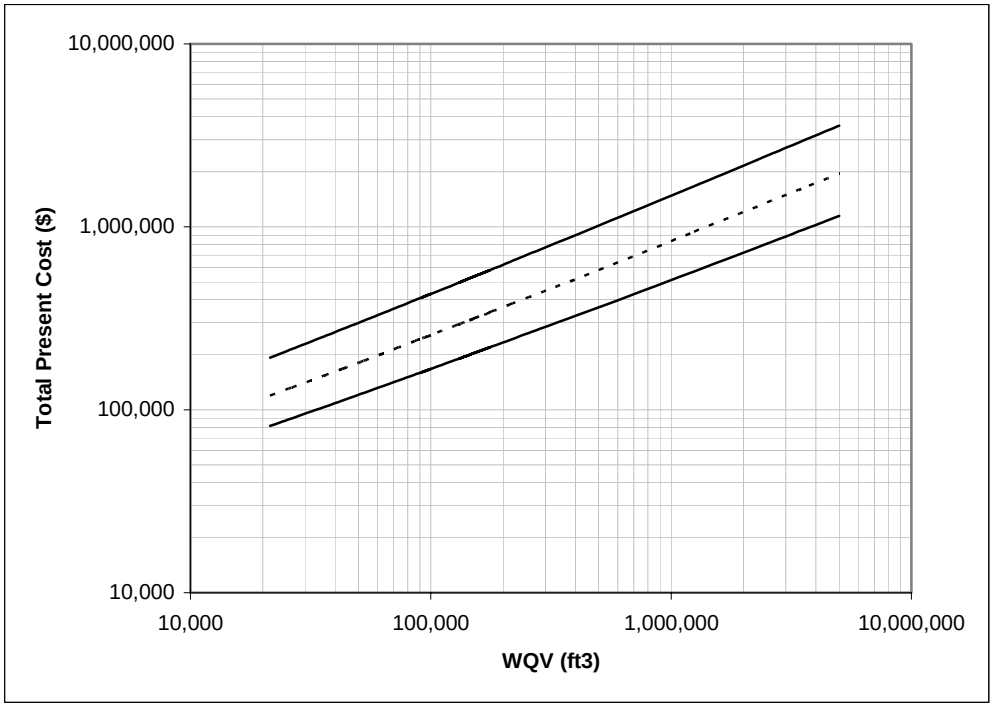

Figure 20. Total Present Cost (TPC) of wet basins with 67% CI. Land costs are excluded and need to be determined separately.

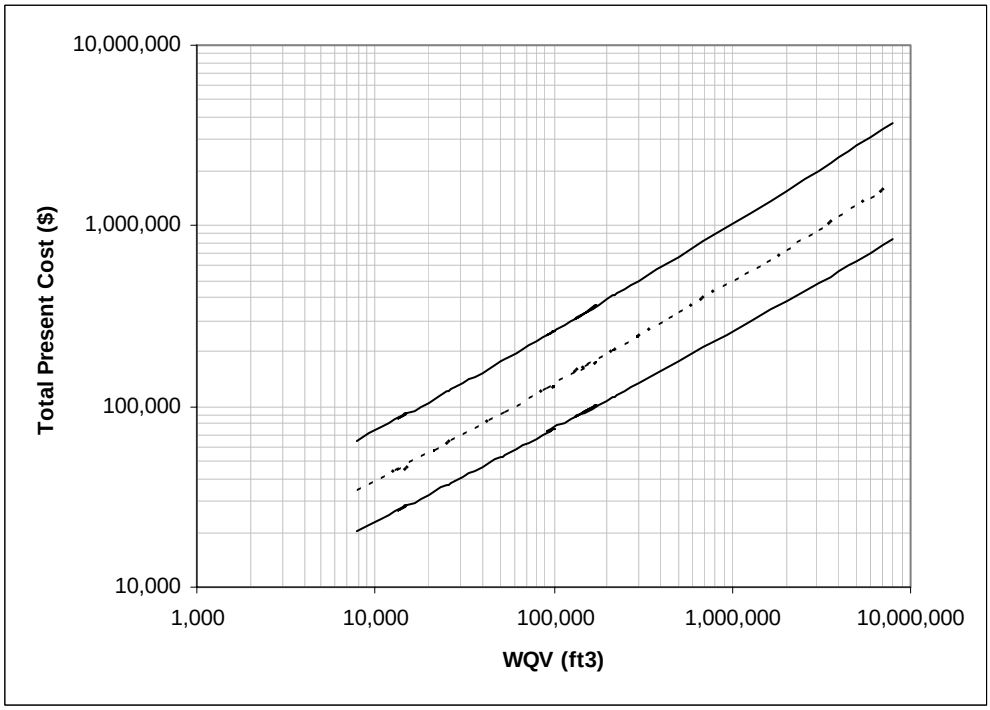

Figure 21. Total Present Cost (TPC) of constructed wetlands with 67% CI. Land costs are excluded and need to be determined separately.

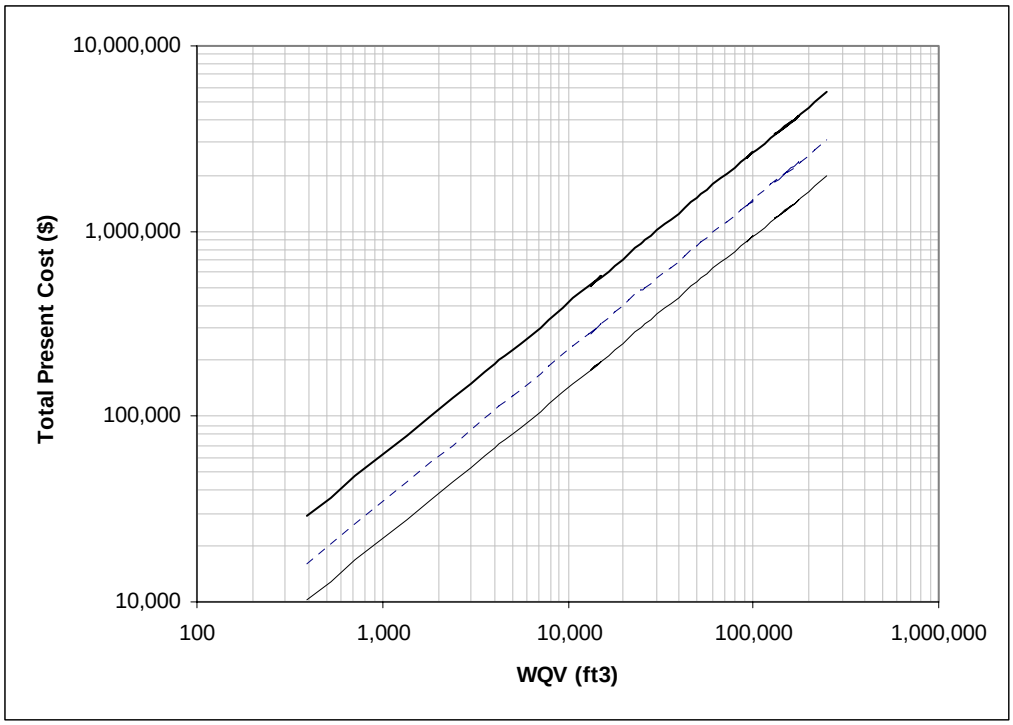

Figure 22. Total Present Cost (TPC) of infiltration trenches with 67% CI. Land costs are excluded and need to be determined separately.

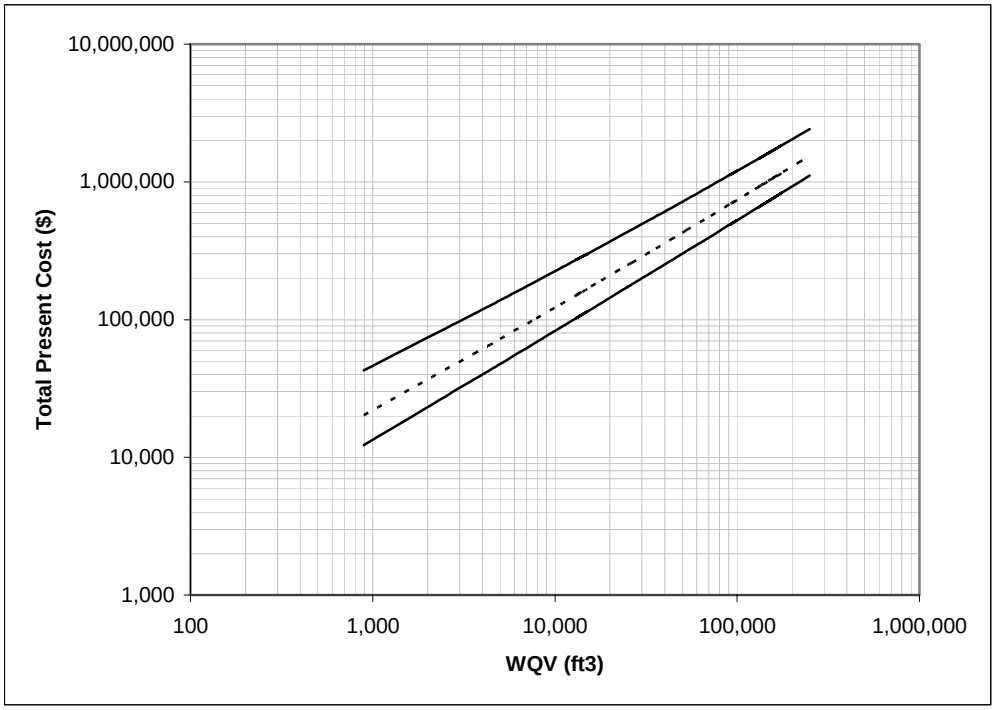

Figure 23. Total Present Cost (TPC) of bioinfiltration filters with 67% CI. Land costs are excluded and need to be determined separately.

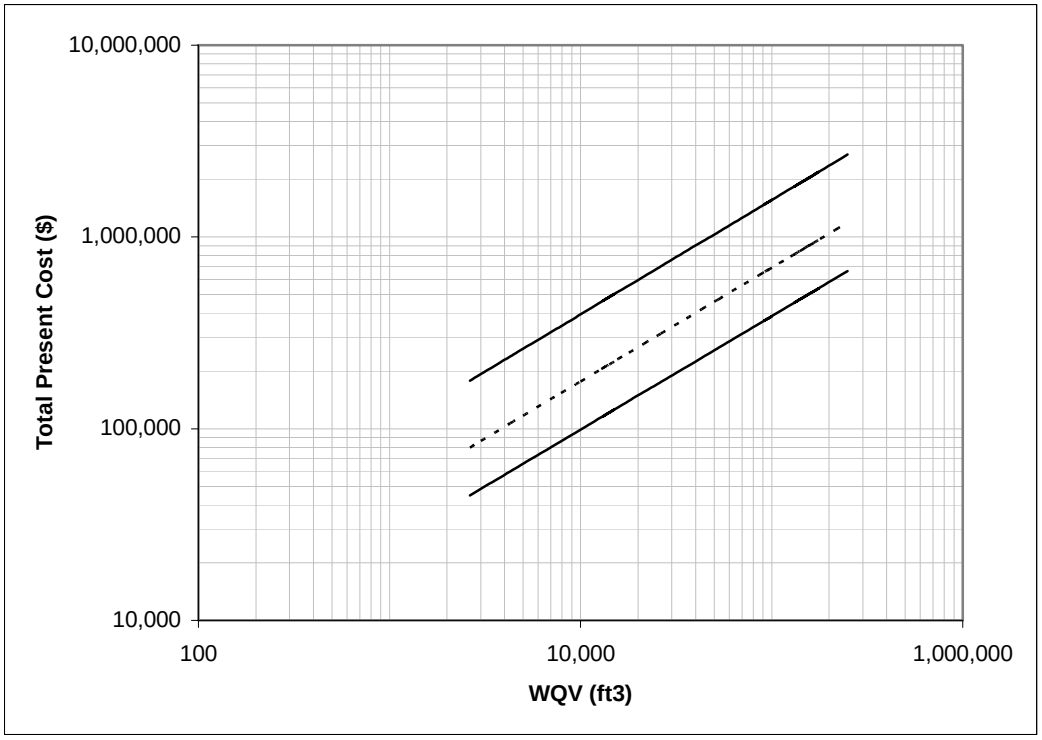

Figure 24. Total Present Cost (TPC) of sand filters with 67% CI. Land costs are excluded and need to be determined separately.

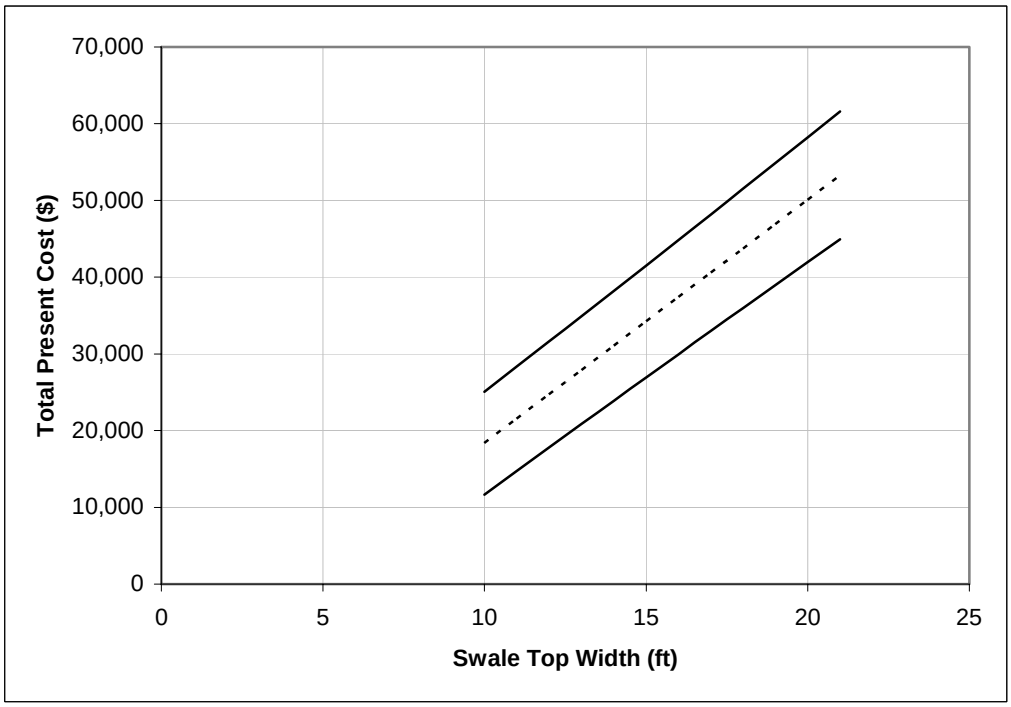

Figure 25. Total Present Cost (TPC) of 1000' long grassed/vegetative swales with 67% CI. Land costs are excluded and need to be determined separately.

SMP will have on water quality is just as important as the cost. In an effort to provide information in this area, an analysis was performed in which the total amount of TSS and phosphorus removed over a 20-year span was estimated as a function of water-quality volume. In this analysis the amount of TSS and P removed is considered to be a function of the fraction of stormwater runoff that will be treated by the SMP, the pollutant load which reaches the SMP, and the removal performance of the SMP itself. Of course, some of the variables listed above depend on other variables such as watershed area, impervious area, rainfall amounts, etc. All of these variables and the analytical method which was used to incorporate them into the estimate of total pollutant load removal is described and discussed below.

Runoff Fraction Treated

Most SMPs are designed for a particular rainfall depth used to estimate a water-quality volume or, in the case of swales, filter strips, and similar SMPs, a peak flow rate. The WQV or peak flow rate is used to size the SMP. Since an SMP is designed for a finite value of rainfall and/or runoff, there is always the chance that a given storm will produce more runoff than the unit was designed to store and/or treat. When that happens, a portion of the runoff bypasses the SMP or is discharged from the SMP via an overflow outlet and receives no treatment. In order to account for this untreated fraction of the runoff, a statistical analysis was performed on historical rainfall data in the Twin Cities. Given the design rainfall depth, the process, as described below, can be used to estimate the fraction of stormwater runoff that will be bypassed or exit the SMP without treatment.

Since design recommendations for SMPs usually state that the devices should be designed to drain in two days, two-day running sum precipitation amounts in the Twin Cities were calculated and analyzed from 1950 through 2003. For example, if the precipitation depths

measured on four consecutive days were 0.21 in., 0.13 in., 0.35 in., and 0.07 in., the data would be combined into two-day precipitation amounts of 0.34 in., 0.48 in., and 0.42 in., respectively. Using the combined data, a two-day running sum (R_S) histogram was generated using 0.10 inch increments from zero to four inches, with the last bin including any two-day sum that was greater than or equal to four inches. Of the 9,720 non-zero entries, five fell into the latter category, with the largest having a value of 10.00 inches. Columns 1 through 4 of Table 7 show the histogram in tabular form along with the frequency and cumulative frequency distributions. Subtracting the cumulative frequency from 1.00 and multiplying by 100 gives the percent exceedance as shown in column 5 and plotted in Figure 26.

Thus Table 7 and/or Figure 26 can be used to determine the fraction of two-day precipitation events that exceeded a particular precipitation depth. For example, based on Figure 26, a two-day rainfall depth of 1.00 inch was exceeded approximately 7 percent of the time over the 54-year period analyzed. Alternatively, using Table 7 and linearly interpolating between 7.43% and 6.24% gives a value of 6.84% exceedance for a precipitation depth of one inch. Furthermore, if an SMP were designed for a precipitation depth of 1.00 inch, the graph area that is both under the curve **and** below the horizontal line that corresponds to an abscissa value of 1.00 inch divided by the total area under the curve, equals the fraction of the two-day summed precipitation amounts that were below the 1.00 inch design storm depth. The values of the graph area, cumulative area, and percent of total area corresponding to each precipitation depth have been calculated and are shown in columns 6, 7, and 8, respectively, of Table 7. Due to infiltration and other abstractions of the stormwater which occur as the runoff makes it way to the SMP, this ratio is not exactly the fraction of runoff that would be treated by the SMP. That

(1) Range (in.)	(2) # of events	(3) Frequency	(4) Culm. Frequency	(5) % exceedance	(6) Area (in)	(7) Culm. Area (in)	(8) % of Total Area	(9) Rainfall Depth (in)
				100.00			0.00	0.00
0<Rs<0.1	4037	0.41533	0.41533	58.47	3.962	3.962	13.88	0.05
0.1<=Rs<0.2	1599	0.16451	0.57984	42.02	5.024	8.986	31.48	0.15
0.2<=Rs<0.3	965	0.09928	0.67912	32.09	3.705	12.691	44.45	0.25
0.3<=Rs<0.4	683	0.07027	0.74938	25.06	2.858	15.549	54.46	0.35
0.4<=Rs<0.5	501	0.05154	0.80093	19.91	2.248	17.797	62.34	0.45
0.5<=Rs<0.6	377	0.03879	0.83971	16.03	1.797	19.594	68.63	0.55
0.6<=Rs<0.7	276	0.02840	0.86811	13.19	1.461	21.055	73.75	0.65
0.7<=Rs<0.8	250	0.02572	0.89383	10.62	1.190	22.245	77.92	0.75
0.8<=Rs<0.9	171	0.01759	0.91142	8.86	0.974	23.219	81.33	0.85
0.9<=Rs<1.0	139	0.01430	0.92572	7.43	0.814	24.033	84.18	0.95
1.0<=Rs<1.1	115	0.01183	0.93755	6.24	0.684	24.717	86.58	1.05
1.1<=Rs<1.2	99	0.01019	0.94774	5.23	0.574	25.290	88.59	1.15
1.2<=Rs<1.3	98	0.01008	0.95782	4.22	0.472	25.763	90.24	1.25
1.3<=Rs<1.4	65	0.00669	0.96451	3.55	0.388	26.151	91.60	1.35
1.4<=Rs<1.5	58	0.00597	0.97047	2.95	0.325	26.476	92.74	1.45
1.5<=Rs<1.6	46	0.00473	0.97521	2.48	0.272	26.748	93.69	1.55
1.6<=Rs<1.7	34	0.00350	0.97870	2.13	0.230	26.978	94.50	1.65
1.7<=Rs<1.8	*27*	0.00278	0.98148	1.85	0.199	27.177	95.20	1.75
1.8<=Rs<1.9	*20*	0.00206	0.98354	1.65	0.175	27.352	95.81	1.85
1.9<=Rs<2.0	18	0.00185	0.98539	1.46	0.155	27.507	96.35	1.95
2.0<=Rs<2.1	18	0.00185	0.98724	1.28	0.137	27.644	96.83	2.05
2.1<=Rs<2.2	16	0.00165	0.98889	1.11	0.119	27.764	97.25	2.15
2.2<=Rs<2.3	14	0.00144	0.99033	0.97	0.104	27.868	97.62	2.25
2.3<=Rs<2.4	16	0.00165	0.99198	0.80	0.088	27.956	97.93	2.35
2.4<=Rs<2.5	9	0.00093	0.99290	0.71	0.076	28.032	98.19	2.45
2.5<=Rs<2.6	9	0.00093	0.99383	0.62	0.066	28.098	98.42	2.55
2.6<=Rs<2.7	10	0.00103	0.99486	0.51	0.057	28.155	98.62	2.65
2.7<=Rs<2.8	8	0.00082	0.99568	0.43	0.047	28.202	98.79	2.75
2.8<=Rs<2.9	8	0.00082	0.99650	0.35	0.039	28.241	98.92	2.85
2.9<=Rs<3.0	8	0.00082	0.99733	0.27	0.031	28.272	99.03	2.95
3.0<=Rs<3.1	5	0.00051	0.99784	0.22	0.024	28.296	99.12	3.05
3.1<=Rs<3.2	5	0.00051	0.99835	0.16	0.019	28.315	99.18	3.15
3.2<=Rs<3.3	2	0.00021	0.99856	0.14	0.015	28.331	99.24	3.25
3.3<=Rs<3.4	2	0.00021	0.99877	0.12	0.013	28.344	99.28	3.35
3.4<=Rs<3.5	2	0.00021	0.99897	0.10	0.011	28.355	99.32	3.45
3.5<=Rs<3.6	0	0.00000	0.99897	0.10	0.010	28.365	99.36	3.55
3.6<=Rs<3.7	2	0.00021	0.99918	0.08	0.009	28.375	99.39	3.65
3.7<=Rs<3.8	2	0.00021	0.99938	0.06	0.007	28.382	99.42	3.75
3.8<=Rs<3.9	1	0.00010	0.99949	0.05	0.006	28.388	99.44	3.85
3.9<=Rs<4.0	0	0.00000	0.99949	0.05	0.005	28.393	99.45	3.95
4.0<=Rs	5	0.00051	1.00000	0.00	0.156	28.548	100.00	10.00

# of Events= 9720 **Total Area= 28.548**

Table 7. Statistical analysis of historical 2-day precip. amounts at the MPLS-St. Paul airport.

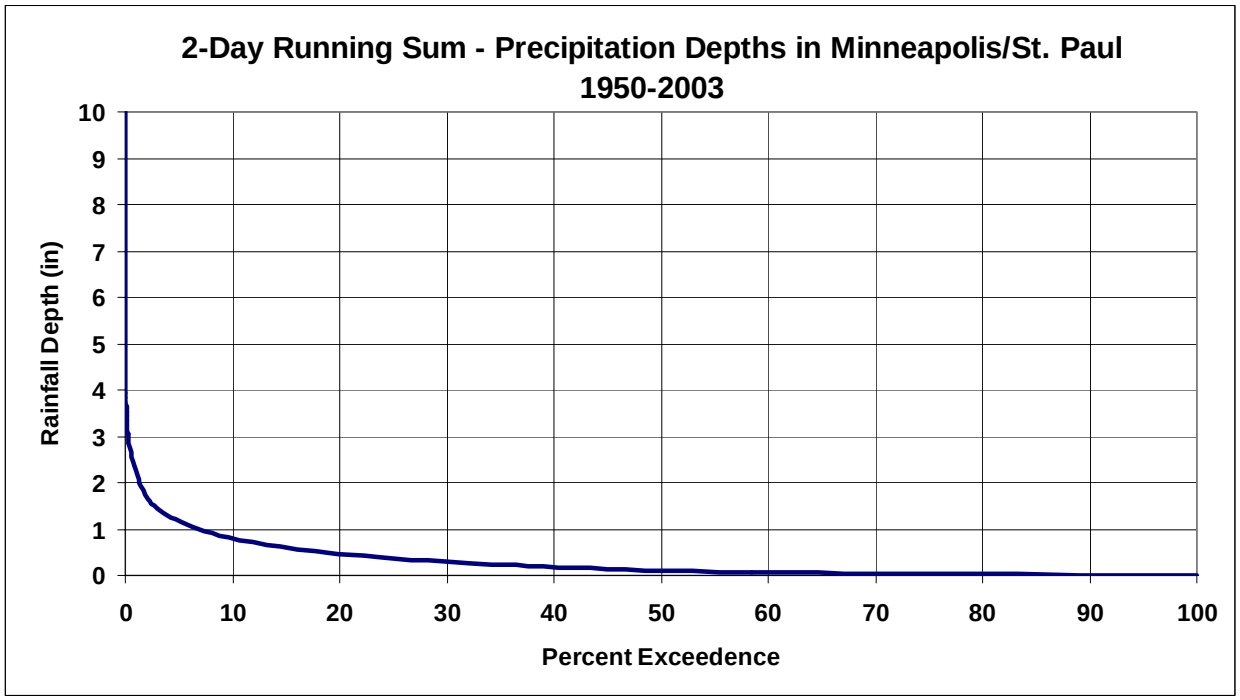

Figure 26. Exceedance probabilities of two-day precipitation depths in the Twin Cities.

would only be the case if 100 percent of the precipitation were to reach the SMP as runoff. However, the percent of total area values shown in column 8 can be used as an approximate estimate of the fraction of runoff that would be treated by an SMP designed for the corresponding rainfall depth in column 9. For example, based on columns 8 and 9 of Table 7, if an SMP was designed for a precipitation depth of 2.25 inches, it could be estimated that, based on historical data, the SMP would treat 97.62 percent of the stormwater runoff over time.

For the purposes of this report it was assumed that all SMPs would be designed for a precipitation depth of 1.45 inches which is approximately the three-month, 24-hour storm for the Twin Cities metro region (Huff and Angel, 1992). As shown in Table 7, a depth of 1.45 inches corresponds to approximately 93 percent of the area under the curve. As discussed above, it was estimated that 93 percent of all stormwater runoff will be treated by an SMP which is designed for the volume of runoff corresponding to this precipitation depth. Thus, when estimating the

total amount of TSS and P removed over 20 years, it was assumed that 93 percent of all stormwater runoff will be treated by the SMPs and the remaining 7 percent of the runoff will receive no treatment. Thus, total suspended sediment and phosphorus removal are given by:

$$\%\text{Total Removal} = 0.93 * (\%\text{Removal by SMP}) \tag{5}$$

where the "%Removal by SMP" is the removal based on inflow and treated outflow concentrations and does not consider overflow conditions. Overflow and/or bypass conditions are accounted for by multiplying the "%Removal by SMP" by 0.93.

Pollutant Loading

Several methods with a wide degree of complexity are available to estimate stormwater pollutant loads. For example, the Stormwater Management Model (SWMM) is public domain software and can be used to model single storm events or watershed basins over time. Additional methods described Young, *et al*. (1995) include regional United States Geological Survey (USGS) equations for estimation of storm loads, runoff volumes, and event mean concentrations. These equations have been developed for three regions in the United States and are based on regression analysis of nationwide data. A simplified, but less accurate, set of USGS regression equations are also available and can be used to estimate storm runoff loads and volumes. The USGS has also derived a set of equations to estimate storm mean concentrations and mean seasonal or annual loads.

The Federal Highway Administration (FHWA) has developed a method to estimate pollutant loading from highway runoff (Driscoll, *et al*., 1990). As with the USGS methods, the FHWA method is a regional method, in this case with nine regions, which involves a relatively large amount of detailed input to arrive at an estimate of annual pollutant mass loading.

The methods described above require a level of detail that is well beyond what is necessary (or perhaps possible) for the comparative purposes of this report. Thus, for this report, a modified version of a less involved method, the Simple Method, was selected to estimate pollutant loads. The Simple Method, first proposed by Schueler (1987), is widely accepted and requires only the mean annual precipitation, percent of rainfall events that produce no runoff, the drainage area, and a runoff coefficient be known. The modified Simple Method used in this report is used by the Lower Colorado River Authority (1998) and has been recommended for use by the State of Texas, Department of Transportation (Landphair, *et al*., 2000). In its modified form, the simple method is:

$$L = (0.2266) * A * R_F * R_V * C \tag{6}$$

where: L = Annual pollutant load (lb.)

A = Watershed area (acre)

R_F = Average annual rainfall (in.)

R_V = Average annual runoff coefficient (*i.e.* runoff:rainfall ratio)

C = Average annual contaminant (*i.e.* TSS & P) concentration (mg/L)

The runoff coefficient R_V, was described for water quality volume calculations and is estimated as:

$$R_V = 0.05 + 0.009 * (I) \tag{2}$$

where: I = Percent of watershed that is impervious

In order to coincide with the 20-year time span used to estimate the total present cost, the pollutant loading must also be estimated for 20 years. To accomplish this, Equation 5 must be multiplied by 20. Also, the variable R_F, must no longer be defined as the average annual rainfall but rather, the 20-year running average of annual rainfall (inches). Incorporating these small but

significant changes, the equation used to estimate the TSS and P loading over a 20-year span becomes:

$$L_{20} = 20 * 0.2266 * A * R_{F20} * R_V * C \tag{7}$$

Where: L_{20} = Estimated pollutant load over 20 years (lb.)

R_{F20} = 20-year running average of annual rainfall (in.)

and all other variables are as previously defined.

For the purposes of this report it was assumed that the watershed area A, percent impervious I, and therefore the runoff coefficient R_V, would be known without any uncertainty. To obtain an estimate of R_{F20}, a statistical analysis on historical precipitation data in Minneapolis and St. Paul from 1950 through 2003 was performed. The results showed that the 20-year running average precipitation depth is 28.44 inches +/- 1.80 inches (67% confidence interval).

In order to determine estimates of the average annual concentration of TSS and P in stormwater runoff, data was compiled from several studies and dozens of sites (Moxness, 1986; Moxness, 1987; Moxness, 1988; Driscoll, *et al*., 1990; Oberts, 1994; Barrett, *et al*., 1995; Stanley, 1996; Wu, J.S., *et al*., 1996; Sansalone and Buchberger, 1997; Barrett, *et al*., 1998; Anderle, T.A., 1999; Legret and Colandini, 1999; Waschbusch, *et al*., 1999; Carleton, *et al*., 2000; Drapper, *et al*., 2000; Brezonik and Stadelmann, 2002; Harper, *et al*., undated). Data analysis revealed that the average values of stormwater concentrations of TSS and P from sites located in the Twin Cities were essentially the same as average values of all other sites located throughout the nation and Australia. Since the data was similar, the national average values of 131 mg/L +/- 77 mg/L (67% confidence interval) for TSS and 0.55 mg/L +/- 0.41 mg/L (67% confidence interval) for total P were used. With values for R_{F20} and C estimated, the total pollutant load for TSS and P in pounds over a 20-year time frame, as estimated by Equation 7,

becomes a function of only two variables; watershed area and, with the use of Equation 2, the percent of the watershed area that is impervious.

With the selection of a storm design depth of 1.45" as previously discussed, the two remaining variables that determine the 20-year pollutant loads (*i.e.* watershed area and percent impervious) are also the same two variables that determine the WQV. Thus, for a watershed of known area and percent impervious, both the WQV and the TSS and P loads over 20 years can be estimated. In other words, for a given watershed, each value of WQV corresponds to a unique value of 20-year TSS and P loads. While pollutant loading is certainly important, the intent of this analysis is to estimate the load removed by the SMPs over a 20-year span. As with the Total Present Cost (TPC), the estimate of the pollutant load removed by each SMP will be estimated as a function of WQV. Before this analysis can be completed, however, one remaining variable, the percent of TSS and P removed by each category of SMPs, must be estimated.

Fraction of Contaminants Removed

With the fraction of runoff treated and the total 20-year pollutant load estimated, the remaining variable that must be estimated is the fraction of TSS and P removed by each type of SMP (*i.e*. "%Removal by SMP" in Equation 5). Once the removal rate of each SMP has been estimated, the total mass of TSS and P removed over the 20-year span may be estimated by multiplying the 20-year pollutant load by both the fraction of runoff treated (i.e. estimated to be 93% for a design precipitation of 1.45 inches) and the fraction of pollutant removed by the SMP. The fraction of TSS and P removed is usually reported in one of two ways; as a percent change between influent and effluent concentrations or as the percent change between the total mass load entering the SMP and the mass load exiting the SMP. Most of the data obtained were based on concentrations, however some values of reported removal rates were not clearly defined.

In order to make the estimate of SMP removal performance (*i.e.* %Removal SMP in Equation 5) as realistic as possible, published data on the performance of the various types of SMPs analyzed in this study was collected and the average removal rate with 67% confidence interval calculated. Only data from actual sites which were field tested were included. When a single site was monitored over time and had more than one removal rate reported, only the average value of the data for that site was included in the analysis.

Ideally, the estimate of total contaminant load removed over 20 years would be based on data reported as the percent of total mass load removed. However, due to limited data of this kind, this analysis combined removal rates based on mass load removed and removal rates based on the percent change in contaminant concentration between inflow to the SMP and treated outflow from the SMP. For each type of SMP the average percent removal of the combined data was calculated and assumed to be the average percent of mass load removed. When accounting for infiltration of stormwater which may occur inside some SMPs (*e.g.* wetlands, dry basins, etc.), the percent drop in the influent to effluent concentration should be smaller than the percent of mass load removed. Thus, by combining concentration-based removal rates with those based on mass loads and assuming the resulting average to be the percent of mass load removed is a conservative one.

The results are summarized in Table 8 below and the full data is included in Appendix B. Sufficient amounts of reliable data which are needed to estimate the TSS removal rate of bioretention filters and TSS and phosphorus removal rates of infiltration trenches were not available. As denoted by the asterisks in Table 8, typical values of 90 percent and 75 percent for TSS removal (for bioretention filters and infiltration trenches, respectively) as reported by the Idaho BMP Manual (undated), were used. Also assumed was the Idaho BMP Manual typical

infiltration trench phosphorus removal of 55%. The assumed values for TSS removal were either in agreement with other reported typical ranges of effectiveness, or conservative as Caltrans (2004) assumed infiltration trenches and basins remove 100 percent of TSS. Some literature, such as Caltrans (2004), have reasoned that since any water entering these SMPs is removed from the surface water, these SMPs achieve 100% removal of TSS and P. However, some dissolved contaminants may potentially reach the groundwater (MPCA, 2000) and could reenter as surface water at a later time. If this were to occur, the actual TSS and phosphorus removal of some SMPs would be less than 100%. The 67% confidence interval for these SMPs were also assumed and are denoted by an asterisk in Table 8.

SMP	%TSS Removal	TSS 67% CI	% P Removal	P 67% CI
Dry Detention Basins	53	±28	25	±15
Wet Basins	65	±32	52	±23
Stormwater Wetland	68	±25	42	±26
Bioretention Filter	90*	±10*	72	±11
Sand Filter	82	±14	46	±21
Infiltration Trench	75*	±10*	55*	±35*
Filter Strips/Grassed Swales	75	±20	41	±33

Table 8. Average percent removal rates of SMPs with corresponding confidence interval.

(* denotes assumed value)

As previously discussed, the published data used to calculate the values shown in Table 8 were reported in either percent drop in concentration between influent and effluent stormwater or percent removal of the total mass load entering the SMP. The values are based only on stormwater treated by the SMP and do not account for any portion of the flow that bypasses the SMP or exits through an overflow outlet. The confidence intervals reported in Table 8 reveal a

large amount of uncertainty in the reported data. The uncertainty is likely due to variations in design and maintenance of the SMPs. If proper maintenance is not performed, removal levels will drop. Also, parameters such as swale slope, pond and wetland residence time, etc. affect removal.

The total amount of TSS that can be expected to be removed by each SMP (except for grassed/vegetative swales) was calculated by multiplying the 20-year total TSS load by 93 percent (*i.e.* estimated percent of runoff treated) and by the corresponding removal rate as shown in Table 8. The results, with a 67% confidence interval, are shown as a function of WQV in Figures 27 through 32 below. Similarly, the amounts of phosphorus that can be expected to be removed from the various SMPs are shown in Figures 33 through 38. As with the Total Present Cost graphs, the contaminant removal estimates are shown on a log-log scale where appropriate. Also, uncertainties in contaminant concentration, 20-year running average precipitation, and percent of contaminant removal by the SMPs were incorporated by the direct analytical method described by Kline (1985).

Since swales are designed for a peak flow rate and not WQV, an estimate of the total load removed by swales over 20 years could not be estimated as a function of WQV. However, if the volume of runoff which will be treated by a swale can be estimated, the removal rates reported in Table 8 for Filter Strips/Grassed Swales may be used to estimate the corresponding total contaminant load removed.

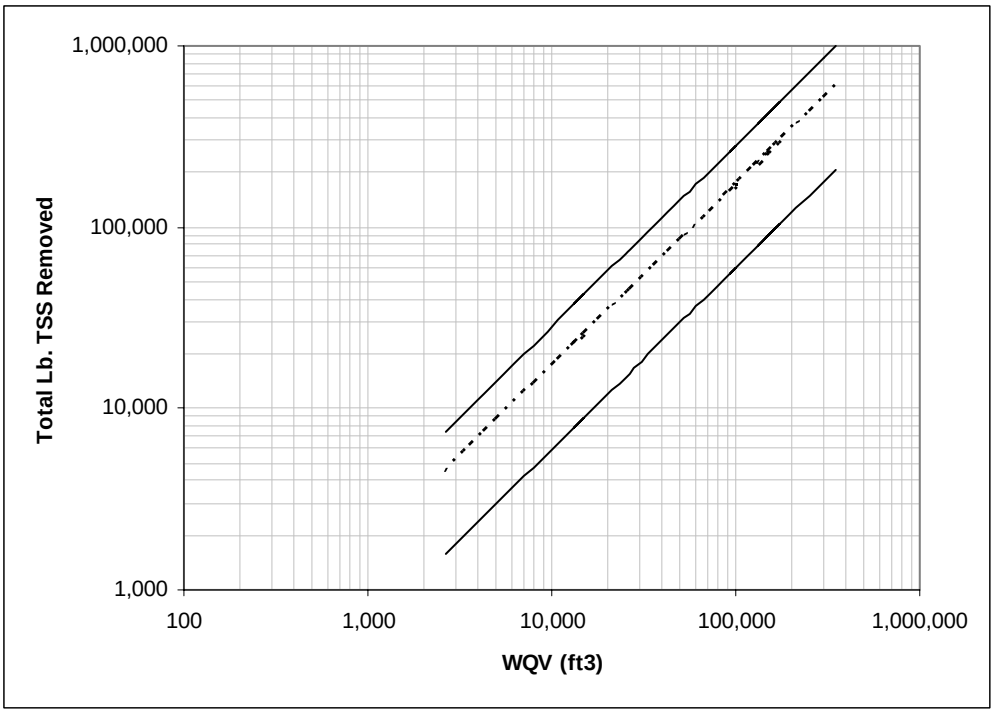

Figure 27. Estimated TSS removed in 20 years for dry detention basins with the 67% CI.

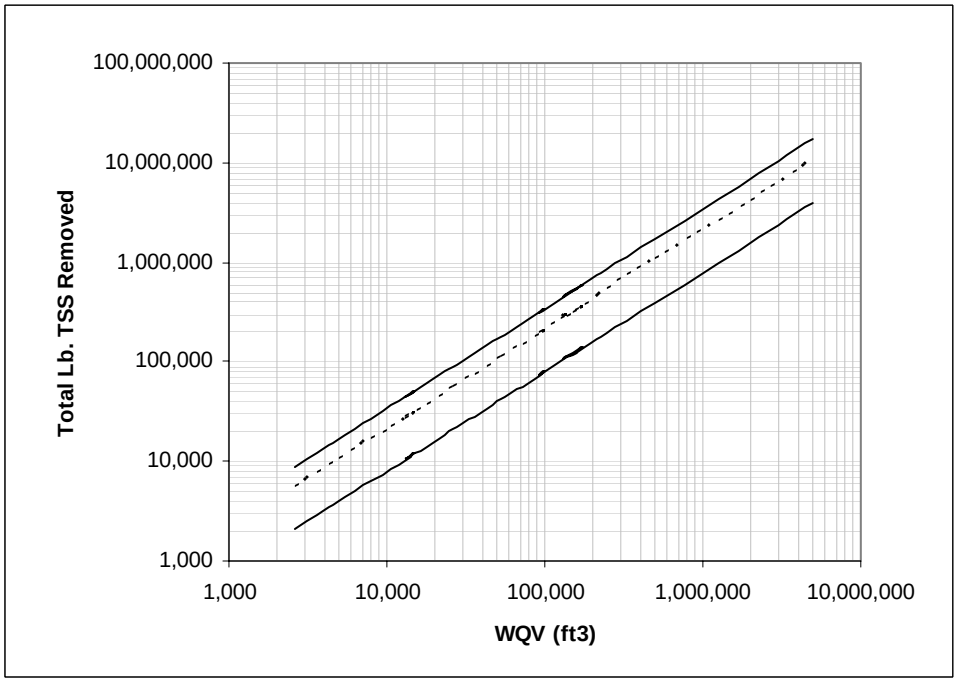

Figure 28. Estimated TSS removed in 20 years for wet basins with the 67% CI.

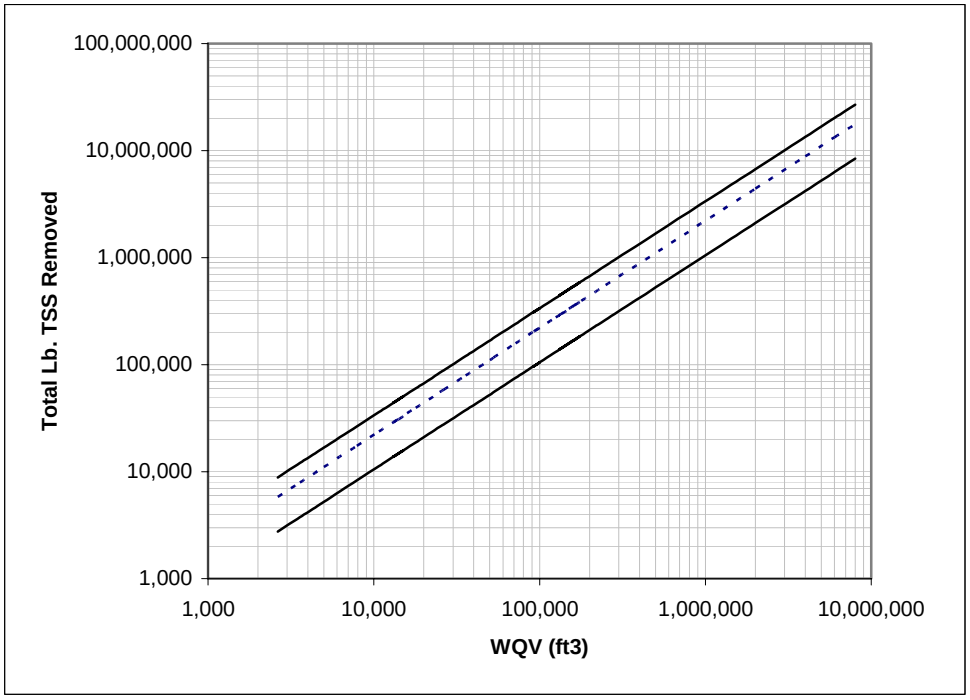

Figure 29. Estimated TSS removed in 20 years for constructed wetlands with the 67% CI.

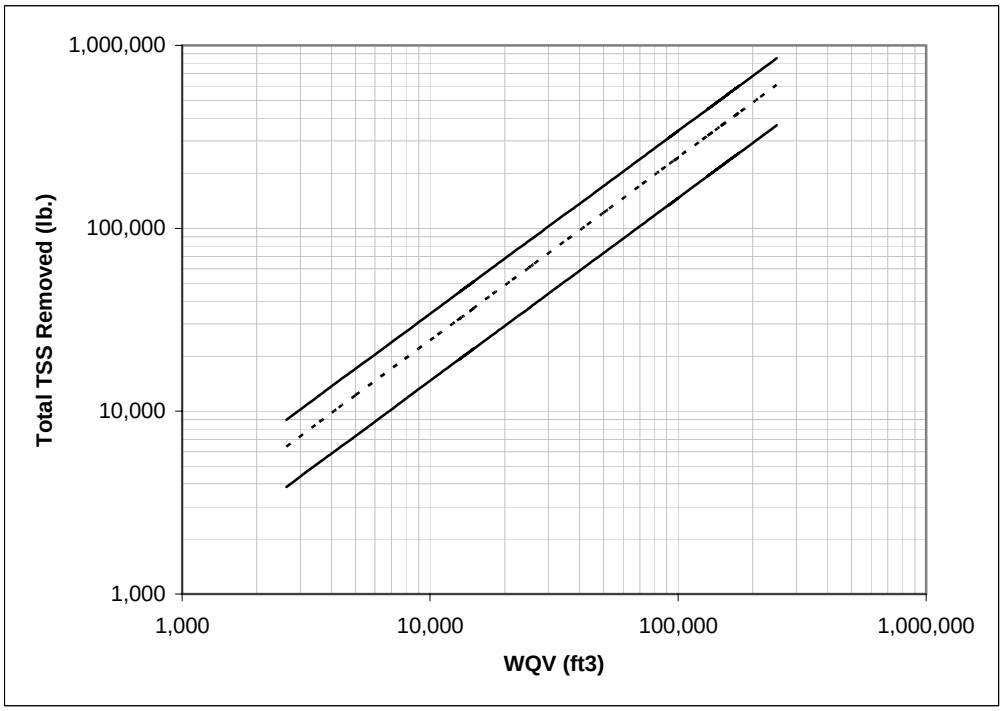

Figure 30. Estimated TSS removed in 20 years for infiltration trenches with the 67% CI.

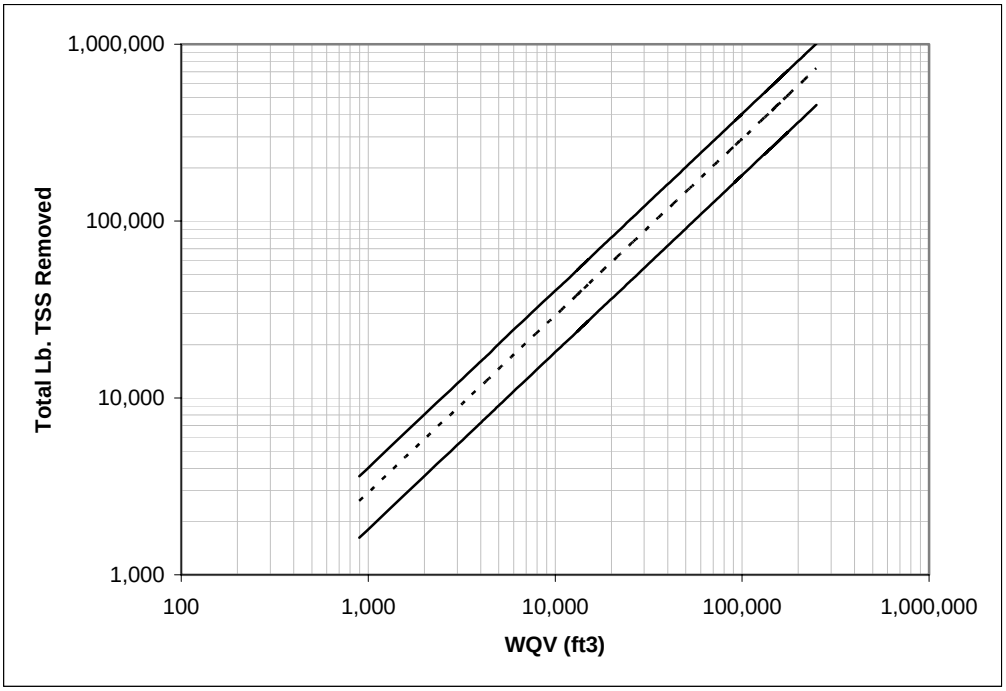

Figure 31. Estimated TSS removed in 20 years for bioinfiltration filters with the 67% CI.

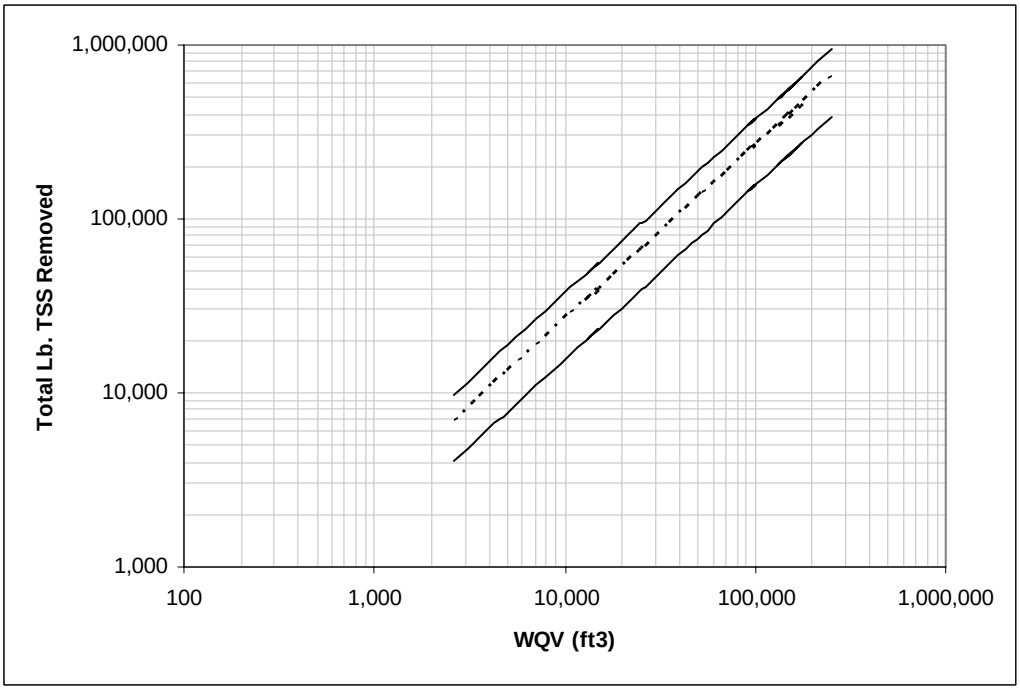

Figure 32. Estimated TSS removed in 20 years for sand filters with the 67% CI.

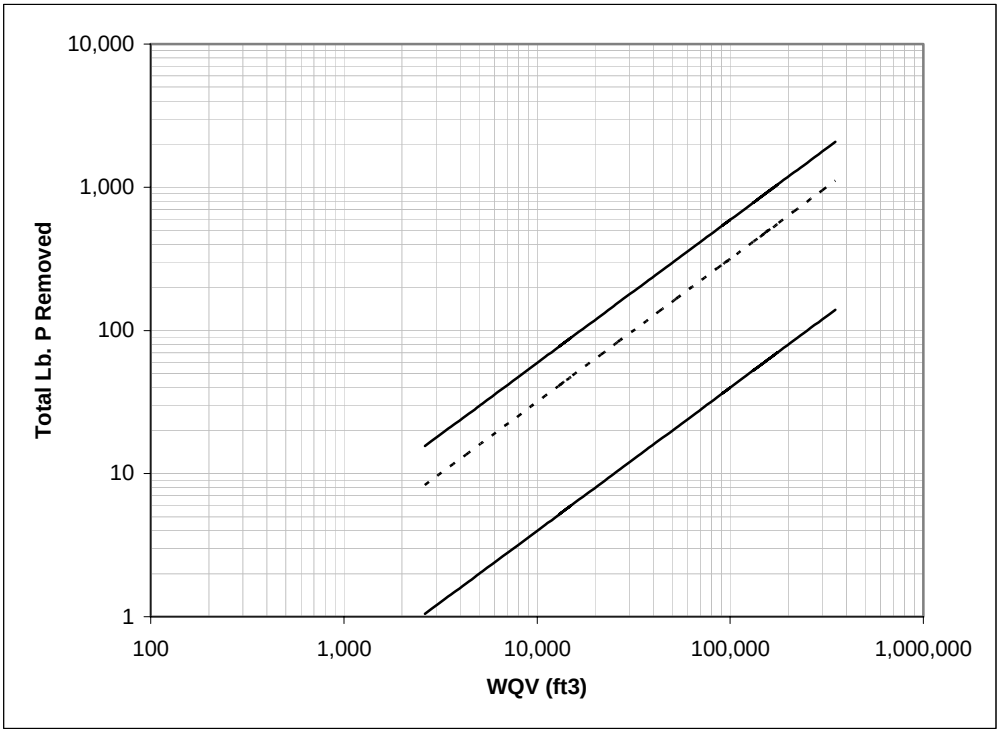

Figure 33. Estimated P removed in 20 years for dry detention basins with the 67% CI.

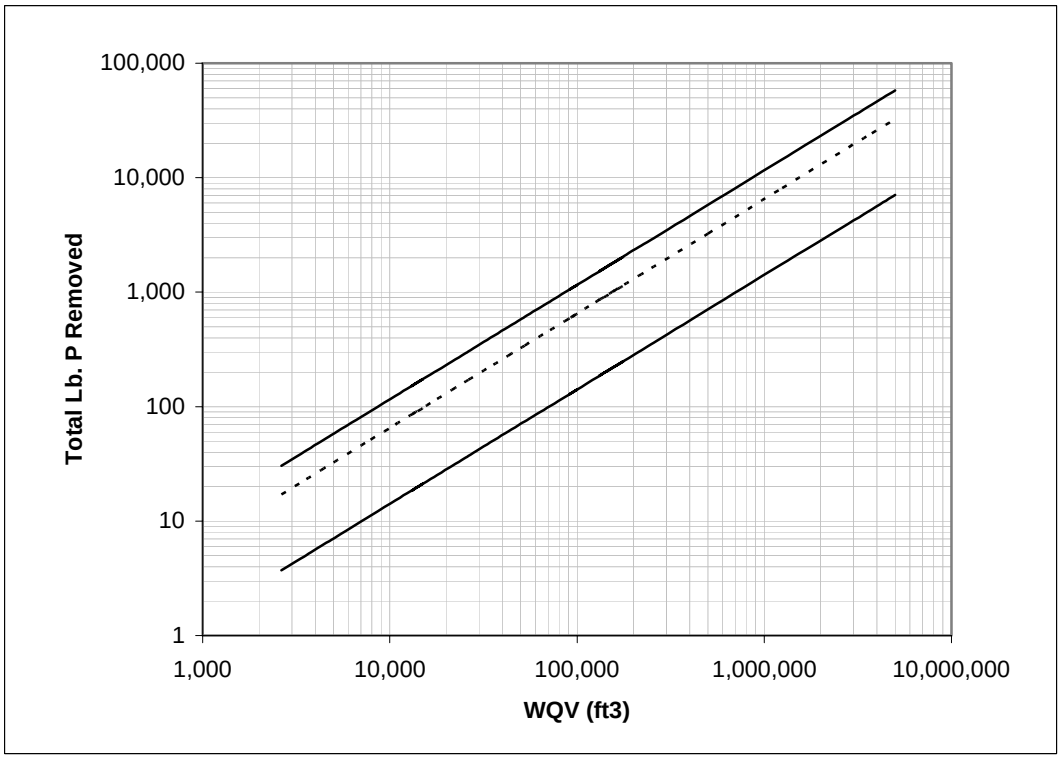

Figure 34. Estimated P removed in 20 years for wet basins with the 67% CI.

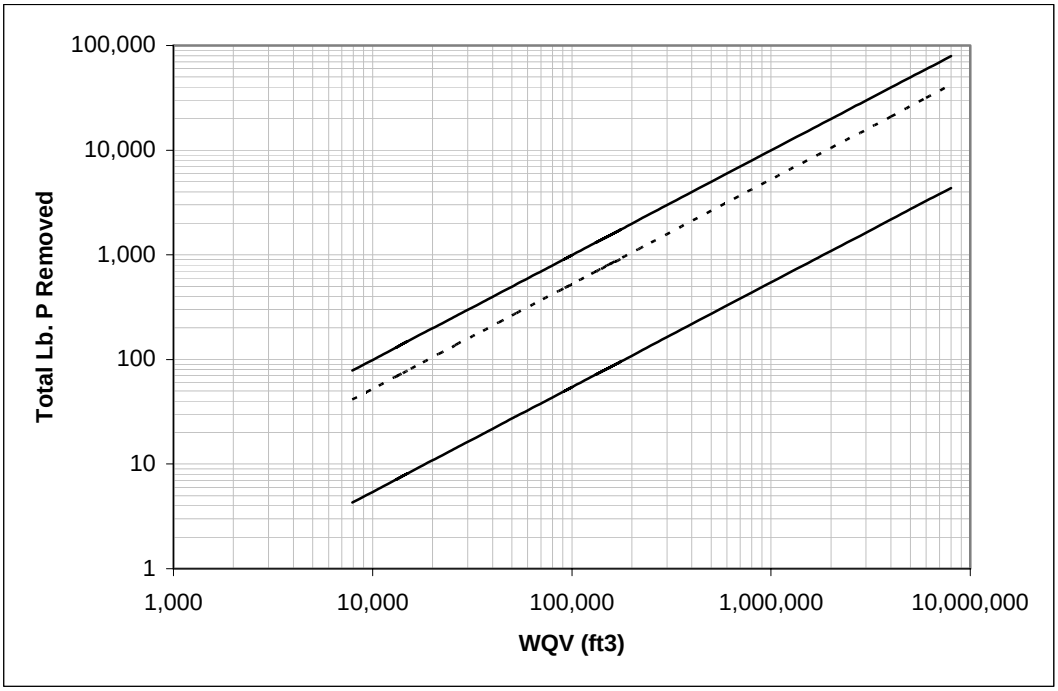

Figure 35. Estimated P removed in 20 years for constructed wetlands with the 67% CI.

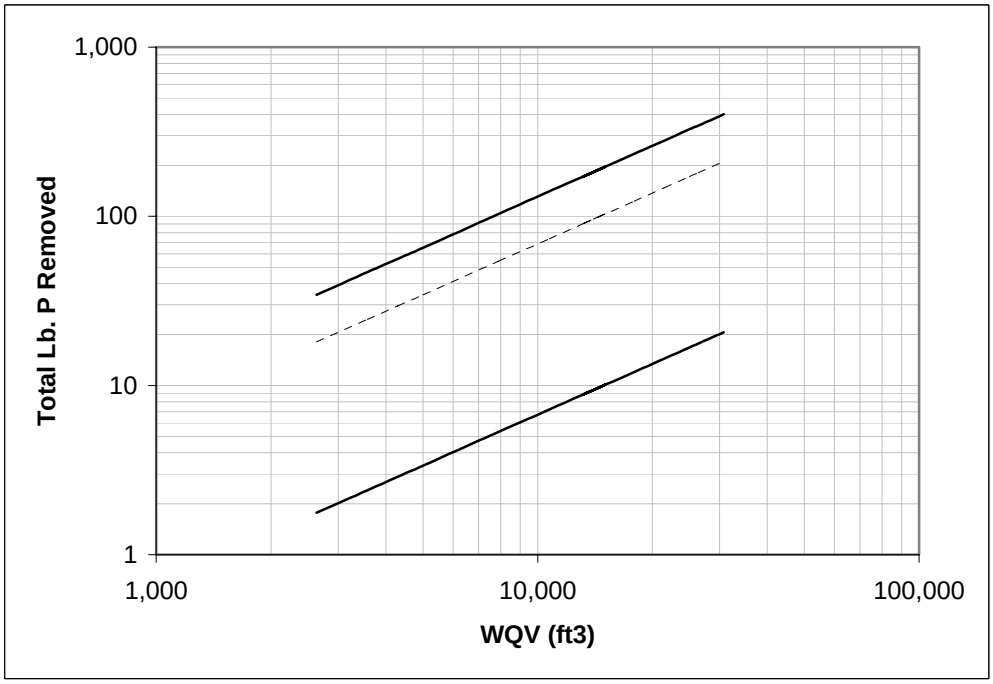

Figure 36. Estimated P removed in 20 years for infiltration trenches with the 67% CI.

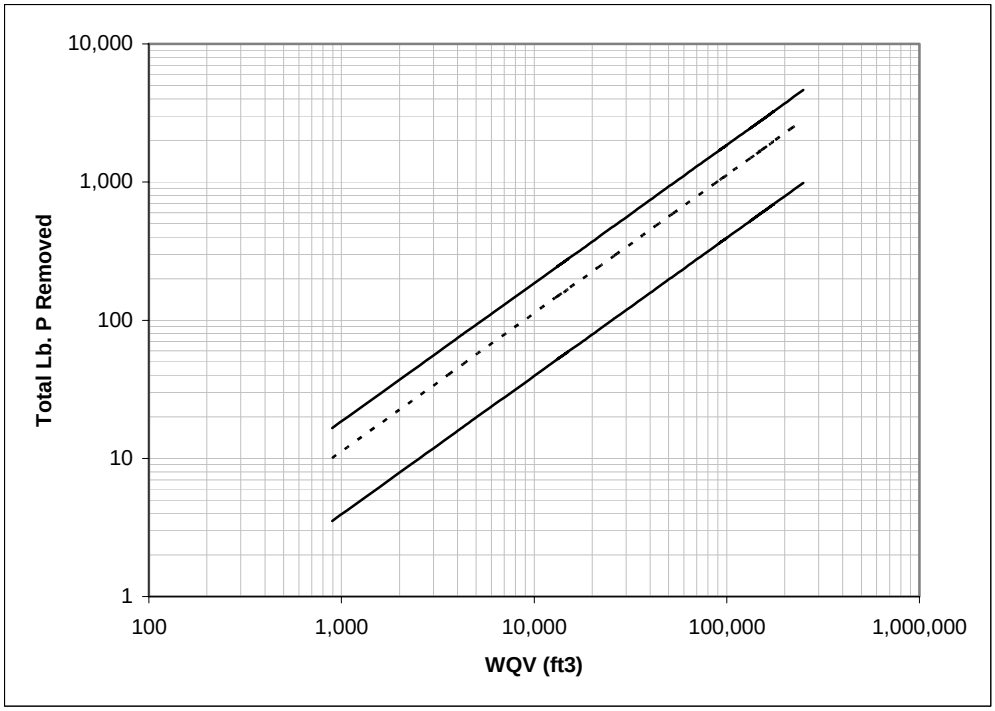

Figure 37. Estimated P removed in 20 years for bioinfiltration filters with the 67% CI.

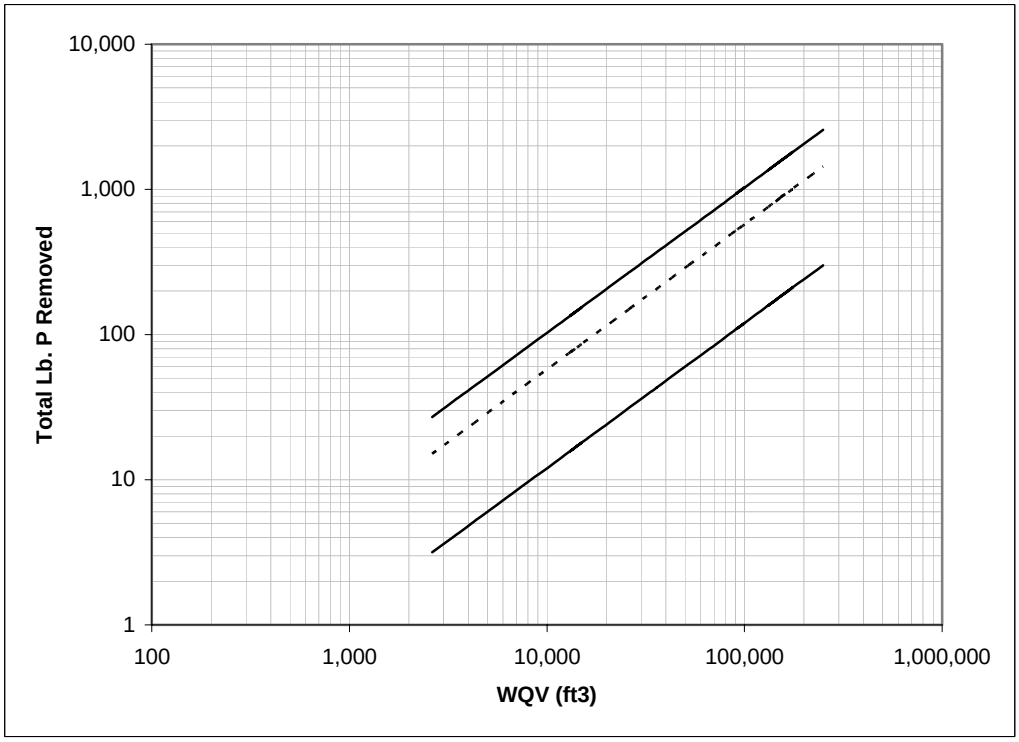

Figure 38. Estimated P removed in 20 years for sand filters with the 67% CI.

Examples

SMPs under consideration for a 50-acre watershed that is 80 percent impervious include a dry detention basin and a constructed wetland. The SMP is to be designed for a 1.45-inch precipitation depth and a comparison of the cost and effectiveness of both SMPs is desired.

Using Equations 1 and 2, the WQV can be determined as follows:

$$\mathrm{WQV} = \left(\frac{43560}{12}\right) * 1.45 * \left(0.05 + 0.009(80)\right) * 50$$

$$\mathrm{WQV} \approx 200{,}000\ \mathrm{ft}^3$$

From Figure 19, the TPC of an average dry detention basin of this size is just over $300,000 with a 67% confidence interval range of about $170,000 to $675,000. A similarly sized average wetland would, based on Figure 21, cost approximately $200,000 with a 67% confidence interval range of $110,000 to $400,000. For a comparison among all SMPs, Table 9 lists the estimated average TPC of all practices analyzed herein for various WQVs. For each SMP, TPCs are not estimated for WQVs that are outside the range of the original construction cost data. Thus some values in Table 9 do not have a cost entry.

Investigation of Table 9 reveals that, based on the collected data and in terms of TPC, wetlands are the least expensive SMP for the range of WQVs listed. This finding is somewhat similar to that of Wossink and Hunt (2003) who concluded that, in terms of construction costs, wetlands were the least expensive of four SMPs (wet ponds, constructed wetlands, sand filters, bioretention basins) for watersheds larger than 10 acres in sandy soils. Contrary to the previous conclusions, the California Stormwater Quality Association (2003) states that wetlands are relatively inexpensive but are typically 25% more expensive than stormwater ponds of equivalent volume. One must also remember that since wetlands generally require more land area, any savings in TPC may potentially be more than offset by larger land acquisition costs.

Over 20 years the estimated TSS removal and 67% confidence interval for the dry detention basin can, with the use of Figure 27, be estimated to be 344,000 pounds with a range of 120,000 pounds to 570,000 pounds. The corresponding wetland TSS removal based on Figure 29 is estimated to be 440,000 pounds with a range of 210,000 pounds to 673,000 pounds.

The phosphorus removed over 20 years can be estimated in a similar manner using Figures 33 and 35. For the dry detention basin the average P removal is approximately 630 pounds with a range of 80 to 1,200 pounds (67% confidence interval). The wetland average P removal is about 1,050 pounds with a range from about 110 pounds to about 2,000 pounds. Thus, for this watershed and design depth, the wetland, on average, would cost less to construct (not including land costs) and it would also remove more TSS and phosphorus. However, land costs must always be considered.

Focusing on associated land costs of each SMP under consideration, Table 3 can be used to estimate the range of expected land area required for each SMP. Using the values based on total watershed area and selecting the high end of each range, the dry detention basin would require 2.0 percent of the total watershed area resulting in a basin land area of 1 acre. Similarly, the wetland would require 5.0 percent of 50 acres or 2.5 acres. If land costs are known, the land areas can be used to estimate land costs associated with each SMP. For example, if land costs were $10,000 per acre, acquiring the land for the detention basin would cost an additional $10,000 and the land for the wetland would cost $25,000. The resulting total cost (now including a rough estimate for land acquisition) for the detention basin and wetland would be $310,000 and $225,000, respectively. Thus, in this relatively low land-cost scenario, the wetland would still be cheaper and more effective, on average. However, if land costs in the vicinity of the project were $250,000 per acre, an average dry detention basin would, including land, have

an estimated total cost of $550,000 and the wetland under consideration would have a total cost of $825,000. Thus, with more expensive land, wetlands are no longer the less expensive option.

	Water Quality Volume (ft^3)				
SMP	**3,000**	**10,000**	**30,000**	**100,000**	**250,000**
Dry Det. Basin	22	46	91	198	359
Wet/Ret. Basin	47	83	141	256	407
Const. Wetland	21	38	68	131	219
Infilt. Trench	84	226	554	--	--
Bioinfilt. Filter	49	122	286	--	--
Sand Filter	86	176	338	691	--

Table 9. Average Total Present Cost (in $1,000) of SMPs at varying WQVs. Land costs are excluded, and need to be determined separately.

However, wetlands are still estimated to remove more TSS and phosphorus, meaning that the parties involved would have to weigh the increased cost of the wetland against its added benefit (*i.e.* more contaminant removal). This example and the intended use for this report are preliminary in nature; to obtain a more accurate estimate of costs a more detailed design of each SMP should be completed.

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Appendix A - Pollutant Removal Capability Table: References, Notes and Notation

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS: A REVIEW

NOTE: The table below provides summary data on the pollutant removal capability of nearly sixty stormwater pond and wetland systems. Each study differs with respect to pond design, number of storms monitored, pollutant removal calculation technique, and monitoring technique, so exact comparisons between studies are not appropriate.

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
DRY ED	1	Lakeridge	VA	28	88.0	0.00	14.0	20.0	(-6.0)	10.0	9.0	(-1.0)		(-10.0)	
	2	London Commons	VA	27	11.4	0.22	A: 29.0 B: 74.0	40.0 56.0		25.0 60.0		17.0 41.0	39.0 25.0	24.0 40.0	
	3	Stedwick	MD	25	34.0	0.30	70.0	13.0		24.0		27.0	62.0	57.0	TKN: 30.0
	4	Maple Run III	TX	17	28.0	0.50	30.0	18.0		35.0	52.0	22.0	29.0	(-38.0)	TOC: 30.0 Cu: 31.0 BOD: 35.0 NH3: 55.0 FColi: 78.0
	5	Oakhampton	MD		16.8	0.50*	87.0	26.0	(-12.0)		(-10.0)				NH4: 53.5
	6	None given	KS	19	12.3	3.42	3.0	19.0	0.0		20.0	16.0	66.0	65.0	

Note: An asterisk (*) denotes an inferred value

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Note: DRY ED stands for Dry Extended Detention. Extended detention systems, as referred to in the above table are synonymous with dry detention basins, and are designed to release all runoff influent within a 24 hour period.

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET PONDS	7	Seattle	WA	5	0.75		86.7	78.4				64.4	65.1	65.2	Cu: 66.5
	8	Boynton Beach	FL	8			91.0		76.0		87.0				TKN: 58.0
	9	Grace Street	MI	18		VB/VR=.52	32.0	12.0		6.0	(-1.0)		26.0		TKN: 7.0 BOD: 3.0
	10	Pitt-AA	MI	6	4872.0	VB/VR=0.52	32.0	18.0			7.0	23.0	62.0	13.0	TKN: 14.0 BOD: 21.0
	11	Unqua	NY	8		VB/VR=3.07	60.0	45.0					80.0		TOC: 7.0
	12	Waverly Hills	MI	29		VB/VR=7.57	91.0	79.0		62.0	66.0	69.0	95.0	91.0	Cu: 57.0 TKN: 60.0 BOD: 69.0
	13	Lake Ellyn	IL	23		VB/VR=10.70	84.0	34.0					78.0	71.0	Cu: 71.0
	14	Lake Ridge	MN	20	315.0	0.08	A: 90.0 B: 85.0	61.0 37.0	11.0 8.0	41.0 24.0	10.0 17.0		73.0 52.0		TKN: 50.0 TKN: 28.0
	15	West Pond	MN	8	76.0	0.15	65.0	25.0			61.0		8.0-79.0	66.0	TOC: 19.0 TKN: 23.0 Cr: 48.0-76.0 Cd: 12.0-91.0
	16	McCarrons	MN	21	608.0	0.19	91.0	78.0		85.0		90.0	90.0		
	17	McKnight Basin	MN	20	725.0	0.22	A: 85.0 B: 85.0	48.0 34.0	13.0 12.0	30.0 14.0	24.0 11.0		67.0 63.0		TKN: 31.0 TKN: 15.0
	18	Monroe Street	WI		238.0	0.26	90.0	65.0	70.0			70.0	70.0	65.0	Cu: 75.0 FColi: 70.0 Pest: 25-50.0 Hydro: 75-90
	19	Runaway Bay	NC	5	437.0	0.33	54.0	24.0						42.0	TKN: 20.0

Note: An asterisk (*) denotes an inferred value

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
	20	Buckland	CT	7	20.0	0.40	61.0	45.0			22.0		18.0–59.0	51.0	Cd: < 0 TKN: 24.0 TOC: 33.0 Cu: 38.0
	21	Highway Site	FL	13	41.6	0.55	65.0	17.0		21.0		7.0	41.0	37.0	
	22	Woodhollow	TX	14	381.0	0.55	54.0	46.0		39.0	45.0	41.0	76.0	69.0	TKN: 26.0 NH3: 28.0 BOD: 39.0 FColi: 46.0
	23	SR 204	WA	5	1.8	0.60	99.0	91.0				69.1	88.2	87.0	Cu: 90.0
	24	Farm Pond	VA		51.4	1.13	85.0	86.0	73.0	34.0					NH3: (–107.0)
	25	Burke	VA	29	27.1	1.22	(–33.3)	39.0	77.0	32.0		21.0	84.0	38.0	
WET PONDS	26	Westleigh	MD	32	48.0	1.27	81.0	54.0	71.0	37.0		35.0	82.0	26.0	TKN: 27.0
(Cont'd)	27	Mercer	WA	5	7.6	1.72	75.0	67.0				76.9	23.0	38.0	Cu: 51.0
	28	I-4	FL	6	26.3	2.35	54.0	69.0			97.0		41.0–94.0	69.0	TOC: 45.0 TKN: 68.0 Cd: 43.0–51.0 Cu: 66.0–81.0
	29	Timber Creek	FL	9	122.0	3.11*	64.0	60.0	80.0	15.0	80.0				
	30	Maitland	FL	30–40	49.0	3.65			90.0		87.0		95.0	96.0	PP: 11.0 Cu: 77.0 NH3: 82.0
	31	Lakeside	NC	5	65.0	7.16	91.0	23.0						82.0	TKN: 6.0

Note: An asterisk (*) denotes an inferred value

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET ED	32	Uplands	ONT	5	860.0		82.0	69.0							FColi: 97.0
	33	East Barrhaven	ONT		2139.0	0.12	52.0	47.0							FColi: 56.0
	34	Kennedy-Burnett	ONT	6	395.0	0.62	98.0	79.0		54.0			39.0	21.0	BOD: 36.0 FColi: 99.0
STORMWATER WETLANDS	35	EWA3	IL				72.0	59.0			70.0				Fe: 48.0
	36	EWA4	IL				76.0	55.0			42.0				Fe: 43.0
	37	EWA5	IL				89.0	69.0			70.0				Fe: 50.0
	38	EWA6	IL				98.0	97.0			95.0				Fe: 92.0
	39	B31	WA	13	461.7	0.01	14.0	(-2.0)			4.0				
	40	PC12	WA	13	214.8	0.03	56.0	(-2.0)			20.0				
	41	McCarrons	MN	21	608.0	0.31	87.0	36.0		24.0		79.0	68.0		
	42	Queen Anne's	MD			0.50*	65.0	39.0	44.0	23.0	55.0				NH4: 55.0 ON: (- 5.0) PP: 7.2
	43	Swift Run	MI	5	1207.0	0.60	85.0	3.0	29.0		80.0	2.0	82.0		BOD: 4.0
	44	Tampa Office Pond	FL	3 - 8	6.3	0.61	64.0	55.0	65.0					34.0	ON: (-3.7)
	45	Highway Site	FL	13	41.6	0.81	66.0	19.0		30.0		18.0	75.0	50.0	
	46	Palm Beach PGA	FL		2340.0	2.00*	50.0	62.0			33.0				NH3: 17.0 BOD: 35.0 TOC: 10.0 TKN: 16.0
ED WETLANDS	47	Benjamin Franklin	VA		40.0	0.08	62.0	14.9	23.6		60.0			(-73.5)	Cd: (-79.8) NH3: 0.0 TKN: 4.4

Note: An asterisk (*) denotes an inferred value

Note: WET ED stands for Wet Extended Detention. Extended detention systems, as referred to in the above table are synonymous with retention basins, and are designed to store runoff until a runoff event displaces the amount of water stored.

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
ED WETLANDS (Cont'd)	48	Tanner's Lake	MN	10	413.0	0.10	A: 62.0 B: 63.0	24.0 7.0	10.0 (-14.0)	36.0 5.0	23.0 1.0		63.0 59.0		TKN: 40.0 TKN: 7.0
	49	Mays Chapel	MD		97.0	0.10*	24.0	16.0	24.0		35.0				NH3: 43.0
	50	Clear Lake	MN		1070.0	0.15*	76.0	54.0	40.0						TKN: 25.0 NH3: 55.0
NATURAL WETLANDS	51	Hidden Lake	FL		55.4	1.08*	83.0	7.0	(-109.0)	(-1.6)	80.2		54.0	40.0	ON: (-24.0) Cu: 40.0 NH3: 62.0 Cd: 70.0 BOD: 81.0
	52	Wayzata	MN		73.0	1.25*	94.0	78.0					94.0	82.0	NH3: (-44.0) Cd: 67.0 Cu: 80.0
POND/WETLAND SYSTEMS	53	Lake Munson	FL	3	23393.0		92.0	64.0		11.0	15.0	28.0	55.0	59.0	NH4: (-39.0) TKN: 11.0 NO3: 15.0 BOD: 42.0
	54	Carver Ravine	MN	15	170.0	.30*	A: 46.0 B: 20.0	24.0 1.0	21.0 1.0	15.0 (-6.0)	18.0 9.0		42.0 6.0		TKN: 14.0 TKN: (-10.0)
	55	McCarrons	MN	21	608.0	>0.50	94.0	78.0		83.0		93.0	90.0		
	56	Lake Jackson	FL		2230.0	.88*	96.0	90.0		75.0	70.0				NH4: 37.0
	57	Highway Site	FL	13	41.6	>1.35	89.0	36.0		43.0			84.0	67.0	
	58	Long Lake	ME	11	18.0	2.0*	95.0	92.0							

Note: An asterisk (*) denotes an inferred value

Note: ED Wetlands stand for Extended Detention Wetlands. Extended detention systems, as referred to in the above table are similar to wetlands, but may store stormwater runoff for a longer period than typical wetland systems. Natural Wetlands refers to systems that have been modified or utilized for stormwater treatment from natural wetlands, as opposed to constructed systems.

Appendix B – Data used to estimate average SMP effectiveness

Appendix B1 – Dry Detention Ponds

Dry Detention Ponds								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#1	77	10	0.188	0.112	87	40	Conc. Basis
Winer, Nat'l Poll. Rem. Database, 2000	#3	68	38	0.21	0.18	44	14	"
Winer, Nat'l Poll. Rem. Database, 2000	#6	98	28	0.35	0.27	71	23	"
Winer, Nat'l Poll. Rem. Database, 2000	#6	--	--	--	--	71	14	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	I5/605 Int	--	--	--	--	5	-4	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	Manchester	--	--	--	--	70	42	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	SR56/I5	--	--	--	--	43	21	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	SR78/I5	--	--	--	--	55	33	"
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Maple Run III	--	--	--	--	30	18	Mass Basis
Commings, Booth, & Horner, 2000. Stormwater Pollutant Removal in two wet ponds in Bellevue, WA. Jour. Environ. Engrg, 126(4):321-330	--	--	--	--	--	61.60	20.00	"
Stanley, 1996. Pollutant Removal by a stormwater dry detention pond. Water Environ. Research, 68(6):1076-1083.	--	127	32	0.41	0.3	75	27	Conc. Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	61	"
BMP Database. Greenville Pond, Greenville, NC	--	--	--	--	--	--	27	"

Dry Extended Detention Pond (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Lakeridge, VA	--	--	--	--	14	20	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	London Commons, VA	--	--	--	--	52	48	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Stedwick, MD	--	--	--	--	70	13	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Oakhampton, MD	--	--	--	--	30	18	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Unknown	--	--	--	--	87	26	unknown basis
Pope, L..M. and L.G. Hess, Date unknown. "Load Detention Efficiencies in a Dry-Pond Basin," from Kansas State Library.	Topeka, KS	--	--	--	--	3	19	Mass Basis

Appendix B2 – Wet Basins

Wet Basins								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Uplands, Ont	--	--	--	--	82	69	Unknown Basis
"	E. Barrhaven, Ont	--	--	--	--	52	47	"
"	Kennedy-Burnett, Ont	--	--	--	--	98	79	"
Winer, Nat'l Poll. Rem. Database, 2000	#11	177	39	0.761	0.214	78	72	Concentration Basis
"	#11	--	--	--	--	60	46	Mass Basis
"	#13	61	49	0.162	0.103	20	36	Concentration Basis
"	#13	--	--	--	--	20	37	Mass Basis
"	#14	16.2	2.9	0.087	0.045	82	48	Concentration Basis
"	#15	--	--	--	--	87	79	Mass Basis
"	#16	--	--	--	--	80.00	37.00	Concentration Basis
"	#17	--	--	0.88	0.13		85	Concentration Basis
"	#18	71	12	0.232	0.112	83	52	Concentration Basis
"	#22	45	14	0.651	0.164	69	75	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#22	--	--	--	--	67	57	Mass Basis
"	#23	28	11	0.4	0.176	61	56	Concentration Basis
"	#23	--	--	--	--	71	62	Mass Basis
"	#24	131	7	0.497	0.053	95	89	Concentration Basis
"	#24	--	--	--	--	94	90	Mass Basis
"	#26	128	9	0.3	0.04	93	87	Concentration Basis
"	#27	22.8	8.9	0.095	0.077	61	19	Concentration Basis
"	#28	20.6	6.5	0.136	0.035	68	74	Concentration Basis
"	#29	7	15	0.272	0.155	-114	43	Concentration Basis

Wet Basins (cont'd)								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#29	--	--	--	--	54	69	Mass Basis
"	#30	52	23	0.3	0.4	56	-33	Concentration Basis
"	#30	--	--	--	--	65	25	Mass Basis
"	#31	47	54	0.247	0.195	-15	21	Concentration Basis
"	#31	--	--	--	--	61	45	Mass Basis
"	#38	45	19	0.17	0.12	58	29	Concentration Basis
"	#42	--	--	--	--	7	40	Concentration Basis
"	#43	--	--	--	--	80.00	80.00	Mass Basis
"	#44	--	--	--	--	75.00	22.00	Concentration Basis
"	#44	--	--	--	--	83.00	37.00	Mass Basis
"	#45	1113	63	2.91	0.27	94.34	90.72	Concentration Basis
"	#45	--	--	--	--	93.00	79.00	Mass Basis
"	#47	--	--	--	--	85.00	48.00	Mass Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#50	134	28	0.45	0.21	79.10	53.33	Concentration Basis
"	#51	--	--	0.12	0.08	--	33	Concentration Basis
"	#52	--	--	0.14	0.08	--	43	Concentration Basis
"	#52	--	--	--	--	93	45	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Wood-hollow	--	--	--	--	54	46	Mass Basis
Cazanacli, 2003. Comparing Sediment Removal Rates of Manufactured BMPs to Wet Basins. Water Resources Conf. Oct. 28, 2003. Brooklyn Park, MN		--	--	--	--	70	--	Mass Basis
Commings, Booth, & Horner, 2000. Stormwater Pollutant Removal in two wet ponds in Bellevue, WA. Jour. Environ. Engrg, 126(4):321-330		--	--	--	--	81	--	Mass Basis
Mallin, Ensign, Wheeler, Mayes, 2002. Surface Water Quality-Pollutant Removal Efficacy of Three Wet Detention Ponds. Jour. Environ Quality 31:654-660.	Ann McCrary	10.5	3.7	0.061	0.047	65	23	Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection. (Data for 4 wet ponds receiving rainfall)		--	--	--	--	78	53	Rainfall Event. Appears to be Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection. (Data for 4 wet ponds receiving snowmelt)		--	--	--	--	39	16	Snowmelt Event. Appears to be Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	76	29	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	93	73	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	94	69	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	68	55	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	64	60	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	--	81	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	--	62	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	66	38	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	82	91	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	60	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	70	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	55	65	Mass Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Lake Side Pond)	--	--	--	--	--	93	45	Concentration Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Waterford Pond)	--	--	--	--	--	41	--	Concentration Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Runaway Bay Pond)	--	--	--	--	--	62	36	Concentration Basis
BMP Database. Site: Lake Ridge Det. Pond, Woodbury, MN	--	--	--	--	--		58	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
BMP Database. Site: Lakeside Pond, Charlotte, NC.	--	--	--	--	--	--	44	Concentration Basis
	--	--	--	--	--	--		Concentration Basis
BMP Database. Site: Pittsfield Ret. Pond, Ann Arbor, MI	--	--	--	--	--	--	15	Concentration Basis
BMP Database. Site: Tampa Office Pond, Tampa, FL	--	--	--	--	--	--	77	Concentration Basis
BMP Database. Site: Traver Creek Ret. Pond, Ann Arbor, MI	--	--	--	--	--	--	40	Concentration Basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Seattle, WA	--	--	--	--	87	78	Concentration Basis
"	Boynton Beach	--	--	--	--	91	--	"
"	Grace Street	--	--	--	--	32	12	"
"	Pitt-AA	--	--	--	--	32	18	"
"	Unqua	--	--	--	--	60	45	"
"	Waverly Hills	--	--	--	--	91	79	"
"	Lake Ellyn, IL	--	--	--	--	84	34	"
"	Lake Ridge, MN	--	--	--	--	88	49	"
"	West Pond, MN	--	--	--	--	25	--	"
"	McCarrons, MN	--	--	--	--	78	--	"

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	McKnight Basin, MN	--	--	--	--	41	13	Concentration Basis
"	Monroe St., WI	--	--	--	--	65	70	"
"	Runaway Bay, NC	--	--	--	--	24	--	"
"	Buckland, CT	--	--	--	--	61	45	"
"	Highway Site, FL	--	--	--	--	65	17	"
"	Woodhollow, TX	--	--	--	--	54	46	"
"	SR204, WA	--	--	--	--	99	91	"
"	Farm Pond, VA	--	--	--	--	85	86	"
"	Burke, VA	--	--	--	--	-33	39	"
"	Westleigh, MD	--	--	--	--	81	54	"
"	Mercer, WA	--	--	--	--	75	67	"
"	I-4, FL	--	--	--	--	54	69	"
"	Timber Creek, FL	--	--	--	--	64	60	"
"	Lakeside, NC	--	--	--	--	91	23	"

Appendix B3. Constructed Wetlands

Constructed Wetlands								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#57	--	--	--	--	93	76	Mass Basis
"	#59	45	42	0.17	0.19	7	-12	Concentration Basis
"	#61	123.6	26.9	0.447	0.11	78	75	Concentration Basis
"	#61	--	--	--	--	78	79	Mass Basis
"	#62	--	--	--	--	61	33	Mass Basis
"	#62	--	--	--	--	50	28	Concentration Basis
"	#63	--	--	--	--	68	62	Mass Basis
"	#64	74.7	20.8	0.35	0.26	72	26	Concentration Basis
"	#64	--	--	--	--	96	70	Mass Basis
"	#65	--	--	--	--	66	4	Mass Basis
"	#67	134	33	0.45	0.201	75	55	Concentration Basis
Forbes, 2004 #80	--	--	--	--	--	--	9	Concentration Basis
"	--	--	--	--	--	--	16	Concentration Basis
"	--	--	--	--	--	--	21	Concentration Basis
"	--	--	--	--	--	--	47	Concentration Basis
"	--	--	--	--	--	--	62	Concentration Basis

Constructed Wetlands (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Forbes, 2004 #80	--	--	--	--	--	--	51	Concentration Basis
Bulc, 2003 #52	--	42	11	0.4	0.1	74	75	Concentration Basis
ASCE, 2002 #81	--	--	--	--	--	--	23	Concentration Basis
"	--	--	--	--	--	--	61	Concentration Basis
"	--	--	--	--	--	--	34	Concentration Basis
"	--	--	--	--	--	--	45	Concentration Basis
"	--	--	--	--	--	--	29	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	LaCosta WB	--	--	--	--	91	2	Concentration Basis
Carleton, Grizzard, Godrej, Post, Lampe, and Kenel, 2000. Performance of a constructed wetlands in treating urban stormwater runoff. Water Environ. Research 72(3):295-304.	Franklin Farms	--	--	--	--	93	76	For storms < wetland capacity. Mass Basis
"	Crestwood	--	--	--	--	58	46	Median - Mass Basis
Dierberg, DeBusk, Jackson, Chimney, Pietro, 2002. Submerged aquatic vegetation-based treatment wetlands for removing phosphorus from agricultural runoff: response to hydraulic and nutrient loading. Water Research 36.	1.5 day HRT	--	--	--	--	--	51	Concentration Basis
"	3.5 day HRT	--	--	--	--	--	73	Concentration Basis
"	7 day HRT	--	--	--	--	--	79	Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection.	--	--	--	--	--	82	68	Unknown Basis

Constructed Wetlands (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection.	--	--	--	--	--	4	7	Unknown Basis
BMP Database. Site: Franklin Wood, Chantilly, VA	--	--	--	--	--	--	5	Concentration Basis
BMP Database. Franklin Wetland, Chantilly, VA	--	--	--	--	--	--	23	Concentration Basis
BMP Database. Site: Hidden River Wetland, Tampa, FL	--	--	--	--	--	--	61	Concentration Basis
BMP Database. Site: Queen Anne's Pond, Centreville, MD	--	--	--	--	--	--	34	Concentration Basis
BMP Database. Site: Swift Run Wetland, Ann Arbor, MI	--	--	--	--	--	--	45	Concentration Basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	EWA3, IL	--	--	--	--	72	59	Unknown Basis
"	EWA4, IL	--	--	--	--	76	55	Unknown Basis
"	EWA5, IL	--	--	--	--	89	69	Unknown Basis
"	EWA6, IL	--	--	--	--	98	79	Unknown Basis
"	B31, WA	--	--	--	--	14	-2	Unknown Basis
"	PC12, WA	--	--	--	--	56	-2	Unknown Basis
"	McCarrons, MN	--	--	--	--	87	36	Unknown Basis
"	Queen Anne's, MD	--	--	--	--	65	39	Unknown Basis
"	Swift Run, MI	--	--	--	--	85	3	Unknown Basis
"	Tampa Office Pond, FL	--	--	--	--	64	55	Unknown Basis
"	Highway Site, FL	--	--	--	--	66	19	Unknown Basis
"	Palm Beach, PGA, FL	--	--	--	--	50	62	Unknown Basis

Appendix B4. Bioretention Filters

Bioretention Filters								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#93	--	--	0.52	0.18	--	65.38	Concentration Basis
Winer, Nat'l Poll. Rem. Database, 2000	#93	--	--	--	--	--	65	Mass Basis
Idaho DEQ BMP Manual (undated)	--	--	--	--	--	90	75	unknown
Caltrans 2002 as ref'd in "Bioretention TC32," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	90	76	unknown
Low Impact Development (LID) A Literature Review, EPA-841-B-00-005. USEPA, Oct. 2000	Beltway Plaza, Greenbelt, MD	--	--	--	--	--	65	unknown
Low Impact Development (LID) A Literature Review, EPA-841-B-00-005. USEPA, Oct. 2000	Peppercorn Plaza, Landover MD	--	--	--	--	--	87	unknown

Appendix B5. Sand Filters

Sand Filters								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#101	76.2	16.84	0.52	0.18	78	65	Concentration Basis
"	#101	--	--	--	--	79	66	Mass Basis
"	#102	16.1	10.3	0.08	0.06	36	25	Concentration Basis
"	#103	97.2	11.8	0.123	0.065	88	47	Concentration Basis
"	#104	204	3.5	0.356	0.126	98	65	Concentration Basis
"	#104	--	--	--	--	98	66	Mass Basis
"	#105	--	--	--	--	87	61	Mass Basis
"	#106	--	--	--	--	92	80	Mass Basis
"	--	--	--	--	--	--	--	Mass Basis
"	--	--	--	--	--	--	--	Mass Basis
"	#107	--	--	--	--	75	59	Mass Basis
"	#108	--	--	--	--	86	19	Mass Basis
"	#109	273	32	0.37	0.11	88	70	Concentration Basis
"	#110	--	--	--	--	98	61	Mass Basis
"	#111	--	--	--	--	78	27	Mass Basis
"	#112	449	112	0.4	0.14	75	65	Concentration Basis
"	#113	--	--	--	--	60	--	Mass Basis

Sand Filters (cont'd)								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Division, 1990 #79	--	--	--	--	--	--	0	Concentration Basis
"	--	--	--	--	--	--	45	Concentration Basis
"	--	--	--	--	--	--	59	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	E Reg MS	--	--	--	--	75	23	Concentration Basis
Glick, et al, 1998. Referenced in above report (pg 2-10)	--	--	--	--	--	89	59	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Foothill MS	--	--	--	--	86	21	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Term P&R	--	--	--	--	89	24	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Escon MS	--	--	--	--	58	37	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	LaCosta P&R	--	--	--	--	91	30	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	SR78/I%P&R	--	--	--	--	87	29	Concentration Basis
Glick, et al, 1998. Monitoring and evaluation of stormwater quality control basins in watershed mgt: Moving from theory to	--	--	--	--	--	89	59	Concentration Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Highwood Apt	--	--	--	--	86	19	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Barton Creek Squ. Mall	--	--	--	--	75	59	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Jollyville	--	--	--	--	87	61	Mass Basis

Appendix B6. Filter Strips/Grass Swales

Filter Strips/Grass Swales								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Barrett, Walsh, Malina and Charbeneau, 1998. Performance of Vegetative Controls for Treating Highway Runoff. Jour. Environ. Engrg. 1121-1128. US 183 median.	US 183	157	21	0.55	0.31	87	44	Concentration Basis/Grassy Median
"	MoPac expway	190	29	0.24	0.16	85	33	Concentration Basis/Grassy Median
BMP Data Base. Austin, TX. Site: Alta Vista planned development det. w/ swales	--	--	--	--	--	29	84	Concentration Basis/Grassy Median
EPA Data Base: Dayton Swale - Dayton Biofilter with grassed Swale (Site ID 1645113921)	--	--	--	0.183	0.192	--	-5	"
BMP Data Base, Seattle. Site: Dayton Biofilter-Grass Swale	--	--	--	--	--	--	-5	"
"Field Test of Grassed Swale Performance in Removing Runoff Pollution," by Jan-Tai Kuo, Shaw L. Yu et al. University of VA	Goose Creek-upper	--	--	--	--	29.7	73.4	Mass Basis/Swale
"	Goose Creek-lower	--	--	--	--	97.2	96.8	Mass Basis/Swale
"	Goose Creek-entire	--	--	--	--	94	98.6	Mass Basis/Swale
Caltrans 2002 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	77	8	Mass Basis/Dry Swale
Goldberg, 2003 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	67.8	4.5	Mass Basis/Grassed Channel
Seattle Metro & Washington Dept. of Ecology, 1992 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	60	45	"
"	--	--	--	--	--	83	29	"

Filter Strips/Grass Swales (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Wang et al., 1981 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	80	--	Mass Basis/Dry Swale
Dorman et al., 1989 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	98	18	"
Harper, et al., 1988 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	87	83	"
Kercher et al., as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	99	99	"
Harper, et al., 1988 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	81	17	Mass Basis/Wet Swale
Koon, 1995 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	67	39	"
City of Austin. 1995 (draft). Characterization of Stormwater Pollution for the Austin, Texas Area. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, Texas. As found at http://www.fhwa.	--	--	--	--	--	68	43	Concentration Basis
Yu, S.L., S.L. Barnes, and V.W. Gerde. 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Department of Transportation, Report No. FHWA/VA-93-R16, Richmond, VA. As found at http://www.fhwa.dot.gov/environment/ultraurb/3fs1	--	--	--	--	--	49	33	Mass Basis

Filter Strips/Grass Swales (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Yu, S.L., and R.J. Kaighn. 1995. The Control of Pollution in Highway Runoff Through Biofiltration. Volume II: Testing of Roadside Vegetation. Virginia Department of Transportation, Report No. FHWA/VA-95-R29, Richmond, VA. As found at http://www.fhwa.dot.g	--	--	--	--	--	30	0	Concentration Basis
Khan, Z., C. Thrush, P. Cohen, L. Kulzer, R. Franklin, D. Field, J. Koon, and R. Horner. 1992. Biofiltration Swale Performance, Recommendations, and Design Considerations. Municipality of Metropolitan Seattle, Water Pollution Control Department, Seattle,	--	--	--	--	--	83	29	Mass Basis
FHWA, 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032.	--	--	--	--	--	83	29	Mass Basis/200 ft swale
"	--	--	--	--	--	60	45	Mass Basis/100 ft swale
Winer, Nat'l Poll. Rem. Database, 2000	#127	--	--	--	--	67.8	4.5	Concentration Basis/Grassed Channel
Winer, Nat'l Poll. Rem. Database, 2001	#128	--	--	--	--	83	29	"
Winer, Nat'l Poll. Rem. Database, 2002	#129	--	--	--	--	60	45	"
Winer, Nat'l Poll. Rem. Database, 2003	#130	--	--	--	--	81	17	Mass Basis/Wet Swale
Winer, Nat'l Poll. Rem. Database, 2004	#131	--	--	--	--	67	39	Concentration Basis/Wet Swale
Winer, Nat'l Poll. Rem. Database, 2000	#126	--	--	--	--	80	--	Mass Basis/Dry Swale
Winer, Nat'l Poll. Rem. Database, 2000	#123	--	--	--	--	98	18	"
Winer, Nat'l Poll. Rem. Database, 2001	#124	--	--	--	--	87	83	"
Winer, Nat'l Poll. Rem. Database, 2002	#125	--	--	--	--	99	99	"

Appendix B7. Infiltration Trenches

Infiltration Trenches								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	Study 132	--	--	0.66	0.63	--	4.5	--
Winer, Nat'l Poll. Rem. Database, 2000	Study 133	--	--	0.2	0	--	100.0	--
Winer, Nat'l Poll. Rem. Database, 2000	Study 134	--	--	0.24	0	--	84.0	--
IDAHO BMP Manual	--	--	--	--	--	90	55	--

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Willingness to Pay for Local Coho Salmon Enhancement in Coastal Communities

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Abstract *Salmon restoration and enhancement are dominant environmental policy issues in Oregon and Washington. In response to salmon species listings under the Endangered Species Act, salmon protection and recovery actions are being implemented throughout the Pacific Northwest at substantial opportunity costs. In this paper, we examine the willingness to pay (WTP) of coastal residents for local coho salmon enhancement programs. A contingent valuation study is completed using survey responses from five rural, coastal communities of Oregon and Washington, where coho salmon are prevalent. Our empirical results indicate that coastal residents are willing to pay for local coho salmon enhancement and that WTP varies considerably with individual opinions of the merit of the enhancement program.*

Key words Willingness to pay, coho salmon, contingent valuation.

JEL Classification Codes Q28, H00, D60.

Introduction

Salmon restoration and enhancement are dominant environmental policy issues in Oregon and Washington State (Lichatowich 1999; Taylor 1999). Within these two states, 18 salmon and steelhead stocks were listed as threatened or endangered under the Endangered Species Act (ESA) in 2001. An additional three stocks were candidates for listing in 2001. Policy actions implemented and proposed to address the marked decline in salmon populations include government actions at local, state, and national levels. Habitat rehabilitation, restrictions on sport and commercial

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catch, changes in operation of hydroelectric power facilities, and hatchery programs are examples of actions undertaken to restore and enhance salmon stocks.

Salmon restoration and enhancement involves fundamental tradeoffs in the use and appreciation of natural resources, and because the lifecycle of anadromous salmon involves migration between rivers and the ocean, these tradeoffs occur over wide expanses of the landscape. As more salmon species are listed under ESA, policymakers are increasingly faced with the consequences of these tradeoffs; namely the conflicts between salmon preservation uses and other economic uses of water and land (Huppert 1999). While the costs of federal and state salmon enhancement programs are distributed widely across taxpayers, other costs are incurred locally at the community level. Concerns over the concentration of such costs at the community level are commonly voiced in petitions regarding the listing of salmonid species as threatened under ESA.

In this paper, we examine the willingness to pay (WTP) of coastal residents for local coho salmon enhancement programs using contingent valuation methods. A range of salmon restoration and enhancement options with diverse opportunity costs is available to decision-makers. Given this abundance of options, we believe that an improved understanding of local willingness to pay for specific protections may inform future salmon restoration and protection decisions. The National Marine Fisheries Service (NMFS) groups West Coast salmon and steelhead species into 51 distinct population segments entitled "evolutionarily significant units" or ESUs, that are eligible for listing under the Endangered Species Act.[1] Coho salmon are grouped into six West Coast ESUs: Central California, Southern Oregon/Northern California Coasts, Oregon Coast, Puget Sound/Strait of Georgia, Lower Columbia River/Southwest Washington, and Olympic Peninsula. The Central California, Southern Oregon/Northern California, and Oregon Coast ESUs were listed as threatened in 1996, 1997, and 1998, respectively. The Puget Sound/Strait of Georgia and Lower Columbia River/Southwest Washington ESUs are candidates for listing (US Department of Commerce 1999).

Substantial government-sponsored efforts to protect and enhance the listed salmon and steelhead stocks have heightened public awareness of salmon conservation and management in the Pacific Northwest. During the course of our survey of coastal residents, the listing of Oregon Coast coho ESU as threatened was being contested in Oregon District Court by the Pacific Legal Foundation (*Alsea River Alliance vs. Evans*) because of the exclusion of hatchery fish in the listing. This case, and other petitions, have caused NMFS to reconsider the listing of salmon ESUs under ESA.[2] We anticipate that the legal contests over the salmon listings will continue and believe that such contests underscore the value of understanding public opinion and support for salmon enhancement programs, such as the one featured in this paper. Furthermore, as government agencies increasingly involve stakeholder groups

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[1] NOAA's National Marine Fisheries Service (NMFS) establishes two criteria for a stock to be considered a "distinct population segment" or ESU under the federal Endangered Species Act (ESA): "(1) It must be substantially reproductively isolated from other conspecific population units; and (2) It must represent an important component in the evolutionary legacy of the species" (*Federal Register*, Nov. 20, 1991).

[2] The Pacific Legal Foundation's lawsuit (Alsea River Alliance vs. Evans Case) was filed in US District Court in 1999, questioning the inconsistent treatment of wild and hatchery fish under the ESA listing. In September 2001, the US District Court vacated NMFS' listing for the Oregon coastal coho because the threatened species listing did not include hatchery fish. The Alsea Valley Alliance v. Evans decision was stayed by the 9th Circuit Court in December 2001 pending an appeal by conservation groups. In February of 2002, NMFS announced that it would formally revisit the salmon listings and begin a new status review of the listed salmon ESUs.

in the design and implementation of restoration and enhancement programs, public opinion and attitudes take on a growing importance in implementing and designing effective policies.

Our study focuses on coho enhancement programs in five estuaries, which are located within the geographic boundaries of the Oregon Coast and Lower Columbia River/Southwest Washington coho ESUs. Coho salmon originating from rivers that empty into the three Oregon estuaries belong to the Oregon coastal ESU, which is listed as threatened, and coho salmon in the two Washington estuaries belong to an ESU that is a "candidate" for listing. We explore public opinion and support for local coho enhancement using responses from a survey of local residents.

Recent studies have examined the WTP for restoration of depleted or threatened salmon stocks in the Pacific Northwest and California. Hanemann, Loomis, and Kanninen (1991) examined the WTP for a program designed to restore flows in the upper San Joaquin River and enhance salmon, other fish and wildlife, and vegetation along the river banks. As defined, the salmon improvement program would increase Chinook salmon returning to spawn annually to 15,000 and raise the total number of chinook caught by sport (increase of 7,500 fish) and commercial (increase of 23,000 fish) anglers. Their contingent valuation study employs a double-bounded dichotomous choice referendum format with a payment vehicle of additional taxes. Data were collected in May 1989 using a combined mail and telephone survey approach. The final sample included responses of approximately 1,004 residents of California, Oregon, Washington, and Nevada. Five different environmental programs were addressed in the study. For the salmon improvement/restored river flows program, Hanemann, Loomis, and Kanninen (1991) report a truncated mean WTP of $181 per year for California households.

Olsen, Richards, and Scott (1991) estimate non-use and sport fishing values for a doubling of salmon and steelhead runs in the Columbia River Basin from 2.5 million to 5 million fish. Their contingent valuation study uses a modified open-ended response format with a payment vehicle of additional electric power bill charges. The data for this study were collected using a telephone survey of both user and nonuser (interpreted here as not involved in the sport or commercial salmon fisheries) households of the Pacific Northwest. The final sample consists of approximately 700 user and 700 nonuser households. Olsen, Richards, and Scott (1991) report mean annual WTP estimates for the doubling of these runs for three categories of households: (*i*) $26.51 per year for households stating that they would never fish for these anadromous species; (*ii*) $58.56 per year for households that currently don't fish but may go fishing at some time in the future; and (*iii*) $74.16 per year for households that currently fish for anadromous species.

Loomis (1996) estimates the WTP for removing two dams on the Elwha River in Washington State. The removal of these two dams is assumed to result in increased populations of four salmon and steelhead species (increase of 300,000 fish). Of these four species, pink salmon were expected to benefit the most from the removal of the dams (an increase of 200,000 fish). Contingent valuation methods are used to analyze the responses to a mail survey of Clallam County, Washington State, and other US residents conducted in fall of 1994. Approximately 1,624 responses were analyzed in this study. A single-bounded dichotomous choice referendum question format is used with a payment vehicle of additional annual federal taxes for 10 years. Loomis (1996) reports truncated mean WTP estimates of $59 per year per household in Clallam county (the location of the two dams), $73 per year per household in the rest of Washington State, and $68 per year per household in the rest of the United States.

Layton, Brown, and Plummer (1999) assess the WTP of Washington State resi-

dents for changes in population levels of five broad categories of fish. They consider two migratory fish categories, which are predominantly composed of salmon species. A contingent ranking format that asks individuals to rank four alternative outcomes relative to a baseline outcome of no new programs is employed to characterize the WTP for multiple enhancement programs. The programs are described using household cost information and the assumed population levels for the five categories of fish in 20 years. Data were collected using a mail survey; their final sample includes the responses of approximately 1,611 Washington State residents. Layton, Brown, and Plummer (1999) report a mean WTP estimate of $9.92 per month ($119.04 per year) per household for a 50% increase in eastern Washington migratory fish (from 2 to 3 million). For western Washington migratory fish, the corresponding WTP estimate for a 50% increase (from 5 to 7.5 million) is $20.83 per month ($249.96 per year).

In this study, we examine the WTP of residents living within 30 miles of five Pacific Northwest estuaries: Grays Harbor and Willapa Bay in Washington and Tillamook Bay, Yaquina Bay, and Coos Bay in Oregon.[3] We estimate the WTP of these coastal residents for the enhancement of local coho salmon stocks from a baseline defined as the 1996–98 average annual coho salmon run size. Programs resulting in the doubling and quadrupling of baseline runs are examined for the Washington estuaries (*e.g.*, increases of 40,000 and 165,000 fish). Whereas programs resulting in the delisting of coho as threatened and increases in the allowable catch of 100,000 fish are evaluated in the Oregon estuaries. Variation in WTP is explained using data on individual opinions of the merit of the enhancement program and causes of salmon decline, involvement in sport fishing, and membership in an environmental organization.

Survey Questionnaire Design and Response

Data for this analysis were drawn from responses to a coastal resident survey undertaken in the spring of 2000. The survey questionnaire was a multi-purpose research instrument, seeking the opinions of coastal residents on a variety of matters including residential location preferences, recreation interests, threats to the local natural environment, and management of these threats. A pre-test mailing of the coastal resident survey was conducted to identify problematic questions and other design flaws. In addition, the entire resident survey was written with the input of local scientists and natural resource managers.

Coho Enhancement

One section of the survey was dedicated to coastal salmon stocks and included a referendum question outlining a hypothetical ballot measure to fund a local coho enhancement program. This section of the survey aimed to incorporate the protocol designated by the NOAA Panel on contingent valuation in 1993 (*Federal Register* 1993; Portney 1994) and the guidelines outlined by Mitchell and Carson (1989) regarding the use of surveys to value public goods. A broad description of native salmon runs along the Pacific Northwest Coast was stated prior to the referendum

[3] The counties surrounding these estuaries are: Grays Harbor County, WA; Pacific County, WA; Coos County, OR; Tillamook County, OR; and Lincoln County, OR, respectively.

question, and each respondent was asked their opinion of the importance of various potential causes of salmon decline. These questions were included to evaluate the sensitivity of voting behavior to individual perceptions of threats to coastal salmon. The enhancement program described in the survey questionnaire targets overfishing and habitat degradation as important causes of salmon decline.

After summarizing the history of coastal coho and chinook salmon stocks, the questionnaire presented figures displaying recent trends in local, coastal chinook and coho salmon catches. The proposed local coho salmon enhancement program was described by contrasting the expected outcome of the enhancement program as of the year 2004 with a baseline characterized as the level of the catch and salmon populations during 1996–98. Expected coho salmon run size and allowable catch under the coho salmon enhancement program and baseline were presented in tabular form and described in the text. The specific wording of the referendum question for one area (Willapa Bay, WA) is shown below:

> Although the state has committed to spending additional money to help salmon in general, local partnerships and watershed councils may need additional funding. Residents of the Willapa Bay area will be asked to provide additional support to improve salmon populations in your local area. The collection of additional taxes to fund these programs can be authorized by a majority vote on a ballot measure in the next election. If no local programs are funded, then coho salmon runs would remain near their current levels, as shown in the table above.
>
> If this Coho Enhancement Program is proposed for the Willapa Bay area in the next election, coho runs will increase to a level that will raise allowable coho catch to an average of 80,000 fish per year by 2004. If this ballot measure will cost your household $25.00 per year for the next 5 years, will you vote in favor of the ballot measure? (circle one response)
>
> 1 YES
> 2 NO
>
> If you answered NO, please briefly explain your response.

The specified annual household cost (annual tax amount or COST) of the program varied randomly from $5.00 to $500.00. Assigned tax amounts were uniformly distributed over this range.

Each respondent voted on one local coho enhancement program. Two levels of enhancement (high and low) were considered. Both levels of enhancement were contrasted with the baseline (current) condition of salmon catch and run size (described using 1996 to 1998 data). For Willapa Bay and Grays Harbor, the low level of enhancement represented a doubling of current runs and catch, while the high level of enhancement involved a quadrupling of current runs and catch. Because the Oregon Coast coho ESU were listed as “threatened” with extinction under the Endangered Species Act at the time of the survey, a different set of programs was evaluated in the three Oregon estuaries. For these bays (Coos, Tillamook, and Yaquina), the low-enhancement program increased stocks to the point that they would no longer be threatened with extinction, and the high-enhancement program protected stocks from extinction and increased allowable coho catch to 100,000 fish per year.

Response Rates and Voting Responses

The coastal resident survey was distributed in spring of 2000. In total, 5,000 mail surveys were distributed, with 1,000 going to each of the five study areas. Surveys were mailed to a random sample of property owners residing within 30 miles of five estuaries. These residents live in communities surrounding estuaries located in Southwest Washington (Grays Harbor and Willapa Bay) and on the outer coast of Oregon (Tillamook Bay, Yaquina Bay, and Coos Bay). As is characteristic in the rural Pacific Northwest, the local economies of these communities have historically depended on natural resource-based industries — fishing, forest products, and farming. As a result, many of these communities have been affected by recent changes in fishing and forest product industries. Compared to the urban areas of the Pacific Northwest, these coastal communities have relatively lower incomes per household, higher unemployment rates, lower population growth rates, and larger proportions of retired people living on pensions and other transfer incomes.

The survey distribution process generally followed the total design method (TDM) guidelines (Dillman 2000, 1975). Table 1 displays the final response rates based upon the number of deliverable addresses. These rates vary from 49.1% in the Grays Harbor area to 61.7% in the Willapa Bay area. Of the 2,209 surveys returned, 2,006 (91%) contained responses to the referendum question. After eliminating "don't know" and "protest" responses, our final samples for the contingent valuation study included 1,771 responses from the five coastal areas.

Responses were categorized as protest or non-protest responses based upon the reasons given for rejecting the hypothetical coho enhancement program (Mitchell and Carson 1989). Responses were categorized as protests if the respondent objected to the payment vehicle. In addition, responses were dropped if individuals expressed a need for further information, entered don't know, and/or stated that they do not vote in local elections.[4] Using this definition of protests, our protest rates were relatively low, ranging from 4% in Yaquina Bay to 10% in Coos Bay. Protest behavior may be consistent with two phenomena observed in these coastal communities and indicated in written comments. First, there is considerable distrust of certain government agencies and dislike of taxes. Second, numerous and varied salmon protection efforts have been tried in these areas, many of which have had limited success. Therefore, there is skepticism among the public regarding government-initiated salmon protection programs. As noted in the introduction, legal conflicts may be an additional source of skepticism regarding salmon enhancement programs.

Table 1
Coastal Resident Survey Response Rates

	Number Delivered	Number Returned	Response Rate
Grays Harbor, WA	849	417	49.1%
Willapa Bay, WA	718	443	61.7%
Coos Bay, OR	883	516	58.4%
Tillamook Bay, OR	770	410	53.2%
Yaquina Bay, OR	708	423	59.7%
Total	3,928	2,209	56.2%

[4] Protest behavior was deduced by review of the open-ended, follow-up responses.

Theoretical Model

Following Hanemann (1984), Cameron (1988), and Hanemann and Kanninen (1999), we employ a random utility modeling framework to examine the dichotomous responses to the local coho salmon enhancement ballot measure. Under this framework, a respondent's voting decision is represented as the comparison of his or her utility at two states: status quo (u_0) and with the local coho salmon enhancement at cost c_1 (u_1). Utility is assumed to be a function of income (y), respondent characteristics (z), choice characteristics (g), and factors that are known by the respondent but are unobservable to us as researchers (ε). If the utility of the respondent is higher with the salmon enhancement, we expect that respondent to vote for the program. Formally, this comparison for respondent j looks as follows. Respondent j votes YES for the program if:

$$u_{1j}(y_j - c_{1j}, z_j, g_1, \varepsilon_{1j}) > u_{0j}(y_j, z_j, g_0, \varepsilon_{0j}). \tag{1}$$

Given the dichotomous responses available to us as researchers, we make probabilistic statements about YES and NO responses and rewrite this expression in probabilistic terms, where the probability that respondent j votes YES is as follows:

$$\Pr_j(YES) = \Pr\left[u_{1j}(y_j - c_{1j}, z_j, g_1, \varepsilon_{1j}) > u_{0j}(y_j, z_j, g_0, \varepsilon_{0j})\right]. \tag{2}$$

Modeling Specifications

A variety of modeling assumptions can be made to estimate the expression shown in equation (2). As part of our contingent valuation study, we experimented with a variety of specifications and assumptions.[5] Our final specification is an adaptation of the linear random utility model (Haab and McConnell 2002). We begin by assuming the utility function is additively separable in form, the sum of deterministic (v) and stochastic (ε) components:

$$u_{ij}(y_j - c_{ij}, z_j, g_i, \varepsilon_{ij}) = v_i\,(y_j - c_{ij}, z_j, g_i) + \varepsilon_{ij}, \tag{3}$$

where i references the state and j references the individual. Next, we specify the deterministic part of the utility function (v) as linear in income (y) and respondent (z) and choice attributes (g).

Finally, we assume that the coho enhancement program will have no income effect. Specifically, although we assume that the marginal utility of income is constant across states, we permit this value to vary across high- and low-income individuals.

Allowing for the marginal utility of income to be different for individuals falling into high (H) and low (L) income categories but constant across states, the probability individual j votes YES on the ballot measure can be written:

$$\Pr_j(YES) = \Pr(\alpha z_j - \eta_L I_{Lj} c_j - \eta_H I_{Hj} c_j + \varphi g_i - \varepsilon_j > 0), \tag{4}$$

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[5] A comparison of log likelihood values determined that the modeling specification featured in this paper fit the data best.

where α, η_L, η_H, and φ are parameters to be estimated; z_j are characteristics of individual j; c_j is the cost of the enhancement program to individual j; I_{Hj} and I_{Lj} are dummy variables that indicate whether or not individual j is in the high- or low-income category; and g_i are characteristics of the local coho enhancement program. Expression (4), a simple varying parameter model, forms the basis of our empirical modeling specification.

Willingness to Pay

One interpretation of willingness to pay (WTP) for the ballot measure is the amount of money that makes a respondent indifferent between the two states, status quo, and with the coho salmon enhancement program. Algebraic manipulation allows for individual j's WTP for program i to be written as:

$$WTP_{Hj} = \alpha z_j / \eta_H I_{Hj} + \varphi g_i / \eta_H I_{Hj} + \varepsilon_j / \eta_H I_{Hj} \tag{5}$$

$$\text{or } WTP_{Lj} = \alpha z_j / \eta_L I_{Lj} + \varphi g_i / \eta_L I_{Lj} + \varepsilon_j / \eta_L I_{Lj} .$$

The two different measures of WTP correspond to the high- and low-income categories.

Empirical Approach

Willingness to pay (WTP) for salmon enhancement is expected to vary across individuals according to their perceptions of the costs of and returns from the program. In this case, we expect WTP to vary directly and positively with the size of the good offered (*e.g.*, the extent of enhancement), fishing participation, income, and membership in an environmental organization. In addition to these priors, we also expect to find a direct and positive relationship between WTP and public confidence in the enhancement program. The familiarity of coastal residents in Washington and Oregon with salmon enhancement programs affords a unique significance to some of our policy variables designed to approximate public confidence. In turn, it also complicates the assessment of WTP because residents may be more likely to reject specific elements of the enhancement program. Lastly, having two different versions (high and low) of enhancement allows us to examine whether WTP is positively related to the extent and type of coho salmon enhancement. As defined, the Willapa Bay and Grays Harbor programs enable us to test whether or not the size of the salmon enhancement (*e.g.*, doubling versus quadrupling run and catch) significantly affects WTP. In addition, the Oregon estuary programs allow us to examine WTP for two fundamentally different types of enhancement programs. The low-enhancement program removes the threatened with extinction label from the local coho salmon stocks but precludes local catch of coho salmon. In contrast, the high-enhancement program removes the label and allows a moderate catch level of 100,000 fish per year. We were interested to see if the two versions used in the Oregon estuaries would speak to the relative influence of use and non-use values in motivating protection and enhancement of local coho stocks.

Variable Definition

Table 2 provides the names and definitions of the variables used to examine the WTP for local coho salmon enhancement. Table 3 presents descriptive statistics for these same variables for each of the five estuary-based samples. Particularly noteworthy demographic characteristics are the relatively advanced age of our samples (AGE) and the predominance of male respondents (MALE). Using 1997 county median income levels as a reference, high (HIGHINC) and low (LOWINC) income categories were defined as household incomes above or below $30,000.[6] We anticipate that these dummy variables will capture additional demographic variation across these groups that is not measured by our existing set of explanatory variables. On average, approximately 65% of residents had household incomes above the median county level, and 35% had household incomes falling below. Comparing the demographics of the survey respondents with those of the general population living

Table 2
Variable Names and Definitions

Name	Description	Units
VOTE	Equals 1 if YES response; 0 if NO response.	0/1 dummy
COST	Stated annual household cost.	Dollars ($)
HIGHEN	Equals 1 if high coho salmon enhancement program; 0 otherwise.	0/1 dummy
LOCSALM	Equals 1 if respondent fished for salmon or steelhead locally in 1999; 0 otherwise.	0/1 dummy
FISH	Equals 1 if respondent fished in the area in 1999; 0 otherwise.	0/1 dummy
ENVIRO	Equals 1 if respondent is a member of any conservation or environmental organization; 0 otherwise.	0/1 dummy
SPORT	Equals 1 if respondent is a member of a sporting club; 0 otherwise.	0/1 dummy
HIGHINC	Equals 1 if the respondent's household income is not below $30,000; 0 otherwise.	0/1 dummy
LOWINC	Equals 1 if the respondent's household income is below $30,000; 0 otherwise.	0/1 dummy
IMPTHR	Equals 1 if respondent ranked "too much commercial fishing" or "degraded river habitats on forest or agricultural lands" as important causes of native salmon decline; 0 otherwise.	0/1 dummy
PARTNER	Equals 1 if respondent believes that existing partnerships between government agencies and citizens (*e.g.*, watershed councils) should be the most or second most influential group in making natural resource management decisions at the county level; 0 otherwise.	0/1 dummy
STATE	Equals 1 if respondent believes the state should be the most or second most influential group in making natural resource management decisions at the county level; 0 otherwise.	0/1 dummy

[6] The 1997-model based US Census median household incomes for the counties surrounding these five bays are as follows: Grays Harbor ($31,091), Pacific ($28,131), Coos ($29,933), Tillamook ($30,713), and Lincoln (30,294). Income data were collected using categories. We used a threshold value of $30,000, since this income category was closest to the median.

Table 3
Means of Explanatory Variables

Name	Grays Harbor	Willapa Bay	Coos Bay	Tillamook Bay	Yaquina Bay
VOTE	0.51	0.52	0.40	0.44	0.52
COST	97.96	93.39	90.13	97.22	88.26
HIGHEN	0.52	0.48	0.42	0.51	0.47
LOCSALM	0.23	0.31	0.15	0.22	0.14
FISH	0.46	0.51	0.45	0.48	0.36
ENVIRO	0.11	0.10	0.09	0.14	0.07
SPORT	0.07	0.09	0.11	0.15	0.14
HIGHINC	0.68	0.64	0.56	0.68	0.70
LOWINC	0.33	0.36	0.34	0.32	0.30
IMPTHR	0.68	0.71	0.55	0.73	0.70
PARTNER	0.50	0.54	0.51	0.49	0.50
STATE	0.34	0.14	0.32	0.34	0.36
MALE	0.75	0.67	0.76	0.76	0.66
AGE	57	58	61	60	60

in these areas, there are meaningful differences.[7] Our respondents tend to be older, wealthier, better educated, and "more" retired.

Local fishing participation rates (FISH) average near 45%, and local salmon fishing participation rates (LOCSALM) are higher in the WA bays than in the OR bays, as might be expected due to the ESA listing of coho in coastal Oregon. The average membership rates in environmental (ENVIRO) and sporting (SPORT) organizations are 10% and 11%, respectively. Tillamook Bay, with approximately 15% membership rates in both types of organizations, had the highest participation rate of all five areas. Interestingly, membership rates in environmental organizations in the WA samples exceed those in sporting organizations; while the converse holds for the OR samples. The fishing participation and environmental organization membership variables are used to measure interest in and attachment to local fish and wildlife. While FISH and LOCSALM may capture motivations for use values of the local coho salmon stocks, we anticipate that ENVIRO may represent motivations for both use and nonuse values of these same stocks.

Turning to the explanatory variables that describe opinions of the merits of the enhancement programs, we observe some interesting trends across the five samples. Fairly high levels of support are expressed for local citizen and government partnerships (PARTNER) to control local natural resource management decisions.[8] Conversely, lower levels of support for state control (STATE) of local natural resource management decisions are expressed. Support for PARTNER and STATE are measures of expected public confidence in the enhancement program, as the featured programs were to be implemented by state and local governments and government-citizen partnerships.

Another measure of public confidence was created using a dummy variable describing attitudes about the causes of salmon decline. IMPTHR is equal to 1 if sport

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[7] We compared the demographics of our sample with data from the 1990 US Census. This comparison was made using zip code level data. Our sample over-represents males (actual gender distribution shows 50% male; 50% female) and older persons (above 46); under-represents younger persons (35 and under); and over-represents persons with higher educational attainment and income levels.

[8] This result may reflect approval for existing and past partnership organizations, such as the watershed councils of Oregon, the Willapa Bay Alliance, and the Tillamook Bay National Estuary Program.

fishing, commercial salmon fishing, or habitat degradation (IMPTHR) were ranked by the individual as extremely important (4 or 5 responses on a scale of 1 to 5) causes of native salmon decline in the Pacific Northwest. Overall, residents believe commercial salmon fishing and/or habitat degradation are extremely important causes of native salmon decline in the Pacific Northwest.[9] Approximately 67% of respondents in all five samples ranked at least one of these three threats as extremely important. The lack of importance awarded to excessive sport fishing may have lessened the extent to which this dummy variable proxied for public confidence, as our hypothetical program did not distinguish commercial and sport fishing when discussing the threats imposed by overfishing.

Finally, the level of enhancement program (HIGHEN) voted on is distinguished across respondents. HIGHEN is a dummy variable that equals 1 if the high-enhancement program was voted on and equals 0 otherwise. This is the variable that permits a cursory test of scope. In selecting the final set of explanatory variables, we dropped some that are commonly used in other studies of WTP because of multicollinearity, as well as the homogenous demographic nature of our samples.

Empirical Model

The linear random utility modeling specifications [refer to expression (4)] are estimated empirically using logit models, where we assume ε_j is distributed logistically (ε_{ij} are distributed extreme value) and estimate the parameters α, φ, η_H, and η_L using conventional maximum likelihood methods.[10] In the results section that follows, we begin our discussion focusing on the logit model results and conclude by examining the associated mean WTP estimates.[11] These mean WTP estimates are calculated using the deterministic portions of the functions shown in expression (5) and by applying the estimated coefficients from the empirical models to the mean values of the respondent and choice attributes.

Results

Ballot Referenda Logit Models

Tables 4 and 5 display logit model results by estuary-based sample. Responses to the high- and low-enhancement referenda are pooled.[12] The dependent variable is the voting response (YES or NO), and the set of explanatory variables is identical in all

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[9] Respondents were asked to rank the importance of several potential causes of native salmon decline using a likert scale of importance ranging from 1 to 5, where 1 represents not important and 5 indicates extremely important. The potential causes of salmon decline included: too much sport fishing for salmon; too much commercial fishing for salmon; poor ocean conditions for salmon; degraded river habitats in forest lands; degraded river habitats in farm lands; degraded marshes in the bay; water pollution in rivers and the bay; and dams on rivers. Generally, responses to the set of threat-ranking questions were similar across the five samples, with water pollution in rivers and bays, too much commercial salmon fishing, and degraded habitat ranked consistently as more important causes of salmon decline. Too much sport fishing and dams on rivers ranked consistently as less important causes of salmon decline.

[10] Probit models, which rest on the assumption that ε_j are distributed normally, were also run. There were no significant differences between the results of the logit and probit models.

[11] The mean and median willingness to pay are identical for these modeling specifications because ε is symmetric and mean zero. The WTP estimates shown in table 6 are those for the first year of payment and have not been annualized.

[12] Separate models were run using the responses to the high- and low-enhancement programs by bay. Likelihood ratio tests comparing the estimated parameters failed to reject the null hypothesis of equivalent parameter estimates across the high and low runs in all five bays.

Table 4
Local Coho Enhancement: Logit Model Results (Coastal Washington)

	Grays Harbor		Willapa Bay	
Parameter	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.
HIGHEN	–0.0109	–0.054	–0.0176	–0.086
ENVIRO	–0.4538	–1.264	0.7262*	1.804
IMPTHR	0.3317	1.566	0.7952**	3.828
STATE	0.4511*	1.826	0.1411	0.429
PARTNER	0.2170	0.988	0.0834	0.408
LOCSALM	0.0314	0.115	–0.2051	–0.863
HIGHINC*COST	–0.0037**	–3.550	–0.0052**	–4.175
LOWINC*COST	–0.0056**	–3.228	–0.0081**	–3.947
N	357		386	
$\ln(L_U)$	–233.2081		–241.2788	
$-2[\ln(L_R) - \ln(L_U)]$	28.42		51.71	
Pseudo R^2	0.08		0.13	

Notes: The dependent variable is the binary voting response (VOTE). Ψ includes α, η, and φ. Significance at the 0.10 level (*) and 0.05 level (**).

five areas, with one exception. Local fishing participation is characterized differently across the Oregon and Washington samples. In the Washington models, LOCSALM is included as an explanatory variable and FISH is not included because the two variables were highly collinear. Because of the recent decrease in salmon fishing opportunities in coastal Oregon, we did not include LOCSALM as an explanatory variable for the three Oregon samples and used the dummy variable, FISH, in its place.

Across all areas, the parameter estimate associated with the COST variable has the expected negative sign and is highly statistically significant, indicating that the likelihood of a YES response declines with the annual household cost. In this modeling specification, the "price" response is allowed to vary across high- and low-income categories (HIGHINC*COST and LOWINC*COST). The relative size of these parameter estimates varies across communities. As might be expected, the marginal utility of income of the lower income category is consistently greater than that of the higher income category.

Membership in an environmental organization (ENVIRO) has mixed influences on voting behavior and WTP. ENVIRO has a positive and significant influence in the Willapa Bay-based sample and a negative and significant influence in the Coos Bay-based sample. In Willapa Bay, the significance of ENVIRO may be partially due to past efforts of the now defunct environmental research and educational group, the Willapa Bay Alliance. In the Coos Bay model, the negative sign of the parameter associated with ENVIRO is unexpected. However, one possible explanation of this sign is that members of environmental organizations in Coos Bay may not see the delisting of coho as threatened as desirable, especially if they regard the actions undertaken when a species is listed as beneficial to the local coastal environment.

The proxies of public confidence in the local coho enhancement programs have mixed influences on WTP. The dummy variable, IMPTHR, has a positive and statistically significant influence on acceptance of the program in the specification for Willapa Bay only. Individual attitudes towards state and local management institu-

Table 5
Local Coho Enhancement: Logit Model Results (Coastal Oregon)

	Coos Bay		Tillamook Bay		Yaquina Bay	
	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.
HIGHEN	–0.1809	–0.918	0.1014	0.504	–0.0566	–0.253
ENVIRO	–0.7868**	–3.730	–0.0158	–0.073	0.2589	1.092
IMPTHR	0.1871	0.498	0.0003	0.001	–0.4474	–1.005
STATE	1.0159**	4.708	0.0904	0.381	0.4985**	2.282
PARTNER	0.1126	0.512	0.5809**	2.371	0.3002	1.272
FISH	0.1991	1.013	–0.1265	–0.574	0.4037*	1.855
HIGHINC*COST	–0.0074**	–4.522	–0.0025**	–2.328	–0.0063**	–4.616
LOWINC*COST	–0.0089**	–4.127	–0.0079**	–3.312	–0.0096**	–3.352
N	424		347		357	
$\ln(L_U)$	–252.4180		–226.4367		–222.5196	
$-2[\ln(L_R)-\ln(L_U)]$	64.55		23.32		49.53	
Pseudo R^2	0.14		0.06		0.13	

Notes: The dependent variable is the binary voting response (VOTE). Ψ includes α, η, and φ. Significance at the 0.10 level (*) and 0.05 level (**).

tions have stronger effects on voter support of the hypothetical coho enhancement program than opinions of threats. One of the two variables concerning the degree to which the state government (STATE) and citizen county-level partnerships (PARTNER) should be influential in making resource management decisions is significant in all cases except for Willapa Bay. In the Grays Harbor, Coos Bay, and Yaquina Bay-based models, the parameter associated with STATE is positive and significant. In the Tillamook Bay model, the parameter associated with PARTNER is positive and significant.[13] Generally, these estimates suggest that public confidence in a salmon enhancement program is inextricably linked to the WTP for such a program. This finding is intriguing and may underscore the importance of dialogue between local scientists, natural resource managers, and residents.

Surprisingly, participation in local sport fishing does not significantly affect WTP for the enhancement program in the five areas. Only in the Yaquina Bay-based model is the parameter on FISH positive and significant.

Our comparison of the low- and high-enhancement programs provides limited fodder for understanding individual perceptions of the scope or types of enhancement programs. The influence of HIGHEN is not significant in any of the specifications. Because each respondent voted on a single enhancement program, we can only test for scope by examining the influence of HIGHEN. We fail to reject the null hypothesis that the influence of HIGHEN is statistically equal to zero (at the 0.05 level). Furthermore, the influence of HIGHEN is often not the expected positive sign, and the negative parameter estimate associated with this variable results in higher mean WTP estimates for the low-enhancement program.

In retrospect, we believe that greater differences in the magnitude and types of our salmon enhancement programs would have improved our ability to explore individual perceptions of the scopes and types of programs. In the Washington samples, the differences between our high- and low-enhancement programs may simply not be large enough to distinguish the services provided by the enhancement program. In addition, it may be the case that many people will support local recovery efforts related to ESA. However, when the issue is increased harvest opportunities for the minority of people who fish salmon, many of those same people may decline to pay. If this is the case, the result is a muddied scope test because for some households, the high-enhancement program does not represent a larger public good. Similar issues arise in contrasting the levels of enhancement faced by the Oregon samples. Respondents who doubt the legal integrity of the ESA listing of the coho stock are likely to perceive little reward from enhancement efforts aimed at removing the title of threatened. Conversely, individuals who highly regard the ESA listing (and its associated actions) may perceive little reward from the removal of this title. Lastly, if WTP is largely motivated on the basis of non-use values, one might expect less sensitivity to changes in run size and harvest opportunities.

WTP Estimates

Mean annual WTP estimates are derived by evaluating the expressions shown in equation (5), employing the mean respondent attributes (refer to table 3), and distinguishing the level of enhancement program. Table 6 displays annual mean willingness to pay estimates (and their standard errors) by area. These estimates cor-

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[13] Tillamook Bay is home to a unique partnership group entitled the Tillamook Bay National Estuary Program.

respond to the payment in the first of five years. Standard errors were calculated using the delta method. When examining the estimates shown in table 6, it is important to note the differences in the local enhancement programs across the five estuaries. In addition to the distinctions between the Oregon and Washington programs, there are further differences because of unique coho baseline and demographic conditions by bay. While it may be sensible to compare the qualitative results in all five areas and perhaps the WTP estimates within state, it is not appropriate to directly compare the WTP estimates for the Oregon and Washington programs.

The Washington estuary-based samples and the Yaquina Bay-based sample provide greater insights, where the WTP estimates are positive and significantly different from zero. Mean WTP estimates in some of the Oregon estuary samples (Tillamook and Coos) are not significantly different from zero. Observing the results, higher income individuals are generally willing to pay more than lower income individuals for local coho enhancement in these areas. Furthermore, and commensurately, the expected mean willingness-to-pay estimates are not statistically different for the high- and low-enhancement programs. As noted previously, the negative parameter estimates on HIGHEN result in a mean WTP estimate for the high-enhancement program that is smaller than that for the low-enhancement program. We acknowledge the necessity of future research devoted to understanding preferences and sensitivity to run sizes to improve the assessment of WTP for salmon enhancement programs.

Table 6
Mean WTP Estimates by Estuary: Local Coho Enhancement

	Mean WTP Estimate (Std. Error)			
Estuary	High Income		Low Income	
Grays Harbor, WA				
HIGH ENHANCE	116.59**	(45.70)	77.00**	(32.30)
LOW ENHANCE	119.54**	(39.64)	78.94**	(30.68)
Willapa Bay, WA				
HIGH ENHANCE	118.44 **	(35.01)	75.99**	(23.14)
LOW ENHANCE	121.81**	(30.33)	78.15**	(23.00)
Coos Bay, OR				
HIGH ENHANCE	25.39	(24.05)	20.88	(20.11)
LOW ENHANCE	50.00**	(15.52)	41.13**	(14.77)
Tillamook Bay, OR				
HIGH ENHANCE	120.50*	(66.62)	37.18*	(22.11)
LOW ENHANCE	79.32	(55.42)	24.48	(17.65)
Yaquina Bay, OR				
HIGH ENHANCE	106.50**	(28.90)	69.81**	(23.98)
LOW ENHANCE	115.54 **	(27.55)	75.74**	(23.05)

Notes: Standard errors were calculated using the delta method. Significance at the 0.10 level (*) and 0.05 level (**).

The mean WTP estimates are very similar in the two Washington samples. In contrast, there is much more variation when comparing the results in the three Oregon samples. Mean WTP is highest in Yaquina Bay, followed thereafter by Tillamook Bay, where the difference between mean WTP across high- and low-income groups is most pronounced. Finally, the mean WTP is consistently lowest in the Coos Bay area.

Comparing these estimates with those derived in previous studies of salmon enhancement programs, the WTP estimates derived are within range of the previous studies. Converting the Hanemann, Loomis, and Kanninen (1991) estimate to 2000 dollars yields an estimate of approximately $254 per year for California households for the enhancement of the San Joaquin River salmon populations. A similar conversion of the Olsen estimates measured in 1989 dollars to 2000 dollars yields estimates of $37.19, $82.15, and $104.04, respectively (doubling of salmon and steelhead runs in the Columbia River; 2.5 million fish). Mean estimates based on Loomis (1996) are $68.94, $85.30, and $79.45, respectively, in 2000 dollars (300,000 fish). Lastly, converting the Layton, Brown, and Plummer (1999) estimates from 1998 to 2000 dollars yields estimates of $126.57 and $265.77, respectively (1 million and 2.5 million fish). Specific comparisons of estimates are difficult because of differences in baseline conditions, as well as the nature of the enhancement program and targeted salmon species. Higher WTP estimates may be expected in the Olsen, Richards, and Scott (1991) and Layton, Brown, and Plummer (1999) studies because the enhancements involve greater increases in fish. However, as our study notes, there is considerable uncertainty regarding individual perceptions of the outcomes of salmon enhancement programs.

Conclusions

We have summarized the results of a contingent valuation survey of residents of five rural, coastal communities in the Pacific Northwest and described the willingness to pay of coastal communities for local coho salmon enhancement programs. Willingness to pay for salmon enhancement initiatives is higher when the public demonstrates confidence in the objectives of the programs and the managing institutions. The linkage between public confidence in the objectives of the program (*e.g.*, causes of salmon decline addressed) and the managing institutions is an extremely interesting result, for it underscores the importance of community outreach and education when devising salmon enhancement and protection strategies. We also find evidence that WTP for local coho enhancement is positively related to income.

We experienced several empirical problems commonly associated with survey research that necessitate further study of individual preferences concerning local salmon stocks. We recognize the limitations imposed by our survey design. Despite these problems, the statistical results presented confirm that residents of coastal communities of the Pacific Northwest are generally willing to pay for local coho salmon enhancement. In addition, the modeling results provide insights about the preferences of residents concerning salmon protection programs. We believe that the explanatory power of the enhancement program related variables (IMPTHR, STATE, PARTNER) underscores the importance of public outreach and education in devising salmon restoration and enhancement strategies. Finally, we hope that these and other findings assist local decisionmakers when making future and inevitably difficult salmon protection choices in the Pacific Northwest. Future research that directly compares the WTP for local enhancement by local residents and non-local residents may provide additional insights on how the magnitude of WTP for enhancing a particular stock varies across regions.

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PROFILE

Hungry Water: Effects of Dams and Gravel Mining on River Channels

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ABSTRACT / Rivers transport sediment from eroding uplands to depositional areas near sea level. If the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for salmon and trout (as smaller gravels are transported without replacement from upstream). Gravel is artificially added to the River Rhine to prevent further incision and to many other rivers in attempts to restore spawning habitat. It is possible to pass incoming sediment through some small reservoirs, thereby maintaining the continuity of sediment transport through the system. Damming and mining have reduced sediment delivery from rivers to many coastal areas, leading to accelerated beach erosion. Sand and gravel are mined for construction aggregate from river channel and floodplains. In-channel mining commonly causes incision, which may propagate up- and downstream of the mine, undermining bridges, inducing channel instability, and lowering alluvial water tables. Floodplain gravel pits have the potential to become wildlife habitat upon reclamation, but may be captured by the active channel and thereby become instream pits. Management of sand and gravel in rivers must be done on a regional basis, restoring the continuity of sediment transport where possible and encouraging alternatives to river-derived aggregate sources.

As waters flow from high elevation to sea level, their potential energy is converted to other forms as they sculpt the landscape, developing complex channel networks and a variety of associated habitats. Rivers accomplish their geomorphic work using excess energy above that required to simply move water from one point on the landscape to another. In natural channels, the excess energy of rivers is dissipated in many ways: in turbulence at steps in the river profile, in the frictional resistance of cobbles and boulders, vegetation along the bank, in bends, in irregularities of the channel bed and banks, and in sediment transport (Figure 1). The transport of sand- and gravel-sized sediment is particularly important in determining channel form, and a reduction in the supply of these sediments may induce channel changes. The supply of sand and gravel may be the result of many factors, including changes in land use, vegetation, climate, and tectonic activity. This paper is concerned specifically with the response of river channels to a reduction in the supply of these sediments by dams and gravel mining.

Sediment is transported mostly as suspended load: clay, silt, and sand held aloft in the water column by turbulence, in contrast to bedload: sand, gravel, cobbles, and boulders transported by rolling, sliding, and bouncing along the bed (Leopold and others 1964). Bedload ranges from a few percent of total load in lowland rivers to perhaps 15% in mountain rivers (Collins and Dunne 1990), to over 60% in some arid catchments (Schick and Lekach 1993). Although a relatively small part of the total sediment load, the arrangement of bedload sediments constitutes the architecture of sand- and gravel-bed channels. Moreover, gravel and cobbles have tremendous ecological importance, as habitat for benthic macroinvertebrates and as spawning habitat for salmon and trout (Kondolf and Wolman 1993).

The rate of sediment transport typically increases as a power function of flow; that is, a doubling of flow typically produces more than a doubling in sediment transport (Richards 1982), and most sediment transport occurs during floods.

KEY WORDS: Dams; Aquatic habitat; Sediment transport; Erosion; Sedimentation; Gravel mining

Continuity of Sediment Transport in River Systems

Viewed over a long term, runoff erodes the land surface, and the river network carries the erosional products from each basin. The rates of denudation, or lowering of the land by erosion, range widely. The Appalachian Mountains of North America are being denuded about 0.01 mm/yr (Leopold and others 1964), the central Sierra Nevada of California about 0.1

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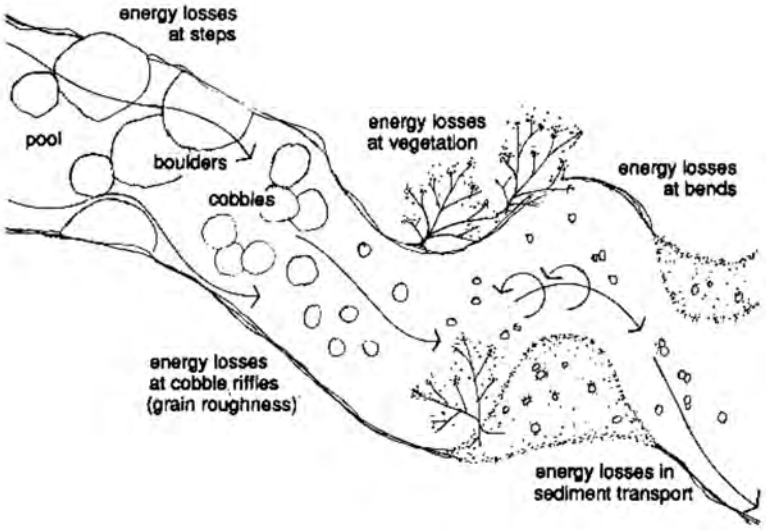

Figure 1. Diagram of energy dissipation in river channels.

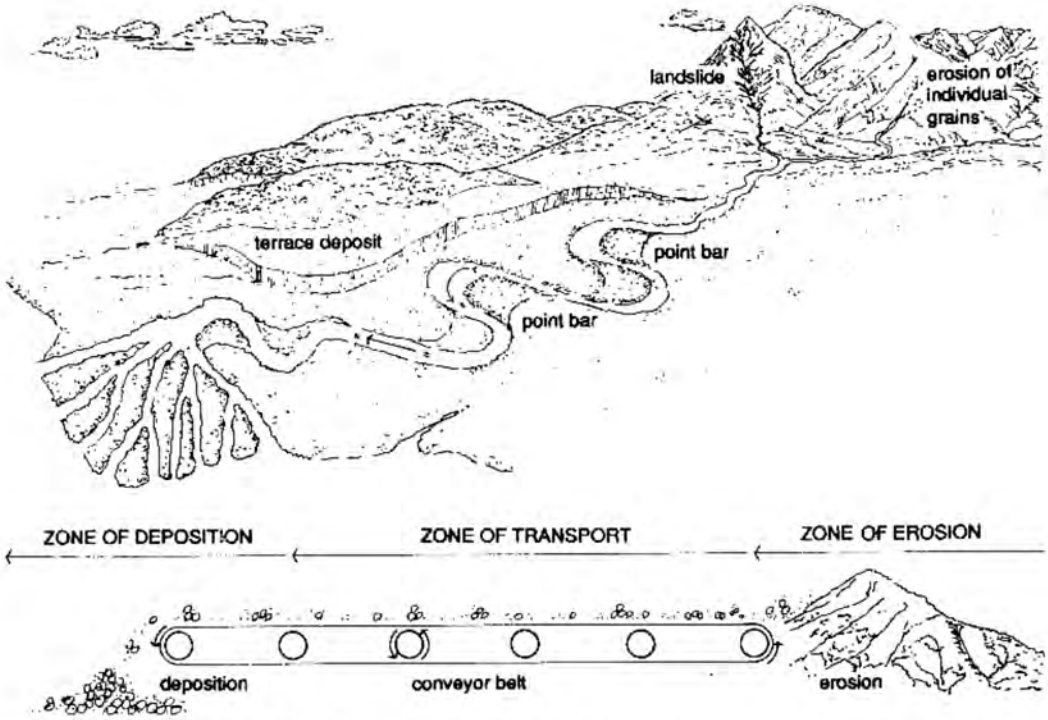

Figure 2. Zones of erosion, transport, and deposition, and the river channel as conveyor belt for sediment. (Reprinted from Kondolf 1994, with kind permission of Elsevier Science-NL.)

mm/yr (Kondolf and Matthews 1993), the Southern Alps of New Zealand about 11 mm/yr (Griffiths and McSaveney 1983), and the southern Central Range of Taiwan over 20 mm/yr (Hwang 1994). The idealized watershed can be divided into three zones: that of erosion or sediment production (steep, rapidly eroding headwaters), transport (through which sediment is moved more or less without net gain or loss), and deposition (Schumm 1977) (Figure 2). The river channel in the transport reach can be viewed as a conveyor belt, which transports the erosional products downstream to the ultimate depositional sites below sea level. The size of sediment typically changes along the length of the river system from gravel, cobbles, and boulders in steep upper reaches to sands and silts in low-gradient downstream reaches, reflecting diminution in size by

weathering and abrasion, as well as sorting of sizes by flowing water.

Transport of sediment through the catchment and along the length of the river system is continuous. Increased erosion in the upper reaches of the catchment can affect the river environment many miles downstream (and for years or decades) as the increased sediment loads propagate downstream through the river network. On Redwood Creek in Redwood National Park, California, the world's tallest trees are threatened with bank erosion caused by channel aggradation (building up of sediment in the channel), which in turn was caused by clear-cutting of timber on steep slopes in the upper part of the catchment (Madej and Ozaki 1996, Janda 1978).

Along the river channel conveyor belt, channel forms (such as gravel bars) may appear stable, but the grains of which they are composed may be replaced annually or biannually by new sediment from upstream. Similarly, the sediments that make up the river floodplain (the valley flat adjacent to the channel) are typically mobile on a time scale of decades or centuries. The floodplain acts as a storage reservoir for sediments transported in the channel, alternately storing sediments by deposition and releasing sediment to the channel by bank erosion. For example, the Carmel River, California, is flanked by flat surfaces (terraces) that step up from the river. The lowest terrace is the channel of sand and gravel deposited by the 1911 flood, but the surface now stands about 4 m above the present, incised channel (Kondolf and Curry 1986). By 1960, the terrace had been subdivided for low-density housing, despite the recent origin of the land and the potential for future shifts in channel position.

A river channel and floodplain are dynamic features that constitute a single hydrologic and geomorphic unit characterized by frequent transfers of water and sediment between the two components. The failure to appreciate the integral connection between floodplain and channel underlies many environmental problems in river management today.

Effects of Dams

Dams and diversions are constructed and operated for a wide variety of purposes including residential, commercial, and agricultural water supply; flood and/ or debris control; and hydropower production. Regardless of their purpose, all dams trap sediment to some degree and most alter the flood peaks and seasonal distribution of flows, thereby profoundly changing the character and functioning of rivers. By changing flow regime and sediment load, dams can produce adjustments in alluvial channels, the nature of which depends upon the characteristics of the original and altered flow regimes and sediment loads.

Dams disrupt the longitudinal continuity of the river system and interrupt the action of the conveyor belt of sediment transport. Upstream of the dam, all bedload sediment and all or part of the suspended load (depending upon the reservoir capacity relative to inflow) (Brune 1953) is deposited in the quiet water of the reservoir (reducing reservoir capacity) and upstream of the reservoir in reaches influenced by backwater. Downstream, water released from the dam possesses the energy to move sediment, but has little or no sediment load. This clear water released from the dam is often referred to as hungry water, because the excess energy is typically expended on erosion of the channel bed and banks for some years following dam construction, resulting in incision (downcutting of the bed) and coarsening of the bed material until equilibrium is reached and the material cannot be moved by the flows. Reservoirs also may reduce flood peaks downstream, potentially reducing the effects of hungry water, inducing channel shrinking, or allowing fine sediments to accumulate in the bed.

Channel Incision

Incision below dams is most pronounced in rivers with fine-grained bed materials and where impacts on flood peaks are relatively minor (Williams and Wolman 1984). The magnitude of incision depends upon the reservoir operation, channel characteristics, bed material size, and the sequence of flood events following dam closure. For example, the easily eroded sand bed channel of the Colorado River below Davis Dam, Arizona, has incised up to 6 m, despite substantial reductions in peak flows (Williams and Wolman 1984). In contrast, the Mokelumne River below Camanche Dam in California has experienced such a dramatic reduction in flood regime (and consequent reduction in sediment transport capacity) that no incision has been documented and gravels are reported to have become compacted and immobile (FERC 1993).

Reduction in bedload sediment supply can induce a change in channel pattern, as occurred on Stony Creek, a tributary to the Sacramento River 200 km north of San Francisco. Since the closure of Black Butte Dam in 1963, the formerly braided channel has adopted a single-thread meandering pattern, incised, and migrated laterally, eroding enough bedload sediment to compensate for about 20% of the bedload now trapped by Black Butte Dam on an annual average basis (Kondolf and Swanson 1993).

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A Question of Balance

Weighing the Options on Global Warming Policies

William Nordhaus

Yale University Press New Haven & London

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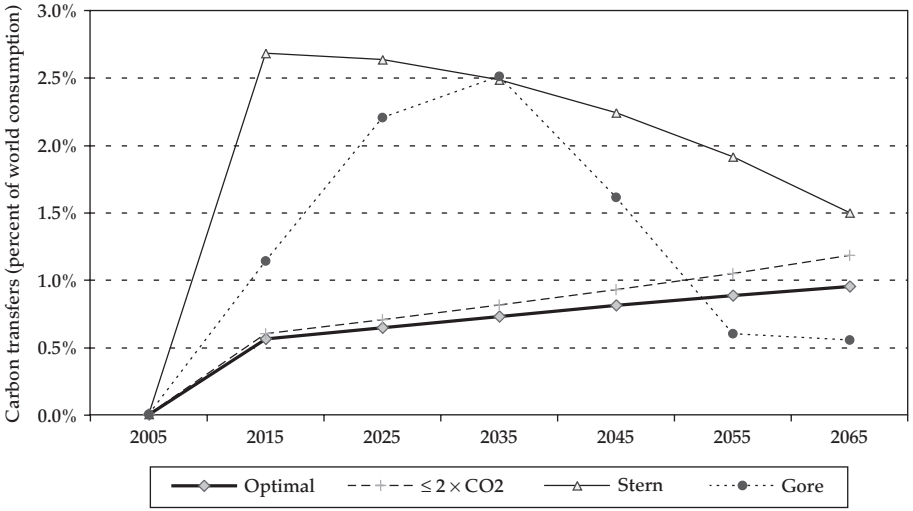

Figure 5-11. Carbon revenue transfers as a percentage of world consumption. The total transfers from consumers to producers and taxpayers due to carbon restrictions. These would apply whether the restrictions were imposed by cap-and-trade measures or by carbon taxes. The transfers are carbon prices times carbon use, while the denominator of the fraction is world consumption expenditures.

The Impact of Climate Change on California's Ecosystem Services

A Paper From:
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FINAL PAPER

DISCLAIMER

This paper was prepared as the result of work sponsored by the California Energy Commission (Energy Commission) and the California Environmental Protection Agency (Cal/EPA). It does not necessarily represent the views of the Energy Commission, Cal/EPA, their employees, or the State of California. The Energy Commission, Cal/EPA, the State of California, their employees, contractors, and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this paper; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This paper has not been approved or disapproved by the California Energy Commission or Cal/EPA, nor has the California Energy Commission or Cal/EPA passed upon the accuracy or adequacy of the information in this paper.

Arnold Schwarzenegger, *Governor*

August 2009
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dark orange is where fire is expected to consume more biomass than historical levels.

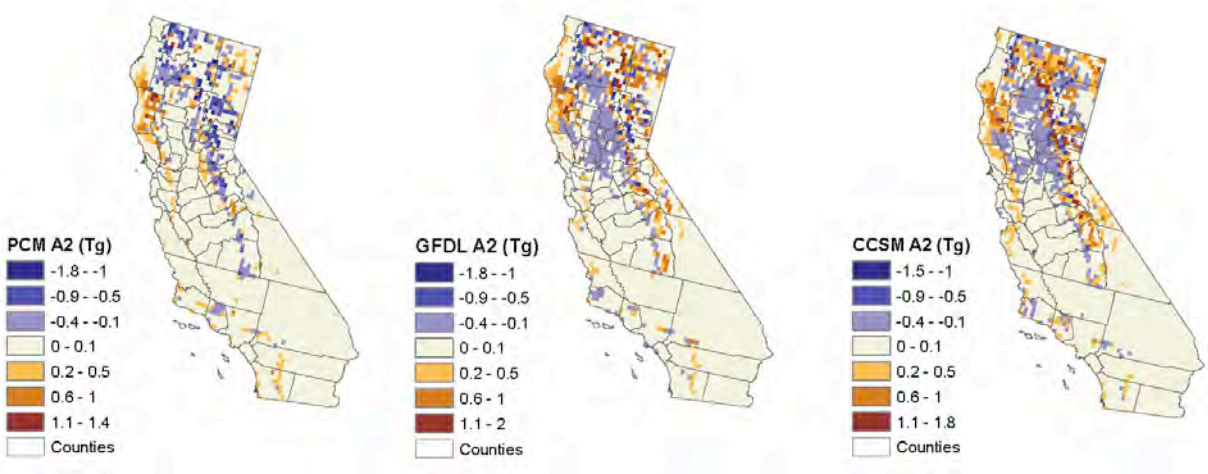

Figure 12. Net change in carbon in biomass consumed by fire by the end of the century (2070–2099 mean) under the high A2 scenario between the neutral climate future scenario and three AOGCMs (PCM1, GFDL, and CCSM3) simulated future climate conditions. Dark blue represents areas where historically fire consumed more than is projected by the end of the century on average and dark orange is where fire is expected to consume more biomass than historical levels.

Carbon Sequestration Valuation

The sequestration of carbon generates both market value, through constructed markets for carbon emissions, and a more comprehensive social value. The market value of carbon reflects the least-cost method for reducing carbon emissions in the atmosphere, as revealed by the market. The social value of carbon sequestration (also known as the social cost of carbon) reflects the global economic consequences of each ton of carbon released into the atmosphere.

To estimate the market and economic values of carbon over time we consider how much carbon will be stored in live trees above ground under the base future climate scenario and under each climate change scenario. We then estimate the value (in 2007 dollars) of the stock of carbon under each scenario and measure the change in value between the base future climate carbon stock and the stock estimated under each scenario.

For this study, we draw upon the literature to provide best estimates of the 2007 market price of carbon per metric ton to estimate the market value of carbon sequestered or released. In addition to estimates based on the market value of carbon, we use the literature to provide a review and best estimates of the societal value of a ton of carbon sequestered (or the costs of a ton of carbon released), recognizing that the value of carbon sequestered also will change over time, mostly as a function of the total stock of carbon in the atmosphere and the time of release or sequestration.

To estimate the value of carbon stored, we valued the costs of carbon emitted, assuming that if the carbon stock at time *t* decreases by one ton of carbon, that ton has (1) a market impact

because it will need to be offset in the carbon market,[2] and (2) an economic impact because it causes a marginal increase in damages associated with climate change.

Market Value of Carbon

We use information from the Chicago Climate Exchange (CCX, a voluntary climate exchange) and the European Union Emissions Trading System (EU ETS), a compliance-based system to estimate market values. To meet the goals of AB32 and reduce the impacts of atmospheric carbon on the global climate, The California Air Resources Board (CARB) has recommended a cap-and-trade program. Forest carbon offsets (aboveground live biomass in trees) are to be included in the program as a limited percentage of allowances. A cap-and-trade program will create a market for carbon and carbon sequestered by forests could be used to offset carbon generated by industry. The actual market value of forest carbon will depend on the development of this program and specific allowances made for forest carbon offsets. Generally, the market price is determined by the total amount of carbon that is permitted to be released into the atmosphere and the cost of meeting this cap through reductions in carbon emissions or the sequestration of carbon (for instance in natural vegetation.) From the perspective of the State of California, carbon sequestration is an important part of the technical portfolio the state must employ in order to meet the goals of AB32. Market price provides a rough estimate of the potential costs of meeting these goals and thus the gross economic value, in terms of cost savings or increases that would result due to changes in the natural ability of terrestrial ecosystems to sequester carbon. (Note, marine systems also play an important role in carbon sequestration, but we do not currently have good quantitative models for marine CO_2 sequestration.)

Currently, carbon trading occurs through a number of allowance-based markets and project-based transactions. The three main markets are the European Union Emissions Trading Scheme (EU ETS) and the New South Whales GHG Reduction Scheme, which are both regulated markets, and the CCX. For this study, we use 2007 annual volumes and transactions on the EU ETS and CCX markets to derive a low and high price for a metric ton of carbon. For each market, we derive the average annual price per metric ton of carbon (MTC) as follows:

$$\left(\frac{Total\ Value\ (M\$)}{Total\ Volume\ (MtCO_2e)} \right) 3.67$$

where 3.67 is the conversion factor from CO_2 to carbon.

The price derived from the EU ETS is $89.19/MTC and from CCX is $11.49/MTC (Capoor et al. 2008). The reason for the large difference in price between the CCX and the EU ETS markets is that the EU ETS is a regulated cap-and-trade market. In a regulated market, buyers have a higher certainty that what they are buying will maintain a value in the market. The CCX is a voluntary market with higher levels of uncertainty. Buyers speculate that the credits they

[2] The AB 32 (Assembly Bill 32 - California's Global Warming Solution Act of 2006) Climate Change Scoping Plan, approved by the Air Resources Board on December 11, 2008, recommends developing a cap and trade program that would link with other Western Climate Initiative partner programs to create a regional market by 2012. The plan recommends reduction measures of 5 MMTCO2e in the sustainable forest sector. It also recommends the use of offsets (include in the forest sector) and allowances from other systems be limited to 49 percent of the required reduction of emissions.

purchase will hold value should a cap-and-trade system be developed. Investors are looking for high potential returns on their investments given the risk they incur.

The CCX price could be considered a lower bound value (should forest offsets not be included in a regulated market). The EU ETS rate could be considered a more accurate estimate if forest carbon offsets are included in a statewide, regional, or national cap-and-trade system.[3]

Social Value of Carbon

The economic value of carbon sequestration can also be measured in terms of the social cost (or economic benefit from avoided damage) of damage avoided when carbon is removed from the atmosphere and climate change is slowed. The social cost of carbon (SCC) measures the full global cost today of emitting an incremental unit of carbon (in the form of CO_2) at some point of time in the future, and it includes the sum of the global cost of the damage it imposes the entire time it is in the atmosphere (Price et al. 2007; Pearce 2003). Damage is a function of the cumulated stock, so one extra unit released in the future is likely to have a higher associated damage than a unit emitted now (Pearce 2003). In theory, the SCC attempts to capture how much society could pay to avoid climate change and still be as well off as they would be in the absence of climate change. In other words, if society were aware of the full costs of climate change, the SCC is what they would be willing to pay now to avoid the future damage caused by incremental carbon emissions (Price et al. 2007). The SCC also represents the appropriate tax on CO_2 emissions that would result in the economically optimal reduction in CO_2 emissions (also known as the Pigouvian tax—a tax levied to correct the negative externalities of a market activity) (Tol 2007). The total social cost is the damage done by carbon emissions compared to a neutral climate future context in which the emissions do not increase. In our analysis, we assume that lost carbon sequestration is not offset by technological reductions in human-created sources of atmospheric carbon dioxide and thus lost carbon sequestration results in global economic cost.

The process for estimating SCC requires a model of atmospheric residence time and a means of discounting economic values back to the year of emissions (Yohe et al. 2007). The amount of damage done by each incremental unit of carbon in the atmosphere depends on the concentration of atmospheric carbon today and in the future. Therefore, the SCC should vary depending on which emissions trajectory the world experiences.

Currently, the peer-reviewed and gray literature provide over 200 different estimates of the marginal costs of climate change with varying levels of sophistication, including differing discount rates, different mechanisms for including discount rates and performing sensitivity analysis, varying estimates of total costs of climate change used, dynamic and static elements, differing assumptions about future climate change, and publication dates (the older the study, the less sophisticated it might be) (Tol 2007). Generally, a higher discount rate implies a lower estimate of the SCC and estimates in the peer reviewed literature tend to be lower than estimates in the gray literature and have fewer uncertainties (Tol 2007).

[3] Note that forest sector offsets are not included in the EU ETS compliance system, but this system still provides the best market estimate for forest sector carbon credits. Also note that the California AB 32 Climate Change Scoping Plan recommended inclusion of forest credits produced in-state, as well as out-of-state and internationally, although the rules for these mechanisms have yet to be created.

In 2005, Richard Tol published a meta-analysis of the marginal damage costs of CO_2 emissions. He reviewed 103 estimates from 28 public studies. Including only peer-reviewed studies and accounting for differences in the types of studies (discount rates, equity weighting, dependence on dynamic climate change scenarios and economic scenarios, and estimations of marginal or average damage costs), Tol determined the mean to be $43 ($54 in 2007 inflation adjusted dollars) per MTC with a standard deviation of $83 (Tol 2005). He found that studies with better methods yielded lower estimates with fewer uncertainties. He also discovered that much of the uncertainty was due to assumptions on the discount rate and around equity weights used to aggregate monetized impacts over countries.

In 2007, Tol presented an as yet unpublished update of his 2005 meta-analysis. With more data (211 estimates from the gray and published literature) and more advanced statistical analysis, Tol's results showed a downward trend in the estimates of the SCC but that uncertainty about the SCC is large (although many of the high estimates were not yet peer-reviewed and used unacceptably low discount rates). In Tol's 2007 analysis, with conservative assumptions, the mean for peer-reviewed estimates is $23/MTC. He states that there is a 1% probability that the SCC is greater than $78/MTC.

Watkiss and Downing (2008) provide further updates of Tol and summarize a number of values for the social cost of capital for carbon emissions in the UK. The authors report that in 2002, the UK Government recommended a marginal global SCC estimate of £70/MTC ($185/MTC in 2007 dollars), within a range of £35 to £140/MTC ($93 to $371/MTC in year 2007 dollars), with all three estimates increasing £1/MTC ($1.50/MTC) per year from the year 2000. Since 2002, the UK Government has used these values widely in regulatory impact assessment and for considering environmental taxes and charges (Watkiss et al. 2008). We conservatively examine a central value from Watkiss and Downing of $185/MTC (2007 dollars) noting that the authors expect significant increases over time. (The authors also provide estimates from the FUND and PAGE models, which are substantially higher than even the UK SCC estimates.)

Using the DICE-2007 model, William Nordhaus shows that the trajectory of optimal carbon prices (or carbon taxes) should rise to reflect the increasing damage caused by climate change and the need for increasingly tight constraints. In the model, the optimal price rises steadily over time, at between 2% and 3% per year in real terms, to reflect the rising damages from climate change. In this trajectory, Nordhaus' carbon price (adjusted to 2007 dollars) rises from $34/MTC to $113/MTC by 2050 and $251 per MTC in 2100. Ultimately, the carbon price will top out at the level at which the backstop technology becomes economically viable (Nordhaus 2008).

The DICE-2007 model is a globally aggregated model. The model incorporates simplified representations of the major analytical dimensions of climate change problems and is focused on analyzing the economic and environmental impacts of alternative policies (Nordhaus 2008). Like the other models, DICE-2007 does not provide for a complete understanding of the major components and has greater error the further into the future the projections move. It contains highly simplified representations of the major relationships relating emissions, concentrations, climate change, the costs of emissions reductions, and the impacts of climate change, and some of the tradeoffs—particularly between rich and poor regions—cannot be explored (Nordhaus 2008).

Realizing that no model is perfect, that each method for estimating the SCC or optimal carbon price provides different perspectives, and that there are complexities and uncertainties relating to how different variables are considered in the models, we use Nordhaus' carbon price trajectory to illustrate the potential costs (and benefits) to society that climate change can have as a result of changes in forest carbon stocks in California. (Note that as mentioned previously, social cost values have been discounted)

Predicting the Value of Future Carbon Sequestration

As the aboveground carbon storage varies, there is subsequent variation in total market value represented by losses or gains in natural carbon sequestration in the future (Table 2a). With the warmer and wetter climate (PCM1), the change in market value is positive, ranging from an average annual difference due to climate change of $19 million to $146 million/year for 2005–2035 under scenario B1 to as much as $1 billion to $7.9 billion annually by 2065–2090. The warm, wet PCM1 climate simulations consistently enhance carbon sequestration for all the periods considered and thus increase the service value, with highest change at the end of the century (2065–2099) under the low emissions scenario (B1). Conversely, under the high (A2) emissions scenario, climate projections by the hot, dry CCSM3 model cause an average annual loss of between $2.9 billion and $22.1 billion.

These estimates for changes in market values are in 2007 dollars with no discounting for present value. It is conceivable that in a market situation, real market prices will change—prices could increase if it becomes more expensive to reduce greenhouse gas emissions and, conversely, technological innovation could cause market prices to fall. Market prices will also vary depending on the types of policies implemented at the state and national level. Research economists from New Carbon Finance predict that if a cap-and-trade program is confined to domestic trading only, the carbon emissions market could be worth $1 trillion by 2020 (Environmental Leader 2008). Allowing trading with other countries like India or China, where emissions reduction measures are relatively inexpensive will yield lower prices and a cost savings to the U.S. economy (New Carbon Finance 2008).

Table 2a. Projected change in live aboveground carbon sequestered and the market value of these changes

2005–2034					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*1,025*			
B1	PCM1	1,027	0%	$19	$146
	GFDL	997	-3%	-$325	-$2,524
	CCSM3	997	-3%	-$323	-$2,504
A2	PCM1	1,035	1%	$115	$891
	GFDL	1,024	0%	-$15	-$118
	CCSM3	992	-3%	-$380	-$2,950

2035–2064					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*1,028*			
B1	PCM1	1,057	3%	$327	$2,541
	GFDL	987	-4%	-$475	-$3,685
	CCSM3	881	-14%	-$1,693	-$13,145
A2	PCM1	1,055	3%	$304	$2,357
	GFDL	968	-6%	-$690	-$5,355
	CCSM3	902	-12%	-$1,446	-$11,223

2070–2099					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*952*			
B1	PCM1	1,041	9%	$1,021	$7,926
	GFDL	935	-2%	-$199	-$1,546
	CCSM3	820	-14%	-$1,516	-$11,769
A2	PCM1	1,023	7%	$815	$6,327
	GFDL	778	-18%	-$1,994	-$15,481
	CCSM3	704	-26%	-$2,850	-$22,129

Table 2b. Projected change in live aboveground carbon sequestered and the economic value including social cost of carbon of these changes

2005–2034						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($34/MTC)	Existing UK SCC ($185/MTC)
Base		*1,025*				
B1	PCM1	1,027	0%	$38	$56	$303
	GFDL	997	-3%	-$651	-$962	-$5,236
	CCSM3	997	-3%	-$646	-$955	-$5,194
A2	PCM1	1,035	1%	$230	$340	$1,847
	GFDL	1,024	0%	-$31	-$45	-$245
	CCSM3	992	-3%	-$761	-$1,125	-$6,119

2035–2064						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($113/MTC)	Existing UK SCC ($185/MTC)
Base		*1,028*				
B1	PCM1	1,057	3%	$655	$3,220	$5,271
	GFDL	987	-4%	-$950	-$4,669	-$7,644
	CCSM3	881	-14%	-$3,390	-$16,656	-$27,269
A2	PCM1	1,055	3%	$608	$2,987	$4,890
	GFDL	968	-6%	-$1,381	-$6,786	-$11,109
	CCSM3	902	-12%	-$2,894	-$14,220	-$23,281

2070–2099						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($251/MTC)	Existing UK SCC ($185/MTC)
Base		*952*				
B1	PCM1	1,041	9%	$2,044	$22,309	$16,443
	GFDL	935	-2%	-$399	-$4,350	-$3,207
	CCSM3	820	-14%	-$3,035	-$33,123	-$24,413
A2	PCM1	1,023	7%	$1,632	$17,807	$13,125
	GFDL	778	-18%	-$3,992	-$43,570	-$32,113
	CCSM3	704	-26%	-$5,707	-$62,281	-$45,904

The expected change in the social value of stored carbon (Table 2b) is similar to that found for the analysis of market values. The warm, wet PCM1 model consistently predicts a higher capacity to store carbon and thus the affect of climate change on natural carbon storage in

California would result in a net benefit to society of between of $38 million annually in the period 2005–2034 and as high as $22 billion annually by 2070. The hotter, drier models, however, project a sharp negative difference in carbon storage capacity in natural areas leading to social costs of -$646 million to -$5.2 billion annually for the period 2005–2034 (under scenario B1 using the CCSM3 model of climate change) to as high as -$62 billion annually by the period 2070–2099, under scenario A2 using the Nordhaus' DICE-2007 model predictions.

Conclusion: Carbon Sequestration

The current voluntary carbon markets that incorporate natural system sequestration focus largely on the aboveground biomass in a forest system and so, for this study, we focused our valuation on aboveground biomass in forested systems. Sequestration of aboveground biomass decreases with all model-emissions scenario combination except the most optimistic, and the declines are more pronounced in the second and third time periods of this study. There are two main reasons why the model projects a decline in biomass: (1) loss of conifer forests due to drought stress, which might be mitigated to some extent by a CO_2 "fertilization effect" that may enhance carbon capture as CO_2 concentrations increase but more importantly should increase water use efficiency—that is, maintaining carbon uptake under a moderate level of drought stress; (2) fire losses will be significant as temperatures rise and humidity drops. When all carbon stocks (i.e., aboveground and belowground live biomass, aboveground and belowground organic carbon) are included in the analysis—not just the aboveground biomass carbon stocks included in the existing voluntary carbon market—the picture changes slightly. Net change in total carbon stocks increases under the warmer, wetter future (PCM1) for both the low and high emissions scenarios (Appendix B). In contrast, we see decreased carbon storage under both emissions scenarios using the hot, dry models (GFDL, CCSM3), largely driven by a combination of decreases in aboveground and belowground organic carbon (Appendix B). In the model-emissions scenarios with carbon loss, fires burn the vegetation and carbon losses are emitted as gases and drought conditions reduce production and carbon capture, resulting in total carbon loss. For California to take advantage of the potential for carbon storage in natural systems stocks in the future, greenhouse gas emissions must be curbed to a B1 scenario that would reduce both drought-stress conditions for natural and commercial vegetation (forests, agriculture, forage) and fire danger.

The results of our carbon projections indicate that forests and other sources of natural carbon storage are critically important assets that need to be considered, employed, and protected if we are going to work to stem the increase in global atmospheric concentration of carbon dioxide. The majority of the model-emissions scenarios find that climate change will lead to a loss of the natural ability of California's forests to store carbon by the end of the century. The result will be annual losses of potentially hundreds of millions and possibly billions of dollars in carbon sequestration capacity—a cost that will be borne by carbon emitters, automobile drivers, factories, homeowners, and others—and will be reflected in future markets for carbon. Similarly, this loss of carbon sequestering capability will result in global economic impacts if the loss of carbon is not offset by other reductions in carbon emissions.

United States
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**Northeastern
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General Technical
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Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States

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Introduction

International agreements recognize forestry activities as one way to sequester carbon, and thus mitigate the increase of carbon dioxide in the atmosphere; this may slow possible climate change effects. The United States initiated a voluntary reporting program in the early 1990's (U.S. Dep. Energy 2005). A system for developing estimates of the quantity of carbon sequestered in forest stands and harvested wood products[1] throughout the United States is a vital part of the voluntary program. This system must be relatively easy to use, transparent, economical, and accurate. In this publication, we present methods and regional average tables that meet these criteria.

Carbon is sequestered in growing trees, principally as wood in the tree bole. However, accrual in forest ecosystems also depends on the accumulation of carbon in dead wood, litter, and soil organic matter. When wood is harvested and removed from the forest, not all of the carbon flows immediately to the atmosphere. In fact, the portion of harvested carbon sequestered in long-lasting wood products may not be released to the atmosphere for years or even decades. If carbon remaining in harvested wood products is not part of the accounting system, calculation of the change in carbon stock for the forest area that is harvested will incorrectly indicate that all the harvested carbon is released to the atmosphere immediately. Failing to account for carbon in wood products significantly overestimates emissions to the atmosphere in the year in which the harvest occurs.

We adopted the approach of Birdsey (1996), who developed tables of forest carbon stocks and carbon in harvested wood to provide basic information on average carbon change per area. The tables are commonly referred to as "look-up tables" because users can identify the appropriate table for their forest, and look up the average regional carbon values for that type of forest. We have updated the tables by using new inventory surveys, forest carbon and timber projection models, and a more precise definition of carbon pools. We also include additional forest types and background information for customizing the tables for a user's specific needs.

The look-up tables are categorized by region, forest type, previous land use, and, in some cases, productivity class and management intensity. Users must identify the categories for their forest, estimate the area of forestland, and, if needed, characterize the amount of wood harvested from the area in a way that is compatible with the format of the look-up tables. The average carbon estimates per area in the look-up tables must be multiplied by the area or, as appropriate, harvested volumes, to obtain estimates in total carbon stock or change in carbon stock.

The estimates in the look-up tables are called "average estimates," indicating that they should be used when it is impractical to use more resource-intensive methods to characterize forest carbon, that is, particularly when more specific information is not available. Because these tables represent averages over large areas, the actual carbon stocks and flows for specific forests, or projects, may differ. The look-up tables should not be used when conditions for a project or site differ greatly from the classifications specified for the tables. Some users may require an alternative to an "all-or-nothing" use of the tables because they may have some information and need to use the tables to supplement, or fill in gaps, in carbon stocks. Alternatively, users may require slight alterations to the tabular data provided. Therefore, we also include the underlying assumptions and appropriate citations so that the tables can be adjusted to data availability and information requirements of individual activities.

The focus of this document is to explain the methodology in a transparent way and present sets of look-up tables for quantifying forest carbon when site-specific information is limited. In the sections that follow, we introduce the tables and provide general guidance for their use. First, tables of forest ecosystem carbon are presented; these are followed by tables to calculate the disposition of carbon in harvested wood products. Additional information on methods and data sources

[1]Traditionally, the phrase "forest products" includes paper, but the phrase "wood products" does not. The literature for forest carbon has not recognized this distinction. Thus, we use the phase "wood products" to include all forest products including paper.

B21.— Regional estimates of timber volume and carbon stocks for alder-maple stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	86.4	4.7
5	0.0	8.0	0.8	4.7	0.8	1.8	86.7	16.1
15	49.5	31.0	3.1	3.7	2.9	4.4	88.9	45.2
25	229.7	99.4	9.9	2.8	9.4	6.2	92.8	127.8
35	380.8	153.8	15.4	2.5	14.6	7.6	97.6	193.9
45	513.7	200.8	20.1	2.4	19.0	8.6	102.4	250.9
55	633.3	242.5	22.2	2.3	23.0	9.4	106.7	299.4
65	742.1	280.1	23.9	2.2	26.5	10.1	109.9	342.8
75	842.1	314.4	25.3	2.2	29.8	10.7	112.2	382.4
85	934.5	346.0	26.6	2.1	32.8	11.1	113.6	418.6
95	1,020.3	375.2	27.7	2.1	35.5	11.5	114.5	452.0
105	1,100.3	402.2	28.7	2.0	38.1	11.9	114.9	483.0
115	1,175.0	427.4	29.6	2.1	40.5	12.2	115.1	511.8
125	1,244.9	450.9	30.4	2.3	42.7	12.4	115.2	538.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.0	1.9
5	0	3.2	0.3	1.9	0.3	0.7	35.1	6.5
15	708	12.6	1.3	1.5	1.2	1.8	36.0	18.3
25	3,282	40.2	4.0	1.1	3.8	2.5	37.6	51.7
35	5,442	62.3	6.2	1.0	5.9	3.1	39.5	78.5
45	7,342	81.3	8.1	1.0	7.7	3.5	41.5	101.5
55	9,050	98.1	9.0	0.9	9.3	3.8	43.2	121.1
65	10,605	113.3	9.7	0.9	10.7	4.1	44.5	138.7
75	12,034	127.2	10.3	0.9	12.1	4.3	45.4	154.7
85	13,355	140.0	10.8	0.9	13.3	4.5	46.0	169.4
95	14,582	151.8	11.2	0.8	14.4	4.7	46.3	182.9
105	15,725	162.8	11.6	0.8	15.4	4.8	46.5	195.4
115	16,792	173.0	12.0	0.9	16.4	4.9	46.6	207.1
125	17,791	182.5	12.3	0.9	17.3	5.0	46.6	218.0

CENTRAL NAPA RIVER WATERSHED PROJECT

SALMONID HABITAT FORM AND FUNCTION

October, 2005

FINAL REPORT

Prepared By

Napa County Resource Conservation District

For

California Department of Fish and Game

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Reach 5 had a canopy density of 97%, and Reach 6 had a canopy density of 97%). In general, revegetation projects are considered when canopy density is less than 80%. Reaches 1 and 2 would benefit from riparian planting and restoration in areas with sparse canopy and narrow buffers. Reach 2 has extensive areas of exotic vegetation that should be removed and replaced with native species.

The percentage of right and left bank covered with vegetation was high at 71% and 73%, respectively. In areas of stream bank erosion or where bank vegetation is sparse, planting native plant species, in conjunction with bank stabilization, is recommended. Bank vegetation was most sparse in Reach 1.

Overall, York Creek is one of the most significant spawning and rearing streams for steelhead within the Napa Basin. Reach 1 and 2 have been adversely affected by riparian encroachment, levee construction, road building, and channel modifications (i.e. straightening). Reaches 2, 3, and 4 are the only reaches currently accessible and suitable for steelhead spawning and rearing. These reaches contain high quality habitat and sustained flow. Reach 1 contains limited rearing habitat, primarily above Highway 29. The instream reservoir on York Creek is scheduled for removal in 2006-2008 by the US Army Corps of Engineers and the City of St. Helena. Removing the reservoir will allow access to over 1.5 miles of high quality steelhead habitat. The upper reaches of York Creek offer excellent rearing and spawning habitat, and creating access to these areas will greatly benefit the overall steelhead population.

A small diversion dam in Reach 3 that was identified in our 2003 habitat survey was removed by the City of St. Helena in 2004 and restored to allow fish passage. The site is a significant improvement to fish migration in York Creek.

A complete inventory of 35 potential restoration sites for York Creek has been compiled and prioritized in section 4 of this report.

The Economic Value of Rogue River Salmon

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wilderness experience offered by the Wild Rogue, the per fish and total willingness to pay (WTP) shown in Table 8 are likely low for that section of the river.

Table 8: Estimated Annual WTP by Sport Anglers for Rogue River Salmon, 2007 Dollars

Species	Catch Location	Estimated 2007 Catch	WTP Per Fish	Estimated Total WTP	Upper Bound WTP
Coho	Ocean	6,488	$64	$412,696	$412,696
	River	1,200	$157	$188,732	$363,404
Chinook	Ocean	5,355	$64	$340,600	$340,600
	River	15,988	$232	$3,711,003	$10,946,101
Steelhead	Ocean	1,040	$126	$131,130	$160,447
	River	4,165	$299	$1,246,599	$3,789,289
Total Sport Fishing		34,236		$6,030,759	$16,012,535

Source: ECONorthwest analysis of results from studies presented in Table 7 and data from Oregon Department of Fish and Wildlife (http://www.dfw.state.or.us/resources/fishing/sportcatch.asp)

3. NON-USE VALUE OF ROGUE RIVER SALMON

Even those who do not consume salmon or steelhead may benefit from their existence. In fact, the non-use value of an environmental resource is often far greater than it's commercial or sport value. Non-use value can take several different forms: option value, which is the value of saving a good for use at another time; bequest value, the value of saving a good for future generations; altruistic value, the value of saving a good for others to use now; and existence value, the value of saving a good for the sake of its existence[21]. Surveys indicate that, in aggregate, residents of the Pacific Northwest and California place a much higher non-use value on salmon than they do use value. Only a relatively small proportion of West Coast residents participate in fishing for salmon and steelhead. Thus there are many fewer households over which to aggregate total value. For example, based on information from the *2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Oregon*, 455,000 Oregonians age 16 or older participated in fishing in 2006, out of a 16+ population of 2,894,050. This represents only 16% of Oregon's 16 and older population[22]. Comparatively, based on household survey results, a much larger percentage of Oregonians (and Americans in general) value Northwest salmon even though they likely will never participate in salmon fishing or even view a wild salmon (see Loomis, 1999, Pate and Loomis 1997, Loomis 1996).

[21] Schuhmann, P.W. and K.A. Schwabe. 2002. "Fundamentals of Economic Principles and Wildlife Management." In L. Clark, J. Hone, J.A. Shivik, R.A. Watkins, K.C. VerCauteren, and J.K. Yoder, eds., *Human Conflicts with Wildlife: Economic Considerations. Proceedings of the Third NWRC Special Symposium*. Fort Collins, CO: National Wildlife Research Center from http://www.aphis.usda.gov/ws/nwrc/symposia/economics/.

[22] U.S. Department of Interior, Fish & Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. *2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Oregon.*

Loomis (1999) estimated the marginal non-use value of salmon and steelhead on the Lower Snake River to residents of Oregon, Washington, and California[23]. The results of the analysis indicate that, as one would expect, the marginal value (i.e., the value of the next additional salmon) goes down as the total population of salmon goes up. At very low populations, (e.g. fewer than 5,000 total fish) the marginal value of an additional fish is more than $1.0 million. This immense per-fish value embodies the scarcity associated with a small fish population and society's desire to preserve the species for current and future generations.

Based on the results of the survey analysis and through the incorporation of information from other surveys, Loomis (1999) developed a *marginal WTP benefit function*, which provides estimates of the marginal value of a fish based on the size of the underlying population. He then demonstrates that as the underlying population increases, the marginal value that society places on increasing the population by one fish decreases. For example, based on a salmon population of 500,000, the marginal value of one additional fish is $1,595. However, the marginal value of a second additional fish (e.g., the marginal value based on a salmon population of 500,001) is only $1,539.

Loomis (1999) developed the marginal WTP benefit function based on analysis of society's WTP to increase the salmon populations on the lower Snake River. Based on comments from one or more reviewers of his analysis, he contends that the benefit function may in fact be representative of the entire Pacific Northwest salmon population. What this means is that, though there are many distinct populations of salmon throughout the Pacific Northwest, many Northwest and California residents do not differentiate between salmon of various populations. Society's concern is for the overall welfare of salmon populations throughout the Northwest. Thus, the value that society places on the marginal fish returning to spawn in any one Northwest river is a function of the aggregate count of all salmon returning to spawn in all Northwest rivers. The result of embracing the assumption that society views all Northwest salmon as members of one Northwest-wide population, is that society's WTP for the marginal salmon of any actual (biological) population will be lower than if society viewed each biological population separately.

To estimate the society's non-use WTP for Rogue River salmon and the value society places on the entire population of Rogue River salmon we embrace the all-Northwest assumption regarding the WTP benefit function for Rogue River salmon. In doing so, we acknowledge that our estimates of the non-use or existence value represents a lower bound estimate of the actual non-use value society places on Rogue River salmon. That is, although we are unsure of society's actual non-use WTP for Rogue River salmon, we are confident

[23] Loomis reviewed and augmented survey data from three other studies which asked households in the Pacific Northwest and California how much they were willing to pay for a specified increase in the number of either salmon or salmon and steelhead on a given river as a result of dam removal. None of the fish in these studies were endangered which is an important consideration when relating the results of these studies to other rivers since individuals will likely place greater existence value on an endangered species than on a non-endangered species.

that it is no lower than and may be much higher than the estimated value based on the WTP benefit function developed by Loomis (1999).

Table 9 shows the estimated marginal and average values of Rogue River salmon, as well as the total value of the Rogue River fishery based on various assumptions about the entire population of Northwest salmon. To our knowledge, "official" estimates of the aggregate population of Northwest salmon are not available.[24] However, based on escapement counts[25] for the Columbia River system from the Pacific Fishery Management Council (PFMC), we estimate the 10-year average annual salmon escapement for the Northwest to be approximately 830,000 fish.[26] Based on this estimate of the Northwest salmon population, we estimate society's annual marginal non-use WTP for a Rogue River salmon to be $1,008, the average WTP to be $1,824, and the total annual non-use WTP of the entire Rogue River salmon fishery to be just over $1.5 billion.

At first glance, these numbers appear to be very large. However, consider that these estimates are aggregated across the entire population of Oregon, Washington, and California—more than 46 million people in 2007. The per-person value of the entire Rogue River salmon fishery is $32.37 per year. Another perspective from which to view the annual value of the fishery is to compare it to the economic output of the 3-state region. Based on Bureau of Economic Analysis data (BEA), the combined gross state product of the three states was $2.28 trillion. The estimated annual value of the Rogue River fishery represents a mere 0.07% of the total annual output for 2007.

[24] We define "aggregate population" as the 10-year average salmon escapement summed across all Northwest river systems.

[25] Escapement is the annual count of salmon and steelhead returning to their spawning ground or hatchery.

[26] The PFMC 2007 report can be found at: http://www.pcouncil.org/salmon/salsafe.html.

Table 9: Annual Non-Use Value of Rogue River Salmon, 2007 Dollars*

Assumed Northwest Salmon Population	Marginal Value of a Rogue River Salmon	Average Value of a Rogue River Salmon	Total Value of Rogue River Salmon Population
500,000	$1,595	$4,892	$2,446,138,182
750,000	$1,112	$2,217	$1,662,959,665
828,282	**$1,008**	**$1,824**	**$1,514,072,103**
1,000,000	$822	$1,266	$1,266,345,698
1,250,000	$793	$821	$1,026,859,060
1,500,000	$525	$576	$863,315,110

Source: ECONorthwest analysis of results from Loomis, J. 1999. *Recreation and Passive Use Values From Removing the Dams on the Lower Snake River to Increase Salmon*. Agricultural Enterprises, Inc. for the Department of the Army Corps of Engineers; data from the Pacific Fishery Management Council (http://www.pcouncil.org/salmon/salsafe.html) and data from Oregon Department of Fish and Wildlife (http://www.dfw.state.or.us/resources/fishing/sportcatch.asp).

* Consistent with the results of the WTP salmon question in the 1996 through 2006 Oregon Population Surveys, we assume no inflationary growth in the WTP between 1996 (the data year of the Loomis 1999 study) and 2007.

Table 9 also provides estimates of the value of Rogue River salmon based on alternative assumptions regarding the size of the entire Northwest salmon population. The declining values associated with increasing salmon populations shown in Table 9 are consistent with economic principles of diminishing marginal value. Under an assumption of relative scarcity (e.g. a total average annual escapement of 500,000 salmon across all Northwest rivers), the marginal value of Rogue River salmon is greater. And under the alternative assumption of relative abundance (e.g. 1.5 million salmon), the marginal value of Rogue River salmon is less. Stated another way, as local, regional, and oceanic conditions worsen for Northwest salmon, the value of the next Rogue River salmon increases.

While the results of Loomis' study provide insight into the values society place on salmon in general, it is important to realize that all salmon populations in the Northwest may not be valued the same. A 2005 report by Goodstein and Matson[27] summarized and augmented research by Layton, Brown, and Plummer in 1999 on people's willingness to pay for specific salmon restoration projects. Goodstein and Matson (2007) used these data to find the perceived economic benefit of restoring salmon populations or, alternatively, of avoiding further declines in salmon populations and they extended the data collected from Washington and Oregon households to households nationwide by assuming that residents outside of Oregon and Washington, on average, placed a value on salmon restoration equal to half that of Oregon and Washington residents. This is a conservative assumption according to other studies on the value of Pacific Northwest salmon for residents outside of the Northwest region. Table 10 summarizes their findings.

[27] Goodstein, E. and L. Matson. 2007. "Climate Change in the Pacific Northwest: Valuing Snowpack Loss for Agriculture and Salmon." In J.D. Erickson and J.M. Gowdy, eds., *Frontiers in Ecological Economic Theory and Applications*. Northampton, MA: Edward Elgar.

Table 10: The Economic Benefits of Restoring Salmon Populations and of Preventing Further Declines in Salmon Populations

The economic benefits to residents of Oregon and Washington of restoring salmon populations:	
Columbia River Salmon	$2,890 per fish
Washington Coastal Chum Salmon	$872 per fish
Oregon Coastal Coho Salmon	$872 per fish
Rogue River Coastal Coho Salmon	$872 per fish
Puget Sound Chinook Salmon	$872 per fish
The economic benefit per year, to residents of Oregon and Washington, of preventing further declines in wild-salmon populations:	
Preventing a one-third decline in populations	$359 million - $3.6 billion
Preventing a two-thirds decline in populations	$718 million - $7.2 billion
The economic benefit per year, to residents of the U.S., of preventing further declines in wild-salmon populations:	
Preventing a one-third decline in populations	$5.4 billion - $54 billion
Preventing a two-thirds decline in populations	$10.9 billion - $109 billion

Source: ECONorthwest with data from Goodstein, E. and L. Matson. 2007. "Climate Change in the Pacific Northwest: Valuing Snowpack Loss for Agriculture and Salmon." In J.D. Erickson and J.M. Gowdy eds., *Frontiers in Ecological Economic Theory and Application*. Northampton, MA: Edward Elgar.

One of the disadvantages of the reports of non-use value viewed thus far is that they take data only from one point in time and do not allow us to observe how residents' willingness to pay for salmon recovery changes with changes in the economy and social structure. To observe trends in Oregonians' willingness to pay for salmon habitat restoration and improved water quality, we look at the Biennial Oregon Population Survey, conducted by the Oregon Office of Economic Analysis and the Oregon Progress Board. The survey provides data from as far back as 1996 and asks Oregon residents, how much per month they are willing to pay for water quality and habitat improvement efforts to help improve salmon runs in Oregon.

In 2006, the survey results showed, on average, that each Oregonian household was willing to pay $4.42 per month in 2008 dollars. Extending that value over the course of a year and multiplying the result by 1,333,723 Oregon households, indicates that Oregonians alone are willing to pay a total of $75,958,977 per year to improve salmon runs. Figure 2 shows the average annual amount Oregonians stated they are willing to pay for water quality and salmon habitat improvements based on the results of the Oregon Population Survey. The willingness to pay remains fairly constant (in nominal dollars) throughout the years for which data are available indicating that Oregonians are willing to make a long-term commitment to protecting and improving salmon habitat. It also indicates that Oregonians have a

NAPA RIVER STEELHEAD AND SALMON MONITORING PROGRAM

2011-2012 SEASON

ADULT STEELHEAD IN MILLIKEN CREEK (MARCH 9, 2012)

SEPTEMBER, 2012

NAPA COUNTY RESOURCE CONSERVATION DISTRICT
1303 JEFFERSON ST. SUITE 500B
NAPA, CALIFORNIA 94559
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Steelhead smolt length (measured as fork length) during the past four years of sampling has averaged 187mm (7.4 inches). The median steelhead smolt size was 179mm (7.0 inches) in 2012. It appears that the size and range of steelhead smolts has varied little during the past four years (Figure 9), despite significant variability in environmental conditions including rainfall amounts and timing as well as seasonal flow patterns. Several studies have found a strong correlation between steelhead smolt size and ocean survival rates, with larger smolts having greater odds of returning as adults (Bond et al 2008, Ward and Slaney1988, Ward et al 1989). Given their large size, we would expect Napa River steelhead smolts to have relatively high ocean survival rates, perhaps 15-25% based on literature.

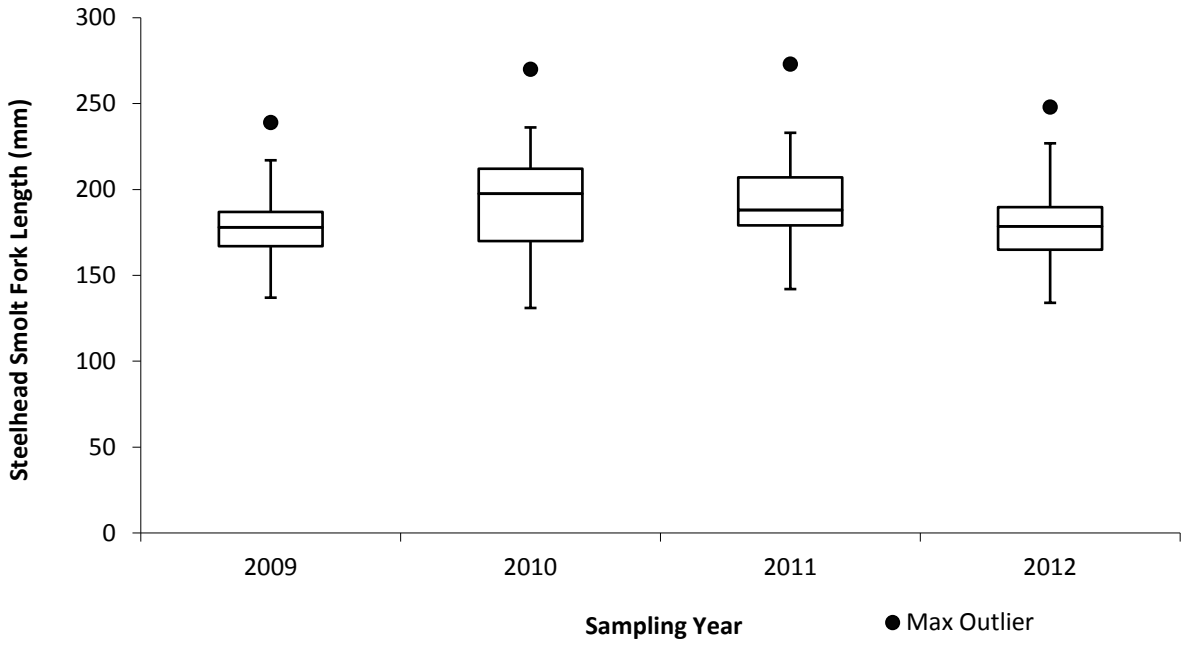


Figure 9. Box plot of steelhead smolt length from the Napa River rotary screw trap 2009-2012. Note: The bottom and top of each box are the 25th and 75th percentiles respectively. The line near the middle of each box is the median, and the vertical lines (whiskers) represent the lowest and highest values within 1.5 times the inter-quartile range. The maximum outlier values represent the largest individual measurement for each year.

Steelhead smolts were collected consistently throughout the 2012 season with the highest numbers captured during the third week in April. As observed in previous years, the highest steelhead catches corresponded with elevated flows following storms (Figure 10). Chinook salmon smolts were collected more regularly toward the end of the season with a peak around early May (Figure 11).

as it fosters "collaborative relationships for a sustainable water resources future" (USACE, 2010a), including development of a Federal Support Toolbox to provide a common data portal to support IWRM (USACE, 2010b).

B. Watersheds and Wetlands

VISION: Watersheds are protected, maintained and restored to provide climate resilience and to preserve the ecological, social and economic benefits they provide; and the nation's wetlands are maintained and improved using integrated approaches that recognize their inherent value as well as their role in reducing the impacts of climate change.

Healthy watersheds and wetlands will be critical to climate adaptation and mitigation. This section addresses how EPA intends to protect healthy watersheds, restore impaired watersheds to enhance climate resiliency, and preserve the important functions and ecosystem services provided by the nation's wetlands, especially in the face of climate change.

Healthy watersheds and wetlands provide a host of ecological services, including water purification, ground water and surface flow regulation, wildlife habitat, flood and surge impact reduction, water temperature moderation, erosion control, and stream bank stabilization. In many cases, they also store carbon and sequester other greenhouse gases. These ecosystems already are threatened with a number of stressors, and climate change will exacerbate existing water quality and ecosystem management issues.

Protecting waters and watersheds inherently involves landscape-scale collaboration involving state, tribal, federal, and local partners. Such collaborations promote a holistic, systems approach, enabling partners to more cost-effectively reach shared goals that increase ecosystem resilience to climate change. In particular, the NWP intends to work to implement the National Fish, Wildlife and Plants Climate Adaptation Strategy (FWP, 2011), which lists seven goals (see Table 1).

Table 1: Draft National Fish, Wildlife and Plants Climate Adaptation Strategy

Goals:

- **Goal 1.** Conserve and Connect Habitat
- **Goal 2.** Manage Species & Habitats
- **Goal 3.** Enhance Management Capacity
- **Goal 4.** Support Adaptive Management
- **Goal 5.** Increase Knowledge & Information
- **Goal 6.** Increase Awareness & Motivate Action
- **Goal 7.** Reduce Non-Climate Stressors

FWP, 2011. Fish, Wildlife and Plants Climate Adaptation Workgroup www.wildlifeadaptationstrategy.gov

"The once seemingly separable types of aquatic ecosystems are, we now know, interrelated and interdependent. We cannot expect to preserve the remaining qualities of our water resources without providing appropriate protection for the entire resource." *Tennessee Senator Howard Baker on the importance of the Clean Water Act on the Senate floor, 1977*

"I ask that your marvelous natural resources be handed on unimpaired to your posterity." *Theodore Roosevelt, Sacramento, CA 1903*

The Goals and Strategic Actions in this section in particular reflect EPA's intention to implement the FWP Strategy.

GOAL 3: Identify, protect, and maintain a network of healthy watersheds and supportive habitat corridor networks across the country that provide resilience to climate change.

EPA, in partnership with others, is embarking on the Healthy Watersheds Initiative (HWI) to expand its efforts to protect healthy aquatic ecosystems using a strategic systems-based approach, prevent them from becoming impaired, and accelerate restoration (EPA, 2011g). This Initiative will greatly enhance our ability to meet the full intent and extent of the CWA 101(a) objective, "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters," and in doing so, will increase the climate resiliency of aquatic ecosystems and their watersheds. This goal would be difficult to achieve without working with our partners and their programs, such as the state-led National Fish Habitat Action Plan, the watershed protection and restoration programs of the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), and the U.S. Forest Service (USFS), the full suite of conservation programs administered by U.S. Department of Agriculture, the U.S. Geological Survey's (USGS) Water Smart Initiative, the Nature Conservancy's Instream Flow and North America Freshwater Conservation Programs, the U.S. Army Corps of Engineers, and others.

Integrated Water Resources Management

Successful adaptation and mitigation of climate change impacts will require a coordinated effort among all levels of government, tribes, communities, nongovernmental groups, scientific entities and the private sector - that is, Integrated Water Resources Management. These voluntary partnerships will be essential to protecting and restoring watersheds, wetlands and coastal areas."

—Nancy Stoner, Acting Assistant Administrator, EPA Office of Water, 2011

The Healthy Watersheds approach is an important component of IWRM. IWRM offers a more holistic approach to water quality protection by addressing surface water and ground water quality and quantity as one hydrologic system. As implementation of the Healthy Watersheds approach increases our understanding of some of these relationships (e.g., hydrologic requirements of aquatic ecosystems), that knowledge will provide building blocks for the foundation of IWRM.

Strategic Action 8: The NWP intends to develop a national framework for a network of remaining healthy watersheds and aquatic ecosystems, including natural infrastructure for habitat corridors, and intends to support state and tribal efforts.

A national framework includes indicators to assess, identify, and track healthy watersheds and the success of protection measures. The NWP intends to support state and tribal efforts to conduct statewide and tribal lands integrated healthy watersheds assessments that include landscape condition (i.e., habitat corridor and floodplain connectivity and headwaters habitat intactness); hydrology; fluvial geomorphologic processes; and aquatic biology, habitat, and chemical condition. The NWP also intends to support state and tribal efforts to implement programs aimed at protecting and maintaining healthy, resilient watersheds and habitat.

The NWP intends to work with partners to develop and pilot watershed projects and management practices that improve the resilience of healthy watersheds to climate change, including the demonstration of methods that preserve and protect natural hydrology, intact active river areas (TNC, 2008), aquatic habitat corridors, natural transport of sediment, and stream geomorphology. The NWP intends to provide technical decision support to local and regional planning commissions and governments for implementing programs to protect identified watersheds in the face of climate change, consistent with the IWRM objective of the ICCATF.

Strategic Action 9: The NWP intends to collaborate with federal and other partners who focus on terrestrial ecosystems and hydrology to promote consideration of potential effects of climate change on water quality and aquatic ecosystems.

Among the multitude of services derived from intact forests are protection of water resources and sequestration of carbon. The NWP intends to continue collaborating with partner agencies (including the ICCATF Fish, Wildlife and Plants Climate Adaptation Workgroup) to support their management objectives that maximize the adaptive capacity of ecosystems (e.g., through the protection of biodiversity, functional forest groups, and keystone species, and protection against invasive species) resulting in reduced vulnerability to disturbance and associated impacts to aquatic ecosystem integrity. In particular, the NWP intends to actively support and promote appropriate forest protection efforts, afforestation (new plantings) and reforestation (replanting of deforested areas) of non-forest lands, and promote and explore partnerships with working lands, land retirement, and forestry programs within other federal agencies such as those administered by the USFS and USDA's Natural Resources Conservation Service and Farm Service Agency.

For example, to date, EPA has been working directly with USFS staff in the State and Private Forestry program to promote the use of afforestation and reforestation as a component of GI, especially as it pertains to water quality protection and stormwater management. EPA has already co-developed a draft manual describing engineered approaches to afforestation and reforestation for stormwater management and has been working through the National Arbor Day Foundation to disseminate this information to arborists, local and state forestry officials, and tree planting volunteers. EPA intends to continue working with the USFS and partners such as the National Arbor Day Foundation to support these types of outreach efforts and broaden them to address the backlog of one million acres of national forests that the USFS has identified as needing replanting.

EPA has also contributed funds to USFS staff working in the EPA Chesapeake Bay Program Office in order to start up a Web-based forestry stewardship program targeting small landowners. A geo-referenced stewardship planning tool has been developed in partnership with the Pinchot Institute and is operational for three mid-Atlantic States. The tool allows private landowners to enter information characterizing landownership in order to obtain information about available federal and state programs that encourage afforestation and reforestation while providing economic benefits. Efforts are underway to expand the coverage of this tool nationwide.

Strategic Action 10: The NWP intends to work to integrate protection of healthy watersheds throughout the NWP core programs.

Strategies that build resilience to climate change include incorporating healthy watershed protection priorities into states' continuing planning processes, promoting GI for managing stormwater, implementing the Section 404 wetlands compensatory mitigation rule, incorporating protection of healthy watersheds into funding and technical assistance programs, working with tribes, and strengthening strategic partnerships throughout EPA and the federal government, including smart growth strategies. EPA intends to encourage permitting authorities to use stormwater permits, as appropriate, to increase watershed resilience; for example, where increased use of GI or reductions in impervious cover can both address water quality issues and increase resilience to climate change. EPA intends to work with states to use the continuing planning process to develop and implement healthy watershed protection and restoration priorities.

Strategic Action 11: Increase public awareness of the role and importance of healthy watersheds in reducing the adverse impacts of climate change.

The critical ecological services watersheds and wetlands provide often go unrecognized by the public. Raising public awareness of the importance of protecting healthy watersheds will garner public support for actions needed to sustain these resources in the face of climate change.

The NWP intends to develop and implement public outreach programs emphasizing the importance of healthy watersheds, including the economic benefits of protecting and restoring watersheds, wetlands, floodplains, and riparian areas. To build support for action, the NWP intends to further articulate the climate-induced risks to aquatic ecosystems, and the associated need to enable ecosystem migration. (See for example EPA, 2011h.)

GOAL 4: Incorporate climate resilience into watershed restoration and floodplain management.

Watershed restoration and a watershed approach to floodplain management focus on re-establishing the composition, structure, pattern, and ecological processes of degraded or altered aquatic and riparian ecosystems necessary to make them sustainable, resilient, and healthy. Incorporating climate change factors into planning efforts will enable watershed strategies to be successful over the long term.

Strategic Action 12: The NWP intends to consider a means of accounting for climate change in EPA funded watershed restoration projects and encourage others funding restoration projects to take climate change and resiliency into consideration.

In partnership with other federal, state, interstate, and local water sector actors, the NWP intends to clarify and encourage implementation of existing investment flexibilities to support investments in climate resiliency in watershed restoration approaches, source water protection, GI, and joint partnerships, consistent with authorizing legislation. For example, CWA Section 319(h) grants can be used to implement nonpoint source management projects to

protect and restore watersheds, including those that are vulnerable to changing land use and/or climate change. The Section 319 grant guidance encourages partnering with other environmental programs with shared goals to leverage funding and strategically target efforts to maximize results. These partnerships are a key element to healthy watersheds protection and have the potential to be effective in meeting common goals of watershed protection across state and federal agencies.

Strategic Action 13: The NWP intends to work with federal, state, interstate, tribal, and local partners to protect and restore the natural resources and functions of riverine and coastal floodplains as a means of building resiliency and protecting water quality.

Floodplains are among the most valuable ecosystems to society, second only to estuaries. Despite representing less than 2% of Earth's terrestrial land surface area, floodplains provide approximately 25% of all terrestrial ecosystem service benefits (Opperman, 2010). Protecting and restoring the natural resources and functions of floodplains will provide numerous environmental as well as economic benefits, such as protecting water quality, enhancing ground water recharge, and ensuring base flow of streams. Buffer areas also provide for flood attenuation, allow potential shoreline and lateral stream movement, modulate water level fluctuations, and minimize impacts on infrastructure. The NWP intends to encourage sound floodplain management, including use of nonstructural measures such as GI and LID, and work with partners to enhance the use of buffers to reduce flood losses, protect riparian ecosystems, improve water quality, and build resilience. The NWP intends to discourage use of structural measures (e.g., stream channelization and levees) whenever possible.

GOAL 5: Watershed protection practices incorporate source water protection, and vice versa, to protect and preserve drinking water supplies from the effects of climate change.

Protecting public health from contaminants in drinking water will require adapting to the impacts of climate change, which poses multiple concerns for public water systems. Warmer waters foster pathogen growth, testing the reliability of drinking water disinfection and potentially increasing costs. Increased precipitation may result in additional pollutant loadings of nutrients, pesticides, and other chemicals, further challenging drinking water treatment. Sea level rise in coastal areas puts freshwater supplies for all uses, particularly drinking water, at increasing risk. Saltwater intrusion into coastal aquifers is a problem in some areas where ground water withdrawals are outstripping recharge; increased pressure head from a higher sea level worsens this problem. As sea level rises, community drinking water intakes may end up in brackish waters as the salt front migrates up coastal rivers and streams.

Strategic Action 14: The NWP intends to encourage states to consider updating their source water delineations, assessments or protection plans to address anticipated climate change impacts.

NWP program staff intend to continue working to assure that states include protecting drinking water supplies (ground water and surface water) in watershed planning and protection programs. States should consider the feasibility and value of periodically updating their source water protection areas and protection plans in concert with state watershed plan updates to address anticipated climate change impacts. EPA and its federal partners intend to

explore opportunities for providing technical assistance to states as they update their source water delineations, assessments, and protection plans to address anticipated climate change impacts.

Strategic Action 15: The NWP intends to continue to collaborate with stakeholders to increase state and local awareness of source water protection needs and opportunities and encourage inclusion of source water protection areas in local climate change adaptation initiatives.

There are many players who influence the effectiveness of source water protection at the national, state, interstate, tribal, and local levels, such as water science and regulatory agencies, water sector utility operators, local decision-makers, and nongovernmental and private sector stakeholders. Acting individually, they may affect aspects of source water protection and preservation, but collaborating on the same watersheds and aquifers increases the potential to protect and preserve those resources. The NWP intends to work to foster increased collaboration to develop decision support tools to inform deliberations at the local and watershed or aquifer scale.

GOAL 6: EPA incorporates climate change considerations into its wetlands programs, including the CWA 404 program, as appropriate.

Since 1989, the federal government as a whole has embraced a policy goal of no net loss of wetlands under the CWA Section 404 regulatory program. In addition, the program operates under a goal of a net increase in the quality and quantity of the nation's wetlands. EPA's Wetlands Program fosters effective wetlands management through strategic partnerships with states, tribes, local governments, and other partners. Key to accomplishing these goals and actions is a watershed approach to aquatic resource protection.

Section 404 of the CWA establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States typically regulated under this program include fill for development, water resource projects (e.g., dams and levees), infrastructure development (e.g., highways and airports), and mining projects. Section 404 requires either a permit from the U.S. Army Corps of Engineers (USACE) or an EPA-approved state program before dredged or fill material may be discharged into waters of the United States.

One basic requirement of the CWA Section 404 permitting program, as implemented by 404(b)(1) Guidelines, is that no discharge of dredged or fill material into wetlands may be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. Significant degradation is broadly defined in the 404(b)(1) Guidelines to include individual or cumulative impacts to human health and welfare; fish and wildlife; ecosystem diversity, productivity, and stability; and recreational, aesthetic, or economic values.

Strategic Action 16: The NWP intends to consider the effects of climate change as appropriate when making significant degradation determinations in the CWA Section 404 Wetlands Permitting and Enforcement Programs.

In light of the growing concerns regarding the adverse effects of climate change and the recognition that protecting the nation's wetlands and other aquatic resources can help mitigate these effects, EPA intends to coordinate with USACE to better understand how climate change may impact Section 404 sites and if/how the systematic consideration of climate change impacts could be incorporated into decision processes (including minimization and compensatory mitigation practices) in a scientifically and legally defensible way. EPA's Section 404 permit review process also includes determining if there would be a "substantial and unacceptable" impact to Aquatic Resources of National Importance (ARNI), as provided in Part IV of the 1992 CWA Section 404(q) Memorandum of Agreement between EPA and the Department of the Army, often called the elevation procedures. Criteria used for identifying an ARNI could potentially consider the chemical, physical, and biological importance, in light of climate change, of an aquatic resource proposed to be impacted. In partnership with USACE, the NWP also intends to consider how to incorporate the anticipated effects of climate change, as appropriate, when determining whether impacts are "unacceptable" (e.g., where discharges would result in harm to wetlands critical to storm surge reduction).

Strategic Action 17: The NWP intends to evaluate, in conjunction with relevant Federal Agencies when applicable, including USDA, USFWS, and the USACE, how wetland and stream compensation projects could be selected, designed, and sited to aid in reducing the effects of climate change.

Consistent with established regulatory policy, impacts must be compensated for "to the extent appropriate and practicable" after they are avoided and minimized to the greatest extent practicable. As an example, in order to offset permitted impacts, the Corps typically requires between 40,000 and 50,000 acres of compensatory mitigation annually. This compensation takes the form of restored, created, enhanced, and/or preserved complexes of wetlands and streams. EPA, in conjunction with the Corps, intends to consider how these wetland and stream compensation projects could be selected, designed, and sited to aid in reducing the impacts of climate change, with a focus on analyzing climate change and associated relative sea level change for coastal mitigation projects. For example, certain types of wetland mitigation projects might be encouraged in the future because of their scientifically assessed relative carbon sequestration benefits or because siting mitigation projects in coastal zones would facilitate wetland migration as sea level rises while also enhancing the natural lines of defense ("resilience") of the coastline and community and creating public green space that enhances the livability and sense of place of the community.

GOAL 7: EPA improves baseline information on wetland extent, condition, and performance to inform effective adaptation to climate change.

Baseline information on the location, extent, and quality of wetlands and aquatic resources will help to measure changes caused by climate change and other stressors. Ongoing monitoring will inform the development of predictive models and management strategies, including for climate change adaptation.

Strategic Action 18: The NWP intends to expand wetland mapping by supporting wetland mapping coalitions and training on use of the new Federal Wetland Mapping Standard.

While Agency conclusions should be informed by detailed, accurate data sources, the existing National Wetland Inventory (NWI) mapping, managed by the USFWS, is a good initial guide about potential wetlands in an area/watershed and is used extensively, including to address the effects of climate change (e.g., modeling relative sea level rise). The NWI maps were innovative when first produced, but additional work is now needed to update these maps to make them current and to better satisfy the demands for sophisticated analysis that supports effective environmental planning. Hardcopy maps are available for approximately 4/5 of the nation, and approximately half of the NWI is available online for use in geographic information system (GIS) applications. However, a significant portion of the arid Western United States has not yet been mapped.

The modernized Wetlands Mapping Standard was developed by the interagency Federal Geographic Data Committee (FGDC), in collaboration with representatives of federal agencies, states, tribes, environmental organizations, and management associations, as well as local government associations from both the wetlands and geospatial communities. The Wetland Mapping Standard was developed to improve and standardize mapping data quality in order to accelerate the rate at which the national wetlands mapping is completed and to enable real-time updates of the national wetlands data layer in the future. Using the new Standard, other groups, such as states, tribes, local governments, and nongovernmental organizations, are able to collect and upload digitally mapped data to the NWI. EPA and other federal agencies intend to train and support a range of organizations to complete the national map.

Strategic Action 19: The NWP intends to produce a statistically valid, ecological condition assessment of the nation's wetlands.

The National Wetland Condition Assessment (NWCA) will be an integrated gauge of wetland condition nationwide, summarizing the cumulative effects of federal, state, interstate, tribal, and local government and private-party actions that either degrade wetlands or protect and restore their ecological condition. The NWCA will be repeated at the national scale every five years and will incorporate those indicators that EPA identifies as most meaningful to detecting and predicting the impacts of climate change on the condition of the nation's wetlands.

EPA worked closely with the USFWS Wetlands Status and Trends program to utilize its network of analysis plots as the sampling frame for the NWCA. When these efforts are paired, we will for the first time be able to measure progress toward the national goal to increase the quantity and quality of the nation's wetlands (Figure 8).

Figure 8: National Wetland Condition Assessment Site Locations

Approx. 1,000 randomly selected wetland sites sampled in 2011. National Wetland Condition Assessment, EPA, 2011n.

Wetland quality or condition speaks to how wetlands differ from their "natural" state, providing an assessment of the overall ecological integrity of the resource and the relative status of wetland processes, such as the ability of a wetland to absorb nutrients. In addition, the NWCA will identify the stressors most associated with degraded wetland condition because they provide insights into the causes of declining wetland quality.

> "Wetlands are inextricably tied to water levels and changes in climatic conditions affecting water availability will greatly influence the nature and function of specific wetlands, including the type of plant and animal species within them."
>
> Secretary of the Interior Ken Salazar, announcing availability of the new wetland mapping standard. August 18, 2009

Strategic Action 20: The NWP intends to work with partners and stakeholders to develop information and tools to support long term planning and priority setting for wetland restoration projects.

Wetlands have the potential to provide added benefits for climate change adaptation as well the potential to store and sequester carbon. The NWP intends to work with partners and stakeholders to share evolving information and tools to encourage consideration of climate change in long term planning and priority setting for wetlands management strategies and sustainable restoration projects.

C. Coastal and Ocean Waters

VISION: Adverse effects of climate change along with collective stressors and unintended adverse consequences of responses to climate change have been successfully prevented or reduced in the ocean and coastal environment. Federal, tribal, state, and local agencies, organizations, and institutions are working cooperatively; and information necessary to integrate climate change considerations into ocean and coastal management is produced, readily available, and used.

Coastal and ocean environments are inextricably linked, both spatially and ecologically. This section borrows the concept of the "baseline" (a legal demarcation of ordinary low tide levels that also crosses river mouths, the opening of bays, and along the outer points of complex coastlines) to facilitate the discussion of strategies that may be more applicable to coastal environments (which we loosely define as being on the landward side of the baseline) or ocean environments (seaward of the baseline). The baseline may affect climate change strategies because of its jurisdictional implications relevant to governmental authority. However, although the terms "coastal" and "ocean" are used primarily to organize this discussion, we recognize that those domains grade into each other and that some strategies may be appropriate on both sides of the baseline.

As in other regions, coastal areas will face challenges to wetlands, watersheds, infrastructure, water quality, and drinking water. Some coastal problems, such as nonpoint source pollution and changing precipitation patterns, have the same causes and effects that are found in inland places.

EAST BAYSHORE OPERATING COSTS

FY09

MG / Month		Lab Cost		Expendures to Date	Expendures plus lab
2.54	July	$ 3,000.60			
3.66	August	$ 2,779.23			
3.83	Septembe	$ 2,665.71			
2.86	October	$ 4,181.25	$ 12,626.79	$ 74,635.09	$ 87,261.88
1.13	Novembe	$ 3,318.46			
1.74	Decembe	$ 2,904.10			
0.57	January	$ 3,346.84			
0.25	February	$ 1,918.54			
0.82	March	$ 2,139.91			
1.93	April	$ 2,641.86	$ 16,269.71	$ 191,323.09	$ 207,592.80
3.66	May	$ 4,285.62			
3.84	June	$ 2,715.45	$ 7,001.07	$ 321,726.87	$ 328,727.94
		$ 35,897.57	$ 35,897.57		
				Winter	$ 120,330.92
				Summer	$ 208,397.02
		Expended		Budgeted	
Labor - Operation		$ 150,727.04	42.1%	$ 87,031.77	173.2%
Labor - Overtime		$ 8,472.20	2.4%	$ 4,142.44	204.5%
Labor - Maintenance		$ -	0.0%	$ 136,189.19	0.0%
Chemicals		$ 26,297.78	7.4%	$ 114,303.00	23.0%
Parts & Materials		$ 1,676.48	0.5%	$ 24,500.00	6.8%
Power		$ 70,321.00	19.7%	$ 72,193.40	97.4%
Laboratory Invoicing		$ 35,897.57	10.0%	$ -	
Other		$ 64,233.72	18.0%	$ 26,597.00	241.5%
Total		$ 357,625.79	100.0%	$ 464,956.81	76.9%
Million Gallons Produ		26.85		**Chemical**	**$26,298**
Cost per million gallo		$ 13,321.77		**Power**	**$70,321**
Acre feet		82.38		**Lab**	**$18,000**
Cost per acre foot		$ 4,340.91		**Total =**	**$114,619**
				Average/MG	**$4,269**

EAST BAYSHORE OPERATING COSTS

FY10

MG / Month		Lab Cost		Expendures to Date	Expendures plus lab
4.86	July	$ 3,865.81			
4.63	August	$ 4,941.06			
3.70	Septembe	$ 3,480.98			
1.35	October	$ 3,670.55	$ 15,958.40	$ 94,647.16	$ 110,605.56
0.74	Novembe	$ 4,886.35			
0.66	Decembe	$ 3,735.27			
0.28	January	$ 4,116.69			
0.36	February	$ 3,998.63			
0.82	March	$ 3,358.37			

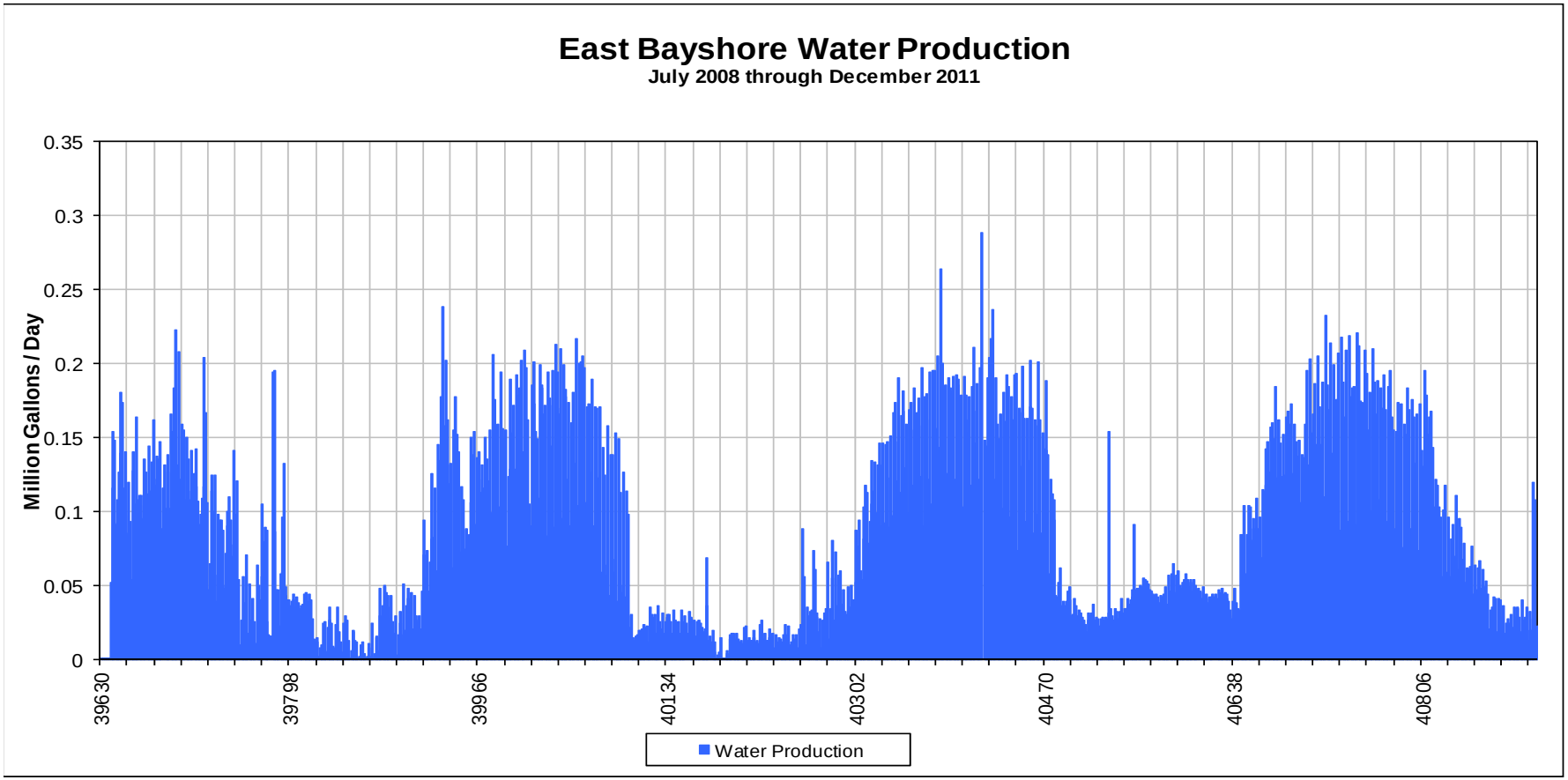
1.04	April	$ 2,437.31	$ 22,532.62	$ 373,871.50	$ 396,404.12
2.80	May	$ 3,982.73			
4.17	June	$ 2,946.09	$ 6,928.82	$ 438,706.74	$ 445,635.56
		$ 45,419.84	$ 45,419.84		
				Winter	$ 285,798.56
				Summer	$ 159,837.00
		Expended		Budgeted	
Labor - Operation		$ 162,649.68	35.7%	$ 116,006.55	140.2%
Labor - Overtime		$ 8,070.67	1.8%	$ 4,214.13	191.5%
Labor - Maintenance		$ 203,106.42	44.5%	$ 31,200.00	651.0%
Chemicals		$ 21,566.36	4.7%	$ 35,929.00	60.0%
Parts & Materials		$ 1,608.58	0.4%	$ 6,900.00	23.3%
Power		$ -	0.0%	$ 79,510.00	0.0%
Laboratory Invoicing		$ 17,393.38	3.8%	$ -	
Other		$ 41,705.03	9.1%	$ 14,757.00	282.6%
Total		$ 456,100.12	100.0%	$ 288,516.68	158.1%
Million Gallons Produ		25.41			
Cost per million gallc		$ 17,947.69			
Acre feet		77.99			
Cost per acre foot		$ 5,848.27			

EAST BAYSHORE OPERATING COSTS

FY11

				Expendures	Expendures
MG / Month		Lab Cost		to Date	plus lab
4.91	July	$ 2,625.96			
4.69	August	$ 2,418.74			
4.51	Septembe	$ 2,708.00			
3.67	October	$ 1,252.00	$ 9,004.70	$ 55,141.45	$ 64,146.15
1.00	Novembei	$ 3,439.00			
1.03	Decembei	$ 2,612.00			
1.45	January	$ 2,953.00			
1.37	February	$ 2,442.00			
1.36	March	$ 2,125.00			
1.98	April	$ 2,274.00	$ 15,845.00	$ 191,913.12	$ 207,758.12
4.14	May	$ 1,903.00			
4.41	June	$ 616.00	$ 2,519.00	$ 284,712.76	$ 287,231.76
		$ 27,368.70	$ 27,368.70		
				Winter	$ 143,611.97
				Summer	$ 143,619.79
		Expended		Budgeted	
Labor - Operation		$ 112,878.93	35.9%	$ 138,404.20	81.6%
Labor - Overtime		$ 9,024.83	2.9%	$ 4,419.68	204.2%
Labor - Maintenance		$ 89,963.24	28.6%	$ 31,200.00	288.3%
Chemicals		$ 495.21	0.2%	$ 35,929.00	1.4%

Parts & Materials	$ 234.27	0.1%	$ 100.00	234.3%
Power	$ 39,519.00	12.6%	$ 79,510.00	49.7%
Laboratory Invoicing	$ 29,555.16	9.4%	$ -	
Other	$ 32,619.28	10.4%	$ 32,619.28	100.0%
Total	$ 314,289.92	100.0%	$ 322,182.16	97.6%
Million Gallons Produ	34.54			
Cost per million gallo	$ 9,100.40			
Acre feet	105.99			
Cost per acre foot	$ 2,965.37			


East Bayshore Water Production
July 2008 through December 2011
Million Gallons / Day
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
39630
39798
39966
40134
40302
40470
40638
40806
Water Production

Estimated demand		
Address	**Irrigation (gpd)**	
5555 Shellmound	3,830	
1903 Powell	1,919	
6425 Christie Ave Emeryville	5354	
6399 Christie Ave Emeryville	3071	
6400 Christie Ave Emeryville	2774	
6400 Christie Ave Emeryville	2889	
6202 Christie Ave Emeryville	1591	
6363 Christie Ave # B Emeryville	787	
6363 Christie Ave # 3 Emeryville	3065	
5700 Christie Ave Emeryville	10367	
6335 Christie Ave Emeryville	1300	
940 Clevland Ave Albany	13100	
585 Gilman St Albany	3200	
613 University Ave Berkeley	5100	
Ashby Ave Berkeley	3200	
1000 Jackson St Albany	13900	
1050 Eastshore Hwy Albany	9100	
800 Bucchanan St Albany	14,200	
1000 San Bablo Ave Albany	123,500	
Berkeley	18,000	
5401 Chiron Way	45,000	
Albany	5,000	
West Frontage Rd Albany	12,500	
Oakland Bay Bridge Approach	19,200	
		MGD
Total =	**321,947**	**0.32**

Average treatment costs			
Treatment	**Cost/AF**	**Cost/MG**	
Wastewater ($44/MG disinfectant)		$44	
Potable water (7 years non-drought)	$159	$482	
Potable water (3 years drought)	$500	$1,515	
Recycled water	$776	$2,586	(1AF=0.3MG)
	$853		(1AF=0.33MG)

Average annual production = = (FY09: 26.85MG + FY10 :25.41MG + FY11:34.54MG)/3 = 28.93 MG = 29MG

Component	**Average Incremental operational unit cost**	**Sources**
Chemicals (chlorine)	$500/month	Operating Budget - Kathy Fagan, Administrative Assistant
Power	$69,000(*) /year	See East Bayshore Operating Cost - FY09 to FY 11

Power = (Power FY09 + Power FY10 + Power FY11)/3 = $70320 + (Use $8,200/month - per Kathy Fagan) + $39,520)/3 = $69,000

Average Avoid Cost per MG = l Power)/Annual production = ($500*12 + $69,000)/29 = $2,586

Average Avoid Cost per AF = $776 (using 1AF=0.3MG)

$853 (using 1AF = 0.33MG)

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Willingness to Pay for Local Coho Salmon Enhancement in Coastal Communities

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Abstract *Salmon restoration and enhancement are dominant environmental policy issues in Oregon and Washington. In response to salmon species listings under the Endangered Species Act, salmon protection and recovery actions are being implemented throughout the Pacific Northwest at substantial opportunity costs. In this paper, we examine the willingness to pay (WTP) of coastal residents for local coho salmon enhancement programs. A contingent valuation study is completed using survey responses from five rural, coastal communities of Oregon and Washington, where coho salmon are prevalent. Our empirical results indicate that coastal residents are willing to pay for local coho salmon enhancement and that WTP varies considerably with individual opinions of the merit of the enhancement program.*

Key words Willingness to pay, coho salmon, contingent valuation.

JEL Classification Codes Q28, H00, D60.

Introduction

Salmon restoration and enhancement are dominant environmental policy issues in Oregon and Washington State (Lichatowich 1999; Taylor 1999). Within these two states, 18 salmon and steelhead stocks were listed as threatened or endangered under the Endangered Species Act (ESA) in 2001. An additional three stocks were candidates for listing in 2001. Policy actions implemented and proposed to address the marked decline in salmon populations include government actions at local, state, and national levels. Habitat rehabilitation, restrictions on sport and commercial

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catch, changes in operation of hydroelectric power facilities, and hatchery programs are examples of actions undertaken to restore and enhance salmon stocks.

Salmon restoration and enhancement involves fundamental tradeoffs in the use and appreciation of natural resources, and because the lifecycle of anadromous salmon involves migration between rivers and the ocean, these tradeoffs occur over wide expanses of the landscape. As more salmon species are listed under ESA, policymakers are increasingly faced with the consequences of these tradeoffs; namely the conflicts between salmon preservation uses and other economic uses of water and land (Huppert 1999). While the costs of federal and state salmon enhancement programs are distributed widely across taxpayers, other costs are incurred locally at the community level. Concerns over the concentration of such costs at the community level are commonly voiced in petitions regarding the listing of salmonid species as threatened under ESA.

In this paper, we examine the willingness to pay (WTP) of coastal residents for local coho salmon enhancement programs using contingent valuation methods. A range of salmon restoration and enhancement options with diverse opportunity costs is available to decision-makers. Given this abundance of options, we believe that an improved understanding of local willingness to pay for specific protections may inform future salmon restoration and protection decisions. The National Marine Fisheries Service (NMFS) groups West Coast salmon and steelhead species into 51 distinct population segments entitled "evolutionarily significant units" or ESUs, that are eligible for listing under the Endangered Species Act.[1] Coho salmon are grouped into six West Coast ESUs: Central California, Southern Oregon/Northern California Coasts, Oregon Coast, Puget Sound/Strait of Georgia, Lower Columbia River/Southwest Washington, and Olympic Peninsula. The Central California, Southern Oregon/Northern California, and Oregon Coast ESUs were listed as threatened in 1996, 1997, and 1998, respectively. The Puget Sound/Strait of Georgia and Lower Columbia River/Southwest Washington ESUs are candidates for listing (US Department of Commerce 1999).

Substantial government-sponsored efforts to protect and enhance the listed salmon and steelhead stocks have heightened public awareness of salmon conservation and management in the Pacific Northwest. During the course of our survey of coastal residents, the listing of Oregon Coast coho ESU as threatened was being contested in Oregon District Court by the Pacific Legal Foundation (*Alsea River Alliance vs. Evans*) because of the exclusion of hatchery fish in the listing. This case, and other petitions, have caused NMFS to reconsider the listing of salmon ESUs under ESA.[2] We anticipate that the legal contests over the salmon listings will continue and believe that such contests underscore the value of understanding public opinion and support for salmon enhancement programs, such as the one featured in this paper. Furthermore, as government agencies increasingly involve stakeholder groups

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[1] NOAA's National Marine Fisheries Service (NMFS) establishes two criteria for a stock to be considered a "distinct population segment" or ESU under the federal Endangered Species Act (ESA): "(1) It must be substantially reproductively isolated from other conspecific population units; and (2) It must represent an important component in the evolutionary legacy of the species" (*Federal Register*, Nov. 20, 1991).

[2] The Pacific Legal Foundation's lawsuit (Alsea River Alliance vs. Evans Case) was filed in US District Court in 1999, questioning the inconsistent treatment of wild and hatchery fish under the ESA listing. In September 2001, the US District Court vacated NMFS' listing for the Oregon coastal coho because the threatened species listing did not include hatchery fish. The Alsea Valley Alliance v. Evans decision was stayed by the 9th Circuit Court in December 2001 pending an appeal by conservation groups. In February of 2002, NMFS announced that it would formally revisit the salmon listings and begin a new status review of the listed salmon ESUs.

in the design and implementation of restoration and enhancement programs, public opinion and attitudes take on a growing importance in implementing and designing effective policies.

Our study focuses on coho enhancement programs in five estuaries, which are located within the geographic boundaries of the Oregon Coast and Lower Columbia River/Southwest Washington coho ESUs. Coho salmon originating from rivers that empty into the three Oregon estuaries belong to the Oregon coastal ESU, which is listed as threatened, and coho salmon in the two Washington estuaries belong to an ESU that is a "candidate" for listing. We explore public opinion and support for local coho enhancement using responses from a survey of local residents.

Recent studies have examined the WTP for restoration of depleted or threatened salmon stocks in the Pacific Northwest and California. Hanemann, Loomis, and Kanninen (1991) examined the WTP for a program designed to restore flows in the upper San Joaquin River and enhance salmon, other fish and wildlife, and vegetation along the river banks. As defined, the salmon improvement program would increase Chinook salmon returning to spawn annually to 15,000 and raise the total number of chinook caught by sport (increase of 7,500 fish) and commercial (increase of 23,000 fish) anglers. Their contingent valuation study employs a double-bounded dichotomous choice referendum format with a payment vehicle of additional taxes. Data were collected in May 1989 using a combined mail and telephone survey approach. The final sample included responses of approximately 1,004 residents of California, Oregon, Washington, and Nevada. Five different environmental programs were addressed in the study. For the salmon improvement/restored river flows program, Hanemann, Loomis, and Kanninen (1991) report a truncated mean WTP of $181 per year for California households.

Olsen, Richards, and Scott (1991) estimate non-use and sport fishing values for a doubling of salmon and steelhead runs in the Columbia River Basin from 2.5 million to 5 million fish. Their contingent valuation study uses a modified open-ended response format with a payment vehicle of additional electric power bill charges. The data for this study were collected using a telephone survey of both user and nonuser (interpreted here as not involved in the sport or commercial salmon fisheries) households of the Pacific Northwest. The final sample consists of approximately 700 user and 700 nonuser households. Olsen, Richards, and Scott (1991) report mean annual WTP estimates for the doubling of these runs for three categories of households: (*i*) $26.51 per year for households stating that they would never fish for these anadromous species; (*ii*) $58.56 per year for households that currently don't fish but may go fishing at some time in the future; and (*iii*) $74.16 per year for households that currently fish for anadromous species.

Loomis (1996) estimates the WTP for removing two dams on the Elwha River in Washington State. The removal of these two dams is assumed to result in increased populations of four salmon and steelhead species (increase of 300,000 fish). Of these four species, pink salmon were expected to benefit the most from the removal of the dams (an increase of 200,000 fish). Contingent valuation methods are used to analyze the responses to a mail survey of Clallam County, Washington State, and other US residents conducted in fall of 1994. Approximately 1,624 responses were analyzed in this study. A single-bounded dichotomous choice referendum question format is used with a payment vehicle of additional annual federal taxes for 10 years. Loomis (1996) reports truncated mean WTP estimates of $59 per year per household in Clallam county (the location of the two dams), $73 per year per household in the rest of Washington State, and $68 per year per household in the rest of the United States.

Layton, Brown, and Plummer (1999) assess the WTP of Washington State resi-

dents for changes in population levels of five broad categories of fish. They consider two migratory fish categories, which are predominantly composed of salmon species. A contingent ranking format that asks individuals to rank four alternative outcomes relative to a baseline outcome of no new programs is employed to characterize the WTP for multiple enhancement programs. The programs are described using household cost information and the assumed population levels for the five categories of fish in 20 years. Data were collected using a mail survey; their final sample includes the responses of approximately 1,611 Washington State residents. Layton, Brown, and Plummer (1999) report a mean WTP estimate of $9.92 per month ($119.04 per year) per household for a 50% increase in eastern Washington migratory fish (from 2 to 3 million). For western Washington migratory fish, the corresponding WTP estimate for a 50% increase (from 5 to 7.5 million) is $20.83 per month ($249.96 per year).

In this study, we examine the WTP of residents living within 30 miles of five Pacific Northwest estuaries: Grays Harbor and Willapa Bay in Washington and Tillamook Bay, Yaquina Bay, and Coos Bay in Oregon.[3] We estimate the WTP of these coastal residents for the enhancement of local coho salmon stocks from a baseline defined as the 1996–98 average annual coho salmon run size. Programs resulting in the doubling and quadrupling of baseline runs are examined for the Washington estuaries (*e.g.*, increases of 40,000 and 165,000 fish). Whereas programs resulting in the delisting of coho as threatened and increases in the allowable catch of 100,000 fish are evaluated in the Oregon estuaries. Variation in WTP is explained using data on individual opinions of the merit of the enhancement program and causes of salmon decline, involvement in sport fishing, and membership in an environmental organization.

Survey Questionnaire Design and Response

Data for this analysis were drawn from responses to a coastal resident survey undertaken in the spring of 2000. The survey questionnaire was a multi-purpose research instrument, seeking the opinions of coastal residents on a variety of matters including residential location preferences, recreation interests, threats to the local natural environment, and management of these threats. A pre-test mailing of the coastal resident survey was conducted to identify problematic questions and other design flaws. In addition, the entire resident survey was written with the input of local scientists and natural resource managers.

Coho Enhancement

One section of the survey was dedicated to coastal salmon stocks and included a referendum question outlining a hypothetical ballot measure to fund a local coho enhancement program. This section of the survey aimed to incorporate the protocol designated by the NOAA Panel on contingent valuation in 1993 (*Federal Register* 1993; Portney 1994) and the guidelines outlined by Mitchell and Carson (1989) regarding the use of surveys to value public goods. A broad description of native salmon runs along the Pacific Northwest Coast was stated prior to the referendum

[3] The counties surrounding these estuaries are: Grays Harbor County, WA; Pacific County, WA; Coos County, OR; Tillamook County, OR; and Lincoln County, OR, respectively.

question, and each respondent was asked their opinion of the importance of various potential causes of salmon decline. These questions were included to evaluate the sensitivity of voting behavior to individual perceptions of threats to coastal salmon. The enhancement program described in the survey questionnaire targets overfishing and habitat degradation as important causes of salmon decline.

After summarizing the history of coastal coho and chinook salmon stocks, the questionnaire presented figures displaying recent trends in local, coastal chinook and coho salmon catches. The proposed local coho salmon enhancement program was described by contrasting the expected outcome of the enhancement program as of the year 2004 with a baseline characterized as the level of the catch and salmon populations during 1996–98. Expected coho salmon run size and allowable catch under the coho salmon enhancement program and baseline were presented in tabular form and described in the text. The specific wording of the referendum question for one area (Willapa Bay, WA) is shown below:

> Although the state has committed to spending additional money to help salmon in general, local partnerships and watershed councils may need additional funding. Residents of the Willapa Bay area will be asked to provide additional support to improve salmon populations in your local area. The collection of additional taxes to fund these programs can be authorized by a majority vote on a ballot measure in the next election. If no local programs are funded, then coho salmon runs would remain near their current levels, as shown in the table above.
>
> If this Coho Enhancement Program is proposed for the Willapa Bay area in the next election, coho runs will increase to a level that will raise allowable coho catch to an average of 80,000 fish per year by 2004. If this ballot measure will cost your household $25.00 per year for the next 5 years, will you vote in favor of the ballot measure? (circle one response)
>
> 1 YES
> 2 NO
>
> If you answered NO, please briefly explain your response.

The specified annual household cost (annual tax amount or COST) of the program varied randomly from $5.00 to $500.00. Assigned tax amounts were uniformly distributed over this range.

Each respondent voted on one local coho enhancement program. Two levels of enhancement (high and low) were considered. Both levels of enhancement were contrasted with the baseline (current) condition of salmon catch and run size (described using 1996 to 1998 data). For Willapa Bay and Grays Harbor, the low level of enhancement represented a doubling of current runs and catch, while the high level of enhancement involved a quadrupling of current runs and catch. Because the Oregon Coast coho ESU were listed as “threatened” with extinction under the Endangered Species Act at the time of the survey, a different set of programs was evaluated in the three Oregon estuaries. For these bays (Coos, Tillamook, and Yaquina), the low-enhancement program increased stocks to the point that they would no longer be threatened with extinction, and the high-enhancement program protected stocks from extinction and increased allowable coho catch to 100,000 fish per year.

Response Rates and Voting Responses

The coastal resident survey was distributed in spring of 2000. In total, 5,000 mail surveys were distributed, with 1,000 going to each of the five study areas. Surveys were mailed to a random sample of property owners residing within 30 miles of five estuaries. These residents live in communities surrounding estuaries located in Southwest Washington (Grays Harbor and Willapa Bay) and on the outer coast of Oregon (Tillamook Bay, Yaquina Bay, and Coos Bay). As is characteristic in the rural Pacific Northwest, the local economies of these communities have historically depended on natural resource-based industries — fishing, forest products, and farming. As a result, many of these communities have been affected by recent changes in fishing and forest product industries. Compared to the urban areas of the Pacific Northwest, these coastal communities have relatively lower incomes per household, higher unemployment rates, lower population growth rates, and larger proportions of retired people living on pensions and other transfer incomes.

The survey distribution process generally followed the total design method (TDM) guidelines (Dillman 2000, 1975). Table 1 displays the final response rates based upon the number of deliverable addresses. These rates vary from 49.1% in the Grays Harbor area to 61.7% in the Willapa Bay area. Of the 2,209 surveys returned, 2,006 (91%) contained responses to the referendum question. After eliminating "don't know" and "protest" responses, our final samples for the contingent valuation study included 1,771 responses from the five coastal areas.

Responses were categorized as protest or non-protest responses based upon the reasons given for rejecting the hypothetical coho enhancement program (Mitchell and Carson 1989). Responses were categorized as protests if the respondent objected to the payment vehicle. In addition, responses were dropped if individuals expressed a need for further information, entered don't know, and/or stated that they do not vote in local elections.[4] Using this definition of protests, our protest rates were relatively low, ranging from 4% in Yaquina Bay to 10% in Coos Bay. Protest behavior may be consistent with two phenomena observed in these coastal communities and indicated in written comments. First, there is considerable distrust of certain government agencies and dislike of taxes. Second, numerous and varied salmon protection efforts have been tried in these areas, many of which have had limited success. Therefore, there is skepticism among the public regarding government-initiated salmon protection programs. As noted in the introduction, legal conflicts may be an additional source of skepticism regarding salmon enhancement programs.

Table 1
Coastal Resident Survey Response Rates

	Number Delivered	Number Returned	Response Rate
Grays Harbor, WA	849	417	49.1%
Willapa Bay, WA	718	443	61.7%
Coos Bay, OR	883	516	58.4%
Tillamook Bay, OR	770	410	53.2%
Yaquina Bay, OR	708	423	59.7%
Total	3,928	2,209	56.2%

[4] Protest behavior was deduced by review of the open-ended, follow-up responses.

Theoretical Model

Following Hanemann (1984), Cameron (1988), and Hanemann and Kanninen (1999), we employ a random utility modeling framework to examine the dichotomous responses to the local coho salmon enhancement ballot measure. Under this framework, a respondent's voting decision is represented as the comparison of his or her utility at two states: status quo (u_0) and with the local coho salmon enhancement at cost c_1 (u_1). Utility is assumed to be a function of income (y), respondent characteristics (z), choice characteristics (g), and factors that are known by the respondent but are unobservable to us as researchers (ε). If the utility of the respondent is higher with the salmon enhancement, we expect that respondent to vote for the program. Formally, this comparison for respondent j looks as follows. Respondent j votes YES for the program if:

$$u_{1j}(y_j - c_{1j}, z_j, g_1, \varepsilon_{1j}) > u_{0j}(y_j, z_j, g_0, \varepsilon_{0j}). \tag{1}$$

Given the dichotomous responses available to us as researchers, we make probabilistic statements about YES and NO responses and rewrite this expression in probabilistic terms, where the probability that respondent j votes YES is as follows:

$$\Pr_j(YES) = \Pr\left[u_{1j}(y_j - c_{1j}, z_j, g_1, \varepsilon_{1j}) > u_{0j}(y_j, z_j, g_0, \varepsilon_{0j})\right]. \tag{2}$$

Modeling Specifications

A variety of modeling assumptions can be made to estimate the expression shown in equation (2). As part of our contingent valuation study, we experimented with a variety of specifications and assumptions.[5] Our final specification is an adaptation of the linear random utility model (Haab and McConnell 2002). We begin by assuming the utility function is additively separable in form, the sum of deterministic (v) and stochastic (ε) components:

$$u_{ij}(y_j - c_{ij}, z_j, g_i, \varepsilon_{ij}) = v_i\,(y_j - c_{ij}, z_j, g_i) + \varepsilon_{ij}, \tag{3}$$

where i references the state and j references the individual. Next, we specify the deterministic part of the utility function (v) as linear in income (y) and respondent (z) and choice attributes (g).

Finally, we assume that the coho enhancement program will have no income effect. Specifically, although we assume that the marginal utility of income is constant across states, we permit this value to vary across high- and low-income individuals.

Allowing for the marginal utility of income to be different for individuals falling into high (H) and low (L) income categories but constant across states, the probability individual j votes YES on the ballot measure can be written:

$$\Pr_j(YES) = \Pr(\alpha z_j - \eta_L I_{Lj} c_j - \eta_H I_{Hj} c_j + \varphi g_i - \varepsilon_j > 0), \tag{4}$$

---

[5] A comparison of log likelihood values determined that the modeling specification featured in this paper fit the data best.

where α, η_L, η_H, and φ are parameters to be estimated; z_j are characteristics of individual j; c_j is the cost of the enhancement program to individual j; I_{Hj} and I_{Lj} are dummy variables that indicate whether or not individual j is in the high- or low-income category; and g_i are characteristics of the local coho enhancement program. Expression (4), a simple varying parameter model, forms the basis of our empirical modeling specification.

Willingness to Pay

One interpretation of willingness to pay (WTP) for the ballot measure is the amount of money that makes a respondent indifferent between the two states, status quo, and with the coho salmon enhancement program. Algebraic manipulation allows for individual j's WTP for program i to be written as:

$$WTP_{Hj} = \alpha z_j / \eta_H I_{Hj} + \varphi g_i / \eta_H I_{Hj} + \varepsilon_j / \eta_H I_{Hj} \tag{5}$$

$$\text{or } WTP_{Lj} = \alpha z_j / \eta_L I_{Lj} + \varphi g_i / \eta_L I_{Lj} + \varepsilon_j / \eta_L I_{Lj} .$$

The two different measures of WTP correspond to the high- and low-income categories.

Empirical Approach

Willingness to pay (WTP) for salmon enhancement is expected to vary across individuals according to their perceptions of the costs of and returns from the program. In this case, we expect WTP to vary directly and positively with the size of the good offered (*e.g.*, the extent of enhancement), fishing participation, income, and membership in an environmental organization. In addition to these priors, we also expect to find a direct and positive relationship between WTP and public confidence in the enhancement program. The familiarity of coastal residents in Washington and Oregon with salmon enhancement programs affords a unique significance to some of our policy variables designed to approximate public confidence. In turn, it also complicates the assessment of WTP because residents may be more likely to reject specific elements of the enhancement program. Lastly, having two different versions (high and low) of enhancement allows us to examine whether WTP is positively related to the extent and type of coho salmon enhancement. As defined, the Willapa Bay and Grays Harbor programs enable us to test whether or not the size of the salmon enhancement (*e.g.*, doubling versus quadrupling run and catch) significantly affects WTP. In addition, the Oregon estuary programs allow us to examine WTP for two fundamentally different types of enhancement programs. The low-enhancement program removes the threatened with extinction label from the local coho salmon stocks but precludes local catch of coho salmon. In contrast, the high-enhancement program removes the label and allows a moderate catch level of 100,000 fish per year. We were interested to see if the two versions used in the Oregon estuaries would speak to the relative influence of use and non-use values in motivating protection and enhancement of local coho stocks.

Variable Definition

Table 2 provides the names and definitions of the variables used to examine the WTP for local coho salmon enhancement. Table 3 presents descriptive statistics for these same variables for each of the five estuary-based samples. Particularly noteworthy demographic characteristics are the relatively advanced age of our samples (AGE) and the predominance of male respondents (MALE). Using 1997 county median income levels as a reference, high (HIGHINC) and low (LOWINC) income categories were defined as household incomes above or below $30,000.[6] We anticipate that these dummy variables will capture additional demographic variation across these groups that is not measured by our existing set of explanatory variables. On average, approximately 65% of residents had household incomes above the median county level, and 35% had household incomes falling below. Comparing the demographics of the survey respondents with those of the general population living

Table 2
Variable Names and Definitions

Name	Description	Units
VOTE	Equals 1 if YES response; 0 if NO response.	0/1 dummy
COST	Stated annual household cost.	Dollars ($)
HIGHEN	Equals 1 if high coho salmon enhancement program; 0 otherwise.	0/1 dummy
LOCSALM	Equals 1 if respondent fished for salmon or steelhead locally in 1999; 0 otherwise.	0/1 dummy
FISH	Equals 1 if respondent fished in the area in 1999; 0 otherwise.	0/1 dummy
ENVIRO	Equals 1 if respondent is a member of any conservation or environmental organization; 0 otherwise.	0/1 dummy
SPORT	Equals 1 if respondent is a member of a sporting club; 0 otherwise.	0/1 dummy
HIGHINC	Equals 1 if the respondent's household income is not below $30,000; 0 otherwise.	0/1 dummy
LOWINC	Equals 1 if the respondent's household income is below $30,000; 0 otherwise.	0/1 dummy
IMPTHR	Equals 1 if respondent ranked "too much commercial fishing" or "degraded river habitats on forest or agricultural lands" as important causes of native salmon decline; 0 otherwise.	0/1 dummy
PARTNER	Equals 1 if respondent believes that existing partnerships between government agencies and citizens (*e.g.*, watershed councils) should be the most or second most influential group in making natural resource management decisions at the county level; 0 otherwise.	0/1 dummy
STATE	Equals 1 if respondent believes the state should be the most or second most influential group in making natural resource management decisions at the county level; 0 otherwise.	0/1 dummy

[6] The 1997-model based US Census median household incomes for the counties surrounding these five bays are as follows: Grays Harbor ($31,091), Pacific ($28,131), Coos ($29,933), Tillamook ($30,713), and Lincoln (30,294). Income data were collected using categories. We used a threshold value of $30,000, since this income category was closest to the median.

Table 3
Means of Explanatory Variables

Name	Grays Harbor	Willapa Bay	Coos Bay	Tillamook Bay	Yaquina Bay
VOTE	0.51	0.52	0.40	0.44	0.52
COST	97.96	93.39	90.13	97.22	88.26
HIGHEN	0.52	0.48	0.42	0.51	0.47
LOCSALM	0.23	0.31	0.15	0.22	0.14
FISH	0.46	0.51	0.45	0.48	0.36
ENVIRO	0.11	0.10	0.09	0.14	0.07
SPORT	0.07	0.09	0.11	0.15	0.14
HIGHINC	0.68	0.64	0.56	0.68	0.70
LOWINC	0.33	0.36	0.34	0.32	0.30
IMPTHR	0.68	0.71	0.55	0.73	0.70
PARTNER	0.50	0.54	0.51	0.49	0.50
STATE	0.34	0.14	0.32	0.34	0.36
MALE	0.75	0.67	0.76	0.76	0.66
AGE	57	58	61	60	60

in these areas, there are meaningful differences.[7] Our respondents tend to be older, wealthier, better educated, and "more" retired.

Local fishing participation rates (FISH) average near 45%, and local salmon fishing participation rates (LOCSALM) are higher in the WA bays than in the OR bays, as might be expected due to the ESA listing of coho in coastal Oregon. The average membership rates in environmental (ENVIRO) and sporting (SPORT) organizations are 10% and 11%, respectively. Tillamook Bay, with approximately 15% membership rates in both types of organizations, had the highest participation rate of all five areas. Interestingly, membership rates in environmental organizations in the WA samples exceed those in sporting organizations; while the converse holds for the OR samples. The fishing participation and environmental organization membership variables are used to measure interest in and attachment to local fish and wildlife. While FISH and LOCSALM may capture motivations for use values of the local coho salmon stocks, we anticipate that ENVIRO may represent motivations for both use and nonuse values of these same stocks.

Turning to the explanatory variables that describe opinions of the merits of the enhancement programs, we observe some interesting trends across the five samples. Fairly high levels of support are expressed for local citizen and government partnerships (PARTNER) to control local natural resource management decisions.[8] Conversely, lower levels of support for state control (STATE) of local natural resource management decisions are expressed. Support for PARTNER and STATE are measures of expected public confidence in the enhancement program, as the featured programs were to be implemented by state and local governments and government-citizen partnerships.

Another measure of public confidence was created using a dummy variable describing attitudes about the causes of salmon decline. IMPTHR is equal to 1 if sport

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[7] We compared the demographics of our sample with data from the 1990 US Census. This comparison was made using zip code level data. Our sample over-represents males (actual gender distribution shows 50% male; 50% female) and older persons (above 46); under-represents younger persons (35 and under); and over-represents persons with higher educational attainment and income levels.

[8] This result may reflect approval for existing and past partnership organizations, such as the watershed councils of Oregon, the Willapa Bay Alliance, and the Tillamook Bay National Estuary Program.

fishing, commercial salmon fishing, or habitat degradation (IMPTHR) were ranked by the individual as extremely important (4 or 5 responses on a scale of 1 to 5) causes of native salmon decline in the Pacific Northwest. Overall, residents believe commercial salmon fishing and/or habitat degradation are extremely important causes of native salmon decline in the Pacific Northwest.[9] Approximately 67% of respondents in all five samples ranked at least one of these three threats as extremely important. The lack of importance awarded to excessive sport fishing may have lessened the extent to which this dummy variable proxied for public confidence, as our hypothetical program did not distinguish commercial and sport fishing when discussing the threats imposed by overfishing.

Finally, the level of enhancement program (HIGHEN) voted on is distinguished across respondents. HIGHEN is a dummy variable that equals 1 if the high-enhancement program was voted on and equals 0 otherwise. This is the variable that permits a cursory test of scope. In selecting the final set of explanatory variables, we dropped some that are commonly used in other studies of WTP because of multicollinearity, as well as the homogenous demographic nature of our samples.

Empirical Model

The linear random utility modeling specifications [refer to expression (4)] are estimated empirically using logit models, where we assume ε_j is distributed logistically (ε_{ij} are distributed extreme value) and estimate the parameters α, φ, η_H, and η_L using conventional maximum likelihood methods.[10] In the results section that follows, we begin our discussion focusing on the logit model results and conclude by examining the associated mean WTP estimates.[11] These mean WTP estimates are calculated using the deterministic portions of the functions shown in expression (5) and by applying the estimated coefficients from the empirical models to the mean values of the respondent and choice attributes.

Results

Ballot Referenda Logit Models

Tables 4 and 5 display logit model results by estuary-based sample. Responses to the high- and low-enhancement referenda are pooled.[12] The dependent variable is the voting response (YES or NO), and the set of explanatory variables is identical in all

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[9] Respondents were asked to rank the importance of several potential causes of native salmon decline using a likert scale of importance ranging from 1 to 5, where 1 represents not important and 5 indicates extremely important. The potential causes of salmon decline included: too much sport fishing for salmon; too much commercial fishing for salmon; poor ocean conditions for salmon; degraded river habitats in forest lands; degraded river habitats in farm lands; degraded marshes in the bay; water pollution in rivers and the bay; and dams on rivers. Generally, responses to the set of threat-ranking questions were similar across the five samples, with water pollution in rivers and bays, too much commercial salmon fishing, and degraded habitat ranked consistently as more important causes of salmon decline. Too much sport fishing and dams on rivers ranked consistently as less important causes of salmon decline.

[10] Probit models, which rest on the assumption that ε_j are distributed normally, were also run. There were no significant differences between the results of the logit and probit models.

[11] The mean and median willingness to pay are identical for these modeling specifications because ε is symmetric and mean zero. The WTP estimates shown in table 6 are those for the first year of payment and have not been annualized.

[12] Separate models were run using the responses to the high- and low-enhancement programs by bay. Likelihood ratio tests comparing the estimated parameters failed to reject the null hypothesis of equivalent parameter estimates across the high and low runs in all five bays.

Table 4
Local Coho Enhancement: Logit Model Results (Coastal Washington)

	Grays Harbor		Willapa Bay	
Parameter	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.
HIGHEN	–0.0109	–0.054	–0.0176	–0.086
ENVIRO	–0.4538	–1.264	0.7262*	1.804
IMPTHR	0.3317	1.566	0.7952**	3.828
STATE	0.4511*	1.826	0.1411	0.429
PARTNER	0.2170	0.988	0.0834	0.408
LOCSALM	0.0314	0.115	–0.2051	–0.863
HIGHINC*COST	–0.0037**	–3.550	–0.0052**	–4.175
LOWINC*COST	–0.0056**	–3.228	–0.0081**	–3.947
N	357		386	
$\ln(L_U)$	–233.2081		–241.2788	
$-2[\ln(L_R) - \ln(L_U)]$	28.42		51.71	
Pseudo R^2	0.08		0.13	

Notes: The dependent variable is the binary voting response (VOTE). Ψ includes α, η, and φ. Significance at the 0.10 level (*) and 0.05 level (**).

five areas, with one exception. Local fishing participation is characterized differently across the Oregon and Washington samples. In the Washington models, LOCSALM is included as an explanatory variable and FISH is not included because the two variables were highly collinear. Because of the recent decrease in salmon fishing opportunities in coastal Oregon, we did not include LOCSALM as an explanatory variable for the three Oregon samples and used the dummy variable, FISH, in its place.

Across all areas, the parameter estimate associated with the COST variable has the expected negative sign and is highly statistically significant, indicating that the likelihood of a YES response declines with the annual household cost. In this modeling specification, the "price" response is allowed to vary across high- and low-income categories (HIGHINC*COST and LOWINC*COST). The relative size of these parameter estimates varies across communities. As might be expected, the marginal utility of income of the lower income category is consistently greater than that of the higher income category.

Membership in an environmental organization (ENVIRO) has mixed influences on voting behavior and WTP. ENVIRO has a positive and significant influence in the Willapa Bay-based sample and a negative and significant influence in the Coos Bay-based sample. In Willapa Bay, the significance of ENVIRO may be partially due to past efforts of the now defunct environmental research and educational group, the Willapa Bay Alliance. In the Coos Bay model, the negative sign of the parameter associated with ENVIRO is unexpected. However, one possible explanation of this sign is that members of environmental organizations in Coos Bay may not see the delisting of coho as threatened as desirable, especially if they regard the actions undertaken when a species is listed as beneficial to the local coastal environment.

The proxies of public confidence in the local coho enhancement programs have mixed influences on WTP. The dummy variable, IMPTHR, has a positive and statistically significant influence on acceptance of the program in the specification for Willapa Bay only. Individual attitudes towards state and local management institu-

Table 5
Local Coho Enhancement: Logit Model Results (Coastal Oregon)

	Coos Bay		Tillamook Bay		Yaquina Bay	
	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.	Estimate (Ψ)	Ψ/St. Er.
HIGHEN	–0.1809	–0.918	0.1014	0.504	–0.0566	–0.253
ENVIRO	–0.7868**	–3.730	–0.0158	–0.073	0.2589	1.092
IMPTHR	0.1871	0.498	0.0003	0.001	–0.4474	–1.005
STATE	1.0159**	4.708	0.0904	0.381	0.4985**	2.282
PARTNER	0.1126	0.512	0.5809**	2.371	0.3002	1.272
FISH	0.1991	1.013	–0.1265	–0.574	0.4037*	1.855
HIGHINC*COST	–0.0074**	–4.522	–0.0025**	–2.328	–0.0063**	–4.616
LOWINC*COST	–0.0089**	–4.127	–0.0079**	–3.312	–0.0096**	–3.352
N	424		347		357	
$\ln(L_U)$	–252.4180		–226.4367		–222.5196	
$-2[\ln(L_R)-\ln(L_U)]$	64.55		23.32		49.53	
Pseudo R^2	0.14		0.06		0.13	

Notes: The dependent variable is the binary voting response (VOTE). Ψ includes α, η, and φ. Significance at the 0.10 level (*) and 0.05 level (**).

tions have stronger effects on voter support of the hypothetical coho enhancement program than opinions of threats. One of the two variables concerning the degree to which the state government (STATE) and citizen county-level partnerships (PARTNER) should be influential in making resource management decisions is significant in all cases except for Willapa Bay. In the Grays Harbor, Coos Bay, and Yaquina Bay-based models, the parameter associated with STATE is positive and significant. In the Tillamook Bay model, the parameter associated with PARTNER is positive and significant.[13] Generally, these estimates suggest that public confidence in a salmon enhancement program is inextricably linked to the WTP for such a program. This finding is intriguing and may underscore the importance of dialogue between local scientists, natural resource managers, and residents.

Surprisingly, participation in local sport fishing does not significantly affect WTP for the enhancement program in the five areas. Only in the Yaquina Bay-based model is the parameter on FISH positive and significant.

Our comparison of the low- and high-enhancement programs provides limited fodder for understanding individual perceptions of the scope or types of enhancement programs. The influence of HIGHEN is not significant in any of the specifications. Because each respondent voted on a single enhancement program, we can only test for scope by examining the influence of HIGHEN. We fail to reject the null hypothesis that the influence of HIGHEN is statistically equal to zero (at the 0.05 level). Furthermore, the influence of HIGHEN is often not the expected positive sign, and the negative parameter estimate associated with this variable results in higher mean WTP estimates for the low-enhancement program.

In retrospect, we believe that greater differences in the magnitude and types of our salmon enhancement programs would have improved our ability to explore individual perceptions of the scopes and types of programs. In the Washington samples, the differences between our high- and low-enhancement programs may simply not be large enough to distinguish the services provided by the enhancement program. In addition, it may be the case that many people will support local recovery efforts related to ESA. However, when the issue is increased harvest opportunities for the minority of people who fish salmon, many of those same people may decline to pay. If this is the case, the result is a muddied scope test because for some households, the high-enhancement program does not represent a larger public good. Similar issues arise in contrasting the levels of enhancement faced by the Oregon samples. Respondents who doubt the legal integrity of the ESA listing of the coho stock are likely to perceive little reward from enhancement efforts aimed at removing the title of threatened. Conversely, individuals who highly regard the ESA listing (and its associated actions) may perceive little reward from the removal of this title. Lastly, if WTP is largely motivated on the basis of non-use values, one might expect less sensitivity to changes in run size and harvest opportunities.

WTP Estimates

Mean annual WTP estimates are derived by evaluating the expressions shown in equation (5), employing the mean respondent attributes (refer to table 3), and distinguishing the level of enhancement program. Table 6 displays annual mean willingness to pay estimates (and their standard errors) by area. These estimates cor-

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[13] Tillamook Bay is home to a unique partnership group entitled the Tillamook Bay National Estuary Program.

respond to the payment in the first of five years. Standard errors were calculated using the delta method. When examining the estimates shown in table 6, it is important to note the differences in the local enhancement programs across the five estuaries. In addition to the distinctions between the Oregon and Washington programs, there are further differences because of unique coho baseline and demographic conditions by bay. While it may be sensible to compare the qualitative results in all five areas and perhaps the WTP estimates within state, it is not appropriate to directly compare the WTP estimates for the Oregon and Washington programs.

The Washington estuary-based samples and the Yaquina Bay-based sample provide greater insights, where the WTP estimates are positive and significantly different from zero. Mean WTP estimates in some of the Oregon estuary samples (Tillamook and Coos) are not significantly different from zero. Observing the results, higher income individuals are generally willing to pay more than lower income individuals for local coho enhancement in these areas. Furthermore, and commensurately, the expected mean willingness-to-pay estimates are not statistically different for the high- and low-enhancement programs. As noted previously, the negative parameter estimates on HIGHEN result in a mean WTP estimate for the high-enhancement program that is smaller than that for the low-enhancement program. We acknowledge the necessity of future research devoted to understanding preferences and sensitivity to run sizes to improve the assessment of WTP for salmon enhancement programs.

Table 6
Mean WTP Estimates by Estuary: Local Coho Enhancement

	Mean WTP Estimate (Std. Error)			
Estuary	High Income		Low Income	
Grays Harbor, WA				
HIGH ENHANCE	116.59**	(45.70)	77.00**	(32.30)
LOW ENHANCE	119.54**	(39.64)	78.94**	(30.68)
Willapa Bay, WA				
HIGH ENHANCE	118.44 **	(35.01)	75.99**	(23.14)
LOW ENHANCE	121.81**	(30.33)	78.15**	(23.00)
Coos Bay, OR				
HIGH ENHANCE	25.39	(24.05)	20.88	(20.11)
LOW ENHANCE	50.00**	(15.52)	41.13**	(14.77)
Tillamook Bay, OR				
HIGH ENHANCE	120.50*	(66.62)	37.18*	(22.11)
LOW ENHANCE	79.32	(55.42)	24.48	(17.65)
Yaquina Bay, OR				
HIGH ENHANCE	106.50**	(28.90)	69.81**	(23.98)
LOW ENHANCE	115.54 **	(27.55)	75.74**	(23.05)

Notes: Standard errors were calculated using the delta method. Significance at the 0.10 level (*) and 0.05 level (**).

The mean WTP estimates are very similar in the two Washington samples. In contrast, there is much more variation when comparing the results in the three Oregon samples. Mean WTP is highest in Yaquina Bay, followed thereafter by Tillamook Bay, where the difference between mean WTP across high- and low-income groups is most pronounced. Finally, the mean WTP is consistently lowest in the Coos Bay area.

Comparing these estimates with those derived in previous studies of salmon enhancement programs, the WTP estimates derived are within range of the previous studies. Converting the Hanemann, Loomis, and Kanninen (1991) estimate to 2000 dollars yields an estimate of approximately $254 per year for California households for the enhancement of the San Joaquin River salmon populations. A similar conversion of the Olsen estimates measured in 1989 dollars to 2000 dollars yields estimates of $37.19, $82.15, and $104.04, respectively (doubling of salmon and steelhead runs in the Columbia River; 2.5 million fish). Mean estimates based on Loomis (1996) are $68.94, $85.30, and $79.45, respectively, in 2000 dollars (300,000 fish). Lastly, converting the Layton, Brown, and Plummer (1999) estimates from 1998 to 2000 dollars yields estimates of $126.57 and $265.77, respectively (1 million and 2.5 million fish). Specific comparisons of estimates are difficult because of differences in baseline conditions, as well as the nature of the enhancement program and targeted salmon species. Higher WTP estimates may be expected in the Olsen, Richards, and Scott (1991) and Layton, Brown, and Plummer (1999) studies because the enhancements involve greater increases in fish. However, as our study notes, there is considerable uncertainty regarding individual perceptions of the outcomes of salmon enhancement programs.

Conclusions

We have summarized the results of a contingent valuation survey of residents of five rural, coastal communities in the Pacific Northwest and described the willingness to pay of coastal communities for local coho salmon enhancement programs. Willingness to pay for salmon enhancement initiatives is higher when the public demonstrates confidence in the objectives of the programs and the managing institutions. The linkage between public confidence in the objectives of the program (*e.g.*, causes of salmon decline addressed) and the managing institutions is an extremely interesting result, for it underscores the importance of community outreach and education when devising salmon enhancement and protection strategies. We also find evidence that WTP for local coho enhancement is positively related to income.

We experienced several empirical problems commonly associated with survey research that necessitate further study of individual preferences concerning local salmon stocks. We recognize the limitations imposed by our survey design. Despite these problems, the statistical results presented confirm that residents of coastal communities of the Pacific Northwest are generally willing to pay for local coho salmon enhancement. In addition, the modeling results provide insights about the preferences of residents concerning salmon protection programs. We believe that the explanatory power of the enhancement program related variables (IMPTHR, STATE, PARTNER) underscores the importance of public outreach and education in devising salmon restoration and enhancement strategies. Finally, we hope that these and other findings assist local decisionmakers when making future and inevitably difficult salmon protection choices in the Pacific Northwest. Future research that directly compares the WTP for local enhancement by local residents and non-local residents may provide additional insights on how the magnitude of WTP for enhancing a particular stock varies across regions.

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Handbook for Estimating Economic Benefits of Environmental Projects

For Inclusion in Benefit-Cost Assessments of Projects Proposed for funding Under California Propositions 84 and 1E

Prepared for the North Bay Watershed Association

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ECONorthwest is the oldest and most comprehensive economics consulting firm in the Pacific Northwest. We have a staff of 40 in offices in Portland and Eugene, Oregon and Boise, Idaho.

We gratefully acknowledge the assistance of the many individuals who provided us with information and insight, but emphasize that we, alone, are responsible for the contents of this handbook. We have compiled the information based on our general knowledge of environmental valuation methods, our review and application of the California Department of Water Resources' Guidelines and Proposal Solicitation Packages for Propositions 84 and 1E, information derived from government agencies, the reports of others, interviews of individuals, or other sources believed to be reliable. ECONorthwest has not independently verified the accuracy of information developed by others but cited here, and makes no representation regarding its veracity or completeness. Any statements nonfactual in nature constitute the authors' current opinions, which may change as more information becomes available

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Measuring the economic benefits of removing dams and restoring the Elwha River: Results of a contingent valuation survey

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Abstract. The contingent valuation method was used to obtain estimates of willingness to pay for removing the two dams on the Elwha River on the Olympic Peninsula in Washington State and restoring the ecosystem and the anadromous fishery. Using the dichotomous choice voter referendum format, the mean annual value per household is $59 in Clallam County, $73 for the rest of Washington, and $68 for households in the rest of the United States. The aggregate benefits to residents of the State of Washington is $138 million annually for 10 years and between $3 and $6 billion to all U.S. households. These estimates suggest that the general public would be willing to pay to remove old dams that block salmon migration.

1. Rivers, Fisheries, and Hydroelectric Dams

Over the past hundred years, construction of dams throughout the northeastern United States and the Pacific Northwest have provided significant supplies of low-priced electricity and stimulated much related economic activity. At the same time, these dams have contributed substantially to declines of anadromous fish such as salmon by blocking access of adult fish to upstream spawning areas and interfering with the movement of juvenile salmon in their downstream migration to the ocean.

While the decline of Atlantic salmon populations has been noted for decades, the decline of Pacific Northwest salmon populations is a relatively more recent concern. Several Congressional acts have attempted to reverse this decline, including the Northwest Power Planning Act and the Elwha River Ecosystem and Restoration Act (PL-106-495). The Elwha Act provided for examination of the feasibility of restoring Elwha River fisheries and ecosystem by removal of two large hydroelectric dams, Elwha and Glines Canyon dams.

The Elwha River is located near Port Angeles, on the Olympic Peninsula in Washington State. Elwha and Glines Canyon dams were built in 1913 and 1927, respectively. The dams were built without any fish passage facilities and block 70 of the Elwha River's 75 miles to migrating salmon. Unlike most other rivers in the Pacific Northwest, the upstream 60 miles of the Elwha River flows within Olympic National Park and is not subject to periodic logging or dewatering for irrigation. For these reasons, biologists conclude that dam removal would result in substantial increases in salmon and steelhead populations [*U.S. Department of the Interior*, 1993].

Analysis of Elwha River dams and fisheries has been conducted recently by the Federal Energy Regulatory Commissions (FERC) to evaluate licensing of Elwha dam and relicensing of Glines Canyon Dam [*FERC*, 1993]. Further analysis has been conducted pursuant to the Elwha Act [*U.S. Department of the Interior*, 1993]. These analyses have produced feasibility and cost information for a range of energy replacement and river restoration options and have concluded that removal of the two dams would be required for substantial improvement in salmon and steelhead populations.

While construction of dams by Federal agencies usually requires a benefit-cost analysis [*U.S. Water Resources Council*, 1983], FERC has been reluctant to embrace benefit-cost analysis for relicensing of dams [*Fargo*, 1991]. However, with cost estimates involving millions of dollars for addition of fish passageways or $100 million for dam removal, it would seem that in order to make an informed public decision, some information on the economic benefits would be useful. This study addresses a component of the benefits that such an analysis would consider: the benefits of dam removals and river restoration beyond the direct market economic effects. To our knowledge, this is the first estimate of the nonmarket benefits of removing dams and restoration of a river and its fisheries to their natural state.

2. Types of Benefits and Measurement Method

The need for an assessment of the nonmarket benefits of removing the dams, restoring the ecosystem and its fishery are clear. Traditional economic analysis would focus primarily on the commercial and recreational fishing benefits as well as any incidental river-related recreation that might be forthcoming in the newly restored Elwha River. However, there has been a growing recognition within society that protection of natural values beyond recreation needs to be incorporated into public decision making. These additional values often reflect peoples' desire to know that ecosystems exist and are naturally functioning (e.g., existence value, first proposed by *Krutilla* [1967]) and will be protected for future generations (bequest value). The sum of recreation, existence, and bequest values is sometimes referred to as total economic value [*Randall and Stoll*, 1983]. The existence and bequest values have been quantified (in dollar terms) for preservation of existing free-flowing rivers [*Sanders et al.*, 1991] but not for removing dams and restoring previously developed riverine ecosystems. Previous research by *Olsen et al.* [1991] has demonstrated that increasing salmon and steelhead populations do have sizeable option, existence, and bequest values.

The objective of this study is to measure the total nonmarket economic value for restoring the Elwha River and its fisheries to residents of Clallam county (the county where the Elwha

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River is located), the state of Washington, and to the rest of the United States. This objective is carried out using a survey approach called the contingent valuation method (CVM). Contingent valuation is a standardized and widely used survey method for estimating willingness to pay (WTP) for recreation, existence, and bequest values [*Mitchell and Carson*, 1989]. CVM involves constructing a hypothetical market or referendum scenario in a survey. The proposed increase (if they pay) or decrease (if they do not pay) in the quantity or quality of the resource is communicated to the respondent in words and visual aids. The respondent uses the hypothetical market to state his or her WTP or vote for or against a public program at a particular tax price. CVM is recommended for use by Federal agencies for performing benefit-cost analysis [*U.S. Water Resources Council*, 1983] and for valuing natural resource damages [*U.S. Department of the Interior*, 1986] and was upheld by the Federal courts [*State of Ohio versus U.S. Department of the Interior*, 1989]. More recently, a blue-ribbon panel, including two Nobel laureate economists, concluded that CVM can produce estimates reliable enough to be the starting point for administrative and judicial determinations [*Arrow et al.*, 1993]. While there are legitimate concerns about the degree of accuracy of CVM estimates of WTP for natural resources the public is unfamiliar with, the method has been shown in empirical studies to be reliable [*Kealy et al.*, 1988; *Loomis*, 1989, 1990]. The accuracy of CVM results is tied, in part, to the accuracy and unbiasedness of the information contained in the survey and the survey implementation. The next two sections detail the survey development efforts and the sample design.

3. CVM Survey Development

Meetings with scientists working for the National Park Service, Bureau of Reclamation, and Lower S'Klallam Tribe provided technical documents and an understanding of the natural resources currently and potentially provided by the Elwha River. For example, information was obtained on current and potential fish populations as well as details on the ecological significance of the Elwha River. The results of this discussion were used to develop the materials used in the focus groups described below.

Focus groups were held with small groups of residents in Port Angeles and Seattle, Washington, and Boston, Massachusetts, during the months of July and August 1994. Random digit dialing was used to select individuals for participation in the 2-hour focus groups. The purpose of these focus groups included discussion, in the respondents' own words, of what rivers such as the Elwha meant to them. One of the primary objectives was to determine if we could clearly communicate the effects that dam removal would have on salmon recovery and river restoration. To measure this, there was a comprehension check question for each visual aid to allow the respondents to describe in their own words what the graph and maps conveyed to them. Additional text on the effect of possible fish ladders and timing of the salmon recovery were added as a result of discussion with focus group participants. The focus groups helped us determine what additional information respondents desired in order to make an informed decision.

The other main objective of the focus group was to determine an acceptable mechanism for respondents to pay for removal of the two dams. As a result of discussions during the focus groups, we added text to make clear that many groups, including recreation users, might be asked to help fund a share of the costs of dam removal and river restoration. We also added wording stressing that because Glines dam was in Olympic National Park, all U.S. taxpayers would be asked to pay.

Following these focus groups, a complete survey was pretested on groups of Port Angeles and Seattle residents as well as Colorado residents during the months of August and September. In each case, the survey was administered just as it would be received in the mail. The person read the cover letter and then answered the survey. This was followed by a discussion of each section of the survey and the reasons individuals had for answering the way they did. This debriefing allowed us to check whether the respondents interpreted the questions and graphics as we intended. Each participant in the pretest was asked to answer a follow-up checklist where we checked on several issues that had been problems for past CVM surveys (e.g., embedding). Because of budget limitations, no formal tests of alternative geographic scales or scope of restoration were to be performed to evaluate the sensitivity of WTP responses. Therefore we used debriefing questions following the pretests to check to see if respondents were overgeneralizing the good they were asked to value. Thirteen out of sixteen respondents indicated that this program would affect salmon on the Elwha River and not the entire Pacific Northwest. Additional modifications were made to the survey instrument on the basis of comprehension check questions regarding the illustrations. For example, we added a bar to the graph showing the number of salmon with addition of fish ladders and other fish passage improvements. Location maps for Olympic Peninsula were relocated to the cover. The survey text was put in more of a "bullet" format to help respondents to quickly obtain the main points. Finally, the pretest was used to establish an appropriate range of bid amounts for the dichotomous choice contingent valuation question.

4. Survey Structure

The cover and first section of the survey provided a series of maps to remind respondents who did not live on the Olympic Peninsula where the Elwha River was. The first section showed the location of the dams and discussed the history of the area before and after the dams were built. The respondents were told that their answers would be used as input by Federal agencies studying dam removal.

Before directly asking how much respondents would pay for removing dams on the Elwha River and for fisheries restoration, it is important to allow the respondents an opportunity to reflect on why they might care about restoring rivers such as the Elwha. *Cummings et al.* [1986] call this "researching their preferences" regarding hydroelectric dams and salmon restoration. Residents of Washington have been exposed to extensive media coverage about the decline in salmon and steelhead in the Pacific Northwest. In addition, fishing seasons had been greatly restricted in the area as a result of the decline in salmon. Thus we believe that at least Washington residents have some knowledge about the trade-off of dams and salmon fisheries and have had some opportunity to reflect on what these resources mean to them. The first set of questions asked about the relative importance of different reasons for caring about rivers such as the Elwha. Reasons included recreational opportunities, a source of hydroelectricity, habitat for fish, water supply, and a source of jobs. A four-point Likert scale allowed individuals to rate the relative importance of these various reasons. This neutral response format (that precedes

the dollar valuation questions) will also aid in explaining the WTP responses people provide later in the survey.

The actual valuation portion of the survey has three elements: (1) portrayal of the resource to be valued, (2) description of the particular mechanism to be used to pay for the resource, and (3) the question format used to elicit the respondent's dollar amount of WTP.

The resource to be valued was removal of the two dams from the Elwha River, restoration of the river to its natural predam state, and associated increases in four species of salmon and steelhead. These facts were emphasized by the use of two half-page maps of the area. The first map showed the river as it currently is with the dams; the second map showed the river as it would be without the dams. The 70 additional miles of stream available as fish habitat with dam removal were described in the legend and shown in dark blue on the second map. The mix of salmon and steelhead populations under current conditions, with the addition of fish ladders or other passage improvements, and after removal of both dams was shown in a stacked bar chart that was extensively pretested to insure its clarity. The bar chart showed that dam removal would result in an increase of over 200,000 pink salmon and sizeable increases in chum, steelhead, and chinook salmon for a total increase of more than 300,000 fish above the current situation or addition of fish ladders. Text adjacent to each figure provided the context and additional explanation of the consequences of each alternative.

The means by which all households would pay was framed as a voter referendum in what is also known as a closed-ended or dichotomous choice question format. The dichotomous choice format mimics an actual vote by simply asking if the person would vote (i.e., pay) for the program if it cost the household a particular dollar amount each year. The individual must just decide if the value is worth at least this price or not. The dichotomous choice format is recommended by the blue-ribbon panel on CVM [*Arrow et al.*, 1993].

Since the printed dollar amount varies across the sample, the dichotomous choice format allows the analyst to statistically trace out a demand-like relationship between probability of a 'yes' response and the dollar amount [*Hanemann*, 1984]. The basic relationship is

$$\text{Prob(Yes)} = 1 - \{1 + \exp[B_0 - B_1(\$X)]\}^{-1} \qquad (1)$$

where B_0 and B_1 are coefficient to be estimated using logistic regression and $\$X$ is the dollar amount the household is asked to pay. From (1), *Hanemann* [1989] provides a formula to calculate the expected value of WTP when WTP must be greater than or equal to zero as

$$\text{Mean WTP} = (1/B_1)\ \ln(1 + \exp(B_0)) \qquad (2)$$

Fifteen different bid amounts (X) ranging from \$3 to \$190 were randomly assigned to surveys. The range was picked such that at the low end, most anyone that valued increasing salmon populations would indicate they would likely pay \$3, while almost no one was expected to pay \$190 per year. The bulk of the dollar bids were in the range between \$15 and \$45, the range where the mean value was expected to occur. Since most of the costs of dam removal and river restoration would take place in the first 10 years, respondents were told they would pay this amount each year for 10 years.

The exact wording of the CVM question section is as follows (a complete copy of the survey will be provided upon request):

> If a majority of people are not willing to pay the cost of dam removal, the dams would remain. Fish populations would be as shown in the bar chart under the Dams & Fish Ladders alternative.
>
> If a majority of people agree to pay the costs, the dams would be removed, the river would be restored to a natural state, and fish populations would increase as shown in the bar labelled Dam Removal.
>
> If an increase in your federal taxes for the next 10 years costs your household $\$X$ each year to remove the two dams and restore both the river and fish populations would you vote in favor? YES NO

Federal taxes were selected as the payment vehicle even though this can be an emotional topic for some respondents. Some people who may value increasing salmon populations and restoring the river may vote no, because they believe the Federal government wastes money or that existing tax monies should be reallocated to projects such as this. To check this possibility, individuals who stated that they would not pay their assigned dollar amount were asked to check specific reasons why they would not pay. These reasons are discussed in the results section.

In order to check the representativeness of our returned surveys against the population of Washington State and the United States, simple demographic questions such as age, education, membership in environmental organizations, and income were asked. The final survey instrument was typeset and made into an eight-page multicolor booklet.

5. Sample Design

Restoration of a river in Olympic National Park and increases in salmon populations are public goods available to all U.S. households. Therefore the geographic extent over which benefits should be measured should be at least national in scope. The questionnaire was sent to a random sample of 600 households in Clallam County (the county where the Elwha River is located), 900 Washington households outside of Clallam County, and 1000 households throughout the rest of the United States. The sample was provided by Survey Sampling, Inc. The overall survey design and mailing procedure follows *Dillman*'s [1978] total design method (first mailing, postcard, second mailing), except we did not send a third survey via certified mail. Each individual was sent a personalized cover letter and postage-paid envelope. Examples provided by Dillman were used for developing personalized cover letters, including an original signature and a \$1 bill attached as a token of appreciation (in the first mailing).

6. Results

6.1. Response Rate

After deletion of undeliverables and deceased individuals, response rates were 77% for Clallam County residents, 68% for rest of Washington residents and 55% for rest of United States residents. The Clallam County and rest of Washington response rates are reasonably good for mail surveys but are still susceptible to nonresponse bias. The rest of U.S. residents responses are likely to exhibit more serious nonresponse bias due to the lower response rate of 55%.

6.2. Comparison of Demographics of Sample and Population

As is typical in mail surveys, the sample education level, income, and age is greater than the respective population level.

Table 1. Distribution of Survey Willingness to Pay Responses

Response	Percent of Respondents		
	Clallam County	Rest of Washington	Rest of United States
Willing to pay bid amount.	37.9	52.2	50.9
"Removing the dams, restoring the river, and increasing fish populations is not worth this much to me."	10.6	7.2	8.5
"I cannot afford to pay this amount."	4.8	4.6	9.0
"It is unfair to expect me to pay to remove the dams."	3.6	2.7	4.9
"Dam removal would not work to increase fish populations."	13.6	3.0	0.2
"I want the dams to remain."	16.7	9.5	4.7
"I am opposed to paying for new government programs."	4.5	6.3	6.7
"Dams should be removed but paid for from existing taxes."*	0.9	6.3	8.3
Other reasons*	7.9	8.3	7.6
Total	100.0	100.0	100.0
Deleted as protests†	5.8	7.2	4.5

*Classified as a protest response.
†Respondents gave a protest response and refused to pay follow-up $1.

Because the majority of names were drawn from telephone books, which are traditionally listed under males' names, the sample overrepresented males relative to females. However, education and age of respondents were not consistently related to WTP in the logit equations estimated for each of the three samples. This may be due to homogeneity among respondents on these two demographic variables and there may well be a systematic relationship if we had obtained data on these two variables from households that were nonrespondents. Income drops out as a variable in *Hanemann*'s [1984] formulation of the logit model. To provide a sensitivity analysis, we calculate a conservative estimate or lower bound on WTP by assuming that nonrespondents would have a zero WTP. It is very unlikely that such an extreme assumption is true, but this procedure does provide a lower bound on estimated WTP.

6.3. Reasons Why Some Respondents Would Not Pay

A series of follow-up check questions are asked after the WTP question to determine if those refusing to pay represent a valid representation of their value or reflect a protest about some feature of the simulated referendum [*Mitchell and Carson*, 1989]. As shown in Table 1, the check question had seven response categories plus an "other" category. The first two categories were, "Removing the dams, restoring the river, and increasing fish populations is not worth this much money to me" (where the 'this much money' refers to the bid amount they were asked to pay) and "I cannot afford to pay this amount." The fifth response category was, "I want the dams to remain on the Elwha River because of the benefits the dams provide." These three categories represent valid reasons for indicating why they would not pay their bid amount and are not considered to be a protest response against the survey. About 12% of all the respondents stating they would not pay their bid amount checked inability to pay as the reason. This response is particularly encouraging, as it meant that the respondents took the commitment to pay seriously.

The third, fourth, sixth, and seventh categories are often classified as protest or scenario rejection responses. These include, "It is unfair to expect me to pay to remove the dams," "Dam removal would not work to increase fish populations on the Elwha River," "The dams should be removed but paid for from existing taxes," and finally, "I am opposed to paying for new government programs." The percentage of each of the three samples selecting each reason is summarized in Table 1.

Most of these response categories are normally not included when WTP is computed [*Mitchell and Carson*, 1989]. However, before considering dropping these responses, we added a further qualifier to allow inclusion in the analysis sample. Many of the individuals who stated they would not pay their particular bid amount (which, recall, ranged from $3 to $190) did indicate they would pay the $1 follow-up amount. To be conservative, we retained individuals that agreed to pay the $1 even if they chose one of the following protest categories: (1) it is unfair to expect them to pay; (b) dam removal would not work; (c) they are opposed to paying for new government programs. Therefore only individuals refusing to pay the $1 and stating that the dams should be removed but paid for from existing taxes or indicating an "other protest" reason, were considered protest responses that did not reflect the value they place on dam removal. Just these responses were dropped from the statistical analysis sample. As shown in the last line of Table 1, the effective protest rate for Clallam county, the rest of Washington and the rest of the United States is quite low, with 5.8%, 7.2%, and 4.5% respectively. Thus 93–95% of the original responses are retained for the statistical analysis.

6.4. Statistical Analysis

Table 2 provides the coefficients and t statistics for the multivariate logit equations for each geographic region. As can be seen, the pseudo R^2 ranges from 12% to 34%, and all of the coefficients have the expected sign and are significant at the 0.01 α level or higher (with the exception of the bid amount on Clallam County, which is significant at the 0.1 level). For example, the higher the dollar amount respondents were asked to pay, the less likely they were to vote for dam removal. The more importance respondents placed on rivers as fish habitat and providing traditional fishing areas to Native Americans, the more likely they were to pay for dam removal. People who viewed rivers as being important as sources for electricity were less likely to pay for dam removal. Age and education were not consistently statistically significant across the three geographic samples.

Mean WTP per household is reported in Table 2 as well. The mean WTP is $59 for households in Clallam County (90%

Table 2. Multivariate Logit Equations for Willingness to Pay (WTP) for Dam Removal

Variable	Coefficient (t Statistic)		
	Clallam County	Rest of Washington	Rest of United States
Constant	−3.8943 (−3.63)	−3.5766 (−4.665)	−1.6441 (−2.32)
Fish importance	1.5618 (5.56)	1.5469 (7.67)	0.6484 (3.51)
Electricity importance	−0.9339 (−5.98)	−0.6650 (−5.26)	−0.3938 (−3.19)
Indian importance	0.4619 (2.76)	0.5234 (4.19)	0.4428 (3.65)
Bid amount	−0.00775 (−1.69)	−0.0171 (−4.84)	−0.01642 (−4.75)
N =	284	467	423
Chi-square	131.5067	187.9507	72.9005
Pseudo R square	0.3486	0.2928	0.1244
Mean WTP	$59	$73	$68
90% Confidence Interval	$21–333	$60–99	$56–92

Fish importance is the importance of rivers as habitat for fish. Electricity importance is the importance of rivers as a source of electricity. Indian importance is the importance of rivers to provide Native Americans with their traditional fishing areas. Bid amount is the dollar amount respondents were asked to pay.

confidence interval is $21 to $333), $73 (90% confidence interval is $60 to $99) for households in the rest of Washington, and $68 (90% confidence interval is $56 to $92) for households in the rest of the United States. The confidence intervals (CIs) are calculated using a simulation approach applied to the variance-covariance matrix [*Park et al.*, 1991]. The rather large CI for Clallam County is due to the low significance of the bid coefficient and the inherent inefficiency of the single bound dichotomous choice procedure [*Hanemann et al.*, 1991]. These mean values would be about $11 per household lower if the six yes responses to the two highest bid amounts ($150 and $190) are removed. The drop in mean WTP indicates that these observations have an influential effect on the logit equations [*Kanninen*, 1995]. A review of the six individuals' response pattern throughout the survey shows internal consistency of answers and middle to upper incomes, however.

We used a likelihood ratio (LLR) test to determine if the valuation behavior across the three geographic regions is similar. The likelihood ratio test involves comparing the individually estimated logit coefficients in Table 2 for the three geographic regions with the coefficients from a single logit equation estimated by pooling the data across all three regions. If the logit coefficients are similar across regions, similar valuation behavior is implied. The LLR test statistic is calculated as

$$-2[\mathrm{LLR}_p - (\mathrm{LLR}_1 + \mathrm{LLR}_2 + \mathrm{LLR}_3)] \qquad (3)$$

where LLR_p is the log likelihood for the single pooled equation. LLR_n, where $n = 1, 2, 3$, are the log likelihoods for each of three equations estimated separately.

The test statistic is distributed chi-square, with degrees of freedom equal to the number of coefficient equality restrictions (5 variables times 3 equations or 15 total coefficient restrictions) minus the number of variables in the pooled equation. We also applied the likelihood ratio test to determine if there were differences between the two Washington regions as well as to compare the rest of Washington sample to the rest of United States sample.

The results indicate that we should reject equality of valuation behavior across the three geographic regions (calculated chi-square equals 46.66 while the critical chi-square with 10 degrees of freedom is 18.307) as well as between any two of the subregions (the calculated chi-square for the comparison between the two Washington regions is 26.96, while for the rest of Washington and rest of United States comparison the calculated chi-square is 19.39). Both of these exceed the critical chi-square with five degrees of freedom of 11.07. Hence the mean WTP of people living in these different areas is best estimated by reliance on the three separate logit equations rather than one pooled equation. Part of the reason for differences in logit equations and WTP between Clallam County and the rest of Washington residents may relate to distribution of benefits and costs. While Clallam County residents may obtain more fishery benefits than a typical Washington household (due to Clallam County residents' proximity), Clallam county residents face uncertainty regarding whether the mitigation measures associated with dam removal will actually work. Of greatest local concern is maintaining water quality while sediment is removed from the dam. In some sense, Clallam County respondents may be providing their net benefits of dam removal (benefits minus possible costs imposed on them), not just their benefits like other Washington residents.

6.5. Expanding From Sample to Population Estimates of WTP

Accurately expanding the sample values to the population is dependent on the representativeness of the sample frame and the survey response rate. The sample frame was a random sample of the three geographic areas' households. The Clallam County and Washington sample response rates (77% and 68%, respectively) compare favorably with other mail CVM surveys performed for benefit-cost analysis, although the rest of United States response rate is lower than desirable. Response rates approaching 70% have been recommended by the *National Oceanic and Atmospheric Administration* [1994] to provide courts with exact figures for compensation of natural resource damages; however, such precision is rarely required in benefit-cost analysis, where society simply asks whether the benefits exceed the costs. Sample respondents are somewhat older and have, on average, one more year of education. However, these two variables were not consistently related to WTP in the logit equations. In order to provide a conservative or lower bound estimate of WTP and to crudely account for the potential of nonresponse bias, we also provide an estimate of annual WTP that presumes that nonrespondents to the survey have a zero WTP. When expanding from the sample to the population, we

therefore ascribe a zero value to the proportion of the population that we estimate would be nonrespondents had a census rather than a sample been used. For example in the rest of U.S. sample, nonresponse was 45%, and therefore the lower bound on WTP would assume that 45% of this population would not have responded if a census rather than a sample were taken. As such, 45% of the households in the United States would be imputed a zero value in this conservative approach.

The range in benefits to Washington residents (Clallam County plus rest of Washington) is from a minimum of $94 million to $138 million annually. The range in national benefits (rest of United States plus Washington) ranges from a lower bound estimate of $3.47 billion to $6.275 billion as our best estimate based on the sample responses. Whether one directly uses the sample mean or even assumes zero WTP for nonrespondents, the annual WTP is quite sizeable.

Comparison of both household values and aggregate WTP estimates to other studies of the total economic value of salmon and water resources suggest that the Elwha River values are reasonable, however. *Hanemann et al.* [1991] estimated the total nonmarket value of increasing chinook salmon populations in the San Joaquin River from the current estimates of about 100 fish to 15,000 fish. While this is slightly larger than our increase in chinook salmon, it is a much larger percentage increase than the dam removal alternative in our Elwha River survey. Using a single-bound logit equivalent to ours, their value per household was $336 per year, while the more precise double-bound logit model yielded a value of $181 [*Hanemann et al.*, 1991, p. 1261]. As can be seen these values are larger than our per household values for the Elwha. At the other end of the spectrum, the CVM study by *Olsen et al.* [1991, p. 52] of doubling the salmon and steelhead runs in the Columbia River drainage estimated sport, option, and existence values averaging about $50 per household, yielding a total value of $93 million in Washington. This is roughly equivalent to what we found for the Elwha River, although differences in methodology may explain some of the variance. For example, Olsen et al. relied solely upon telephone interviews, so respondents had no visual aids, such as our bar chart, to put the increase in perspective. Olsen et al., also used an open-ended WTP question, which in nearly all CVM studies produces lower estimates of mean WTP than dichotomous choice [*Walsh et al.*, 1992, p. 711]. Thus the values produced by the Elwha study fall in between the values obtained from the two other CVM studies that have measured total nonmarket economic value of salmon improvement programs. Nonetheless, the values from the Elwha study dichotomous choice responses may be subject to some of the concerns expressed by *Kanninen* [1995] regarding yea-saying which could inflate our "best estimate."

In terms of previous CVM studies for riverine ecosystems, the closest previous study is by *Sanders et al.* [1990]. Using an open-ended WTP question format, these authors calculated an annual WTP of $58 per household (in 1994 dollars) to preserve the undammed portions of three rivers. Their value is in the same range as ours, although there are several differences between study methodologies.

7. Conclusion

The contingent valuation method was used to obtain estimates of willingness to pay values for removing the two dams on the Elwha River and restoring the ecosystem and the fishery. The mean annual value per household in the sample obtained using the dichotomous choice voter referendum format was $59 in Clallam County, $73 for the rest of Washington and $68 for households in the rest of the United States. The best estimate of the benefits to residents of the State of Washington is $138 million annually for 10 years. The best estimate of total nonmarket benefits to all U.S. households including Washington residents is $6 billion, with a lower bound of $3 billion.

The study illustrates that there is a substantial nonmarket willingness to pay to remove dams in order to restore salmon and steelhead runs in the Pacific Northwest. This valuation information should be used by the Federal Energy Regulatory Commission in its relicensing decisions on the east and west coasts. In addition, Bonneville Power Administration should consider incorporating such information in its evaluation of alternative Columbia River restoration actions.

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Q.13.5.3.1 Commercial and Recreational Fisheries

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Existence and Sport Values for Doubling the Size of Columbia River Basin Salmon and Steelhead Runs

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ABSTRACT: In the Pacific Northwest, large public agency expenditures are being devoted to the protection, mitigation, and enhancement of salmon and steelhead runs in the Columbia River Basin. The goal is to double the size of the runs (5 million fish) by the year 2000. Resource economists and regional planners have generally conceded that much of the importance of the doubling goal stems from an assumption that Pacific Northwest residents—those paying the costs of the mitigation and enhancement effort—place an existence value on improvements to the fishery. This article (1) summarizes the results of an existence valuation study using a state-of-the-art contingent valuation approach, (2) provides a set of initial guidelines to be followed in conducting existence valuation studies, and (3) summarizes the results of a new sport value study for salmon and steelhead fishing in the Pacific Northwest. The study results demonstrate that Pacific Northwest residents do place an existence value on doubling the run. The recommendation is made that existence and sport values be considered in mitigation and enhancement decisions.

KEY WORDS: Columbia River Basin, contingent valuation method, existence value, fisheries economics, recreation values, sport values.

INTRODUCTION

"The problem with economic analyses for fishery mitigation is that they fail to capture all of the economic benefits held by society."—Comment by Pacific Northwest Fisheries Biologist

Under the authority of the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (16 U.S.C. 837–839), the Northwest Power Planning Council has introduced one of the most comprehensive fishery management programs in the nation (NPPC 1987). The pro-

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gram establishes new public expenditure levels to "protect, mitigate, and enhance" salmon and steelhead fish runs in the Columbia River Basin, with the goal of doubling the size of the runs by the year 2000. Both the provisions of the Act and the Council's directives are based on the premise that fisheries mitigation and enhancement will promote social well-being and coincide with public preferences for increased fishery stocks, as expressed through congressional mandate and the collective voice of various interest groups.

Although the Act clearly calls for equitable consideration of fishery resources—in conjunction with the costs of operating the hydroelectric power system—public policy makers would be negligent if they failed to review formally mitigation benefits and costs. In calculating fishery benefits, resource economists have relied on market and nonmarket valuation techniques to capture the economic value of the fishery recognized by society. But resource economists and regional planners have generally conceded that much of the importance granted to fishery mitigation under the Council's program stems from the tacit assumption that Pacific Northwest residents—those who will pay the bulk of the expense for the mitigation and enhancement effort—place an existence value on improvements to the fishery. However, the level of this existence value, as it relates to improving and increasing the size of the salmon and steelhead runs, has been unknown.

To measure the marginal existence value of doubling the size of the Columbia River Basin fish runs, a contingent valuation method (CVM) study was conducted during 1989. The CVM approach employs a survey format to directly solicit from subjects their willingness-to-pay for resources or changes in resource abundance. Key study features included a comprehensive review of the critical literature on existence value theory, empirical assessments, and CVM technology; an extensive review of the study design by independent reviewers; and a thorough pretesting of the survey instrument used within the study (Olsen et al. 1989).

Along with the existence value component of the study, a sport value module for resource users was also incorporated. The sport value module was included because the study sought to measure the total value of the resource held by all actors (Smith 1987; Freeman, in press)—information needed by resource decision makers. There has also been a need to update the sport values currently being used in economic analyses, and to provide a regional context for salmon and steelhead fishing values.

Both theoretical and methodological features of the existence and sport value modules are described below. This technical review is followed by an interpretation of the major study findings and by an initial discussion of proposed guidelines for preparing existence value studies.

EXISTENCE VALUE CONCEPTS AND METHODOLOGY

An analytical process for conducting an existence value study—or pursuing a more conventional application of the CVM—traverses four fundamental steps that (1) define the theoretical and definitional context; (2) identify the institutional setting and proper welfare measures; (3) design the survey instrument, integrating state-of-the-art CVM technology; and (4) analyze and interpret the data. Reviewed in greater detail, this analytical process serves as a guide to highlight the many procedures and methodological decisions made during the existence value study presented here.

Theoretical and Definitional Context of Existence Value

The Concept of Existence Value. Existence value represents the benefit that individuals gain from the knowledge that doubling the Columbia River Basin salmon and steelhead runs would provide the runs with greater ecological stability and diversity. The runs are perceived as being preserved in a more favorable state, even though an individual does not intend to directly use the fishery resource in the future. Existence value essentially consists of an in-

trinsic or inherent value that individuals attach to the fishery resource.

The concept of existence value advanced here is grounded in both the classic literature and more recent writings. The primary works that have brought existence value to prominence are those of Krutilla (1967) and Krutilla and Fisher (1985). Krutilla states (1967:781): "There are many persons who obtain satisfaction from the mere knowledge that part of the wilderness of North America remains, even though they would be appalled by the prospect of being exposed to it." Krutilla and Fisher (1985: 124) elaborate that existence value forms "the value some individuals place on the knowledge of the mere existence of gifts of nature, even though they feel certain they will never have or choose an opportunity to experience them in situ." This conceptual interpretation is further stressed by Walsh (1986:85): "Existence value is the willingness-to-pay for the individual satisfaction that a recreational or natural resource is protected . . . [it represents] a stock of knowledge or psychic capital."

Although the motives for and derivatives and legitimacy of existence value have been keenly explored (Brookshire et al. 1986), recent literature on the subject suggests that "the concept of existence value should be broadened back to something more closely resembling the original notion of existence value put forth by Krutilla . . . [the] value from knowing this natural environment exists" (Loomis 1988:23). This recommendation is characteristic of the use of the concept by Mitchell and Carson (1989), whereby they assert that nonuse value is a relatively pure expression of existence value. Although the authors recognize—as do others—variations or derivatives of existence value, they place nonuse values primarily in the existence category. The need for a consistent definition for existence value has also been voiced by Smith (1987).

Within the CVM survey instrument, the concept of existence value was explained to respondents as the value (satisfaction) obtained from the knowledge that doubling the Columbia River Basin fish runs would provide greater ecological stability and more species diversity. But to avoid an implied value cue, it was further stated that some people do hold an existence value, whereas others do not.

Existence Value and the Regional Context. An important study component is the recognition of the interdependence of mitigation and enhancement measures, such as water budget and spill to assist downstream migration patterns, that affect regional fishery production and hydroelectric project operations. A doubling of the fish runs is definitely a regional management action that depends on the cooperation of all of the hydroelectric projects on the Columbia and Snake rivers.

The study population was limited to Pacific Northwest households (Washington, Oregon, Idaho, and western Montana), reflecting the assumption that Pacific Northwest residents are the primary recipients of the benefits and costs provided by the fishery and electric power system. This assumption further holds that the values derived represent a dominant portion of the total national value that could be described as existence value.

Identifying Existence Value—Resource Nonusers. A primary focus of the study was to estimate the existence value of resource nonusers. Resource nonusers were defined as individuals who have not been involved in the commercial fishing industry and who have not participated in the sport fishery during the past 5 years. The survey instrument determined whether any member of the respondent's household participated in the sport fishery during the past 5 years.

It is assumed that resource nonusers—those who have not participated in the commercial or sport fishery and do not plan to do so—retain an almost "pure" form of existence value; that is, resource nonusers project a very small to nonidentifiable amount of expected consumer surplus (recreation value) or option value in their total willingness-to-pay to preserve the resource or know that the resource would be altered to a more desirable condition. The survey instrument included a question to determine whether respondents would likely participate in the sport fishery during the following 5 years. Those who responded either "no" or "uncertain" to this question are considered to have a zero probability of future use (or are considered

to comprehend their future use probability as zero).

Institutional Setting and Welfare Measure

The Property Right. The Northwest Power Planning and Conservation Act has designated the Columbia River—fishery and water resources—as reflecting a mixed property right. Columbia River water must be used for fisheries protection (commercial, Indian, and sport fishermen's property rights) and for electric power generation (rate payers' property rights). Collectively held goods usually possess mixed property rights—the requirement of purchase to obtain the good in question or the right to sell it. Therefore, it is theoretically correct to employ both Hicksian compensating surplus willingness-to-pay (WTP) measures and equivalence surplus willingness-to-accept (WTA) compensation measures. Excellent reviews of welfare measure theory and implementation in CVM studies are provided by Desvousges et al. (1983) and Mitchell and Carson (1989). In practice, for a quantity increase of the Columbia River Basin fish runs—in which an individual's utility (satisfaction) is held constant and the quantity increase is fixed—the proper WTP measure is compensating surplus; under the same conditions, the proper WTA measure is equivalence surplus.

Willingness-to-Pay as the Primary Measure. From a purely theoretical perspective, it would be appropriate to give equal weight to either WTP or WTA measures, depending upon the property right involved. However, the literature abounds with considerable apprehension about whether WTA measures can or should be used to estimate benefits (Brookshire et al. 1983; Knetsch and Sinden 1984, 1987; Cox 1986; Coursey et al. 1987; Carson and Navarro 1988), although some counter perspectives have been asserted (Meyer 1979; Power 1988). Many researchers simply reject the WTA measure because of concerns related to market transaction simulation, respondent cognitive dissonance, or respondent failure to "understand" their true entitlement to the resource. Given these concerns, WTP measures are the primary analysis measures within the study, but WTA measures are estimated for comparative purposes. It is assumed here that WTP and WTA measures of value actually depict two different, and perhaps incomparable, contexts of how people view the resource (Gregory 1986; M. W. Hanemann, unpublished data).

The WTP measure is advocated as the "proper" measure under the "new property rights approach" discussed by Mitchell and Carson (1989). This approach, yet to receive broad acceptance by resource economists, suggests that under conditions in which collective goods are involved with open access, each change made by society to the state of the resource should be accepted as the new societal status quo (presumably including any resulting externality costs). Under this perspective, both increments to the existing resource level or the avoidance of resource decrements should be analyzed using WTP measures.

Survey Instrument Design and CVM Technology

Survey Application. The CVM survey instrument was implemented through telephone interviews. The Social and Economic Sciences Research Center (SESRC) at Washington State University conducted the survey, relying on the Center's Total Design Method (Dillman 1978; Rossi et al. 1983; Lavrakas 1987). The SESRC and the study principal investigators conducted two survey pretests and special training sessions for the survey interviewers before initiating the formal survey. Also, the survey instrument was reviewed by survey research specialists and several resource economists familiar with CVM applications.

The sample population consisted of all Pacific Northwest households with telephones. A probability sample of approximately 700 resource nonusers and 700 resource users (salmon and steelhead fishermen) was selected and interviewed using a dual sampling frame, employing both random digit dialing and directory samples. Survey respondents were screened to identify the person who normally paid the household electric power

bill and to identify resource users and non-users. Also, the head-of-household was identified.

Framing the Simulated Market. Respondents received background information before and during the elicitation process. This information included (1) a statement about the size of the fish runs before industrial development of the Columbia River Basin, (2) a statement about the effort currently being made to double the size of the salmon and steelhead runs, (3) a statement that federal law (Northwest Power Act) requires that those who enjoy the benefits of hydroelectric power must pay for its portion of associated environmental costs, and (4) a statement about the definitional context of existence value—the value derived from the satisfaction of knowing that the runs would be altered to a more stable and diverse condition. An introduction to the payment question defined the contingent market as payment for a guarantee that the fish runs would be doubled in size. Within the CVM literature, a cogent review of the context effects related to market framing is provided by Boyle (1989) and J. C. Bergstrom and J. R. Stoll (unpublished data).

CVM Elicitation Process and Payment Vehicle. To control for the effects of bidding game starting point bias (Boyle et al. 1985; Cummings et al. 1986) and the discrete choice analogue ("yea-saying") of starting point bias (Boyle and Bishop 1988; Mitchell and Carson 1989), a modified open-ended elicitation format was used. First, respondents were queried about their last electric power bill payment (monthly bill) and their estimated average monthly power bill throughout the year. This query served to prompt the respondent to begin thinking about a "market-like" transaction and to introduce the payment vehicle. Second, respondents were asked to identify the maximum amount they would pay above their average monthly (or last) power bill to double the size of the fish runs. Third, the interviewers repeated to the respondents their payment level and indicated to them what percentage of their average (last) monthly power bill this additional amount represented. And fourth, respondents were asked if they would like to change their payment level, and were again requested to state their maximum payment level.

As noted above, the electric power bill served as the payment vehicle. Within the framing information, respondents were told that a portion of their current bills are and will continue to be used by fisheries managers to double the size of the fish runs through mitigation and enhancement actions. Respondents were further told that the electric power bill was the only way to finance the doubling of the runs, to minimize protest bids. However, a second payment vehicle was introduced to respondents who indicated that they did not want to make a payment and suggested that they were either rejecting the electric power bill as a payment vehicle or were concerned about the involvement of the electric power industry. The "second-stage" payment vehicle consisted of a direct solicitation by the respondent's state fishery agency for an annual contribution to be used for doubling the fish runs.

All "no payment" responses were followed with an extensive set of control questions to determine whether a protest bid was being offered or whether the respondent was actually providing a "true" zero-value bid. Adhering to current practice, protest bids were recorded (percentage relative to total sample), but they were not included within analysis.

RESOURCE USER VALUE CONCEPTS AND METHODOLOGY

The resource user and sport value component of the study was composed of two parts: (1) resource user values associated with doubling the size of the Columbia River Basin salmon and steelhead runs, and (2) "regional" sport fishing values for salmon and steelhead derived through a conventional CVM format. Several of the study design features for estimating these resource user/sport values are identical to the existence value study features discussed above.

Theoretical and Definitional Context

Resource User Value. Resource users were defined as respondents who have partici-

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pated in either the 1987 or 1988 salmon and steelhead sport fishing seasons, although participation in the sport fishery during the past 5 years was recorded to differentiate between user and nonuser households. The 2-year "user" time frame was adopted to reduce the likelihood of memory bias, a factor that could affect the accuracy of CVM responses. The resource user probability sample was drawn from the same study population—Pacific Northwest households—as the resource nonusers.

Consistent with the recent literature on CVM measurement theory, the values indicated by respondents are assumed to be an estimate of their "total value." When resource users responded to the CVM question about doubling the size of the runs, they were projecting expected consumer surplus (sport value), option value, and existence value.

The contingent market for resource users was the availability of more fish for ocean and river basin sport catch, as a result of doubling the Columbia River Basin salmon and steelhead runs; no probability function or hypothetical catch increase was proposed. For resource users, their WTP and WTA values were tied to their perception of how doubling the size of the fish runs could affect future fishing quality (use value) and their concerns for fishery stability and diversity.

Regional Sport Value. The regional sport value feature of the study estimated two value components: (1) the value held by users that exceeded the costs of their last fishing experience, with no change or improvement to the catch level; and (2) the value held by users for an incremental change—doubling the number of fish caught—in their catch levels, in excess of the value for present fishing conditions. The former component identified users' average net value for existing catch levels, while the latter expressed a marginal net value for increased sport catch.

Although this study feature relied upon the theory and design constructs of "standard" CVM approaches for measuring recreation values, the geographical scope was unconventional. The respondents' average and net values for their salmon and steelhead fishing experience was aggregated across different geographical areas, thus representing salmon and steelhead fishing values drawn from a broad "regional" context. The geographical areas were Puget Sound and drainage, the ocean off the Washington or Oregon coasts, Washington or Oregon rivers with coastal drainage, and Columbia River Basin drainage.

This "regional factor" engenders both positive and negative attributes. On the positive side, the values project a regional experience. However, it is not possible to use these regional data to make site-specific estimates of fishing values for a distinct fishing spot within a geographical zone. The values derived for each zone compose an average fishing value given the diverse conditions across each zone.

Institutional Setting and Welfare Measure

Both WTP and WTA measures were used for the resource user value tied to doubling the fishery run size. Only the WTP measure was included for the regional sport value component. A review of the welfare measures applied within the study is provided in the existence value section above.

Survey Instrument Design and CVM Technology

Sample Population. A probability sample of approximately 700 households was interviewed to solicit the regional sport values and the resource user values for doubling the runs. To estimate the ratio of Pacific Northwest households with resource users versus nonusers, the survey instrument contained a question about overall household participation in the fishery.

CVM Format and Contingent Market. For resource users, the CVM format was identical to that of the nonusers' (existence) value format, with the exception of the WTP/WTA framing information. The contingent market for resource users was a payment for the availability of more salmon and steelhead, for the Columbia River and ocean catch, given a doubling of the fish runs along with assurances of ecological stability and diversity.

For the regional sport value component,

the contingent market was payment for (1) a continuation of the existing fishing experience but with additional costs required; and (2) an enhanced fishing experience provided by a doubling of a respondent's stated catch, for example, "one" fish caught for respondents who indicated a "zero" catch during their last trip. The former payment question requested respondents to state their maximum WTP, above existing costs, for the same catch level. The latter payment question solicited respondents to state their maximum WTP for a marginal improvement in catch—a payment in excess of respondents' WTP for current fishing conditions.

STUDY FINDINGS AND INTERPRETATION

Existence and User Values for Doubling Fish Runs

A random probability sample of 4,028 Pacific Northwest households was contacted during survey implementation. From this sample, 2,907 households provided successful interviews: either they successfully answered a complete nonuser or user interview or they answered a more limited "screening" interview. Screening interviews were conducted to collect accurate nonuse/use ratio data from the probability sample and still fulfill the goal of acquiring approximately 700 nonuser and 700 user questionnaires (users responded to both the doubling-the-runs and "standard" CVM questions). The successful interviews composed a 72% cooperation rate.

Responses from 2,053 individuals indicated that they were resource nonusers; of this group, 21% indicated that a member of their household had participated in the sport salmon or steelhead fishery during the past 5 years. The remaining households (1,622) represent "true" nonuser households. Based on this sample, 56% of the regional households can be classified as resource nonusers and 44% as users.

Over 700 respondents answered a complete nonuser questionnaire. After the removal of difficult-to-understand responses (about 25 questionnaires that the interviewers considered distorted), 695 usable questionnaires remained. The nonusers offered a roughly even split between those willing to make a payment to ensure a doubling of the salmon and steelhead runs versus those not willing to make a payment: 54% responding "yes," and 46% responding "no." By employing a two-stage payment vehicle (as discussed above) and carefully classifying respondent reasons for nonpayment (control questions), it was determined that 204 (29%) cases reflected "true" zero bids. These respondents indicated that doubling the fish runs held no economic value to them. Through use of the control questions—containing 14 designations for nonpayment—it was further determined that 110 (16%) nonpayment responses comprised protest bids. Respondent reasons for protesting the contingent market reflected a wide range of concerns, such as involvement by the electric power industry in mitigation and enhancement efforts, a lack of confidence that state or federal agencies would take the proper actions to restore the runs, and the perception that all the additional fish would be caught by Indian or commercial fishermen.

The two-stage payment vehicle elicitation format was replicated for resource users, and 482 usable responses were obtained. Approximately 19% of the user nonpayment responses consisted of protest bids. A higher number of users (603) answered the "standard" CVM questions (increased fishing activity expenses) for sport value than the total number of respondents answering the WTP/WTA question for doubling the fish runs. Follow-up responses offered by resource users indicated that a higher response rate for the standard CVM questions was largely due to the perception that they "already pay enough" in licensing fees for fishery management.

Nonuser and user WTP and WTA values for doubling the fish runs are presented in Table 1. The average WTP bid for nonusers who stated no probability of future participation in the sport fishery was $2.21 per month; for nonusers who stated some probability of future participation, $4.88 per month; and for resource users, $6.18 per month. These values follow a trend that matches theoretical assumptions. For example, nonuser estimates, those with no probability of future participation, should represent a pure expression of existence

value. Nonusers who possess some perceived notion of future use should hold existence value and some fraction of option price (option value and consumer surplus). Resource users should possess an existence value and a "full measure" of option value and consumer surplus. Theory suggests that the value magnitude levels across the three groups should follow an upward trend. (The empirical data presented in Table 3 support theoretical expectations.)

The WTA values for respondents who stated a WTP bid are also presented in Table 1. Over 80% of both resource nonusers and users rejected compensation in exchange for knowing that the fish runs would be doubled in size. Also, the ratios for WTA/WTP values—where WTA bids were reported—are relatively low given that much greater differences have been observed in other CVM studies. Although several variables are responsible for this relatively "close" ratio, the outcome may be primarily due to the degree of "realism" surrounding the survey instrument and payment source and to respondents' general level of knowledge about efforts to increase the size of the fish runs. Both of these factors would tend to make the market transaction more authentic.

TABLE 1
Values by nonuser and user groups

Nonuser, no probability of future use	
Mean value: $2.21/month = WTP	
Median value: $1.00/month = WTP	
SD: $2.98	
WTA = 83% say "no sale"	
Mean value: $3.39/month = WTA[a]	
WTA/WTP ratio = 1.53	
Nonuser, with some probability of future use	
Mean value: $4.88/month = WTP	
Median value: $3.00/month = WTP	
SD: $9.33	
WTA = 85% say "no sale"	
Mean value: $5.82/month = WTA[a]	
WTA/WTP ratio = 1.19	
User value	
Mean value: $6.18/month = WTP	
Median value: $3.50/month = WTP	
SD: $9.92	
WTA = 84% say "no sale"	
Mean value: $10.25/month = WTA[a]	
WTA/WTP ratio = 1.66	

[a] For those accepting compensation.

Economic Value for Doubling the Columbia River Salmon and Steelhead Runs

An estimate of the existence and user values for doubling the size of the fish runs is displayed in Table 2. The average WTP values derived from the CVM survey are multiplied by all Pacific Northwest households, taking into account the resource nonuser and user ratios estimated from the probability sample. Also, ratios for nonusers with some probability of future use versus nonusers with zero probability of future use are incorporated into the analysis.

In total, regional rate payers, or households, are willing to pay $171 million (1989 dollars) annually for a doubling of the salmon and steelhead runs, or an amount equivalent to $68.49 per additional fish (direct net value). Resource users contribute 65% to the total value; nonusers with zero probability of future participation in the sport fishery, 25%; and nonusers with some probability of future participation, 10%. This "total value" captures resource nonusers' and users' existence value, option value, and expected consumer surplus. Collectively, the resource nonuser and user values reported here are less than many "older" sport value estimates applied within the Columbia River Basin (U.S. Army Corps of Engineers 1989).

Estimated Regional Sport Value

Table 3 provides an estimate of the sport-effort day activity for salmon and steelhead fishing in the Pacific Northwest. When asked about the location of their last fishing trip, salmon anglers replied that 37% fished in the Puget Sound area, 33% off the Washington or Oregon coasts, 6% within a coastal drainage river, and 24% within the Columbia River Basin drainage (includes Buoy 10 area). Steelhead anglers replied that 72% fished within the Columbia River Basin drainage and 28% within a coastal river drainage.

The sport-effort day catch levels reported by anglers who fished off the Washing-

TABLE 2

Estimated existence (nonuse) and user values for doubling the size of the Columbia River Basin fish runs 1989 $

	Existence (nonuser), no probability of future use	Nonuser, with some probability of future use	User
$/month	2.21	4.88	6.18
$/year	26.52	58.56	74.16
Regional households	1,599,360	304,640	1,496,000
Total regional annual value ($)	42,415,000	17,840,000	110,943,000
Fish/year	2,500,000	2,500,000	2,500,000
(doubling goal)	(Marginal)	(Marginal)	(Marginal)
Value/fish ($)	16.97	7.14	44.38
Net regional benefit (total annual value) = $68.49/fish[a]			

[a] Includes "total value," which is existence value, option value, and consumer's surplus.

TABLE 3

Estimated sport-effort day (SED) and catch levels for salmon and steelhead fishing (for last fishing trip)

	Average days/trip	Average fish/trip	Average fish/SED
Salmon location			
Puget Sound (n = 156)	1.62	1.48	0.91
Washington-Oregon coast (n = 146)	1.75	2.15	1.23
Coastal rivers (n = 32)	1.79	1.59	0.89
Columbia River Basin[a] (n = 103)	2.25	2.44	1.08
Steelhead location			
Coastal rivers (n = 47)	1.72	0.93	0.54
Columbia River Basin (n = 119)	1.95	0.68	0.35

[a] Includes fishing in Lower Columbia River and at Buoy 10.

ton or Oregon coasts and within the Columbia River drainage are consistent with the sport-effort catch levels estimated by the Pacific Fishery Management Council (PFMC 1989). For example, the Management Council estimated that the 1988 sport-effort day catch level for anglers off the Washington or Oregon coasts ranged between 1.56 (Washington) and 1.06 (Oregon) and for anglers in the Buoy 10 area (mouth of the Columbia River), 0.94. The estimates provided by the CVM study for the 1987–1988 period are 1.23 for the Washington or Oregon coasts and 1.08 for the Columbia River drainage, including the Buoy 10 area.

Current sport-effort day catch level estimates for Idaho (1987–1988) are congruent with the study estimates for the Columbia River Basin. The Idaho Department of Fish and Game (IDFG 1989) estimated a statewide average catch level (Snake, Clearwater, and Salmon rivers) of 0.32 fish per sport-effort day; angler reports from the study establish the catch level at 0.35 fish per sport-effort day. Both the IDFG and study estimates reflect an increase in catch levels that coincides with improvements to the upper river steelhead runs (Pratt and Chapman 1989). Also, the 0.35 study estimate has been directly discussed with fishery agency officials, and it is considered to be reasonable (Al Van Vooren, personal communication).

Tables 4 and 5 display average and marginal net value estimates for salmon and steelhead fishing on a value per trip, value per sport-effort day, and value per fish basis. Average net values for salmon fishing off the Washington or Oregon coasts and within the Columbia River Basin (including Buoy 10 area) are $41.61 per fish and

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User
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TABLE 4

Estimated sport values (average net value) for existing fishing experience, without change (for last fishing trip)

	Average fish/trip	Average fish/SED	Average net value/ trip ($)	Average net value/ SED ($)	Average net value/ fish ($)
Salmon location					
Puget Sound	1.48	0.91	75.88	46.66	51.27
Washington–Oregon coast	2.15	1.23	89.47	51.59	41.61
Coastal rivers	1.59	0.89	58.39	32.68	36.72
Columbia River Basin[a]	2.44	1.08	111.46	49.33	45.68
Steelhead location					
Coastal rivers	0.93	0.54	59.58	34.59	64.06
Columbia River Basin	0.68	0.35	90.08	46.36	132.47

Note: Average fish per trip is based on multiple-day fishing at the site.
[a] Includes fishing in Lower Columbia River and at Buoy 10.

TABLE 5

Estimated sport values—average and marginal net values (for last fishing trip)

	Average net value/ trip ($)	Marginal 2(X) fish net value/ trip ($)	Average net value/ fish ($)	Marginal 2(X) fish net value/ fish ($)
Salmon location				
Puget Sound	75.88	26.89	51.27	18.17
Washington–Oregon coast	89.47	54.31	41.61	25.26
Coastal rivers	58.39	23.55	36.72	14.81
Columbia River Basin[a]	111.46	45.07	45.68	18.47
Steelhead location				
Coastal rivers	59.58	23.21	64.06	24.96
Columbia River Basin	90.08	37.29	132.47	54.84

[a] Includes fishing in Lower Columbia River and at Buoy 10.

$45.68 per fish, respectively. For the same fishing areas, anglers reported marginal net values—based on a doubling of their catch—of $25.26 per fish and $18.47 per fish, respectively. The average net value reported by the ocean fishermen in the CVM study is consistent with value estimates from a recent travel cost study sponsored by the Oregon Department of Fish and Wildlife (ODFW) and conducted by Oregon State University (Abdullah 1989; Brown 1990). The ODFW estimates for the Oregon Coast sport salmon fishery range from about $40.00 to $60.00 per fish, depending upon the coastal site.

Steelhead anglers fishing in the Columbia River Basin reported an average net value of $132.47 per fish and a marginal net value of $54.84 per fish (marginal value estimate based on a doubling of catch). A smaller sample of steelhead anglers fishing at different coastal river sites reported an average net value of $64.06 per fish and a marginal net value of $24.96 per fish.

Comparison of Use and Regional Sport Values

For Columbia River steelhead, there is an important similarity between the user value estimates for doubling the size of the Columbia River Basin fish runs and the regional sport value estimate for a marginal increase in catch. The user value for doubling the runs ($44.38 per fish) and the marginal steelhead sport value ($54.84) are

approximately equal. This observation is consistent with the hypothesis that users should offer roughly equivalent values for either a doubling of the runs or marginal increases in fish catch. This observation also supports the concept that much of the value users (and perhaps nonusers) assign to a doubling the runs stems from potential increases to upper river stocks.

Interpreting Existence and User Values

Given the parameters of the CVM study, Pacific Northwest households have established existence and use values for doubling the size of the Columbia River Basin salmon and steelhead runs. When combined, these values mark a point of caution or threshold that can be used to assess the overall economic value society places on proposed fishery mitigation and enhancement projects. For example, if the cost per incremental fish in a proposed mitigation or enhancement project is substantially greater than the combined existence and user value average for doubling the runs ($68.49 per fish), then the project should be reconsidered in light of other alternatives. Most projects should be screened on an individual basis, taking into account cumulative effects where possible.

The existence and user value threshold provides a clear economic boundary for resource decisions. Prudent resource managers will not exceed this economic threshold. By more fully evaluating project decisions through adoption of a societal economic threshold, resource managers will be more likely to meet the doubling goal objective by the year 2000—dollars will be effectively spent.

GUIDELINES FOR CONDUCTING EXISTENCE VALUATION STUDIES

Since the early 1980's, resource economists have attempted to quantify the existence or nonuse values (or preservation values depending upon the preferred nomenclature) previously discussed within the theoretical literature. A representative overview of the applied studies can be found in Rowe et al. (1980), Brookshire et al. (1983), Schulze and Brookshire (1983), Kneese (1984), Walsh et al. (1984), Mitchell and Carson (1985), and Edwards (1988). Underlying much of this research has been a recognition that existence or nonuse values should be taken into account when economic analyses are conducted to evaluate the merits of various resource projects.

It is likely that greater attention will be placed on existence and nonuse values in the future as resource managers confront the need to assess ever more diverse societal preferences for resource allocation. Therefore, it is important to establish some fundamental guidelines for when and how existence and nonuse values can be applied. The points offered below serve to "initiate" this task, reflecting the authors' experience in conducting an existence value study.

1. The "general concept" of existence value is adequate for evaluating resource decisions. The concept of existence value of Krutilla (1967) and Krutilla and Fisher (1985) should not be transformed into impotent theoretical definitions and distinctions, impossible to apply to resource allocation decisions. Existence value as the value an individual (or society) places on the knowledge that a resource exists in a certain state is theoretically sound and can be measured for assessment within the resource decision making arena.
2. The existence value contingent market should be tied to a well-defined policy action. Avoid "open-ended" contingent value markets. The contingent value market and its framing should be matched to relevant policy questions that resource managers can act upon once values are obtained.
3. Public understanding or knowledge about a resource, even if only general in nature, should be a prerequisite to conducting an existence valuation study. Obscure resources are poor candidates for existence valuation.
4. It is unrealistic to expect individuals to place a meaningful existence value upon an ecologically or geographically "fragmented" resource. The

temptation to isolate a portion of a resource—either biologically or geographically—for existence valuation should be resisted. This partitioning invites problems related to part/whole bias and requires individuals to develop a cognitive distinction that cannot be adequately invoked through CVM research methods.

As more applied existence value work is conducted, additional guidelines should be added to the above list. The use of existence valuation and formal guidelines for implementation should be brought into agency resource decision making on a standard basis.

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Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates

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Abstract

This paper offers a methodological contribution to estimate marginal values of selected ecosystem services for world forest biomes, following the Millennium Ecosystem Assessment. Economic losses from policy inaction are estimated for future scenarios in year 2050. The highest impact is expected in boreal and warm mixed forests, followed by tropical forests, which might be surprising to some who argue that the most significant loss should be in tropical forests. A detailed analysis, however, shows that this is not the case. The best estimates point to greater losses in areas where use and non-use values are highest, which includes North America.

Keywords: forest, ecosystem services, value transfer, Millennium Ecosystem Assessment, market values, non-market values.

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1 Introduction

In recent years we have been witnessing a major debate on the potential effects of biodiversity loss. The central question being: as biodiversity decreases, what are we losing in terms of goods and services to humans? Far from being a mere accountability issue, this question is about the impact on the welfare and wellbeing of current and future population and societies, as well as about wider ethical questions on the role humans in the stewardship of the planet's natural resources. So far, this has triggered many studies trying to provide economic estimates of the costs and benefits of land conversion and human activities inducing biodiversity losses (e.g. see Costanza et al. 1997). Still, the coverage of the available economic estimates of the costs of biodiversity loss is partial, and the required research effort massive.

By using *ad hoc* value transfer protocols, this paper offers a methodological contribution and provides accurate per hectare estimates of the economic value of a set of forest ecosystem services (ESs) for all forest biomes in the world. The research also estimates potential total economic losses from inaction in year 2050, by using data on forest areas and land use changes from 2000 to 2050 as provided by the EU-funded COPI project "Cost of Policy Inaction: the case of not meeting the 2010 biodiversity target" (see Braat et al., 2008).

The analysis is focused on a selected set of relevant forest ecosystem services identified following the Millennium Ecosystem Assessment taxonomy (MEA, 2005). The estimation of such services, although not covering the full range of forest instrumental values, contribute to the quantification of those values which are expected to be relevant to contexts where it is necessary to make decisions and trade one value against the other. The assessment provided is anthropocentric, as non-anthropocentric values, such as moral and spiritual values, which should be taken into account in decision-making, do not lend themselves to this kind of quantification.

The reminder of the paper is organized as follows. Section 2 provides a brief review of the valuation of forest services and discusses current challenges. Section 3 illustrates the methodological approach employed to estimate forest services worldwide. Section 4 presents and discusses results, while Section 5 offers some conclusive remarks, while discussing future challenges.

2 Valuing forest ecosystem services: where do we stand

Forests are critically important habitats in terms of the biological diversity they contain and in terms of the ecological functions they supply (e.g., Miller et al., 1991; Mendelshon and Balick, 1995; Pearce, 1996, 1998, 1999). Similarly, the ecological and anthropocentric services of forest are many and, although the area-species and the species-services relationships are still debated (e.g. Pimm and Raven, 2000), the loss of forest ecosystem services driven by deforestation is expected to be serious if the rate of deforestation is maintained at the current alarming level of approximately 13 million hectares per year (FAO, 2007). The value that forests provide therefore arises from the estimated rates of loss of forest areas and, hence, in terms of the services they provide humans. Forests not only provide timber but regulate local and global climate, enhance soil retention and water quality, ameliorate water events, facilitate pollination, improve landscape aesthetics and provide habitats for a vast store of species, and genetic information yet to be uncovered.

The forest evaluation challenge has gradually reached the international policy agenda. Forest conservation or prevention of deforestation in order to stabilize Green House Gas (GHG) emissions – questions not originally included in the Kyoto Protocol – have been officially recognized in COP13 in Bali on December 2007 as important issues. Countries rich of forested areas, such as Brazil, are asking for compensation for the environmental services that they give to the planet by helping future conservation of millions of hectares of native woodland in the tropics. Besides, as

deforestation is mainly due to conversion of forests to agricultural land in South America and Asia (FAO, 2005), paying farmers for the environmental services they may conserve or provide is generating growing interest worldwide from policy makers to non-governmental and private decision-makers (see FAO, 2007). As such policy initiatives are currently being debated, the availability of reliable and accurate estimates of forest values is becoming pivotal. Although it is not yet clear what will be the policy framework on deforestation in the near future, shading light on this issue from a scientific perspective will facilitate and accelerate the policy process.

So far, the estimation of the economic value of forest ecosystem services has been limited by a number of pitfalls. The first point regards the coverage of the economic valuation of forest services. Some recent works, e.g. the CBD report (2001) on the *Value of Forest Ecosystems*, have tried to fill this gap by providing comprehensive literature reviews of the values of a vast array of forest services (from provisioning services to genetic information). The estimations help us to understand the typologies and orders of magnitude of the services involved; however, they cannot be seen as representative of all forest areas. As the current body of knowledge become clearer, we still lack a common and replicable methodological framework to transfer available figures to new, unexplored and heterogeneous, policy contexts, thus allowing a worldwide coverage of the cost estimation to be achieved. A common platform of analysis of forest biodiversity services is needed.

Equally importantly, many studies estimate marginal effects as being equal to the average impact, and do not estimate the former by taking into account statistically significant explanatory factors that may control for heterogeneities across forest areas (and their related socio-economic context). This leads to potential estimation biases. According to a recent review promoted by the European Commission (Markandya et al., 2008), available values tend to be very site and forest specific and transfer to other forests and locations are difficult or often not credible.

Thirdly valuation exercises need to be incremental ones. There is little advantage in knowing the total value of an ecosystem unless there is a threat to eliminate it or a policy to reconstruct it in its entirety, which is rarely the case. Yet many valuation studies provide estimates of the total costs of whole systems and the famous work by Costanza et al. (1997) even estimates the value of the whole world's ecosystems. Performing an incremental analysis (which may entail estimating significant non-marginal changes in ecosystems), however, is not as easy as it might sound, and revealed or stated preferences valuation exercises need to be designed accurately. Besides, many ecosystem services that individuals receive are multidimensional and there is an 'adding up' problem (Markandya et al., 2008). The value attached to one forest area for recreational or other use is not independent of whether another forest nearby is conserved or not. The implication is that studies need to be undertaken allowing for substitution effects, which makes them more specific to a particular application and less capable of being transferred to other applications.

All and all, the question of the extent to which forest values can be transferred from one site to another and from one type of biome to another is a crucial and controversial one. Economists have devoted a great deal of effort to see how far such transfers are possible, given that full valuation studies are expensive and time-consuming to conduct (see, e.g., Brower, 2000; Navrud and Ready, 2007). In principle, the most comprehensive way to carry out transfers is to use a 'meta analysis', which takes all existing studies and figures and statistically estimates a relationship which gives changes in the benefit values as a function of site characteristics, attributes and size of the population affected, type of statistical method used etc. in the sample of existing studies. This is then transferred to the 'policy site' in a procedure referred to as value transfer, which can provide a 'single value' for the policy site or a 'meta-value function', which gives a range of values depending on the characteristics of the object of valuation. Overall, the result of recent discussions on this subject seem to suggest that while value transfer is possible for some ecosystem services it is not appropriate for others (see Braat et al. 2008; Markandya et al., 2008). It should be possible, for example, to derive estimates of some categories of recreational benefits; it is much more difficult to carry out credible benefit transfer for most other categories of value.

Notwithstanding such difficulties, the international community urgently seeks estimates of the foregone forest benefits at the local and global level. Given that there are thousands of forest ecosystems and sites of importance, some kind of value transfer and rules of thumb for acceptable estimates will be essential if the goal of obtaining regional, national and global estimates of the damages from forest loss in the absence of any actions is to be obtained. The present paper presents value transfer protocols for estimating a small but significant array of provisioning, regulating and cultural forest ecosystem services. In this regard, the methodological approach and analyses presented in the following sections can be seen as a pilot case study showing how research synthesis could be used to fill knowledge gaps on biodiversity values.

3 A worldwide assessment of forest ecosystem services: methodological approach

3.1 Introduction: forest ecosystem services, biomes, land use and world regions

The methodological framework applied to derive marginal monetary values and potential total losses of a restricted set of services provided by forest biomes worldwide is illustrated in Figure 1.

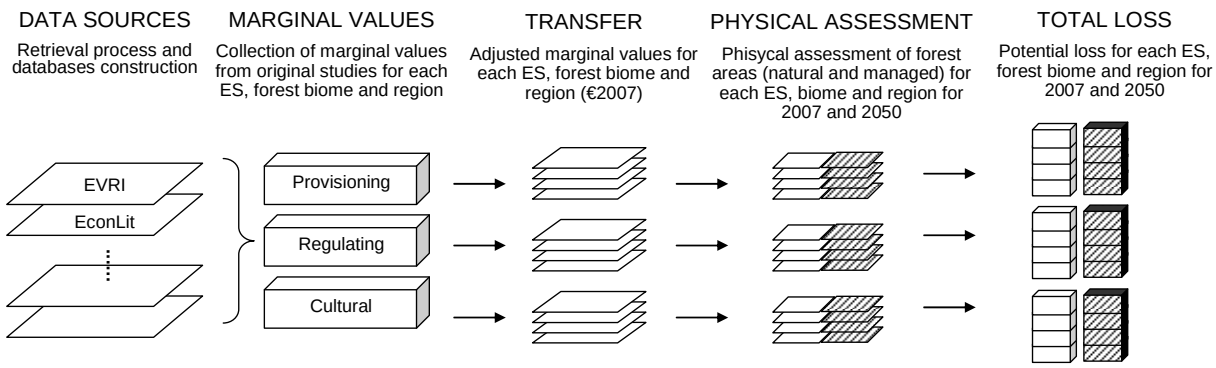

Figure 1: A schematic illustration of the overall methodological approach

The services considered in this study are selected according to data availability and relevance to decision making; this leads to the restricted set presented inv Table 1. As defined by the Millennium Ecosystem Assessment (MEA, 2005), provisioning services are the goods obtained from ecosystems and they include food, fiber, fresh water, and genetic resources. For forestry, we consider in particular wood and non-wood products (both plant and animal) extracted from natural or managed forested areas. Regulating services include benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, water regulation, erosion regulation, pollination and natural hazard regulation. As for regulating services, above all, deforestation is responsible for a huge amount of carbon emissions. We thus include the role of forests in climate regulation as important carbon storage reservoirs. Cultural services are the nonmaterial benefits that people obtain from the ecosystem through aesthetic experience, reflection, recreation and spiritual enrichment. We refer to recreation and ecotourism and passive use of forests, these two dimensions being better covered by the economic valuation literature.

Table 1: List of forest Ecosystem Services addressed for the monetary estimation

MEA category	Ecosystem Services
Provisioning	Food, fiber, fuel: wood and non wood products
Regulating	Climate regulation: carbon storage
Cultural	Recreation and ecotourism
	Passive use

Source: modified from MEA (2005).

For each service under analysis a thorough retrieval process has been performed in order to collect the largest possible set of available data and information that is relevant to estimating marginal values. The literature retrieval process comprised checking several economic and forest databases (among others EconLit, EVRI, FAO), reference chasing, and approaching key scholars in the field. This resulted in three different set of estimates, one for each service category, described in the following sections. Several of these values, however, do not provide usable estimates. Thus, the marginal values actually employed for the transfer exercise represent a sub-sample of the whole body of the literature. Still they are intended to provide the maximum coverage of the variety of forest biomes that populate forest areas worldwide.

Given that there are thousands of different forest ecosystems worldwide – each of which leading, in principle, to different degrees of biodiversity ecosystem services – it is essential that we can capture such variability in the value transfer process. This is done here by using the estimations of the status of biodiversity, for the main forest biomes and world regions, as provided by the EU-funded COPI[1] project "Cost of Policy Inaction. The case of not meeting the 2010 biodiversity target" (see Braat et al. 2008). The classification of forest biomes and world regions – as proposed by the OECD GLOBIO[2] model framework (Alkemade et al., 2006) employed by COPI – distinguishes 6 main different forest biomes distributed across 10 world regions (see Table 2, Table 3 and Figure 2). COPI provides estimates of the spatial coverage and distribution of each forest biomes for different drivers and pressures scenarios. In particular, we consider the forest biomes distribution for 2000 and 2050 as described by the OECD Baseline Scenario (see Bakkes and Bosh, 2008). Changes over time are mainly driven by land use changes (see Table 3). For forestry, among the others, the role of agricultural land-use change (forest areas converted into farmland) and forest management (natural forests versus managed forest) remain the largest of all the pressure factors. In particular, in the reminder of the paper, the term "natural" refers to relatively untouched forest areas, while "managed" refers to forest areas also partially designated to extensive cultivation, wood production or recreational activities. The marginal values of forest ecosystem services estimated in this paper thus refer as much as possible to these forest varieties (biomes and type of management) and world regions.

As shown in Table 3, forest area is expected to decrease by around 76 million hectares by 2050 worldwide. The highest loss in absolute terms is expected for Russia (47 million hectares), followed by Africa (12 million hectares). As regards forest biomes, boreal forests reveal the highest absolute loss, followed by warm mixed forests. It should be noted that, while natural forests decline, managed forests are expected to increase. For some world regions, the increase in managed forest is higher than the expected decrease in natural areas, which results in a total increase in the forest area by 2050 (e.g. Europe). But of course this change in composition has environmental implications. The percent decrease over the period (based on year 2000) is expected to range from 0.5% for North America and Mexico (NAM) to 27% for Eastern Europe and Central Asia (ECA).

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[1] In COPI, a model framework and a biodiversity indicator were used for assessment of terrestrial biodiversity dynamics which are able to reflect the impacts of the most important direct and indirect drivers: the extent of biomes and ecosystems, trends in abundance and distribution of species, protected areas, nitrogen deposition, climate change and fragmentation. The biodiversity indicator chosen for use in the COPI study is the Mean Species Abundance (MSA), as used in the GLOBIO model, and the IMAGE framework. The numerical values of the MSA in the COPI study represent the biodiversity impacts of the drivers and pressures in the OECD Baseline Scenario.

[2] The GLOBIO 3 model (Alkemade et al., 2006) contains generalised cause-effect relationships between a selection of pressure factors and the mean species abundance (MSA). The pressures considered in GLOBIO 3 include land-cover change (agriculture, forestry, built up area), land-use intensity, atmospheric nitrogen (N) deposition, infrastructure development, fragmentation and climate change. The current version of the GLOBIO model does not capture that biodiversity is typically lost quickly and regained or restored only slowly. Therefore the overall totals generally underestimate the amount of change.

Table 2: World regions

World regions	Description
NAM	North America
EUR	OECD Europe
JPK	OECD Asia (Japan & Korea)
ANZ	OECD Pacific (Australia & New Zealand)
BRA	Brasil
RUS	Russia & Caucasus
SOA	South Asia (and India)
CHN	China Region
OAS	Other Asia
ECA	Eastern Europe & Central Asia
OLC	Other Latin America & Caribbean
AFR	Africa

Table 3: Area change by forest biome and land use type across world regions 2000-2050 (1000 hectare)

Forest biome and land use type	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	**-4,031**	**1,867**	**27**	**-116**	**0**	**-35,674**	**-760**	**212**	**-1**	**-531**	**-723**	**0**	**-39,731**
Natural	-24,301	-6,425	-590	-125	0	-36,080	-1,400	-4,526	-2	-1,238	-836	0	-75,523
Managed	20,270	8,293	618	8	0	406	639	4,738	0	707	112	0	35,791
Tropical	**219**	**0**	**4**	**-24**	**27**	**0**	**-39**	**19**	**-6,288**	**0**	**392**	**-3,282**	**-8,973**
Natural	-10	0	6	-225	-205	0	-654	-236	-16,503	0	-2,905	-13,824	-34,556
Managed	229	0	-1	201	232	0	615	254	10,215	0	3,296	10,542	25,583
Warm mixed	**17**	**282**	**102**	**-1,270**	**459**	**-1**	**-3,730**	**243**	**-705**	**0**	**-4,194**	**-8,187**	**-16,983**
Natural	-13,248	-1,335	207	-1,935	397	-1	-10,089	-7,811	-2,018	0	-4,745	-10,181	-50,760
Managed	13,265	1,617	-105	665	62	0	6,359	8,053	1,313	0	552	1,994	33,777
Temperate mixed	**303**	**1,870**	**1,666**	**-147**	**0**	**-6,252**	**-427**	**12**	**0**	**-5,584**	**-115**	**0**	**-8,674**
Natural	-14,299	-8,620	-864	-167	0	-6,231	-1,008	-759	0	-5,254	-147	0	-37,347
Managed	14,602	10,489	2,530	20	0	-21	580	771	0	-331	32	0	28,673
Cool coniferous	**-1,252**	**-781**	**57**	**0**	**0**	**-4,621**	**-437**	**-5**	**0**	**-216**	**0**	**0**	**-7,254**
Natural	-5,257	-5,288	-981	0	0	-4,627	-869	-1,078	0	-671	0	0	-18,772
Managed	4,005	4,507	1,038	0	0	7	432	1,073	0	455	0	0	11,517
Temperate deciduous	**200**	**5,673**	**1,366**	**-280**	**0**	**-426**	**-613**	**92**	**-25**	**-423**	**-19**	**-146**	**5,400**
Natural	-8,342	-4,056	2,424	-449	0	-422	-4,092	-5,043	-83	-401	-40	-153	-20,657
Managed	8,542	9,729	-1,058	169	0	-4	3,479	5,135	58	-21	21	6	26,057
Total	**-4,545**	**8,912**	**3,224**	**-1,836**	**486**	**-46,974**	**-6,007**	**572**	**-7,019**	**-6,754**	**-4,659**	**-11,616**	**-76,216**
% Δ (2000 base):total	-0.5%	+3.8%	+7%	-3.3%	+0.3%	-4.2%	-17.3%	+0.2%	-3.4%	-26.6%	-1.6%	-7.1%	-2.2%

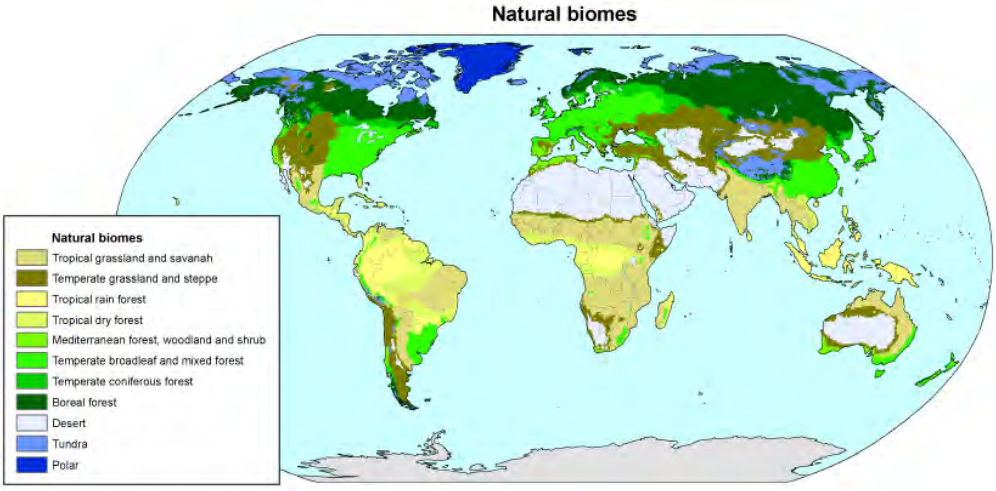

Figure 2: Current geography of the major world biomes, as used in the GLOBIO model framework (source: Braat et al. 2008).

3.2 Valuing forest ecosystem services: from site-specific values to world wide estimates

Several valuation methods can be applied to estimate the monetary value attached to environmental services (ESs) provided by forest biomes. By using the well-known notion of Total Economic Value (TEV), and depending on the nature of the good being valued, we can identify the best available valuation methodology to be employed for the monetary estimation of each ES of concern (see, e.g., Pearce and Moran, 1994). Broadly speaking, depending on the nature of the ecosystem service to be quantified, both market and non-market (revealed and stated preference) valuation techniques have been applied in the literature from which draw suitable marginal values for forest services, to be scaled up at the global level using proper transfer protocols. Given the global perspective of this exercise, it is essential to rely on the full body of knowledge already available in the environmental economics literature in order to gather estimates that cover, for each service to be valued, the highest variability in terms of countries (OECD regions) and forest types (biomes). In this regard, a crucial role is played by the use of research synthesis techniques, such as meta-analysis and value transfer. Thus, for each forest ES, we first performed a meta-analysis whenever possible and, second, applied value transfer protocols to adjust available values to new, unexplored, contexts.

Meta-analyses have been applied to cultural forest ecosystem services, namely recreation and passive use. By means of multivariate meta-regressions, meta-analysis enables us to explain the variance of the available WTPs (Willingness-To-Pay) as a function of few statistically significant explanatory variables. In particular, main explanatory factors for forest recreation and passive use are: i) size of recreational forest sites – and, for passive use, size of forest areas designated to biodiversity conservation – ; and ii) income level in the study area.

As for provisioning and regulating services, the estimation process was based on market data, actual and estimated, respectively. Data on forest products were drawn from the database on forests of the Food and Agriculture Organization (FAO) of the United Nations. Marginal values were estimated with adjustments taking into account: product category or industrial sector; country of origin; forest biome; forest size designated to production; profitability of the forest sector. The estimated prices per ton of carbon sequestered were taken from the EU-funded project CASES "Cost Assessment of Sustainable Energy System", providing price ranges for the baseline year of reference (2007) and few future scenarios (see CASES).

In the following sections we discuss in detail the methodological approach applied for estimating the economic marginal values of each of the four ecosystem services under analysis.

3.3 Provisioning services

Bearing in mind the MEA (i.e. food, fiber, and fuel), we classify the forest provisioning services into two main categories: wood forest products (WFPs) and non-wood forest products (NWFPs). Each of them is further detailed in table 4, according to different industrial sectors in the market, as proposed by the FAO forest database (see FAO/ForestSTAT).

Table 4: The Provisioning Services Provided by Forest Ecosystem

Wood forest products (WFPs)	Non-wood forest products (NWFPs)	
	Plant products	**Animal products**
• Industrial Roundwood • Wood pulp • Recovered paper • Sawnwood • Wood-based panels • Paper and paper board • Wood fuel	• Food • Fodder • Raw material for medicine and aromatic products • Raw material for colorants and dyes • Raw material for utensils, crafts & construction • Ornamental plants • Exudates • Other plant products	• Living animals • Hides, skins and trophies • Wild honey and beeswax • Bush meat • Other edible animal products

Sources: FAOSTAT and FAO/FRA 2005.

The economic value of the provisioning services is a direct use value and is estimated using market valuation methodologies based on quantities and prices available from Food and Agriculture Organization of the United Nations (FAO) database on forests.

The methodological framework to derive the marginal values as presented in Figure 3, involves two main valuation steps. The first calculates total provisioning values for each world region and forest biome. For this purpose, FAO export values at country level by different product categories are adjusted for domestic production quantity and converted into estimates of net income. The second step combines the estimated total values with information about the different forest biomes size, in order to derive the annual marginal values per hectare, by forest biome and world region. For this purpose only the hectares actually designated to production are used (See Braat et. al, 2008 and FAO, 2005). According to this framework, marginal values for forest provisioning services vary in relation to the product category or industrial sector (WFPs and NWFPs), the country of origin, the forest biome, and the forest size designated to production.

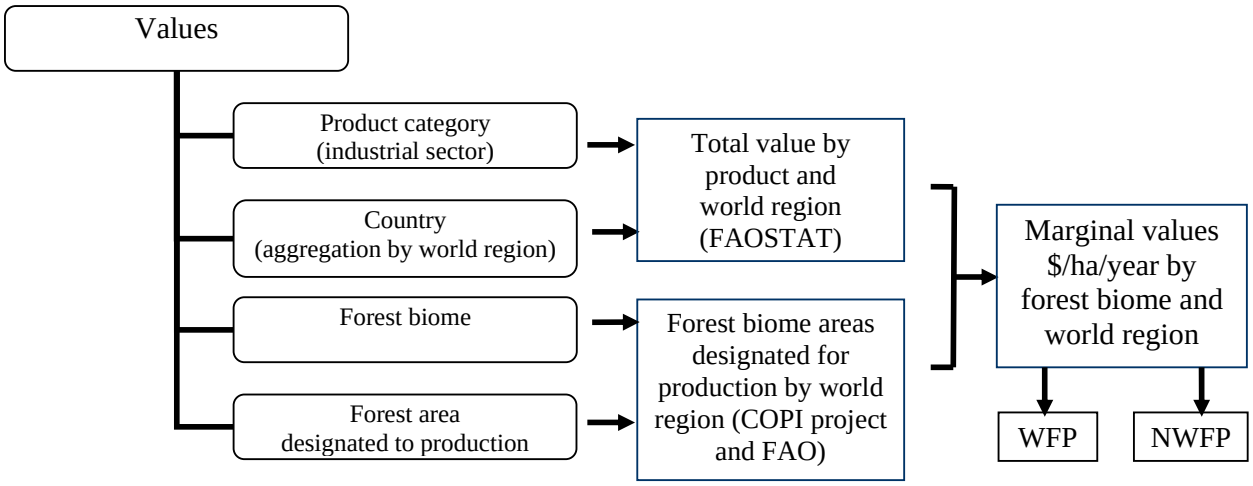

Figure 3: Methodological valuation framework for forest provisioning services

In the first valuation phase, for each forest product, export values at the country level are adjusted for estimating total provisioning values, taking into account domestic production and export quantities (FAOSTAT), as follows:

(1) $$TV_i = EV_i \frac{Pq_i}{Eq_i}$$

Where:
TV_i = annual total forest provisioning value by country i
EV_i = annual export value by country i
Pq_i = annual domestic production quantity by country i (forest products produced within country i)
Eq_i = annual export quantity country i
i = country

Total values are further corrected for the profitability of the forestry sector, taking into account financial returns from the wood forest production. Returns to the forest owner consist of sales of timber and other wood forest products, increases in the value of the lands, less costs of production and any net payments of taxes. The costs are employment and other purchases costs. For the want of anything more detailed and reliable, the net financial return from forestry is here assumed to be the same for all regions and equal to 8.2 percent per annum in the three-year period 2003-2006 (see UK Forestry Statistics, 2007).

The resulting net values are then summed up across sectors and countries to compute the aggregate benefits deriving from forest provisioning services, for each world region and for each industrial sector:

(2) $$NV_{wr} = \sum_{wr=1}^{n} NV_{i \subset wr}$$

Where:
NV_{wr} = annual forest provisioning net value by world region wr, adjusted for profits
NV_i = annual forest provisioning net value by country i, adjusted for profits
wr = world region: 1, 2, …, n
i = country

In the second valuation phase, by assuming a linear relationship between marginal values and forest biome size, annual forest provisioning net values by world region *wr*, $NV_{wr,b}$, are attributed to each forest biome in proportion to their respective forest area (source: COPI project and FAO 2005):

$$V_{wr,b} = \frac{NV_{wr,b}}{Sp_{wr,b}} \tag{3}$$

Where:
$V_{wr,b}$ = annual value per hectare by world region *wr* and forest biome *b*
$NV_{wr,b}$ = annual total provisioning value per world region *wr* by forest biome *b*
$Sp_{wr,b}$ = forest area size designated to production per world region *wr* by forest biome *b*
wr = world region
b = forest biome

Marginal values are computed in US$ 2005, and then converted into € 2007. To project the future trends of real wood price in 2050, we refer to two studies (Clark, 2001; Hoover, and Preston, 2006) that analyze long-term historical data. Clark (2001) offers a theoretical analysis and an empirical examination of wood prices, based on aggregated global wood market data over the last three decades. Hoover and Preston (2006) analyses trends of Indiana (USA) forest products prices using statistical data from 1957 to 2005. Although different in the spatial scale of the analyses, both papers lead to a similar conclusion: there is no evidence of increase in real prices for wood. We therefore assume that real prices of wood products will remain stable in the future, while allowing different prices to exist across countries and continents.

3.4 Regulating services: carbon sequestration

The methodological framework for valuing carbon sequestration is built on two phases. First, we identify the biomass carbon capacity by forest type and world region (measured as ton of C stocked per hectare, tC/ha). Secondly, we compute annual marginal values of carbon stocked per hectare by using some available estimated market values.

Quantities of carbon stored by forest biome and geographical region (measured in tons of carbon, tC) are drawn from studies by Myneni et al. (2001) and Gibbs (2007). Myneni et al. (2001) provides estimates of carbon stocks for temperate and boreal forest in Canada, Northern America, China, Japan, Russia, Finland, Sweden, Eurasia and South Eastern Asia. Gibbs (2007) provides estimates of carbon stocks for tropical and warm mixed forests in Brazilian Amazon, Latin America, Sub-Saham Africa and Tropical Asia (see Table 5). For world regions not directly covered by these studies, values are transferred from similar geographical regions.

Table 5: Biomass carbon capacity in the world forests (tC/ha)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	37.37*	37.37*	37.37**	37.37**	-	37.37*	59.4**	25.77*	59.4**	37.98*	34**	-
Tropical	92**	-	149**	149**	186*	-	225*	96**	92*	-	149*	200*
Warm mixed	92**	92**	100**	134**	168*	92**	180*	78**	78**	-	134*	168**
Temperate mixed	51*	59.4*	47.35*	51**	-	37.98*	168**	25.77*	0	59.4*	59.4**	-
Cool coniferous	37.37**	37.37**	37.37**	-	-	37.37**	59.4**	25.77**	0	37.98**	-	-
Temp. deciduous	51*	59.4*	47.35*	51**	-	37.98*	168**	25.77*	59.4*	59.4*	34.88*	59.4**

Note: (*) Directly reported from the original studies by forest type and geographical region. (**) Transferred from the original studies to similar world regions. Source: R.B. Myneni et al. (2001); H.K. Gibbs (2007).

Carbon stocks vary mainly according to two factors: forest type, tree species having different biomass); and forest area. Following the equation below one can thus estimate annual per hectare values of carbon sequestration:

$$V_{wr,b} = \left(tC / ha_{wr,b}\right) * \$ / ha \tag{4}$$

Where:
$V_{wr,b}$ = annual value per hectare by world region *wr-th* and forest biome *b-th*
$tC/ha_{wr,b}$ = tons of carbon stocked per hectare by world region *wr* and forest biome *b*
$/ha = value per hectare of carbon stocked
wr = world region

Estimated prices per ton of carbon sequestered are taken from the EU-funded project CASES ("Cost Assessment of Sustainable Energy System"), providing price ranges for the baseline year of reference (2007) and for future period scenarios. In particular, lower estimates are based on the Marginal Damage Cost (MDC) approach; while higher estimates are based on the Marginal Avoidance Cost (MAC) approach, assuming the EU target of a 30 percent reduction in 2020 compared to 1990 (for details see CASES). Table 6 reports lower and upper bound monetary values for 2007 and 2050.

Table 6: Monetary values for carbon sequestration (Euro)

Costs [Euro]			
MDC (lower-bound)		MAC (upper-bound)	
Year 2007	Year 2050	Year 2007	Year 2050
6.43	23.11	15.8	179.6

Note: Source http://www.feem-project.net/cases/documents/deliverables/ExternalCosts_per_unit_emission_080313.xls

3.5 Cultural services: recreation and passive use

3.5.1 The economic model

Not being traded in regular markets, recreation and passive use values are usually measured as willingness to pay (WTP) figures using non-market valuation approaches (namely: travel cost method, contingent valuation and choice experiments). According to previous literature reviews on cultural values, a simple expected utility specification can be used to describe how individuals are willing to trade wealth for increases or decreases of forest cultural services, under the assumption that the estimated marginal value of the service decreases with an increase in the size of the forest site, and increases with an increase of the income level of the country where the forest is located (e.g., Hammitt, 2000).

The results of our meta-analyses confirms such expectations both for forest recreation and passive use values: income level and size of forest areas are the main statistically significant factors explaining variation in WTP estimates for changes in forest cultural services (see Tables 13 and 17). The meta-regression function can therefore be written as:

$$V = f\left(S, I\right) \tag{5}$$

Where:
V is the marginal value (willingness to pay, WTP) of a given forest site designated to recreation or conservation of biodiversity (*effect size*).
S is the size of the forest area designated to recreation or conservation [hectares]
I is the income level [measure as PPPGDP]

By running the regression function expressed by equation (5):

(6) $$\log V = \alpha + \beta \log S + \gamma \log I$$

we can therefore obtain an estimate of the marginal effect − on the recreational or passive use value of a given site, V − of: i) the size of the forest site designated to recreation (or conservation), represented by β, and ii) of the income level of the country where the site is located, represented by γ. These coefficients are used for the geographical as well as the inter-temporal value-transfer.

For recreation and passive use services the following operational steps have been applied: (i) creation of a database of all available WTP estimates selected from a worldwide literature review; (ii) estimation of a meta-regression function based on suitable WTP values; and (iii) application of value transfer procedures for spatial and inter-temporal transfer. Firstly, the literature retrieval process has lead to a selection of suitable case studies providing WTP estimations of recreational and passive use values in different unit of measure[3]. Secondly, after conversion of all values in WTP per hectare[4], and following Equations (5-6), the usable WTP estimates have been employed to estimate - for recreational and passive use separately - the income level and forest site's size coefficients (see Tables 13 and 17). Lastly, marginal values have been transferred in space and time following a two-step approach. The following sections illustrate the transfer strategies used for the each of the two cultural services: recreation and passive use.

3.5.2 Value transfer for recreational forest use

Building on the results of the meta-analysis for the recreational values, we can apply a simple value transfer exercise to measure the total annual value of a forest recreational site (the 'policy site') not yet estimated by previously performed original case-studies (the 'study sites'). In doing this, we focus on one single exemplar country, the UK, for which we have a representative and high quality picture of forest recreational sites and their monetary values, and estimate a recreational value for all the existing forest sites in it[5]. For the sake of this exercise, the study-site is the one addressed by Scarpa, et al. (2000); β is the meta-regression size coefficient; H denotes the size of the forest recreational site; and V denotes the marginal (per hectare) value of the site. Results of the meta-regression are provided in section 4.3.

The marginal value of the n-th recreation policy site in the UK, V_n, can thus be estimated with a transfer based on the study-site value, V_s, as:

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[3] Part of the literature review and computations of standardized marginal values per hectare per year in US$2000 has been conducted within Ojea, E., Nunes, P.A.L.D. and M.L.G. Loureiro (2008) "Impacts of Climate Change and Biodiversity Effects: Evidence from a Worldwide Meta-analysis on Forest Ecosystem Values", Mimeo, Fondazione ENI Enrico Mattei, Venice, Italy. Further details are available upon request to the authors.

[4] All the estimates are computed in US$2000 (standardized WTP estimates per hectare per year) and then converted into €2007.

[5] The literature is rich of many studies on the value of forest recreation for UK. In addition, UK has a rich and completed database on protected forest areas, the so called Special Areas of Conservation (SACs). By definition, SACs are strictly protected sites designated under the European Habitats Directive. For the sake of the present study, only the forest related SACs are considered for recreational use. The reasons for this choice are related to the availability of detailed data on recreational forest size and to the notion of accessibility of the site. This latter is a crucial feature in the valuation process, because the use of recreational services and the associated economic value depends strongly on the accessibility of the area. The values for recreational use are higher in accessible systems while they drop significantly in degraded systems.

(7) $$V_n = V_s (H_n / H_s)^{\beta}$$

where *n* denotes the policy sites (with *n* =1,2,.., *N*); and *s* denotes the study site.

From Equation (7) we are now able to derive the marginal annual value of an average recreational forest site in UK, V_{UK}, as:

(8) $$V_{UK} = \sum_{n=1}^{N} V_n \Big/ \sum_{n=1}^{N} H_n$$

V_{UK} can then be transferred to all the other *i-th* geographical regions in the world, by correcting for income differences and population density as illustrated by Equation (9).

(9) $$V_i = V_{uk} \left(\frac{N_i}{N_{uk}} \right) \left(\frac{Sr_{uk}}{Sr_i} \right)^{\beta} \left(\frac{PPPGDP_i}{PPPGDP_{uk}} \right)^{\gamma}$$

Where:
V_i = estimated annual value per hectare for country *i-th*
V_{UK} = estimated annual value per hectare for UK
Sr_i = forest area designated to recreation in country *i-th*
S_{UK} = forest area designated to recreation in UK
N_i = number of households in country *i-th*
N_{UK}= number of households in UK
$PPPGDP_i$ = GDP adjusted for PPP (purchasing power parity) in country *i-th*
$PPPGDP_{UK}$ = GDP adjusted for PPP (purchasing power parity) in UK
i = country
γ = income coefficient
β = size coefficient

Information about forest areas designated to recreational activities by country is drawn from FAO/FRA 2005. Marginal values are computed in €2000, and then converted into €2007. Lastly, values are projected from 2007 to 2050 using projections on population, *PPPGDP*[6] and forest area in different biomes and land cover types (from COPI project), according to the following computation for inter-temporal transfer:

(10) $$V_{i,T_1} = V_{i,T_0} \left(\frac{H_{i,T_1}}{H_{i,T_0}} \right) \left(\frac{S_{i,T_0}}{S_{i,T_1}} \right)^{\beta} \left(\frac{PPPGDP_{i,T_1}}{PPPGDP_{i,T_0}} \right)^{\gamma}$$

Where:
T_1 = year 2050

[6] Population and GDP per capita in PPP are computed in year 2000 and projected in year 2050, according to the figures used in the COPI project (see Braat et al. 2008). As for population, the UN projections based on a "medium" scenario are used, showing a stabilization of the world population at around 9.1 billion inhabitants by 2050 (UN, 2005). Almost all of this increase is expected in the developing world. As for GDP, the baseline scenario in the COPI project expects a positive and uniform growth in real GDP of 2.8% per year between 2005 and 2050.

T_0 = baseline year (2000 for population, *PPPGDP* and forest size; 2007 for monetary values)

3.5.3 Value transfer for forest passive use

As for passive use, the transfer procedure is based on somewhat different methodological assumptions. Due to lack of information on protected forest sites for different types of forest, the approach developed for recreation cannot be used for passive use values, which are strongly influenced by the type of forest ecosystem. After screening the available literature, we select few high-quality valuation studies providing marginal values (at country level) associated with specific forest typologies (see Table 7). When several representative case studies are available, the mean marginal value is used.

Table 7: Original studies selected for the first step value-transfer

OECD world Region	Original case study	Reference study	Forest type
EUR	UK	Garrod, G.D. and Willis, K. G. (1997) Hanley, N., Willis, K, Powe, N, Anderson, M. (2002) ERM Report to UK Forestry Commission (1996)	Temperate
EUR	Finland	Kniivila, M., Ovaskainen, V. and Saastamoinen, O. (2002) Siikamaki, Juha (2007)	Boreal
EUR	Spain	Mogas, J., Riera, P. and Bennett, J. (2006)	Warm mixed
NAM	USA	Phillips, S., Silverman, R. (2007) Loomis and Ekstrand (1998) Walsh, R.G., J. B. Loomis and R. A. Gillman (1984)	Temperate
BRA	Brazil	Horton, B., Colarullo, G., Bateman, I., Peres, C. (2003)	Tropical
CHN	China	Kontoleon, A. and Swanson, T. (2003)	Temperate
AFR	Madagascar	Kramer, R.A., Sharma, N., and Munashinghe, M. (1995)	Tropical

Estimates for forest types from original case studies are then scaled up to the corresponding higher geographical region and forest biome, by taking into account the effect of the size of the forest area under valuation, β:

(11) $$V_{wr,b} = V_{i,b}\left(\frac{Sc_{i,b}}{Sc_{wr,b}}\right)^{\beta}$$

Where:
$V_{wr,b}$ = estimated annual value per hectare by world region *wr* and forest biome *b*
$V_{i,b}$ = annual value per hectare for country *i-th* by forest biome *b-th* (from representative case studies for different forest biomes)
$Sc_{i,b}$ = forest area designated to conservation in country *i-th* by forest biome *b-th*
$Sc_{wr,b}$ = forest area designated to conservation in the world region *wr-th* by forest biome *b-th*
i = country
wr = world region
b = forest biome

Lastly, similarly to what done for recreation values, we transfer forest biome values to world regions not yet covered, by correcting for income and population effects, as illustrated in Equation (12):

$$V_{WR,b} = V^{*}{}_{wr,b}\left(\frac{N_{WR}}{N_{wr}}\right)\left(\frac{S_{wr,b}}{S_{WR,b}}\right)^{\beta}\left(\frac{PPPGDP_{WR}}{PPPGDP_{wr}}\right)^{\gamma} \tag{12}$$

Where:
$V_{WR,b}$ = estimated annual value per hectare by region *WR* and forest biome *b*
$V^{*}_{wr,b}$ = annual value per hectare by region *wr-th* and forest biome *b-th* (first step estimation)
$Sc_{wr,b}$ = forest area designated to conservation in region *wr-th* by forest biome *b-th*
Sc_{WRb} = forest area designated to conservation in region *WR* by forest biome *b-th*
N_{WR} = number of households in region *WR*
N_{wr} = number of households in region *wr-th*
$PPPGDP_{WR}$ = GDP adjusted for PPP (purchasing power parity) in region *WR*
$PPPGDP_{wr}$ = GDP adjusted for PPP (purchasing power parity) in region *wr-th*
$w_{r,b}$ = world region (first step valuation)
$W_{R,b}$ = world region (to be estimated)
b = forest biome

Data on forest areas designated to biodiversity conservation by country are taken from FAO/FRA2005. Marginal values are computed in €2000, and then converted into €2007. Finally, values are projected from 2007 to 2050, by using projected population, *PPPGDP* and forest area in different biomes and landuse types, following using Equation (9).

3.6 Estimation of total economic value changes

The estimated marginal values for 2007 and 2050 are combined with information about forest size (by world region, forest biome and land use type), in order to compute the value of total economic changes for the four ecosystem services in the two time frames. The difference between the two values represents the cost or benefit associated with biodiversity loss in year 2050. For this purpose we use the estimated forest size, calculated within the COPI project in the baseline year 2000 and projected figures for 2050. For provisioning services, we use only the forest areas actually designated to production (within the managed forest)[7]. Carbon sequestration is instead expected to occur in both natural and managed forests, so all the forest areas are considered to compute total economic values. As for cultural services, we use the forest area designated to recreation (which might occur in both natural and managed forest) or conservation of biodiversity (in natural forest). This information is available from FAO for the year 2005 (see FAO/FRA 2005). For projections in 2050, we assume no variation over time in the percentage of forest area designated to recreation or conservation. This approach allows us to estimate total economic changes in the value of forest biodiversity services according to three main dimensions: ecosystem service, forest biome and geographical region.

In order to calculate the cost or benefit associated with potential loss of biodiversity, the projected total values in year 2050 are discounted using the conventional 3 percent discount rate (used by the European Commission), and then compared to the total values estimated for the baseline year 2007.

[7] No provisioning service exists, by definition, in a natural ecosystem.

4 Results

Results are presented for each ecosystem service, by forest biome and world region, in terms of marginal values in year 2007, projected marginal values in year 2050, and total economic losses in year 2050.

4.1 Provisioning services

Table 8Table 8 reports the marginal values of provisioning services, estimated by world region and forest biome, adjusted for profitability, and converted in €2007. Differences in marginal values across world regions and forest biomes can be interpreted as the combined result of: i) total production values by forest product and distribution of wood and non-wood sectors across forest biomes and world regions, ii) distribution of forest area across world regions, and iii) incidence of forest area designated to production in each world region. Wood forest products represent the most relevant part of the economic value.

The reasons for some high marginal values (in AFR, ANZ, JPK and CHN) can be explained as follows. For AFR this is due to the high production value of wood fuel, while for CHN this is explained by the high production value of two sectors, paper and paperboards, and wood fuel. Finally, for ANZ and JPK, the effect is attributable to the small forest area designated to production.

Table 8: Marginal value of provisioning services by world region and forest biome, adjusted for profits (2007€/ha/year)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	740	246	770	1,765	-	96	874	1,134	1,375	147	619	-
Tropical	10	-	2.4	126	368	-	59	17	916	-	300	1,886
Warm mixed	177	14	51	827	98	0.1	550	469	72	-	138	402
Temperate mixed	304	99	943	67	-	73	56	55	-	159	6	-
Cool coniferous	158	107	1,490	-	-	13	372	217	-	91	-	-
Temp. deciduous	155	142	631	252	-	4.9	231	431	1.9	12	1.8	15

Total economic value changes due to biodiversity loss in 2050 are presented in Figures 4-5. Results show large economic losses for provisioning services in all the world regions and forest biomes. This is the result to the combined effect of marginal price estimates and incidence of forest area designated to production. Total costs are expected be around €48 billion worldwide. They range from €374 million for ECA to €17 billion for NAM (Figure 4), which is expected to face the highest costs (more than one third of total costs worldwide). After NAM, the highest costs are foreseen for OAS, CHN and EU, accounting for respectively 14 to 11 percent of total costs. As shown in the Annex (Table A1), the economic value for provisioning services in 2050 is expected to decrease by about 49% globally with respect to the baseline year 2007, ranging from -22% in AFR to -72% in RUS. As regards the forest biomes, the highest loss is expected in boreal and tropical biomes, the former and the latter accounting for 38 (mainly in NAM) and 26 (mainly in OAS) percent of the total global loss respectively (Figure 5 and Table A1 in Annex).

Figure 4: Total economic value changes for provisioning services by world region, in 2050 (Million Euro 2007, r=3%)

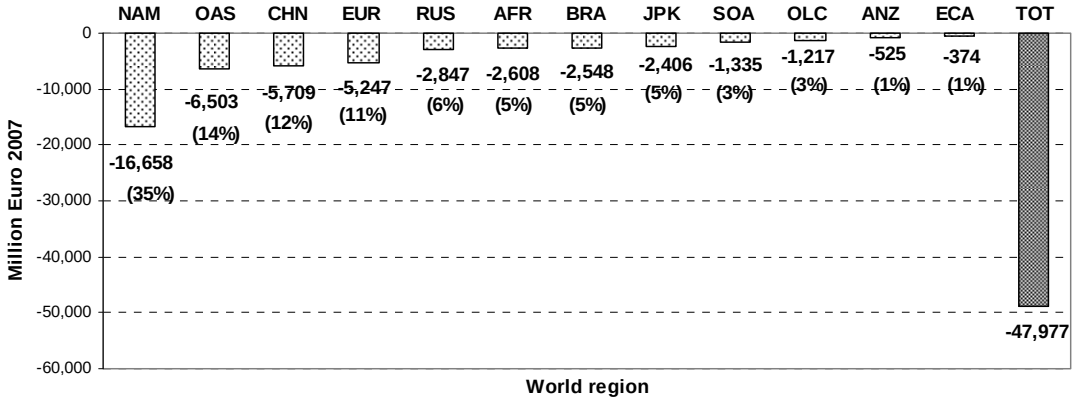
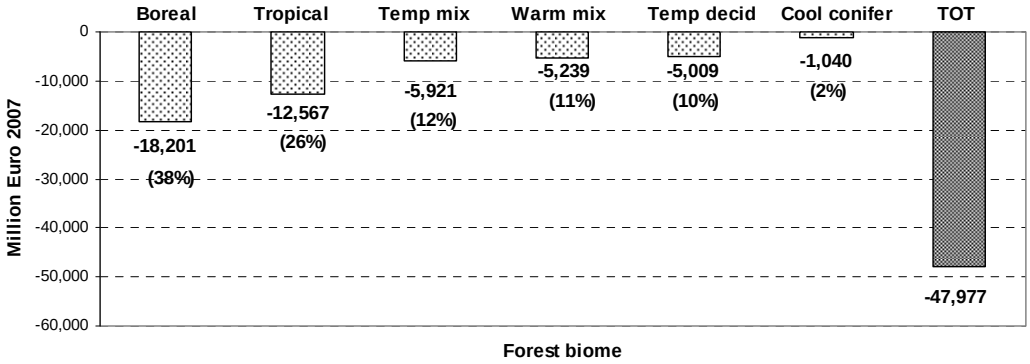


Figure 5: Total economic value changes for provisioning services by forest biome, in 2050 (Million Euro 2007, r=3%)



4.2 Regulating services: carbon sequestration

Tables 10-11 show the most conservative estimates for carbon sequestration in terms of annual per hectare values in €2007 and €2050. As expected, given the high capacity of carbon sequestration estimated in tropical and warm mixed forest biomes, the highest marginal values are estimated for BRA, SOA and AFR.

Table 10: Marginal value of carbon sequestration by world region and forest biome (2007€/ha/year) - Lower bound estimates

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	240	240	240	240	-	240	382	166	382	244	219	-
Tropical	592	-	958	958	1,196	0	1,447	617	592	-	958	1,286
Warm mixed	592	592	643	862	1,080	592	1,157	502	502	-	862	1,080
Temperate mixed	328	382	304	328	-	244	1,080	166	-	382	382	-
Cool coniferous	240	240	240	-	-	240	382	166	-	244	-	-
Temp. deciduous	328	382	304	328	-	244	1,080	166	382	382	224	382

Table 11: Marginal value of carbon sequestration by world region and forest biome, projections in 2050 (2050€/ha/year) - Lower bound estimates

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	864	864	864	864	-	864	1,373	596	1,373	878	786	-
Tropical	2,126	-	3,443	3,443	4,298	0	5,200	2,219	2,126	-	3,443	4,622
Warm mixed	2,126	2,126	2,311	3,097	3,882	2,126	4,160	1,803	1,803	-	3,097	3,882
Temperate mixed	1,179	1,373	1,094	1,179	-	878	3,882	596	-	1,373	1,373	-
Cool coniferous	864	864	864	-	-	864	1,373	596	-	878	-	-
Temp. deciduous	1,179	1,373	1,094	1,179	-	878	3,882	596	1,373	1,373	806	1,373

Figures 6-7 present final computations of total economic value changes for year 2050. Total losses are expected to be around €25 billion worldwide. Some regions (mainly located in the developed world) show a benefit, which is explained by an increase in total forest size in those regions. This is specifically due to the fact that the expected increase in total managed forest is higher than the corresponding decrease in natural forests in those regions.

Figure 6: Total economic value changes for carbon sequestration by world region, in 2050 (Million Euro 2007, r=3%)

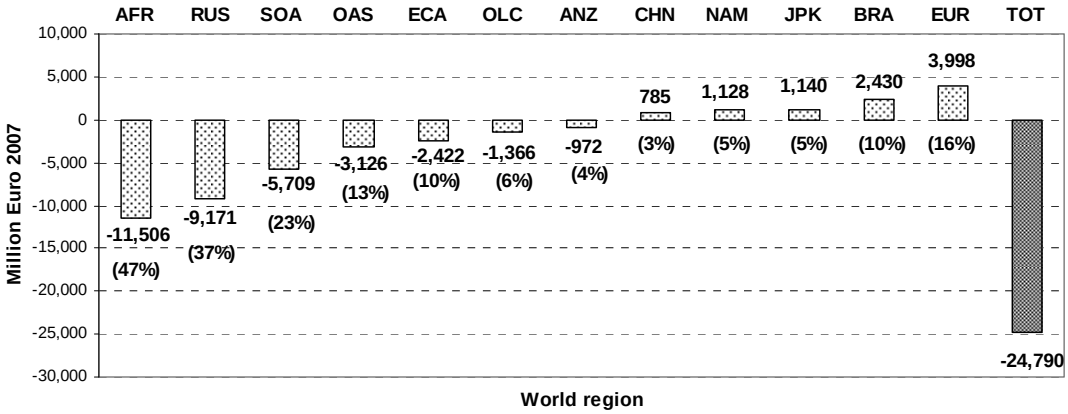
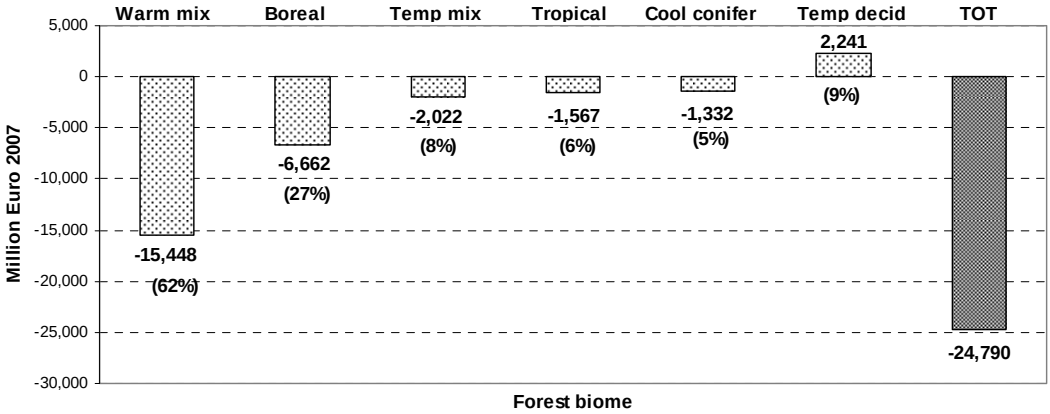


Figure 7: Total economic value changes for carbon sequestration by forest biome, in 2050 (Million Euro 2007, r=3%)



Most of the regions in the developing world, instead, report a loss, ranging from €1.3 billion for OLC to €12 billion for AFR, which accounts for almost 50% of the total loss worldwide. RUS and SOA follow with respectively 37 and 23 percent of total loss (Figure 6). The total economic value for carbon sequestration in 2050 shows a decrease by about 2% worldwide on average (Table A2 Annex) relative to the baseline year 2007. The highest relative loss is expected in ECA with a 27% decrease in value and in SOA with a 16% decrease relative to year 2007. Warm mixed (mainly AFR, SOA and OLC) and boreal forest biomes (mainly RUS) show the highest damage (Figure 7 and Table A2 Annex), while temperate deciduous forests report a benefit, which is explained by the projected increase in managed forest area in that biome.

4.3 Cultural services: recreational and passive use

Below, results for forest recreational use and passive use are reported and discussed separately. In the next sections we present the results of the meta-regression functions, marginal values for the baseline year 2007, projected values in year 2050, and finally total economic losses in 2050.

4.2.1 Recreational use

The results of the meta-regression for recreational forest sites are reported in Table 13. Overall, by using multiple sampling, 59 observations were used in the meta-regression. The β coefficient on forest recreation size (logSIZE) is negative and significant, showing that the marginal value of recreation decreases with a marginal increase in forest area. The γ income coefficient (logINCOME) is positive and significant, showing that the estimated marginal value of recreation increases with a marginal increase in income.

Table 13: Results of the meta-regression function for forest recreational values

Dependent variable: LogWTP	Coefficient (std.error)	T-value
Explanatory factors:		
constant	3.274 (3.698)	0.89
LogSIZE	-0.445 (0.073)	-6.14
LogINCOME	0.599 (0.352)	1.70
Nobs	59	
R^2	0.452	
Adj R^2	0.433	

Tables 14-15 report the results for annual marginal values of forest recreational services by world region and forest biome, in €2007 and €2050. As forest type changes, marginal values remain stable as we assume that this variable does not affect the recreational use of forest, in accordance with the original studies used for valuation where WTP is estimated regardless of the type of forest.

Overall, recreation marginal values appear to be rather small, ranging from 0.11 to 4.74 €2007. This result is mainly driven by the large forest area dedicated to recreational use, which leads to a low value per hectare. Highest values are estimated for CHN and JPK. As regards CHN, this is due to a population effect (i.e. high number of households). As for JPK, the high value signals an income effect. As for OAS, the marginal value is mainly influenced by the value estimated for Singapore, characterized by high income level and very small forest size. Finally, for SOA, the high value can be explained as a result of the small forest recreational size registered in Bangladesh and Pakistan; while the low marginal values in NAM are due to large forest recreational areas.

Table 14: Marginal value (WTP estimates) of recreational forest services by world region and forest biome (2007€/ha/year)

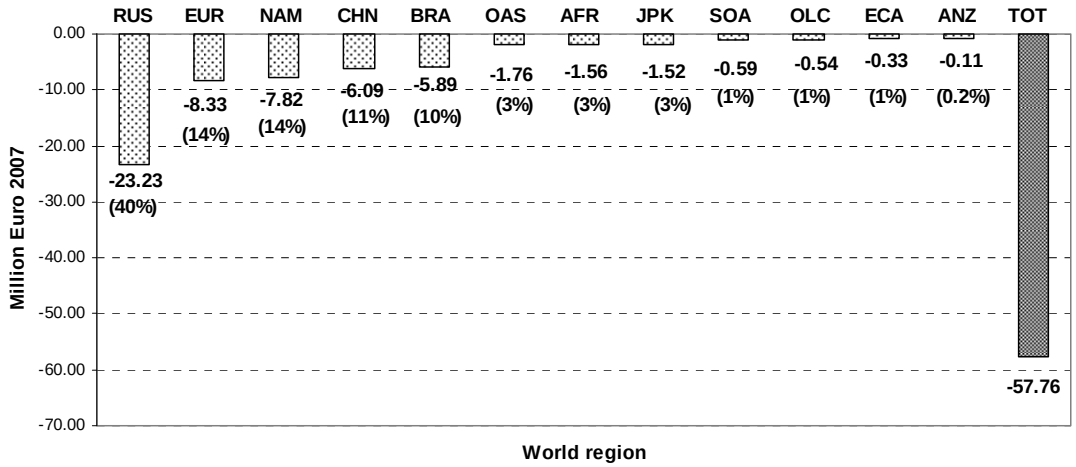
Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	0.46	1.33	3.28	0.11	-	0.28	2.50	4.74	2.28	0.20	0.30	-
Tropical	0.46	-	3.28	0.11	0.32	-	2.50	4.74	2.28	-	0.30	0.57
Warm mixed	0.46	1.33	3.28	0.11	0.32	0.28	2.50	4.74	2.28	-	0.30	0.57
Temperate mixed	0.46	1.33	3.28	0.11	-	0.28	2.50	4.74	-	0.20	0.30	-
Cool coniferous	0.46	1.33	3.28	-	-	0.28	2.50	4.74	-	0.20	-	-
Temperate deciduous	0.46	1.33	3.28	0.11	-	0.28	2.50	4.74	2.28	0.20	0.30	0.57

Table 15: Marginal value (WTP estimates) of recreational forest services by world region and forest biome, projections in 2050 (2050€/ha/year)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	0.94	2.74	6.75	0.22	-	0.58	5.15	9.76	4.70	0.41	0.62	-
Tropical	0.94	-	6.75	0.22	0.66	-	5.15	9.76	4.70	-	0.62	1.17
Warm mixed	0.94	2.74	6.75	0.22	0.66	0.58	5.15	9.76	4.70	-	0.62	1.17
Temperate mixed	0.94	2.74	6.75	0.22	-	0.58	5.15	9.76	-	0.41	0.62	-
Cool coniferous	0.94	2.74	6.75	-	-	0.58	5.15	9.76	-	0.41	-	-
Temperate deciduous	0.94	2.74	6.75	0.22	-	0.58	5.15	9.76	4.70	0.41	0.62	1.17

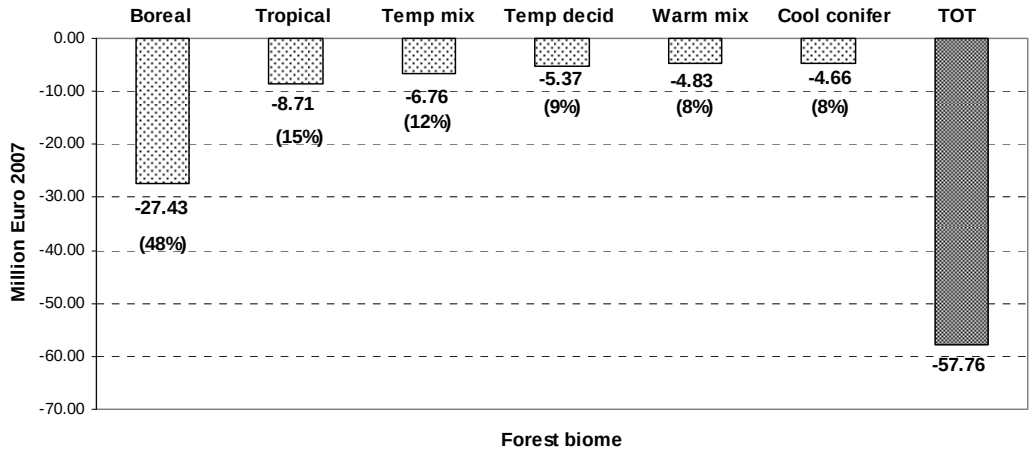
The estimated marginal values are applied to derive total values attributable to forest areas designated to recreation and the expected economic loss in year 2050, as reported in Figure 8 and 9.

Figure 8: Total economic value changes for recreational services by world region, in 2050 (Million Euro 2007, r=3%)



Results show an economic loss for all the regions and all the forest biomes, although rather low if compared with the figures estimated for provisioning and carbon sequestration. Total costs are expected to amount to €58 million in 2050, ranging from €0.11 million for ANZ to €23 million to RUS, which accounts for 40% of the total loss of recreation services. EUR, NAM, CHN and BRA account for 14% to 10% of total losses (Figure 8). Inter-temporal comparison between year 2050 and year 2007 shows a decrease in recreational values of about 47% globally, ranging from -42% in JPK and BRA to -83% in SOA (Table A3 Annex). As regards the forest biomes, the highest costs are registered in the boreal forests (mainly in RUS), followed by tropical (mainly in BRA) and temperate mixed forests (mainly in EUR) (Figure 9 and Table A3 Annex).

Figure 9: Total economic value changes for recreational services by forest biome, in 2050 (Million Euro 2007, r=3%)



4.2.2 Passive use

The results of the meta-regression for forest passive use are reported in Table 17. A total number of 23 observations are used for the regression. The β size coefficient (LogSIZE) on conservation forest area is negative and significant. The γ coefficient on income (logINCOME) is instead positive and significant, showing a negative correlation of marginal values and income. If compared with the results obtained for recreational activities, these coefficients are higher, showing a higher sensitivity of forest size and income on marginal values.

Table 17: Results of the meta-regression function for forest passive use values

Dependent variable: LogWTP	Coefficient (std.error)	T-value
Explanatory factors:		
constant	3. 972 (2.835)	1.40
LogSIZE	-0.603 (0.079)	-7.58
LogINCOME	0.889 (0.255)	3.49
Nobs	23	
R^2	0.797	
Adj R^2	0.797	

Table 18 presents the results from the first step value-transfer, estimating the marginal values from the original case study based on a country level to the corresponding world region.

Table 18: Value transfer results of passive use values from country level to the corresponding world region ($2000).

Forest type	Original case study country	COPI region	Designated forest area for conservation in the studied country (ha)	Designated forest area for conservation in EU (ha) (FAO/FRA 2005)	Value transfer of marginal value by forest type for Europe (2000$/ha)
Temperate	UK	EUR	42,988	12,602,559	119
Boreal	Finland	EUR	267,455	7,022,622	99
Warm mixed	Spain	EUR	274,235	1,745,662	254
Temperate	USA	NAM	11,524,983	21,912,059	501
Tropical	Brazil	BRA	16,350,329	16,350,329	53
Temperate	China	CHN	210,908	449,327	203
Tropical	Madagascar	AFR	4,143,307	33,898,452	10

Tables 19-20 show final results about annual marginal values for forest passive use services by world region and forest biome, in €2007 and €2050. These estimated marginal values are applied to derive total values of passive use applicable to forest areas designated to natural conservation. Outlier values, such as the one for tropical biomes in Japan are due to very small forest sizes.

Table 19: Marginal value (WTP estimates) of passive use by world region and forest biome (2007€/ha/year)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	22**	99*	855**	11**	-	2**	87**	113**	471**	14**	17**	-
Tropical	947**	-	7,404**	62**	53*	-	171**	847**	59**	-	30**	10*
Warm mixed	60**	254*	1,102**	3**	17**	243**	42**	108**	39**	-	7**	26**
Temperate mixed	501*	119*	293**	153**	-	8**	29**	203*	-	6**	8**	-
Cool coniferous	34**	99*	350**	-	-	3**	88**	185**	-	12**	-	-
Temperate deciduous	501*	119*	145**	46**	-	16**	42**	203*	207**	12**	57**	113**

Note: Some of the marginal values displayed have been estimated in the first step value-transfer, for which representative original studies exist (*), while the others (**) have been estimated by transferring these latter to the other world regions taking into account the forest type.

Table 20: Marginal value (WTP estimates) of passive use by world region and forest biome, projections in 2050 (2050€/ha/year)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR
Boreal	59	212	1,482	30	-	7	579	678	2,107	61	53	-
Tropical	2,511	-	12,837	164	142	-	1,146	5,095	262	-	96	62
Warm mixed	159	546	1,910	8	46	1,028	279	648	175	-	22	160
Temperate mixed	1,328	256	508	404	-	35	193	1,221	-	28	25	-
Cool coniferous	90	212	607	-	-	13	589	1,113	-	50	-	-
Temperate deciduous	1,328	256	252	122	-	69	281	1,221	925	50	182	692

Figures 10-11 show an economic loss for all the regions and all the forest biomes in year 2050, except for CHN and AFR. Total loss is estimated around €6 billion. The highest costs are expected in developed countries. NAM accounts for 62 percent of global damage (€3.6 billion), followed by EUR with 15 percent of total loss (€900 Million) (Figure 10). Total economic value associated with passive use of forests in 2050 is projected to decrease by about 34% worldwide with respect to the baseline year 2007 (ranging from -1% in RUS to -67% in JPK) (Table A4 Annex). As regards the forest biomes, the highest costs are registered in temperate mixed and temperate deciduous forests (NAM and EUR being the main responsible), followed by tropical forest (AFR, OAS and BRA) (Figure 11 and Table A4 Annex).

Figure 10: Total economic value changes for passive use by world region, in 2050 (Million Euro 2007, r=3%)

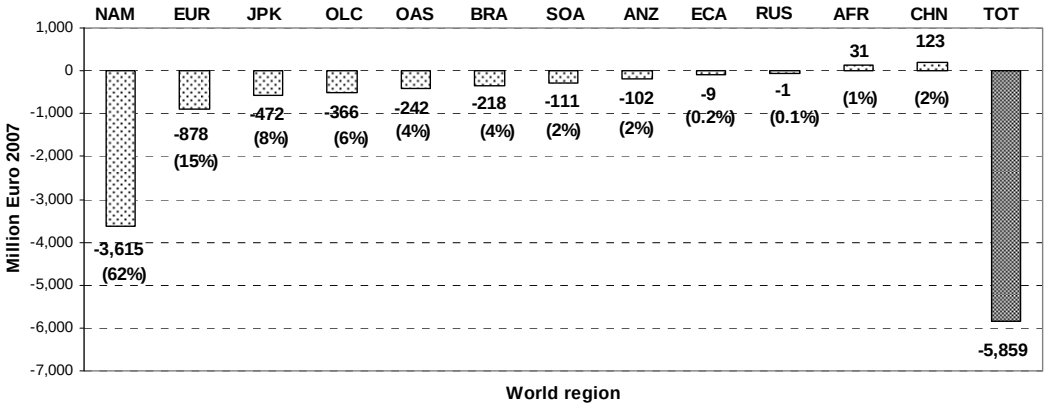
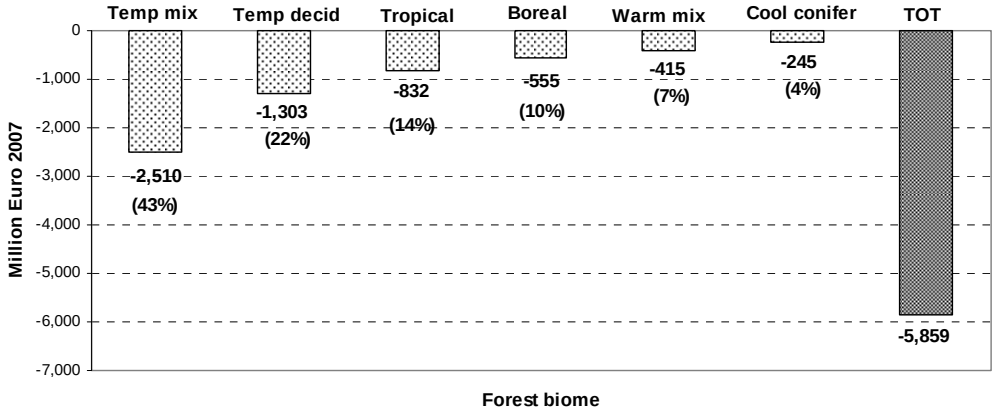


Figure 11: Total economic value changes for passive use by forest biome, in 2050 (Million Euro 2007, r=3%)



4.3 Total biodiversity loss

Table 22 gives the estimated 'total' biodiversity loss in one year (2050) resulting from business as usual in the way forests are managed and exploited. We put total in inverted commas because not all values are included: we could not value for example, supporting services (primary production like gas, oil, sand, shelves, etc, nutrient cycling and soil formation), some regulating services (air quality maintenance, soil quality, water and temperature regulation, natural hazard control), and some provisioning services (pharmaceutics, ornamental resources and fresh water), due to the difficulties in finding reliable data for value estimates. As the figures show, however, the quantified losses are significant. The total figure is around €79 billion, the greatest losses coming from NAM, followed by AFR, RUS and OAS. It should be noted that the high economic loss expected in NAM is attributable to a small reduction in the forest area, estimated around 0.5% (see Table 3). Other regions, like ECA, instead, show a small economic loss against a large reduction in forest area (around 27%, Table 3). Most of the global loss is attributable to provisioning services (€48 billion) and carbon sequestration (€25 billion), while only a minor part is due to loss of cultural services (€6 billion) (Figure 12).–In terms of biomes the greatest losses are from boreal forests followed by warm mixed and tropical forests (Figure 13). These results may be surprising to some who argue that it is the loss of tropical forests, particularly the Amazon that is the most significant. A detailed analysis shows, however, that this is not the case. The best estimates point to greater losses in areas where use and non-use values are highest, which includes North America.

Finally Figures 13-14 show the share of total loss among the three ecosystem services (provisioning, carbon and cultural services) according to geographical regions and forest biome. Most of the economic loss due to carbon sequestration is expected in developing countries (mainly AFR and RUS), in boreal and warm mixed forests. As for cultural services, the highest loss is expected instead in developed countries (mainly NAM), in temperate mixed and temperate deciduous forests. Finally for provisioning services, NAM is expected to face most of the loss, followed by OAS, CHN and EUR, mainly in boreal and tropical forests.

Figure 12: Total economic loss by ecosystem service, worldwide projections 2050 (Million Euro 2007, r=3%)

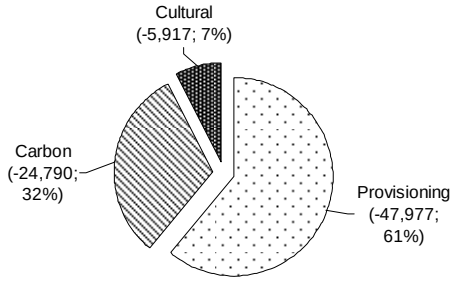


Figure 13: Total economic loss by forest biome, worlwide projections 2050 (Million Euro 2007, r=3%)

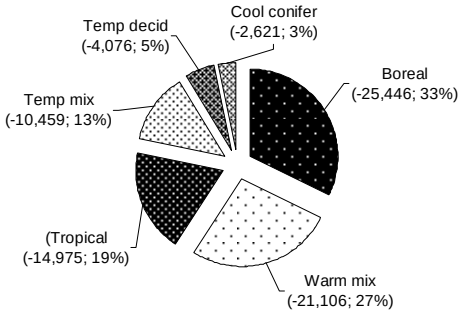


Table 22: Total economic value changes for ecosystem services by world region and forest biome, in 2050 (Million € 2007, r=3%)

Forest Biomes	NAM	AFR	RUS	OAS	SOA	CHN	OLC	ECA	EUR	JPK	ANZ	BRA	Total
Boreal	-11,054	0	-9,402	8	-438	-2,365	-220	-99	-1,883	36	-30	0	-25,446 (32%)
Tropical	53	-9,217	0	-9,494	-57	26	-1,035	0	0	-7	-17	-946	-14,975 (19%)
Warm mixed	-1,406	-9,417	0	-372	-5,147	-1,397	-3,628	0	113	32	-1,346	604	-21,106 (27%)
Temperate mixed	-4,450	0	-1,589	0	-465	-1	-38	-2,502	-416	-929	-76	0	-10,459 (13%)
Cool coniferous	-666	0	-952	0	-219	-88	0	-42	-839	185	0	0	-2,621 (3%)
Temp. deciduous	-1,630	-57	-99	-13	-831	-982	-6	-162	890	-1,057	-130	0	-4,076 (5%)
Total	-19,152 (24%)	-18,691 (18%)	-12,042 (15%)	-9,872 (13%)	-7,156 (9%)	-4,807 (6%)	-4,927 (4%)	-2,805 (4%)	-2,135 (3%)	-1,740 (2%)	-1,599 (2%)	-342 (0.4%)	-78,684

Figure 14: Total economic value changes by world region and ecosystem service, in 2050 (Million Euro 2007, r=3%)

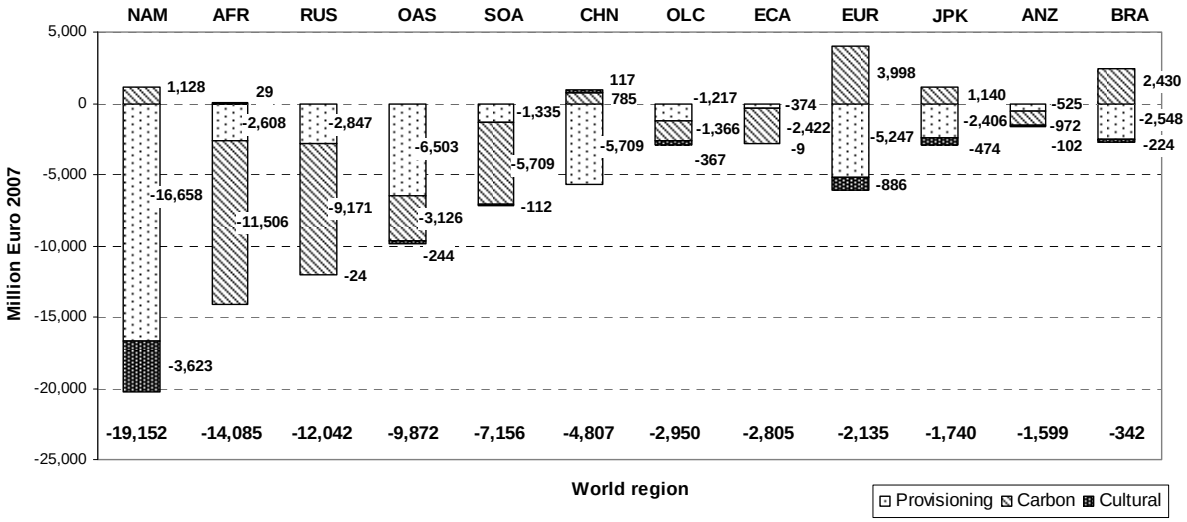
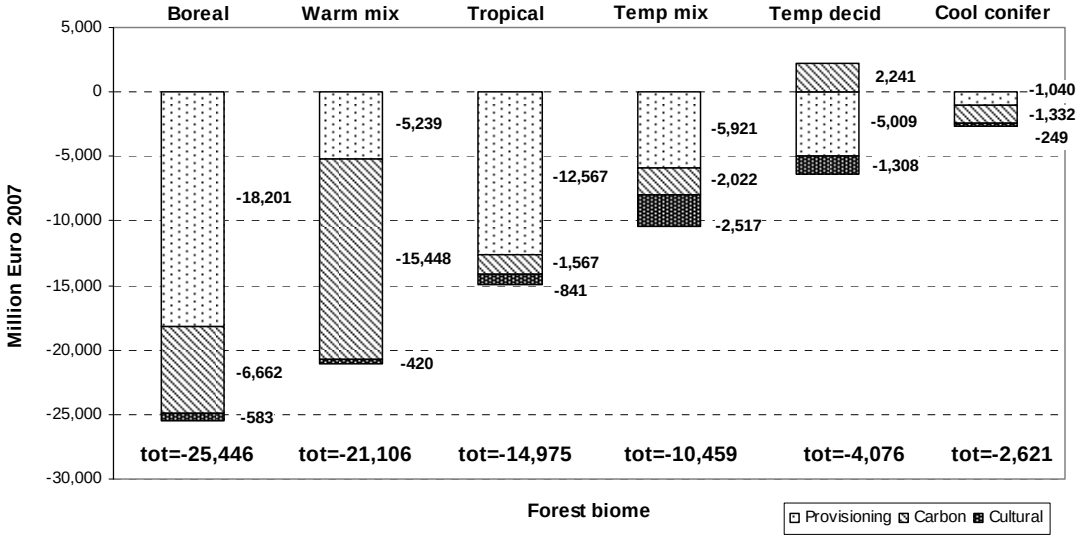


Figure 15: Total economic value changes by forest biome and ecosystem service, in 2050 (Million Euro 2007, r=3%)



5 Conclusions

The paper reports the methodology and the estimation of some of the services provided by forest biomes in different world areas, by applying consolidated methods for the monetary valuation of market and non-market goods. The objective is to provide a methodological framework for estimating marginal values and an outline on how to use value-transfer techniques.

The valuation framework has been applied to forest biomes, and specifically to key ecosystems services identified following the Millennium Ecosystem Assessment (MEA, 2005) taxonomy: provisioning services (wood forest products and non-wood forest products), regulating services (carbon sequestration), and cultural services (recreation and passive use values). This selection has been based on the availability of data and on their relevance to decision-making. The estimation of such services, although not covering the full range of forest instrumental values, allow the quantification of those values which are expected to be relevant to context where it is necessary to make decisions and trade one value against the other. Both market and non-market valuation techniques are applied; however, the present study mainly relies on the existing body of knowledge already available in the literature to draw suitable marginal values for forest services, to be scaled up at the global (OECD regions) level using proper transfer protocols.

Based on the nature of the ecosystem service of concern, we have identified the valuation methodologies already available in the literature for the monetary estimation. Provisioning services have been valued using a market-based approach (based on market prices). Carbon sequestration valuation is based on the Marginal Damage Cost (MDC) approach and the marginal avoidance cost (MAC), with the latter resulting in higher estimates then the first. Finally, cultural services are estimated using non-market valuation methods, based on both stated and revealed preferences approaches (travel cost method, contingent valuation and choice experiments). The valuation framework has been built in order to cover, for each ecosystem service, the highest variability in terms of geographical regions and forest biomes. In this context meta-analysis and value-transfer techniques appear to be the most suitable for cultural services valuation.

Regarding provisioning services, the valuation framework is comprised of two main phases: (i) calculation of total annual values, based on FAO export values at country level by different industrial sectors, and adjusted for domestic production and profits, and (ii) calculation of marginal

values taking into account the forest size designated to production only. Marginal values for forest provisioning services have been therefore estimated taking into account the industrial sector (product category, wood forest products and non-wood forest products), the country of production, the forest type, and the size of the forest designated to production (plantations).

Carbon stocks have been estimated by identifying the capacity of carbon sequestration by forest type and country, and applying the monetary value estimated in the EU project CASES (Cost Assessment of Sustainable Energy System), based on damage and avoidance cost methodologies.

For cultural values, the meta-analysis has produced significant results in terms of the marginal effect of forest size and income level on the marginal value of the forest site, showing, as expected under the conventional assumptions, that the estimated marginal non-market value of forest cultural services decreases with an increase of the forest size, and increases with an increase of the income level. Value-transfer methodologies have been applied in order to transfer the estimates available from the original studies to the new policy contexts for which no original study exist. The value-transfer exercise has been developed based on a two-step approach. For recreational values we have first estimated marginal values for United Kingdom which provides a representative picture of forest recreation (value-transfer to UK forest recreational sites). The marginal value estimated for UK has been transferred to other world regions in the second step of the calculation. For passive use values, in the first step we estimated the marginal values by forest biome in some world regions (by transferring the values from country level to the corresponding world region), while in the second step we transferred these values from the estimated world regions to the other world regions. This approach has been applied taking into account not all the forest area, but only those forest sites designated to recreation or conservation of biodiversity.

Final results show that total losses are significant. The total figure is €79 billion, the greatest losses coming from North America and Mexico, followed by Africa, Russia and some Asiatic countries (like Indonesia, Thailand, Malaysia, Philippines, Mongolia, Singapore, Vietnam). Most of this loss is attributable to provisioning services (€48 billion) and carbon sequestration (€25 billion), while only a minor part is due to loss of cultural services (€6 billion). In terms of biomes the greatest impacts are expected in boreal forests followed by warm mixed and tropical forests. These results may be surprising to some who argue that it is the loss of tropical forests, particularly the Amazon that is the most significant. A detailed analysis shows, however, that this is not the case. The best estimates point to greater losses in areas where use and non-use values are highest, which includes North America.

Our work suggests that any attempt to provide a monetary estimation of the services provided by biodiversity – here seen in terms of biomes – still represents a very challenging task for researchers. On the one hand this task is made difficult due to the partial lack of original valuation studies providing reliable estimates of the WTP for forest biodiversity values. On the other hand, the worldwide approach adopted here, will need to be reinforced by taking into consideration uncertainty and a lack of information on the local biodiversity conditions that are expected to influence the results of the valuation process.

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Annex

Table 9 A1: Total economic value changes for provisioning services in managed forest biomes by world region, in 2050 (Million € 2007, r=3%)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	-10,703	-2,249	103	-6	0	-2,575	-153	-2,571	0	29	-78	0	-18,201 (38%)
Tropical	-1	0	0	-18	-2,479	0	-8	-2	-6,440	0	-1,056	-2,563	-12,567 (26%)
Warm mixed	-1,676	-22	-9	-468	-69	0	-912	-1,892	-63	0	-83	-46	-5,239 (11%)
Temperate mixed	-2,917	-1,084	-1,258	-1	0	-218	-9	-21	0	-412	0	0	-5,921 (12%)
Cool coniferous	-438	-615	220	0	0	-54	-47	-116	0	10	0	0	-1,040 (2%)
Temp. deciduous	-923	-1,276	-1,463	-32	0	0	-207	-1,107	0	-1	0	0	-5,009 (10%)
Total	-16,658 (35%)	-5,247 (11%)	-2,406 (5%)	-525 (1%)	-2,548 (5%)	-2,847 (6%)	-1,335 (3%)	-5,709 (12%)	-6,503 (14%)	-374 (1%)	-1,217 (3%)	-2,608 (5%)	-47,977
% Δ (2007 baseline)	-51%	-57%	-50%	-54%	-71%	-72%	-35%	-46%	-51%	-67%	-57%	-22%	-49%

Table 12 A2: Total economic value changes for carbon sequestration in natural and managed forest biomes by world region, in 2050 (Million € 2007, r=3%, lower bound)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	-1	563	11	-21	0	-6,814	-281	133	0	-125	-127	0	-6,662 (27%)
Tropical	148	0	5	25	1,748	0	-38	28	-2,834	0	2,056	-2,703	-1,567 (6%)
Warm mixed	436	216	73	-871	682	0	-4,179	489	-284	0	-3,262	-8,747	-15,448 (62%)
Temperate mixed	428	934	572	-40	0	-1,365	-451	15	0	-2,086	-30	0	-2,022 (8%)
Cool coniferous	-126	-138	21	0	0	-894	-163	17	0	-50	0	0	-1,332 (5%)
Temp. deciduous	242	2,423	458	-65	0	-98	-597	103	-8	-160	-2	-56	2,241 (9%)
Total	1,128 (5%)	3,998 (16%)	1,140 (5%)	-972 (4%)	2,430 (10%)	-9,171 (37%)	-5,709 (23%)	785 (3%)	-3,126 (13%)	-2,422 (10%)	-1,366 (6%)	-11,506 (46%)	-24,790
% Δ (2007 baseline)	0.4%	5%	8%	-3%	1%	-3%	-16%	1%	-3%	-27%	-1%	-6%	-2%

Table 16 A3: Total economic value changes for recreational services by world region and forest biome, in 2050 (Million € 2007, r=3%)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	-4.49	-1.97	-0.10	-0.01	0	-18.97	-0.06	-1.74	0	-0.04	-0.03	0	-27.43 (48%)
Tropical	-0.03	0	0	-0.01	-5.29	0	-0.02	-0.08	-1.60	0	-0.39	-1.2	-8.71 (15%)
Warm mixed	-0.79	-0.36	-0.03	-0.06	-0.60	0	-0.32	-2.16	-0.15	0	-0.11	-0.26	-4.83 (8%)
Temperate mixed	-1.10	-2.43	-0.85	-0.01	0	-1.85	-0.03	-0.23	0	-0.25	-0.01	0	-6.76 (12%)
Cool coniferous	-0.83	-0.95	-0.19	0	0	-2.32	-0.03	-0.33	0	-0.02	0	0	-4.66 (8%)
Temp. Deciduous	-0.59	-2.63	-0.35	-0.02	0	-0.08	-0.13	-1.56	0	-0.01	0	0	-5.37 (9%)
Total	-7.82 (14%)	-8.33 (14%)	-1.52 (3%)	-0.11 (0.2%)	-5.89 (10%)	-23.23 (40%)	-0.59 (1%)	-6.09 (11%)	-1.76 (3%)	-0.33 (1%)	-0.54 (1%)	-1.56 (3%)	-57.76
% Δ (2007 baseline)	-47%	-51%	-42%	-46%	-42%	-45%	-83%	-47%	-48%	-62%	-44%	-51%	-47%

Table A4: Total economic value changes for passive use by world region and forest biome, in 2050 (Million € 2007, r=3%)

Forest Biomes	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	-346	-195	-78	-3	0	6	-4	74	8	-3	-14	0	-555 (10%)
Tropical	-94	0	-12	-23	-210	0	-10	0	-219	0	-324	59	-832 (14%)
Warm mixed	-165	-81	-31	-7	-8	-1	-56	8	-25	0	-22	-27	-415 (7%)
Temperate mixed	-1,960	-262	-242	-35	0	-4	-5	6	0	-5	-2	0	-2,510 (43%)
Cool coniferous	-101	-85	-57	0	0	-2	-10	11	0	-1	0	0	-245 (4%)
Temp. deciduous	-948	-254	-52	-34	0	-1	-26	24	-5	-1	-4	-2	-1,303 (22%)
Total	-3,615 (62%)	-878 (15%)	-472 (8%)	-102 (2%)	-218 (4%)	-1 (0.1%)	-111 (2%)	123 (2%)	-242 (4%)	-9 (0.2%)	-366 (6%)	31 (1%)	-5,859
% Δ (2007 baseline)	-44%	-59%	-67%	-41%	-32%	-1%	-47%	18%	-8%	-37%	-23%	11%	-34%

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Economic Measures of Soil Conservation Benefits

Regional Values for Policy Assessment

LeRoy Hansen and Marc Ribaudo

Abstract

This report describes data and methodologies that the Economic Research Service has used to apply monetary values to changes in soil erosion. Values and methodology are clearly described so that analysts can apply the data to specific soil conservation projects. ERS has used the values to estimate soil conservation benefits of changes in farm programs and practices, but no analyses of farm programs or practices are provided here. The benefit values are regional dollar-per-ton measures of 14 different categories of soil conservation benefits. There are other soil conservation benefit categories beyond those reported here, so a full accounting of benefits is not possible. As a result, monetary values derived from applications of these data are likely to be lower-bound estimates of the benefits or costs of changes in soil erosion. The data are thought to be detailed enough for national and regional estimates, but lack precision for smaller scale estimates.

Keywords: Soil conservation, benefit analysis, soil conservation benefits, nonmarket value, soil erosion, water quality benefits, air quality benefits, soil productivity

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Online only: www.ers.usda.gov/publications/tb1922/tb1922App2.xls

Summary

Annual conservation program expenditures have doubled to more than $5 billion per year over the last decade. A major focus of these programs is on reducing soil erosion. This report describes the per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between agricultural erosion and environmental benefits. Values and methodology are described so that analysts can apply the data to calculate regional and national benefits of specific soil conservation projects. Analysts can also use the per-ton benefit estimates to determine where a 1-ton reduction in soil erosion might be most beneficial.

What Is the Issue?

Conservation programs best serve the public when their funding, design, and implementation maximize benefits relative to costs. Unlike the cost of soil conservation efforts, environmental benefits of decreasing soil erosion are not easy to measure. Information on the values of soil conservation benefits can aid in designing more cost-effective programs and evaluating accomplishments of programs, policies, and practices.

What Does the Report Do?

Past research has generated per-ton soil conservation benefit estimates for 14 types of environmental benefits that are suitable for use in national analyses. The benefit types can be placed in three general categories:

- Twelve benefit types reflect soil conservation impacts on water quality and the subsequent impacts on industries, municipalities, and households.
- One benefit type captures the effect of wind erosion reductions on household cleaning costs.
- One benefit type has values of soil productivity preserved through reductions in wind and water erosion.

The report describes the development of each estimate, and provides some insight into regional variations in soil conservation benefits. The values can be viewed as prices that people, businesses, and government agencies would be willing to pay for a 1-ton reduction in soil erosion. For example, the reduction in municipal water-treatment costs due to a 1-ton reduction in erosion represents municipalities' willingness to pay for that much reduced erosion.

The per-ton benefit values are available on the ERS web site (www.ers.usda.gov) in two databases. One provides per-ton benefits of soil erosion reduction for the 3,074 counties within the 48 contiguous States. The other provides per-ton benefits for the 2,111 8-digit Hydrologic Unit Code (HUC) watersheds within the contiguous States. While the benefit categories in these data encompass many of the benefits of soil conservation, the categories do not measure every benefit. For example, some people may value knowing that water quality is improved—even though they do not use the water—or that endangered species have an improved habitat, but estimates of these benefits

are not available. As a result, applications of the available data will provide lower-bound estimates of total soil conservation benefits.

How Was the Study Conducted?

The per-ton benefit estimates are derived from models developed since the 1980s by ERS. The estimates are believed to be the best available for national analyses of soil conservation benefits, and the ERS data are updated as improved models become available. Four of the models generate marginal dollar-per-ton benefit estimates; the others generate average per-ton estimates. Descriptions of the economic frameworks, data sources, and models supporting estimates within each of the 14 benefit categories were synthesized from USDA published reports and peer-reviewed journal articles. All of the reported values were adjusted for inflation by the Consumer Price Index, so that all values are in year 2000 dollars. The values can be directly applied to observed and potential changes in soil erosion. They can also be applied to nonagricultural changes in soil erosion, as long as the changes are appropriately calibrated. Although the data have county- and HUC-level values, the benefit values are credible only when reported at national and multi-State levels. The model descriptions provide insights on how the benefit values can best be applied and results interpreted. Values are reported by category, so users can choose those they feel are appropriate to their own applications.

Introduction

This report describes data and methodologies the Economic Research Service has used to assign monetary values to changes in soil erosion, and then explains how the results are best interpreted. The report presents estimates of per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between erosion and the public's willingness to pay to reduce erosion's environmental impacts. There is one model for each type of benefit.

The data can be used to determine the value of soil conservation benefits of specific practices and programs. They can be applied directly to changes in field erosion and, with appropriate modification, to off-farm measures of soil erosion.

The benefit categories in the data sets, while not comprehensive, are the most complete set of benefit measures currently available for national assessments of soil conservation programs and practices. Many of these categories have been used to value soil conservation impacts of the Conservation Reserve Program (Hansen, 2007; Sullivan et al., 2004; Claassen et al., 2001, Ribaudo et al., 1989), the Environmental Quality Incentive Program (USDA, NRCS, 2003), and the Conservation Security Program (USDA, NRCS, 2004). The values are also built into the Regional Environmental and Agriculture Programming Model (Johansson et al., 2007).

The data are located on the ERS web site (www.ers.usda.gov/publications/tb1922/tb1922App1.xls and www.ers.usda.gov/publications/tb1922/tb1922App2.xls), so a user can easily access and apply the values and adjust them, as appropriate. Though the data do not have a comprehensive set of benefit categories, they still offer a probable lower-bound estimate of the public's willingness to pay for reductions in soil erosion and the subsequent impacts on environmental quality. However, estimates in each benefit category have weaknesses due to limits on the precision of the economic models and the underlying biological, physical, and ecological process models available at the time the benefits were estimated.

The first section of this report discusses each of the soil conservation benefit categories, concepts behind their applications, and interpretation of results. The second section provides the technical background on how the per-ton benefit estimates were derived. The economic reasoning, analytic approach, and primary data supporting each value are discussed.

Benefit Types and Values and Their Applications

Fundamentals of Per-Ton Benefit Estimates

The ERS per-ton benefit values can be found in HUC_MB (app. table 1, online only: www.ers.usda.gov/publications/tb1922/tb1922App1.xls). HUC_MB has 2,111 observations—one for each of the U.S. Geological Survey's (USGS's) 8-digit Hydrologic Unit Code (HUC) watersheds. Per-ton benefit values can also be found in COUNTY_MB (app. table 2, online only: www.ers.usda.gov/publications/tb1922/tb1922App2.xls). County_MB has 3,074 observations—one for each county of the contiguous States. Both datasets have the 14 benefit categories (see box "Soil Conservation Benefit Categories," p. 4, for names and definitions). HUC_MB has the variable *HUC*, which has the 8-digit USGS code for each observation. COUNTY_MB has the variable *county*, which has the 5-digit State-county FIPS code. COUNTY_MB also has the location variables *County_name*, *State_name*, and *State_abrv*, which contain county names, State names, and abbreviated State names, respectively. Both HUC_MB and COUNTY_MB have the weight variables *Water_weight*, *Soil_productivity_weight*, and *wind_erosion_weight*. Under special circumstances, these data may improve benefit calculations.

Twelve of the benefit categories are applicable to changes in water (sheet and rill) erosion only. One benefit category, *dust cleaning*, is applicable only to changes in wind erosion. The benefit category *soil productivity* is applicable to changes in both wind and water erosion. All benefit estimates have been adjusted for inflation, based on the Department of Labor's Consumer Price Index for all urban consumers (CPI-U), to year 2000 dollars.

The per-ton benefit values are conceptually similar to prices of market goods and services. Therefore, just as total revenue is equal to price times quantity (summed across all goods), total benefits are equal to the benefit values times the changes in erosion. For example, suppose there is a 5-ton reduction in water erosion and a 2-ton reduction in wind erosion within a specific HUC (or county). Then, to estimate the value of the 5-ton reduction in water erosion, we would multiply each of the 12 water-related benefit categories and *soil productivity* of that HUC (county) by 5 tons and sum all 13 values. To estimate the wind erosion benefits, we would multiply *dust cleaning* and *soil productivity* of that HUC (county) by 2 tons and sum the two values. The total benefit of these erosion reductions is equal to the sum of the water and wind erosion benefits within the specific HUC (county). The benefit categories are independent, so benefits are not double-counted.

In more general terms, the total benefit ($Total_benefits_i$) of a change in water and wind erosion in HUC or county *i* can be expressed as:

$$Total_benefit_i = \sum_{j=1}^{12} (water_erosion_value_{i,j} * \Delta Water_erosion_tons_i)$$
$$+ soil_productity_i * (\Delta Water_erosion_tons_i + \Delta Wind_erosion_tons_i) \qquad (1)$$
$$+ dust_cleaning_i * \Delta Wind_erosion_tons_i.$$

The water-related benefit categories—$water_erosion_value_{i,j}$, designated by the j subscripts—are the first 12 of the 14 benefit categories. (See box, "The Soil Conservation Benefit Categories," p. 4). The values of $\Delta Water_erosion_tons_i$ and $\Delta Wind_erosion_tons_i$ are the change in water and wind erosion that an analyst wishes to value. The i subscript indicates the relevant HUC or county. Keep in mind that $Total_benefits_i$ is not a total of all soil conservation benefits. It is a total of what can be estimated from the available data.

Equation 1 can be estimated for all HUCs or counties, when erosion estimates are available. To provide reliable estimates, the HUC-level values of equation 1 must then be aggregated to larger watersheds, such as the U.S. Geological Survey's 12 2-digit hydrologic drainage basins. And the county-level values must be aggregated to multicounty regions that are larger than States, such as the U.S. Department of Agriculture's 10 Farm Production Regions (FPRs) and the Economic Research Service's 9 Farm Resource Regions (FRRs). In general, benefits estimated for smaller geographic regions will be less reliable, given that 11 of the benefit values are multi-State—specifically, FPR-level—averages. Note that three benefit values are estimated by HUC and, as a result, are likely to provide reliable estimates for HUCs and larger regions.

Equation 1 is relevant when HUC- or county-level estimates of erosion are available. But when erosion changes are reported on a larger geographic scale, mean-value estimates of $water_erosion_value_i$, $soil_productivity$ and $dust_cleaning$ suited to the geographic scale will need to be calculated. That is, suppose the analyst has access to FRR-level estimates of changes in soil erosion. Then, in order to estimate the value of the changes in erosion, the analyst needs FRR-level values of $water_erosion_value_i$, $soil_productivity$, and $dust_cleaning$. A linear average of the per-ton values is not likely to be appropriate because erosion levels are higher in some counties and HUCs, and it is reasonable to assume that erosion changes are more likely to occur where erosion is greater. To facilitate calculations based on this assumption, $Water_weight_i$ is set equal to the total water erosion in the county or HUC $_i$. The weighted mean value of water-erosion benefit j for region k, weighted_ $mean_water_erosion_value_{k,j}$ is:

$$weighted_mean_water_erosion_value_{k,j} = \frac{\sum_{i=1}^{N} water_erosion_value_{i,j} * Water_weight_i}{\sum_{i=1}^{N} Water_weight_i} \quad (2)$$

The counties i=1 through N lie in region k. And weighted mean values of $soil_productivity$ and $dust_cleaning$ ($weighted_mean_soil_productivity_k$ and $weighted_mean_dust_cleaning_k$, respectively) are similarly calculated, but using the weights $Soil_productivity_weight_i$ and $Dust_cleaning_weight_i$, respectively, instead of $Water_weight_i$.

Then total benefit (inasmuch as the data allow) for region k ($Total_benefits_k$) of a change in water and wind erosion in region k is expressed as:

The Soil Conservation Benefit Categories

Categories	Consumer/producer surplus gain due to	Level of aggregation	Range of values ($/ton)	Year estimated
Reservoir services	Less sediment in reservoirs	HUC	0 to $1.38	2007
Navigation	Shipping industry avoidance of damages from groundings	HUC	0 to $5.00	2002
Water-based recreation	Cleaner fresh water for recreation	HUC	0 to $8.81	1997
Irrigation ditches and channels	Reduced cost of removing sediment and aquatic plants from irrigation channels	FPR	$0.01 to $1.02	2007
Road drainage ditches	Less damage to and flooding of roads	FPR	$0.20	1986
Municipal water treatment	Lower sediment removal costs for water-treatment plants	FPR	$0.04 to $1.45	1989
Flood damages	Reduced flooding and damage from flooding	FPR	$0.10 to $0.77	1986
Marine fisheries	Improved catch rates for marine commercial fisheries	FPR	0 to $0.93	1986
Freshwater fisheries	Improved catch rates for freshwater commercial fisheries	FPR	0 to $0.12	1986
Marine recreational fishing	Increased catch rates for marine recreational fishing	FPR	0 to $1.57	1986
Municipal & industrial water use	Reduced damages from salts and minerals dissolved from sediment	FPR	$0.07 to $1.47	1986
Steam powerplants	Reduced plant growth on heat exchangers	FPR	$0.04 to $1.05	1986
Soil productivity	Reduced losses in soil productivity	FPR	$0.37 to $1.21	1990
Dust cleaning	Decrease in cleaning due to reduced wind-borne particulates	FPR	0 to $1.14	1990

HUCs are watersheds defined by USGS's 8-digit hydrologic unit codes; FPRs are USDA's multi-state Farm Production Regions.

All dollar values are adjusted to year 2000.

$$Total_benefit_i = \sum_{j=1}^{12} (weighted_mean_water_erosion_value_{k,j} * \Delta Water_erosion_tons_i)$$
$$+ weighted_mean_soil_productivity_k * (\Delta Water_erosion_tons_k + \Delta Wind_erosion_tons_k) \quad (3)$$
$$+ weighted_mean_dust_cleaning_k * (\Delta Water_erosion_tons_{k)}$$

$Water_weight_i$, $Soil_productivity_weight_i$, and $Dust_cleaning_weight_i$ are based on the USDA's 1997 National Resources Inventory (NRI), the most recent data that provide a means of generating county- and HUC-level erosion estimates (USDA, NRCS, 2000). While erosion is likely to have changed since 1997, we know that if erosion changes were proportionately equal across counties and HUCs, the weights would not change. But if changes are not proportional, as is likely the case, then the reliability of the weights may be decreased. Note that 11 of the 14 variables are FPR-level averages, so that when a region *k* is an FPR, weights will not affect benefit estimates. The weights in these data are updated as better erosion estimates become available.

Data Shortcomings

While the data and equations 1, 2, and 3 make it relatively easy to value 14 soil conservation benefits, interpretation of results requires an understanding of the data's shortcomings. The four most important are:

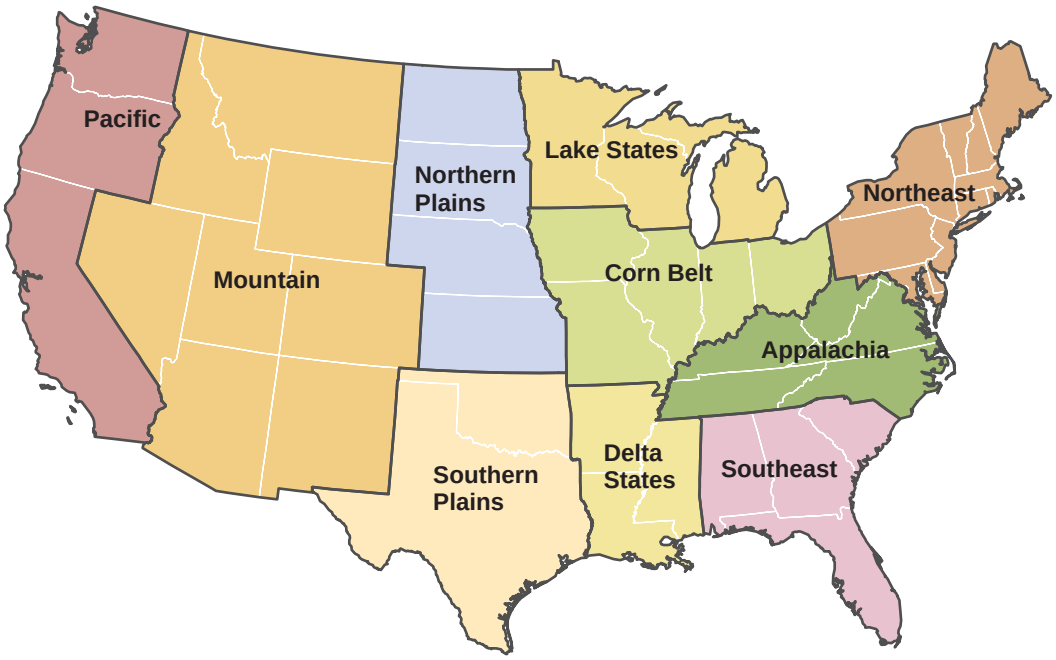
1. **The values in each soil conservation benefit category are average regional values, which do not capture intraregional variations in values**. Values in 11 of the benefit categories of the ERS data have been generated by models that provide values for each of the 10 FPRs (fig. 1). As a result, the per-ton benefit values do not vary across counties or HUCs within the same FPR. The actual value of a 1-ton reduction in erosion is likely to vary across HUCs and counties within each region. Because this variation is not captured, the estimated HUC and county values might be equal to, greater than, or less than the actual values. However, as we aggregate HUC- and county-level estimates, the standard error around benefit estimates is likely to fall.

   In contrast, three of the soil conservation benefit categories—*reservoir*, *shipping*, and *recreation*—have values that are taken from studies that generate HUC-level values. The county-level estimates are based on the HUC/county overlaps and are expected to provide fairly reasonable estimates. But neither the HUC- nor county-level estimates capture the variation in values within HUCs or counties. In other words, these per-ton benefit estimates do not capture field-to-field variations in soil conservation benefits.

   The actual value of a 1-ton reduction in erosion depends both on physical factors—the quantity of sediment that reaches a stream or lake and the subsequent ecological impact—and economic factors, the willingness of firms and individuals to pay to prevent or eliminate the ecological impacts.[1] The per-ton benefit values embody these relationships, or more precisely, the average value of these relationships. When evaluating changes in farm programs and practices, consideration of field-to-field variation is important when erosion changes occur on acreage with greater, or less than, average physical or economic impacts. For example,

[1]To the extent that nutrient and sediment effects on benefits are correlated, the reported dollar-per-ton benefit estimates will include effects of nutrients.

Figure 1
USDA's Farm Production Regions



analyses of programs that target land with specific characteristics, such as riparian buffers, could produce biased results. A 1-ton reduction in erosion by riparian buffers is likely to have greater water quality impacts than a 1-ton reduction elsewhere in the region (HUC, county, etc.) (Khanna et al., 2003). Consequently, a program that reduces relatively more erosion on riparian lands will likely have greater-than-average water quality impacts per ton of erosion. The benefit values are still useful, but conclusions drawn from such analyses must include the caveat that the estimated benefits might be biased downward.

2. **Not all soil conservation benefits are included.** A further shortcoming of the benefit estimates derived from the 14 soil conservation benefit categories is that the estimates do not include all soil conservation benefits. The impacts on wetlands, endangered species, and most coastal recreational activities, as well as people's willingness to pay simply to know that water quality is improved, are examples of conservation benefits that have not been modeled. Finally, to a smaller degree, benefit estimates are likely to be biased downward because 13 of the models are built on theoretical frameworks (the replacement cost, damage function, and averting-behavior frameworks) that cannot capture full willingness to pay (Ribaudo and Hellerstein, 1992).

3. **Benefit values are designed to be applied to farmland erosion**. The per-ton values are applicable to changes in erosion on agricultural lands. However, the benefit values can also be applied to nonagricultural erosion, if properly calibrated. The calibration must be based on an equivalence of the environmental quality impacts of agricultural erosion

and erosion from the nonagricultural source. For example, if, in a given region, a 1-ton reduction in agricultural erosion has the same water quality impact as a 2-ton reduction in erosion at construction sites (measured by the quantity of sediment reaching a stream), then the water quality benefit of a 1-ton reduction in erosion at construction sites is half the value of a 1-ton reduction in agricultural erosion.

4. **Values have been adjusted for inflation, but other time-related factors may be relevant.** Ten of the 14 benefit values were estimated more than 20 years ago, 1 was estimated in the late 1990s, and the remaining 3 were estimated within the last 6 years. Over time, the benefit values might have changed, but the size and direction of change in any one of the benefit values are unknown. For example, municipal water treatment costs are likely to increase with increases in the population served, but advances in water treatment technology are likely to lower treatment cost. Increases in populations might tend to increase the total willingness to pay for improvements in environmental quality, but increases in the availability of substitute activities and goods that come with increases in populations might decrease willingness to pay. Increases in incomes can raise the value of surrounding amenities, but improved transportation can make alternative sites comparable substitutes. These and other factors might affect some or all of the benefit values discussed here. At this point, there appears to be no means of capturing the net effect of these factors. Lacking evidence to suggest otherwise, we assume, after adjusting for inflation, that the benefit values have not changed over time. We do know that, over time, inflation decreases the real purchasing power of the dollar. We therefore have adjusted all benefit values for inflation, based on the Department of Labor's Consumer Price Index for all urban consumers (CPI-U), to year 2000 dollars.

The Benefit Models: Economic Theory and Empirical Methodologies

Four theoretical frameworks—travel cost, damage function, replacement cost, and averting expenditures—underlie the 14 soil conservation benefit models. (For a detailed discussion of these and other methods, see Lew et al., 2001.) All are indirect means of estimating environmental benefits.

Travel Cost

This method uses expenditure and trip data to estimate the demand for a recreation activity where environmental quality is one of the determinants of demand. Changes in consumer surplus associated with changes in environmental quality can be derived from the estimated demand function. The approach requires data on respondents' recreational activities and travel costs (including the cost of time) and the environmental quality of recreation sites the person visited, as well as potential substitute sites.

Damage Function

This approach applies to businesses that use an environmental input, such as water. It is based on the assumption that the loss in welfare due to a decrease in environmental quality is approximately equal to the value of the loss in revenue or increase in costs. The approach is thought to provide conservative benefit estimates, first, because it implicitly assumes that no remedial actions are taken and, second, because market effects are not considered (Freeman, 1993). However, in the case of a single-product firm, the damage function approach will not underestimate the change in welfare, as long as the change in environmental quality does not change the quality or quantity of the firm's output (Ribaudo and Hellerstein, 1992).

Replacement Cost

This method assumes that the loss in welfare due to a change in environmental quality is approximately equal to the expenditures made to replace, repair, or restore goods and capital assets. Like the damage function approach, the replacement cost approach is believed to provide a conservative benefit estimate because, first, if there are no expenditures, the approach sets the value of the damages equal to zero. Second, as with the damage function approach, the replacement cost method assumes that no remedial action is taken. And third, the approach ignores the cost of reduced performance before the good is replaced.

Averting Expenditures

This approach assumes that the loss in welfare due to a change in environmental quality is approximately equal to the change in expenditures made to counteract the change in quality of the environmental asset. The approach assumes that marginal changes in defensive expenditures leave the quality of the environmental good(s) unchanged (changes in expenditures are a perfect substitute for changes in environmental quality). However, because it is commonly accepted that this assumption does not hold, the averting-expenditures approach is believed to provide conservative benefit estimates

(Freeman, 1993; Ribaudo, 1989). In practice, it can be difficult to isolate the portion of expenditures that is attributable to averting activities (Winpenny, 1991).

Averting expenditures occur before losses are incurred. For example, suppose forest lands are cleared in order to create or expand downhill ski slopes. Without the tree canopy and the ecology of a forest floor, runoff from summer rains swells streams and increases downstream flood frequency and levels. In response, individuals living in the flood plain raise the foundations of their houses. The cost of raising foundations is an averting expenditure and represents part of what people would be willing to pay, in advance, to have prevented the environmental impacts of the ski slopes. Others might move away, or stay and deal with the additional losses; all would be willing to pay to prevent impacts, but their willingness to pay is not captured by the averting-expenditures approach.

Model and Data Descriptions

All of the benefit models are reduced-form models in that the per-ton benefit estimates embody a complex set of physical processes, linking changes in erosion on agricultural lands to environmental quality and the economic values that individuals, firms, and the public sector place on changes in environmental quality. For example, the per-ton estimates related to water quality capture water's effect on soils and nutrients in fields and on their movements to waterways, the subsequent changes in water quality and ecology, the effects that these changes have on water users (individuals, firms, and the public sector), and the values individuals place on changes in these effects (fig. 2).

Of the 14 models described in this report, three models, estimated since 1997, generate dollar-per-ton benefit values for each of the 2,111 8-digit hydrologic unit code (HUC) watersheds of the contiguous States. Each of these models estimates the value of reductions in water erosion. The sum of the per-ton values, by HUC, ranges from zero to $14.38. The other 11 models, most of them estimated in the 1980s, generate benefit values by the multi-state Farm Production Regions (FPRs) (fig. 1). One benefit category—soil productivity benefits—accounts for changes in both water and wind erosion. Ten are applicable only to water erosion. The remaining benefit category is applicable to changes in wind erosion. The sums of the per-ton water erosion and soil productivity benefits by FPR range from $1.46 to $7.12 per ton. The sums of the wind erosion and productivity benefit values within the FPR range from $0.41 to $1.54 per ton (table 1).

Watershed Benefit Models

The three watershed studies apply very different approaches. However, they are similar in that each begins by estimating values of soil conservation impacts at sites and then aggregates across sites to generate HUC-level estimates.

Table 1
Benefit estimates ($/ton) produced by models that generate estimates for Farm Production Regions[1]

Farm Production Region[2]	Irrigation ditches and canals	Road drainage ditches	Municipal water treatment	Flood damages	Marine fisheries	Freshwater fisheries
Appalachia	0.01	0.2	0.05	0.26	0.01	0.02
Corn Belt	0.01	0.2	0.18	0.10	0.00	0.01
Delta States	0.12	0.2	0.04	0.71	0.02	0.12
Lake States	0.03	0.2	0.32	0.50	0.00	0.12
Mountain	0.54	0.2	1.06	0.21	0.00	0.00
N. Plains	0.12	0.2	0.22	0.13	0.00	0.00
Northeast	0.01	0.2	0.27	0.77	0.93	0.00
Pacific	1.02	0.2	0.47	0.33	0.42	0.00
S. Plains	0.22	0.2	1.45	0.27	0.14	0.03
Southeast	0.16	0.2	0.31	0.53	0.00	0.00

—continued

[1]Values reflect a 1-year reduction in erosion.
[2]See figure 1 for the location of each FPR.

Reservoir Services

As sediment accumulates in reservoirs, the quantity and quality of reservoir services are reduced. For example, reservoir sediment can reduce the quality of beaches, shoreline boating, water reserves for power generation, capacity for holding flood waters, and the quality of spawning grounds. An increase in erosion can increase the rate that sediment settles in a reservoir and, as a result, leave the sediment level higher and service lower in subsequent years. Conversely, reducing erosion will reduce the rate that sediment settles in a reservoir and leave future reservoir service levels higher (Hansen and Hellerstein, 2007). Dredging a reservoir restores services, so dredging expenditures can be assumed to represent a restoration (replacement) cost.

The parameters of the benefits model are estimated by applying the replacement cost method and assuming that reservoir owners/managers dredge reservoirs at the optimal time, when marginal benefits equal marginal costs. Dredging costs are assumed to be a function of reservoir characteristics and the quantity of sediment dredged. The reservoir benefits model by Hansen and Hellerstein (2007) is estimated using public and private reports of dredging costs. They also estimate a sedimentation model, linking changes in erosion to changes in reservoir sedimentation, and couple it with the benefit model so benefits can be linked to changes in erosion. Given the historical nature of the dredging data, Hansen and Hellerstein assume the decisions to dredge were based on erosion rates similar to those observed in the 1982 National Resources Inventory (NRI). The NRI contains 800,000 statistically based sample points on U.S. non-Federal range, crop, pasture, and forest lands (USDA, SCS, 1984).

The reservoir benefits model and sedimentation model are used to generate reservoir-level marginal benefit estimates. The model estimates account for the multiyear impacts that a one-time reduction in soil erosion will have. With the marginal benefit estimates, we can value the increase in present and

Table 1
Benefit estimates ($/ton) produced by models that generate estimates for Farm Production Regions[1]—continued

Farm Production Region[2]	Marine recreational fishing	Municipal and industrial use	Steam power-plants	Soil productivity	Dust cleaning	Total water-related	Total wind-related
Appalachia	0.01	0.43	0.92	0.57	0.00	2.47	0.57
Corn Belt	0.00	0.21	1.05	1.01	0.00	2.77	1.01
Delta States	0.02	0.68	0.44	0.43	0.00	2.76	0.43
Lake States	0.00	1.36	0.94	1.21	0.00	4.68	1.21
Mountain	0.00	0.21	0.29	0.26	0.60	3.37	0.86
N. Plains	0.00	0.07	0.33	0.41	0.64	1.46	1.05
Northeast	1.57	1.45	0.66	1.27	0.00	7.12	1.27
Pacific	0.49	0.17	0.04	0.40	1.14	3.54	1.54
S. Plains	0.41	0.28	0.24	0.37	0.38	3.61	0.75
Southeast	0.00	0.48	0.42	0.41	0.00	2.51	0.41

[1]Values reflect a 1-year reduction in erosion.
[2]See figure 1 for the location of each FPR.

Figure 2

Reduced-form models implicity capture the links between changes in erosion and benefit values

Changes in Erosion Are Estimated

Estimates of erosion changes are based on:
1) rainfall erosivity
2) soil erodibility
3) slope characteristics
4) crop management
5) conservation practices

Movement of Soil to Waterway Are Implicitly Captured

Factors that affect the amount of eroded soil that reaches a waterway:
1) distance to waterway
2) slope of the land to the waterway
3) cover on the land

Sediment's Impacts on Physical and Biological Resources Are Implicitly Captured

Sediment's impacts on physical and biological resources:
1) water looks 'dirty'
2) beaches become muddy
3) sediment settles in reservoirs and shipping lanes
4) sediment in flood waters increases flood damages
5) sediment decreases the quality of fish habitat

Physical and Biological Effects on Environmental Amenities Are Implicitly Captured

Environmental amenities that are affected
1) swimming, boating, and recreational fishing
2) commercial fishing
3) navigation
4) water storage

Benefit Values Are Measured

Benefit values are measures of changes in:
1) consumer surplus
2) producer surplus
3) government costs

future reservoir services resulting from a marginal reduction in agricultural erosion.

The HUC-level marginal benefit values for reservoir services are derived from the reservoir-level marginal benefit estimates. Values are calculated in four steps. First, the marginal benefit of a 1-percent reduction in the erosion rate is calculated for each of the more than 70,000 reservoirs in the United States. Second, the marginal benefits are summed across the reservoirs within each HUC. Third, the change in erosion (number of tons) associated with a 1-percent change in the erosion rate on agricultural lands is calculated for each HUC. Finally, each HUC-level marginal benefit estimate is converted to a per-ton estimate by dividing the benefit estimate by the number of tons represented by a 1-percent change in the erosion rate.

The estimates of marginal reservoir benefits vary widely across HUCs. In 163 HUCs, marginal benefits equal zero. These HUCs appear to have no reservoirs affected by agriculture. In the remaining watersheds, per-ton soil conservation benefits are as high as $1.38.

Navigation Industry

Sediment buildup in shipping channels and harbors delays water traffic and damages ships and barges that run aground. To avert these delays and damages, the navigation industry, through the Army Corps of Engineers, dredges harbors and shipping channels. Because the dredging is done to avoid future damages, the costs represent averting expenditures.

The navigation industry model provides HUC-level estimates of the expected reduction in averting expenditures resulting from a 1-ton reduction in erosion. The model is estimated in two steps. First, an average dollar-per-ton cost of erosion is estimated for each site dredged by dividing total site-level dredging costs—where sites are harbors and segments of shipping channels—by total upstream erosion. Data on erosion and a hydrologic model are used to estimate the total tons of erosion upstream of each site. Second, HUC-level per-ton benefits are estimated by summing the dollar-per-ton estimates across all relevant downstream sites (Hansen et al., 2002).

The hydrologic data are from the River Reach File of the U.S. Environmental Protection Agency (EPA), which interconnects 3.2 million miles of streams. Estimates of agricultural erosion by HUC are based on data from the 1997 NRI (USDA, NRCS, 2003). Dredging-cost data are from the U.S. Army Corps of Engineers (1999a; 1999b). Results show that, across HUCs, a 1-ton reduction in soil erosion can reduce dredging costs by from $0.0 to $5.00.

Water-Based Recreation

Suspended sediment in lakes, rivers, and streams harms aquatic wildlife and decreases the water's aesthetic appeal, which lowers the quality of fishing, swimming, and other water-contact activities. To calculate sediment's impact on consumer surplus, a multisite travel-cost demand model for water-based recreation is estimated, where demand is a function of—among other things—

travel costs to each site and its water quality (Feather and Hellerstein, 1997; Feather et al., 1999).

The travel cost model is estimated in a two-step process. First, the site selection process is characterized by a random utility model (RUM). The RUM is estimated using data on individual and site characteristics. The estimated model is then applied to each observation to predict the probability that an individual will select a given recreation site. The second step begins by using the RUM probability estimates. Based on these estimates, an expected price (travel cost) and expected level of environmental quality (where erosion levels and the size and type of water body serve as proxies) are calculated for each individual. The estimates of expected price and site quality are probability-weighted averages of the prices and qualities of the relevant sites.

In the second step, the demand for water-based recreation is estimated by regressing the number of trips taken against expected price, expected environmental quality, and other demand determinants. The marginal change in consumer surplus associated with a change in soil erosion within a HUC is calculated for each affected individual. The HUC-level marginal benefit estimate is the sum of individuals' consumer surplus changes.

The model is estimated using behavioral data from the 1994-95 National Survey of Recreation and the Environment (2005) and environmental data from the 1997 NRI.

Estimates from the water-based recreation model indicate that a 1-ton reduction in soil erosion can increase societal benefits of water-based recreation by from $0.0 to $8.81 across the 2,111 U.S. watersheds.

Farm Production Region Benefit Models

The remaining 11 models deliver benefit estimates at the FPR level. Six were originally derived from State or sub-State models, but the model estimates were aggregated and subsequently reported by FPR. The others were derived from national-level data on costs that were then apportioned to FPRs.

Marine Recreational Fishing

Soil erosion can harm marine fisheries by damaging estuaries. Estuaries provide year-round habitat and are the principal spawning grounds for shellfish and a wide variety of fin fish. Sediment and nutrients can impair estuarine habitats, adversely affect fish populations, and decrease the quality of marine recreational fishing.

Clark et al. (1985) generated a national estimate of erosion's impact on marine sport fisheries, based upon analyses by Freeman (1982). Ribaudo (1986) allocated this national estimate to FPRs based upon which estuaries were impaired and the number of saltwater angling days affected. Ribaudo used water quality monitoring data from the National Stream Water Quality Accounting Network (NASQUAN) of the U.S. Geological Survey (USGS) monitoring system to determine which watersheds (USGS's Aggregated Sub-Areas) were impaired by sediment. He assumed that estuaries adjacent to sediment-impaired Aggregated Sub-Areas were also impaired. Data on the

location of 180 major estuaries were obtained from the National Oceanic and Atmospheric Administration.

The total number of saltwater angling days within each FPR was obtained from the U.S. Fish and Wildlife Service's Hunting and Fishing Survey (U.S. Dept. of the Interior, 1997). The number of impaired fishing days is estimated by multiplying the percentage of estuaries affected by erosion within an FPR by the total angling days. Affected angling days then become weights for allocating total damages. Damages in each FPR were divided by total erosion in each FPR to arrive at an average damage per ton of erosion. A unit reduction in erosion would produce approximately the same level of benefits. Soil conservation benefits, based on the marine recreational fishing model, range from $0.0 in the five inland FPRs to $1.57 per ton.

Marine Commercial Fisheries

Sediment in estuaries also affects commercial fisheries. As with modeling of impacts on recreational fishing, Ribaudo (1986) used the damage function approach. His analysis begins with a national estimate of total damages to marine commercial fisheries.

Bell and Canterberry (1975) provide an estimate of total annual damages to marine fisheries from all water pollution. Ribaudo assumes that erosion's share of damages to commercial fisheries is the same as erosion's share of damages to marine recreational fishing, as assumed by Clark et al. (1985). His erosion damage model allocates soil erosion damages equally across all impaired estuaries. Impaired estuaries are assumed to be all those that are part of USGS Aggregated Sub-Areas that have been designated as having water quality problems due to erosion. The model then links the damaged estuaries to the FPRs. Those estuaries that lie along the coast of an FPR are linked to that FPR. Total FPR-level damages are estimated by summing across estuaries within each FPR. Finally, per-ton damage estimates are derived by dividing each FPR-level damage estimate by total erosion in the region.

Soil conservation benefits, based on the marine commercial fisheries model, range from $0.0 in the five inland FPRs to $0.94 per ton.

Freshwater Commercial Fisheries

Water pollutants associated with sediment inhibit fish populations and decrease revenues of the freshwater fisheries industry. To derive soil conservation benefits to freshwater fisheries, a model, based on the damage function approach, is estimated from data on sediment's cost to the fisheries.

The national costs of sediment's impact on the commercial freshwater fisheries industry reported by Clark et al. (1985) are allocated across FPRs, based on the FPR's share of the total river-miles with concentrations of suspended sediment, nitrate-nitrite, and total phosphorus above thresholds considered relevant for water-based recreation (Ribaudo, 1986). Estimates of national and regional water quality-impaired river miles are based on USGS NASQAN data, National Water Discharge Inventories data from Resources for the Future, and the EPA River Reach File (Ribaudo, 1986). Recreation-

based water quality thresholds were obtained from EPA (Zison, Haven, and Mills, 1977). Damage estimates are divided by total sheet and rill erosion in the FPR from the 1982 NRI to arrive at an average cost per ton of erosion. A unit reduction in erosion would produce a like-level of benefits.

Soil conservation benefits across FPRs range from $0.0 to $0.12 per ton.

Steam-Electric Powerplants

Sediment and algae caused by soil erosion can affect the operation of steam-electric powerplants—most powerplants are steam-electric—and other facilities that use large amounts of water. Suspended sediment and algae can clog condensers, reducing the efficient operation of cooling systems. Periodic removal of algae from condensers restores water inflow rates. The benefits of reducing these costs are estimated by using the replacement cost approach.

Clark et al. (1985) generated a national estimate of annual restoration costs, based on a study of the cost of removing algae from water cooling systems. Ribaudo (1986) allocated these costs across the 10 FPRs, based on the amount of sediment withdrawn in water used for thermoelectric power generation. A proxy for sediment withdrawn is the product of gallons withdrawn and sediment concentration. Data on gallons of water withdrawn within each FPR were obtained from USGS. Average suspended sediment concentrations in each FPR are calculated using NASQUAN monitoring data. The FPR restoration cost estimates are then divided by total sheet and rill erosion in the FPR, based on the 1982 NRI, to arrive at an average cost per ton of erosion.

Soil conservation benefits range from $0.04 to $1.05 per ton.

Municipal and Industrial Water Use

Treated water can still contain minerals, salts, and other materials that damage water-use equipment. The model of erosion's impact on municipal and industrial water use is therefore based on the damage function approach.

Clark et al. (1985) used EPA estimates of the costs of achieving Clean Water Act goals to estimate the annual removal and damage costs of dissolved materials associated with soil erosion. Ribaudo (1986) allocates these damages among the 10 FPRs, based on the amount of water withdrawn for municipal and industrial uses. Ribaudo used the same procedure as for steam cooling, the only difference being that gallons of water withdrawn by industry and households were used to create the weights. FPR-level damage estimates were divided by total sheet and rill erosion from the 1982 NRI to arrive at an average damage per ton of erosion. A unit reduction in erosion would produce a like-level of benefits.

Soil conservation benefits range from $0.07 to $1.44 per ton.

Flood Damages

Suspended sediment in stream waters increases the frequency and severity of flooding. Reservoirs and flood plains have helped reduce flood damages,

yet damages still occur. Erosion plays a dual role in flood damages. First, it increases suspended sediment in stream flow, which then adds to the volume of the flow. The greater volume increases flood frequencies and the height of flood waters. Second, with greater concentrations of suspended sediment, floodwaters deposit more sediment, which increases damages to roads, farm fields, homes, and other flooded sites. With available data, the benefits of soil conservation's impacts on flood damages are estimated using the damage function approach.

The total cost of agricultural sediment-related flood damages was obtained from Clark et al. (1985). The national damage estimate was allocated to FPRs based on the distribution of total (sediment and nonsediment) flood damages reported by the U.S. Water Resources Council (1978). The FPR-level flood damage estimates were then divided by total agricultural erosion within the regions to generate dollar-per-ton benefit estimates.

Soil conservation benefits of reduced flood damages range from $0.10 to $0.77 per ton.

Irrigation Ditches and Canals

Nutrients and sediment originating on fields can cause excessive sediment buildup and weed growth in irrigation canals, impeding water flow in irrigation systems. Removing the sediment and weeds can restore the irrigation system to its original condition. With data on sediment and weed removal costs, soil conservation benefits are calculated using the replacement cost approach.

Clark and others (1985) estimated that approximately 15 to 35 percent of the operation and maintenance costs for irrigation systems is for weed control and ditch clearing. Ribaudo (1989) used the midpoint of this range, along with data on maintenance costs from the 1978 Census of Agriculture's *Ranch and Irrigation Survey* (U.S. Bureau of the Census, 1982) to estimate annual weed control and ditch-clearing costs associated with erosion for each State, which he then aggregated to the FPR level. Dividing this value by total sheet and rill erosion provides an estimate of the cost per ton of erosion.

We have used Ribaudo's approach and assumptions, erosion estimates from NRCS (2007), and weed control and ditch maintenance costs from the *2001 Census of Agriculture* to generate a more up-to-date estimate of soil erosion's impact on irrigation ditches and canals.

Soil conservation benefits range from $0.01 to $1.02 per ton.

Soil Productivity

Erosion carries topsoil off fields, which reduces the land's productivity. Some, but not all, yield loss can be offset by increasing nutrient use. Because soil loss decreases output and increases costs, the damage function approach is appropriate for modeling erosion's impact on soil productivity.

The Erosion Productivity Impact Calculator (EPIC) model (Williams et al., 1985) was used to estimate soil and yield losses and increases in input use

across 12,000 combinations of geographic regions, soil groups, crops, tillage, and conservation practices (Ribaudo et al., 1990). (The analysis assumes that farmers, in order to maximize profits, increase nutrient use to offset some of the productivity impacts of soil loss). These estimates were aggregated to generate FPR-level estimates of soil loss and the value of its productivity impact (Ribaudo et al., 1990). Per-ton estimates were derived by dividing total productivity impacts by total erosion (water and wind).

Values of *soil productivity* are based on the assumption that the land is in production. Benefits will not accrue while the land is fallow. Calculations for valuing the productivity effects of retired lands must discount benefits from the time when the land returns to production.

Soil conservation benefits, based on the soil productivity model, range from $0.26 to $1.27 per ton.

Road Drainage Ditches

Sediment carried off farms can fill roadside ditches, reducing the capacity of ditches to store and move floodwaters. Floodwaters can damage roads and impede traffic flows. Appropriate maintenance prevents or reduces these costs. With data on road maintenance costs, a model, based on the averting-expenditures approach, was developed to estimate the value of this benefit of soil conservation.

Ribaudo (1989) estimated a model where the annual cost of road maintenance was specified as a function of gross sheet and rill erosion, rural road mileage, and the cost of removing a cubic yard of sediment. Data on ditch maintenance costs were obtained from 33 State highway departments.

Results indicate that each ton of gross erosion reduction translates into an average reduction in ditch maintenance costs of $0.20.

Municipal Water Treatment

Sediment in surface waters can increase municipal water treatment costs. Sediment, in effect, damages or degrades the quality of water. A model that captures municipalities' willingness to pay to improve water quality can be estimated using the damage function approach.

A model of the effect of sediment on water treatment costs was estimated, using a water treatment cost model developed by Holmes (1988). The model expresses operation and maintenance costs of a treatment plant per million gallons of water withdrawn, as a function of the amount of water treated, the water's turbidity, labor cost, and electricity cost. This water treatment cost model was estimated with data from 294 treatment systems around the country.

To apply the treatment cost model to changes in erosion, Ribaudo (1989) estimates a water turbidity model, where turbidity is a log-linear function of soil erosion, streamflow, and water storage capacity. He uses the turbidity model to estimate the change in water turbidity within a USGS Aggregated Sub-Area due to a change in erosion. He then uses the treatment

cost model to calculate the marginal benefits of reductions in turbidity for each Aggregated Sub-Area. The per-unit costs were multiplied by estimated changes in turbidity given a marginal change in erosion. To develop FPR estimates of marginal per-ton benefits, estimates within each FPR were summed and weighted by the quantity of surface water the municipalities withdraw.

Soil conservation benefits, based on the municipal water treatment model, range from $0.05 to $1.16 per ton.

Dust Cleaning

Wind-borne particulates pass through cracks and openings in homes and settle on floors and furniture. Cleaning is necessary to get rid of the dust. Available cleaning-cost data and a replacement cost model are used to estimate the benefits of reduced wind erosion.

Huszar and Piper (1986) estimated a household-cleaning-cost model (which was subsequently improved by Huszar, 1989), where costs are a nonlinear function of household characteristics and wind erosion within the household's resident county. Their cost model is estimated with data from a survey of households in New Mexico. Ribaudo et al. (1990) used the model, along with data from 1980 Household Census and data on wind-erosion from the 1982 NRI, to estimate household cleaning costs and changes in costs due to changes in erosion by State for all States in the Northern and Southern Plains, Mountain, and Pacific FPRs. Marginal, per-ton benefit values were derived by dividing the changes in cleaning costs by the associated changes in wind erosion (Ribaudo et al., 1990).

Soil conservation benefits, based on the dust cleaning model, range from $0.0 in the six eastern FPRs to $1.14 per ton.

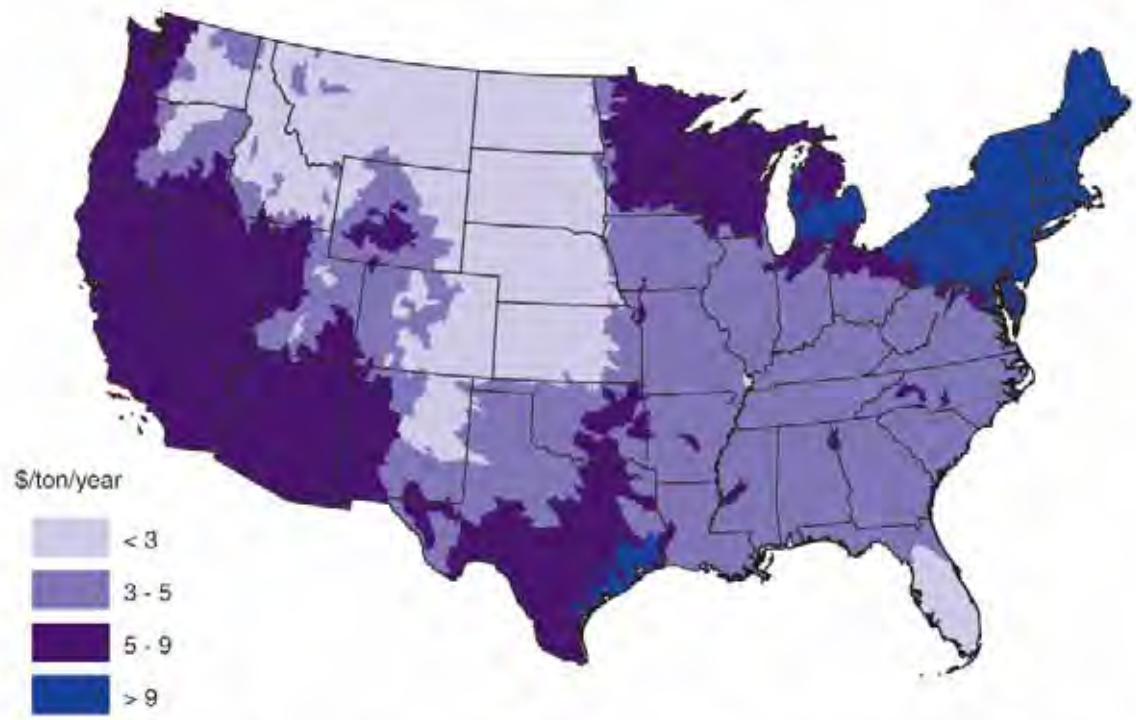
Most of the per-ton benefit estimates of the 11 FPR models are less than $0.50 (table 1). Though per-ton values are not high, each provides insight into the benefits of soil conservation programs and practices. Furthermore, the values provide a rough perspective on where the value of a reduction in erosion might be greatest.

Soil Conservation Benefits: HUC- and County-Level Values

The HUC-level water quality benefit categories *(reservoir services, navigation, and water-based recreation*) vary across HUCs. For those water quality benefit categories based on FPR-level estimates, values are broken down to HUC-level estimates based on the location of the HUC. Most HUCs lie in a single FPR. In these cases, the HUC-level values are set equal to the FPR-level values. Where HUCs lie in more than one FPR, the HUC-level values are erosion-weighted average values of the appropriate FPRs. The HUC-level sums of all categories of water-erosion benefits range from $1.11 to $17.55 per ton (fig. 3).

Values of wind-erosion impacts are estimated at the FPR level. The same approach as that used for HUC-level water quality benefits is used to generate HUC-level estimates of wind-erosion values. Wind-erosion benefit values, for the most part, follow FPR boundaries (fig. 4). Values vary along the borders of FPRs, where HUC-level estimates are weighted averages of he

Figure 3
Range and distribution of all water-erosion benefit values, by HUC



HUC-level[1] water-erosion benefit categories are: *reservoir services, navigation, water-based recreation, marine fisheries, freshwater fisheries, municipal industrial, steam electric, irrigation ditches, flood damages, soil productivity, road ditches*, and *municipal water treatment*. Only *reservoir services, navigation*, and *water-based recreation* are estimated at the HUC level. Other values are based on FPR-level[2] estimates.

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

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The HUC-level water quality benefit categories (*reservoir services, navigation, and water-based recreation*) vary across HUCs. For those water quality benefit categories based on FPR-level estimates, values are broken down to HUC-level estimates based on the location of the HUC. Most HUCs lie in a single FPR. In these cases, the HUC-level values are set equal to the FPR-level values. Where HUCs lie in more than one FPR, the HUC-level values are erosion-weighted average values of the appropriate FPRs. The HUC-level sums of all categories of water-erosion benefits range from $1.11 to $17.55 per ton (fig. 3).

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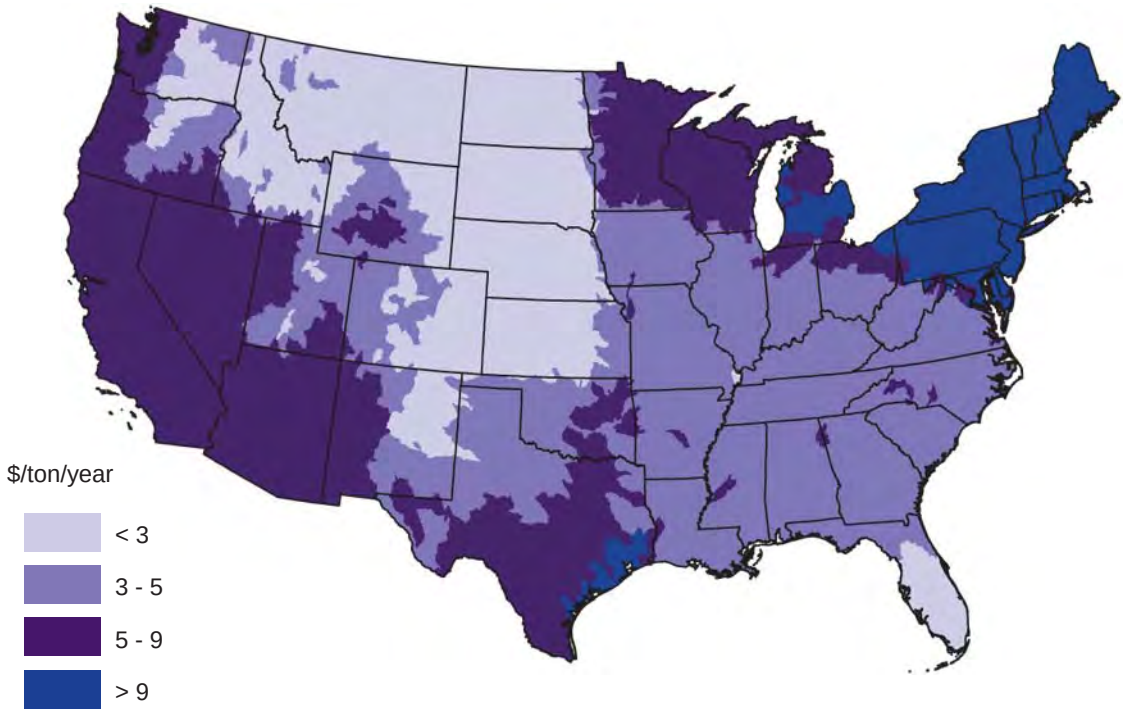

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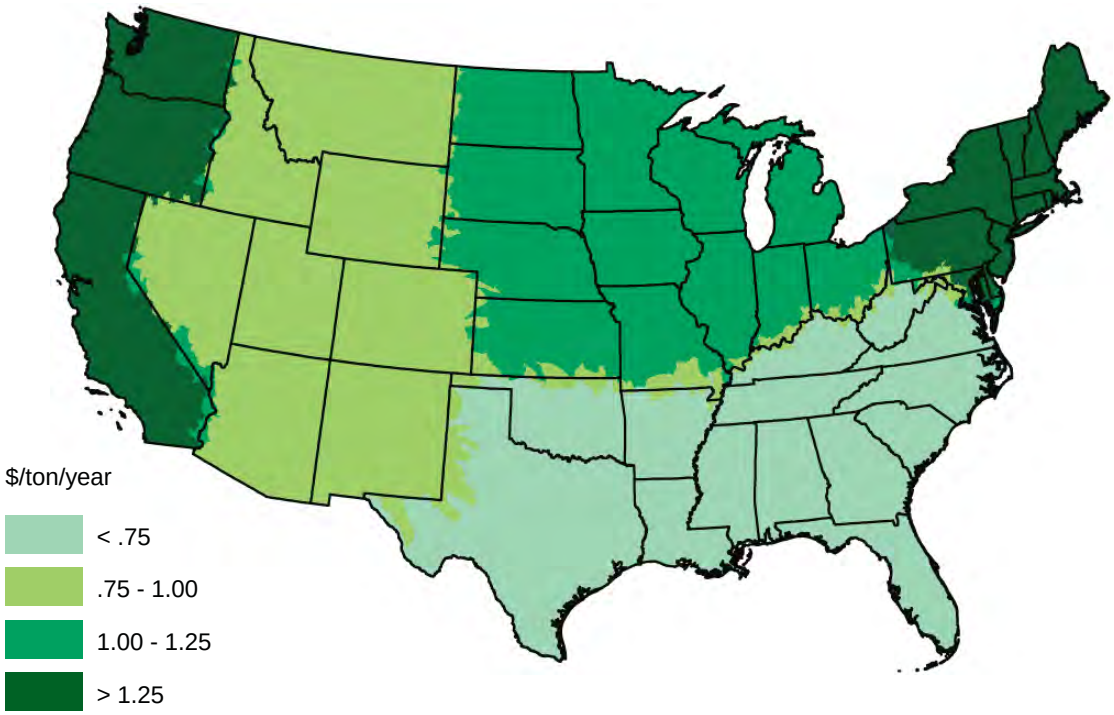
[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

Figure 4
Range and distribution of all wind-erosion benefit values, by HUC[1]



HUC-level wind erosion benefit categories are *dust cleaning* and *soil productivity*. Values are based on FPR-level[2] estimates.

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

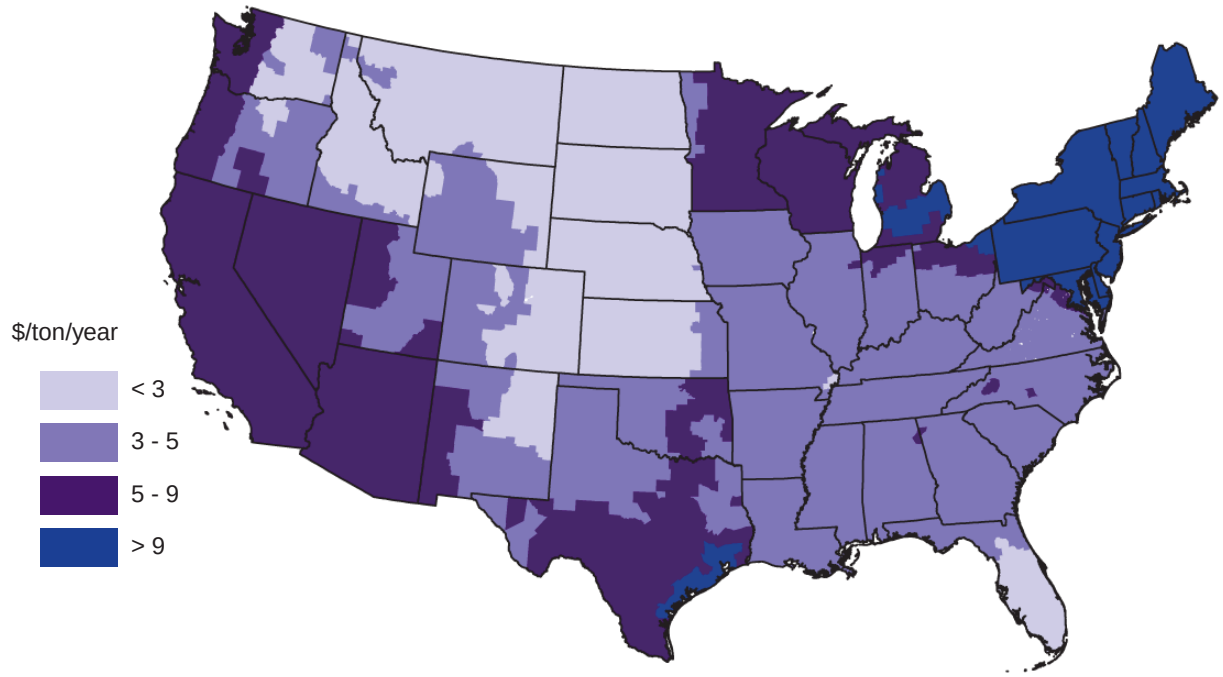
value of two or more FPRs. When the HUC-level wind-erosion benefit values are summed, values range from $0.41 to $1.54 per ton.

The county-level estimates of the benefit values that are derived from HUC-level models (*reservoir services, navigation, and water-based recreation)* are erosion-weighted average values. Note that for counties that lie in a single HUC, the county-level values equal the HUC-level values. The county-level benefit values are, in effect, taken directly from the FPR-level estimates because counties do not cross FPR borders. The county-level sums of the water-erosion benefit estimates range from $1.70 to $18.24 per ton (fig. 5). The county-level sums of the wind erosion benefit values range from $0.41 to $1.54 per ton. Because both wind-erosion benefit values have been estimated at the FPR level, values follow FPR boundaries (fig. 6).

Although many of the benefit models were formulated some time ago, the values they generate are the most complete summary of soil erosion reduction benefits available. More accurate assessment of soil conservation benefits will be possible in the future if additional research improves the accuracy and geo-resolution of available estimates or expands upon the benefits that have been assessed to date.

Figure 5

Range and distribution of all water-erosion benefit values, by county

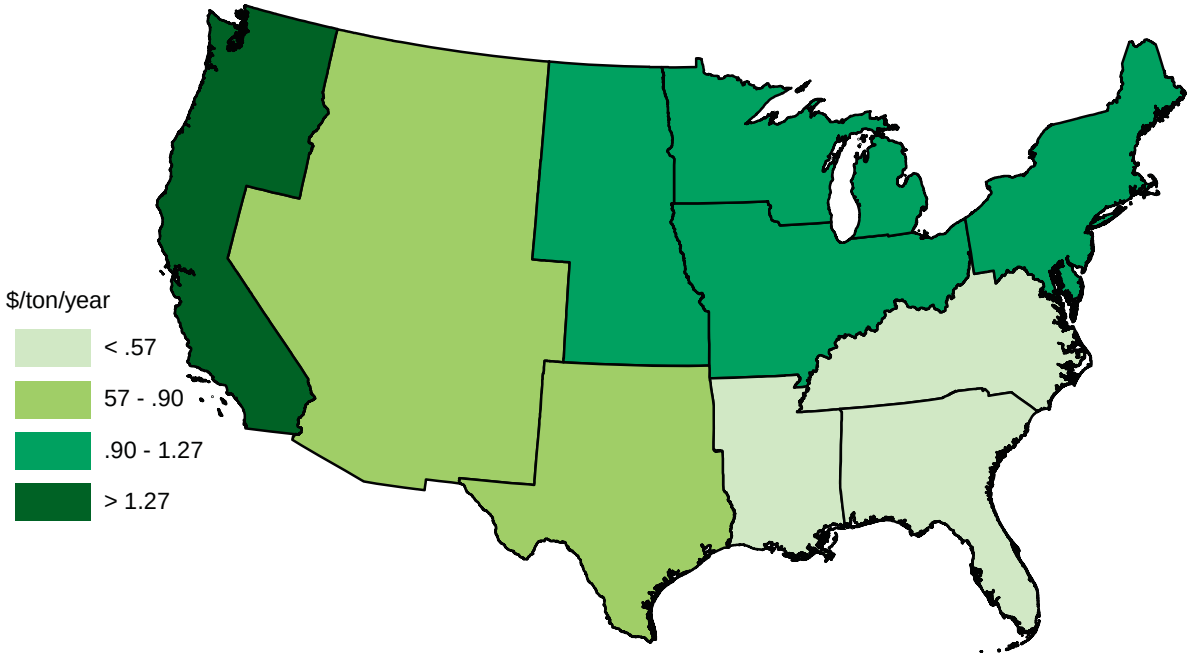


County-level water-erosion benefit categories are: *reservoir services, navigation, water-based recreation, marine fisheries, freshwater fisheries, municipal industrial, steam electric, irrigation ditches, flood damages, soil productivity, road ditches*, and *municipal water treatment*. None are estimated at the county level. *Reservoir services, navigation*, and *water-based recreation* are estimated at the HUC level.[1] Other values are based on FPR-level estimates.[2]

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

Figure 6

Range and distribution of all wind-erosion benefit values, by county



County-level wind erosion benefit categories are *dust cleaning* and *soil productivity*. Values are based on FPR-level[1] estimates.

[1]FPRs are USDA's multi-state Farm Production Regions.

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Economic Linkages Between Coastal Wetlands and Habitat/Species Protection: A Review of Value Estimates Reported in the Published Literature

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Economic Linkages Between Coastal Wetlands and Habitat/Species Protection: A Review of Value Estimates Reported in the Published Literature

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Summary

This manuscript summarizes a total of 8 peer-reviewed studies,[1] published from 1975 to 2001, reporting 24 separate estimates for the disaggregate[2] value of habitat and species protection services provided by coastal and non-coastal wetlands. Estimates varied within a single order of magnitude and were fairly tightly bounded. Considering only coastal zone wetlands across all study categories, the value of habitat and species protection ranged from $168.96/acre/year to $403.16/acre/year, with a mean and median of $249.44/acre/year and $253.47/acre/year, respectively.[3, 4] By comparison, reported estimates of willingness-to-pay (WTP) values for wetland habitat and species protection services ranged from a low of $30.12 to $434.67, with a mean and median of $211.59 and $213.86, respectively. Geographic location and type of wetland appeared to have a relatively minor impact on the estimated values.

Introduction

Coastal wetlands are increasingly recognized as essential to natural systems and human activities because of the environmental services that they provide. However, this recognition has not resulted in capitalized economic value for landowners (Heimlich et al. 1998). Nonmarketed wetland benefits may be important to society, but the lack of a market value for the services means that they are often de-emphasized relative to physical loss or the private economic gains that can arise from conversion of wetlands to other land uses (van Vuuren and Roy 1993). While the search for quantitative measures of wetland values is challenging due to the diversity, socioeconomic context, and complex hydro-biological functions of wetlands (Scodari 1990), informed policy requires that both market and nonmarket wetland values be incorporated into the decision making process.

One of the most important, but nonmarketed, services provided by coastal wetlands is habitat and species protection, and in particular the provision of reproductive habitat for threatened and endangered species. Wetland preservation efforts began early in the last century out of concern for waterfowl habitat when President Roosevelt established the first National Wildlife Refuge in 1903 to protect Pelican Island,

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[1] To the author's knowledge this represents all the peer-reviewed published studies that explicitly seek to value the linkage between wetlands and water quality/purification services.

[2] From a theoretical economic perspective, the services provided by wetlands generally should not be disaggregated and valued separately due to the potential for double counting and offsetting effects (see Pendleton and Shonkwiler [2001] for a discussion of this in a different context). For example, the provision of water purification services may, in many cases, simultaneously provide for increased habitat and species protection. Valuing each of these services separately (when, in fact, they are inseparable) and summing will lead to overestimating total potential wetland value.

[3] All values in year 2000 dollars (see Table 1).

[4] In a partial review of wetland valuation studies, Heimlich et al. (1998) calculated a much broader range on the per acre value estimates, in part because they considered the provision of a number of different services besides water quality, but also because they converted household and individual willingness-to-pay (WTP) values to per acre values using various assumptions not necessarily contained in the original studies. The review presented in this manuscript does not take this approach, and instead lists the WTP values separately (if not originally presented on a per acre basis) for comparison purposes.

a nesting site for colonial water birds. The Migratory Bird Hunting Stamp Act of 1934 established a special fund to finance wetlands acquisitions for duck habitat. In 1961, the Wetlands Loan Act allowed advanced appropriations for the purchase of wildlife refuges and waterfowl production areas (National Aududon Society 1996), leading to the current National Wildlife Refuge system that contains over 500 refuges and nearly 200 Waterfowl Protection areas (Stewart 1996). Recent legislative and administrative efforts to protect wetlands and the critical habitat that they encompass include the 1970 Water Bank program, Section 404 of the Federal water Pollution Control Act Amendments of 1972, Executive Order 11990 issued by President Carter in 1977, the Small Wetlands Acquisition program of the U.S. Fish and Wildlife Service, "Swampbuster" provisions in the 1985 Food Security Act, and the Wetland Reserve Program (Heimlich et al. 1998). Most of these programs and polices were implemented without any explicit consideration of the economic benefits associated with habitat and species protection.

This report documents the current status of knowledge concerning the economic value of the habitat and species protection services generated by coastal and other wetlands. In particular, studies that focus on valuing habitat and species protection services as an unbundled product of wetland function are highlighted.[5] A brief overview of the economic linkages between wetland ecosystems and habitat/species protection is first presented, thus providing a basic framework for understanding why specific variables and measurement methods are of interest. Second, the common methods used to value the habitat and species protection services of wetlands are outlined, along with their major advantages and disadvantages. This information can help the reader evaluate the usefulness of any particular estimate. Next, the results of individual valuation studies are presented and summarized. Lastly, the report concludes with a complete list of the literature cited.

Relationship Between Wetlands and Habitat/Species Protection

Policymakers face complex, multi-objective trade-offs when attempting to develop strategies for coastal restoration and protection.[6] Implementation of any specific strategy will result in benefits and costs that will, in general, be different than those experienced under alternative strategies. Economics can be used to help inform policymakers about the relative benefits and cost of different strategies, but analysts require information on (1) the relationship between anthropogenic activities and coastal wetland loss, (2) the costs imposed on society from coastal wetland loss, and (3) the costs of taking action to prevent coastal wetland loss. In the typical environmental management scenario, human activities are considered to be a cause of degradation, and the management of these activities via regulation or the use of economic instruments has the goal of reducing environmental impacts. Changing established human activities is potentially costly, and the cost will vary by the specific type of activity and its interrelationship with the environment. While some Louisiana coastal wetland loss can be attributed to traditional human industrial, municipal, and agricultural activities, natural environmental processes on a regional, hemispheric, and global scale are also important. Complicating the identification of causal linkages and their importance to habitat and species protection is the heterogeneity of existing wetlands. Some wetlands perform many functions, but some may perform few or even none. In addition, many of the environmental services are generated simultaneously in varying degrees by the same wetland function. From this perspective, the habitat and species protection services of wetlands can best be understood as part of an economic joint product. This jointness-in-products creates difficulties in measuring the economic importance of specific wetlands functions, and as a result the literature contains a limited

[5] A substantial part of the wetland valuation literature attempts to measure the theoretically correct multi-product value of wetlands and not the individual service components. An overview of the results generated by these studies is presented in the report (Table 2) for comparison to the single-product water quality value estimates.
[6] The following discussion was adapted from Keithly and Ward (2001) and Heimlich et al. (1998).

number of empirical studies that isolate the habitat and species protection benefits associated with wetland integrity.

Abstracting from the technical measurement difficulties, there a number of general benefits that accrue to society from its interaction with any large-scale ecosystem such as coastal wetlands (Pearce and Turner 1990). Ecosystems supply both stock and flow resources that can be used as direct and indirect inputs to production and consumption activities, thereby generating productivity and growth in the overall economic system. While the resources can be either renewable or nonrenewable, goods and services provided by Louisiana's coastal wetlands (and their associated marine ecosystems) are generally considered renewable resources.[7] The provision of habitat and species protection services via ecological support processes can be considered one of these renewable resources.

Wetlands are the most biologically productive ecosystems in the temperate regions, rivaling tropical rain forests (Mitsch and Gosselink 1993). Their biological productivity derives from an ability to recycle nutrients and energy, and provide habitat for living organisms.[8] Some fish and wildlife species spend their entire lives in wetlands and others using them intermittently for feeding or reproduction. Amphibians and reptiles also depend on wetlands, and are particularly sensitive to wetland degradation. In addition, over one-third of all bird species in North America rely on wetlands for migratory resting places, breeding or feeding grounds, or cover from predation (Kroodsma 1979). Many larger animals, such as muskrat, beaver, otter, mink, and raccoon prefer wetlands as their habitat, and wetland habitats are critical for the survival of a number of threatened and endangered species. The linkage of these habitat-related biophysical functions with economic value comes from the nonconsumptive, nonmarket value of the species and the nonmarket value of wetland aesthetics. This nonmarket orientation complicates wetlands policy because the habitat services rendered by wetlands are public goods whose benefits accrue to society at large, not specifically to wetland owners. As a result, many private wetland owners may find it more profitable to convert wetlands to alternative uses or abandon its maintenance altogether.

Once the conceptual benefits of an ecosystem are identified, economic values need to be assigned to these benefits. Having these assigned values allows policy makers to quantitatively assess the economic benefits that society might gain from marginal improvements in the integrity of the ecosystem. Value is associated with the amount that society (both current and future generations) would be willing to pay for the economic system characteristics (primarily the services and attributes) provided by the ecosystem if they were not provided free of charge. The greater the benefits derived from the services provided by any particular ecosystem, the more that ecosystem is valued by society. In general, the value of these services tends to be positively related with the integrity of the ecosystem. Of course, any action taken to decrease the loss of Louisiana's coastal wetlands, and thus increase the welfare of society at large, comes with a cost. These costs must be weighed against the benefits to determine, from the criteria of welfare economics, whether action is warranted, and to what extent.

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[7] While significant nonrenewable mineral extraction, and the related economic activity, takes place in coastal Louisiana and the adjacent continental shelf, to a large extent its continued existence is not dependent on maintaining the integrity of the coastal wetlands. The extraction industry's cost structure may change if coastal wetlands are lost, but not likely to the extent that they would become economically infeasible. Navigation and port activities, however, are more likely to be negatively affected by the loss of coastal wetlands.

[8] And thus the joint-product link between habitat/species protection and the water quality services of wetlands.

Valuation Methods

The total economic value of a wetland area is the sum of the amount of money that all people who benefit from the wetland area would be willing to pay to see it protected (Whitehead 1992). If this definition of wetland value is to be empirically viable, individuals that benefit must (1) realize that they benefit, (2) understand the full extent to which they benefit, and (3) be capable of placing a dollar value on the level of their benefits, either through reference to market-based prices or some alternative, nonmarket pricing system. Methods for valuing the stock of natural capital assets and service flows generated by wetlands have been extensively discussed in both the published and unpublished literature.[9] While philosophical debate has occurred over the ability to empirically measure the full range of benefits that flow from an environmental resource, economists generally agree that accurate measurement is possible if valuation studies are carefully conducted (U.S. Department of Commerce 1993). In fact, review of past nonmarket valuation studies suggests that previously perceived variability and unreliability in the estimated values does not actually exist, particularly if one controls for the varying characteristics of the resources being valued and the way in which the estimated values are presented (Carson et al. 1996). Thus, published value estimates might be useful in analyzing the economic impact of Louisiana's coastal wetlands as long as careful attention is given to the details of the study and the resources being valued.[10]

Four theoretically plausible valuation methods have been used in the neoclassical economic literature to place valid dollar values on wetland resources.[11] These methods are the net factor income (NFI) method, the contingent valuation method (CVM), the travel cost method (TCM), and the hedonic price method (HPM). A fifth set of methods found in the literature, but not theoretically valid under typical application, is the damage cost or replacement cost methods (DCM or RCM). All of these methods are briefly described below. In addition, the non-neoclassical literature, as well as the biological literature, often contains studies employing energy analysis methods (EAM), whereby the value of ecosystem assets are directly related to their energy processing abilities.[12] Shabman and Batie (1978) detailed the fundamental problems and economic fallacies imbedded in this approach,[13] and no further discussion of its use is included in this report. The results from two studies employing EAM, however, are reported in Table 2 in order to completely characterize the wetland valuation literature.

The NFI method uses market prices to measure the additional profit earned by firms due to the contribution of the wetlands to production activities, and it generates use values. Thus, the NFI method is

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[9] For excellent early overviews, see Greenley et al. (1982) and Amacher et al. (1989). Scodari (1990) provides a thorough review of the advantages and disadvantages of various methods specifically within a wetland valuation context, while Whitehead (1992) contains a lucid, if somewhat terse, review of the methods and the theory behind them. More recent papers detailing established and newer methods include Feather et al. (1995), Apogee Research, Inc. (1996), Mahan (1997), Bockstael (1998) and Pendleton and Shonkwiler (2001). For comprehensive reviews of the theory and application of contingent valuation methods for nonmarket goods and services, see U.S. Department of Commerce (1993) and Bishop et al. (1998).

[10] This type of detailed examination was beyond the time constraints of this study, but it should be seriously considered for inclusion in future phases of a valuation project.

[11] The brief methods discussion borrows from Amacher et al. (1989), Whitehead (1992), and others.

[12] This approach, which first received widespread publicity and policy attention due to a study by Gosselink et al. (1974), is based on the Odum and Odum (1972) contention that society's use of resources should maximize the net energy production of the total environment (including its natural and developed components).

[13] The fundamental problem is that EAM fails to recognize the nature of the process by which economic values are determined, and makes an "illegitimate marriage" of the principles of systems ecology with economic theory (Shabman and Batie 1978). "This leads to estimates of marsh service value that are, at best, inaccurate. At worst, these inaccurate estimates may capture the focus of policy debate, and hinder, rather than improve, the resource management process for coastal wetlands."

most appropriate when the wetland provides a service that leads to an increase in producer surplus, or the economic gains attained by the users of the resource, because it exploits the relationship between the value of the production activity and the wetland acreage. In the NFI method the physical relationship between wetland areas and the economic activity is empirically estimated from data on the production activity. It is then possible to identify the increase in producer surplus (economic gain) associated with the use of the wetland resource.[14] If the empirical estimates are obtained through statistical regression, then estimates of the marginal value product (MVP) of the wetland resource can be generated. In this context, the MVP provides a direct measure of the firm owner's willingness-to-pay to avoid wetland degradation.

Producer surplus generated by the use of a wetland can also be estimated using the RCM. This approach values the wetland=s service based on the price of the cheapest alternative way of obtaining that service. For example, the value of a natural wetland in the treatment of wastewater might be estimated using the cost of chemical, mechanical, or constructive alternatives. The use of RCMs needs to be governed by three considerations (Shabman and Batie 1978): (1) the alternative considered should provide the same services, (2) the alternative selected for cost comparison should be the least-cost alternative, and (3) there should be substantial evidence that the service would be demanded by society if it were provided by that least-cost alternative. Taken together, these condition differentiate RCM from the more general class of DCMs, where the entire value of a marketable good or service is tied to the preservation of a wetland resource, ignoring consumer and producer substitution possibilities. Even with restrictive application, the RCM can only be considered to yield an upper bound on the true WTP for the wetland service because the producer may not choose to actually use the alternative considered (Anderson and Rockel 1991).

The CVM is a survey approach that measures the total economic value of all wetland goods and services by directly asking individuals about their WTP. The CVM establishes a hypothetical market by providing information about wetland resources, specifying payment rules and vehicles, and posing valuation questions. Answers to these questions can be used to directly measure WTP, and CVM may be the only way to estimate many non-use values of environmental resources. But, in order for CVM to yield valid economic measures, study participants must be both willing and able to reveal their values. Other valuation approaches, such as TCM and HPM discussed below, depend on revealed preferences through market transactions and other behavior. Statements from economic actors about how they would act under hypothetical circumstances, as used in the CVM, are a very different measure and ultimately need to assessed for validity (Bishop et al. 1998). A panel of experts organized by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, and co-chaired by Nobel laureate economists Kenneth Arrow and Robert Solow, concluded that (1) there is too much positive evidence to dismiss CVM and its usefulness in providing information about values, (2) CVM studies do not automatically generate value information, but are highly dependent on the content validity of the survey, and (3) CVM is an evolving market valuation technique (U.S. Department of Commerce 1993). In the words of the panel (p. 4610), “CV studies convey useful information. We think it is fair to describe such information as reliable by the standards that seem to be implicit in similar contexts, like market analysis for new and innovative products and the assessment of other damages normally allowed in court proceedings . . . . Thus, the Panel concludes that CV studies can produce estimates reliable enough to be a starting point of a judicial process of damage assessment, including lost passive-use values.”

The TCM approach is often used to measure the recreational benefits of wetlands, but it is generally applicable to valuing any nonmarket wetland good or service that individuals are willing to

[14] In practice, it is often assumed that the demand for the good being produced by the user is perfectly elastic, and thus changing wetland services has no effect on consumer surplus.

travel to and use at the wetland site. The TCM method estimates the costs incurred traveling to visit and use the site, with the concept being that the travel and time costs are measures of implicit market prices. The estimated costs are then used to construct demand functions that use travel and time costs as independent variables.[15] Consumer surplus per recreation trip and year can then be approximated from the estimated demand curve. The application of TCM assumes that (1) users have identical utility functions for the activity, and thus will have identical demand functions, (2) users are indifferent between incurring costs as user fees or travel costs, (3) weak complimentarity holds in that changes at competing sites do not affect use at the site being valued, and (4) site use is not congested. Given these assumptions, TCMs cannot be used to value nonmarket goods and services that either do not require the user to visit the site or that are offsite products. Furthermore, TCM generally cannot account for multiple sites, visits to multiple sites on the same trip, or the impact of small resource changes on user perceptions and travel patterns.

The HPM has been used to measure the contribution of wetlands for flood control and the role of wetland aesthetics in housing and property prices. Thus, HPMs attempt to tie wetland service value directly to a market price (Freeman 1998). In a market at equilibrium, land values and land rents should be a function of land characteristics, including the proximity to and services provided by wetlands. The increment to the land or housing price arising from wetland services is a measure of the implicit price of that service. There are three key assumptions required to apply HPM to estimate the wetland contribution to land values. First, there must be data on a continuum of sites with varying wetland characteristics and acreage. Second, purchasers and sellers of wetland parcels are assumed to have access to the same information regarding the condition of the site and the nature and use of the wetland. Third, wetland purchasers (or purchasers of property near wetlands) are assumed to have identical preferences for wetland characteristics. The assumption of identical preferences makes estimation of demand curves possible when data does not exist about individual preferences.

The valuation method employed in any particular habitat and species protection valuation study depends primarily on the ability to quantitatively discern the biophysical linkages between characteristics of a particular wetland area and the potential changes in the quality and quantity of habitat for a given species. Given that this relationship is often poorly understood from a quantitative perspective, CVM may be most appropriate valuation approach even in light of its limitations. No habitat/species protection valuation studies were found that employed NFI, TCM, HPM, or RCM approaches.

Review of Estimated Values

No estimates for the value of Louisiana wetlands in the provision of habitat and species protection services were found in the published literature. Studies conducted for wetlands in other regions of the U.S. reported habitat and species protection service values that ranged from a low of $168.96/acre/year to a high of $403.16/acre/year, with a mean and median value of $260.09/acre/year and $258.14/acre/year, respectively.[16, 17] One international study reported an aggregate world-wide wildlife habitat service value of $142.92/acre/year for coastal wetlands. Considering only coastal zone wetlands across all study categories, the value of habitat and species protection ranged from $168.96/acre/year to

[15] Other independent variables are also employed, including the theoretically requisite income and various potential demand shifters, depending on the situation being modeled.

[16] All values in year 2000 dollars.

[17] It should be emphasized that all but one of the reported U.S. valuation studies were conducted by one set of authors in the mid-1970s. The importance of this information to understanding the value of habitat and species protection services derived wetlands is not clear, although it is always preferable to have multiple, independent studies on which to base inferences.

$403.16/acre/year, with a mean and median of $249.44/acre/year and $253.47/acre/year, respectively. For comparison purposes, reported estimates of willingness-to-pay (WTP) values for habitat and species protection ranged from a low of $30.12 to $434.67, with a mean and median of $211.59 and 213.86, respectively. Geographic location and type of wetland appeared to have a relatively minor impact on the estimated values.

Table 1. Published estimates of habitat and species protection service values provided by wetlands, 1975-2001.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					U.S. Specific Studies						
Gupta and Foster 1975	White Cedar Bog, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	670	36.01[b]	168.96
Gupta and Foster 1975	Otis Fresh Meadows, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	744	39.99[b]	187.64
Gupta and Foster 1975	Bear Meadows, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	893	46.39[b]	217.67
Gupta and Foster 1975	Hyannis Wooded Swamp, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	911	48.97[b]	229.77
Gupta and Foster 1975	Moore's Pond, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	1,005	54.02[b]	253.47
Gupta and Foster 1975	Chicopee River Marshes, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	1,042	56.01[b]	262.80
Gupta and Foster 1975	Hoosic River Swamp, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	1,079	58.00[b]	272.14
Gupta and Foster 1975	Lawrence Swamp, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	1,172	63.00[b]	295.60
Gupta and Foster 1975	Wenham Swamp, Massachusetts	-----	Wildlife habitat	-----	Average state acquisition price scaled by wildlife habitat productivity score	5.375	Infinite	1970	1,228	66.01[b]	309.73

Table 1. Published estimates of habitat and species protection service values provided by wetlands, 1975-2001 – continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
U.S. Specific Studies											
Woodward and Wui 2001	-----	Mixed	Wildlife habitat	-----	Econometric meta-analysis of 39 studies yielding per acre values; excludes WTP where per acre value was not generated	-----	-----	1990	-----	306 90% C.I. of 95 - 981	403.16
International Studies											
Costanza et al. 1997	World wide	Coastal wetlands	Wildlife habitat	815 million	Mixed aggregation of various studies; little detail given concerning specific studies	-----	-----	1994	-----	123	142.92
Studies Where Value Not Reported on an Area Basis											
Morrison et al. 1999	New South Wales, Australia	Ephem. wetlands	Habitat and endangered species; non-use employment	297,000	WTP using choice modeling	-----	-----	1997	-----	34.04-73.19 [e] with job losses ($Australian)	30.12 [c e]
Morrison et al. 1999	New South Wales, Australia	Ephem. wetlands	Habitat and endangered species; non-use employment	297,000	WTP using choice modeling	-----	-----	1997	-----	48.75-102.62 [e] no job losses ($Australian)	41.01 [c e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Protection of wildlife from contamination	90,000	WTP mail survey of Oregon residents, with emphasis on distance effect	-----	-----	1989	-----	51.92 [e]	72.10 [e]
Stevens et al. 1995	New England	General wetlands	rare species protection	-----	WTP contingent valuation mail survey	-----	-----	1993	-----	88.42 [e]	105.37 [e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Protection of wildlife from contamination	90,000	WTP mail survey of Washington residents, with emphasis on distance effect	-----	-----	1989	-----	86.35 [e]	119.92 [e]
Creel and Loomis 1992	San Joaquin Valley, California	Wetland recreation areas	Viewing	-----	Linked site selection and trip count models	-----	-----	1988	-----	140.00 [d e]	203.79 [e]

Table 1. Published estimates of habitat and species protection service values provided by wetlands, 1975-2001 – continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
---------- Studies Where Value Not Reported on an Area Basis ----------											
Loomis et al. 1991	San Joaquin Valley, California	General wetlands	Preservation and maintenance	85,000	WTP contingent valuation with acreage reference	-----	-----	1989	-----	154.00[e]	213.86[e]
Loomis et al. 1991	San Joaquin Valley, California	General wetlands	Waterbird protection from increased contamination	-----	WTP contingent valuation	-----	-----	1989	-----	188.00[e]	261.08[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Protection of wildlife from contamination	90,000	WTP mail survey of Nevada residents, with emphasis on distance effect	-----	-----	1989	-----	203.08[e]	282.02[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Protection of wildlife from contamination	90,000	WTP mail survey of California residents outside the San Joaquin Valley, with emphasis on distance effect	-----	-----	1989	-----	222.69[e]	309.25[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Protection of wildlife from contamination	90,000	WTP mail survey San Joaquin Valley residents, with emphasis on distance effect	-----	-----	1989	-----	233.86[e]	324.76[e]
Loomis et al. 1991	San Joaquin Valley, California	General wetlands	Improvement	125,000	WTP contingent valuation with acreage reference	-----	-----	1989?	-----	254.00[e]	352.73[e]
Loomis et al. 1991	San Joaquin Valley, California	General wetlands	Decrease contamination of waterbirds	125,000	WTP contingent valuation	-----	-----	1989?	-----	313.00[e]	434.67[e]

[a] Study values inflated to common year 2000 values using the Bureau of Labor Statistics (BLS) CPI Inflation Calculator, which bases yearly adjustments on the average consumer price index by year.
[b] All values were based on a $70/acre/year value for a site with a score of 100 on the productivity scale.
[c] Inflated to year 2000 using the BLS CPI Inflation Calculator and converted to U.S. dollars using the ratio $1.89 Australian/$1.00 U.S.
[d] Mean of two differently specified models.
[e] Value is not reported on a per acre per year basis. In most cases, the value represents household willingness-to-pay for the service where the service/wetland quantity relationship is not defined.

Table 2. Published estimates of total service values provided by wetlands, 1975-2001.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Louisiana Specific Studies											
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Coastal Louisiana	Summation of commercial fishing, trapping, recreation, and storm protection	650,000	Simple summation of mixed method estimates of individual services	8.0	Infinite	1983	586.73	46.94	81.16
Costanza et al. 1989	Louisiana	Coastal wetlands	Commercial fishing, trapping, recreation, and storm protection	-----	Production function, revenue accounting, travel cost, and WTP contingent valuation	8.0 , 3.0	Infinite	1983	2,429 - 8,977	194.32[b]	335.96
Costanza and Farber 1987, Costanza et al. 1989	Terrebonne Parish, Louisiana	Fresh coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	6,400	512.00	885.20
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Saltwater coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	6,700	536.00	926.70
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Brackish coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	10,602	848.16	1,466.40

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
---------- **Additional U.S. Studies** ----------											
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	741 undiked	Travel cost	4.0	50	1985	4,435	83.55	133.71
Gupta and Foster 1975	Massachusetts	LLNN Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	500	40	165
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	370.7 diked	Travel cost	4.0	50	1985	6,027	113.54	181.71
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	49.4 diked	Travel cost	4.0	50	1985	6,968	131.27	210.08
Roberts and Leitch 1997	Mud Lake, MN-SD	Fresh wetland	All services	-----	Cost savings, residual return to water utilities, contingent valuation	-----	-----	1995	-----	375	423.72
Gupta and Foster 1975	Massachusetts	HLNN Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	1,400	113	466
Gupta and Foster 1975	Massachusetts	LLNH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	1,700	137	564

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
---------- **Additional U.S. Studies** ----------											
Gupta and Foster 1975	Massachusetts	MMNM Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	3,000	242	997
Gupta and Foster 1975	Massachusetts	LHNL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	4,100	330	1,359
Gupta and Foster 1975	Massachusetts	HHNH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	6,000	484	1,994
Gupta and Foster 1975	Massachusetts	LLLL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	6,400	519	2,138
Gupta and Foster 1975	Massachusetts	HHLH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	11,700	943	3,885

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Additional U.S. Studies											
Gupta and Foster 1975	Massachusetts	HHMH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	26,000	2,095	12,750
Gupta and Foster 1975	Massachusetts	LLHL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	40,700	3,280	13,512
International Studies											
Gupta and Foster 1975	Massachusetts	HHHH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	46,000	3,707	15,271
Thibodeau and Ostro 1981	Charles River Basin	Costal wetlands	All services	8,535	Simple summation of mixed method estimates of individual services	6	Infinite	1978	171,772	10,306.32	27,220
Gren et al. 1995	Danube floodplain	Mixed	All ecosystem services	4.3 m	Summation of individual service estimates	5.0 and 2.0 percent	infinite	1991	3,027 ecu to 7568 ecu per acre	151.35 ecu	174.13[c]
Costanza et al. 1997	World wide	Coastal wetlands	All services and products	815 m world wide	Mixed aggregation of various studies; little detail given concerning specific studies	-----	-----	1994	-----	5,983	6,952

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
International Studies											
Sathirathai and Barbier 2001	Thailand	Mangrove wetland	Direct and indirect use (timber, fishing, coastline protection)	988	various	-----	-----	1993	-----	1,553[d]	1,851
Studies Where Value Not Reported on an Area Basis											
Mullarkey and Bishop 1999	Northwest Wisconsin	Fresh wetland	Total value under high certainty	110	WTP mail survey; respondent certainty and scope test included	-----	-----	1995	-----	20.77 [e]	23.47 [e]
Mullarkey and Bishop 1999	Northwest Wisconsin	Fresh wetland	Total value under low certainty	110	WTP mail survey; respondent certainty and scope test included	-----	-----	1995	-----	57.83 [e]	65.34 [e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Oregon residents	-----	-----	1989	-----	67.80 [e]	94.15 [e]
Loomis et al. 2000	Nebraska	Platte River	Wastewater dilution, water purification, erosion control, habitat, and recreation	300,000	WTP mail survey	-----	-----	1998	-----	252 [e]	100.79 [e]
Stevens et al. 1995	New England	General wetlands	Recreation, rare species, food production, flood protection, water supply and pollution control	-----	WTP contingent valuation mail survey	-----	-----	1993	-----	114.29 [e]	136.20 [e]

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Studies Where Value Not Reported on an Area Basis											
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Washington residents	-----	-----	1989	-----	99.75[e]	138.52[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Nevada residents	-----	-----	1989	-----	196.01[e]	272.20[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey California residents outside the San Joaquin Valley	-----	-----	1989	-----	210.77[e]	292.70[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of San Joaquin Valley residents	-----	-----	1989	-----	215.55[e]	299.34[e]

[a] Study values inflated to common year 2000 values using the Bureau of Labor Statistics (BLS) CPI Inflation Calculator, which bases yearly adjustments on the average consumer price index by year.
[b] Storm protection accounted for 79 percent ($153.20/acre/yr) of the total value.
[c] Inflated to year 2000 using the BLS CPI Inflation Calculator and converted to U.S. dollars using the ratio 1.10 ecu/$1.00 U.S.
[d] Value is strongly influenced by estimates for coastline protection, which account for 96% of the total.
[e] Value is not reported on a per acre per year basis. In most cases, the value represents household willingness-to-pay for the service where the service/wetland quantity relationship is not defined.

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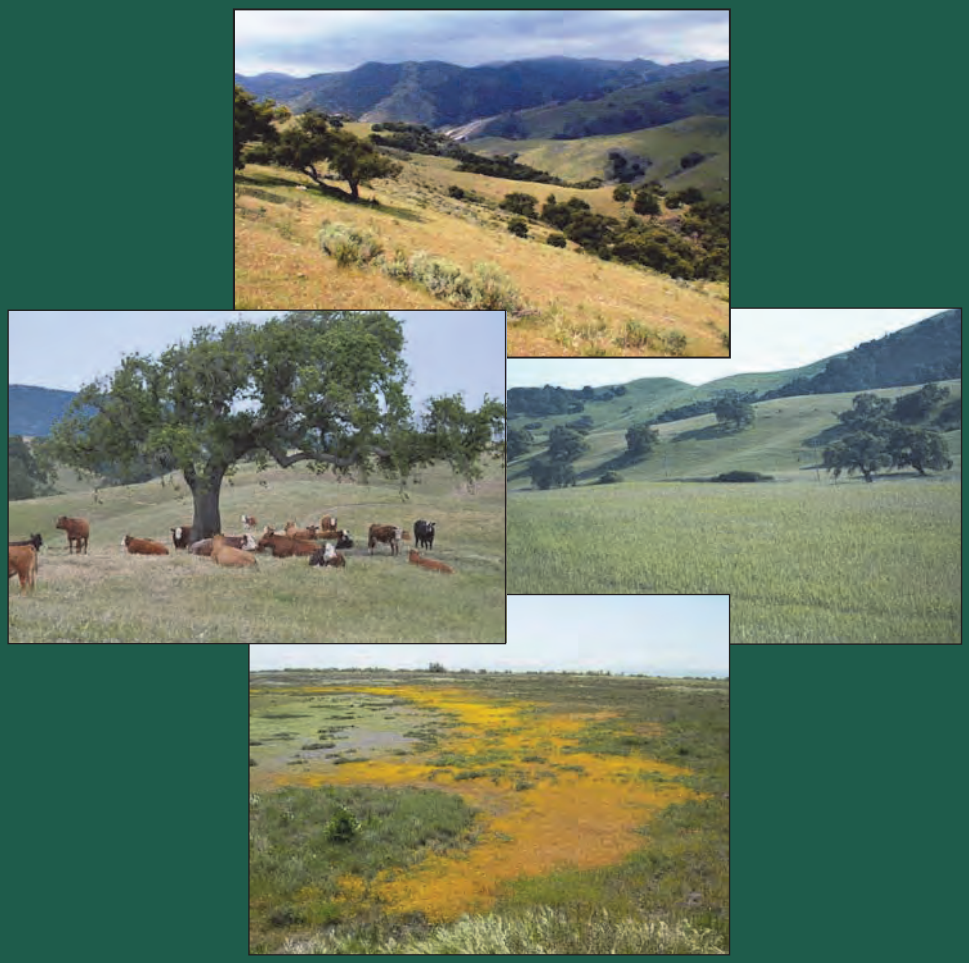
An Economic Analysis of the Benefits of Habitat Conservation on California Rangelands



CONSERVATION ECONOMICS WHITE PAPER

Conservation Economics Program

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Executive Summary

This report presents the results of a study to investigate the private and *public* economic benefits associated with the conservation of wildlife habitat and other natural resources on rangelands in California's Central Valley. There are over 11 million acres of grasslands within and encircling the Central Valley and the interior Coast Range, much of which are privately owned and managed as rangelands for livestock production. These ranches provide the last, best remaining habitats for many of what previously were wider-ranging species, including freshwater fish, wintering birds and waterfowl, invertebrates and mammals. There are 75 plant and animal species associated with California grasslands that are listed as threatened or endangered under the Endangered Species Act. These same grasslands are located in some of the state's fastest-growing counties and are under severe threat from conversion and development. California lost 105,000 acres of grazing lands to urbanization between 1990 and 2004 and it could lose 750,000 acres more by 2040. Biodiversity conservation in the Central Valley is inextricably linked to the continuation of private ranching landscapes that are sustainably managed through the adoption of resource conservation practices.

The sustainability of the ranching industry in California is linked to improved access to resource conservation incentives and the development of financial incentive mechanisms for ecosystem services in the form of markets and payment programs. We analyze two types of economic benefits associated with the adoption of selected conservation practices - riparian fencing, water development, prescribed grazing and re-vegetation of riparian areas with native plant species, re-establishment or afforestation of oak trees, and restoration of rangelands with native grasses - that are known to have positive impacts on wildlife. The first analysis addresses the *private financial* costs and benefits accrued by ranchers from the adoption of selected resource conservation practices. The second analysis identifies, and to the extent possible, quantifies the *public benefits* of enhancing ecosystem services that result from rangeland conservation practices. These services include carbon sequestration, water quality, biodiversity conservation and pollination, among many others.

Our analysis of the *private* financial costs and benefits from adopting various combinations of conservation practices indicates that private financial and resource conservation objectives can be compatible. Under the assumption of a common 50% USDA cost-share for the installation of various combinations of conservation practices, key financial performance indicators including the internal rate of return (IRR), benefit/cost ratio, and net present value (NPV) are positive for the analyzed practices under given empirically-based assumptions about increases in forage availability and carrying capacity. At the same time, practices associated with prescribed grazing, fencing of riparian areas and water point development can produce substantial ecosystem service benefits related to water quality and wildlife habitat. However, assuming no cost-share assistance, none of the conservation practice scenarios is financially viable for the rancher given the current market conditions for cow-calf operations that dominate rangeland use in California. Without cost share, private installation costs almost double in all cases, the IRRs are zero, the benefit-cost ratios are below 1 (where costs and benefits are equal), and the NPV is negative for all conservation practice scenarios. These results suggest that (1) private investment in rangeland conservation practices with no cost-share assistance is not likely, unless markets are created and are accessible by ranchers for various ecosystem services resulting from conservation practices but for which currently there frequently is no compensation, and unless the prices

on those markets are sufficiently high to make ecosystem service provision financially competitive with development; and (2) the financial attractiveness of adopting conservation practices depends on the economic, biophysical and product marketing conditions faced by *each individual* rancher.

Our review of the ecosystem services and associated benefits provided by California Central Valley rangelands and by rangeland conservation practices yields several general conclusions. First, California rangelands generate a wide range of services that carry considerable total economic value. These services support benefits like livestock production, wildlife- and water-based recreation activities, drinking and irrigation water, species conservation, aesthetic benefits in the form of scenic views, and avoided damages to health, private property and public infrastructure. The second finding is that while some of the value generated by the services provided by rangelands can be captured by landowners – for example, improvements in forage quantity, quality or availability and in carbon sequestration – a substantial portion of the overall benefits accrues off-site. The latter include avoided water treatment and dredging costs, avoided health costs and property damages, passive use values for threatened, endangered or rare species, and aesthetic benefits associated with scenic views. In such cases, ranchers are unable to prevent others from enjoying the benefits that their resource conservation efforts produce and fail to reap the full value of these benefits. Ranchers therefore do not have an incentive to take the full value of these benefits into account when making rangeland management decisions.

For the re-establishment or afforestation of blue oaks (*Quercus douglasii*) on grasslands and the restoration of native perennial grasses and riparian areas, private costs exceed private benefits. Cost share programs in some cases can reverse this result, as is true for some riparian fencing or restoration measures. To the extent that the public benefits from these conservation practices exceed the increases in cost share levels needed to make these practices attractive to landowners, increased public funding for these practices would yield positive net benefits for society as a whole. The alternative approach would be to promote the establishment of viable ecosystem service markets for public goods associated with mitigation of greenhouse gasses through carbon sequestration, biodiversity conservation and water quality. Which of these two approaches for generating increased incentives for the provision of ecosystem services is the preferred one depends on the characteristics of the particular ecosystem services that are being generated by a conservation practice. Those practices that primarily generate public-benefit services like biodiversity and endangered species conservation generally are not suitable to commodification and thus to being traded in markets. Therefore, the primary financial incentive mechanisms for managing private rangelands for the provision of these services are public conservation payments and cost share programs. Those services which are amenable to commodification because they can be quantified and because rationable demand for them exists in principle can be promoted through ecosystem service markets. Carbon and water quality are two prime examples of such services. In many cases, the demand for these services likely will need to be created through regulatory drivers like greenhouse gas emission limits or clean water regulations. Overall, both payment programs and markets for ecosystem services will play important roles in achieving rangeland conservation and the increased provision of ecosystem services from these lands.

Major Conclusions

Ranches in the California Central Valley provide the last, best remaining habitats for many of what previously were wider-ranging species, including freshwater fish, wintering birds and waterfowl, invertebrates and mammals. These lands are also critical for wildlife adaptation to climate change.

Private, ranch-level, financial costs and benefits from adopting various combinations of conservation practices indicate that private financial and public resource conservation objectives can be compatible.

Our results suggest that (1) private investment in rangeland conservation practices with no cost-share assistance is not likely, unless markets are created and are accessible by ranchers for various ecosystem services resulting from conservation practices but for which currently there frequently is no compensation, and unless the prices on those markets are sufficiently high to make ecosystem service provision financially competitive with development; and (2) the financial attractiveness of adopting conservation practices depends on the economic, biophysical and product marketing conditions faced by *each individual* rancher.

With respect to the provision of public-benefit ecosystem services, ranchers are unable to prevent others from enjoying the benefits that their resource conservation efforts produce and fail to reap the full value of these benefits. Ranchers therefore do not have an incentive to take the full value of these benefits into account when making rangeland management decisions. Consequently, without cost share programs or without the creation of service markets, these services will not be provided at the levels that would generate the highest benefits for society as a whole.

Under current economic conditions, the re-establishment or afforestation of blue oaks on grasslands and the restoration of native perennial grasses and riparian areas, private costs exceed private benefits. Cost share programs in some cases can reverse this result, as is true for some riparian fencing or restoration measures. Increased private market prices for carbon sequestration and water quality could induce ranchers to supply more of these public benefits.

Both payment programs and markets for ecosystem services, as well as other types of incentive measures, will play important roles in achieving rangeland conservation, the preservation and recovery of endangered species, and the increased provision of ecosystem services.

1. Introduction

A. Background

This white paper constitutes our final report to the Richard and Rhoda Goldman Fund to present the results of a study of the economic benefits associated with the conservation of natural resources on grasslands and oak woodlands in California's Central Valley and surrounding foothills. The study has been a priority of the California Rangeland Conservation Coalition, a unique collaboration between Defenders of Wildlife, the California Cattlemen's Association and more than 90 other organizations, agencies, and local government entities. We report our findings with respect to the private and public economic benefits associated with the adoption of selected natural resource conservation practices, including benefits associated with wildlife habitat protection and restoration.

California has more than 34 million acres of rangelands within and encircling the Central Valley and the interior Coast Range that are grazed. This area is a unique and valuable natural resource for California as it includes a mix of oak woodlands, open grasslands, vernal pools and wetland habitats. Much of the Central Valley grasslands and foothills are privately owned and managed as rangelands for livestock production (Huntsinger et al., 1997). Many sites on these private rangelands are the last, best remaining habitats for what were previously wider-ranging species.

In general, California grasslands are divided into two plant communities: the Coastal Prairie dominated by perennial grasses, and the Annual Valley Grasslands (Valley Grasslands) dominated by annual grasses (Bartolome et al., 2007). This report focuses on the environmental and economic benefits provided by Valley Grasslands.

California grasslands are located in some of the state's fastest-growing counties and are under severe threat from conversion and development. As a result, California lost 105,000 acres of grazing lands to urbanization between 1990 and 2004, according to the state Department of Conservation. The California Oak Foundation projects it could lose 750,000 acres more by 2040. Managed appropriately, private ranches can benefit California's plants, fish and wildlife. The conservation of biodiversity in the Central Valley and surrounding foothills is inextricably linked to the continuation of private working landscapes and the sustainable stewardship of private grasslands by ranchers.

B. Wildlife Benefits from California Rangelands

Ecosystem services provided by rangelands include supporting services such as wildlife habitat, carbon sequestration, water quality and pollination (Daily et al., 1997). Rangelands also provide provisioning services such as forage for livestock and wildlife (Havstad et al., 2007) and other ecosystem services like open space and cultural amenities (Brunson and Huntsinger, 2008). In this report, we address the importance of California grasslands to selected supporting services (carbon sequestration, water quality) in addition to wildlife habitat because of the co-benefits that can accrue to wildlife when these supporting services are enhanced. Although we provide a more in-depth examination in Chapter 3 of the benefits to wildlife, and particular species, from the adoption of resource conservation

practices, we briefly describe here the importance of current rangeland ecosystems and selected management practices for conserving native wildlife species and their habitats.

Grasslands in the Central Valley of California support a wide variety of wildlife species including freshwater fish, birds, invertebrates and mammals (Hunting, 2003). The Central Valley grasslands not only provide forage for livestock, but also for wildlife populations that rely on these areas for a significant portion of their diet (George et al., 2001; Heady, 1988). There are 75 species associated with California grasslands including 10 vertebrates, 14 invertebrates and 51 plants that are listed as threatened or endangered under the Endangered Species Act (Jantz et al., 2007). In the four-county study area covered in this report, there are 10 listed species in Butte, 5 in Glenn, and 7 in Shasta and Tehama counties (California Department of Fish and Game, 2009). We describe a sampling of some important species that inhabit California rangelands below.

A number of reptile species breed in Valley Grassland habitats including the western fence lizard, common garter snake, and western rattlesnake (Basey and Sinclear, 1980). Reptile species that depend on grassland habitat for food include the San Joaquin whipsnake (California Department of Fish and Game, 2009). Amphibians like the threatened California red-legged frog are also present on annual grasslands and rely on the presence of livestock stock water ponds for habitat (Fellers and Kleeman, 2007).

California Valley Grasslands provide arguably the most important wintering habitat for raptors in the North America (Pandolfino 2006). Twenty-one species of hawks, eagles and owls are regularly recorded on Christmas Bird Counts in the Central Valley, including species of continent-wide conservation concern like Burrowing Owl, Northern Harrier, Golden Eagle, and Ferruginous Hawk (FWS 2002). Grassland birds, more than any other guild, are in decline across the country (Pettyjohn and Sauer 1999, Sauer et al. 2005). Those declines are mirrored in the Central Valley with significant, long-term decreases in both breeding and wintering populations of very common species like Killdeer, Horned Lark, Lark Sparrow, and Western Meadowlark (Sauer et al. 1995, Pandolfino 2006). The Swainson's Hawk, listed as Threatened in California, forages in Central Valley grasslands in spring and summer. California Bird Species of Special Concern (Shuford and Gardali 2008) which use these habitats extensively include Northern Harrier, Mountain Plover, Burrowing Owl, Loggerhead Shrike, Grasshopper Sparrow, and Tricolored Blackbird.

Vernal pools on Central Valley Grasslands provide unique habitats because of special topographic and environmental characteristics that support a multitude of endemic species. These seasonal pools provide habitat for a diverse flora of native plant and several threatened and endangered animal species including invertebrates like the vernal pool fairy shrimp and the tadpole shrimp (Helm, 1998) and vertebrates like the California tiger salamander (United States Fish and Wildlife Service, 2004). Vernal pools in the California Central Valley also support a number of wintering migratory birds (Silveira, 1998, 2000).

In the Central Valley there are 28 native fish species including four different stocks (runs) of Chinook salmon and 40 introduced species (Moyle, 2002). Some important native species found on California rangelands include the California roach, Chinook salmon, rainbow trout/steelhead, Sacramento pikeminnow, Sacramento sucker and speckled dace (Thompson

et al., 2006). There are also several non-native game fish species like the green sunfish, largemouth bass, and smallmouth bass (Thompson et al., 2006).

Mammal species that depend on Valley Grassland habitat include the black-tailed jackrabbit, California ground squirrel, Botta's pocket gopher, western harvest mouse, California vole, badger and coyote (White et al., 1980). Central Valley Grasslands also provide habitat for the endangered San Joaquin kit fox (United States Fish and Wildlife Service, 1983). The Tulare grasshopper mouse is a species of concern that typically inhabits arid grass and shrub land habitats that are mostly in ranching (United States Fish and Wildlife Service, 1998).

Pollination by bees and other animals is an essential ecosystem service that increases the yield, quality and stability of 75% of globally important crops (Klein et al., 2007). It has been estimated that the value of crop pollination in the United States by the honey bee ranges from $5-$14 billion dollars annually (Morse and Calderone, 2000). Wild bee species are also important for the provision of pollination services (Greenleaf and Kremen, 2006; Winfree et al., 2007).

Recent studies stress the importance of rangelands for pollinators. Pollinator activity depends on the availability of nesting sites (Frankie et al., 2002; Hraniz et al., 2009) and the diversity and abundance of floral resources (Murray et al., 2009; Kremen et al., 2002), both of which are provided by California rangeland that is adjacent to cropland. Numerous studies report that the ability of wild and introduced bees to pollinate crops decreases as distance to natural and semi-natural habitat increases (Kremen et al., 2002, 2004; Ricketts et al., 2004; Greenleaf and Kremen, 2006; Morandin and Winston, 2007). In a review of case studies around the world, Ricketts et al. (2008) found a pattern of decreasing pollinator abundance in crop fields with increasing distance from natural or semi-natural habitats. A study in Canada showed that bumble bee and wild bee abundance was positively correlated with the amount of surrounding pastureland (Morandin and Winston, 2007).

In California, Kremen et al. (2002) have found a strong positive relationship between nearby natural habitat (much of which is in rangeland) and pollinator activity of native bees on croplands. A study of native bees in Northern California showed that both the amount and the stability of pollination services increased with increasing area of upland habitat (riparian forest, chaparral and oak woodland) which, in Northern California, is mostly provided by private ranches (Kremen et al., 2004). A species of native bee (*Bombus vosnessenkithat*) that pollinates tomato plants relies on adjacent natural habitat for nesting sites (Greenleaf and Kremen, 2006). The same authors concluded that farmers benefit from having adjacent rangelands which are essential for the health of native pollinator populations because which in turn helps reduce their costs of managing commercial honeybees (Kremen et al., 2004). A meta-analysis of the effects of anthropogenic disturbance on wild bees showed that habitat loss was the most important factor decreasing population abundance and richness, contributing to their recent decline in the United States (Winfree et al., 2009). With increased losses of California rangelands, it is likely that the state's pollinator bee populations will also decrease, which could have very adverse consequences for California's crop production.

Although we provide a more detailed analysis in Chapter 3 of the benefits to ecosystem services, including wildlife habitat, resulting from the adoption of conservation practices on California rangelands, we briefly illustrate here why this topic is important. Some of these

practices include stock pond maintenance, managed grazing, and fencing and restoration of riparian areas.

Ranch stock ponds (not analyzed in this report) play an increasingly important role in providing habitat for amphibians. In the Bay Area, livestock stock water ponds on ranchlands provide up to 50% of the remaining habitat for the threatened California tiger salamander (United States Fish and Wildlife Service, 2006). The California red-legged frog also thrives in stock ponds (Fellers and Kleeman, 2007). These two species also seem to benefit from livestock grazing around or near these ponds (DiDonato, 2007).

Managed grazing by ranchers is a cost-effective and natural tool for managing vegetation and enhancing wildlife habitat. It is also a tool that is being used by several land management agencies in California (Huntsinger et al., 2007). For example, it has been demonstrated that managed grazing can improve habitat for threatened and endangered species such as the Bay checkerspott butterfly, considered an umbrella species for grassland ecosystems (Murphy and Weiss, 1988). Through the removal of competition from non-native annual grasses, cattle grazing increases the abundance of native forb dwarf plantain (*Plantago erecta*) that the checkerspot feeds on (Weiss, 1999).

Recent research in California also suggests cattle grazing can be an essential management tool in maintaining native vernal pool ecosystems. Cattle contribute to maintaining biodiversity by selectively grazing on the invasive exotic grasses, reducing evapo-transpiration, and thereby extending the inundation period of the pools which allows the invertebrates to complete their life cycle (Marty, 2005; Pyke and Marty, 2005).

A few wildlife species on California rangelands benefit from having a shorter vegetation structure, which grazing creates, thereby increasing chances of wildlife finding available prey or allowing them to avoid predation (Barry et al., 2006). The San Joaquin Kit fox also benefits from grazing because the species favors flat and open space to avoid predators (Warrick and Cypher, 1998; United States Fish and Wildlife Service, 1998). Habitat enhancement by sheep grazing has been shown to increase populations of the Stephens kangaroo rat, a federally and state listed species (California Department of Fish and Game, 2009). Other species that benefit from livestock grazing are the California ground squirrel (Fehmi et al., 2005) and the burrowing owl (Barry et al., 2006).

C. Purpose

Defenders of Wildlife, along with the California Cattlemen's Association, has worked with California ranchers, environmentalists and agencies to create an agreement, titled The California Rangeland Resolution (Appendix 1). The Resolution is based on a multi-party effort to conserve and enhance private working landscapes and wildlife habitat within the Central Valley, surrounding foothills and interior Coast Range. Together, signatories to the Resolution formed the California Rangeland Conservation Coalition (Coalition). The long-term goal of the Coalition is to conserve private grasslands and promote habitat enhancement projects on these lands for the benefit of listed and unlisted species. The Central Valley and surrounding foothills encompass more than 28 million acres of rangelands. Those areas that were identified as the most critical for conservation are shown in Figure 1.1.

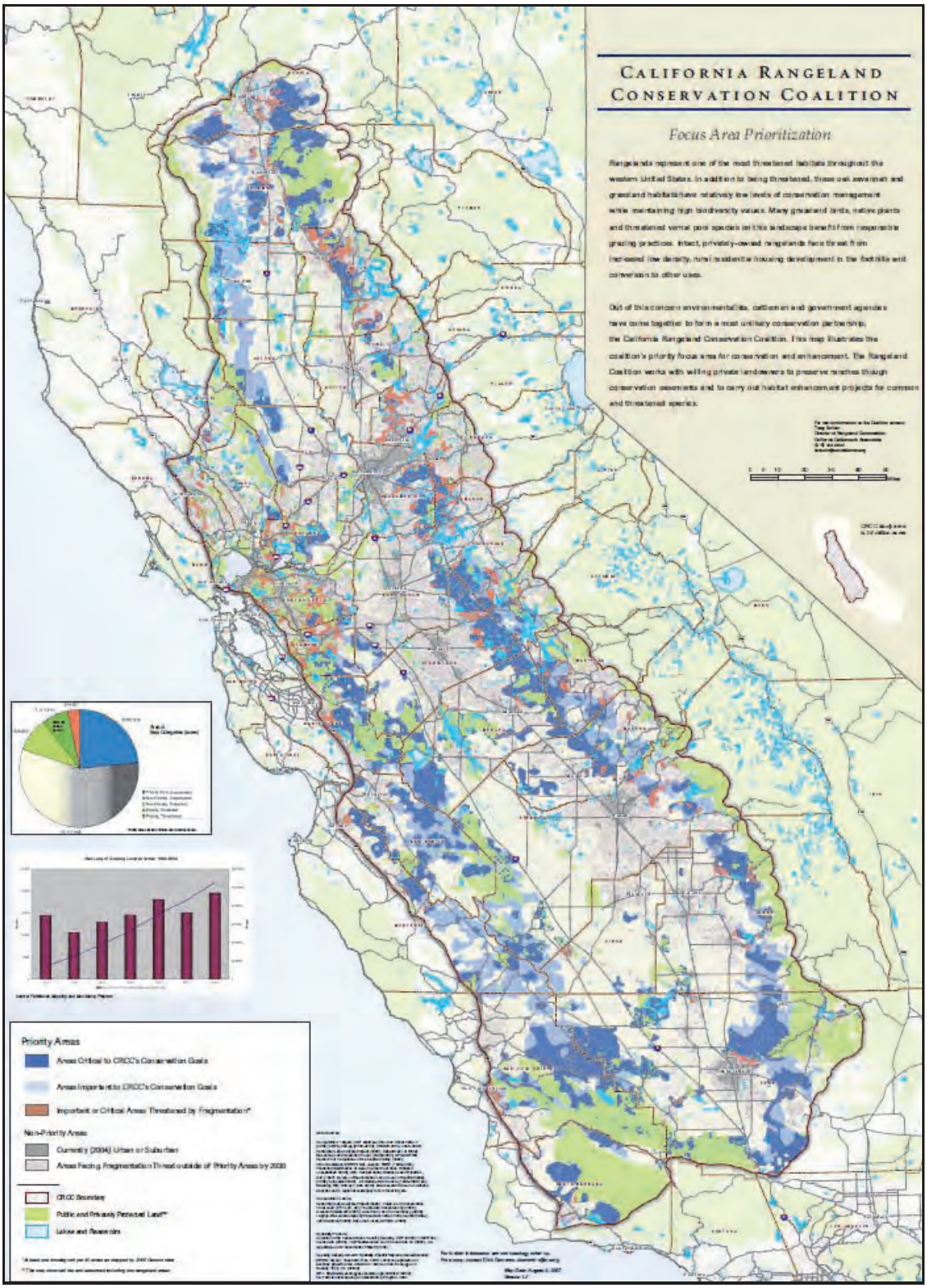

Figure 1.1: California Rangeland Conservation Coalition priority areas

The sustainability of the ranching industry in California is linked to the development of markets for ecosystem services such as wildlife habitat. More specifically, it is linked to the ability of ranchers to benefit from those markets to create incentives that will increase the likelihood of achieving conservation goals. In order to make the case for the development of markets for ecosystem services on and from California rangelands, this report describes and analyzes the prospective ecological and economic benefits that could result from the conservation and restoration of these important ecosystems. We investigate two types of economic benefits associated with the adoption of selected conservation activities: those that would or could be captured by private ranchers, and those public benefits that are derived from improved environmental conditions and/or ecosystem services.

This report consists of three types of integrated economic analyses. The first addresses the relative *private* financial costs and benefits of alternative resource conservation management regimes to improve wildlife habitat on working rangelands in California. We analyze these costs and benefits by investigating the economic and financial impacts resulting from the adoption of specific resource conservation practices on a "typical" ranch in our study area. We employ a Grazing Economic Analysis model (Gordon, 2008) that generates estimates of financial returns and benefit-cost ratios to the ranching operation resulting from the impact of conservation practices on forage production and livestock (cattle) productivity. These conservation practices include riparian fencing, water development, prescribed grazing and re-vegetation of riparian areas with native plant species.

The second type of economic analysis identifies and, to the extent possible, quantifies the value of ecosystem services that result from rangeland conservation practices that benefit wildlife. We address the question of what market and non-market ecosystem services, including wildlife habitat, will be affected and improved as a result of adopting conservation practices. We provide some preliminary estimates as to how much these services may be worth. The ecosystem services investigated include increased forage production, carbon sequestration, improved water quality and wildlife habitat. Practices investigated include re-establishment or afforestation of oak trees, riparian protection and revegetation and restoration of native grasses.

Lastly, we address the general economic conditions under which wildlife habitat conservation on working grasslands is profitable for private ranchers and identify potential policy mechanisms and/or incentives (private markets; public payments) that would allow ranchers to more fully capture the economic benefits from providing increased ecosystem services to the public. We also address the question of what policy/incentive instruments can be employed to compensate ranchers/landowners for ecosystem services provided, including greater access to public conservation programs.

Although the data employed in this report comes from ranching sites throughout the state of California, the economic analysis presented here is meant to reflect conditions in four counties in north-central California: Butte, Glenn, Shasta and Tehama (Figure 1.2). Relevant data and literature for other areas of the western U.S. was consulted and used wherever appropriate.

Figure 1.2: Four-county project focus area

D. Organization of the Report

The next chapter provides a ranch-level financial analysis of the costs and benefits from the adoption selected resource conservation practices that directly or indirectly result in improved wildlife habitat or species protection. Chapter 3 provides a description and, to the extent possible, quantifies selected market and non-market ecosystem service benefits generated by the adoption of rangeland conservation practices. Chapter 4 provides recommendations with respect to future public policy options to encourage habitat and species conservation on California ranchlands, including markets for ecosystem services and various other landowner incentive mechanisms.

2. Financial Analysis of Adopting Selected Conservation Practices on California Rangelands

This chapter addresses the question "What are the relative *private* financial costs and benefits of alternative treatments and management regimes to improve wildlife habitat and other natural resources on California rangelands?" Profitability at the ranch level, or even a neutral impact on ranch income, is a major factor in ranchers' decisions to adopt resource conservation practices, including those aimed at protecting wildlife species and their habitats.

We analyze the question of on-ranch profitability of conservation practice adoption through the use of a Grazing Economic Analysis model (Gordon, 2009) developed by the USDA Natural Resources Conservation Service (NRCS). Given the installation of a particular resource conservation practice, or suite of practices, the model estimates the financial/economic impact on a "typical" ranch operation as a result of implementation costs (labor and materials) and changes in forage availability, harvest efficiency and livestock carrying capacity. We define a "typical" ranch as a 900-acre cow-calf operation that is located in the four-country study area. The four conservation practices we consider, as defined through the California State NRCS office, are fencing of riparian areas, active restoration of native plants in riparian zones[1], prescribed grazing management, and water point development. We describe and analyze the following three resource conservation practice adoption scenarios through the model: Scenario I: adoption of a conservation practice package that includes fencing off riparian zones combined with water point development; Scenario II: the same as Scenario I, but with active re-planting of fenced riparian zones with native plant species; Scenario III: the combined adoption of water point development and prescribed grazing management. The conservation practices for each Scenario have been put in place by some ranchers, but adoption over a wider area could be promoted more extensively from a natural resource management perspective. Each of the practices investigated addresses several resource concerns simultaneously, and although they are not *directly* aimed at particular species, they do have beneficial impacts on both wildlife and their habitats. These *non-market* benefits are described in more detail in Section D of Chapter 3.

A. Grazing Economic Analysis Model

The Grazing Economic Analysis model is applied to a "typical" ranch from our four-county project study area (Butte, Glenn, Shasta and Tehama counties) in order to determine the private economic net benefits from the adoption of resource conservation practices. Key model parameter values were chosen to be representative of conditions in our study area, based on consultations with local NRCS experts. Parameter values may differ from other rangeland areas in California due to differences in environmental conditions. For example, the costs and the benefits generated by the model are dependent on several site and location characteristics (soil type, present condition of rangeland forage, trend in the condition of rangeland resources) and evaluation criteria (cost of practices, lifetime of treatment, interest rate, total acres to which conservation practices are applied, etc.). The model variables are described below and the results from each of the three Scenario outputs are provided in Appendix 2, Tables A2.1 to A2.3. The next sections of this chapter provide a general

[1] Riparian zones are mainly restored by planting native trees and shrubs and sometimes with an understory of grasses and forbs.

description of the model and the results of the Grazing Economic Analysis for the three conservation practice Scenarios.

B. General Model Description and Assumptions

The Grazing Economic Analysis model (Gordon, 2009) is a set of interactive spreadsheets that estimates the profitability and selected other financial performance indicators of a management practice or bundle of practices for a particular ranch, based on treatment costs and improved livestock carrying-capacity, forage availability and harvest efficiency expected to result from the adoption of the treatment. The other financial performance indicators include the break-even period for an investment, the internal rate of return, the benefit-cost ratio and the net present value per acre generated by the adoption of a suite of conservation practices. The value of these economic indicators determines whether a rancher should invest in these conservation activities, all of which benefit particular species or wildlife habitats. The key concept here is that for there to be widespread adoption of resource conservation practices by California ranchers that benefit wildlife or improve other natural resources such as water and air quality, these practices must either have a positive or neutral impact on ranch income.

The various parameters used in the model runs that represent site and location characteristics, evaluation criteria, and forage availability and utilization efficiency are shown in Appendix 2. The time-frame chosen for the analysis is 20 years. Site and location characteristics include descriptive identifiers such as county/state, soil type, present condition of rangeland forage, and the trend in forage production. None of these variables directly impact the model's output of key indicators, although they inform the choice of appropriate, empirically-based values of key model parameters such as forage availability and carrying capacity. Based on consultations with local NRCS experts, we assume that the present forage production condition of rangelands in the four-county study area is "good" and that the current trend in this condition is "stable".

Evaluation criteria for the model include information about the conservation practice or suite of practices to be adopted (called the grazing land treatment), the cost per acre of the practice(s), the duration of the life of the practices, the applicable interest rate, the value of an Animal Unit Month (AUM)[2], and the total acres treated (see Appendix 2). For each of the conservation practice Scenarios, we assume an average ranch size of 900 acres for the four-county area. Additionally, we hold constant the duration of the life of the selected practices (20 years)[3] and the interest rate (7%) to allow comparisons of the different suites of practices examined. Costs per acre are derived from a state-wide cost list that is maintained by NRCS for various conservation practices, and the basis on which NRCS will cost share. The only evaluation criteria that differ across Scenarios are the type of grazing land treatment (i.e., conservation practices adopted) and the initial treatment and annual maintenance costs per-acre.

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[2] An Animal Unit Month (AUM) is defined as the amount of forage needed by an "animal unit" (AU) for grazing for one month. The quantity of forage required is based on a cow's metabolic weight, and the animal unit is defined as one mature 1,000 pound cow and her suckling calf. For this analysis we assume a standard forage amount of 790 lbs/AUM.

[3] Although we use a 20 year time frame, the duration of specific practices can be adjusted for in the model.

The variables under "Forage Utilization" include forage availability, pounds per AUM, forage harvest efficiencies both with and without the conservation practice, current forage availability, maximum carrying capacity and the number of months the ranch operation can be grazed each year (See Appendix 2). Average forage availability for the four-county study area is assumed to be 2000 pounds/acre.[4] Forage per AUM is a standard weight at 790 pounds. Harvest efficiency is the percent of annual above-ground biomass consumed by an animal unit. For each of the conservation practice Scenarios, we assume (based on consultation with local NRCS experts) a slight increase in harvest efficiency (from 20% to 25%) due to the adoption of the suite of resource conservation practices. Current forage availability and maximum carrying capacity are variables that are generated through formulas that draw on the data in the cells that indicate pounds of forage required per AUM and harvest efficiency percentages. The number of months that California rangelands can be grazed each year varies with climate, herd size and location. In our study area, rangelands are grazed, subject to climatic conditions, between four and eight months per year. For this analysis, we assume a grazing period of six months for each of the Scenarios.

A crucial variable that determines the size of the economic impacts of adopting resource conservation practices is the setting of the percentage change in carrying capacity of the ranch before and after the practices have been implemented (see Appendix 2). These percentages are based on the field knowledge of local range management specialists in California and vary by resource conservation practice.

C. Model Details and Results

Scenario I: Riparian Fencing and Water Development

The first conservation practice Scenario is based on the combined adoption of the practices of riparian fencing and water development. Appendix Table A2.1 shows the results of the Grazing Economic Analysis for these practices. We assume that a rancher pays 50% of the total cost of the practices adopted, which is what would typically be paid under the Environmental Quality Incentives Program that is managed by the USDA Natural Resources Conservation Service.[5] This conservation practice Scenario has been adopted by ranchers in California for (1) the purpose of protecting riparian areas and improving water quality, with potential benefits to aquatic habitat; and (2) to increase livestock access to under-utilized forage through a more even utilization of the property by livestock by developing additional watering points. The latter outcome has the impact of creating healthier range conditions, which in turn benefits several wildlife species, and can control the spread of exotic invasive weeds. There are also private benefits to ranchers from the adoption of fencing riparian areas and water development. These benefits take the form of improved forage utilization, better animal health and higher beef production due to better water quality, more reliable water sources, and erosion control in riparian zones (Belding et al., 2000).

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[4] Personal communication. Dr. Melvin George, Rangeland Ecologist, University of California at Davis. July 2009.

[5] Personal communication. Jon Gustafson, State Rangeland Management Specialist, California NRCS office. July, 2009.

In Scenario I we assume that forage harvest efficiency is 20% before adoption of the conservation practices, and 25% in the first year following adoption through the end of the 20-year period. The improvement is due to increased access to forage in the areas near new watering points. Based on input from local range managers, we assume that there would be no change in the carrying capacity of rangelands over the 20-year period of analysis *without* adoption (before treatment) of the conservation practices.[6] However, *with* adoption (i.e., under the treatment), we assume that the carrying capacity of the ranch increases by 10% in the first year, and then increases by 20% for years 3 thru 20.

Scenario I model outcomes for primary production and economic indicators are shown in Table 2.1. The value of the indicators make it clear that, given the 50% cost share level, and assumed increases in harvest efficiency and carrying capacity, it is profitable for the rancher to implement fencing and water development practices.

Table 2.1 Economic and production results - conservation practice scenario I: Riparian fencing and water point development

Years to Break-Even on Investment:	0
Increase in Carrying Capacity (AUMs/Ac):	0.24
Increase in Stocking Rate, (#Head/Total Ac):	31
Total Installed Treatment Cost ($/Total Ac):	$21,236
Amortized Installed Treatment Cost ($/Ac/yr):	$2.23
Internal Rate of Return:	99%
Breakeven $/AUM	$9.14
Benefit/Cost Ratio:	1.36
Net Present Value ($/Ac) under 50% cost share:	$9.91

Stocking rate immediately increases from 76 to 107 head of cattle upon installation of the conservation practices and remains at the higher level for the life of the project. The total cost of the two practices is about $21,000/acre and includes the cost of foregone income from taking acreage out of forage production.

The internal rate of return (IRR), defined as the interest rate at which the present value of the income stream generated by the practice becomes zero, is 99%. The decision to invest in the conservation practices is made by comparing the 99% IRR to the cost of capital faced by the ranch. Needless to say, such a high rate of return far exceeds the cost of borrowing capital, indicating that the adoption of the practices represents a good investment for the rancher. Further evidence of the profitability of adopting the suite of practices, as illustrated by the benefit/cost ratio of 1.36, indicates that overall benefits exceed costs by about 36%. The IRR and the benefit/cost ratio illustrate that adoption of the Scenario I conservation practices, which have beneficial impacts on wildlife, can be profitable at the ranch level.

With the adoption of the riparian fencing and water development practices, the breakeven price at which the practice bundle becomes profitable is estimated at about $9.15/AUM, which indicates what the value per AUM needs to be for a rancher to recoup the costs of the conservation investment. The net present value (NPV) of the investment is estimated to be about $10.00/acre. NPV is the sum that results when the discounted value of expected costs

[6] Ibid.

is deducted from the discounted value of expected returns generated from the conservation investment. If the NPV is positive, then the investment is potentially worth making, depending on how this particular suite of conservation practices ranks with other Scenarios and investment opportunities the rancher faces.

In addition to the private financial benefits/returns from adopting riparian fencing and water development practices, there is a range of *non-market*, *public* benefits that could be jointly generated by these practices. These types of benefits could include improved water quality for both human and aquatic species' use, control of invasive exotic species, and improved habitat for both riparian and upland wildlife species.

Scenario II: Active Riparian Restoration (Native Species), Riparian Fencing, and Water Development

The conservation activities in Scenario II differ from those in Scenario I only by the addition of "active" restoration of riparian areas with native plant species, after fencing has been installed. With the exception of the added costs of native re-vegetation of riparian areas, ranch size, evaluation criteria and forage utilization variables assumed in Scenario I are unchanged (See Appendix A2.2). Restoring riparian areas with native vegetation is assumed to *not* have an appreciable impact on either harvest efficiency or an increase in carrying capacity. The average total cost of a riparian planting for our sample ranch of 900 acres is estimated at about $6.40/acre, based on NRCS cost data. With an assumed 50% cost share, the added increment for riparian re-vegetation is about $3.25/acre compared to Scenario I, which results in an overall treatment cost for the whole package of practices of $26.84/acre.

Table 2.2 provides the production and economic results of the combined practices of restoration of native plant species in riparian areas, riparian fencing and water development. Compared to Scenario I, the additional element of restoration of native plant species in riparian areas does not result in a decrease in carrying capacity. Thus, the ranch still enjoys augmented production as a result of adding a native species restoration practice that may have more of a public rather than private benefit. If planting native species resulted in increases in marketable sequestered carbon over some baseline, then both private (depending on market conditions) and public benefits would increase compared to Scenario II.

Table 2.2 Economic production results - conservation practice scenario II: Fencing and restoration of riparian zones and water development

Years to Break-Even on Investment	0
Increase in Carrying Capacity (AUMs/Ac):	0.24
Increase in Stocking Rate, (#Head/Total Ac):	31
Total Installed Treatment Cost ($/Total Ac):	$24,153
Amortized Installed Treatment Cost ($/Ac/yr):	$2.53
Internal Rate of Return:	53%
Breakeven $/AUM	$10.40
Benefit/Cost Ratio:	1.22
Net Present Value ($/Ac) under 50% cost share:	$6.67

Both the total and amortized costs of adopting the new suite of conservation practices rise, but only marginally on a per-acre basis. For example, total treatment costs with riparian re-vegetation are estimated to be about $24,000/acre, as compared to nearly $21,200/acre without riparian re-vegetation, or an increase of about 13%.

The additional costs associated with adding riparian re-vegetation to the suite of Scenario I conservation practices does not significantly impact the financial benefits that a rancher would receive for the additional investment. The IRR decreases from 99% in Scenario I to 53% in Scenario II, but is still significantly high to warrant the investment. The breakeven point as measured by the price of an AUM ($/AUM) increases from about $9.00/acre to $10.40/acre. The benefit/cost ratio of 1.22 shows that benefits exceed costs by over 20%. The NPV per acre decreases with riparian re-vegetation from about $9.90/acre to $6.70/acre, or by nearly 32%, but it is still positive and an indicator that restoring riparian areas with native vegetation as part of fencing riparian areas and water development would still be profitable. Given that riparian restoration with natives is expected to not have a significant impact on forage, and therefore livestock production, adoption of the restoration practice alone would probably not be expected to be attractive to ranchers, at least from a financial return standpoint.

The incremental addition of riparian restoration with native plant species to the Scenario I suite of conservation practices does not provide increased financial benefits to the rancher because the restored areas are not expected to be grazed. However, there may be public benefits associated with improved carbon sequestration, water quality, and wildlife habitat, and perhaps other ecosystem services as well.

Scenario III: Water Development and Prescribed Grazing Management

Our third conservation practice scenario is based upon the adoption of prescribed grazing management in combination with the water development practice that was included in Scenarios I and II. The details of prescribed grazing schemes can differ from ranch to ranch, depending on ecological and forage conditions, but the practice generally involves rotating cattle to prevent overgrazing, to improve and protect the long-term viability of forage species, and to improve cover and forage for wildlife. In some cases, the use of prescribed grazing may also be complemented by fencing and placing mineral supplements. This practice mostly involves increased labor costs to manage and move cattle and to monitor rangeland conditions to determine when cattle need to be herded to another location (see Table A2.3. in Appendix 2 for model details). Water development is required in order to move livestock to sections of the ranch that may not have watering wells or stream access.

As a new prescribed grazing management program is implemented, it is expected that there will be a gradual increase in forage availability over the 20-year period of analysis. This translates into an increase in livestock carrying capacity for the ranch. Based on consultation with local NRCS range experts, we assume a 5% increase in carrying capacity in the second year of the project, 15% in the third year, and then 20% in years four through the end of the project. With the exception of the carrying capacity and labor cost increases, and the active restoration costs, all other model parameters remain the same as in Scenarios I and II.

Table 2.3 shows the values of the production and economic indicators for Scenario III. The total installed treatment cost for the rancher, at a 50% cost share rate for water development and at the 75% EQIP rate for materials needed for monitoring grazing, is about $15,600/acre. The IRR is estimated at 216%, well above those for Scenarios I and II, and is an indicator that the investment in prescribed grazing and water development would be financially beneficial. The breakeven AUM price is estimated at about $7.00/AUM. At the given cost share levels, benefit/cost ratio and NPV are estimated at 1.61 and $14.00/acre, respectively. The values for the benefit/cost ratio and the NPV strongly indicate that it would be profitable for the rancher to invest in prescribed grazing management in conjunction with water point development.

Table 2.3 Economic and production results - conservation practice scenario III: Water development and prescribed grazing management

Years to Break-Even on Investment	0
Increase in Carrying Capacity (AUMs/Ac):	0.24
Increase in Stocking Rate, (#Head/Total Ac):	30
Total Installed Treatment Cost ($/Total Ac):	$15,600
Amortized Installed Treatment Cost ($/Ac/yr):	$1.64
Internal Rate of Return:	216%
Breakeven $/AUM	$6.80
Benefit/Cost Ratio:	1.61
Net Present Value ($/Ac) under 50% cost share:	$13.95

As in the case of Scenarios I and II, there are likely ecosystem service benefits that cannot be readily quantified in monetary terms. These benefits include improvements in water quality and wildlife habitat and are described in Section D of Chapter 3.

D. Comparison of Conservation Practice Scenarios and Preliminary Conclusions

What are the relative *private* financial costs and benefits of alternative treatments and management regimes to improve wildlife habitat and other natural resources on California rangelands? We have approached this question by using a Grazing Economic Analysis model (Gordon, 2009) as a tool to estimate the financial impact on a ranching operation of three suites of conservation practices.

The analysis of the production and economic impacts on ranching operations in the four-county project area from the adoption of the selected conservation practices indicates that private financial and resource conservation objectives can be compatible. Although the conservation practices investigated do not target wildlife conservation *per se*, their effects on increasing water and land resource quality do benefit rangeland aquatic and terrestrial habitats.

Table 2.4 summarizes some of the major production and economic indicators for each of the conservation practice Scenarios for the 50% cost-share level, and compares each of these parameters for the three Scenarios to the case of no cost-share. The comparison is meant to illustrate how the financial viability of the various conservation practice packages would change drastically if ranchers had to bear the entire costs of implementation.

Table 2.4: Financial indicators for conservation practice scenarios at 50% and zero cost share

Indicator	*Scenario I*		*Scenario II*		*Scenario III*	
	50% CS	0%CS	50% CS	0% CS	50% CS	0% CS
Total Installed Treatment Cost ($/ Total Ac):	21,236	42,471	24,153	45,389	15,600	31,200
Internal Rate of Return:	99%	0	53%	0	216%	0
Benefit/Cost Ratio:	1.36	.73	1.22	.69	1.61	.92
Net Present Value ($/Ac):	9.91	-13.70	6.67	-16.93	13.95	-3.39

Under the 50% cost-share assumption, each of the conservation practice scenarios is a viable financial investment at the private ranch level. The combined practice of prescribed grazing management and water development (Scenario III) has the least cost and the highest economic returns in terms of the estimated IRR, benefit/cost ratio and NPV. Scenario I is the second-most attractive investment alternative, followed by Scenario II which includes restoring riparian vegetation with native plant species. All three conservation practice combinations will have beneficial impacts on wildlife habitat, which are described in Section D of Chapter 3. The selection of which conservation practices ranchers decide to ultimately adopt will depend on their particular financial situation, the ecological condition of their ranches, and expected environmental and product price conditions over the medium to long term. For example, the cost-effectiveness of a particular practice will depend on how the rancher will arrange for installation, that is, whether the rancher installs the practice with his own labor, or contracts out. Likewise, the economic indicators presented here do not account for the transactions costs faced by ranchers in enrolling in and implementing conservation programs, or the costs of obtaining permits, which could be substantial.

Table 2.4 also provides estimates for selected economic indicators under the assumption of no cost-share from the NRCS, thereby illustrating the case of what returns ranchers could gain if they were to invest in the given conservation practices entirely on their own. Under the no cost-share assumption, none of the conservation practice scenarios is financially viable for the rancher. Costs of installation almost double in all cases, the IRRs are zero, the benefit-cost ratios are below 1.0 (where costs and benefits are equal), and the NPV for all conservation practice scenarios is negative. There are three major implications of these findings. First, under the production and financial assumptions we employed, private investment in rangeland conservation practices with no cost-share assistance is not likely, especially under the current market conditions for maintaining cow-calf operations in California. This conclusion changes to some extent if and where markets exist and are accessible by ranchers for various ecosystem services (carbon sequestration, water quality, wildlife habitat) that are co-benefits of installing conservation practices but for which currently there frequently is no compensation.

A second implication is that there is likely some median point (not investigated here) at which the costs of adopting resource conservation practices are just offset by the private economic benefits achieved. However, the 50% cost share would appear to leave enough

room to accommodate any margin for error associated with assumptions behind the Grazing Economic Analysis on either the cost or the benefit side.

The third implication from the analysis presented here is that the financial attractiveness of each of the suites of conservation practices will depend on the economic, bio-physical, and product marketing conditions faced by *each individual* rancher. Overall installation costs for practices may be higher or lower than assumed by NRCS, depending on the physical characteristics of any particular ranching operation. Likewise, any increases in carrying capacity, and hence the potential for augmented income, will depend on the response in forage quantity and quality to improved management at any specific site.

Although we can generally conclude that there are private, on-ranch benefits from the adoption of the resource conservation practices illustrated here, we have also shown the important role that public investment has on financial viability of the rancher's decision to invest in these practices under current economic circumstances. Chapter 3 will provide an investigation of the types of *public* ecosystem service benefits that can be generated by specific conservation practices and the extent to which these benefits can be captured by private ranchers through market mechanisms.

3. Ecosystem Services Provided by California Grasslands

A. Introduction

Like all ecosystems, grasslands provide a wide array of goods and services that contribute to human wellbeing (White et al., 2000; Maczko and Hidinger, 2008). For reasons of convenience, we will refer to these outputs collectively as "ecosystem services."

The ecological literature provides several rather broad definitions of ecosystem services as natural processes and products that support human existence and enhance human well-being (Daily, 1997; Daily et al., 1997). The Millennium Ecosystem Assessment (2005) followed this broad definition, distinguishing between supportive services (those that lead to the maintenance of the conditions for life, such as nutrient cycling), provisioning services (those that provide direct inputs to human economy, such as food and water), regulating services (such as flood and disease control), and cultural services (such as provision of opportunities for recreation and spiritual or historical purposes).

While such broad definitions have many useful purposes, they lump together ecosystem functions or processes (such as nutrient cycling or habitat provision), ecosystem products (such as food, fiber, or water), and benefits (the economic value of a service, such as flood control or aesthetic beauty). This creates two problems when attempting to place an economic value on ecosystem services. First, since ecosystem products are the output of ecosystem processes or functions, counting both the products and the biophysical processes producing them will tend to raises issues of double-counting (Boyd and Banzhaf, 2007). Second, ecosystem functions and their outputs describe only the biophysical supply side of nature's outputs. The economic value of those outputs, however, is a function of both their supply and demand (Tallis and Polasky, 2009; McDonald, 2009). In other words, human beneficiaries are required for an output of nature to become an ecosystem service– there must be people who actually benefit from that output.

To avoid the problems associated with too broad and economically imprecise definitions of ecosystem services, Brown et al. (2007) argue that ecosystem services should be defined as "flows from an ecosystem that are of relatively immediate benefit to humans and occur naturally" (Brown et al., 2007:334). Boyd and Banzhaf (2007:619) suggest narrowing this definition even further to include only end-products – "components of nature, directly enjoyed, consumed, or used to yield human well-being."

A corollary of the foregoing is that ecosystem services are benefit-specific, that is, they are contingent on, and specific to, particular human activities or wants (Boyd and Banzhaf, 2007). For example, aquifer or surface water quality is an ecosystem service for the provision of drinking water, because humans directly value the quality of the water they drink. On the other hand, water quality is not an ecosystem service for sport fishing, because anglers do not generally value the quality of the water body *per se*. Rather, they value the fish themselves. Therefore, the ecosystem service in this case is the target species (e.g., trout, bass). In economic terms, water quality is but one of many inputs in the production function of the target fish species, and its contribution to the value of the output (the fish) is part of the total value humans assign to that output. The value of the quality of the surface water body is

embedded in the value that anglers assign to the target species. Another rangeland example that demonstrates how this benefit-specificity defines what qualifies as an ecosystem service is erosion control. People generally do not value avoidance of topsoil loss *per se*. Rather, ranchers value the productivity of their land for livestock production. Therefore, forage production is the ecosystem service for this benefit because it is the forage that is the immediate input to livestock production. Likewise, people downstream generally do not value erosion control *per se*. Rather, they value the avoidance of damages in the form of reduced reservoir dredging costs or flood damages. The ecosystem service producing these benefits is natural land cover, which controls erosion.

Developing a definition of ecosystem services that complies with economic and accounting principles is not merely an academic exercise. Rather, a precise definition of ecosystem services that identifies the latter as discrete, countable and identifiable end-products is a necessary condition for their quantification, which in turn is a prerequisite for the establishment of ecosystem service markets. It is not surprising that all such markets or market-like arrangements that have developed are for services that conform to the definition advocated here – directly valued end-products such as water, sequestered carbon stocks, trees or species (Kroeger and Casey, 2007). Table 3.1 provides a non-exhaustive list of the services provided by California rangelands and the economic benefits they support.

Table 3.1: Selected benefits and associated ecosystem services provided by California rangelands; the services discussed in this report are underlined

Benefit	*Ecosystem Service*
Livestock harvest	Forage production, water availability
Crop harvests (nearby properties)	Pollinator populations
Recreation – hunting, fishing	Relevant species populations; natural land cover
Recreation – wildlife viewing	Relevant species populations
Wildlife passive use benefits	Relevant species populations (threatened/ endangered/rare species and habitats)
Drinking water provision – Avoided treatment cost	Aquifer and surface water quality (run-off nutrient absorption)
Drinking water provision – Avoided pumping/transport cost	Aquifer and surface water availability (aquifer infiltration)
Aesthetic benefits (open space property value premiums; outdoor recreation)	Natural land cover in view shed
Damage avoidance – Health benefits	Drinking water quality (nutrient and bacterial control)
Damage avoidance – Property	Natural land cover (trees, grasses), soils, wetlands (climate change, rain storm events)
Damage avoidance – Harvests (forage)	Native plants resistant to invasion by unpalatable weeds (e.g., cheat grass)
Damage avoidance – Reservoirs, stream channel dredging	Natural land cover

Sources: Boyd and Banzhaf (2007); Maczko and Hidinger (2008); Valerie Eviner (personal communication).

In this report, we focus only on a few of these ecosystem services, underlined in Table 3.1, that are produced by a sample of rangeland conservation measures: Forage production for livestock; threatened, endangered or rare species and their habitat; natural land cover (trees and grasses) and soils that sequester atmospheric carbon dioxide; drinking and aquifer and surface water quality associated with prevention of nutrient and bacterial runoff; and erosion control. These services are, to varying degrees, provided by all rangelands. However, implementation of particular rangeland conservation measures can increase the provision of some of these services from a particular area. Importantly, all of the rangeland conservation practices we examine in our analysis also have been documented to benefit wildlife. Thus, adoption of these practices in many cases may make economic sense for ranchers while also generating economic value for third parties, including neighboring agricultural lands – which can benefit for example from services provided by pollinators that rely on rangeland habitat – and society at large – which benefits from scenic views, cleaner water and the preservation of species, to name but a few of the benefits provided by intact rangelands.

In the following sections, we discuss some of the benefits provided by oak reestablishment and afforestation, restoration of native perennial grasses, grazing management and riparian fencing and restoration. Whenever available data permit, we generate quantitative estimates of the benefits and associated values brought about by these rangeland conservation practices. In many cases, available data and the limited scope of this analysis do not allow quantification of all of the benefits produced by the set of conservation measures analyzed in this report. In those cases, we at least identify the benefits and briefly point out how their value could be estimated. Where possible, we also generate cost estimates for these conservation practices. The chapter closes with a comparison of the economic benefits and costs associated with the practices that highlights the existing discrepancies between private and public perspectives on the economic feasibility of implementing the selected practices.

B. Oak Reestablishment and Afforestation

Oak reestablishment on and afforestation of range grasslands has the potential to generate a wide range of economic and ecological benefits, including increased carbon sequestration, forage production, provision of wildlife habitat and improved downstream water quality. In this chapter, we discuss these benefits in some detail and develop quantitative estimates for some of them.

Forage impacts of oak reestablishment on grasslands

From the late 1950's through the early 1970's, several studies reported that palatability and production of forage in the understory of blue oak was low when compared to forage in open grassland areas (Johnson et al., 1959; Burgess, 1987; Kay, Burgess and Leonard, 1980; Murphy and Berry, 1973; Murphy and Crampton, 1964). These studies formed the basis for statewide "rangeland improvement" activities that resulted in the removal of blue oak from grazing areas and the loss of 1 million acres (0.4 million ha) of woodlands (Bolsinger, 1988; IHRMP, 1998). According to some assessments, these losses may lead to a long-term decrease in soil quality and forage productivity (Dahlgren et al., 1997; Camping et al., 2002).

In contrast, more recent studies (Table 3.2) found that blue oak cover did not decrease forage production (Bartolome et al., 1994), at least for canopy cover levels of up to 40-60 percent (Battles et al., 2008; Connor and Willoughby, 1997), or actually did increase forage production (Frost and McDougald, 1989; Frost et al., 1991; Ratliff et al., 1991). Furthermore, oak cover was found to significantly increase forage quality, with one study reporting that forage under oaks was higher in crude protein concentration and lower in acid detergent fiber and lignins, and exceeded livestock crude protein requirements for six months compared to one month on open grasslands (Frost et al., 1990).

Several hypotheses have been offered to resolve the discrepancy of the effects of blue oak on forage production between early and later studies. The reasons advanced for variation in forage impacts include tree density, climate and soil factors (Duncan and Clawson, 1980; Kay, 1987; Menke, 1987). In particular, mean annual precipitation has been identified as a factor influencing the relationship between forage yield and oak canopy, with oak canopy reported to reduce forage yields only where mean annual precipitation exceeds 20 inches (McClaran and Bartolome, 1989) but increasing understory production on dry sites (Bartolome, 1987; Ratliff et al., 1991). The latter would be consistent with the observation that canopy shading becomes extremely valuable in drought years by reducing moisture loss from evapotranspiration (Frost et al., 1989). Another study (Callaway et al., 1991) indicates that blue oaks with shallow, fine roots inhibit understory production, which may be partially attributable to allelopathic blue oak root exudates as well as competition for water and nutrients. Variations in root morphology may therefore explain differences in understory production of blue oak.

Most studies examining the forage impact of oaks do not address the question of causality. Is higher productivity under blue oak canopies due to the inherent properties of the sites occupied by oaks? Some authors, finding that the removal of oaks did not significantly decrease forage production, argue that oak may simply be found on sites that are

Table 3.2: Recent literature findings on the impact of oaks on forage production

Author	*Study Location*	*Rangeland Type*	*Mean Rainfall (mm/yr)*	*Soil Type*	*Study Details*	*Forage Quantity and/or Quality Impacts*
Bartolome et al. (1994)	W. of Paso Robles 35°40' N, 120°37' W	Blue oaks w/ understory of annual herbs	360	Dibble clay loam	Removed all blue oaks from sample plots to test effect on understory production	Forage production: No significant effect. 36.6 g/m^2 (1989), 60.2 g/m^2 (1990) and 58.1 g/m^2 (1991). Herbaceous cover: significantly increased (24.3% uncut, 32.6% in openings); Species composition: remained relatively stable, except for increase in Redstem filaree (*Erodium cicutarium*)
Connor and Willoughby (1997)	Sierra Nevada foothills (UC SFREC) Yuba County	Small open grasslands, savannas, and dense oak woodlands	724	rocky loams	Measured forage clippings at 4 sites w/ varying % of blue oak canopy	No consistent relationship btw. oak canopy and forage production,; strong relationship btw. yearly rainfall and yearly forage production.
Frost et al. (1989)	San Joaquin Exp. Range, 25 mi NE of Fresno	Savanna w/ >400 annual herb species, 21% tree cover	587; but study in drought year)	coarse-loamy mixed thermic	Measured herbaceous production under canopy and in open grasslands	Blue oak consistently yielded higher forage production (kg/ha) every month (Nov-May). Herbaceous production was higher during higher rainfall years.
Ratliff et al. (1991)	San Joaquin Experimental Range, 25 mi NE of Fresno	6% swales, 11% open-rolling uplands, 83% rocky-brushy uplands	483	coarse loams	Compared livestock and herbage response to repeated seasonal, rotated seasonal, and continuous grazing on unfertilized pastures and pastures fertilized with elemental sulfur	In open-rolling uplands and rocky-brushy uplands, average peak herb standing crops were highest under blue oaks: in swales, forage was greatest on open land
Battles et al. (2008)	Sierra Nevada foothills (UC SFREC) Yuba County, 39° 15' N, 121° 17' W	Savanna with watershed-level mean of 56% canopy cover. Dominated by annual grasses.	775	fine, mixed, thermic	Determined pattern of net primary productivity (NPP); examined relationship between blue oak biomass and productivity	Canopy cover levels of around 40-60% do not suppress forage growth. Herb productivity increased with increasing canopy cover and began to decline only once this saturation point was reached. Total NPP increased linearly with increasing canopy cover until it saturated at approximately 50% cover.

-over-

Table 3.2 continued

Jackson et al. (1990)	Sacramento Valley foothills, Approx. 38°N	Savanna grasslands with 70% oak cover	n/a	various types	Analyzed nutrient content of soils and plants under canopy and on open grasslands	Soils beneath the oak canopies have approximately one-third more carbon and N, a higher cation exchange capacity and lower pH. Phosphate levels are slightly higher under the oak canopies.
Malmstrom et al. (2009)	Sierra Nevada foothills (UC SFREC) Yuba County, 39° 15'N, 121° 17'W	Grasslands and oak savannas	568	Palexeralfs, entic chro-moxererts, and typic haploxeralfs	Used remote sensing to evaluate effectiveness of native bunchgrass restoration project. Performed prescribed burns for weed control	Biomass declined in first year after native grass reseeding, followed by 1-2 years of biomass increase, and more varied responses afterwards. 3-5 years after the treatments, biomass had decreased in some fields but increased in fields where mixed approaches (flash grazing, fencing or reburning) were utilized. Native bunchgrasses did particularly well in areas of deep soil and short-duration, high-intensity grazing.
Frost et al. (1991)	San Joaquin Experimental Range, 25 mi NE of Fresno	blue oak-interior live oak/grass cover type	483	coarse loamy	Compared forage quantity and quality under blue oak canopy and in open grasslands	Forage production was significantly higher under blue oaks. Average 1987-1990 peak standing crop was 1,089 lbs/acre more under blue oaks. Forage quality under blue oaks was 54% higher in crude protein concentration and lower in acid detergent fiber (ADF) and lignins (LS). Open grasslands exceeded crude protein requirements of nursing cow only in one month (March), while forage under blue oak canopies exceeded them from mid-Dec to May.

inherently more fertile (Bartolome et al., 1994). Conversely, a number of studies have shown how oaks impact the microclimate of a site (Frost et al., 1989, 1991; Ratliff et al., 1991), which in turn would explain increases in forage production. Other studies do support a causality that runs from oaks to site fertility and not the other way around, showing that oak trees create islands of enhanced fertility through the incorporation of organic matter and enhanced nutrient cycling (Dahlgren et al., 1997; Camping et al., 2002; Jackson et al., 1990).

The empirical evidence on the relationship between the level of canopy cover and understory forage production is contradictory as well. Battles et al. (2008) found that herb productivity was increasing for relatively open sites (canopy closure less than 40 percent) and then monotonically declined as canopy closure increased further. In contrast, Connor and Willoughby (1997) found no consistent effect of canopy level on forage yield.

Oak cover has been shown to impact the timing of understory forage growth, producing much faster forage growth early in the season (March-May) compared to open areas (Frost et al., 1991; Duncan and Clawson, 1980). Forage under blue oak remained green after surrounding forage had dried, and Duncan and Clawson (1980) reported that cattle preferred forage beneath blue oak to that of open grassland, even in summer after forage in both areas has dried.

Table 3.3 summarizes the impacts of blue oak cover on rangeland forage quantity for the studies listed in Table 3.2. The general conclusion of the findings reported in studies that detected significant forage impacts is that blue oaks increase forage quantity on uplands, with impacts ranging from -0.3 to 1.3 AUMs (790 lbs) per acre, if we exclude Battles et al.'s (2008) findings for areas with 80 percent oak cover.[7] Thus, based on these studies, and depending on the particulars of a site, oak cover on upland sites is expected on average to produce a forage increase of 0.5 AUM per acre, or the equivalent of half the forage consumed by one mature 1,000 pound cow and her suckling calf.

[7] Canopy cover levels this high are not typical of most rangelands, and generally would not be the goal for oak reestablishment on grasslands.

Table 3.3: Differences in forage yield under blue oaks reported in more recent studies

Study	*Terrain type and study years*	*Blue oak cover*	*Annual forage production*				
			Blue oak	*Open grassland*	*Increase under blue oak*		
		%	*kg/ha*	*kg/ha*	*kg/ha*	*%*	*lb/ac*
Bartolome et al. (1994)	*Oak removal did not produce significant difference in forage production*						
Battles et al. (2008)	Hilly, rolling terrain	20%	2,450	2,250 *	200	9%	178
		43%	2,750		500	22%	445
		60%	2,250		0	0%	0
		80%	1,500		-750	-33%	-668
Connor and Willoughby (1997)	*No consistent effect of canopy level on forage yield across study years*						
	Uplands			1,631			
	1990-95 avg.	25%	1,478 **		-153	-9%	-136
		50%	1,408 **		-223	-14%	-199
		75%	1,424 **		-207	-13%	-184
Frost and McDougald (1989)	Open-rolling						
	1986-87	Under canopy	2,789	1,672	1,117	67%	994
	1987-88		2,667	1,622	1,045	64%	930
Frost et al. (1991)	Open-rolling						
	1986-1990	Under canopy	2,392	1,303	1,089	84%	970
Ratliff et al. (1991)	1961-1968						
	Swales (unfertilized)		3,664	4,295	-631	-15%	-562
	Open-rolling uplands	Under canopy	3,802	3,118	684	22%	609
	Rocky-brushy uplands		2,828	2,070	758	37%	675
	Overall weighted average:		3,086	2,795	291	10%	259

Notes: * 4% blue oak cover. ** Blue and Interior Live oak.

Carbon sequestration through oak reestablishment or afforestation

Due to their large spatial extent, rangelands may represent an important component in the global carbon cycle (Svejcar et al., 2008). Although grazing has not been shown to have a consistent effect on soil carbon, at least in the semiarid and Mediterranean climates of the Western United States (Jackson et al., 2007; Silver, 2009), conversion of rangelands releases large quantities of carbon (Lal, 2002; Potthoff et al., 2005; Kern, 1994). The inverse is true for conversion of cultivated lands into grasslands (Conant et al., 2001). Thus, avoided conversion of rangelands results in large avoided carbon emissions (Conant et al., 2001; Laca, 2009).

Carbon fluxes in California's Mediterranean-climate rangelands are influenced by a variety of factors including management practices (e.g., grazing pressure, application of organic amendments), vegetation type (savanna vs. grassland), species (native vs. exotic annuals), precipitation and soil type. The defining difference between grasslands and oak savannas is that the former have very little or no tree cover, while oak savannas are generally and somewhat arbitrarily defined as having between around five and 50 percent canopy coverage (Allen-Diaz et al., 1999; Henderson, 1995), with oaks being the dominant tree species. Generally, grasslands in the region are carbon neutral while savannas are moderate carbon sinks (Baldocchi, 2009). Total net carbon sequestration of California's Mediterranean grasslands and savannas (Figure 3.1) at the biome scale is estimated at 8.6 Tg/yr (avg. of 150 $gC/m^2/yr$) (Figure 3.1; Baldocchi, 2009). This amount is equivalent to 1.8 percent of California's gross greenhouse gas emissions in 2006 (California Air Resources Board, 2009), or 0.12 percent of total U.S. gross greenhouse gas emissions in 2007 (U.S. Environmental Protection Agency, 2009). Reforestation of cleared areas in current oak woodlands over a 75-year time horizon could sequester an additional 1.37 million tons of carbon per year, equivalent to another one percent of California's current annual greenhouse gas emissions (Gaman, 2008).[8] Thus, management of California's oak savannas and woodlands represents an important part in the State's climate change mitigation efforts.

Laca (2009) identifies eight practices (including rangeland conservation) that can reduce carbon emissions from the different rangeland types found in our study area (Table 3.4). These include the restoration of perennials and riparian corridors and improved grazing management, all of which are examined in this report, as well as restoration of woody species, the subject of this section. Like all of the rangeland practices included in this report, oak reestablishment and afforestation have the potential to increase revenues for ranchers. Planting of oaks can benefit ranch operations in two ways: First, by improving forage quantity and quality, which increases net revenue by increasing livestock output or reducing input costs (feed, pasture); and second, by increased net sequestration of atmospheric carbon dioxide by rangeland soils and vegetation.

Around 80 percent of oak woodlands in California are privately owned, and the primary use of these lands is livestock production (Bolsinger, 1988). In the Sacramento Region that includes three of our study area counties - Butte, Glenn and Tehama - the percentage of private ownership of oak woodlands is over 80 percent; in Shasta County, it is 73 percent (Gaman and Firman, 2006). An important question in evaluating the possibility of re-

[8] One ton of carbon is equivalent to 3.667 tons of carbon dioxide.

establishment of oaks on rangelands therefore is: Can livestock and oaks be "raised" together?

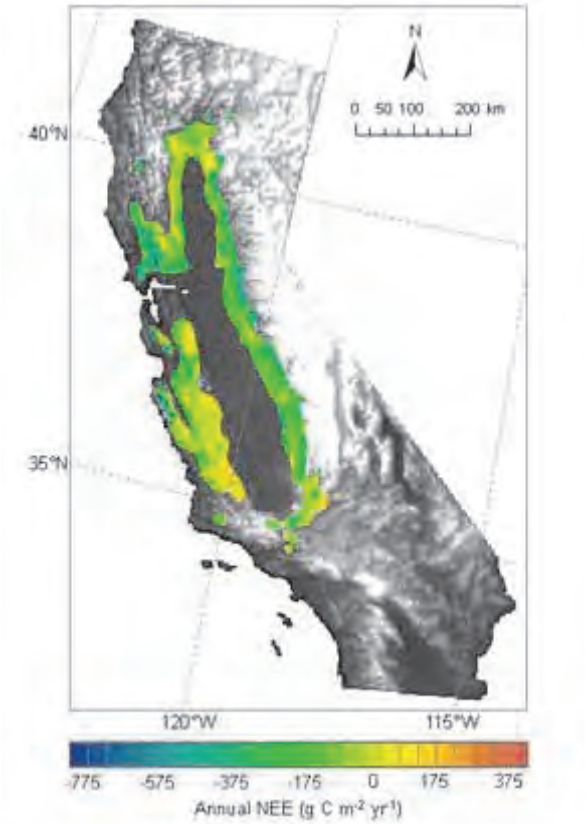

Figure 3.1: Estimated net carbon fluxes of California's Mediterranean rangelands
Source: Xiao and Baldocchi, cited in Baldocchi (2009)

Table 3.4: Relative magnitude of potential carbon benefits associated with particular management practices on California rangelands

Project type	*Rangeland Types*		
	Chaparral	*Oak-Woodland*	*Annual Grassland*
Reduction of wildfires	++	+	+
Restoration of woody species		+++	+
Restoration of riparian corridors	+	++	+++
Restoration of perennial grassland	+	++	+++
Control of invasive weeds	+++	++	+++
Management of expanding shrubs and trees	+++		
Conservation as rangeland (REDD)		++	+++
Improved grazing management	++	++	++
Addition of carbonate/black carbon	?	?	?
Area (million acres)	5.8	7.4	7.1

Source: Laca (2009).

Drawing on the results of several studies that assessed the impacts of livestock on oaks of various sizes, McCreary and Tecklin (2005) found that native California oaks can be

established in pastures grazed by cattle, as long as individual seedlings are protected from browsing and rubbing until they are approximately two meters tall. One study showed that in riparian plantings, protection of individual trees with shelters was necessary for successful oak restoration, with total survival rates of sheltered trees of 58 percent vs. 5 percent for fenced plots and less than one percent for unprotected trees (McCreary, 1999). Another study showed that exclusion of cattle from young (less than seven years old) plots with tree shelter-protected oak seedlings did not reduce tree mortality, although the damage from cattle browsing led to reduced height and basal diameter growth of the seedlings (Tecklin et al., 2002). One study that analyzed the impact of opening up plots with 13-15 year-old oaks to cattle grazing found that there appeared to be a threshold height of around two meters above which oaks generally are large enough to withstand cattle damage. Smaller trees were heavily impacted by cattle browsing, suffering substantial losses in height compared to the ungrazed control plot (McCreary and Tecklin, 2005). However, in moderately-grazed pastures, such damage from livestock clipping appears to have little long-term impacts on seedling survival or growth (McCreary and Tecklin, 2005). This is confirmed by the results reported by Koenig and Knops (2007), who found that regeneration of blue oaks, although very slow, can occur in open oak savannas in California despite significant grazing pressure. Another study (Hall et al., 1992) found that cattle damage to unprotected oak seedlings was significantly less in winter, when the oaks did not have foliage and were apparently less appetizing to cattle, compared to spring, when clover patches near seedlings seemed to attract cattle and to lead to incidental browsing of oaks. The largest damage occurred in summer, when the young oaks often were the only green vegetation in the grazed pastures and were more palatable than dry annual grasses.

A study analyzing the impacts of herbaceous interference and small mammal and insect depredation on oak seedling establishment and survival at seven sites in California found that herb exclusion was the most important factor for seedling establishment and survival (Adams et al., 1991). The study found that establishment and survival of (blue and valley) oak seedlings in California Oak-grass savannas can be significantly increased through both exclusion of herbs and screens against insect depredation (Adams et al., 1991).

The evidence of the existing literature thus shows that reestablishment or afforestation of oaks on rangelands is indeed compatible with livestock production. It also shows that the growth of planted trees, and the concomitant ecosystem service and ranch financial benefits, can be improved through implementation of comparatively simple practices.

Reestablishment and afforestation of oaks will need to take into account expected changes in oak habitat that may result from climate change. For example, a recent study suggests that portions of blue oak habitat in our study area may shift over the next 100 years, with habitat expansions in some areas and contractions in others (Kueppers et al., 2005).

The potential carbon impact of oak restoration and afforestation

To assess potential carbon sequestration from afforestation and reforestation of native oaks on rangelands in the study area, we construct low and high estimates of the changes in net carbon sequestration from oak planting. These estimates are developed by comparing the annual carbon balance of grasslands with that of oak savannas. The difference between the

carbon balances of the two systems is the quantity of carbon uptake that could be achieved by planting oaks on current range grasslands.

There are very few published studies that estimate net carbon uptake, or net ecosystem exchange (NEE) of grasslands and oak savannas in California (Table 3.5). NEE represents the total net flow of carbon between the atmosphere and the biosphere, including all changes in above- and belowground carbon. If there is carbon accumulation in the biosphere, the particular ecosystem is acting as a net carbon sink. If there is a net flow from biosphere to atmosphere, the ecosystem represents a net carbon source. By meteorological convention, net carbon flows into the biosphere carry a negative sign, indicating a loss in atmospheric carbon; net flows from the biosphere carry a positive sign, indicating an increase in atmospheric carbon. With the exception of Valentini et al. (1995), grassland studies in California are for sites with exotic annual grasses. The study results indicate that the carbon balance of annual grasses ranges from moderate carbon source (126 $gC/m^2/yr$, or 0.51 tC/ac/yr) to small sink (-51.1 $gC/m^2/yr$, or -0.21 tC/ac/yr).[9] By contrast, the one study that examined a native perennial grassland found that the site was a moderate carbon sink (-133 $gC/m^2/yr$, or -0.54 tC/ac/yr). These values fall within the range of grassland NEE values reported in the literature (Novick et al., 2004), but are an order of magnitude lower than those reported for most forests (Curtis et al., 2002; Scott et al., 2006; Schmid et al., 2000; Turner et al., 2007; Xiao et al., 2008), indicating the generally low productivity of California's Mediterranean climate grasslands (Battles et al., 2008).

There is only one study (Ma et al., 2007) that examines net carbon fluxes of a Mediterranean-climate oak savanna in California, with the results indicating that the savanna is a small to moderate carbon sink (-98 $gC/m^2/yr$ or -0.40 tC/ac/yr). Another study in the same climate zone (Battles et al., 2008) develops estimates of the net primary productivity (NPP) of three adjacent watersheds covered by oak savannas. To convert NPP estimates into net ecosystem exchange (NEE) estimates, the former need to be reduced by the carbon released through heterotrophic respiration (R_h). Battles et al. do not provide information on R_h in their systems. However, Ma et al. (2007) develop a system of equations describing their savanna system, located in the same area of the Sierra Nevada foothills that allows estimation of R_h. Based on these equations and their reported measurements, R_h of Ma et al.'s savanna is estimated as an average of 346 $gC/m^2/yr$ during 2000-2006. Subtracting this amount from Battles et al.'s average NPP for their three savanna systems yields an average estimated NEE of -176 $gC/m^2/yr$ (Table 3.5). This value is almost twice that reported by Ma et al., a discrepancy that could be attributable to the higher oak cover (56 percent vs. Ma et al.'s 40 percent) and higher average annual precipitation (77.5 cm vs. Ma et al.'s 56.2 cm) of Battles et al.'s site. These results indicate that grasslands are carbon neutral while savannas are moderate carbon sinks (Baldocchi, 2009).

In developing our estimates of the potential carbon sequestration that may result from oak afforestation of grasslands, we use the following scenarios:

[9] We use Chou et al.'s (2008) value from their high root contribution scenario (RC= 70%), 126 $gC/m^2/yr$, as that RC value is based on a study of an annual grassland in southern California; their low RC estimate (RC= 35%) is based on studies of perennial grasslands.

Table 3.5: Net carbon sequestration by grasslands and oak savannas in central western California

Rangeland type	*NEE* $gC/m^2/yr$	*Study period*	*Location*	*Vegetation*
Grassland				
Chou et al. (2008) * - Field - Adjusted **	80-387 *** 126-433 ***	2003-06 water years	Sierra Foothill Research and Extension Center (39.15°N, 121.17°W)	Annual grassland, historically grazed but cattle removed for experiment
Ma et al. (2007)	38 ±52	2000-06 avg.	Vaira Ranch (38.41° N, 120.95° W) (Sierra Nevada foothills)	Open C_3 annual grassland
Valentini et al. (1995)	-133	1990-91	Jasper Ridge (37.27°N, 122.13°W) (Eastern foothills of Santa Cruz Mountains)	Low-productivity, serpentine grassland with mostly **native** C_3 annual and perennial fortes and perennial bunchgrasses
Xu and Baldocchi (2004)	-51.5	avg., 2000-01 and 2001-02 growing seasons	35km southeast of Sacramento (38° 24.4 N, 120°57 W) (Sierra Nevada Foothills)	Grazed grassland opening, cool-season C_3 annuals
Savanna				
Ma et al. (2007)	-98±51	2001-06 avg.	Tonzi Ranch (38.43° N, 120.96° W) (Sierra Nevada foothills)	Oak/C_3 annual grass savanna; Blue oak, 144 stems/acre, 9 m ± 4.33 m avg. height; ~40% oak cover
Battles et al. (2008)	-176 #	2001-02	Sierra Foothill Research and Extension center (39.15°N, 121.17°W)	Blue oak savanna (some Interior live oak and foothill pine) with introduced annual grasses and forbs; watershed-level mean canopy cover: 56 percent

Notes: NEE – Net ecosystem Exchange. Following meteorological convention, negative values indicate a flow from atmosphere to biosphere; positive, a net C flow from biosphere to atmosphere. * Data are for control plots only, not for irrigated plots. ** Upward adjustment of belowground NPP by 50% based on Higgins et al. (2002). *** Estimated values assume root contributions of 70% (low values) and 35% (high values), respectively. # Avg. of NPP of three watersheds, converted to NEE by subtracting estimated heterotrophic respiration, derived using equations and data from Ma et al. (2007); see text for explanation.

Scenario 1: Low Carbon Gain: Change from a small carbon sink, -51.5 $gC/m^2/yr$ (Xu and Baldocchi, 2004) to a slightly larger carbon sink, -98 $gC/m^2/yr$ (Ma et al., 2007)

Scenario 2: High Carbon Gain: Change from a moderate carbon source, 126 $gC/m^2/yr$ (Chou et al., 2008) to a small to moderate carbon sink, -98.0 $gC/m^2/yr$ (Ma et al., 2007)

Our Low and High Carbon Gain scenarios thus assume that planting oaks on grasslands results in a net carbon uptake of 47 and 224 $gC/m^2/yr$, respectively, or 0.19-0.91 tC/ac/yr.

The Low Carbon Gain scenario results in a very conservative estimate as it relies on the only study that reports a net carbon uptake by an exotic annual grassland (Xu and Baldocchi, 2004). In both scenarios, we rely on the lower (Ma et al., 2007) of the two estimates of the net carbon balance of an oak savanna. Our adjusted NEE estimates for the Battles et al. (2008) study are higher but may be less reliable due to the fact that our adjustment of their NPP estimate is based on heterotrophic respiration values from a site with lower oak cover and precipitation (Ma et al., 2007).

The above scenarios are based on carbon flux values from mature oak savannas, not for young savannas characterized by recently planted trees. The actual net carbon balance (NEE) of young savannas depends on the rate of carbon accumulation (i.e., biomass growth) of the planted oaks and on the associated impacts of oaks on the understory grassland carbon balance.[10] Our carbon gain scenarios thus should be corrected for the trend in NEE of oak savannas with tree age. Unfortunately, the literature does not provide these estimates. As a second-best method for incorporating tree age into carbon gain estimates, we assume that the change in NEE of planted oak savannas is approximately proportional to tree growth. We incorporate this assumption by scaling our savanna NEE estimates to the basal area increments (BAI) of oak trees, which measure changes in tree stem diameter and whose trajectory over time serves as a general indicator of tree growth (Kertis et al., 1993).

Oak growth depends on a variety of factors, including species, precipitation, browsing pressure (from livestock and wildlife), length of the growing season and exposure to direct sunlight (vs. growing in the understory). Blue oak in particular are very slow-growing. One study (Koening and Knops, 2007) of blue oak seedlings in Monterrey County, California found that even seedlings protected from grazing by large herbivores and, to some extent, rodents as well, needed two decades to reach a mean height of 66 cm. Unprotected seedlings grew much slower still, reaching a mean height of only 77 cm after over four decades. The average growth rate of the latter oaks increased markedly near the end of the study period, presumably because more of the oaks had achieved a height or width that provided some protection against grazing.

Growth rates in much of our study area likely are higher than those reported by Koening and Knops because mean precipitation in the four counties is substantially higher. The overall range of mean annual precipitation across our study area spans 38.4-50.8 cm to 203.5-254 cm. However, annual means in most of the oak woodlands in the area (Gaman

[10] Understory grasslands in Mediterranean climate oak savannas in California are higher net emitters of carbon than open grasslands. However, this effect is overcompensated through the carbon sink created by the oaks themselves (Ma et al., 2007).

and Firman, 2006) ranged from 63.5-76.2 cm to 152.4-177.8 cm during 1961-1990 (Daly and Taylor, 2000), compared to a mean annual precipitation (1939-2006) of 53.3 cm for Koenig and Knops' site (Koenig and Knops, 2007). The average precipitation in much of the oak rangelands in our study area thus is substantially higher than at Koenig and Knops' site. Since oak growth is strongly correlated with precipitation (Kertis et al., 1993), blue oak growth rates in our study area are expected to be higher than those observed by Koenig and Knops. This assumption is supported by the few studies measuring oak growth closer to our study area. For example, in a study of blue oaks planted at the University of California's Sierra Foothills Research and Extension Center (SFREC), located in northern Yuba County, just south of Butte County, McCreary and Tecklin (2005) report that seven year-old oak seedlings protected from grazing through tree shelters were exceeding 1.3 m in height. Another study at SFREC (Bartolome and McClaran, 1985) recorded vertical growth rates from 0-60 cm and 0-135 cm (browse line) of 34 cm/yr and 16.5 cm/yr, respectively for sprouts and 18 cm/yr and 11.3 cm/yr, respectively for seedlings. The long-term average mean annual precipitation at SFREC was 72.4 cm (Connor and Willoughby, 1996), 19 cm (36 percent) higher than at Koenig and Knops' site (2007). Since the average annual mean precipitation in most of the oak woodlands in our study area is higher than at SFREC, it is likely that oak seedlings in much of our study area would grow faster. Nevertheless, the absolute increments in total aboveground and root biomass of new oak trees will be small for several decades, and as a result, "planted oaks don't begin to register appreciable CO_2 storage for at least 20 years, longer for very slow-growing blue oak" (California Oak Foundation, 2008).

Kertis et al. (1993) analyzed long-term growth trends of oaks at five sites in California, including sites in Soeth (Glenn County) and Butte (Butte County). Their reported BAI for the Soeth and Butte sites are replicated in Figure 3.2. Trees at the Butte site show rapid growth until approximately year twenty, from which time on growth is slower but continues for the next sixty years (there were no trees older than 80 years at the site).

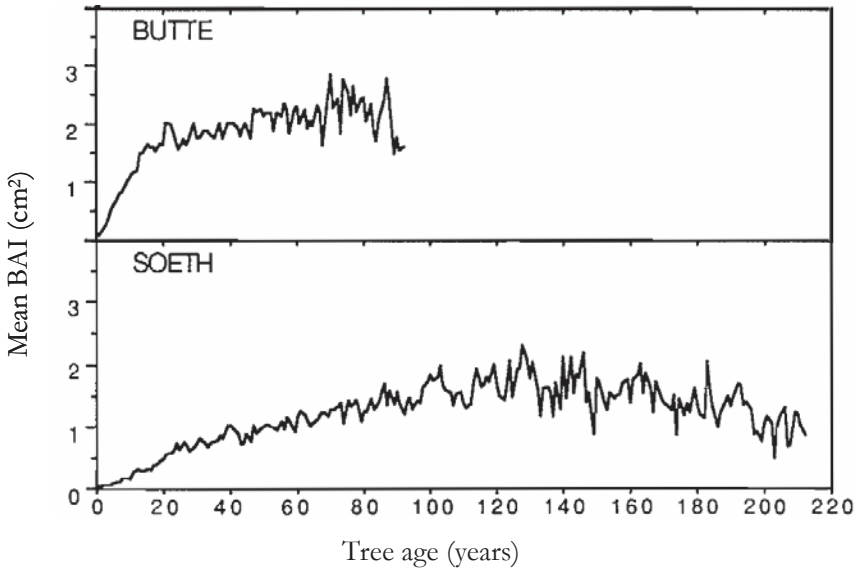

Figure 3.2: Mean annual BAI curves for Kertis et al.'s (1993) Butte and Soeth study sides, from Kertis et al.'s Fig. 2

The overall trend is approximated by a logarithmic curve. Trees at the Soeth site grow much slower as indicated by the smaller slope of the BAI curve, possibly as a result of the steep slopes (70%) (Kertis et al., 1993). Although a change in the growth trend is less obvious than at the Butte site, the data show a slightly faster growth until about year 25, with a somewhat smaller but overall relatively constant BAIs during the following 100 years. Key characteristics of the Butte and Soeth sites are reported in Table 3.6.

Table 3.6: Key characteristics of Kertis et al.'s (1993) Butte and Soeth and Ma et al.'s (2007) Tonzi Ranch blue oak savanna sites

	Butte (Butte Co.)	*Soeth (Glenn Co.)*	*Tonzi Ranch (Amador Co.)*
Slope (%)	20	70	-
Density (stems/ha)	464	518	144
Basal Area (m^2/ha)	15	9	11
Mean annual precipitation (cm)	52	55	56
Soil depth	45	70	75

Sources: Kertis et al. (1993); Ma et al. (2007).

We use the historic growth trends of blue oaks at these two sites to scale our carbon gain estimates to the age of the hypothetically planted oaks. We employ the information on mean basal area (BA) per stem and total number of stems per hectare from Ma et al.'s site to calculate the mean stem BA per hectare for their site. Similarly, we use the annual BAI reported in Kertis et al. to calculate historic mean BA per stem during the first 90 years at their two sites (see dark green lines in Figure 3.3) and then multiply the values by the stem density for their Butte and Glenn County sites to calculate the history of total stem BA per hectare for the oaks. We estimate equations that describe the historic trends in total mean BA per stem at the two sites (see polynomial lines and equations in Figure 3.3). We then scale our low and high carbon gain estimates to the oak growth at the Butte and Soeth sites by multiplying for each of the first 90 years of oak growth the scenario values by the ratio of the total BA per hectare of the respective site in a given year and the total BA per hectare at Ma et al.'s site (10.656 m^2 per hectare).[11] These estimates of annual NEE are constructed using the estimated curves that describe the total BA/stem as a result of tree age (see the polynomial functions in Figure 3.3), not the actually-observed mean BA/stem. This slightly smoothes the estimated annual NEE (compare the polynomial to the Total BA/stem line in Figure 3.3). It also allows us to generate estimates of average annual projected NEE for oak restoration that are not based on the year-to-year historic variability in annual BAI at the particular sites.

The resulting scaled carbon gain scenario estimates show the expected increase in annual net carbon gains from the planting of blue oaks. Gains are close to zero in the beginning ten to 20 years and then steadily increase over the 90-year period analyzed here (Figure 3.3).

[11] Ma et al. report an average of 144 stems per hectare for their site and a mean BA per stem of 0.074 m^2 ($\pm$0.0869 m^2).

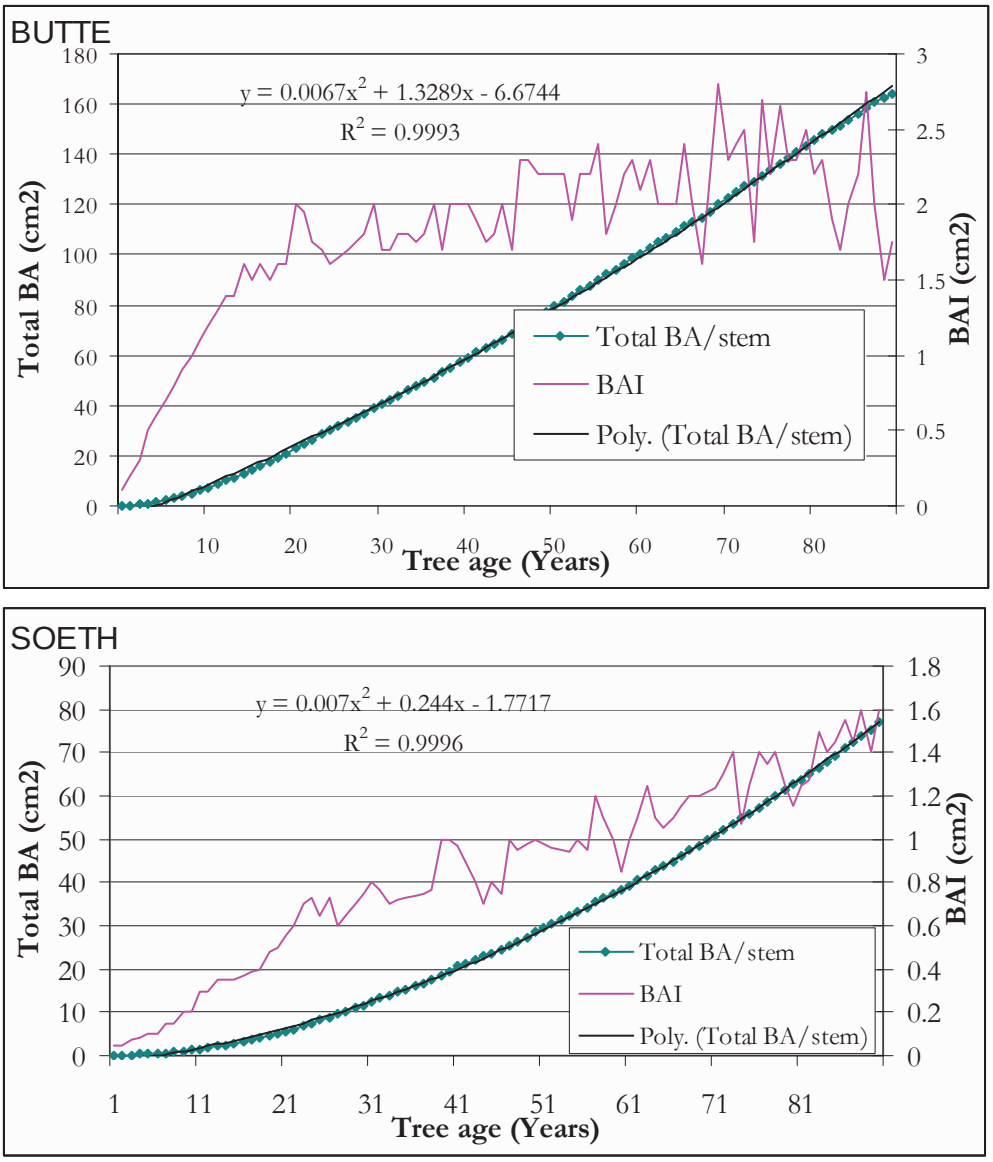

Figure 3.3: Actual BAI and mean BA/stem at Butte and Soeth sites studied by Kertis et al. (1993) and polynomial equation best describing growth in mean BA/stem at each site

Combining our low and high carbon gain scenarios with our two sites for which we have tree growth information (Butte and Soeth) yields four possible carbon gain trajectories (Figure 3.4). Of these, we select the "Butte-High" and "Butte-Low" trajectories for use in our carbon gain estimates for oak planting in our study area. The "Soeth-Low" trajectory – the one in Figure 3.4 that falls outside the carbon gain range covered by the "Butte-High" and "Butte-Low" trajectories – is the result of combining the very conservative low carbon gain scenario – based on the only study in Table 3.5 reporting a net carbon uptake by an exotic annual grassland (Xu and Baldocchi, 2004) – with oak growth estimates from a particularly unproductive site. For this reason, we exclude the "Soeth-Low" trajectory from our estimates of potential carbon gain from oak planting in our four counties.

Even after eliminating the lowest of the four carbon gain trajectories, the spread between the high and low carbon estimates for reestablishment of oaks on grasslands remains very large, due to the almost five-fold difference between the high and low carbon gain scenarios for oak planting.

Carbon in the California Blue oak savanna is cycled much more slowly than typical of savanna ecosystems, with the low productivity of the California Blue oak savannas being more typical of arid tropical tree-grass sites (Battles et al., 2008). As a result, the expected total above- and belowground net carbon uptake associated with the oak planting on grasslands in our study area is rather low, with values that reach only around 0.12 tons per-acre per-year (low scenario) to 0.55 tons per-acre per-year (high scenario) (Figure 3.4).

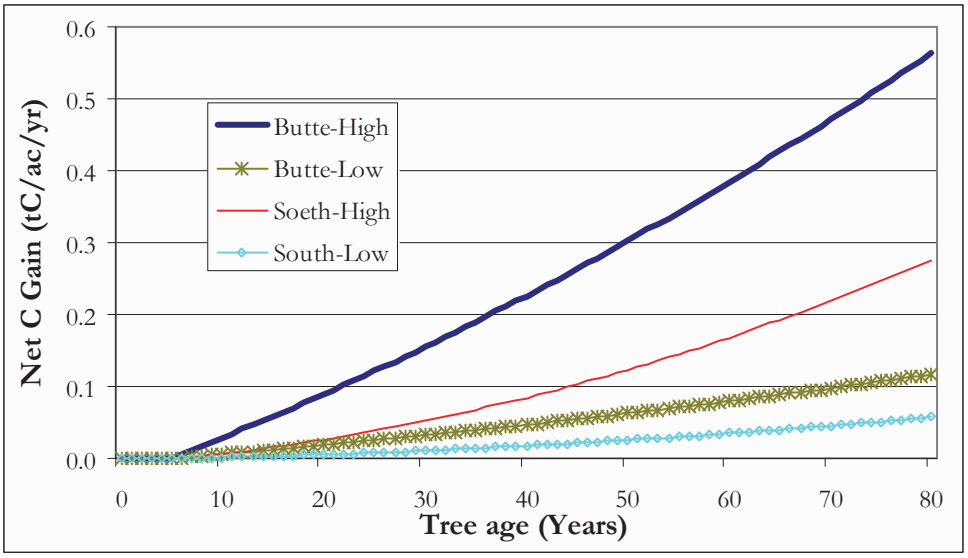

Figure 3.4: Projected carbon gain trajectories based on high and low net gain scenarios for oak planting on grasslands and high (Butte) and low (Soeth) tree growth sites

Nevertheless, over decadal time spans, the total amount of carbon that could be taken as a result of oak reestablishment is substantial, with an acre of savanna accumulating an estimated seven to 33 tC over the first 100 years after oak establishment (Table 3.7). By comparison, current blue and interior live oak (*Quercus agrifolia*) woodlands in our study region are estimated to contain on average 31 and 46 tC per hectare, respectively in tree biomass alone (Gaman, 2008). These numbers do not include downed woody debris or duff or litter layers, which together are estimated to account for another 42 and 37 tC per hectare in blue and interior live oak woodlands, respectively (Gaman, 2008). These tree and duff and litter layer carbon pools together are similar in size to our high carbon gain estimate (82 tC/ha) from oak planting on grasslands. However, they still do not take into account the increase in soil organic carbon associated with oak establishment. For example, in their study of live oak encroachment on grasslands in central Texas, Jessup et al. (2003) found that concentrations and densities of soil organic carbon were generally greater in woody patches than in grasslands. Similarly, Dahlgren et al., (1997) found that compared to adjacent grasslands, soils beneath oak canopy have greater concentrations of organic carbon. Jackson et al. (2002) found that the proportional change in soil carbon after woody plant invasion of

grasslands was negatively related to precipitation, with wetter sites losing and drier sites gaining soil carbon after invasion.

Table 3.7: Estimated cumulative average net carbon uptake per acre from oak planting on grasslands in the study area

Scenario:	*High C Gain*	*Low C Gain*
Time span	*tC/ac, cumulative*	
10 yrs	0.1	0.0
20 yrs	0.7	0.1
30 yrs	2.0	0.4
40 yrs	3.9	0.8
50 yrs	6.6	1.4
60 yrs	10.0	2.1
70 yrs	14.3	3.0
80 yrs	19.6	4.1
90 yrs	25.7	5.3
100 yrs	32.9	6.8

With mean annual precipitation of their driest sites approximately four times that of the sites on which our carbon gain estimates are based, the relative size of increases in soil organic carbon would be expected to be even higher in our study sites than those observed by Jackson et al. (2002). These findings have been confirmed in central California by the Marin Carbon Project, which found that woody plants increased rangeland soil carbon by about 30 percent (Silver, 2009).

Thus, our high average per-acre carbon gain estimate is likely to be a more realistic representation than our low estimate of the carbon accumulation that would be expected to result from oak planting.

Total potential carbon sequestration through oak reestablishment and afforestation on study area grasslands

To develop first approximations of the total amount of carbon that could be sequestered through oak reestablishment and afforestation in Butte, Glenn, Shasta and Tehama counties, we first calculated total grassland acreage in each county using California Land Cover Mapping & Monitoring Program (LCMMP) GIS data (California Department of Forestry and Fire Protection, 2009). The current spatial distribution of oak woodlands and grasslands is shown in Figure 3.5, which is an excerpt from a Fire and Resource Assessment Program (FRAP) land cover map (California Department of Forestry and Fire Protection, 2003). Most of the oaks in the study area are blue oaks followed by black (*Quercus kelloggii*) and live (Interior and Canyon) oaks (Gaman and Firman, 2006).

Next, we assumed that all grasslands located within the potential modern distribution of blue oak (Kueppers et al., 2005) are suitable for oak planting. This includes all grasslands in Butte and Shasta Counties, and an estimated 90 percent of grasslands in Glenn and Tehama Counties (Table 3.8). However, these estimates do not take into account projections of climate change-induced shifts in oak habitat. A visual assessment of the climate change-induced projected changes in oak habitat by 2080-2099 from Kueppers et al.'s (2005)

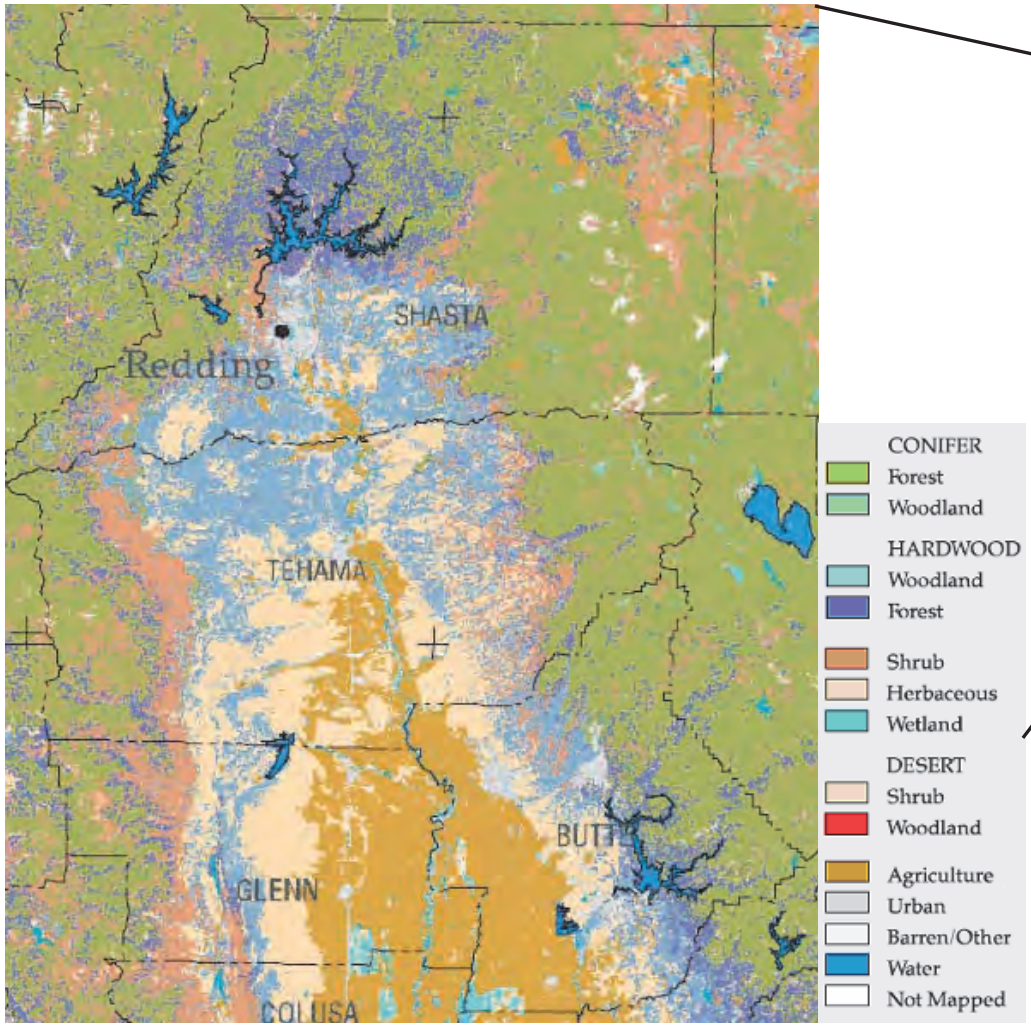

Figure 3.5: Land cover in the four study area counties
Source: California Department of Forestry and Fire Protection (2003)

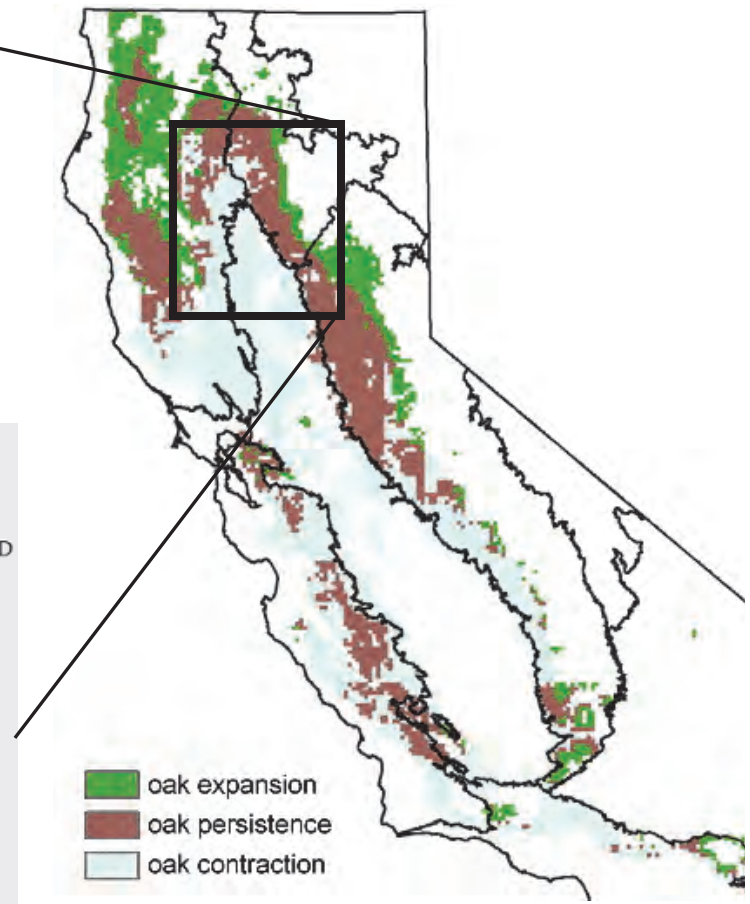

Figure 3.6: Kueppers et al.'s (2005) projections of changes in blue oak habitat in California based on regional climate change model
Source: Fig. 2 A in Kueppers et al. (2005)

regional climate model-based analysis suggests that estimated acreage suitable for oak reestablishment and afforestation may be reduced by around 50 percent in Butte and Shasta Counties, 75 percent in Tehama County and 100 percent in Glenn County (Figure 3.6). These two sets of estimates form the basis for our High and Low scenarios, respectively for oak plantings (Table 3.8).

Table 3.8: Grassland acreage in the study area by county, and percentages and acres potentially suitable for oak planting

County	*Acres*	*Potentially suitable for oak planting*			
		Scenario 1 (High)		*Scenario 2 (Low)*	
		Percent	*Acres*	*Percent*	*Acres*
Butte	77,768	100%	77,800	50%	38,900
Glenn	170,570	90%	153,500	0%	0
Shasta	127,333	100%	127,300	50%	63,700
Tehama	438,757	90%	394,900	23%	98,700
Total	814,428		753,500		201,300

Note: Includes both wet herbaceous (wet meadows and Tule-Cattail-Sedge) and dry herbaceous grasslands (annual grasses and forbs). See text for scenario details.

Some current shrub lands may convert to grasslands under the projected temperature and precipitation changes, and may become potential candidates for oak plantings (see green areas in Figure 3.6). Thus, our Kueppers et al.-based afforestation estimate, which does not consider these potential new candidate lands for oak plantings, likely understates the acreage available for oak planting under climate change projections.

In the High scenario, an estimated 753,000 acres are suitable for oak planting; in the low scenario, this area is reduced to just over 200,000 acres.

Multiplying the potential cumulative net carbon uptake (Table 3.7) by the high and low acreage scenarios, respectively (Table 3.8) yields our estimates of total (above and belowground) potential net carbon uptake that could be achieved by planting oaks on the grasslands in the four-county study area (Table 3.9). Over the 100-yr time horizon commonly used in CO_2 offset calculations, planting of oaks on study area grasslands could sequester between 1.4 and 24.8 million tC, or 5 to 91 millions tCO_2e, respectively. The assumptions underlying the High and Low total net sequestration estimates are summarized in Figure 3.7. Both of these estimates are somewhat extreme as they assume, respectively, that all grasslands that are ecologically suitable for oak planting could in fact be planted with oaks and that net carbon accumulation on these lands will occur at the higher of the two rates reported in the literature (High scenario), or that net carbon accumulation per acre will occur at the lower of the two rates reported in the literature and that only a fraction of currently suitable lands will remain suitable due to climate change (Low scenario). The average of the sequestration values from these two scenarios, 13 million tons of carbon (48 million tCO_2e) perhaps is a more realistic figure for assessing oak planting potential. This amount is equivalent to an average annual sequestration of 480,000 tCO_2e, or 0.1 percent of California's 2006 greenhouse gas emissions of 484 million tons of CO_2e (California Air Resources Board, 2009).

Table 3.9: Total potential net carbon uptake from planting of oaks on study area grasslands

Cumulative uptake per acre:		*High*	*Low*	*High*	*Low*
Acreage suitable for oak planting:		*High (Scenario 1)*		*Low (Scenario 2)*	
		1000 tC			
		High Est.			*Low Est.*
Years:	10 yrs	66	14	18	4
	20 yrs	530	110	142	29
	30 yrs	1,472	305	393	82
	40 yrs	2,932	608	783	162
	50 yrs	4,949	1,026	1,322	274
	60 yrs	7,564	1,568	2,020	419
	70 yrs	10,816	2,243	2,888	599
	80 yrs	14,745	3,057	3,938	816
	90 yrs	19,391	4,021	5,178	1,074
	100 yrs	24,795	5,141	6,621	1,373

Notes: Based on Tables 3.7 and 3.8.

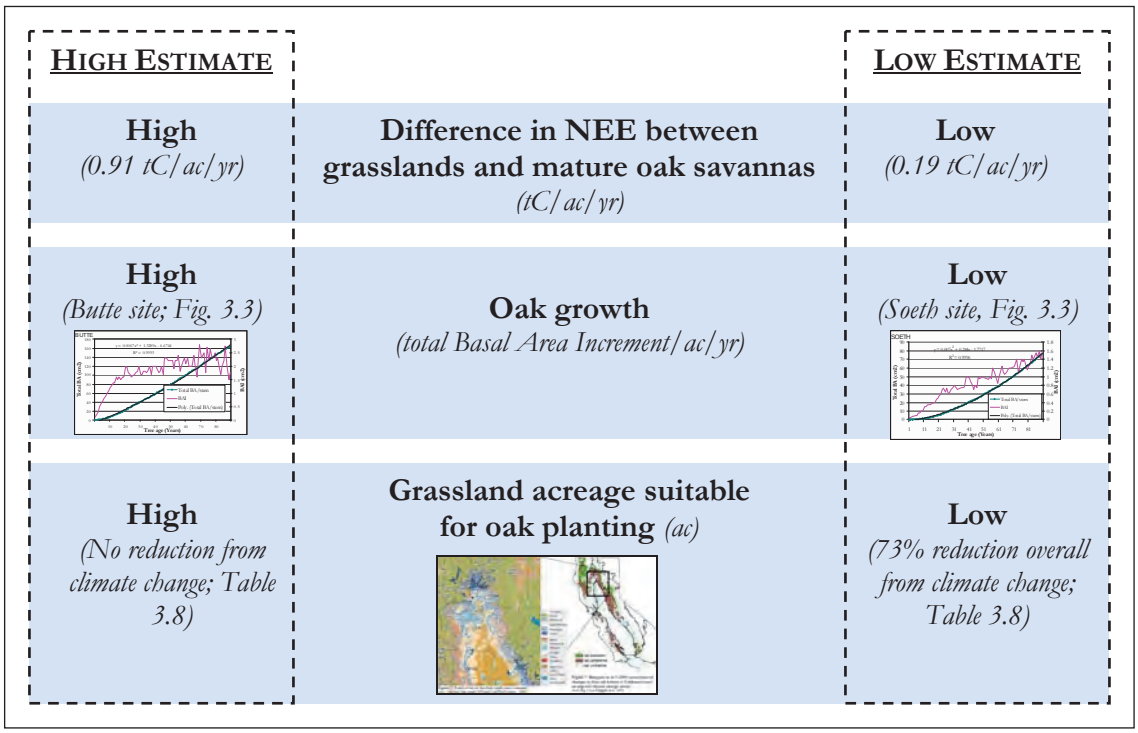

Figure 3.7: Major assumptions underlying the net carbon uptake estimates for oak planting

How do these numbers compare to the carbon bound up in current oak savannas? A recent comprehensive assessment of oaks in California (Gaman, 2008) estimates that oak woodlands in the four counties contain approximately 17.2 million tons of carbon in live and dead trees (not including downed logs, litter and soil borne carbon) (Table 3.10).

Table 3.10: Total carbon stored in oak tree biomass in study area counties

County	*Total tC*
Butte	3,283,286
Glenn	1,341,899
Shasta	4,955,757
Tehama	7,616,397
TOTAL	17,197,339

Source: Gaman (2008)

This value is about a third more than the mean of our high and low estimates of 13 million tons of carbon. Thus, based on our analysis, oak afforestation in the four counties over 100 years could absorb an amount of atmospheric carbon roughly similar to that already stored in current oak woodlands in these counties.

Our estimates also are in line with the estimated 103 million tons of carbon in tree biomass alone that reforestation of California's oak woodlands may sequester (Gaman, 2008). Thirty-eight percent of oak woodland and forest plots in Gaman's (2008) analysis fell into non-forest inclusion areas in oak woodlands that may be suitable for reforestation. Reforestation of these 4.9 million acres (38 percent of the total statewide mapped oak woodland and forest acreage of 12.9 million acres) would result in a carbon accumulation in tree biomass of an estimated 103 million tons (Gaman, 2008). This equates to 21 tC per acre, compared to our mean estimate of 27 tC per acre, with the difference between the two estimates likely due to the omission in Gaman's estimates of soil carbon increases.[12] Gaman (2008) estimates that through measures including interplanting, enhanced grazing management and conservation-based sustainable forestry, and through continued sequestration on existing oak lands, California's oak woodlands and forests combined have the potential to sequester up to a billion tons of carbon in the 21st century.

Water quality benefits of oak reestablishment

Planting oak trees on rangelands increases ground cover and root structures, both of which are beneficial to water quality of surrounding surface waters. Erosion and runoff from rangelands need to be controlled in order to limit emissions of pathogens (i.e. *E. coli, C. parvum*), sediment and nutrients (nitrogen and phosphorous) into waterways (Hubbard et al., 2004). Water bodies on rangelands provide human and livestock drinking water as well as fish habitat, all of which are uses that can be adversely impacted by runoff of pathogens, nutrients and soil particles.

The root structure of mature blue oaks can decrease soil erosion on rangelands by binding together the soils of watersheds (Burns et al. [1990], cited in Sacramento Valley Conservancy [no date]). Similarly, the practice of oak removal has been shown to negatively impact soil stability, with clearing of oak trees from California oak savannas leading to excessive soil

[12] 13.1 million tC divided by our mean suitable acreage of 477 thousand acres (Table 3.8).

erosion (Bartolome et al., 1994; IHRMP, 1998). One study reported that removal of oaks led to a 59 percent increase in runoff (Pitt et al., 1978).

Research indicates that many rangeland owners appear to be aware of the beneficial impacts of oaks on water quality. A survey conducted in 1985 indicated that 64 percent of owners of parcels under 5,000 acres thought that blue oaks had value for erosion control on their land (Huntsinger and Fortmann, 1990).

Wildlife benefits of oak reestablishment and afforestation

Oak savannas are a crucial component of California's Mediterranean climate region and provide habitat for a large variety of species. These are described in detail in Chapter 1.

Social economic and private financial value of benefits from oak planting

This section has presented an overview of some of the benefits provided by oak afforestation, focusing specifically on increases in forage production, carbon sequestration, water quality and wildlife habitat. Where possible, we developed quantitative estimates of these benefits, as in the case of forage production and carbon sequestration. In the cases of water quality and wildlife habitat, quantitative analyses could not be completed for this study. Nevertheless, the values associated with water quality and wildlife habitat benefits are very real and are easily identifiable.

Lower soil erosion rates on oak savanna rangelands lead to a reduced silt loading of streams and downstream water bodies in the watershed. This in turn increases the attractiveness of these water bodies for recreational uses (angling, swimming, boating) and thereby the enjoyment of recreationists. Given the number of water-based recreation participants downstream of our study area and with the net value of a water-related recreation day to participants (in economics referred to as the consumer surplus) ranging from around $30 to $50 per day in the Pacific coast region (Loomis, 2005), it is likely that reductions in sediment loading carry substantial aggregate recreational economic value.

Reducing soil erosion also slows the siltation of downstream reservoirs, canals and streams and thus reduces the need for costly dredging and the loss of ecosystem services like provision of habitat for wildlife dependent on healthy river channels and visibility. As of 2006, California had a total of 87 waters classified as impaired due to sediment loading, many of which are located in or downstream of our study area (U.S. EPA, 2009b). As of March 2007, the state had a total of 56 Total Maximum Daily Load (TMDL) limits in place for sediment, siltation or a combination of the two (ibid.), although none of these are located in the four counties that comprise our study area. In other areas of the state where rangelands lie upstream of sediment TMDL-limited areas, reductions of soil erosion from rangelands into water bodies resulting from rangeland management practices such as oak conservation or afforestation or riparian buffers can have real economic benefits for sediment point sources bound by TMDLs. In those cases, rangeland conservation practices effectively reduce the severity of the sediment TMDL limits imposed on point sources, and thereby result in reduced compliance costs for those sources. In several areas of the country, owners of agricultural lands are compensated by regulated point sources for management activities on their lands that produce water quality improvements. Examples for such point-source

non-point source water quality markets are found for nitrogen in the Susquehanna River and Connestoga watershed in Pennsylvania, the Kalamazoo River in Michigan (World Resources Institute, 2009) and for water temperature in the Tualatin River in Oregon (Oregon Department of Environmental Quality, 2009), to name but a few, and further ones currently are being designed for example for the Ohio River (Electric Power Research Institute, 2009).[13] These markets have the dual benefits of potentially achieving water quality goals more efficiently and allowing land owners to reap economic benefits from activities that provide additional benefits for society – in our case, from oak afforestation and riparian restoration or planting.

Even in the absence of any TMDLs for sediment, there are a total of 43 major dams in our four-county study area (National Atlas of the United States, 2009). Sedimentation of reservoirs imposes economic costs in the form of a reduction in the quality and availability of the services provided by reservoirs, such as recreation, electricity generation, water provision and flood control (Hansen and Hellerstein, 2007). Hansen and Hellerstein (2007) estimated that across the 2,111 U.S. watersheds, a one-ton reduction in soil erosion provides reservoir benefits ranging from zero to $1.38. As the authors note, this estimate only includes a small portion of total soil conservation benefits. The cost of dredging of reservoirs is highly variable, with $2.70 per ton to $41.90 per ton reported in the literature (ibid.; all values expressed in 2000 dollars). Thus, reductions in erosion from rangelands through oak planting and other practices are likely to lead to substantial avoided costs in our study area.

Because of the importance of study area's blue oak savannas and woodlands for terrestrial wildlife (see chapter 1) in addition to aquatic species, oak conservation, reestablishment and afforestation generate economic benefits in the form of terrestrial (mammal and bird) wildlife populations that are directly used by humans for recreational purposes (hunting, wildlife viewing) or are valued simply because of their existence (passive use values).

Wildlife-associated recreation activities attract large numbers of participants both in California (U.S. Fish and Wildlife Service and U.S. Census Bureau, 2007a) and nationwide (U.S. Fish and Wildlife Service and U.S. Census Bureau, 2007b). These activities generate substantial net benefits for participants (Aiken, 2009) and as well as large economic impacts in the local and regional economies (Carver, 2009; Leonard, 2008). By providing habitat for the species supporting these activities, oak savannas and woodlands directly contribute to these values and impacts.

Forage production and carbon sequestration

Increases in forage production resulting from the presence of blue oaks on rangelands generate benefits for land owners or lessees to the extent that the increase in forage availability leads to increased stocking rates or reduced feed costs. As discussed in the section on forage impacts of blue oaks on California's rangelands, the literature suggests that in California's Mediterranean climate uplands, blue oak cover on lands with up to 40-60

[13] A complete list and program information of the water quality trading programs operating in the U.S. can be found at Environmental Trading Network (2009). See also Selman et al. (2009) for a review and analysis of these programs.

percent oak canopy cover may result in an average increase in forage of around 0.5 AUM per acre. At the average 2008 price paid per AUM on private lands in California of $17.80 (National Agricultural Statistics Service [NASS], 2009), the potential value of this increased forage production was $8.90 per acre.

The forage benefits from blue oaks reported in the literature are for mature trees. Thus, the estimated value in 2008 of this increase was $8.90 per acre on uplands is a realistic *average* estimate for mature oak savannas. In contrast, newly planted oak acorns or seedlings will not produce these benefits until their root structures are sufficiently developed to alter soil nutrient cycles in their locations, something that is likely to take several decades even under favorable conditions.

The economic value of net carbon uptake from oak restoration and afforestation is more difficult to quantify than that of forage increases. This value consists of reduced damages from climate change-related impacts. Although projections of potential impacts and their associated economic costs are available, including for California (Climate Action Team, 2009), at this time the uncertainties surrounding these cost estimates and the marginal damages caused by changes in greenhouse gas emissions are too large, and the impact of oak planting on rangelands in our study area on overall emissions too small, to allow the generation of reasonably defensible estimates of avoided climate change costs due to oak afforestation.

Even though the full, social economic value of reductions in atmospheric concentrations of greenhouse gases resulting from oak planting is difficult to estimate at this time, carbon sequestration through oak planting on rangelands has the potential to generate private financial benefits for rangeland owners. Currently, voluntary carbon markets allow landowners to sell so-called carbon offsets - financial instruments aimed at a reducing greenhouse gas emissions. The volume of carbon offsets transacted on voluntary carbon markets globally has recorded strong and continued annual growth since 2003, with the bulk of that growth in the last three years occurring on the Chicago Climate Exchange (CCX) (Hamilton et al., 2009). Voluntary over-the-counter (OTC) markets, which handle deal-by-deal transactions of more tailored offsets than those that take place in the CCX also have recorded strong growth since 2003, and as of 2008 still accounted for over half of all offset transactions globally. Both markets allow landowners to sell emission offsets resulting from carbon sequestration, with the major difference between the two being that CCX offsets satisfy well-published and consistent standards for credit calculation and verification. Currently, the CCX only accepts credits for changes in soil carbon stocks on rangelands for prescribed changes in management - sustainable stocking rates, rotational grazing and seasonal use (CCX, 2009), with standardized credit rates (0.12-0.32 metric tCO_2 per acre per year) for particular project types and locations. Currently, projects in Butte, Glenn and Tehama counties are eligible for offset generation, while those in Shasta are not (CCX, 2009). Thus, the CCX currently does not permit the generation of offsets via oak afforestation. However, OTC markets do accept afforestation and reforestation credits, and in 2008 the U.S. was home to the majority of OTC afforestation and reforestation projects worldwide (Hamilton et al., 2009). The average OTC price in 2008 for projects in the U.S. was $6.9 per ton of CO_2e (ibid.). Thus, based on our 100-yr per-acre carbon gain scenarios for rangelands in our study area (Table 3.7), rangeland oak afforestation projects would have generated credits worth between $47 and $227 per acre. Since credits generally are accrued

with actual sequestration, landowners would not have received these amounts as lump sums, but rather over time. Furthermore, due to the comparatively slow growth especially of blue oaks, annual payments would be small in the early years and even decades, and then would increase with increasing total annual carbon sequestration by maturing oaks. These payment levels probably are an underestimate of what oak afforestation could yield in land owner income from the sale of OTC carbon offsets because most analysts expect carbon prices to increase (e.g., see New Carbon Finance, 2008; U.S. EPA, 2009c). The generated credits would have accounted for a very small share of total OTC transaction volume and thus would not have affected average credit prices. Furthermore, the demand for offsets is likely to increase, as the California Global Warming Solutions Act (AB32) encourages voluntary greenhouse gas reductions, and California's Forestry Greenhouse Gas Accounting Protocols will register reforestation projects (Climate Action Reserve, 2009).

Voluntary carbon markets pale in comparison to regulated markets, with the former accounting for less than three percent of the total global volume of transactions in 2008 (measured by weight of CO_2e). In the U.S., there are several currently operating and emerging state and regional regulatory carbon markets, and a federal cap-and-trade based market is expected to develop. Development of these regulatory carbon markets will drive up demand and prices for offsets on both regulated and voluntary carbon markets. For example, under the Western Climate Initiative (WCI) that comprises 11 partner and 14 observer states and provinces from Nova Scotia to Mexico, including California, up to 49 percent of reductions may initially be achieved through offsets (California Air Resources Board, 2008). Thus, it is likely that planting of oaks on California rangelands will become more financially attractive for land owners than it currently is. Even under current carbon prices, however, such afforestation may make economic sense for land owners as long as the associated transaction costs are not too onerous. Meeting of the latter condition becomes more likely over time as familiarity of landowners with carbon markets increases and technical advances make offset verification cheaper and more efficient.

Cost of oak planting

Guides for landowners on how to artificially regenerate oaks are readily available (for example, McCreary and Nader, 2007). Unfortunately, information on the cost of this regeneration is much more difficult to obtain.

Below we present the one example of oak reestablishment costs that was available (Table 3.11). The data are from an oak planting project on California Audubon's Bobcat ranch. In this particular case, 200 acorns were planted and protected using herb control and tree shelters. The cost of this planting is substantial, at around $100 per acorn. On the other hand, the project includes all the measures recommended in the literature to ensure high acorn and seedling survival and growth rates. Private landowners may be able to reduce planting costs compared to those listed in Table 3.11 if they are able to reduce labor costs to below the $50 per hour used for landowner, Audubon and FWS labor in the example. For example, at $15 per hour for these labor inputs, costs per planted acorn drop by half, to $51.

Per-acre costs from this example can be extrapolated to other sites by incorporating particular desired target tree densities and acorn survival rates from artificial regeneration projects reported in the literature.

Table 3.11: Budget of oak restoration project on Bob Cat Ranch, California

Description	*Quantity*	*Unit*	*Cost/Unit*	*Total*
Services and Labor				
Labor – Landowner, Audubon, US FWS	280	hours	50	$14,000
Hired crews (cage installation)	80	hours	10	$800
Equipment rental	40	hours	40	$1,600
Subtotal services and labor				$16,400
Supplies and Expendables				
Acorns	200	unit	0.25	$50
Tubex tree protectors and stakes	100	units	3.65	$365
Native grass straw	20	bales	9	$180
Round-up herbicide	128	oz	0.5	$64
Woven wire 12 gauge 4x2 4ft tall	9	rolls	128	$1,152
T-Post 6ft	200	post	4.15	$830
Electrical wire	1	rolls	15	$15
Irrigation hose	4	rolls	100	$400
2 inch PVC	200	feet	0.6	$120
Pressure compensating emitters	100	units	0.45	$45
Miscellaneous irrigation supplies	1	lump	200	$200
Bird boxes (4 blue bird and 1 owl)	6	lump	40	$240
Subtotal Supplies and Expendables				$3,661
TOTAL				$20,061

Source: Personal Communication. Chris Rose. California Audubon Society. May, 2008.

Table 3.12 shows the survival rates of a number of artificial regeneration projects, for both acorn-based and seedling-based plantings. Since survival rates differ for the two approaches, we use only the rates reported for acorn planting projects - 33 percent (Kraetsch, 2001) and 75 percent (Tecklin et al., 1997).

Table 3.12: Survival rates for artificial blue oak regeneration

	Survival rate	*Treatment*	*Source:*
Planted blue oak acorns that become strong saplings after 4-5 years	33%	Screens, tree shelters	Kraetsch (2001)
Three-year survival rate of seedlings	45%	Screens, herb control	Adams et al. (1991)
Three-year survival rate of acorns	75%	Treeshelters, herb control	Tecklin et al. (1997)
Three-year survival rate of seedlings	88%	Treeshelters, herb control	Tecklin et al. (1997)
Four-year survival rate of seedlings	58%	Treeshelters, fencing	McCreary (1999)

Multiplying the 200 planted acorns from the example presented in Table 3.11 by the average of these two survival rates (54 percent) yields an expected 108 acorns that mature into robust seedlings. These can be planted at desired densities. Table 3.13 presents per-acre cost examples for acorn-based oak plantings at densities ranging from 27 to 108 stems per acre.

Table 3.13: Cost per acre of oak plantings for different tree densities

Oak density (Stems/acre)	*Project acreage at given seedling density*	*Cost/acre*	
		*High **	*Low **
108	1	$20,061	$10,261
54	2	$10,031	$5,131
27	4	$5,015	$2,565

* High costs are based on labor costs shown in Table 3.11; low costs are based on reduced costs of $15 per hour of landowner labor input.

The corresponding costs range from around $2,600 to $20,000 per acre, depending, in addition to tree density, on labor cost. On rangeland sites in California, typical oak planting costs (at the labor cost rates shown in Table 3.11) are $3,000 to $6,000 per acre.[14]

The foregoing numbers indicate that the cost of planting oaks on grasslands in our study area is likely to be one to two orders of magnitude higher than the revenues, even without taking into account that the landowner would not receive a large portion of those revenues for many years, whereas all of the costs are incurred upfront. This result is partly due to the rather low productivity of the Mediterranean climate grasslands in the study area, the low growth rates of blue oaks, the relatively low present prices on carbon markets accessible to grassland owners, and the absence of sediment and nutrient water quality trading programs in the area. Thus, from a private financial perspective, at this point in time oak afforestation of these grasslands does not make economic sense for private landowners. Even under cost share programs that cover 50-75% of the total cost of oak planting, most such planting projects likely would not be financially viable at this time.

From the perspective of society at large, the economic rationale for oak planting may be much more favorable given that such planting can provide both offsite (e.g., water quality) and onsite (e.g., wildlife habitat) public benefits. Oak planting thus exemplifies the fairly widespread problem of a divergence of privately- from socially-desirable land management actions. If socially-desirable actions are to be achieved – oak planting in this case – it is necessary to align private incentives with social objectives. This could be achieved through several different approaches, including higher cost shares, the creation of missing markets (for example, water quality trading), or payment programs that compensate landowners for implementing desired management actions. Examples of the latter already exist in the form of federal and state conservation payment programs. However, there may be an economic case for increasing the payment levels in situations where the payments do not reflect the full value of the third-party benefits generated by private management actions and where they are insufficient to bring about the socially-desirable management types or levels of conservation actions.

[14] Personal communication. Vance Russell, California Audubon Landowner Stewardship Program. August, 2009.

C. Restoration of Native Perennial Grasses

In the past two hundred years the grasslands in California's Central Valley have gradually changed from predominantly native perennial species to a landscape dominated by non-native annual species. Only two percent of California grasslands contain native perennials (USDA, ARS) and these areas most likely are not "pristine" native grasslands, but contain some non-native species (Stromberg et al., 2007). There are many questions regarding the feasibility of restoring native perennials to California grasslands. Many argue that restoring native perennials to the landscape will increase forage value (Bartolome, 2007; Dyer, 2002), wildlife habitat and biodiversity, and improve soil ecosystems and functions (Menke, 1992; D'Antonio and Myerson, 2002). But, what constitutes a restored grassland ecosystem varies by location (Stromberg et al. 2007), and restoration requires long-term management with variable results (Brown and Rice, 2000; Bartolome et al., 2007; Stromberg et al., 2007). This section will briefly discuss the historical landscape changes within California rangelands, successful restoration case studies within Shasta, Butte, and Tehama counties, and the effectiveness of three selected restoration practices along with their associated costs. These practices include prescribed burning, managed grazing, and re-seeding native grass species.

Historical landscape

Before the 1800s, large areas of grasslands were burned regularly by Native Americans (Anderson, 2005) and grazed by large herbivores like elk and antelope (Stromberg et al., 2007) defining the surrounding landscape. After the early 1800s, European settlement began changing the landscape and populations of native perennial grasses started declining. There are many plausible reasons for the shift from native perennials to non-native annuals and most likely it is a combination of many factors (Bartolome et al., 2007). With European settlement, fires were suppressed, roaming wild megafauna were replaced with intense livestock grazing, and rangelands were converted to agriculture and urban uses (DiTomaso, 2000, 2006). These changes in land use benefited non-native annual grass species, which have higher rates of growth and reproduction, enabling them to invade disturbed sites much more quickly and efficiently than native perennials (D'Antonio and Myerson, 2002).

Another theory about what may have contributed to the decline of native perennials is the introduction of viruses from European agriculture. These viruses target native perennials and in some locations where they are prevalent native perennials may only be able to exist in small populations within larger populations of non-native grasses (Malmstrom, 2005).

The proliferation of suburban development, road building (Gelbard and Belnap, 2003; Gelbard and Harrison, 2005), and the expansion of the ranching industry (DiTomaso, 2006) over time slowly changed soil structure, biodiversity, and forage value of California rangelands (Menke, 1992; D'Antonio et al., 2007). Presently, many rangelands contain invasive non-native annuals like yellowstar thistle (*Centaurea solstitialis*), medusahead (*Taeniatherum caput-medusae*), and barbed goatgrass (*Aegilops triuncialis*), which are not palatable to livestock after maturation and require intensive management practices to control spreading. Also, they tend to be fierce competitors with native perennials, monopolizing resources and decreasing the biodiversity and habitat for wildlife (DiTomaso, 2000). There are some native perennial grasses that compete well with non-native annuals when management practices such as burning and grazing are introduced. The native, purple

needlegrass (*Nassella pulchra*) in many restoration cases rebound successfully (Dyer and Rice, 1997). However, purple needlegrass does very well in disturbed sites and careful management is required to not create a monoculture at the expense of a diverse stand of native grasses and forbs.[15]

Native grass restoration practices

Successfully restoring native perennial grasses and/or increasing biodiversity of native species including annual species to Central Valley grasslands requires consideration of many factors such as current site conditions (soil, slope, water availability, species diversity), historical use of the site, and future land managers objectives (DiTomaso, 2000; D'Antonio, 2002; Stromberg, 2007; Lulow, 2007). All require significant investment of time and money from a landowner. Given that these landscapes are dynamic and constantly changing, a landowner must be flexible and adaptive to various circumstances and conditions (Bartolome, 2004).

Within Butte, Shasta, and Tehama there are some restoration projects that represent successful examples of restoration practices (Stromberg et al., 2007). Llano Seco Tract 1 owned by the USFWS in Butte County was burned in 1999 and disking and herbicide were applied to the site before it was drill seeded in 2002. In 2006 the USFWS reported close to 90 percent cover of six native grasses. Turtle Bay Discovery Park, owned by the City of Redding in Shasta County, was treated with herbicide before it was plug planted in 2004 and achieved a good establishment of two native perennials valley: wild rye (*Leymus triticoides*) and valley sedge *Carex barbarae*) in 2006. Dye Creek, owned by the Nature Conservancy in Tehama County, was rotated between burning and grazing before it was seeded with purple needlegrass in 1997 using hay designed to reduce medusahead and improve native grass establishment. In 2006, purple needlegrass cover was close to that of remnant local stands. This project illustrates the concern of restoring native grassland species that could result in monoculture and potentially reducing the biodiversity of the site.

Other restoration projects have reported re-establishment of some non-native species and potentially needing long-term management to maintain native perennials. Sunset Ranch, owned by the Nature Conservancy in Butte County, had a cover crop of legumes before it was mowed twice in 2003 and 2004. Herbicide was applied in 2004 before it was drill seeded ten months later and twice again after the planting. In 2006, there were still problems with noxious weeds fluevellin (*Kickxia elatine*), Johnson grass (*Sorghum halepense*) and Russian thistle (*Salsola spp.*). It was recommended to avoid legume cover crops and leave land barren two years prior to planting (Stromberg et al., 2007).

Sulphur Creek, owned by the City of Redding in Shasta County, planted seven species of native perennials along one mile of stream bank[16]. The seed was hand-broadcasted in 1997 and 2005 along areas where extensive erosion control, soil stabilization, and stream bank restoration were also conducted. In 2006, yellowstar thistle was still a problem, but an excellent stand of seven native perennials was reported. Many other restoration projects have

[15] Personal Communication. Rodd Kelsey, California Audubon. February, 2009.
[16] The Sulpher Creek project does not involve grazing, but it does provide valuable cost information and an example of successful re-establishment of native perennials.

seen the re-establishment of non-native species after a few years, requiring long-term management and up-keep of restored areas. Some site examples are Audubon's Corral Pasture, Yolo County; Ranchette Private, Yolo County; Citrona Farms, Yolo County; Hedgerow Farms, Yolo County; and Russian Ridge, San Mateo County projects (Stromberg et al., 2007).

It may be more beneficial to introduce a mixture of management practices such as prescribed burnings where appropriate, grazing, and re-seeding of native perennials. These practices have mixed results and vary between site locations, so it is important to understand the ecosystem in which the restoration practice is taking place (Bartolome et al., 2007).

Prescribed Burning

The purpose of prescribed burning is to decrease populations of invasive plants such as medusahead, barbed goatgrass, and yellowstar thistle before they can produce viable seeds. The results are variable because it can be very difficult to ensure proper timing and the effectiveness of burning for the re-establishment of native perennial species depends on site location and timing of precipitation (Marty, 2005). For example, a study by Bartolome (2004) showed that prescribed burning in the coastal range grasslands had no effect on increasing native perennial species. However, DiTomaso (1999, 2006a, 2006b) argues that prescribed burning can decrease the seed banks of yellowstar thistle and effectively control their proliferation, while at the same time increasing native perennial grass cover.

Several studies have demonstrated success of burning with the re-introduction of purple needlegrass. A study by Dyer (2002) found that the seed size of purple needlegrass increased with prescribed burning, improved the likelihood of germination, and increased its competitiveness against invasive species. Lulow (2007) also recorded an increase in seed size of native perennial grasses with prescribed burning and that the increase was correlated with increased cover.

Generally, the best timing for prescribed burns is late spring when undesirable non-native annual grasses have not yet seeded (Wirka, 1999). However, burning can frequently result in a flush of extensive, dense populations of filaree (*Erodium botrys*) (DiTomaso et al., 2006a). The exception was purple needlegrass, which was able to thrive within the filaree (DiTomaso, 2006a; Lulow, 2007). Another study (Marty, 2005b) found that prescribed burning actually decreased the population of purple needlegrass after two years. Bartolome (2007) and DiTomaso (2006b) indicate that it takes 3-5 years to see viable results.

Although burning can be a very good range management tool, it is not widely used in California because of the difficulties in getting permits and associated problems related to air quality concerns and the risk of wildfires. Also, burning can be quite expensive. Out-of-pocket expenses for labor, fuel, minor equipment repairs, permits, and seed and fertilizer for firebreaks are estimated at $23 per burned acre (Connor [2003] cited in DiTomaso [2006b]).

Managed grazing

Using grazing as a management tool for restoring native plant species in California rangelands is a controversial and complex subject. There is little substantive research that

replicates and supports the conclusions of studies done in the Central Valley and elsewhere. For example, studies done within different California ecosystems like vernal pools (Marty, 2005a) and coastal grasslands (Bartolome, 2004) have shown an increase in native perennial plant communities resulting from managed grazing. A study by Hayes and Holl (2003) in the coastal grasslands showed that managed grazing increased native annual forbs, but *decreased* native perennial grass species.

Many ranches in the Central Valley practice some form of managed grazing and certain grazing practices have proven to be an effective tool in the restoration of native perennials when combined with prescribed burning (Menke, 1992). Light to moderate managed grazing for eradicating some invasive species have shown to increase aboveground biomass of native grasses, especially purple needlegrass (Marty, 2005b). Lulow (2006) argues that maintaining diversity and increasing the aboveground biomass of targeted native grass species enables them to resist invasions by non-native annuals. In general, established native grasses have shown to respond favorably to long-term managed grazing when site specific characteristics are taken into account (Jackson and Bartolome, 2007). Managing for native perennial diversity will require a mixture of grazing and non-grazing practices that will vary by location (Hayes and Holl, 2003).

The absence of livestock grazing has been shown to actually increase invasives like yellowstar thistle, medusahead and barbed goatgrass. These species are not palatable to livestock after maturation and decrease the carrying capacity of rangelands over time (Bartolome, 2007). They should be grazed while still young and before seeds are established, thereby reducing their abundance (Thomsen, 1993, 1996). Managed grazing is a relatively cheap management practice and may be a good alternative to burning for invasives control.

According to DiTomaso (2006b) the costs associated with controlling yellow star thistle with managed grazing include purchasing or leasing of the animals, maintaining them in proper health, and monitoring their grazing activity to minimize harm to desirable forage. Other expenses may include leasing land, spraying molasses to increase palatability, herding dogs, fencing, and sometimes supplemental feeding.

Seeding Native Grass Species

Seeding native grass species is expensive and requires thorough knowledge of a site, including species presence, soil type, water availability, and species life cycles (Lulow, 2007). Re-seeding with native perennials can be successful if these factors are taken into account (Corbin and D'Antonio, 2004). Two types of seeding techniques are used: plug planting and drill seeding. In general "plugs" are more expensive, but the survival rate is high at about 90 percent (Stromberg et al., 2007; Cunliffe and Meyer, 2002; Corbin and D'Antonio, 2004; Huddleston and Young, 2004). Plugs are most cost effective if used on small plots. A restoration project in Shasta County (Turtle Bay Discovery Park) used plug plantings on 28 acres in 2004. After two years there was a good establishment of two native perennials (Stromberg et al., 2007).

Drill seeding can be used for larger areas with a tractor operated seed drill. Four years after drill seeding, a restoration project in Llano Seco (Butte County) reported 90 percent cover of native grasses on 65 acres. The land was treated a few years prior to seeding with burning,

disking, and herbicides. Drill seeding is expensive for large tracts of land and in cases where there are still natives mixed-in with the exotic grasses the use of prescribed burning and managed grazing is a cheaper option. There are many cases where direct seeding has not established a good healthy stand of native perennials (see Stromberg, 2007). For example, non-natives can re-invade a site, indicating that long-term management is necessary. Jetter et al. (2003) argues that establishing native perennials will effectively control the proliferation of yellowstar thistle because they have similar water intake and root structure. However, getting an established native perennial stand takes many years and requires repeated burning and grazing of a targeted invasive species.

The costs associated with re-seeding native species include seedbed prep, seeding, and follow-up management. According to the Agricultural Research Service (USDA), a pound of native grass seed costs $40. Approximately 15 pounds of native grass seed are needed to effectively sow one acre of land, thereby costing about $600/acre.[17] Re-seeding native grass species varies by location and size of tract. For example, The Cottonwood Slough Restoration Project conducted by California Audubon is a 17-acre tract with estimated costs of $4200/acre the first year and $880/acre the second year. These costs include management, site preparation, seeding, irrigation, erosion control, habitat enhancements, and weed control. In contrast Bobcat Ranch, also a restoration project conducted by Audubon, is a 6,800-acre tract with estimated costs of $9.50/acre. Costs include staff time, fence installation, equipment rental, seeding, and weed control. According to DiTomaso (2006b), costs recorded for re-seeding in a native legume and perennial grass restoration effort at Fort Hunter Liggett were between $500 and $2000/acre. In this trial, the native species represented 5 to 30 percent of the total vegetative cover two years after seeding.

California grasslands now have a mixture of European annual species and native perennial and annual species. Non-native annual species are an integral part of the landscape and how they interact with native species and change the ecosystems is still not widely understood. Restoring native perennial grassland species to vernal pool sites and coastal grassland areas has had more success than in drier areas of the Central Valley. These site locations should be seriously considered and management practices accommodated appropriately. Range manager objectives must be seriously considered. For example, if biodiversity is an objective, purple needlegrass must be carefully managed so as not to create a monoculture in the site area. If establishing perennial grasses for forage is the objective, then the life cycles of invasives such as yellowstar thistle, medusahead, and barbed goatgrass should be well understood so as to graze and burn them before they have seeded. More research is needed on how these non-native annuals affect wildlife, soils and the pathogenic microorganisms that positively affect native perennial species (D'Antonio et al., 2007).

Forage impacts of restoring native perennials

Restoration of native perennials in California's Mediterranean climate rangelands is expected to increase forage value (Bartolome, 2007; Dyer, 2002). In one recent study, restoration of perennials led to moderate forage gains after several years, following a short-term decrease in forage immediately after the establishment of native grasses. This short-term decrease was due to the strong control measures applied to suppress annual forage grasses and noxious

[17] Personal Communication. John Anderson, Hedgerow Farms. August, 2009.

annual weeds (Malmstrom et al., 2008). Despite encouraging signs, there is a lack of sufficient quantitative information on forage impacts of perennials restoration. Thus, in this section we focus on the impact of perennials on soil carbon stocks.

Carbon impacts of restoring native perennials

California rangelands exhibit a wide range in soil carbon pools, with studies showing ranges between 20-140 t/ha in the top 50 cm, ~80-180 t/ha in the top 1 m, and 210-250 t/ha in the top 1.5 m for woody lands, and 20-65 t/ha in the top 30 cm depth, 40-100 t/ha in the top 50 cm, and 80-100 t/ha in the top 60 cm for non-woody lands (Figure 3.8; based on data in Silver [2009]). Because of this variation in soil carbon among sites, it is not possible to directly compare the soil carbon content of different sites with native perennial grasses with others covered by non-native annual grasses. Rather, what is needed are studies that measure net carbon fluxes (NEE) or soil carbon content of sites characterized by patches of both grass types in close proximity.

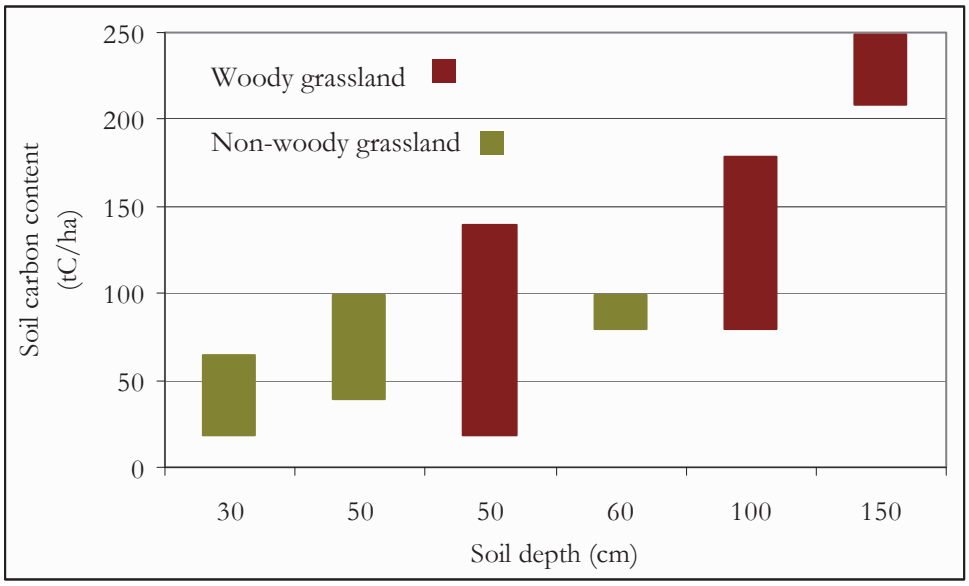

Figure 3.8: Soil carbon content of woody and non-woody California grasslands

Of the few available grasslands NEE studies, none examine NEE for patches of native perennials and exotic annuals on the same site. Although potential productivity differences between sites as well as interannual variability in climatic variables limit the validity of comparisons of the findings of those studies, it should be noted that the only study examining a native grassland (Valentini et al., 1995) reported by far the highest net carbon uptake of all grassland studies (Table 3.5).

While suitable NEE studies are not available, there are three soil carbon content studies of sites that contain patches of both native perennial and exotic annual grasses (Table 3.14). Koteen (2007) and Koteen et al. (2005) analyzed differences in total soil carbon between exotic annual and native perennial grasses at two sites in Marin County. They found that the soil carbon content in the top 50 cm of patches of native grasses was between eleven and 57

percent higher than in patches of exotic grasses. Thus, the displacement of native perennial by exotic annual grasses at those sites is estimated to cause soil carbon losses of between 7.1 to 21.2 metric tons per acre in the top 50 cm of soil, depending on species type and site. Total losses are likely to be even higher, since perennials have deeper roots than exotic annual grasses.

Conversely, restoration of native perennials can increase soil carbon stores. For example, Potthoff et al. (2005) (see also Jackson et al., 2007) examined total soil carbon of plots of old field annual grassland (fallow for 65 years) and restored perennial grassland (4 yrs old). They found that total soil carbon was little affected by plant species composition at this early stage of restoration (4 yrs). However, as the authors note, and despite the fact that tilling strongly reduces soil carbon due to carbon mineralization (the restored patches had been tilled several times before seeding), total soil carbon of the perennial sites already had recovered to levels similar to those of the untilled old-field annual site, indicating rapid carbon stock recovery. In addition, the authors note that the deeper (15-80 cm) distribution of total soil carbon and soil microbial carbon pools in perennial grasslands may increase soil carbon stocks over time based on the trend for more roots below 15 cm in the perennial compared to the annual grassland. As a result, the authors expect that restoration of perennial grasses will lead to net gains in soil carbon.

The fact that Valentini et al. (1995) (Table 3.5) report moderate net uptake for a native grassland, compared to the on-average neutral or weakly negative carbon balance of California grasslands (Baldocchi, 2009), supports the hypothesis that reestablishment of native grasses can improve the carbon balance of rangelands.

The potential carbon sequestration that could be achieved through large-scale restoration of native perennials on California rangelands can only be tentatively gauged, due to the very limited available empirical data. Koteen et al.'s (2005) and Koteen's (2007) estimates of the difference between soil carbon contents in the top 50 cm of patches of native and exotic grasses could be used as the amounts by which soil carbon stores could be increased through restoration of perennials. This would yield estimates of carbon sequestration of 21.2 tC/ac and 7.1 tC/ac, respectively. These are estimates of the total amount of soil carbon that would be restored through perennials. The annual increases in carbon stocks would be much smaller, depending on the time it takes to restore soil carbon pools to pre-invasion levels.

Due to the large expanse of grasslands found in our study area (Table 3.8), restoration of native grasses - even on a relatively modest scale - can generate substantial total quantities of net carbon uptake. For example, if five percent of grasslands in the four-county area are restored, soil carbon stocks would increase by an estimated 288 thousand to 865 thousand tons (1.06 to 3.17 million tons of CO_2e), depending on the carbon gain scenario (Table 3.15).

Table 3.14: Comparisons of total soil carbon in exotic annual and native perennial grasslands in California

Study	*Grassland type*		*Total soil C*		*Location*
			kgC/m²	*gC/kg*	
Koteen et al. (2005)	Mixed exotic **annual**		9.3 *		Bolinas Lagoon Preserve, Marin County (37°56'40"N, 122°41'W)
	Native **perennial** (*Bromus carinatus* and *Elymus glaucus*)		14.5 *		
Koteen (2007)	Mixed exotic **annual**		15.3 *		Tennessee Valley, Golden Gate National Recreational Area, Marin County (37°52'N, 122°31'W)
	Native **perennial** (*Agrostis halli* and *Elymus glaucus*)		17.5 *		
	Native **perennial** (*Festuca rubra*)		17.0 *		
Potthoff et al. (2005)	Old field **annual** grassland (65 yrs fallow)			26.0 **	UC Hastings Natural History Reservation, Upper Carmel Valley, Monterey County (121°0'31"W, 36°30'12"N)
	Restored native **perennial** grassland	- near bunches		21.3 **	
	(*Nassella pulchra*, *Elymus glaucus* and *Hordeum brachyantherum californicum* (4 yrs after seeding)	- between bunches		21.8 **	

Notes: * Top 50 cm. ** Top 80 cm.

Table 3.15: Examples of potential soil carbon sequestration from restoration of native perennial grasslands in the four county study area

% Grassland acreage restored	*Low C gain (7.1 tC/ac)*	*High C gain (21.2 tC/ac)*
	1000 tC	*1000 tC*
5%	288.4	865.2
15%	865.2	2,595.6

If 15 percent of grasslands were restored, total soil carbon stocks would increase by 865 thousand to 2.60 million tons (3.17 to 9.52 million tons of CO_2e).

Carbon accumulation from restoration of native perennials could be achieved in savanna soils, too. However, the studies listed in Table 3.14 looked at carbon differential in grasslands only. In savannas and woodlands, trees are likely to increase soil carbon stores, so the incremental increase in soil carbon from restoration of perennials may be smaller than in grasslands. Nevertheless, due to the large acreage of woodlands in the study area (1.4 million acres; Gaman and Firman, 2006), the total carbon sequestration potential in savannas in our study area is very large.

Social economic and private financial value of carbon sequestration from restoration of native perennials

Restoration of native perennial grasses on rangelands can generate a variety of benefits that carry economic value. These include the provision of habitat for wildlife people value for direct (hunting, fishing, wildlife viewing) or passive (existence values) uses. In addition, the longer period of green cover provided by perennials extends the foraging season and reduces the risk and spread of catastrophic wildfires and the economic costs associated with fire control and loss of life, health and property.

Perennials restoration also is likely to increase soil carbon stocks, which in turn increases site productivity and may generate carbon offsets that can be sold on carbon markets. (For a general discussion of carbon markets, please refer to the section *Social economic and private financial value of benefits from oak planting*.) At 2008 average OTC prices of $6.9 per ton of CO_2e (Hamilton et al., 2009), the quantity of carbon sequestered through restoration of perennials on rangelands (7.1 - 21.2 tons/acre) could generate an estimated $49 to $147 per acre over the multi-decade period over which the carbon uptake would occur. These potential revenues, even without the transaction costs associated with project accreditation and verification, are substantially lower than the costs of perennials restoration. However, from a socio-economic perspective, restoration of perennials may nevertheless be a worthwhile undertaking because of the other, public on- and offsite benefits such restoration creates (reductions in fire-related costs, wildlife habitat, conservation of native habitats and species). In the absence of compensation for the provision of these benefits as a result of perennials restoration, the landowner has no economic incentive to undertake such restoration projects. This presents another example of why achieving socially desirable outcomes may require economic incentives for private land owners.

D. Grazing Management, Riparian Fencing and Restoration, and Water Development

In this section we examine *public* ecosystem service benefits that are derived from adopting resource conservation practices associated with improved grazing management. These practices were discussed in Chapter 2 and include prescribed grazing, water development, fencing of riparian areas and restoration of riparian buffers. These practices are frequently adopted by ranchers using NRCS conservation programs and recommended as a package that can improve overall range health. For example, prescribed grazing, in combination with water development to disperse livestock from riparian areas, can help control invasive species. Thus, although we do not address the ecosystem service impacts of water development *per se*, we do consider this practice as contributing to the overall ecological health of a particular rangeland landscape. The ecosystem services we address are carbon sequestration, water quality and wildlife habitat/species conservation.

Generally, improved grazing management can have beneficial impacts on biodiversity on California's rangelands. Improved grazing management mimics "natural" systems through manipulation of animal grazing patterns, typically using a rotation-based system. To date, direct scientific evidence of the benefits of many grazing practices is lacking for California grasslands (Huntsinger et al., 2007). Some environmentalists maintain that livestock grazing is incompatible with native biodiversity preservation. DiTomaso (2000), Stromberg et al. (2007), and Barry et al. (2006) have argued that *intensive* grazing is unsustainable, decreases biodiversity, and is partly responsible for the decrease in native perennial plants and an increase in non-native species. Other researchers have concluded that managed grazing can have a neutral or positive effect on grassland health. Managed grazing practices are endorsed as a tool for promoting biodiversity in native grassland remnants and for restoration projects (Menke, 1982; Edwards, 1995, 1996; Reeves and Morris, 2001; Hayes and Holl, 2003; Stromberg et al., 2007, cited in Huntsinger et al., 2007). In a review of the impacts of grazing in riparian areas, Skovlin (1984) reported that the literature on wildlife response to moderate and seasonally controlled grazing is encouraging.

The success of managed grazing to achieve biodiversity conservation varies between locations and is dependent on external factors such as climate, particularly precipitation levels. The interaction between climate and grazing in relation to native plants is likely important but has not been rigorously examined (Huntsinger et al., 2007). Although studies of California grasslands are numerous, most suffer from design flaws and results cannot always be unambiguously assigned to grazing treatments or generalized across sites (Huntsinger et al., 2007).

*Under*grazing California rangelands can be detrimental to native biodiversity. In a study by Bartolome (2007), ungrazed plots showed an increase in invasive plant species such as medusa head, barbed goat grass and yellowstar thistle. Many invasive plants may alter ecosystem structure and functional processes, including hydrologic, fire, and nutrient cycles. Structural changes in invaded plant communities typically cause reduced native species richness and diversity and changes in canopy structure (Belcher and Wilson, 1989; Parmenter and MacMahon, 1983; Rikard and Cline, 1980; Wallace et al., 1992, cited in DiTomaso et al.,

2007). Marty (2005) has shown that some grazing is essential for maintaining the hydrology and species diversity of vernal pool grasslands.

Allen-Diaz et al. (2004) found that light cattle grazing near natural springs on California rangelands had desirable impacts on ecological functions. Carroll et al. (2007) concluded that rotational grazing was successful in providing summer nesting habitat to dabbling ducks and Aleutian Goose in the Central Valley study area.

Carbon

Silver (2009) notes that an unanswered question is whether grazing management *alone* increases soil carbon storage. Grazing by itself has not been shown to have a consistent effect on soil carbon, at least in the semiarid Mediterranean climates of the western U.S. (Jackson et al., 2007). Conant et al. (2001) completed a comprehensive literature review on grasslands and found that improved grazing increased total soil carbon on average by 0.35 tC/ha/yr. Many of the studies reviewed, however, were from outside the U.S., including Australia, the United Kingdom, New Zealand, Canada and Brazil. Their findings therefore are likely not quantitatively applicable to California due to the wide range in soil types and grazing treatments contained in the data, and the fact that none of the studies were conducted in California.

Passive and active restoration of riparian areas through the installation of buffers likely has beneficial impacts on carbon sequestration. However, there are as yet no research findings that indicate the extent to which the restoration of riparian areas does increase carbon storage.

Ranchers can market carbon offsets from prescribed grazing on the Chicago Climate Exchange (CCX). The CCX grants credits for changes in soil carbon stocks on rangelands for prescribed changes in management - sustainable stocking rates, rotational grazing and seasonal use, with a standardized offset credit rate of 0.16 metric tCO_2 per acre per year in California (CCX, 2009). Currently, projects in Butte, Glenn and Tehama counties are eligible for offset generation, while those in Shasta are not (CCX, 2009).

Water Quality

Restoring vegetated riparian buffers can be an affordable and easy-to-maintain tool for rangeland managers to reduce runoff into local watersheds. Vegetated buffers not only can attenuate water temperature, but also reduce sediment, phosphorus, and nitrogen discharge to drainage water in agricultural areas (Osborne and Kovacic, 1993).

The primary relationship between soil erosion and water quality is that soil erosion increases runoff into surface waters, which in turn increases turbidity and nutrient content. Here, runoff refers to nutrients (nitrogen, phosphorous), pathogens (*E. coli, C. parvum*), and sediment/soils (Hubbard et al., 2004). A vegetative buffer strip acts as a sponge that filters and can reduce the amount of runoff (Hubbard et al., 2004). Generally, the water quality of upland rangelands is very important for an entire watershed because these areas are often the headwater tributaries for larger rivers (Lewis et al., 2002).

Fencing riparian areas prevents livestock from trampling riparian areas and causing increased erosion of sediment and direct deposits of fecal matter into streams. However, the trade-off for the rancher is that fencing will exclude cattle from forage that may be higher in nutritional value compared to other grazed areas. There is a potential for up to 6 times more forage in riparian areas, which may also be higher in crude protein concentrations (Bailey, 2005). The opportunity cost for a rancher is that although exclusion is important for water quality and rangeland sustainability in the long run, fencing riparian areas cuts cattle off from valuable forage and can decrease ranch income. However, impacts on soil stability and water quality are difficult to reverse and mitigate once they have taken effect, and riparian forage is likely to decrease anyway as erosion claims stream banks.

Several factors contribute to the rate and amount of runoff received by a water body. These factors include but are not limited to slope, soil type, rainfall intensity and duration, type of pollutant, and the total size of the drainage area (Castelle et al., 1994; Schmitt et al., 1999; Bharati et al., 2002; Bedard-Haughn et al., 2004 cited in Tate et al., 2006). Generally, the effectiveness of a vegetated buffer strip depends heavily on the site-specific micro topography (Landry and Throw, 1997, cited in McEldowney et al., 2002). Sites with larger slopes had greater concentrations of *C. parvum* runoff (Tate et al., 2000). In addressing the impacts of riparian buffers on water quality, we examine issues related to microbial contamination, nutrient pollution, erosion and sediment pollution, and water temperature.

Prevention of microbial/protozoan contamination

Vegetated riparian buffers on rangelands have been shown to filter pathogens. Pathogenic contaminants are the most common surface water impairment in California, and pose a significant public health concern (Knox et al., 2007). They are not only dangerous to human end-users, but also to downstream wildlife and livestock (Tate et al., 2004). Vegetated buffers can minimize water contamination of pathogenic materials (Tate et al., 2006; Tate et al., 2004). Studies have shown that buffers ranging in size from 0.1 to 1.8 meters can filter pathogens by 90-100 percent (Knox et al., 2007; Tate et al., 2006).

Buffer width is an important factor for maximizing filtration and uptake effectiveness. One study (Tate et al., 2006) found that a 1-meter buffer had a 95-100 percent effectiveness rate on preventing *E. coli* runoff into a waterway. Another study (Fleming et al., 2001) proposed that twenty yards is an appropriate width for vegetative buffers under otherwise healthy range conditions, and more width would be necessary for areas of large slope or heavy fertilization. A third study found that a 1-2 yard buffer reduced pathogen contamination by 90-99 percent under heavy rainfall conditions (Knox et al., 2007).

Decreased nutrient runoff

Another concern is the runoff of nutrients into rangeland surface waters. Nutrient runoff can be detrimental to both humans and aquatic species (Hubbard et al., 2004). Vegetative buffers reduce nitrogen runoff through the process of denitrification, infiltration, and plant uptake (Hill, 1996 cited in Berard-Haughn et al., 2004). According to Berard-Haughn, et al. (2004), runoff was effectively cut by the use of buffers. In an 8-meter buffer, for example, nitrogen loads decreased by 28 percent, ammonium by 34 percent, and dissolved organic nitrogen by 21 percent.

Erosion prevention

A physical component of water quality is the runoff of sediment into surface waters caused by erosion. Severe erosion has the potential to claim land that could be used for grazing. Additionally, the runoff of sediment into water bodies can fill small streams and/or increase the turbidity of the water, which is harmful to aquatic species and overall water quality (Lewis et al., 2002). Vegetated buffers can reduce stream bank erosion and increase water infiltration by providing a root structure to hold soils together (Beschta, 1997).

Water temperature improvements

Riparian vegetation can lower water temperatures of streams and rivers, which benefit aquatic species such as salmon and trout, both of which are listed as endangered species and found in the study area. However, Larson and Larson (1996) argue that although stream shading may have some value for in-stream water temperature attenuation, there are too many factors that can diminish the effectiveness of buffers. For instance, vegetation must be tall and abundant enough to cover the stream during peak direct sunlight hours. Additionally, the stream would need to be fairly narrow in order to be significantly covered. Using riparian buffers for stream temperature attenuation is either too unrealistic or will yield limited benefits (Larson and Larson, 1996). This argument is countered by Beschta (1997) who suggests that riparian vegetation is like a 'hat' that prevents light and heat from impacting the surface waters. Additionally, there is a proportional increase in stream temperature when solar radiation reaches water, so it is critical to take advantage of all the shading possible.

Wildlife habitat

Even though riparian zones only represent 1-2 percent of western forest and rangeland landscapes, they are considered hot-spots for the provision of ecosystem services such as biodiversity, wildlife habitat and water quality (Kauffman and Kruger, 1984; Kauffman et al., 2004; Gregory et al., 1991; Naiman and Decamps, 1997). It is well known that riparian vegetation plays an essential role in the provision of ecosystem services by regulating light and temperature regimes, providing nutrients and energy and maintaining biodiversity (Naiman and Decamps, 1990). Research suggests that plant community structure and composition determines the density and composition of the wildlife community (Johnston and Anthony, 2008; Nur et al., 2008). Riparian buffer zones can provide valuable refuge areas for wildlife in otherwise homogeneous agricultural landscapes (Triquet et al., 1990).

Riparian buffers offer generally undisturbed land for nest sites, den locations, and bedding areas in habitats exposed to periodic disturbance by farming machinery (Best et al., 1995). Buffers harbor a variety of foods including plant seeds, vegetative material, and arthropods. Finally, buffers can serve as travel corridors between fragmented habitats, thus facilitating gene flow among otherwise isolated wildlife communities (Dickson et al., 1995; Haas, 1997; Jobin et al., 2001). These corridors will increase wildlife's ability to adapt to climate change impacts.

In California, over 225 species of birds, mammals, reptiles and amphibians depend on riparian habitat (Knopf et al., 1988; Dobking, 1994 citing Vaghti and Greco, p. 426). California riparian ecosystems provide habitat for 83 percent of the amphibians and 40 percent of the reptiles known in that state (Brode and Bury, 1984).

Riparian habitat in our Central Valley study area provides for the needs of more California mammals than any other habitat in the state (Williams and Kilburn, 1984). Great Valley riparian habitats are also important for native fish such as winter-run Chinook (Sommer et al., 2001). Some native fish such as the delta smelt and the Sacramento splittail that are threatened by extinction (Moyle, 2002) can also benefit from fencing riparian areas.

Riparian habitats in the Central valley of California also provide important habitat for invertebrate species. The Valley elderberry longhorn beetle (elderberry beetle) is endemic to California's Central Valley (Barr, 1991), and was listed as federally threatened in 1980 (USFWS, 1980). The elderberry shrub (*Sambucus spp.*) serves as the sole host for the elderberry beetle (USFWS, 1980). Previous studies reveal that the size or maturity, density, and connectivity of elderberry shrubs strongly affect the beetle's presence (Collinge et al., 2001; Talley et al., 2007) and stress the importance of riparian areas for this species' recovery (Holyoak and Koch-Munz, 2008).

Riparian areas in rangelands are particularly vulnerable to disturbance. Uncontrolled livestock grazing can be detrimental to wildlife by altering vegetation through defoliation and trampling, reducing water quality through fecal contamination, and increased erosion (Knopf et al., 1988; Fleischner, 1994; Belsky et al., 1999). Due to the potential negative impacts of livestock grazing, fencing has been advocated as a protective measure to minimize impacts of livestock on riparian and aquatic habitats (Knopf et al., 1988; Elmore and Kauffman, 1994; Platts and Rinne, 1985). Other practices include off-site water development, herding, mineral supplement placement, and animal breeding. Riparian vegetation experiences a rapid recovery after the removal of livestock (Kondolf, 1993; Platts and Wagstaff, 1984; Popotnik and Giuliano, 2000). Willow (*Salix spp*) or cottonwood (*Populus spp*) densities and/or cover increases with livestock exclusion (Case and Kauffman, 1997; Green and Kauffman, 1995; Sarr, 1995). In turn, water quality improves as stream banks stabilize, excess nutrients are trapped by riparian vegetation, and the stream is shaded (Kauffman and Kruger, 1984; Belding et al., 2000).

The recovery of riparian vegetation after livestock exclusion often results in an increase in the abundance and diversity of wildlife populations. Research has shown that birds (Popotnik and Giuliano, 2000), fish (Platts and Wagstaff, 1984) and small mammals (Hayward et al., 1997) benefit from the exclusion of livestock from stream zones. Warren and Schwalbe (1985) found that improved vegetation structure in riparian plant communities supported larger insect fauna and greater lizard density. Some herpetofauna (northern queen snake, eastern garter snake, and tadpoles) exhibit positive responses to the improved conditions provided by stream bank fencing (Kauffman et al., 2004). Fenced areas, with increased vegetative diversity and structure, can support a more abundant and diverse reptile and amphibian community, as suggested by Busack and Bury (1974), Szaro et al. (1985), and Bock et al. (1990).

Different species respond differently to livestock fencing in riparian areas. Homyack and Giuliano (2002) reported no differences in the abundance of reptile and amphibian communities after livestock exclusion. In a similar study, Rinne (1988a) also found few differences in the macro-invertebrate community between grazed and un-grazed stream sections. Fenced riparian areas may attract predators, thereby reducing reptile and amphibian numbers. For example, great blue herons, green herons, and belted kingfishers occur more commonly in areas with stream bank fencing than in unfenced areas (Popotnik and Giuliano, 2000). More research is needed to determine the different responses of species to livestock exclusion (Homyack and Giuliano, 2002).

Differences in the responses of native fishes and their habitat to livestock fencing have been noted as well. Some studies indicate a rapid recovery of aquatic and fisheries habitat, such as decreased stream bank angles, increases in shading, water column depth, and substrate quality for salmonids (Rinne, 1988a, b; Knapp and Matthews, 1996). Numerous studies have documented greater biomass and abundance of trout in livestock ex-closures (Keller and Burnham, 1982; Knapp and Matthews, 1996), but others have shown little or no difference (Rinne 1988b; Rinne and LaFayette, 1991). In California, fencing riparian areas can improve fish habitat for species like steelhead by shading, improving large woody debris and creating narrower, deeper and more complex channel morphology (Opperman and Merlender, 2004).

Restoration of Riparian Vegetation

In general, the literature on the wildlife impacts from riparian vegetative restoration practices is scarce. Both passive and active restoration methods have resulted in the establishment of woody vegetation and improved plant community structure and composition.[18] A recent survey of restoration sites on private ranches in Marin, Mendocino, and Sonoma Counties showed that both passive restoration methods (grazing management and fencing) as well as active re-vegetation techniques (planting and/or bioengineering) are beneficial to plant communities and wildlife (Lennox et al., 2007).

Few studies have compared long-term results from active and passive re-vegetation (Thayer et al., 2005). Active restoration methods have been shown to accelerate the benefits associated with canopy cover and bank stability in the first ten years after project implementation. In general, however, the magnitude of the benefits from active and passive restoration methods converges after approximately 10 to 15 years (Lennox et al., 2007).

In a survey of restoration project managers, 59 percent cited significant improvements in wildlife habitat and populations, including more diverse fish and avian species, from riparian restoration efforts. There have also been documented sightings of threatened and endangered species in restored project reaches (Kondolf et al., 2007).

A restoration site in the Carmel River in California was successful in establishing vegetation but after two years no differences between abundance of reptilian and amphibians and

[18] Active restoration entails physical modifications to or treatments of the riparian zone (e.g., disking, application of herbicides, burning, planting), generally with the intent of re-establishing native species. Passive restoration does not involve such interventions, but simply allows already-present vegetation to grow or allows colonization of the site by plants from neighboring areas.

species richness and occurrence of mammals were detected. However, greater bird species richness was observed on restored sites in the summer (Queheillalt and Morrison, 2006). Even though vegetation may recover rapidly, sometimes restoration sites take decades to provide habitat for wildlife species (Homyack and Giuliano, 2002). Riparian re-vegetation in the Sacramento Valley has been largely successful in terms of providing habitat for a diverse community of breeding birds (Gardali et al., 2006).

E. Oak reestablishment and afforestation, restoration of native perennials and riparian restoration measures – some concluding remarks

Our review in this chapter of the ecosystem services and associated benefits provided by California rangelands and by rangeland conservation practices has yielded several general observations. First, rangelands generate a wide range of services that carry considerable total economic value. These services support benefits like livestock production, wildlife- and water-based recreation activities, drinking and irrigation water, species conservation, aesthetic benefits in the form of scenic views, and avoided damages to health, private property and public infrastructure (Table 3.1).

The second finding is that while some of the value supported by the services provided by rangelands can be captured by landowners – for example, improvements in forage quantity, quality or timing and carbon sequestration – a substantial portion of the overall benefits accrues off-site. The latter include avoided water treatment and dredging costs, avoided health costs and property damages, passive use values for threatened, endangered or rare species, and aesthetic benefits associated with scenic views.

Rangeland conservation thus provides an illustrative example of what economists refer to as incompletely specified property rights (Freeman, 2003; Randall, 1987). In such cases, landowners are unable to prevent others from enjoying the benefits their land conservation produces and thus fail to reap the full value of these benefits. They therefore do not have an incentive to take the full value of these benefits into account when making land management decisions (Kroeger and Casey, 2007). If, even in the presence of such positive externalities or third-party effects, rangeland conservation actions would be economically beneficial for landowners, divergence between private and public benefits would not be a major concern as most landowners likely would adopt these practices anyway. However, for the rangeland practices examined here – reestablishment or afforestation of blue oaks on grasslands; restoration of native perennial grasses; and riparian conservation and restoration – this is not the case. Rather, for all three practices, their private costs exceed their private benefits, in some cases by a considerable margin. Cost share programs in some cases can reverse this result, as is true for some riparian fencing or restoration measures (see Chapter 2). However, for oak reestablishment or afforestation and for restoration of native perennials, current cost share levels generally are not sufficient to make these practices economically attractive for landowners. To the extent that the public benefits from these conservation practices exceed the increases in cost share levels needed to make these practices attractive to landowners,

increased public funding for these practices would yield positive net benefits for society as a whole.[19]

[19] This does not automatically imply that such funding increases for these practices would be efficient. Given limited public conservation funds, there may be other conservation practices that yield even higher net benefits for given investments.

4. Economic Policies and Incentives to Promote Habitat Conservation on California Ranchlands

California's rangelands are a valuable natural resource that produces ecosystem services that support a wide range of benefits for ranchers and society at large. These benefits include forage production for livestock and wildlife, pollination of nearby crop lands, erosion control and water quality, outdoor recreation, scenic views, carbon sequestration, and the provision of habitat for threatened, endangered and rare species, to name but a few. As noted in the Introduction to this report, conservation of California's rangelands is essential to maintaining the State's biodiversity heritage.

Rangeland conservation practices such as prescribed grazing, restoration of riparian areas and native perennial grasses, and oak reestablishment and afforestation increase the flow of ecosystem services on and from rangelands, and thus increase the economic benefits supported by rangelands.

There are a number of rangeland conservation practices that currently generate benefits for society at large whose adoption also can be financially beneficial for ranchers. Thus, many ranchers should have an economic incentive to adopt these practices. However, as our analysis has shown, these practices often are financially attractive to ranchers only because a substantial portion of their total implementation costs are absorbed by public agencies through cost share programs. Public cost sharing thus is vital for the implementation of these conservation practices and for securing the large public benefits they generate. Nevertheless, due to a number of constraints that we will discuss below, these practices are not adopted by ranchers on as widespread a basis as one would expect based on financial grounds alone.

Our analysis also has demonstrated that, as illustrated by the examples of oak reestablishment or afforestation and restoration of native perennial grasses, that there are rangeland conservation practices that generate substantial public benefits but that currently are not profitable or at least financially neutral for ranchers. There are two reasons for this. First, these practices are relatively more costly to implement than those that currently are profitable or revenue neutral for ranchers. Second, they produce benefits that disproportionately accrue to people other than the ranchers, and for many of which there are no established markets that would allow ranchers to require compensation from beneficiaries for the services provided. As a result, these practices are not adopted on a widespread basis, even though from the perspective of the public at large there may be an economic case for adopting them because their total benefits for society exceed their total costs.

This presents a problem common to the management of natural resources that generate large non-market benefits, and where an important share of these benefits accrue to people other than the landowner. Ranchers have no incentive to adopt management practices whose adoption would be beneficial for society as a whole, because they absorb all the costs but receive few of the benefits. Thus, society at large forgoes the net benefits these natural resource management practices would produce.

As a result, adoption levels are too low both for those rangeland conservation practices that generally are financially profitable for ranchers and for those that are not but that would be

economically beneficial for society as a whole. What is needed are approaches that can overcome the constraints currently limiting the more widespread adoption of rangeland conservation practices that are desirable on economic grounds. In identifying such approaches, it is helpful to distinguish between what economists refer to as "private good" ecosystem services and those that have "public good" character.

Increasing the provision of public-good ecosystem services from rangelands

Public good ecosystem services are those services that are non-exclusive – meaning that once provided, it is infeasible to prevent anyone from enjoying them – and that are non-rival – meaning that enjoyment by one individual does not reduce their enjoyment by others. Examples of such public good ecosystem services are clean air or the conservation of threatened, endangered or rare species. Whenever an ecosystem service is a public good, landowners cannot demand compensation for its provision to others and thus do not have an incentive to provide this service at the level that would be economically efficient (that is, the level that would maximize net benefits for society). To overcome this problem, approaches are needed that would allow landowners to be compensated for the economic value of the benefits generated by the ecosystem services their lands provide. This would provide rangeland owners with an incentive to take into account these benefits in their land management decisions and thus could increase the flow of ecosystem services from these lands.

One approach frequently chosen is to have a government agency act on behalf of the public at large (who is the recipient of the benefits) and pay the landowner for the provision of the services. Examples of this are found in the form of environmental payment programs such as USDA's Conservation Stewardship Program (CSP), the Environmental Quality Incentives Program (EQIP), the Conservation Reserve Enhancement Program (CREP), the Wildlife Habitat Incentives Program (WHIP) or the Wetlands Reserve Program (WRP). However, the budgets of these programs are not sufficient to fund a truly comprehensive system of payments to private rangeland owners, especially if payment or cost share levels need to be increased for those practices that carry high costs but also produce large public benefits. As a case in point, our analysis shows that current incentives in the form of NRCS cost share programs are insufficient to make conservation practices such as oak reestablishment and afforestation or restoration of native perennial grasslands economically viable propositions for private landowners in our study area.

However, the social benefits of these practices may make them economically viable (i.e., generating positive net benefits) for society at large. Thus, it may make sense to invest more public resources to encourage adoption of these practices. To assess how public funds could be used efficiently to achieve more widespread adoption of rangeland conservation practices, what is needed is a comprehensive economic assessment – including both costs and benefits – of a larger variety of rangeland conservation measures than are examined in this study, in order to determine the net-benefit ranking of these measures and their per-acre costs. Furthermore, because of the spatial heterogeneity of both the costs and benefits of the practices, this analysis should be sufficiently detailed spatially. To yield credible results, it also should be based on sound valuation approaches, relying on ecosystem service production functions and ecosystem service demand analysis. To carry out such a valuation for all or a significant portion of the state's rangelands is a challenging task that will require a well-

planned and -coordinated research effort. One promising new ecosystem services valuation tool, InVEST (Tallis and Polasky, 2009), fulfills the requirement of incorporation of spatial heterogeneity of services and service values. This tool, which relies on outputs of existing biophysical and economic models and can accommodate different model complexities, has been applied to several case studies. Ideally, its application to California rangelands would involve a collaborative effort between ranchers, state natural resource and environmental agencies and university researchers to assure the most accurate and comprehensive assessment.

Once a net-benefit ranking of rangeland conservation practices has been carried out by comparing estimates of the ecosystem service benefits generated by rangeland conservation practices with the costs of these practices, this ranking then could be used to inform the allocation of scarce public conservation funds to practices for maximum economic benefit, by identifying, across all rangelands, the optimal conservation practices for a given location, and the locations where those practices would generate maximum economic net benefits. If desired, this allocation of conservation resources based on net benefits could be modified subject to particular conditions to fulfill goals other than the generation of maximum net benefits, such as spatial or distributional equity concerns. For example, allocation of funds could be divided among counties based on rangeland acreage, county population, ranch size, or some other variable of concern for distributional equity, and then within each county the ecosystem services net benefit ranking would be used to allocate conservation payments to ranchers. It bears noting that subjecting conservation fund allocation to any such conditions will reduce the cost-effectiveness of the public investment, so these concerns would be better addressed directly via other measures like reductions in income or property taxes.

Once the highest net benefit generating practices and properties are identified, conservation funds could be allocated cost-effectively using reverse auctions (Eigenraam et al., 2006; Greenhalgh, 2007). The NRCS would appear the logical choice for overseeing and coordinating the research effort to produce a net benefit ranking of rangeland conservation practices as well as the auctions and implementation and oversight of the contracts with local ranchers.

Increasing the provision of private-good ecosystem services from rangelands

Ecosystem services that are not intrinsically of public good character (i.e., non-rival and non-exclusive) can in principle be traded. Thus, markets can develop or be developed for these services. However, even for many of these private good-type services generated by rangelands and rangeland conservation practices, markets currently are missing. This means that, just as in the case of public-good type services, landowners cannot reap the full value of the services their lands provide, which in turn reduces their incentive to manage their lands for these services. This is due to a number of factors, including a lack of a sufficiently quantitative link between cause and effect (e.g., By how much does upstream rangeland management practice x reduce service provision and value at downstream facility y?); the difficulty for potential buyers of monitoring practice implementation by potential sellers or a lack of awareness of available mechanisms for ensuring seller compliance (such as third-party verification of compliance); and the large numbers of potential beneficiaries of some services, which increases transaction costs and may lead some potential buyers to refuse to

participate in coordinated action in the hope to benefit for free from the actions taken by others.

These problems are more difficult to overcome for some rangeland ecosystem services than for others. In some cases, information about the biophysical flow of services is available to academic experts but is not easily available to potential sellers (ranchers) or buyers. Examples of this are the impact of specific conservation practices on nutrient concentrations at particular points downstream. In other cases, ranchers may be unaware of market opportunities or lack information on potential payment levels or how to access a particular market. This appears to be the case for rangeland conservation-based carbon credits in much of California, as it is unknown if any ranchers in the state are participating in the Chicago Climate Exchange's Sustainably Managed Rangeland Soil Carbon Sequestration Offset Project Protocol (CCX, 2009). Both of these limitations could be overcome through increased outreach efforts by extension services or aggregators.

In some cases, markets for a particular service may exist and ranchers may be aware of those markets, but the prices paid for the service are too low to provide an economic incentive to adopt appropriate conservation practices. One example may be oak reestablishment and afforestation of California's Mediterranean climate rangelands. At current prices on the CCX and over-the-counter (OTC) markets, planting of oaks on rangelands does not generate sufficient income from carbon credits to make this practice financially viable for landowners. Oaks do generate additional private benefits for ranchers such as increased forage production and aesthetic attractiveness, but these, just like significant carbon sequestration, only occur once the trees have reached a certain age. Thus, carbon credits would not necessarily have to cover the full costs of oak planting, but current credit prices are too low to make up the difference.

What is needed for each of the ecosystem services generated by rangeland conservation practices is an assessment of the key constraints that currently prevent this service from being traded in markets. This would allow the identification of possible approaches for overcoming these constraints, and of those services that simply are not suited to markets due to their characteristics. The basis for this analysis is well-developed (Kroeger and Casey, 2007; Brown et al., 2007), but it has not been applied rigorously and comprehensively to rangeland conservation practices.

Markets for ecosystem services can be created through regulation. Domestic examples of such markets are the many wetland mitigation banking and water quality markets that exist in the U.S., as well as the state or regional carbon markets that already are in operation (e.g., the Regional Greenhouse Gas Initiative, or RGGI in the northeast) or entering their operative phase (California's Climate Action Registry, or CAR; Western Climate Initiative, or WCI). In these cases, regulation is the driver that creates a demand for ecosystem services, which then in turn stimulates a supply. In California, there are a few water quality markets, but they cover a small area and none of them is found in the four-county area studied in this report. However, the potential for the development of these markets exists for California rangelands, many of which are located upstream of waters classified as impaired due to sediment loading. The creation of total maximum daily load (TMDL) restrictions for sediment discharges in the respective waters, pursuant to the Clean Water Act, would be expected to stimulate exchanges between regulated point sources and ranches in which the

former pay the latter to adopt management practices that reduce sediment loading from ranchlands. However, this issue requires further investigation to assess the likelihood of setting sediment TMDLs in the area, who the participating entities would be and at what level load reductions would be set.

Many rangeland conservation practices do benefit wildlife even though wildlife conservation may not be their stated or primary objective. However, wildlife and their habitat are ecosystem services whose provision can be incentivized not only directly through government payment programs such as CSP or WHIP, or indirectly through programs targeted at other natural resources such as CREP, EQIP or WRP. Their provision also can be promoted via markets for other ecosystem services such as carbon and water quality that are joint products of wildlife habitat. Thus, if wildlife can be "bundled" with other ecosystem services whose conservation can be achieved through some form of incentive system (government payment programs or markets), it could be protected indirectly through incentives that lead to the conservation of those other services. However, wildlife habitat and other ecosystem services often are not perfect co-products. As a result, there generally are trade-offs when managing a site for more than one ecosystem service, and attempts to maximize output of one service can lead to a reduction in some or all of the other services (Chan et al., 2006). This true for managing single species as well. Carbon sequestration and wildlife habitat provide an illustrative example. A native forest sequesters carbon and provides habitat for native wildlife. Therefore, conservation of such a forest or afforestation of grasslands or agricultural lands using native tree species generates both carbon and wildlife benefits. However, if sequestration of carbon is sought to be maximized, then plantations of fast-growing species, often non-natives, may be preferred over afforestation to a native forest. Such plantations are far less suited to providing habitat for native species. To ensure wildlife conservation is achieved through incentives for other ecosystem services, those incentives need to be designed explicitly such that they are conditional upon specific management practices that benefit wildlife species of concern. In the carbon sequestration example, credit protocols could stipulate that credits could be earned only through projects that utilize native vegetation, not exotic plant species.

In regulation-driven markets (e.g., Clean Water Act TMDL-based trading areas; climate legislation-based regional or national carbon markets), this could be achieved through the regulatory agency applying appropriate credit definitions or through the setting of conditions that eligible practices need to fulfill to earn credits. In the case of California, this would be the California Air Resources Board for carbon credits (until such time when a federal carbon market supersedes state carbon regulations), or the U.S. EPA for water quality trading credits. At the federal level, the newly created Office of Ecosystem Services and Markets, housed in the U.S. Department of Agriculture, could assist with appropriate credit definitions and standards.

In voluntary markets, credit definition is up to the exchange that manages credit transactions (e.g., Chicago Climate Exchange) or individual agreements between buyers and sellers. Thus, ensuring appropriate credit definitions and verification is more difficult than in regulated markets. Nevertheless, eco-labeling initiatives and public awareness campaigns are some of the tools that are available to influence the adoption of credit definitions that fulfill wildlife conservation goals.

Policy suggestions for identifying effective and efficient incentive mechanisms for promoting increased restoration of rangelands to induce increased ecosystem services

Rangeland conservation practices provide many benefits for society at large. Many of these practices are costly to ranchers and are not viable in purely private financial terms. Hence, their adoption often is contingent upon ranchers' receiving some form of payment. This compensation can take two forms: Public payment programs or income from markets for ecosystem services.

Based on our study, we offer the following recommendations for distribution of our findings and increasing the adoption rate of rangeland conservation practices that will benefit California's native biodiversity on rangelands:

- In many cases, there exists a lack of sufficient quantification of the ecosystem service impacts of some practices (erosion from native perennial grass sites vs. exotic annual sites; habitat quality improvements from perennials restoration). Currently NRCS is carrying out an evaluation of the bio-physical impacts of rangeland conservation practices. This project, called the Conservation Effects Assessment Program (CEAP) will improve the information about the quantity of services and benefits that are generated through adoption of specific practices. This information needs to be widely communicated to ranchers and its usefulness for developing ecosystem service credits assessed.

- The California Rangeland Conservation Coalition (Rangeland Coalition) and its partner organizations should make the results of this study widely known to policy makers, ranchers, state and federal technical agents, conservation organizations, foundations and the general public for the purpose of developing and funding an institutional framework and increased incentive mechanisms for conserving California rangeland ecosystems and native biodiversity.

- There is a need to expand farm bill program funding for conservation practices and technical assistance. Such an expansion could take place through the current Conservation Stewardship Program, which is based on public payments for environmental outcomes, and could be a precursor for the development of private markets for some resources. To encourage cost-effective investment of public funds, conservation payments should take into account the actual economic value generated by the ecosystem services provided by a particular practice in a particular location. This will require the increased deployment of emerging ecosystem service value assessment models such as InVEST, coupled with results from the Conservation Effects Assessment Program. There also needs to be better coordination and targeting of farm bill conservation programs through the Cooperative Conservation Partnership Initiative in California to simplify access by landowners and provide landscape-level resource conservation. Increased availability of public (NRCS) technical assistance for rangeland ecosystem conservation is essential.

- To increase rates of adoption of rangeland conservation practices that generate large public benefits but are costly to implement (e.g., oak reestablishment or afforestation, restoration of native perennials), higher cost shares are needed to make these practices economically viable for land owners.

- The U.S. Environmental Protection Agency should aggressively pursue the development of the legislatively mandated TMDL limits for those impaired waters that still are missing such limits. The design of watershed plans should assess the potential of water quality trading to aid in achieving compliance with TMDLs. In California's Central Valley and its respective watersheds, the design of trading schemes should specifically explore the role rangeland conservation practices can play in generating water quality credits. These efforts should draw on the experiences gained in other parts of the country with the generation of water quality credits from agricultural lands. Specifically, outreach efforts to ranchers are needed to increase awareness of trading opportunities and reduce information constraints and transaction costs that may depress rancher participation. Rancher organizations, extension services and NCRS all could assist in these efforts.

- Carbon markets also would increase the financial attractiveness of several rangeland conservation measures such as oak afforestation or reestablishment or restoration of native perennial grasses. Awareness of existing market opportunities such as the Chicago Climate Exchange's Sustainably Managed Rangeland Soil Carbon Sequestration Offset Project Protocol still appears to be low in California, based on the expected low participation rates of California ranchers compared to those in other states. Increased outreach efforts by aggregators, rancher organizations and extension services are needed to overcome this deficiency. Perhaps even more importantly, market access for rangeland-based credits should be increased. For example, afforestation-based sequestration on rangelands, through oak planting or riparian restoration and soil-based sequestration from restoration of native perennial grasses, currently do not qualify for participation in the Chicago Climate Exchange's rangeland sequestration offset protocol. These are severe shortcomings that should be corrected, given that the per-acre carbon sequestration potential of these practices may far exceed that of prescribed grazing. Likewise, rangeland sequestration credits should be made eligible for all emerging regional and federal carbon markets. Whether or not credit prices would make rangeland-based sequestration efforts competitive is a question that should be left to the market to decide, not to arbitrary ex-ante decisions. It is important that verification of actual sequestration be credible. Currently, this is not always the case, with verification in many cases not even requiring site visits. To this effect, verification protocols in exiting carbon markets should be strengthened, and those of emerging and future markets should be designed to be credible from the outset.

  Higher prices of sequestration credits would increase revenues from sequestration-enhancing practices for participating ranchers and thus would provide incentives for the implementation of such practices. Since prices form in response to credit supply and demand, stricter CO_2 reduction levels would increase ranch revenue from sequestration projects.

- The California Safe Harbor legislation has been adopted. This will encourage ranch owners to conserve and manage lands for endangered species and biodiversity conservation because it removes the threat of financial penalties for violations. Outreach efforts to ranchers to provide assurances and incentives to create and manage for wildlife habitat should be expanded.

- California should promote a diverse array of incentive mechanisms to protect wildlife habitat, of which ecosystem markets are just one. For example, eco-tourism, eco-labeling initiatives can complement public investment in conservation and private ecosystem service markets. Mitigation banking and ranchland easements also should have expanded resources for increased technical assistance and monitoring and enforcement of contracts.

- There are efforts throughout the US to develop a "habitat metric" that would be the basis for defining the biological and physical characteristics of a credit suitable for trading in a voluntary biodiversity market. Under the NRCS Conservation Innovations Grant that the Rangeland Coalition has recently obtained, these efforts should be tracked for their suitability for developing a similar metric for California rangelands.

- California should identify a stable funding stream to support the continuation of the Williamson Act. This is a broad based state program that provides tax relief to landowners who forgo conversion of agricultural lands, including ranchlands. Without this tax relief, it is expected that many ranchers will sell their lands, thus leading to conversion and fragmentation.

- It is recommended that Congress adopt targeted and permanent reforms of estate tax laws that discourage the preservation of working ranches. In California, the estate tax is one of the leading causes of the break-up and loss of family-owned ranching operations.

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6. Appendices

Appendix 1

California Rangeland Resolution

The undersigned recognize the critical importance of California's privately owned rangelands, particularly that significant portion that encircles the Central Valley and includes the adjacent grasslands and oak woodlands, including the Sierra foothills and the interior coast ranges. These lands support important ecosystems and are the foundation for the ranching industry that owns them.

WHEREAS, these rangelands include a rich and varied landscape of grasslands, oak woodlands, vernal pools, riparian areas and wetlands, which support numerous imperiled species, many native plants once common in the Central Valley, and are home to the highest diversity and density of wintering raptors anywhere in North America;

WHEREAS, these rangelands are often located in California's fastest-growing counties and are at significant risk of conversion to development and other uses;

WHEREAS, these rangelands, and the species that rely on these habitats, largely persist today due to the positive and experienced grazing and other land stewardship practices of the ranchers that have owned and managed these lands and are committed to a healthy future for their working landscapes;

WHEREAS, these rangelands are a critical foundation of the economic and social fabric of California's ranching industry and rural communities, and will only continue to provide this important working landscape for California's plants, fish and wildlife if private rangelands remain in ranching;

THEREFORE, we declare that it is our goal to collaboratively work together to protect and enhance the rangeland landscape that encircles California's Central Valley and includes adjacent grasslands and oak woodlands by:

- Keeping common species common on private working landscapes;
- Working to recover imperiled species and enhancing habitat on rangelands while seeking to minimize regulations on private lands and streamline processes;
- Supporting the long-term viability of the ranching industry and its culture by providing economic, social and other incentives and by reducing burdens to proactive stewardship on private ranchlands;
- Increasing private, state and federal funding, technical expertise and other assistance to continue and expand the ranching community's beneficial land stewardship practices that benefit sensitive species and are fully compatible with normal ranching practices;
- Encouraging voluntary, collaborative and locally-led conservation that has proven to be very effective in maintaining and enhancing working landscapes;
- Educating the public about the benefits of grazing and ranching in these rangelands.

California Rangeland Resolution Signatories

Agricultural - Natural Resources Trust of Contra Costa County
Alameda County Board of Supervisors
Alameda Co. Resource Conservation District
Amador Resource Conservation District
American Farmland Trust
American Land Conservancy
Audubon California
Bureau of Land Management
Butte County Resource Conservation District
Butte Environmental Council
Calaveras Co. Resource Conservation District
California Association of Resource Conservation Districts
California Cattlemen's Association
California CattleWomen's Association
California Chapter of the International Soil and Water Conservation Society
California Deer Association
California Department of Conservation
California Dept of Fish and Game
California Dept of Food and Agriculture
California Dept of Forestry and Fire Protection
California Farm Bureau Federation
California Grazing Lands Coalition
California Invasive Plant Council
California Native Grasslands Association
California Native Plant Society
California Oak Foundation
California Open Lands
California Rangeland Trust
California Resources Agency
California Wildlife Foundation
California Wool Growers Association
Cal-Pac Section Society For Range Management
Central Coast Rangeland Coalition
Central Sierra Region of Resource Conservation Districts
Central Valley Bird Club
Central Valley Land Trust Council
Chimineas Ranch Foundation
City of Livermore
Coarsegold Resource Conservation District
Committee for Green Foothills
Community Alliance with Family Farmers
Contra Costa Resource Conservation District
Contra Costa County Board of Supervisors
Defenders of Wildlife
Ducks Unlimited
East Bay Regional Park District
El Dorado Resource Conservation District
Endangered Species Coalition
Environmental Defense
Friends of Swainson's Hawk
Glenn County Resource Conservation District
Hollister Ranch
Institute for Ecological Health
Jumping Frog Research Institute
Land Conservancy of San Luis Obispo
Land Trust for Santa Barbara County
Marin Agricultural Land Trust
Marin County Resource Conservation District
Mariposa Co. Resource Conservation District
Middle Mountain Foundation
Napa County Board of Supervisors
National Wild Turkey Federation
National Cattlemen's Beef Association
Natural Resources Conservation Service
Nevada County Board of Supervisors
Nevada Co. Resource Conservation District
Nevada County Land Trust
Northern California Regional Land Trust
Placer County Resource Conservation District
Placer Land Trust
Rocky Mountain Elk Foundation
Sacramento River Watershed Program
Sacramento Valley Conservancy
Santa Barbara County Farm Bureau
San Joaquin Et Al
San Joaquin Raptor/Wildlife Rescue Center
San Joaquin Valley Conservancy
San Luis Obispo County Board of Supervisors
Sierra Foothills Audubon Society
Sierra Nevada Conservancy
Sonoma County Board of Supervisors
State Water Resources Control Board
Sustainable Conservation
Sutter County Resource Conservation District
Tehama County Resource Conservation District
The Nature Conservancy
Trust for Public Land
Tuleyome
Tuolumne Co. Resource Conservation District
University of California
UC California Rangeland Research and Information Center
Upper Salinas-Las Tablas Resource Conservation District
US Fish and Wildlife Service
US Forest Service
VernalPools.org
Western Shasta Resource Conservation District
Wildlife Conservation Board
WildPlaces
Yolo County Board of Supervisors
Xerces Society for Invertebrate Conservation

July 8, 2009

Appendix 2

Table A2.1: Model input and output for Grazing Economic Analysis Scenario I: Fencing, Riparian fencing and water development

Grazing Economic Analysis: Scenario I: Riparian Fencing and Water Development

SITE AND LOCATION CHARACTERISTICS		Year	Percent Change in Carrying Capacity: Before Treatment	After Treatment	Other Costs/Ac
Cooperator/Ranch Name:		1	0.0%	0.0%	$0.39
County and State:	CA Butte/Tehama/Yolo/Shasta	2	0.0%	10.0%	$0.39
Soil/Site Description:		3	0.0%	20.0%	$0.39
Present Condition (good/fair/poor):	Good	4	0.0%	20.0%	$0.39
Apparent Trend (up, down):	Stable	5	0.0%	20.0%	$0.39
		6	0.0%	20.0%	$0.39
EVALUATION CRITERIA		7	0.0%	20.0%	$0.39
Grazing Land Treatment:	Rip Fence and Water dev	8	0.0%	20.0%	$0.39
Initial Treatment Cost ($/Acre) 50% cost share	$23.60	9	0.0%	20.0%	$0.39
Life of Treatment (Years):	20	10	0.0%	20.0%	$0.39
Interest Rate (%):	7%	11	0.0%	20.0%	$0.39
Value of one AUM ($):	$15.00	12	0.0%	20.0%	$0.39
Total Acres Treated:	900	13	0.0%	20.0%	$0.39
		14	0.0%	20.0%	$0.39
FORAGE UTILIZATION		15	0.0%	20.0%	$0.39
Current Forage Availability (Lbs/Ac)	2,000	16	0.0%	20.0%	$0.39
Pounds/AUM:	790	17	0.0%	20.0%	$0.39
Harvest Efficiency Without Treatment:	20%	18	0.0%	20.0%	$0.39
Harvest Efficiency With Treatment:	25%	19	0.0%	20.0%	$0.39
Current Forage Availability (AUMs/Ac):	0.51	20	0.0%	20.0%	$0.39
Maximum Carrying Capacity (AUMs/Ac):	1.75				
Months Grazed/Year	6				

RESULTS OF ANALYSIS		
Years to Break-Even on Investment:	0	
Increase in Carrying Capacity (AUMs/Ac):	0.24	
Increase in Stocking Rate, (#Head/Total Ac):	31	
Total Installed Treatment Cost ($/Total Ac):	$21,236	under 50% cost share
Amortized Installed Treatment Cost ($/Ac/yr):	$2.23	
Internal Rate of Return:	99%	
Breakeven $/AUM	$9.14	
Benefit/Cost Ratio:	1.36	
Net Present Value ($/Ac) under 50% cost share :	$9.91	

Hal Gordon
USDA - NRCS
Portland, Oregon

Table A2.2: Model input and output for Grazing Economic Analysis Scenario II: Fencing, active restoration of riparian zones and water development

Grazing Economic Analysis: Scenario II Fencing, Active Restoration of Riparian Zones and Water Development

SITE AND LOCATION CHARACTERISTICS	
Cooperator/Ranch Name:	
County and State:	CA Butte/Tehama/Yolo/Shasta
Soil/Site Description:	
Present Condition (good/fair/poor):	Good
Apparent Trend (up, down):	Stable
EVALUATION CRITERIA	
Grazing Land Treatment:	Rip Fence+Planting+Water dev
Initial Treatment Cost ($/Acre) 50% cost share:	$26.84
Life of Treatment (Years):	20
Interest Rate (%):	7%
Value of one AUM ($):	$15.00
Total Acres Treated:	900
FORAGE UTILIZATION	
Current Forage Availability (Lbs/Ac)	2,000
Pounds/AUM:	790
Harvest Efficiency Without Treatment:	20%
Harvest Efficiency With Treatment:	25%
Current Forage Availability (AUMs/Ac):	0.51
Maximum Carrying Capacity (AUMs/Ac):	1.75
Months Grazed/Year	6

Percent Change in Carrying Capacity			
Year	Before Treatment	After Treatment	Other Costs/Ac
1	0.0%	0.0%	$0.39
2	0.0%	10.0%	$0.39
3	0.0%	20.0%	$0.39
4	0.0%	20.0%	$0.39
5	0.0%	20.0%	$0.39
6	0.0%	20.0%	$0.39
7	0.0%	20.0%	$0.39
8	0.0%	20.0%	$0.39
9	0.0%	20.0%	$0.39
10	0.0%	20.0%	$0.39
11	0.0%	20.0%	$0.39
12	0.0%	20.0%	$0.39
13	0.0%	20.0%	$0.39
14	0.0%	20.0%	$0.39
15	0.0%	20.0%	$0.39
16	0.0%	20.0%	$0.39
17	0.0%	20.0%	$0.39
18	0.0%	20.0%	$0.39
19	0.0%	20.0%	$0.39
20	0.0%	20.0%	$0.39

RESULTS OF ANALYSIS		
Years to Break-Even on Investment:	0	
Increase in Carrying Capacity (AUMs/Ac):	0.24	
Increase in Stocking Rate, (#Head/Total Ac):	31	
Total Installed Treatment Cost ($/Total Ac):	$24,153	assuming 50% cost share
Amortized Installed Treatment Cost ($/Ac/yr):	$2.53	
Internal Rate of Return:	53%	
Breakeven $/AUM	$10.40	Hal Gordon
Benefit/Cost Ratio:	1.22	USDA - NRCS
Net Present Value ($/Ac) under 50% cost share:	$6.67	Portland, Oregon

Table A2.3: Model input and output for Grazing Economic Analysis Scenario III: Water Development and Prescribed Grazing

Grazing Economic Analysis: Scenario III Water Development and Prescribed Grazing Management

SITE AND LOCATION CHARACTERISTICS	
Cooperator/Ranch Name:	
County and State:	CA Butte/Tehama/Yolo/Shasta
Soil/Site Description:	
Present Condition (good/fair/poor):	Good
Apparent Trend (up, down):	Stable
EVALUATION CRITERIA	
Grazing Land Treatment:	Water develp. & Prescribed grazing
Initial Treatment Cost ($/Acre) under 50% cost share:	$17.33
Life of Treatment (Years):	20
Interest Rate (%):	7%
Value of one AUM ($):	$15.00
Total Acres Treated:	900
FORAGE UTILIZATION	
Current Forage Availability (Lbs/Ac)	2,000
Pounds/AUM:	790
Harvest Efficiency Without Treatment:	20%
Harvest Efficiency With Treatment:	25%
Current Forage Availability (AUMs/Ac):	0.51
Maximum Carrying Capacity (AUMs/Ac):	1.75
Months Grazed/Year	6

	Percent Change in Carrying Capacity		
Year	Before Treatment	After Treatment	Other Costs/Ac
1	0.0%	0.0%	$0.52
2	0.0%	5.0%	$0.52
3	0.0%	15.0%	$0.52
4	0.0%	20.0%	$0.52
5	0.0%	20.0%	$0.52
6	0.0%	20.0%	$0.52
7	0.0%	20.0%	$0.52
8	0.0%	20.0%	$0.52
9	0.0%	20.0%	$0.52
10	0.0%	20.0%	$0.52
11	0.0%	20.0%	$0.52
12	0.0%	20.0%	$0.52
13	0.0%	20.0%	$0.52
14	0.0%	20.0%	$0.52
15	0.0%	20.0%	$0.52
16	0.0%	20.0%	$0.52
17	0.0%	20.0%	$0.52
18	0.0%	20.0%	$0.52
19	0.0%	20.0%	$0.52
20	0.0%	20.0%	$0.52

RESULTS OF ANALYSIS		
Years to Break-Even on Investment:	0	
Increase in Carrying Capacity (AUMs/Ac):	0.24	
Increase in Stocking Rate, (#Head/Total Ac):	30	
Total Installed Treatment Cost ($/Total Ac):	$15,600	under 50% cost share
Amortized Installed Treatment Cost ($/Ac/yr):	$1.64	
Internal Rate of Return:	216%	
Breakeven $/AUM	$6.80	Hal Gordon
Benefit/Cost Ratio:	1.61	USDA - NRCS
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ON THE COVER

Joe Morris sits his horse in a stand of belly-high creeping wildrye on one of the ranches managed by T.O. Cattle Company, San Juan Bautista, California.

GRAZING FOR CHANGE

Range and Watershed Management Success Stories in California

WRITTEN BY DAN MACON
FOREWORD BY DAN DAGGET

A Project of the California Cattlemen's Association. Funding provided by the USDA Natural Resource Conservation Service Environmental Quality Incentives Program, the U.S. Environmental Protection Agency and the Livestock Memorial Research Fund.

FOREWORD

BY DAN DAGGET

When Dan Macon and I gave a talk to a group of ranchers, urban environmentalists, government staffers and just plain folks in East Quincy, California, recently, Dan asked the audience, "What does a ranch produce?" Since that gathering took place not too long after the Columbine, Colorado, tragedy I remember that one response was: "Kids who have a strong sense of right and wrong." I don't remember exactly what the other responses were, but to the best of my recollection they were things like: food for the U.S. and the world, jobs, healthy rural economies and things like that.

The stories that the California Cattlemen's Association (CCA) and Dan tell here expand that list significantly, not just in terms of the number of things that ranches produce but in terms of types of things. In addition to commodities such as beef, lamb, wool and other types of food and fiber, Dan gives us examples of ranches producing open space, native grasses, functional watersheds, and healthy wildlife habitats.

These stories are heartening for anyone who values open, uncluttered landscapes inhabited by healthy populations of plants and animals and people. And they are encouraging for those of us who take heart in examples of people living in harmony with Nature and with one another.

These stories are so heartening in fact that they may give some of us cause to sit back a bit and rest on the laurels of the good stewards CCA profiles here.Today, with the winds of conflict blowing hard across America's rangelands and with beef and other commodity prices yo-yoing as usual, with the weather being even more unpredictable than most of us remember it, and with one third of the ranches in the West up for sale, who could blame ranchers for resting on anything that even resembled laurels. Certainly, I couldn't.

So, sit back and take pride in what these exceptional stewards have achieved. But don't settle too deep into that easy seat. This book is as much a beginning as it is a celebration. And as is the case with all beginnings, it portends that there is work to do, hard work for anyone interested in the future of the rangelands of California and anywhere else.

This book remains a beginning in spite of the fact that it is not the first book chronicling the successes of ranchers in achieving environmental goals. It remains a beginning because all of those books have yet to achieve the desired result – to bring ranchers and environmentalists together in a broad, effective and sustainable synergy that makes them both better able to achieve the interests they have in common. I wrote one of those books in 1995. It was called, *Beyond the Rangeland Conflict, Toward a West that Works* and gained fairly broad recognition because I am a life-long environmentalist. Traditionally, environmentalists have written books to bury ranching rather than to praise it. Books have been written about the value of good ranching stewardship in Colorado and Montana and I don't know where else, but none before this have been written about California and the unique challenges and opportunities that exist there and about the people who are successfully addressing those challenges and opportunities.

That is what CCA and Dan have done, and we are all in their debt for it. We are in their debt because without this account we face the challenge of shaping a sustainable, healthy future for the rural lands of California seriously blinded: Blinded to some of the most effective tools we have to address those challenges – tools that CCA has described in this book. Blinded to the capabilities of individuals who have skills vital to effectively address those challenges – skills of which CCA has made us aware in this book. And blinded to the best we can achieve if we reject the assumption that merely removing rural land managers from the land and accepting whatever ensues as somehow "natural" will get us what we want.

I've taken the message that CCA and Dan make here – that the best way to achieve what is natural is to manage for it – to venues across the West, and I've presented it to audiences that range from ranchers and private property rights advocates to gatherings of vegetarians and preservationists who advocate an end to all ranching. Encounters of the latter sort have been the most instructive. Those who are actively working to remove ranching from the public and in some cases private land, have remained skeptical and even hostile, until I've showed them photos of results such as those described in this book.

At that point, the dialogue inevitably changes. Some of the responses I have received have included: "I never knew anything like this was happening." "It's just the opposite of what we've been told." and "These people should be commended. How can I help." In fact, all except those who have had a vested interest in the rancher/environmentalist conflict have responded in a supportive manner when I showed them examples of ranchers achieving environmental goals – their goals.

What that means to me is that even those people who are opposed to ranching want the environmental values ranchers can produce. If that's not a bridge waiting to be built, I don't know what is. If that's not a new market awaiting some pioneering entrepreneurs to develop, I don't know what is.

With that in mind, if those of us who read this book want it to amount to more than the welcome but fleeting glow most of us will get from reading it, there are a couple of things we can do. We can treat these success stories as a catalogue of environmental values ranchers can produce for a public which has identified the environment as one of its top priorities. And we can start working to develop the means to market those values to the people who want them.

The end result of that, the success of the free market tells us, will be an increase in the amount of environmental value produced by ranchers and greater prosperity for the ranchers that produce it. That, in turn, will be good for both ranchers and for those of us who call ourselves environmentalists, and for the land as well.

I realize that some of us are already doing this – selling or donating conservation easements, marketing beef, lamb or wool that is natural or organic or warranted to be produced in a manner that is beneficial to the environment. In fact, CCA is doing that through the creation of the California Rangeland Trust. However, the stories that the California Cattlemen's Association and Dan give us here confirm that well-run ranches have plenty more to offer than we have yet given them credit for.

Dan has given us a beginning. It is up to us to put that beginning to work.

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The following individuals provided nominations of ranches and watershed groups and helped identify the tools and strategies highlighted in this publication. Their input helped ensure a broad perspective in evaluating the success of each operation.

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INTRODUCTION

Like all other businesses, the business of ranching continues to evolve. Ranchers blend new ideas with proven range management methods to improve both the environment and their bottom line. While domestic livestock grazing has had a controversial past, land managers and policy makers are beginning to understand its value in improving rangelands and restoring native species.

The ranches and groups highlighted in this publication are outstanding examples of innovative range and watershed management.They are proving that economic and ecological success can go hand in hand. While each of these ranches is an outstanding example, it is by no means the only example of success in California. Ranchers throughout the state are finding ways to improve the economic positions of their operations through ecosystem improvements.

The California Cattlemen's Association would like to thank the individuals and organizations that made this publication possible. First and foremost, we would like to thank the U.S. Department of Agriculture Natural Resource Conservation Service for providing an Environmental Quality Incentives Program education grant to help produce this booklet. In addition, the U.S. Environmental Protection Agency and the Livestock Memorial Research Fund have supported this project through grant funding. Our steering committee helped provide clear direction about the types of innovations we have highlighted. Our steering committee also helped us understand the partnerships that will help the ranching community address ecological matters in an economically sustainable manner. Finally, we wish to thank and commend each of the ranchers and groups that are included – your creativity and willingness to share your operations made this effort possible!

A NOTE ON PHOTOGRAPHY

Most of the photographs in this publication were taken between July 1999 and November 1999. Given California's Mediterranean climate and our dry spring in 1999, most of the rangelands featured here had not received significant precipitation for several months at the time that these photographs were taken.

Even so, the management employed by each of these ranchers speaks for itself. We especially want to thank photographer and wildlife biologist Kent Reeves for his outstanding work.

NCBA PHOTO

PG&E's Diablo Canyon power plant, adjacent to the Pecho Ranch.

BLANCHARD RANCH

Bob and Terri Blanchard
Cayucos, California

Few ranches are as spectacular as the Pecho Ranch that Bob and Terri Blanchard lease from Pacific Gas and Electric (PG&E) on California's central coast near Los Osos. Rolling hills drop suddenly to the Pacific Ocean along more than three-and-one-half miles of coastal frontage. In stark contrast, the neighboring Montaña de Oro State Park, which has not been grazed for some time, lacks the ecological health and biodiversity of the Pecho Ranch. "Experiencing and analyzing the evidence available right here, it is easy to conclude and demonstrate that flora, fauna and the natural resources are worse with the prolonged exclusion of grazing," says Bob.

The Pecho Ranch includes roughly 3,500 acres of steep mountain country with a predominately flat, narrow coastal shelf. The ranch produces a mix of grass, forest and brush species and supports a wide variety of animal species including deer, quail, bobcats, mountain lions, burrowing owls, eagles, and other coastal birds and mammals. The balance of the Blanchard's operation is on 3,500 acres of leased land surrounding their headquarters in Cayucos.

"Although we deal with a wide variety of terms and conditions in our leases – including three verbal agreements – we've had basically the same operation for 30 years," explains Bob. "We believe that our continuous efforts to improve our land stewardship practices are largely responsible for our longevity on these leases."

HISTORIC MANAGEMENT

Like many ranches in California, the ranches leased by the Blanchards had been managed using continuous grazing and large pastures. Crossbred cows weaned large 650 to 700 pound calves, but historic stocking rates resulted in high production costs and lower returns. Higher stocking rates, on the other hand, led to poor conception rates and other challenges, including environmental problems that also added costs to the operation. The lack of acceptable returns and Bob and Terri's concern for the environment caused them to look at and experiment with other alternatives.

CURRENT MANAGEMENT

In 1985, the Pecho Ranch was purchased by PG&E, who maintained the previous owner's desire to run as many cattle as possible to

maximize rental income. In 1990, PG&E formed a Land Stewardship Committee, consisting of PG&E employees, to take over management of the ranch. "They were mostly environmentalists," laughs Bob, "and a conflict seemed inevitable between them and me, the traditional rancher." Rather than butt heads, Bob and Terri met with the committee to compare goals. "We found that we had more in common than we had differences," recalls Terri.

Beginning in 1992, the Blanchards implemented a high density, short duration management strategy. "We just call it 'managed grazing' as opposed to continuous grazing," explains Bob. The Pecho Ranch is now divided into 25 pastures. The entire herd grazes a pasture for several days, creating a brief period of intense impact on the rangeland vegetation. Following each grazing period the pasture is rested for 45 to 60 days (or more). According to Bob, "the point is to mimic the beneficial effects of the migratory herds present during the evolution of our grasslands while eliminating or at least minimizing any negative impacts associated with continuous grazing. This helps us meet our environmental and economical goals."

STEWARDSHIP GOALS

Bob and Terri understand that establishing clear goals indicates the proper path. Working with their lessors, the Blanchards have established the following goals:

- Gain further understanding of responsible, sustainable use of natural resources within an economically viable grazing operation.

"Grazing is so essential to California's rangeland that striking a balance between the environmental and economical needs of a ranch in California is very achievable," says Bob. "We are not doing anything radical with our management. In fact, many ranchers in California are working hard to strike the same balance. We are just fortunate in that we have been recognized for our efforts."

- Re-establish (to the extent possible) the natural coastal prairie ecosystem, focusing on native perennial grasses and plants.

As with most resource goals, a long-range plan is needed to accomplish the task. By shifting some paradigms, the Blanchards are providing much-needed time to re-establish species. The benefits are increased productivity and biodiversity.

- Educate others as to the essential role that grazing animals play in maintaining a healthy, diverse ecosystem.

Bob and Terri have always been strong grazing advocates and have challenged other producers to share their knowledge with the public. "Many ranches have been in the same family for generations and could not be in any better ecological condition. I just wish all producers could take the time to show their communities all the environmental benefits resulting from their grazing operations," says Terri.

INNOVATIONS AND TOOLS

Water and water systems: The Blanchards use gravity-distributed spring and creek water, as well as some seasonal pumping, to distribute water to

NCBA PHOTO

Terri and Bob Blanchard

The western edge of the Pecho Ranch ... "Managed grazing is justified on economic issues," Bob believes; "the environmental benefits come along for free!"

NCBA PHOTO

"It is a source of great personal satisfaction for Terri and me, and I believe for the folks at PG&E, to be involved in these projects. As time goes on, we expect to find better answers to the questions we have today, probably come up with many new questions, and hopefully continue to seek answers to them.

We know we are working on some issues regarding sustainable agriculture and the responsible use of natural resources that have importance far beyond the benefits that may accrue directly to ourselves."

– Bob Blanchard

their livestock. While Bob and Terri have not completed a formal Rangeland Water Quality Management Plan, they evaluate water quality and distribution continuously. Bob points out, "As ranchers know, high quality water and proper distribution are essential tools in proper grazing management. Having good water in strategic locations has also attracted the diversity of other animals we see on our ranches."

Vegetation: Using high density, short duration grazing with cattle, and now browsing coastal scrub with goats, the Blanchards aim to restore the remnant population of native perennial grasses on the ranch.

The Blanchards are using Spanish meat goats to control vegetation to reduce the threat of wildfire near the Diablo Canyon power plant (adjacent to the ranch). Rather than using the traditional approach of confining goats in a given area until all of the vegetation is removed, Bob and Terri manage these brushy plants much the same way they manage the grass – by rotating through a given area two to three times per year. "We believe that we'll be able to demonstrate effective and environmentally sensitive vegetation management within the scope of an economically viable meat goat business," says Terri.

By feeding hay to cattle confined in an isolated area of coastal scrub habitat, the Blanchards have broken down old, decadent brush and encouraged the reintroduction of younger stands of brush and perennial grasses. Though very effective, the practice is expensive and has been replaced by the use of the goats.

Wildlife: Bob and Terri focus on the dramatic differences in the number and diversity of wildlife between the ranch and the adjacent state park. Their integrated approach to grazing management appears to have tremendous benefits. The most visible example of this has to do with bird populations. Informal counts indicate a greater than ten-fold increase in the number and species of birds that occupy a given area of the ranch vs. a similar area in the park.The explanation is simple – grazing gives rise to a higher level of plant diversity and productivity, in turn supporting a larger and more diverse population of insects and small animals like birds, reptiles, and rodents, which in turn are available to support a much larger population of predatory birds and mammals. All this complex life activity contributes ultimately to the health of the soil and more productive plants. "In the absence of the ruminant animal this process just grinds to a halt!" insists Bob.

Soils: Soil tilth and fertility are managed by influencing the uniform distribution of manure and urine (which Bob says "are not pollutants, but important results of the grazing/browsing process.") Bob also believes that grazing management that encourages larger plants will improve soil condition by increasing above and below ground decomposition.

ENVIRONMENTAL BENEFITS

All too often, the only remedy offered to continuous overgrazing is the elimination of grazing. The proximity of the Pecho Ranch to Montaña de Oro State Park offers a unique chance to compare the Blanchards' managed grazing approach to the absence of grazing.

Increased production of higher quality forage has benefited both wildlife and livestock. The ranch is home to diverse wildlife, while the adjacent park is home to fewer animals and less diverse species. The burrowing owl, for example, requires a gopher or squirrel hole that has been routed out by a badger or coyote in an area that is fairly clear of vegetation for good visibility. The occurrence of these conditions declines rapidly with the exclusion of grazing.

While the Land Stewardship Committee originally insisted on fencing cattle out of riparian areas, the Blanchards' success in managing the rest of the ranch has led to the reintroduction of grazing (plus browsing by goats) to reduce the buildup of thatch and overgrown, inefficient plants that had begun to choke these areas in the absence of livestock.

Grasslands on the ranch have shifted to a more desirable mix of common rye, burr clover and filaree. Relatively nonexistent native perennials have also recovered.

Erosion along cattle trails has been eliminated as pastures are seldom used long enough for trailing to occur or for vegetation to be completely removed from those trails that do develop.

Brush management has improved wildlife habitat and reduced the potential for catastrophic wildfire.

Soil fertility has increased with more uniform distribution of manure and urine. "We've also observed increases in bird activity in the fields where cattle are or have recently been," Bob explains, joking, "The cowpie is the key!"

Better management has increased the amount and distribution of residual dry matter (both above ground and in the root zone). As a result, water penetration and retention have improved and soil erosion has been prevented.

ECONOMIC BENEFITS

Economic benefits have been significant and numerous. "Managed grazing is justified on economic issues," Bob believes; "the environmental benefits come along for free!"

Carrying capacity has increased by 30 percent. As a result, fixed costs per cow have dropped from over $18 to under $14 per month.

The Blanchards now feed no hay except for the rare occasion that animals need to be confined to the corrals. Even the horses now graze year round with the cattle.

At the Pecho Ranch, a previously significant parasite problem has been eliminated by the rotational grazing system.

Bull costs have been reduced from over $55 per weaned calf to just $25. Previously, Bob and Terri used five to six bulls per 100 cows – while just two bulls can do the same job today.

Management efforts were greatly reduced once ranch improvements were completed. Cattle become very easy to handle. "We used to think we needed eight to 10 saddle horses to be prepared for busy seasons," Terri laughs, "but now we're down to five – and we wouldn't need that many if we didn't like to team rope."

MONITORING

The Blanchards have used photo monitoring techniques extensively and have documented conditions both before and after their change in management. "Short-term and long-term trends have to be monitored to see if you are moving in the direction of your goals. For us, photo monitoring has been the simplest and most productive approach," says Terri.

NCBA PHOTO

Bob and Terri are using Spanish meat goats to control vegetation and reduce the threat of wildfire at the Diablo Canyon facility.

FINAL NOTE

Bob says, "It is a source of great personal satisfaction for Terri and me, and I believe for the folks at PG&E, to be involved in these projects. As time goes on, we expect to find better answers to the questions we have today, probably come up with many new questions, and hopefully continue to seek answers to them. We know we are working on some issues regarding sustainable agriculture and the responsible use of natural resources that have importance far beyond the benefits that may accrue directly to ourselves."

Bob and Terri also note that most ranchers do a great job with their cattle and their land and that we all need to work together. The answers we find and share will benefit us economically and the state environmentally.

BYRNE BROTHERS RANCH

Mike and Dan Byrne
Tulelake, California

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Overhanging vegetation along a creek on a U.S. Forest Service grazing allotment managed by Mike and Dan Byrne.

Few ranchers are as active in their local communities and industry organizations as Mike and Dan Byrne. In addition to serving in leadership roles in the California Cattlemen's Association, the California Farm Bureau Federation, the National Cattlemen's Beef Association and numerous local organizations, Mike and Dan have managed their family operation since their father's passing in 1988. The ranch was established in the very early 1900s by their grandfather.

With headquarters in Tulelake, California, the operation consists of both private land and approximately 100,000 acres of public lands. The private land consists of irrigated pastures, meadows and some dry land range. The public lands vary from low sagebrush to western juniper uplands, with riparian draws and flats scattered with volcanic rocks and ledges. The area receives average annual precipitation of 11 to 12 inches, mostly in the form of winter snow and summer thunderstorms.

HISTORIC MANAGEMENT

Prior to 1950, the Byrne Ranch used herding to move their cattle over a 50-mile circle of public lands during an 11 month grazing season. After 1950, the area was fenced into several pastures and cattle were rotated through these fenced areas. The Byrne brothers, as with many western ranchers, have witnessed a positive change in weaning weights and production as they have implemented rotational grazing and other innovations in range and livestock management. As Mike points out, "Years ago if we had a calf that weighed 500 pounds by the end of January we were thrilled – now we look for 600 pound calves by early December."

CURRENT MANAGEMENT

In the early 1980s, Mike and Dan began working with the U.S. Forest Service to increase the number of pastures so that a new rotation system would mimic the original herding regime. By strategically placing 15 miles of fence to create 12 individual pastures, Mike and Dan can graze two separate herds in a five-year rotation system. They have also developed eight solar wells in upland areas to create off-steam watering opportunities. These wells disperse animals more evenly, achieve greater late season grazing use of upland areas, and relieve pressure on riparian areas during the hot

summer months. Finally, Mike and Dan have removed western junipers from areas that still have adequate understory vegetation and soil depth to respond to such treatment. While the Byrnes have attempted to employ controlled burning to remove juniper from the most heavily infested areas, to date the only method of removal available to them has been to cut the trees down.

STEWARDSHIP GOALS

- Manage private lands in conjunction with public lands to enhance the vegetation communities across the entire landscape.
- Improve the shrub and vegetation component of the upland ranges through juniper removal.
- Improve riparian systems on public and private lands.

INNOVATION AND TOOLS

Water and Water System: The Byrnes have installed eight wells and solar-powered pumps to provide off-stream watering sites. This system better distributes livestock, relieves pressure on streams, and creates new water for wildlife.

Vegetation: Western junipers are removed by cutting, especially near riparian areas to encourage grass and shrub reproduction

A solar well installed by the Byrnes to provide offstream water for livestock.

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Mike and Dan Byrne

The Byrnes' rotational grazing system results in high quality forage production, benefitting both wildlife and livestock.

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The Byrnes' management approach has benefit a wide range of wildlife.

"The Byrne brothers have been at the forefront of pushing better collaboration between agencies and landowners. They have the unique ability to blend the differing point of views of the agencies into a cohesive management plan."

– Rick Delmas, Farm Advisor

and growth. Rotational grazing has provided periods of rest, allowing plants to regenerate.

Wildlife: By managing for increased shrub growth, especially bitterbrush, the Byrnes are also benefiting the deer population.

ENVIRONMENTAL BENEFITS

The Byrne's management strategy has improved water quality by increasing vegetation in riparian zones, which increases sediment entrapment. Increased riparian vegetation has also increased shading along stream courses, resulting in cooler water temperatures that are beneficial to native fish populations.

Increased forage production on lands cleared of western juniper benefits both livestock and wildlife. The management changes have created a situation that allows the native plant communities to take advantage of weather conditions conducive to maximum plant growth, seed production and regeneration.

ECONOMIC BENEFITS

Improved wildlife habitat on public lands has increased the recreational value of the areas grazed by the Byrnes. While the Byrnes do not benefit directly, their communities benefit through increased recreational use.

In the face of pressure to decrease stocking rates on public lands allotments throughout the West, the Byrnes have been able to maintain stocking rates due to improved range conditions and livestock distribution patterns.

MONITORING

Mike and Dan, in cooperation with U.S. Forest Service, U.S. Fish & Wildlife Service, National Resource Conservation Service (NRCS), University of California Cooperative Extension and Tulelake High School, monitor riparian systems using permanent channel transects and annual stubble height measurements.They also record stream temperatures to evaluate the effects of increased shading. Finally, riparian habitat is monitored for successful willow regeneration and plant community composition.

FINAL NOTE

Mike and Dan Byrne are working closely with the U.S. Forest Service, the U.S. Fish and Wildlife Service, the Natural Resource Conservation Service and the University of California Cooperative Extension to monitor riparian improvement and water quality.

Says farm advisor Rick Delmas, "The Byrne brothers have been at the forefront of pushing better collaboration between agencies and landowners. They have the unique ability to blend the differing point of views of the agencies into a cohesive management plan."

FORD RANCH

John and Charline Ford
Willits, California

The Ford Ranch, just north of Willits in Mendocino County, appears to be a typical north coast ranch at first glance. At approximately 1,175 acres, the property sits in Little Lake Valley. Like most of California, the region is characterized by warm, dry summers and wet winters. The ranch, which is grazed primarily in the spring, summer and fall months, receives an average of just over 54 inches of precipitation each year, most of it coming November through April. Since the majority of the ranch was originally a large, shallow lakebed, it is characterized by relatively flat, deep, fertile soils. After purchasing the property in 1979, the Fords established lush stands of grass and clover on much of the ranch. These fields are grazed and hayed during the growing season under an intensively managed and monitored system.

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Riparian vegetation along Baechtel Creek.

HISTORIC MANAGEMENT

In the mid 1800s, a large, shallow lake occupied the north end of the Little Lake Valley. By the turn of the century, the lake had been drained to make way for agricultural development. Ditches were dug by hand or by teams of horses to discharge the water that flowed into the area. "Most of those early efforts were ineffective," says John, "and we have had seasonal flooding ever since." Little was done with the waterways in the valley until the mid 1950s, when heavy storms caused extensive flooding. This resulted in an effort to remove the debris and excess vegetation that clogged the waterways. Again, however, the streams were virtually neglected until the mid 1980s when the Fords, in close coordination with California Department of Fish and Game fishery biologist Weldon Jones, began a concerted, major effort to restore the creeks on the ranch and improve water quality and drainage.

In 1998, the Fords completed a Rangeland Water Quality Management Plan for the ranch. The plan itself has provided the Fords with a valuable tool to articulate their accomplishments as well as monitor and measure the effects their efforts have had on production and the environment.

CURRENT MANAGEMENT

The Fords currently run a commercial cow herd on the ranch, grazing 160 cows, six bulls and 30 replacement heifers year round. The cows begin calving in early October, while the first-calf heifers begin calving a month earlier. Calves are weaned in late June or early July and, depending on the market, are sold or retained as stockers. In addition, the Fords purchase up to 700 stocker calves in August through February, marketing them as 850-pound yearlings or feeding them out in Colorado. When feed conditions are appropriate, the Fords will also run an outside herd of 450 mother cows from late May into October.

JOHN FORD PHOTO

Using treated wastewater, the Fords have increased forage production significantly.

All the cattle remain on seasonal grasslands in the area from November through late spring. The cattle return to the ranch in late spring and remain there until the rains return in the fall. From late spring through early autumn when the ground is dry, the Fords use a rotational grazing system to maximize forage use and production. Each pasture is rested for 21 to 25 days between uses, which allows for irrigation and disrupts the parasite cycle, reducing the need to deworm the cattle. In the fall, after the rains begin, the cattle are again moved to nearby winter pasture.

Using treated effluent from the city of Willits, the Fords irrigate pastures and put up about 400 tons of grass and clover hay each year. Fields are rotated on a three-year cycle for hay production.

The Fords are strong believers in keeping detailed records. "One of the ways that we work to increase the pounds of beef this ranch produces," relates John, "is to maintain detailed records on each cow. If a cow doesn't breed back quickly and wean a heavy calf, we sell her."

STEWARDSHIP GOALS

- Increase perennial grasses and clovers.
- Ensure open passage for migrating salmon and steelhead.
- Correct minor erosion problems as they occur, rather than letting them escalate into major problems.
- Continue to install rock weirs and riprap to control erosion and stabilize the creek banks.

INNOVATION AND TOOLS

Water and Water System: The Fords work closely with the California Conservation Corps to keep Baechtel, Berry, Davis and Mill Creeks free from debris and log jams, allowing migrating salmon and steelhead to continue on their way to spawning grounds. The Fords have also worked extensively with the California Department of Fish and Game to rechannel the streams resulting in improved drainage and fish habitat. They have then used riprap, weirs, grade stabilization structures and grass seedings to stabilize stream courses and reduce erosion. To substantially reduce the use of the streams by the cattle for stock water, the Fords have installed four wells, over 35,000 feet of water lines and 30 water troughs. Additionally, to minimize erosion and soil compaction, the Fords mounted the troughs on cement pads and gravel.

Vegetation: Rotational grazing has increased plant vigor and growth. The Fords also plant native and hybrid perennial forage species to boost production and lengthen the growing season. Any bare ground, especially on stream banks, is immediately seeded with perennial grasses. Brush lands have been maintained for wildlife habitat, as has adequate riparian vegetation for fisheries, deer and upland game birds.

Wildlife: In addition to the federally listed salmon and steelhead species that pass through the property, the Ford Ranch is home to wild turkeys, deer, pheasants, quail and numerous duck species. Brush lands are maintained as cover areas for deer, pheasants and quail, and the Fords maintain high quality riparian habitat on at least one side of the creeks on the ranch. These riparian zones provide cover for wildlife and provide shade for the streams, keeping the water cooler for migrating and resident fish. Finally, the Fords worked with a local Eagle Scout in 1994 and with the California Waterfowl Association in 1995 to place more than 25 wood duck nesting boxes on the ranch.

Under the Fords' management, riparian vegetation and forage production are compatible and even complimentary. This is the outside portion of the same riparian area pictured on page 13.

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Manure: Corrals and cattle working areas are at least 600 feet from the nearest stream with concrete slabs where necessary to avoid excessive mud and erosion.

Erosion: The Fords closely monitor and maintain the amount of residual dry matter, retaining between 750 and 1,000 pounds per acre at the end of the grazing season to catch sediment and disburse the water during the winter months.

ENVIRONMENTAL BENEFITS

Stream channel improvements have reduced the number of young fish that are stranded and die in the flooded fields. Nearly 50 miles of spawning and nursery habitat have been reopened and maintained for Chinook Salmon and Steelhead Trout.

Ponding time on the northern end of the ranch has decreased, thereby increasing soil fertility and productivity.

The wood duck nesting program is the most successful of those run by the California Waterfowl Association, according to Malcom King, Mendocino County coordinator. In 1998, 100 ducklings were hatched in 25 nest boxes.

ECONOMIC BENEFITS

Improved drainage has lengthened the growing season on the northern end of the ranch. Increased access to treated effluent will allow the Fords to irrigate more land, increasing forage and hay production.

Stocking rates and forage production have increased substantially over the years. The Fords have controlled the annual flooding and erosion and constantly work to fine-tune their inputs and to optimally use the natural resources available on the ranch.

MONITORING

Since their most substantial and environmentally beneficial effort to date has been the cleaning and rechannelization of the creeks on the property, the Fords, both visually and with the use of gradient stakes, closely monitor the creeks for undesirable sediment deposits. They are removed annually with the approval of the California Department of Fish and Game.

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FINAL NOTE

The Fords are an excellent example of the proactive approach taken by some landowners to improve both the economic and ecological health of their property. "We believe doing what is good for the environment translates into doing what is right for our agricultural operation," says John. As with many cattle ranchers, the Fords are also evaluating opportunities for diversifying into other crops such as berries and artichokes. John explains, "Fixing the small problems before they get big is just good management." Since the Ford Ranch remains near the bottom of the valley downstream from an urban, industrial area, John is constantly dealing with an unbelievable amount of manmade debris that washes down the creeks during the rainy season. "We get little help in this area," according to John, "and it remains as one of the ranch's greatest environmental challenges."

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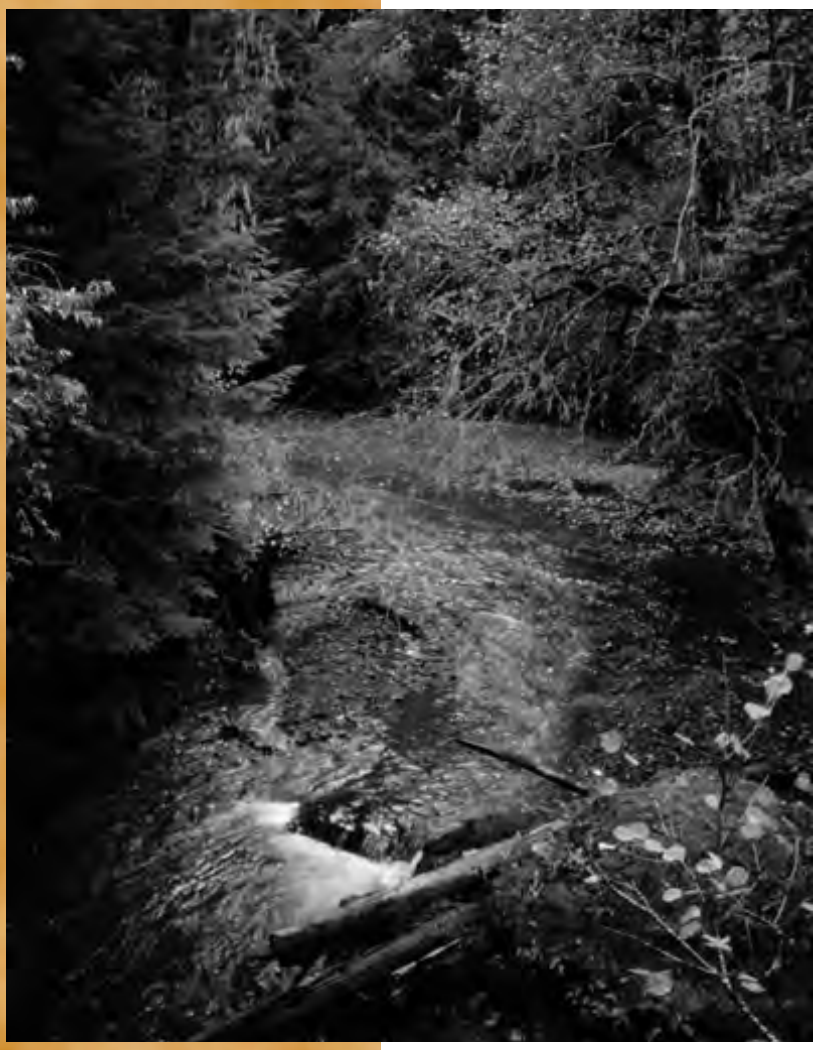
John and Charline Ford

"We believe doing what is good for the environment translates into doing what is right for our agricultural operation," says John Ford.

FORT BAKER RANCH

John Rice, Humboldt County, California



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A riparian zone on the Fort Baker Ranch.

Located in northeastern Humboldt County, Fort Baker Ranch is a family-owned operation run by three generations of Rices. The ranch sprawls over 24,000 acres, and like most Humboldt County ranches, Fort Baker Ranch includes open grasslands, oak woodlands, and fir timber. Geologically speaking, the region is relatively young, making the terrain extremely rugged and naturally unstable. While average precipitation is roughly 75 inches per year, annual rainfall can be as high as 100 inches. Located in the heart of salmon and steelhead habitat, water quality and fisheries habitat are of primary concern.

HISTORIC MANAGEMENT

John Rice indicates that the management of the ranch has changed over the years. "In the 1950s," he says, "we ran 1,000 cows with a calf crop of 80 percent or less." Calves were weaned at 350 pounds and the cowherd ran year around in most of the pastures.

While the logging practices in the 1940s and 1950s were more lax than today, John's father still paid particular attention to water quality in the streams. He insisted that logging contractors "pay close attention to protect water bodies when constructing roads and log decks," John explains, "and went beyond what was required when reclaiming logged areas."

CURRENT MANAGEMENT

While John has reduced his cowherd to 700 to 800 females depending on the year, his current management produces a 90 percent calf crop and weans 600-pound calves (thus marketing more pounds of beef). John's strategy includes moving the cattle to different pastures an average of four times per year, rather than allowing the entire ranch to be grazed all season long.

Since severe winter weather is always a concern, John manages the cattle carefully through the winter months. Cows are moved into winter range in November or December. During good weather, the Rices push the cattle to the upper parts of the winter range to give the lower, more protected reaches of the ranch a short rest. Cattle are sorted and separated in late April. Steer calves are shipped in late September.

The Rice family has recently entered the Partnership of Quality Program with Harris Ranch Beef to market its calves. "We hope this program will greatly improve the genetics of our bulls while improving the quality of our calves – ultimately adding value to our calf crop," says John.

STEWARDSHIP GOALS

- Continue to improve water facilities for livestock and wildlife.
- Continue to use controlled burns to improve forage production for livestock and wildlife, as well as to control brush encroachment.
- Reduce erosion potential.

INNOVATION AND TOOLS

Water and Water System: The Rices use 10,000-gallon tanks that fill with rainwater during the winter months. This water is used by the livestock during the dry season and may be supported with a water truck if necessary. The Rices are continually fencing and developing springs and piping water into troughs.

Vegetation: Like many ranchers in northern California, John Rice occasionally harvests timber on the Fort Baker Ranch. While his logging operation complies with California's Forest Practices Act, John adds the extra steps of removing logging roads after use, restoring all creeks to their original channels, and piling slash. Finally, all logging sites are immediately seeded with perennial grasses. The Rices have had some limited success with controlled burns to manipulate vegetation. John says, "When conditions are good for a fire, you can't do it." Further, John expresses the opinion, "That the only good fire scares you to death." They have had some cool controlled burns; however, these fires have produced minimal long-term benefits.

Wildlife: The Rice's water and spring development, along with their burning and reseeding programs, have had a positive effect on deer populations; however, this has been more than offset by a dramatic increase in the predator population.

Soil: By reseeding logged areas, John holds soils in place, reducing erosion and sedimentation.

Manure: To mitigate the effects manure has on water quality, all areas where cattle are confined, such as corrals and small holding fields, are sloped away from creeks or have ample grassland buffers to filter and trap manure before the runoff enters the streams.

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John and Peggy Rice with three of their seven grandchildren, T.J., Skylar and Mackenzie Rice.

"My feeling is that if you take good care of your cattle, your grass and water will also benefit. For example, keeping cattle healthy and in reasonably good shape requires taking good care of the grass above the ground and the roots below. The same principle applies to water, I believe."

– John Rice

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Typical north coast rangeland. Steep terrain and high rainfull can make ranching challenging.

In-stream Structures: John has installed culvert crossings in creeks to be used by cattle as they enter the corral areas, eliminating cattle activity in the streams. In the larger pastures, John has installed hard rock crossings in the creeks where cattle tend to cross, which has successfully reduced bank chiseling and streambed disturbance.

ENVIRONMENTAL BENEFITS

Water quality has improved and erosion has been reduced through the use of culverts, rock crossings and rock weirs.

Feed quality has improved along with pasture recovery by moving cattle more frequently, which benefits wildlife and livestock.

Controlled burning programs have improved wildlife habitat and increased soil productivity by adding potash to the system.

Off-stream watering sites and reseeding in logged areas has reduced the potential for erosion and sedimentation.

To distribute cattle more uniformly and protect springs and seeps, John Rice has developed a network of 10,000-gallon water tanks and troughs.

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ECONOMIC BENEFITS

Weaning weights have increased from 375 to 400 pounds in the 1950s to 600 to 625 pounds in the late 1980s and 1990s. While the Rice family has reduced the total number of livestock that run on the Fort Baker Ranch, the total pounds of beef sold have increased.

John's burning program has had a positive effect on the health of deer herds; however, the lack of effective predator control has severely modified any gains in the overall deer population. John has, therefore, seen only limited improvement in his hunting program.

MONITORING

"Since I've been on this ranch for 48 years," John says, "I do most of the monitoring by sight. I keep a close eye on the grass and check the cattle often. Based on these observations, I make decisions about when to move cattle and how heavy to stock the ranch." The Rices have started a detailed photo-monitoring program that has been enhanced by using his mother's collection of historic photos to graphically validate improvements.

FINAL NOTE

Like the Fords (see pages 13-15), little things seem to make a difference with the Rice family. University of California watershed specialist Ken Tate relates, "John carries a shovel with him in his pickup. You'll be driving over the ranch and John will stop the truck, jump out and fix a plugged culvert or blocked drainage ditch before it becomes a washout."

John says, "My feeling is that if you take good care of your cattle, your grass and water will also benefit. For example, keeping cattle healthy and in reasonably good shape requires taking good care of the grass above the ground and the roots below. The same principle applies to water, I believe."

McDONALD RANCHES

Merv, Dorothy and Mike McDonald, Owners
Petaluma, California

The McDonald family has ranched near the Marin County coast north of San Francisco Bay for 55 years, 20 years at the present location. Located 14 miles west of Petaluma, their home ranch sits at the upper end of Walker Creek, a major tributary to Tomales Bay. Merv and Dororthy McDonald and their son Mike manage 1,400 acres of their own land along with 3,450 acres of leased private and public land. Their operation ranges in elevation from sea level to 2,000 feet and receives average precipitation of 35 inches per year. Most of their rain comes from October to May. Typical of the ranches in the area, most of the McDonald's rangeland produces annual ryegrass and clover.

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McDonald Ranch headquarters. Even in a dry year like 1999, the McDonald's leave sufficient residual dry matter to prevent erosion and sedimentation.

HISTORIC MANAGEMENT

Merv McDonald has lived in Marin County his entire life. "We ran cattle at Pierce Point in the Point Reyes National Seashore until the Park Service pushed us out to increase the elk population," he says. Merv bought his current ranch in 1980. "We run Angus and Hereford cattle, as well as Angus-Hereford crosses," he explains. Initially, Merv stocked the ranch at 20 acres per cow per year. Weaned calves weighed just over 600 pounds.

CURRENT MANAGEMENT

Through improved management, the McDonalds have increased their stocking rate to 10 to 15 acres per cow per year. They currently run 400 mother cows and 40 heifers on the ranch year round. The cows calve in the fall and calves are marketed in July. Bulls and replacements are purchased from similar ranches throughout northern California. Current weaning weights are between 750 and 800 pounds. An aggressive marketer, Merv has installed a scale at the ranch to allow him to sell cattle directly to Midwest feedlots. He has also implemented an extensive vaccination and backgrounding program prior to shipping.

To improve their rangeland resources, the McDonalds have developed multiple water sources to minimize the travel of cattle to water and to reduce impacts on riparian areas. Additional water sources also improve the distribution of grazing over the ranch. Merv leaves enough forage to ensure fall regrowth of desirable plants.

"If you don't take care of the land, it won't take care of you."
– Merv McDonald

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Merv McDonald

A lush setting along Walker Creek.

"Merv is very conscious of water quality issues," says livestock farm advisor Stephanie Larson. "He began water quality projects on his ranch 15 years ago before anyone was even aware of nonpoint source pollution." In addition to developing offstream water sources, Merv has fenced portions of Walker Creek to protect water quality.

Finally, the McDonalds have used the information garnered at a University of California Cooperative Extension ranch planning short course to develop a ranch plan that addresses water quality issues. "We hope that our plan will enable us to maintain our family operation, enhance our agricultural production and maintain water quality," says Merv.

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STEWARDSHIP GOALS

- Keep the ranch in the family and maintain its agricultural viability.
- Leave the ranch in better condition than when it was purchased in 1980.
- Maximize production while minimizing erosion.
- Maintain adequate residual dry matter levels to enhance fall regrowth of important forage plants.
- Reduce brush cover.
- Balance grazing program with calf management to utilize grass resources at their optimum level.
- Ensure that water is as clean when it leaves the property as it is when it enters.

INNOVATIONS AND TOOLS

Energy: Rangelands are properly grazed to maintain adequate residual dry matter.

Water and Water Systems: The McDonalds have developed 11 stock ponds and 26 spring-fed troughs, which have all been rocked to reduce hoof impact. These water systems are designed to aid in the distribution of livestock.

Vegetation: Several acres of coyote brush have been removed by chopping and management to improve forage vegetation. The McDonalds have also planted willows in riparian zones to increase water-holding capacity and reduce erosion.

Wildlife: Deer are managed using selective harvesting techniques on private land. Targeted brush removal favors bird species by providing nesting habitat and increasing grass seed production.

Soils: Erosion control projects, including placing feeding racks on ridges away from streams and rock armored roads, have been implemented to prevent further loss of soil. Adequate amounts of residual dry matter are retained to hold soil at the beginning of the rainy season. The McDonalds have also constructed an extensive alleyway that allows cattle to be moved from pasture to pasture and back to the home ranch and corral system, reducing trailing impacts and subsequent erosion.

Manure: Cattle are distributed so that excessive manure is not deposited in sensitive areas, like riparian zones.

ENVIRONMENTAL BENEFITS

In nearly 20 years of management, the McDonalds have provided the following environmental benefits:

Improved water quality has benefitted terrestrial and aquatic wildlife.

Better livestock distribution has improved forage quality and diversity, also benefiting wildlife.

ECONOMIC BENEFITS

Stocking rates have improved from 20 acres per animal to between 10 and 15 acres per animal, and weaning weights have increased by over 200 pounds.

By using four corrals and an alleyway system to move and process cattle, the McDonalds have reduced animal stress.

Improved cattle health management has resulted in lower veterinary costs and a 95 to 98 percent conception rate.

MONITORING

The McDonalds weigh calves periodically to determine performance, which also allows for long-term tracking of weaning weights. Farm advisor Stephanie Larson attests to the fact that the McDonalds leave plenty of grass. "They run cattle here year round," she says, "But only about five percent of the cows are ever fed any hay."

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McDonald Ranch grazers at work.

FINAL NOTE

Merv McDonald has been involved in conservation programs for many years, serving on the Sonoma-Marin Farm Services Agency Board and the Tomales Bay Watershed Group.

"If you don't take care of the land, it won't take care of you," Merv believes, adding, "it's a landowner's responsibility to maintain the health of the land and the quality of the water for all that use it, including cattle and wildlife."

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Merv McDonald uses historic photos of the ranch to evaluate the benefits of his current management.

PETE'S VALLEY RANCH

Pete's Valley Partnership Susanville, California

Pete's Valley Partnership consists of: Darrell Wood, General Partner; Rick Harrison; Richard Steward; and Kimball Timothy.

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Lasson County's Pete's Creek.

The Pete's Valley Partners purchased the Pete's Valley Ranch, about 12 miles east of Susanville, in 1993. The ranch had been in Darrell Wood's family once before – his great grandfather purchased the property in the early 1940's, building a reservoir and irrigation system during his tenure.

The ranch consists of over 1,200 acres of wet meadows, wetlands, riparian habitat (adjacent to Pete's Creek), and sagebrush-covered uplands. Typical of many of the ranches in northeastern California, the private lands are surrounded by public lands managed by the Bureau of Land Management. The partnership also has a permit to graze an allotment on these BLM lands. Average annual precipitation in the region is 9 to 12 inches, with most of it coming in the form of winter snow or summer thunderstorms.

HISTORIC MANAGEMENT

From 1945 to 1970, the ranch supported approximately 200 cow/calf pairs. As the ranch was not cross-fenced, the entire property was grazed season long. Calves were weaned at 400 pounds, fed hay all winter, and pastured again the next spring. While no formal marketing strategies existed, most calves were sold in the late summer as 850 to 900 pound yearlings. Season long grazing led to heavy grazing in riparian areas and wet meadows. Lack of vegetation along streambanks caused substantial erosion and downcutting, resulting in a lower water table and sagebrush encroachment.

CURRENT MANAGEMENT

Darrell manages the Pete's Creek Ranch as a commercial cow/calf operation. Cows are wintered in the Sacramento Valley and arrive on the ranch with 400-pound calves in mid-April to early May. These calves are weaned at 650 pounds and backgrounded in a nearby feedlot for several months. Heifer and steer calves are marketed from the feedlot weighing approximately 800 pounds. The cow herd is shipped back to the Sacramento Valley in November after the first rains have fallen.

The ranch is divided into seven grazing units and livestock are rotated in a short-duration grazing pattern, keeping forage plants in a phase II condition (high quality, high quantity) for the entire grazing season. Darrell spreads water throughout the ranch through a series of irrigation ditches. Ceci Dale-Cesmat of the USDA Natural Resource Conservation Service (NRCS), who works with Darrell on the project,

says that the ranch does not have a formal grazing plan. "We developed objectives for improving habitat and water quality, and Darrell has developed a grazing strategy that is moving us toward these objectives."

The Pete's Creek Ranch has developed a Rangeland Water Quality Plan in conjunction with a Conservation Plan. Both were developed in collaboration with NRCS and the U.S. Fish and Wildlife Service.

STEWARDSHIP GOALS

- Increase water-holding capacity of the land by restoring the riparian habitat along Pete's Creek, thereby increasing the amount and diversity of vegetation.

- Decrease the amount of erosion on the streambank and from upland areas.

- Restore the trout fishery on Pete's Creek by using the reservoir to maintain perennial flows.

INNOVATIONS AND TOOLS

Water and Water Systems: The Pete's Creek Wetlands Restoration Project was initiated in 1996 in partnership with NRCS and the U.S. Fish and Wildlife Service Partners in Wildlife. Currently in the second year of a ten-year project, this effort has already produced dramatic improvements in riparian condition and forage quality and quantity. The creek is being placed back into its historic channel and the reservoir structure is being improved to provide perennial flows.

Vegetation: An exclosure fence has removed roughly 345 acres of the ranch from grazing and willows have been planted to stabilize streambanks and provide shade. Later in the project, cottonwoods will be planted as well. The project cooperators have chopped encroaching sagebrush on about 100 acres and re-seeded limited areas with native grasses (although Darrell indicates that most of the grass has come back on its own). Improved livestock management has allowed native grasses to colonize formerly bare areas.

Wildlife: The project cooperators are managing for sage grouse, antelope, waterfowl, quail, deer, neotropical migratory songbirds, sandhill cranes, bald eagles and shore birds. The Pete's Valley

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Darrell Wood

"Darrell's efforts have benefited both his own ranch and the landowners downstream from the project."

– Ceci Dale-Cesmat, National Resource Conservation Service

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Willows and other riparian vegetation shown at left provide streambank stability and shading along Pete's Creek.

Ranch is also involved in the Wildlife Habitat Incentives Program and the Wetlands Reserve Program through NRCS. The California Department of Fish and Game provides technical assistance on fisheries issues. Finally, Darrell manages the ranch to provide waterfowl and upland game bird hunting, which brings in additional ranch income.

Soils: Brush chopping in the upland areas of the ranch has shifted species composition from woody sagebrush to herbaceous vegetation, which has increased groundcover and reduced wind, sheet and rill erosion. In the riparian zone, groundcover is increasing on the streambank and floodplain, also reducing the potential for erosion.

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Great Basin wild rye is being re-established on the ranch.

Manure: Darrell's rotational grazing system has improved nutrient cycling by spreading livestock and manure more evenly throughout the fields. The wetland and riparian management practices retain moderate stubble heights to filter nutrients that might otherwise reach the watercourse.

ENVIRONMENTAL BENEFITS

While Darrell's new management strategies have been in place for only two years, remarkable improvements have occurred.

Vegetative diversity and quantity have increased in the riparian area. New grazing practices have increased the native perennial grasses present in the uplands, improvements in forage quality and quantity have benefited wildlife as well as livestock. Increased vegetation has improved water quality.

ECONOMIC BENEFITS

Livestock carrying capacity has increased from 200 to 300 pairs, and weaning weights have increased from 400 to 650 pounds. The partners have achieved a 90 percent calf crop. Hunting of waterfowl, upland game birds, deer and antelope has diversified ranch income.

MONITORING

Darrell monitors livestock performance on a computer spreadsheet that tracks animal performance based on calf crop, calf weight, weaning weights, grazing period in each pasture and length of grazing season. Hunting use is monitored by tracking income derived from users.

Environmental monitoring includes the use of photo points along the creek and vegetation transects in the riparian and upland areas. Seeding trials are being monitored for germination rates based on soil types and seeding rates.

For Darrell, such monitoring is critical. "Our monitoring in the exclosure area shows that we'll need to graze it soon," he says, "but our agency partners won't agree unless we have the numbers to back it up."

Darrell is also involved with a fecal analysis profiling program developed by NRCS and Texas A&M. This new program provides producers with information on feed quality through fecal analysis and helps them determine if supplemental feeding is necessary. The two-year pilot program with which Darrell is involved will provide information regarding diet quality for this region of northeastern California.

FINAL NOTE

Darrell is actively involved in cost-share projects with NRCS and the U.S. Fish and Wildlife Partners for Wildlife program. "These programs have allowed me to make improvements to the ranch that would not be financially feasible otherwise," he says.

Ceci Dale-Cesmat of the NRCS adds, "Darrell's efforts have benefited both his own ranch and the landowners downstream from the project."

THREE CREEKS RANCH

Chet Vogt, Elk Creek, California

The Vogt family has owned the Three Creeks Ranch in Glenn County since 1993. The ranch, which consists of 5,000 deeded acres and an adjacent 6,000-acre property that the Vogts lease, varies in elevation from 900 to 1,500 feet above sea level. Located on the eastern edge of the northern Coast Range, the Three Creeks Ranch receives approximately 20 inches of precipitation annually. The terrain varies from broad, open valleys to steep, brushy hillsides.

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Even in autumn when this creek is no longer running, riparian vegetation flourishes. "This creek wil be in good shape during next year's high water," says Chet.

While the Vogts have owned the ranch for a relatively short time, their management has created tremendous change on the land. Many of these changes have been implemented in partnership with government agencies and nonprofits, both traditional partners like the Natural Resource Conservation Service (NRCS) and nontraditional partners like the California Wildlife Conservation Board and the California Waterfowl Association.

Like many innovators, Chet's ability to think outside of the box of traditional ranch management is often met with skepticism (if not outright opposition) by some neighbors.

"Traditional ranchers really struggle with some of my concepts," explains Chet. "The thought that grazing may be for the benefit of the land rather than the land always being for the benefit of grazing is pretty hard for some to swallow."

HISTORIC MANAGEMENT

For the last 50 years, cattle were turned out onto the Three Creeks Ranch in the fall and gathered in the spring with little or no regard for grazing or grass management. "Overgrazing happens one plant at a time," Chet explains, "and the ranch had become a monoculture through selective grazing." He relates that the ranch was "loaded with medusahead" (an invasive grass that reduces rangeland productivity and health) when he purchased it.

Past grazing management had also allowed livestock to congregate along stream corridors and reservoirs, damaging and destroying sensitive riparian zones.

CURRENT MANAGEMENT

The Vogt family utilizes a base cow herd of 200 mother cows on the ranches year round. With more than 70 paddocks, cattle are rotated every few days depending on grass growth and paddock size. Each paddock is grazed for about 15 days per year, or as Chet likes to say, "each paddock is rested for 350 days per year."

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Vogt studies a perennial bunchgrass that has sprouted through a stand of yellow starthistle.

Chet sees livestock as a tool for restoring the land. By controlling and intensifying grazing time periods and by providing long rest periods following such intensive use, Chet hopes to make the ranch economically and ecologically sustainable. "We plan to increase carrying capacity by increasing forage quality, quantity and diversity, while protecting fragile riparian zones," he says, adding, "we have two growing seasons here – spring and fall, as well as a green dormant season in the winter and a dry dormant season in the summer."

While the growing seasons are the traditional grazing seasons in the area, Chet believes that cattle are a critical tool during the summer months as well. "We manage for the land during the summer," he explains. Chet uses cows during the summer to incorporate seeds and other plant material into the soil and to knock down medusahead.

Three Creeks Ranch calves are born in the spring, weaned in the fall, and carried over to the next spring. Additional stocker cattle are purchased depending on feed conditions.

"Livestock are a tool that can benefit the land."

– Chet Vogt

The management changes outlined below have been accomplished in partnership with NRCS, the California Department of Fish and Game, the Wildlife Conservation Board and the California Waterfowl Association. Monitoring programs have been developed with the Point Reyes Bird Observatory and the National Fish and Wildlife Foundation. "We'd have made these changes on our own," Chet remarks, "but government assistance has sped up the process."

STEWARDSHIP GOAL AND EXPECTED RESULTS

Chet's goal is to "create a landscape diverse in both flora and fauna that allows for maximum harvest of grasses and forbs for livestock." He expects the following results from his management:

- More efficient water cycle through less capped soil, higher plant populations, and expanded perennial grass production.
- More effective mineral cycle because of better incorporation of organic material plus dung and urine into soil through high density grazing.
- Higher energy cycle utilization because plants are in the growth stage for a longer period and are better able to photosynthesize.

INNOVATIONS AND TOOLS

Livestock are run in high density herds with short duration grazing and long rest periods through the creation of many paddocks. According to Chet, cattle learn when it's time to move, making herding them from one paddock to the next extremely easy.

Water systems have been developed for each paddock to provide clean, fresh drinking water while avoiding loitering by cattle in riparian zones along creeks and reservoirs.

Working with the Wildlife Conservation Board, the California Waterfowl Association, the local Resource Conservation District and NRCS, the Vogts have constructed fencing around Mad Creek and Clover Creek as well as around two

large reservoirs. These fenced corridors exclude approximately 130 acres from grazing for most of the year. The corridors are up to one-half mile wide in places, and they are each grazed for short duration (12 to 24 hours) at least once per year by very high concentrations of cattle.

The ranch is fenced and cross-fenced using both barbed wire and electric fencing to provide better cattle distribution. "All of our barbed wire fencing is 'wildlife friendly,' with a smooth wire both top and bottom," says Chet.

Soil erosion is controlled by stabilizing roads. "Put them in once, grade them so that the water runs off as naturally as possible, and then leave them alone," Chet explains, adding that he owns no road grading equipment. Erosion is further reduced by allowing streams to re-vegetate, which stabilizes streambanks.

ENVIRONMENTAL BENEFITS

While Chet admits that many of his management changes are still too new to be able to measure objective improvements, many of the changes are startling:

The re-growth of riparian areas with willows, cottonwoods, redbud, mule fat and other woody plants has provided tremendous foraging and nesting habitat for neotropical birds.

All other types of wildlife (deer, bear, mountain lions, quail, doves, and ducks, to name a few) also benefit from these improved riparian zones. Summertime green feed is an important source of protein for the resident deer herd.

ECONOMIC BENEFITS

Chet acknowledges that he has had to subsidize the management changes on the Three Creeks Ranch with income from other enterprises, but the ranch is now beginning to provide sufficient cash flow to be self sustaining and profitable. Chet has measured these economic benefits:

After many years of declining stocking rates, current stocking rates are higher than they were prior to Chet's ownership.

Since perennial grasses green-up earlier than most annuals, Chet is able to extend his grazing season. This higher quality forage has increased gains per animal, and put cattle on a higher nutritional plane, increasing conception rates.

MONITORING

The Vogts initiated an extensive photo monitoring program upon purchasing the ranch, which vividly demonstrates their progress. In 1998, the Point Reyes Bird Observatory and the National Fish and Wildlife Foundation began monitoring neotropical migratory birds in the ranch's riparian areas. "They feel that these birds are early indicators of habitat recovery and are comparing our restored areas to control areas of traditional grazing," Chet explains.

FINAL NOTE

In Chet's mind, livestock are a tool that can benefit the land. A strong believer in setting management goals for his operation, Chet says, "You've got to know where you want to go."

The marked improvement in rangeland and riparian health on the Three Creeks Ranch indicates that the Vogts are well on their way to getting where they want to go.

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Chet Vogt

Under Chet Vogt's management, native bunchgrasses like this deer grass are making a comeback on the Three Creeks Ranch.

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The Morris family's Holistic Management™ approach uses grazing animals as a tool for achieving a variety of goals, including ecological restoration.

T.O. CATTLE COMPANY

Joe and Julie Morris, San Juan Bautista, California

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The Morris Family: Julie, Joe, Sarah and Jack

The Morris family, owners of T.O. Cattle Company, spend a great deal of time on the road. With grazing operations on four ranches in four counties (San Benito, Santa Cruz, Santa Clara and Monterey), the mileage adds up quickly. Joe and Julie manage approximately 5,500 acres of coastal rangeland comprised of gently rolling to steep annual grasslands, oak savannahs and woodlands, and redwood forest.

The San Benito County ranch, which is part of the Hollister Hills State Vehicular Recreation Area, receives a meager 14 to 16 inches of precipitation in an average year. The ranches in Santa Cruz, Santa Clara and Monterey Counties receive a bit more. Each of the four ranches includes remnant populations of native grasses.

HISTORIC MANAGEMENT

Before the Morris family took over the management of these ranches, they were run as fall calving cow/calf operations. Stocking rates averaged 8 to 12 acres per cow/calf unit year round. Calves were traditionally weaned in June and weighed about 600 pounds.

CURRENT MANAGEMENT

Currently, T.O. Cattle Company owns cows and calves, rents a cow herd from another owner, owns stocker cattle, and runs yearlings for other ranchers. Cows now begin a 45-day calving season in late March. "We set a target for conception rate at 96 percent in 45 days," says Joe, "which we exceeded last year." Heifers are bred at 15 months. Any cows that are not bred are exposed to bulls again in November and December and then sold as fall calving females during the next summer. Calves are weaned onto green grass in December or January (if the weather cooperates), weighing an average of 450 to 475 pounds. Stocker cattle generally gain 275 to 325 pounds and are marketed in June.

The Morris family ties its marketing strategy to the ten-year cattle market cycle. "We try to invest in cows at the bottom of the cycle," explains Joe, "and then sell them at the top." T.O. Cattle Company uses English cross cows and Angus bulls, and has been able to sell yearlings at a premium without using implants. "We're also experimenting with a fledgling direct marketing program," says Julie.

"T.O. Cattle Company uses the Holistic Management™ decision-making process, grazing and animal impact to manage watersheds. We use these tools to improve the effectiveness of the water and mineral cycles while enhancing biodiversity," explains Joe.

The Morris operation uses a holistic grazing plan to time the grazing and animal impact to the recovery needs of the perennial plants. Their grazing plan is adjusted throughout the grazing season to address actual weather conditions, growth patterns and unforeseeable management needs.

STEWARDSHIP GOALS

- Move the lands managed by T.O. Cattle Company to a more complex and stable state of community dynamics using animals to encourage the vigor and proliferation of perennial plants and to maintain organic matter cover on the soil surface.

- Manage watersheds so that intermittent creeks and springs run year round.

- Increase the diversity and abundance of wildlife, again using animal impact and careful planning.

- Produce excellent food for the human community while producing the values outlined above.

INNOVATIONS AND TOOLS

Joe and Julie believe that their management is unique because of their understanding that "rangeland is comprised of the communal values inherent in the capture and storage of water and solar energy." Joe adds, "Our use of the land must simulate the natural processes through which these lands evolved." Annual planning and monitoring are also critical components of their management approach.

To optimize their stewardship of energy, water, air, vegetation, wildlife, and soil, the Morris family has worked to use larger herds of animals with greater control and with as little stress as possible. Using grant funding in 1998, Joe and Julie experimented with high-density short-duration grazing, using a minimum stocking density of 30 pairs per acre.

"We even raised the density to 300 pairs per acre at times," says Joe, "for anywhere from several hours to a day and a half." Post-project monitoring revealed remarkably even utilization of forage, universal litter coverage of the soil surface, and almost no trailing impacts. "Because of the high stocking rate," explains Julie, "we wasted almost no forage, which translates into the ability to run more cattle on the same number of acres."

ENVIRONMENTAL BENEFITS

Even in the short period since the Morris family began its management changes, remarkable improvements are taking place on the land.

Native perennial grasses (purple needle grass, California brome, California oat grass, blue wild rye and creeping wild rye) have proliferated on parts of the ranches, especially in drainage and riparian zones.

Managed grazing has increased biodiversity. These wildflowers are on one of the ranches managed by the Morris family.

JOE MORRIS PHOTO

Coast live oaks, valley white oaks and blue oaks have shown rapid seedling and sapling growth. Natural recruitment has been tremendous.

Riparian areas have experienced recruitment of willows, grasses, sedges and forbs, dramatically improving coverage.

Nutrients from manure and urine, as well as plant litter, are universally dispersed.

Animal impact has opened brush thickets for wildlife access and has maintained chaparral in a succulent, vegetative form edible for wildlife.

The water cycle shows evidence of improvement. Creeks begin to run with water sooner and run longer into the spring and summer. Ponds remain wet longer, and the grass season has extended.

Soil loss is impeded by the near elimination of trailing and by more complete coverage of the soil by plants and litter.

ECONOMIC BENEFITS

According to Joe, "The economic benefits of using Holistic Management™ are, in a word, increased profits."

While moving to spring calving has reduced weaning weights, lower input costs for feed, labor and machinery, coupled with improved reproductive efficiency and forage use, have dramatically improved the bottom line.

Subdividing pastures has improved control over animals and has allowed T.O. Cattle Company to more closely imitate the patterns of wild ungulates. This has allowed for increased stocking rates, producing more pounds of beef per acre.

"The financial planning process has encouraged greater creativity and control. The Holistic Management™ decision-making process has helped us do the things we want to do and produce profit, while elminating the things we don't enjoy and that don't produce profit," Julie explains.

MONITORING

The Morris family monitors its management decisions in two ways. "First," says Joe, "by more or less having a daily presence on our ranches, we ensure that our plan is being implemented and that the outcomes are positive." Second, T.O. Cattle Company monitors permanent transects on each ranch, providing information on the diversity and density of perennial plants as well as soil cover. Finally, the financial plan is monitored regularly and controls are applied as necessary.

FINAL NOTE

Joe and Julie are not shy about sharing their approach when invited. "We host field days at the ranch and participate as a guest speaker at conferences throughout the state," says Joe. "We tell people that there are several reasons for implementing these or similar practices:

- *It's good for you.*
- *It's good for the land.*
- *It's good for the community.*
- *It's good marketing.*
- *It's profitable.*

It's intellectually challenging and emotionally satisfying to learn about and implement better, more sustainable ways to steward our lands. Cattle producers should understand their work in terms of maintaining and enhancing the communal values inherent in the watersheds they manage, as well as producing valuable food and fiber."

Native oaks have responded tremendously to the Morris family's management. The recent growth on this tree shows exactly when management changed.

JOE MORRIS PHOTO

VINA PLAINS PRESERVE

The Nature Conservancy, Tehama County, California

The 4,600-acre Vina Plains Preserve is situated in the northern Central Valley on the eastern edge of the Lassen foothills. The Vina Plains are an undulating, open, treeless grassland dominated by annual grasses. The thin soils are underlain with a hard pan that causes winter rains (20 to 25 inches) to collect in vernal pools. The pools and surrounding grasslands are rich in rare plants, animals, and aquatic invertebrates.

The Nature Conservancy (TNC) owns and manages this preserve as a demonstration cattle ranch. "Our vision," says TNC's Rich Reiner, "is to show that grasslands can be managed for both livestock production and endangered species."

RICH REINER PHOTO

A profusion of wildflowers on the Vina plains.

HISTORIC MANAGEMENT

Vina Plains has been grazed by livestock for over 100 years. As part of the historic Stanford Ranch, it was first grazed by sheep and then cattle beginning in the 1940's. "We acquired a portion of the Preserve in 1982 to protect endangered plant species found in and around the vernal pools," Reiner explains. TNC discontinued grazing in 1986, thinking this was the best way to protect the endangered plants. By 1995, weedy annual grasses had come to dominate the Preserve at the expense of many native plants. Monitoring in 1995 revealed nearly twice as much medusahead on the Preserve as on an adjacent grazed property. Grazing was reestablished in 1996 and an intensive monitoring program begun.

CURRENT MANAGEMENT

The preserve is currently leased to two local cattle operators – one runs a commercial cow-calf operation and the other, a stocker operation. Cattle are grazed on a rotational basis in conjunction with prescribed burning and rest. Pastures are periodically rested to allow grassland bird nesting and for perennial grasses to set seed. Rodenticides are prohibited because bird species, like burrowing owls and raptors, depend on ground squirrels for burrows and food. In partnership with the U.S. Environmental Protection Agency, TNC has been intensively monitoring grazing and its effect on the plant and animal communities at Vina Plains for the past three years in an effort to develop a more fine tuned approach to grazing vernal pool grasslands. An annual workshop is help with local ranchers and government agencies to encourage communication and discuss results.

STEWARDSHIP GOALS

"We are working with partners at Vina Plains to develop and demonstrate range management techniques that are compatible with both

RICH REINER PHOTO

Prescribed fire is an important tool on the Vina Plains.

ranching and the conservation of vernal pool ecosystems," Reiner says. Toward that end, specific resource stewardship goals include:

- Maintaining rare species (plants and invertebrates) populations.
- Improving forage quality and native plant composition.
- Controlling noxious weeds.

INNOVATIONS AND TOOLS

Rotational grazing: Cattle are grazed in a single herd to improve distribution of livestock on the Preserve. Grazing removes annual grass mulch, which if allowed to accumulate would decrease the abundance of native wildflowers.

Prescribed burning: Each year the weediest pasture is selected for burning. Livestock are removed in April to allow fuels to accumulate. The pasture is then burned in the late spring, with the help from the California Department of Forestry Vegetation Management Program, when exotic weed seeds are ready to set. Monitoring has shown that the burns will nearly eliminate medusahead *(Taeniatherum caput-medusae)* and will begin to control yellow star-thistle *(Centaurea solstitialis)*.

University collaborations: TNC encourages academic research on the Preserve. TNC is cooperating with C.S.U. Chico students and faculty on projects that increase understanding of grassland ecology. Professor Rob Schlising completed a study on the demographics of rare vernal pool grasses. Dr. Doug Alexander has studied the vernal pool invertebrates and Jay Bogiatto has been quantifying the use of the Preserve by waterfowl. All of this information helps fine tune the ranch management.

Conservation easements: The Nature Conservancy was able to reduce the cost of purchasing portions of the Preserve by selling a conservation easement to the Natural Resource Conservation Service (NRCS). The Wetland Reserve Program allows private ranches with wetlands such as vernal pools to sell the subdivision and development rights. Because grazing can be a compatible use with wetland protection, the ranch may be grazed for profit after developing a management plan with the NRCS. Private ranchers can also sell conservation easements to nonprofit private conservation groups and to land trusts such as the California Rangeland Trust.

ENVIRONMENTAL BENEFITS

- Protection of endangered grassland and vernal pool plants and animals.
- Improved nesting for waterfowl and grassland birds in pastures deferred from grazing.
- Reduction in weed abundance.

ECONOMIC BENEFITS

While TNC's foremost goal is not monetary, Reiner explains that the organization "feels that the stewardship programs we are advocating are best demonstrated within a economically productive ranch setting." Thus the Preserve leases forage to local ranchers at a competitive rate. "To date our lessees say that the conservation techniques used on the Preserve benefit their operations," Reiner says, adding, "there is also preliminary data indicating that the rotational grazing and burning program is

increasing the abundance of desired forage species." In addition, an ongoing study of cattle fecal nitrogen by Texas A&M and the NRCS indicates that cattle which graze the burned pastures receive higher quality diets than those grazing weedy pastures.

MONITORING

Monitoring plays a critical role in management decisions at the Preserve. Intensive baseline surveys have been completed for the grasslands and all the major vernal pools. The Preserve is systematically monitored annually for both species composition and for the amount of residual dry mater remaining after the grazing season ends. This information is used as part of an "adaptive management strategy" to annually adjust the ranch's management. Monitoring to date has shown a reduction in weeds, an increase in native plants, and higher forage protein in pastures that have been grazed and periodically burned.

FINAL NOTE

"The Vina Plains Preserve is managed as part of a program of the Nature Conservancy called the Lassen Foothills Project," says Reiner. The project's vision is to protect in perpetuity the biodiversity of a large landscape of working cattle ranches in eastern Tehama County. The strategy is to protect this landscape in private ranch ownership, mostly by conservation easements. This year the Nature Conservancy negotiated and purchased an easement over a 36,000 acre working ranch, the largest easement in California history.

A second objective is to help develop sustainable ranching techniques that are compatible with biodiversity protection. Both Vina Plains and Dye Creek Preserves are used by TNC for this purpose.

In 1998, TNC expanded its medusahead burning program onto private ranch lands in the project area and in 1999, with its private and public partners, burned over 6,000 acres of weed infested grasslands. "Our hope is that by working cooperatively with the cattle industry and our neighbors, the Preserve can be used to develop conservation practices that will be viewed as useful for ranchers."

"The project's vision is to protect in perpetuity the biodiversity of a large landscape of working cattle ranches in eastern Tehama County. The strategy is to protect this landscape in private ranch ownership, mostly by conservation easements."

– Rich Reiner

GARY N. GRABBE PHOTO

Wildflowers and vernal pools.

WATERSHED GROUPS

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Top: The SFPUC grazing lessees have completed many fencing projects under the new management plan.

SFPUC grazing lessees, left to right, Bud Nielsen, Paul Banke, Tim Koopman, Russell Fields, Robert Nielsen, Jim Coehlo, Jeff Nielsen, Darrel Sweet and John Cronin.

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THE YAGER/VAN DUZEN ENVIRONMENTAL STEWARDS

Back row, left to right: Graham Cotrell, Denver Nelson, John Rice, Mark Moore, Ron Samuelson, Philo Barnwell, Mel Shuman, Kim Lucas, Sean O'Day, Howard May and Don Tuttle.

Front row, left to right: Gloria Cottrell, Christine Barkdull, Peggy Rice, Dina Moore, Karen Fredrickson, Gloria Barnwell and Jorie Brundy.

While individual ranchers throughout California are using innovative tools to improve ecosystem health and economic viability, others are discovering the strength of working together. These group efforts are generally organized around a watershed or other geographic boundary, or around a specific issue. The following information highlights three rancher-based groups that are addressing economic and ecological issues in California

SAN FRANCISCO PUBLIC UTILITIES COMMISSION GRAZING LESSEES

Alameda and Santa Clara Counties, California
Tim Koopmann, Watershed Resource Specialist

The San Francisco Public Utilities Commission (SFPUC) provides water for more than 2.5 million people – roughly 8 percent of California's population. The commission owns approximately 40,000 acres in the Southern Alameda Creek watershed on the border between Alameda and Santa Clara Counties. These lands encompass about 30 percent of the watershed for SFPUC's storage/distribution reservoirs (San Antonio Reservoir and Calaveras Reservoir). Both SFPUC and its predecessor, Spring Valley Water Company, have leased these lands for grazing for more than 100 years. Currently, 17 lessees graze cattle and horses on more than 32,000 acres.

In addition to providing important water catchment and storage benefits, these lands are home to diverse plant and animal life. Vegetation is predominantly oak grassland with interspersed bay laurels and sycamores. These rangelands are home to black-tailed deer and tule elk, as well as to such endangered and special status species as the California red-legged frog, the western pond turtle, the great blue heron, and the Cooper's hawk. These lands also support the largest population of nesting golden eagles in North America. While the watershed also supports a sizeable feral pig population, efforts are underway to reduce this population due to the ecologic damage it creates.

In 1997, the commission was pressured to terminate grazing on these lands immediately to eliminate the threat of contamination by *Cryptosporidium parvum*, a waterborne organism that can be carried by most warm-blooded mammals and transmitted to humans. People whose immune systems have been compromised are especially vulnerable. Rather than accept the uninformed decision to eliminate grazing on SFPUC lands or take their battle to court, local ranchers sought a wide range of partners to address public health and safety concerns while maintaining grazing operations. On August 22, 1997, a Grazing Management Accord was signed, signaling a new chapter in the history of the South Alameda Creek watershed. The San Francisco Public Utilities Commission, the Alameda County Resource Conservation District, the California Cattlemen's Association, the University of California, San Francisco AIDS activists and the USDA Natural Resource Conservation Service (NRCS) signed the accord, which adapted a Hazard Analysis Critical Control Points (HACCP) approach typically associated with food safety. The plan defined strategies for grazing and feral pig management.

San Francisco's mission for managing the watershed is to provide the highest quality water possible for its urban and suburban customers. The SFPUC seeks to accomplish this by developing, implementing and monitoring its HACCP-based resource management plan. Grazing lessees play a critical role in devising and implementing this plan. Grazing is managed to provide for proper ecosystem function, including management of fire fuel loads.

In addition to protecting water quality and enhancing wildlife habitat, group participants hope that their innovative approach will improve livestock health and rates of gain. Improved stock water distribution should provide for a more efficient pattern of range utilization. More efficient distribution also reduces the need for supplemental feeding. Revised leasing contracts link lease rates with current market conditions, and the SFPUC has developed a strong relationship with its lessees, giving these ranchers an ownership interest in resource-based range management.

YAGER/VAN DUZEN ENVIRONMENTAL STEWARDS (Y.E.S.)

Humboldt County, California
Dina Moore, President

Geologically, California's Humboldt County coast is one of the youngest regions in the state. Steep slopes and average precipitation between 60 and 120 inches per year mean that the north coast's watersheds transport a large amount of water quickly. While the area is generally associated with productive redwood and fir forests, its oak woodlands and open uplands support numerous grazing and browsing animals – both wild and domestic. Yager Creek and the Van Duzen River support steelhead and coho salmon, both of which are protected as endangered species by the National Marine Fisheries Service.

Each of the 16 ranches in these watersheds is privately owned. Most ranchers run commercial cow-calf pairs and some stocker cattle. All of the group's goals are designed to "ensure the environmental integrity of our watershed while maintaining our heritage and the economic sustainability of our endeavors," says Y.E.S. president Dina Moore. Each individual ranch has established its own management and stewardship goals. To be an active member, the group's bylaws require that a ranch or individual have a Rangeland Water Quality Management Plan or any other plan that incorporates best management practices designed to protect water quality.

The group hopes that its efforts to protect water quality on and below their ranches will reduce the need (and therefore the cost) of implementing state and federal water quality and endangered species regulations. In addition to enhancing water quality, Y.E.S. works toward increasing forage production and maintaining or increasing important native grasses – benefiting both wildlife and livestock. The group hopes that the economic benefits of increased forage production, as well as voluntary compliance with regulations will be substantial enough to keep them in business.

"As a group, we have participated in the University of California Cooperative Extension's water quality course and hosted field days," says Y.E.S. president Dina Moore. "We have had goal setting sessions, we are drafting our own best management practices, and we have entertained agencies and politicians." She adds, "We are now more than neighbors, we are proactive partners in resolving natural resource issues from the range up. We love this land and know it more intimately than anyone else. We want to manage this working landscape in a manner that will ensure its sustainability for the next generation."

BRIDGEPORT VALLEY RANCHERS ORGANIZATION

Mono County, California; Hunewill Land and Livestock; Plymouth Land and Livestock; Ascuaga Ranch Company; Lacey Livestock – Point Ranch; F.M. Fulstone, Inc.; Jackie D. Sceirine Ranch

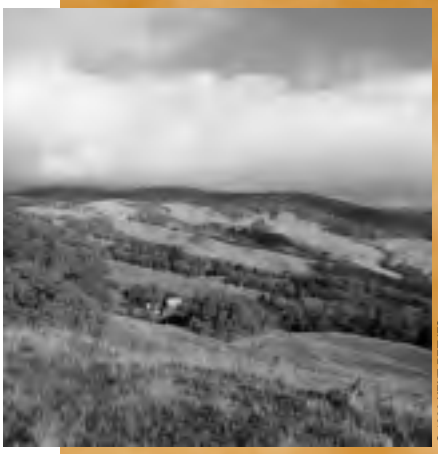
Few places in California are as spectacular as the Bridgeport Valley. Nestled between the sagebrush uplands of the Sweetwater Range and the Bodie Hills and the granite spires of the Sierra Nevada, the Bridgeport Valley was created to grow grass. Situated at 6,500 feet in elevation, the valley floor consists of flood-irrigated pasturelands that support a mixture of native and improved grasses and legumes. Several year-round streams flow through the valley, including the East Walker River, Virginia Creek, Green Creek, Robinson Creek, Buckeye Creek, Aurora Creek and Swauger Creek. The Walker River Irrigation District of Nevada has developed Bridgeport Reservoir in the northern end of the valley. The Twin Lakes reservoirs, above the valley and to the southwest, store irrigation water for valley ranches and provide recreational opportunities to the area's many visitors.

Settled in the early 1860's, the Bridgeport region has provided summer grazing for domestic livestock for more than 130 years. Indeed, most of the ranches in the valley were founded in the 1860's, and at least one ranch is still owned by one of the pioneering families who settled the valley. Today, most ranches include a mix of public and private land and are managed to provide summer range. While individual ranchers vary in their grazing management strategies, most practice some form of rotational grazing. Cows and calves, as well as some stocker cattle, are brought into the valley in May and are shipped out in October.

Obviously, water is a critical resource in the valley – both wildlife and ranchers depend on it. Bridgeport Reservoir and the East Walker River are internationally recognized blue ribbon trout waters, and the valley's waterways are home to a number of migratory duck species. To protect this resource, the Bridgeport Valley Ranchers Organization and individual landowners have implemented an extensive water quality monitoring program. Most ranchers are also working to improve irrigation ditches, stabilize streambanks, improve fencing and enhance vegetation through the use of fire and weed control. While each rancher is working on his or her own Rangeland Water Quality Management Plan, the group works together to monitor the success of their efforts.

While the environmental issues outlined above are important to the group, their concerns go beyond ecosystem health. "This effort is unique," says University of California Cooperative Extension farm advisor Rhonda Gildersleeve, "because each of these ranchers is committed to maintaining the local environment, their ranching heritage, and the economic sustainability of their individual operations."

"In Bridgeport, we use the water over and over as it passes from the higher ranches to the lower lands, so it makes good sense to look at the water quality from the perspective of the whole valley," explains Jeff Hunewill.



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Top: Humboldt County's Van Duzen River drainage.

Looking south from the Bridgeport Valley toward the boundary of Yosemite National Park.

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Bridgeport Valley ranchers, left to right, Stan Hunewill, Todd Sceirine, Jeff Hunewill, researcher Linda Vance and Devere Dressler.

TECHNICAL ASSISTANCE AND COST-SHARE OPPORTUNITIES

Contact the following organizations for technical assistance or cost-share programs:

University of California Cooperative Extension:
Dr. Ken Tate, Watershed Specialist,
(530) 754-8988

Local Livestock and Natural Resource Farm Advisors:
Check Local Listings

USDA Natural Resource Conservation Service State Office:
(530) 792-5502
www.ca.nrcs.gov

California Association of Resource Conservation Districts:
(916) 447-7237
www.carcd.org

Wildlife Conservation Board:
Marilynn Cundiff, (916) 445-1093
Scott Clements, (916) 445-1072

Society for Range Management:
Ceci Dale-Cesmat, President,
(530) 257-7271
www.casrm.org

California Board of Forestry Range Management Advisory Committee:
Tom Randolph, (916) 653-9449

California Cattlemen's Association:
(916) 444-0845
www.calcattlemen.org

California Rangeland Trust:
(916) 444-2096
www.rangelandtrust.org

California Farm Bureau Federation:
(916) 561-5500
www.cfbf.com

The Nature Conservancy:
(415) 777-0487
www.tnc.org

Sierra Nevada Alliance:
(530) 542-4546,
www.sierranevadaalliance.org

TOOLBOX

	BLANCHARD RANCH	BYRNE BROS. RANCH	FORD RANCH	FORT BAKER RANCH	MCDONALD RANCHES	PETE'S VALLEY RANCH	THREE CREEKS RANCH	T.O. CATTLE COMPANY	VINA PLAINS PRESERVE	GROUP EFFORTS
Rotational grazing.	X	X	X	X		X	X	X	X	X
Offstream water development.	X	X		X	X		X	X		X
Brush and woody vegetation control/removal.	X	X			X	X				
Rangeland Water Quality Management Plan or other management plan in place.	X	X	X	X	X	X	X	X	X	X
Riparian restoration	X	X	X		X	X	X	X		X
Controlled burning program.				X					X	
Native perennial grass restoration.	X	X	X	X		X	X	X	X	
Conservation Easements									X	

PARTNERS

	BLANCHARD RANCH	BYRNE BROS. RANCH	FORD RANCH	FORT BAKER RANCH	MCDONALD RANCHES	PETE'S VALLEY RANCH	THREE CREEKS RANCH	T.O. CATTLE COMPANY	VINA PLAINS PRESERVE	GROUP EFFORTS
Natural Resource Conservation Service		X				X	X			X
U.C. Cooperative Extension		X		X	X		X			X
Research Institutions									X	X
U.S. Fish and Wildlife Service		X				X			X	
U.S. Forest Service		X								
U.S. Environmental Protection Agency									X	X
Bureau of Land Management										
California Department of Fish and Game			X							
Wildlife Conservation Board							X			
California Department of Forestry and Fire Protection									X	
California Department of Parks and Recreation								X		
Resource Conservation Districts										X
Private Foundations								X		

PROJECT MANAGEMENT

This project was managed by Dan Macon of AgResource Solutions, a rural-based firm dedicated to enhancing the economic and environmental sustainability of ranching and farming. ARS provides conflict resolution services, organizational and project management services and diversification planning for landowners, businesses and organizations.

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ANALYSIS

The economic value of wetland services: a meta-analysis

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Abstract

The number of studies quantify the value of wetlands and the services provided by these ecosystems is rapidly expanding. The time is ripe for an assessment of what has been learned from this literature. Using results from 39 studies, we evaluate the relative value of different wetland services, the sources of bias in wetland valuation and the returns to scale exhibited in wetland values. While some general trends are beginning to emerge, the prediction of a wetland's value based on previous studies remains highly uncertain and the need for site-specific valuation efforts remains large. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

The valuation of wetlands' ecological services is a relatively recent phenomenon. Historically, wetlands were viewed as a waste of valuable land that could only be 'improved' through drainage and destruction of the wetland (Mitsch and Gosselink, 1986). Today, while there is now widespread recognition that wetlands provide valuable ecological services, there remain substantial debates over whether particular areas are in their highest economic use as wetlands, and to what extent public and private resources should be used for their protection and restoration. Hence, there is a growing need to quantify the value of wetland services.

The services provided by wetlands include habitat for species, protection against floods, water purification, amenities and recreational opportunities. Because these services typically have no market price, a measure of their values can only be obtained through non-market valuation techniques. Many wetland valuation studies have been conducted and the range of the estimates is remarkable. A recent review by Heimlich et al. (1998) lists 33 studies over the last 26 years with per acre values ranging from US$0.06 to US$22050. Even within the same study looking at a single ecosystem function, Batie and Wilson (1978) find values per acre that differ by two orders of magnitude from one site to another.

The purpose of this paper is to assess whether any systematic trends can be distilled from the

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breadth of wetland valuation studies conducted to date, and to shed light on what factors determine a wetland's value. We maintain an assumption that there exists an unobserved valuation function that determines a wetland's value given its physical, economic and geographic characteristics. After reviewing 46 studies, data from 39 wetland valuation studies were identified that had sufficient commonalties to allow inter-study comparisons. We used two techniques to learn about the valuation function, both of which can be broadly described as meta-analysis since many studies are used to identify general relationships. The first method that we employ uses bivariate graphical and standard techniques. This gives us both an indication of the extent to which particular characteristics influence wetland values while also portraying the full distribution of the data. The second technique is more standard, using a multivariate regression of wetland values on the characteristics of both the wetlands and the studies. Together, these two techniques provide a richer basis from which we can draw lessons on the factors determining wetland value.

There are numerous reasons why understanding the value of wetland services might be useful. The most obvious is that if the value of these services were known, benefits transfer efforts could be substantially improved. As Deck and Chestnut (1993) point out, benefits transfer may play a variety of different roles, ranging from an attempt to place a precise value on a particular resource to providing information that feeds into the process of building support for projects already implemented. While benefits transfer is rarely suitable for the former case, it might often be appropriate for the latter. Another form of benefits transfer is the use of estimated values to predict the aggregate value of similar systems nationally or globally. Such estimates can be useful in setting national priorities or the evaluation of policies with impacts that are national or global. Costanza et al. (1997), for example, placed a value on the entire globe's ecosystems. While such expansive efforts may be overambitious, the aggregate numbers do help to get the attention of policy makers and the public.

Estimates of the value of a wetland can also influence site-specific valuation efforts in two ways. First, they might provide Bayesian priors that might be formally incorporated into the valuation exercise. Secondly, they may give researchers a sense of where the values at stake are likely to be of greatest social importance and might, therefore, influence where detailed studies are carried out.

The paper is organized as follows. In the next section we provide a brief overview of the economics of wetland valuation. We survey the ecological functions and economic services provided by these areas, the basis for their valuation and the techniques that are used to place an economic value on wetlands. Section 3 provides a brief summary of meta-analysis as a tool. In Sections 5 and 6 we explore the trends in the data, identifying the sources of variability in wetland values. We conclude by reflecting on the implications of our analysis both for our understanding of wetland values and for future research.

2. The value of wetland functions

2.1. Wetland functions and services

While an inclusive definition of wetlands is difficult to state, they are generally characterized as being moist during an extended period each year with soils, plants and animals that are distinct from their aquatic and terrestrial neighbors. These transition areas are highly diverse, ranging from coastal mangroves that are inundated with water most of the year to areas that are moist for only a few months during the year. Partly because they share features of both terrestrial and aquatic systems, wetlands are remarkably productive.

In assessing the value of wetlands, it is useful to distinguish the systems' ecological functions from the associated services that are directly valued by humans (Costanza et al., 1997). Larson et al. (1989) list 17 services and functions provided by the world's ecosystems (Table 1). In our data set, the services were grouped into ten categories as indicated in the table. The measurement of the value of these services varies substantially both in

Table 1
Wetland functions, the associated economically valuable goods and services and the names of variables that capture the presence of these in the data[a]

Function	Economically valuable good(s) and/or service(s) (variable names)	Technique(s) typically used to quantiiy the value of the service(s)
Recharge of ground water	Increased water quantity (quantity)	Net factor income or replacement cost
Discharge of ground water	Increased productivity of downstream fisheries (com.fish)	Net factor income, replacement cost or travel cost
Water quality control	Reduced costs of water purification (quality)	Net factor income or replacement cost
Retention, removal and transformation of nutrients	Reduced costs of water purification (quality)	Net factor income or replacement cost
Habitat for aquatic species	Improvements in commercial and/or recreational fisheries either on or offsite (com.fish and rec.fish). Nonuse appreciation of the species (habitat)	Net factor income, replacement cost, travel cost or contingent valuation
Habitat for terrestrial and avian species	Recreational observation and hunting of wildlife (birdwatch & birdhunt). Nonuse appreciation of the species (habitat)	Travel cost or contingent valuation
Biomass production and export (both plant and animal)	Production of valuable food and fiber for harvest (birdhunt & com. fish)	Net factor income
Flood control and storm buffering	Reduced damage due to flooding and severe storms (flood)	Net factor income or replacement cost
Stabilization of sediment	Erosion reduction (storm)	Net factor income or replacement cost
Overall environment	Amenity values provided by proximity to the environment (amenity)	Hedonic pricing

[a] The first two columns are adapted from Larson et al. (1989).

the methods that are used and the economic theory that underlies the valuation exercise. The most common methods for measuring the economic value of these services are also presented in the table. Though not indicated in the table, the contingent valuation method can, in principle, be used to measure the value of all these services.

2.2. The valuation of wetland services

The economic value of resources such as wetlands is equal to the benefits (net of costs) that these systems provide to humans (Freeman, 1993). Four methods are listed in Table 1 as commonly used to place a value on wetlands. The net factor income (NFI) method is most appropriate when the wetland provides a service that leads to an increase in producer surplus. In the NFI method the physical relationship between wetland area and the economic activity is estimated. It is then possible to identify the increase in producer surplus associated with the wetland's area. In practice, it is often assumed that demand is perfectly elastic so that the impact of the wetland on consumer surplus can be ignored. Other times the producer surplus that is generated by a wetland is estimated using the replacement cost (RC) method. This approach values the wetland's service based on the price of the cheapest alternative way of obtaining that service. For example, the value of a wetland in the treatment of wastewater might be estimated using the cost of chemical or mechanical alternatives. As noted by Anderson and Rockel (1991), the replacement cost method is actually an upper bound on the true value since the producer may not choose to actually use that alternative considered.

Non-market values can be measured using travel cost (TC), contingent valuation (CV), or hedonic pricing (HP) methods. There is, however, substantial variability within each of these approaches, much more than can be discussed here (Freeman, 1993), and the literature is filled with reasons why results might be biased or otherwise

deficient. While in principle each method can give a correct estimate of economic value, it is easy to misuse the method and obtain results that may have little relation to the true value.

Some wetland values are obtained using methods that do not estimate economic surplus and, therefore, lack a foundation in standard economic theory. Of the studies identified in our review of the literature, two values were estimated using energy analysis in which the value is based on the gross primary production of the ecosystem, and five values were obtained using the market value of the products extracted. These methods have been strongly criticized (Anderson and Rockel, 1991). Energy analysis equates the energy embodied in a wetland's biota with the energy purchased in fossil fuels. Since the correlation between energy content and consumer preferences is quite weak, the technique is a poor predictor of economic value. The market value technique is also flawed since it cannot capture consumer surplus and can lead to over-estimate producer surplus if cost of extracting the valued products is not subtracted.

3. Meta-analysis as a tool in understanding non-market valuation

First used by psychologists (Glass, 1976; Schmidt and Hunter, 1977), meta-analysis has proved to be a useful tool for synthesizing the results of numerous studies. The method has recently gained attention in economics as a way to appreciate numerous studies that have placed economic values on environmental goods and services (see Brouwer (2000) for a review). The central advantage of meta-analysis is that it provides a rigorous statistical synthesis of the literature that cannot be achieved using more qualitative analysis.

There are two main types of meta-analyses: those that use the actual data from multiple studies, and those that use the results of multiple studies. It is the later method that has been applied to interpret valuation studies. Brouwer lists ten studies that have used meta-analysis to study valuation efforts. Smith and Kaoru (1990) were the first to use meta-analysis in the context of nonmarket valuation, looking at values placed on outdoor recreation. Since then, meta-analysis has been used to study air pollution, recreational fishing, visibility, health risks, endangered species and wetlands.[1]

The basic approach used in most valuation meta-analyses is the same. A set of studies is selected yielding a number of values that become the dependent variable. The independent variables are the characteristics of each study and study site. If a single study reports numerous values, then several data points are obtained. Meta-analysis allows the evaluation of the effect of changes in the underlying environmental attribute on value. Such analysis is usually not possible in the context of a single study since most such attributes are held constant.

A good example of the benefits of meta-analysis is seen in Smith and Osborne's (1996) analysis of the value of improvements in visibility. Since visibility varies continuously from zero to one, the authors are able to estimate the marginal benefit of improvements in visibility. One of the most significant limitations of meta-analysis, however, is the lack of comparability across studies (van den Bergh and Button, 1997). Characteristics of the resource being valued are often presented in such diverse fashion that the best that the analyst can do is to use a binary variable to indicate whether an attribute is reflected in each value. Boyle et al. (1994), for example, have no data on the level of cancer risk in each of their eight studies, only an indication of whether such a risk was mentioned in the study. Similarly, in this study wetland services are captured using qualitative variables.

Brouwer et al. (1997) is, to our knowledge, the only other attempt to carry out meta-analysis of wetland valuation studies. In their work, only contingent valuation studies are considered. This narrow focus allowed the authors to develop a

[1] The analysis of wetlands by Brouwer et al. (1997) looked at WTP estimates from CV studies and used a more expansive interpretation of 'wetlands' than we retain in this paper. Hence, their results are not directly comparable to the results here.

rich set of variables characterizing the qualities of the studies. However, this is also a limitation in that it eliminates any variability associated with valuation method and reduces the variability in services that can be considered. In the next section we discuss how we attempted to overcome these limitations in our data.

4. The wetland valuation data

After a lengthy review of the literature, we identified 39 studies that contained sufficient data to allow inter-study comparisons. Many other studies were identified but could not be used. The values are taken from published reports, 'gray' literature, and theses.[2] Because of our desire to synthesize wetland values from all different services, we use annual value per acre in 1990 US dollars. This distinguishes our work from other meta-analyses which typically use willingness to pay (WTP) per person (e.g. Brouwer et al., 1997). WTP per person is not applicable here because some methods (e.g. NFI) do not lead to a WTP per person measure. On the other hand, if WTP per person is available, then value per acre can be calculated with knowledge of the relevant population and the wetland's size. When capitalized values were reported, they were annualized assuming constant value per year and using discount factors provided in the studies or a 6% rate in the two studies that did not state a discount rate.

In our analysis we assume that a wetland's value is a function of the system's ecological characteristics and its socio-economic environment. Each wetland in our data is interpreted as a (not necessarily random) draw from the population of all wetlands. We assume that there exists a true public WTP at a given moment for a particular wetland. While this true WTP cannot be observed directly, it can be estimated using the methods discussed above. Seen in this way, there are two sources of variability in the wetland values: variation due to differing characteristics of the wetlands, i.e. along the function; and variation due to error in the estimation of the true value, i.e. deviations from the function.

Of course, the wetlands that have been valued were almost certainly not chosen at random from the total population. First there is the problem of selection bias. It seems likely that wetlands that are considered valuable a priori are much more likely to be studied and valued. This need not lead to errors in our estimation of the valuation function if all important variables are accurately measured, but given the limitations in the available data, the likelihood of such bias should be taken into account in benefits transfer exercises or any other attempt to extrapolate estimated values. Similarly, the fact that many of the studies have been filtered by the peer review process might have excluded some estimates. Good estimates that are either not statistically different from zero or are much higher than anticipated may not be published.

The values in our data are also not independent draws. Numerous studies generate multiple measures of wetland value, so that, as pointed out by Smith and Kaoru (1990), the data have panel characteristics. Furthermore, researchers who work closely together are likely to share practices that differ in important ways from others. Finally, since there has no doubt been learning over time, both in terms of methodology and the values that are reasonable, the data also probably suffer from some autocorrelation.

5. Bivariate meta-analysis

Using the available data, we now evaluate the sources of variation in estimates of wetland value. Two complementary techniques are used. In this section we explore some of the relationships in the data using graphical presentation and bivariate statistics. The advantage of this analysis is that it allows us to present the full data set graphically, making possible a richer appreciation of the data. However, the bivariate analysis ignores interactions between explanatory variables. Hence, a second and more standard technique is also used,

[2] The complete data set, including a description of each study and an explanation of the interpretations of the data that were made is available from the authors on request or via the internet at http://ageco.tamu.edu/faculty/woodward/.

that of estimating a valuation function using multivariate regression techniques.

5.1. Variation due to measurement error or bias

As noted above, there are two types of variation with which we are concerned, deviations from the valuation function due to bias or errors in estimation, and variations along the valuation function attributable to different wetland characteristics. We begin by looking at sources of systematic error because of study weaknesses and bias because of the valuation method used.

One might expect study quality to affect estimates of wetland value. Attention to this issue is potentially important because there is substantial variability in the quality of wetland valuation studies. While some studies are characterized by sound theoretical foundations and state-of-the-art econometric methods, others are crippled by faulty logic, poor data or incorrect economic analysis.

The weakness of many wetland valuation efforts is widely recognized. In their review of wetland valuation studies, Anderson and Rockel (1991) found only five studies that they deemed credible enough to list in their summary table. However, while it may appear obvious that only high quality analyses should be used in meta-analysis, it is also clear that the evaluation of quality is likely to be quite subjective. The problem of subjectivity is particularly problematic in wetland valuation studies because few efforts satisfy the highest standards of quality, in large part because of data limitations. In CV studies, for example, strict adherence to the guidelines of the NOAA panel (Arrow et al., 1993) is often impossible because of budgetary restrictions. Hence, there is a great deal of subjectivity in assessing how good is good enough.

As Cooper (1989, p. 67) points out, "The decision to include or exclude studies on an a priori basis requires the reviewer to make an overall judgment of quality that is often too subjective to be credible." He argues that it makes more sense to enumerate characteristics of each study and then evaluate whether 'good' methods lead to different results than 'bad' methods. "When no difference is found it is sensible to retain the 'bad' studies because they contain other variation in methods (such as different samples and locations) that, by their inclusion, will help answer many other questions surrounding the problem area."

Following Cooper's advice, some meta-analyses include objective indicators of study quality such as response rate or study format (Brouwer et al., 1997; Loomis and White, 1996). Given the diversity of studies considered in our analysis, no standard objective indicator of quality was available; only a subjective assessments of study quality could be used. Each study was ranked on a scale of 1–3 in four categories: the apparent quality of the data, the theoretical consistency of the methodology, econometric techniques and statistical certainty. A study was given a rank of 1 if we felt that this feature of the study made the results highly questionable. Studies with a 1 in any of the quality categories are called 'weak' in the figures and econometric analysis below.[3] A 'weakness' in a study should not be interpreted as a condemnation since valuation may not have been the authors' primary objective or data limitations may have been prohibitive.

On average, the weak and strong studies do not yield statistically different values. Excluding the highest value in our data set, the average of the weak studies is US$986 per acre versus US$915 for the strong studies.[4] When looking at the complete distribution of these studies however, there do appear to be some systematic differences two sets of values. Fig. 1 plots the rank of both the weak and the strong studies in their respective

[3] For studies that are also evaluated by Anderson and Rockel (1991) our critique was generally consistent. Some studies which we ranked as a 2 were questioned, but did not appear to be completely rejected by Anderson and Rockel.

[4] The highest value from the Amacher et al. (1989) study is excluded as it is over 60 times the second largest value. After excluding this value, the mean of the weak studies is not significantly different from the mean of the strong studies at the 10% level. This value, one other value estimated using energy analysis and five values estimated using the market value of the output are excluded from the econometric analysis below.

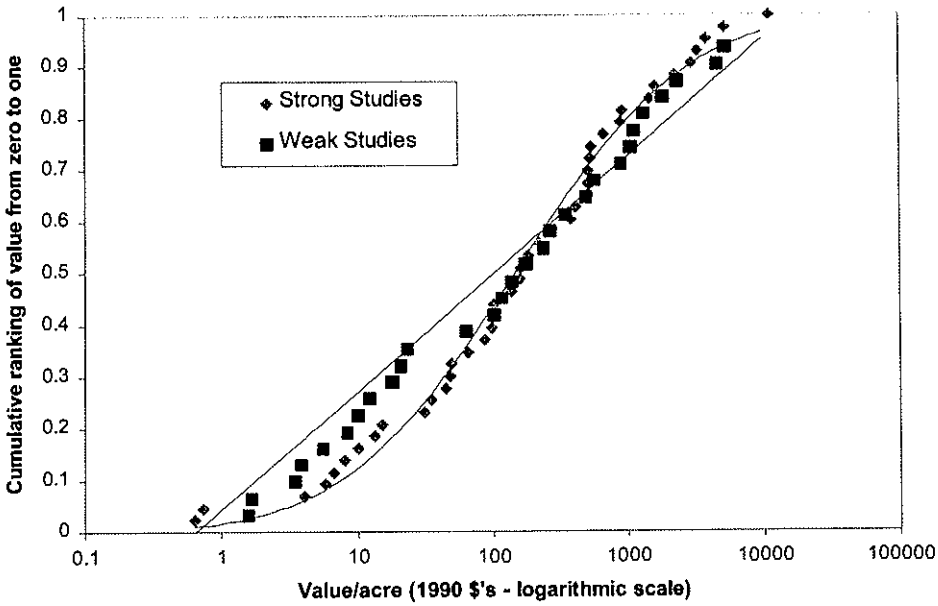

Fig. 1. Cumulative distributions of wetland values broken down by study quality.

categories on the vertical axis, against the estimated values per acre on the horizontal axis. The solid lines in the figure represent cumulative distribution functions (cdfs) of distributions from which the data appear to be drawn. While the distribution of the strong data closely resembles a log normal distribution, the weak data seem to be drawn from a uniform distribution. There is also slightly less variance in the strong studies, indicating that the lack of quality may not bias the estimated value, but it might have implications for the accuracy of the predictions. This result is confirmed in the multivariate analysis below. Nonetheless, we do not find the kind of dramatic difference between the two groups that would justify discarding the weak studies from the data set.

Another potential reason that the estimated value may deviate from the valuation function might be bias due to the method that was used in the study. In principle, if two methods seek to estimate consumer surplus from the same wetland then they should yield similar values. If there is no systematic difference between two techniques, then they are said to satisfy the criterion of convergent validity. Numerous studies have tested the convergent validity of CV analysis relative to other methods (e.g. Carson et al., 1996).

Fig. 2 presents the distributions of the values taken from the four primary methods used to measure wetland values. The means of the values from these methods vary from a low of US$198 for the travel cost method to a high of US$1555 for the replacement cost method. However, because of the substantial variability in the data, none of the means are statistically different from each other. Still, some patterns are evident. At one extreme, the net-factor input method is a lower bound on the distribution of values. At the other extreme, the distribution of values obtained using CV nearly stochastically dominates the distributions of values from the other three methods. These findings do not necessarily indicate biases in these techniques. Because of the small sample size we cannot statistically reject the hypothesis that the distributions are the same. Moreover, different methods are used to value different services. It may be that CV is used for high-value services while the NFI method is used for low-value services. Hence, the question of whether the method itself is a source of bias can only be explored using multivariate analysis.

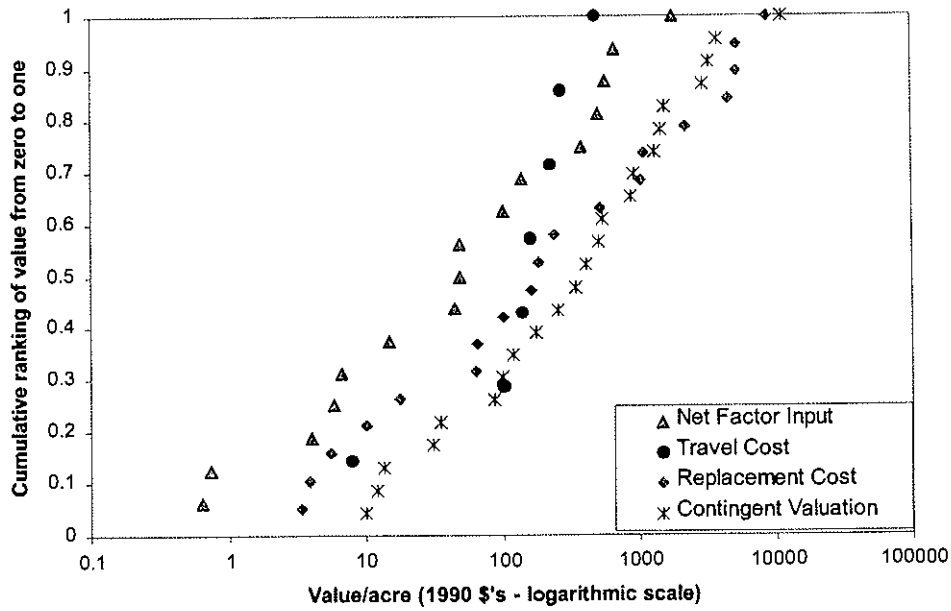

Fig. 2. Cumulative distributions of wetland values broken down by valuation method.

5.2. Variation in value due to wetland characteristics

We now turn an initial analysis of the sources of variation in the valuation function. Ten variables were defined indicating whether a particular wetland service was reflected in each study. These are listed in Table 1. Identifying the services reflected in a study often involves some subjectivity, particularly in CV studies since respondents might be aware of services other than those about which they had been explicitly asked in the survey.[5]

A relatively weak hypothesis would be that increasing the number of services considered in a valuation exercise would tend to increase a wetland's estimated value. This relationship is presented in Fig. 3. While almost two-thirds of the studies measured the value of only one wetland service, more than 30% of the studies measured three or more services. Contrary to our hypothesis, there is no noticeable relationship between the value of a wetland and the number of services valued. The correlation between estimated value per acre and the number of services is only 0.10 and, based on the Spearman rank criterion, the hypothesis of no correlation cannot be rejected at the 10% level.

In addition to being affected by wetland services, one might also expect the value per acre to be a function of the wetland's area. In this case there is no clear a priori expectation as to the form that such a relationship might take. Economic intuition would suggest that the marginal value of each acre would tend to decline. On the other hand, based on ecological principles of functional interdependence, one might expect that larger wetlands would provide a richer and more valuable set of services. This relationship is plotted in Fig. 4. There is no apparent relationship between wetland area and value in the figure and, once again, the hypothesis of no significant correlation cannot be rejected at the 10% level.

Our analysis to this point is quite inconclusive. There is some evidence that CV studies tend to yield greater values than any other method, but no visible relationship between value per acre and either the number of services or the size of the wetland. However, while we find the bivariate

[5] In a few instances authors were contacted to assist us in obtaining the most accurate interpretation possible.

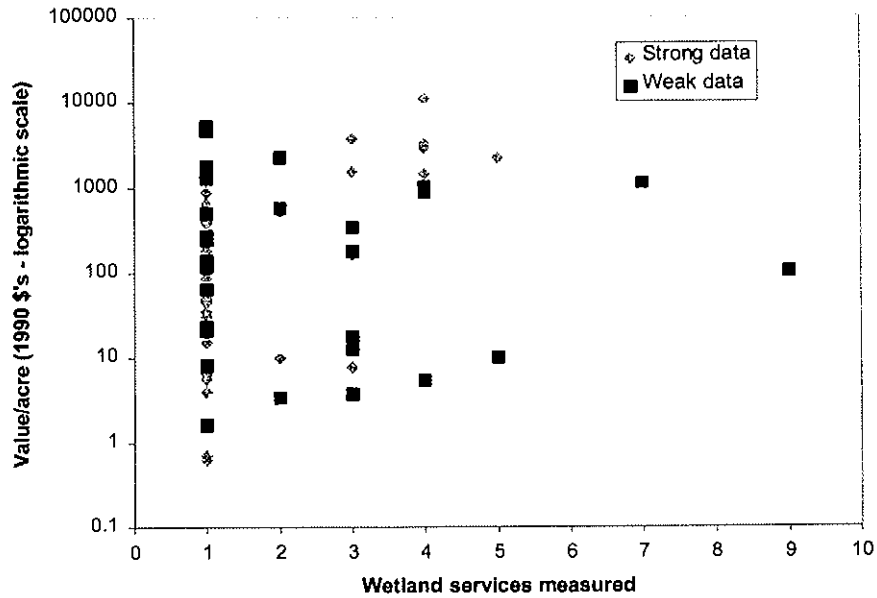

Fig. 3. Wetland values and the number services present.

analysis useful, it cannot distinguish how multiple factors might be interacting to influence wetland value. In the next section we attempt to tease out more understanding of the wetland valuation function using multivariate regression analysis.

6. Multivariate meta-analysis of wetland values

In this section we estimate a parametric specification of the valuation function using the data discussed above. After excluding incomplete observations and values based on either energy analysis or the market value methods, the 65 observations of wetland values were obtained.

6.1. The estimated model and results

The dependent variable in all regressions is the natural log of the value per acre of wetland converted to 1990 dollars, the mean of which is 4.92. In addition to the variables discussed above representing services, area and study quality, we included variables indicating date of the study (1960 = 0), year; whether the wetland was a coastal wetland, coastal; whether the value was an estimate of producer's surplus, PS; and whether the results had been published, published. The variables data0, theory0 and metric0, are dummy variables set at one if the data, theory or econometrics used in the study were deemed highly questionable.[6]

We should recognize that there are certainly important variables that determine a wetland's value that are omitted from our model. Characteristics of the population near a wetland are particularly likely to influence the value placed on the area. However, such data could not be identified in most of the studies; we were unable to include any such variables in our model. While the absence of these variables no doubt greatly diminishes the explanatory power of our analysis, it need not bias the estimated coefficients if these variables are uncorrelated with the included set (Kennedy, 1986).

Our econometric model is based on a maintained hypothesis that measured wetland value

[6] Since only two studies were deemed weak based on statistical significance, and many studies did not report sufficient information to gauge the statistical accuracy of their estimates, this variable was excluded from the econometric analysis.

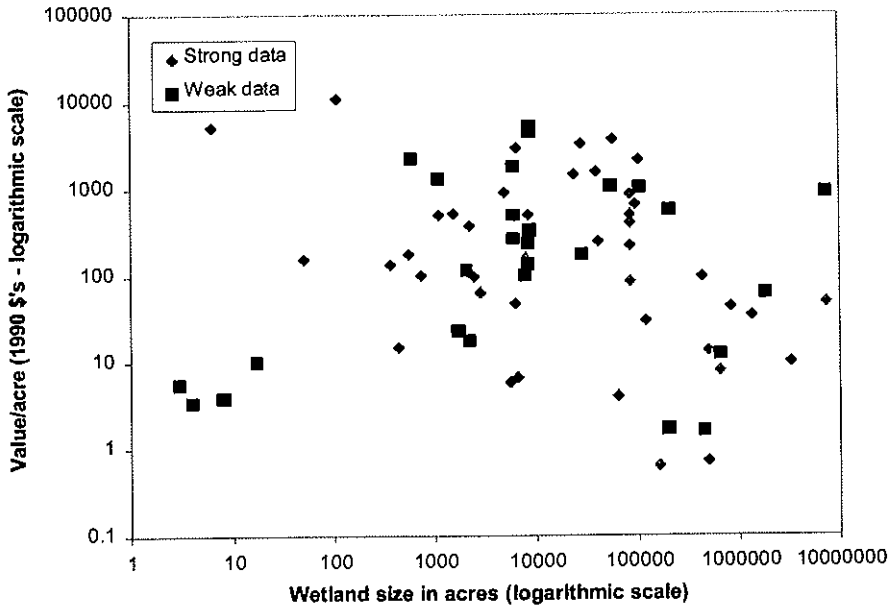

Fig. 4. Wetland area and values.

per acre, y, is a function of the services provided, $\mathbf{x}_s$, the methodology used, $\mathbf{x}_m$, the acres of the wetland x_a, other variables describing the study including year and location, $\mathbf{x}_0$, and a constant term. The fit was substantially improved by using the logs of both the per-acre value and the acres. Hence, the estimated linear model is

$$\ln(y) = a + b_a \ln(x_a) + \mathbf{b}_s'\mathbf{x}_s + \mathbf{b}_m'\mathbf{x}_m + \mathbf{b}_0'\mathbf{x}_0 \qquad (1)$$

where a is the constant term and the b's are the estimated coefficients on the respective explanatory variables.

The results of several regressions are presented in Table 2. In each case the hypothesis of homoskedasticity was rejected at the 5% significance level using the BPG test. Accordingly, the standard errors were estimated using White's (1980) correction. Model A presents the estimated coefficients of a model in which it is assumed that the variability in the values is solely a function of the physical characteristics of the wetland systems, ignoring any systematic variation due to the way that the values were estimated. Model B takes the opposite approach, explaining the values based solely on the methods used to measure those values and the quality of the studies. Model C combines both the characteristics of the sites and variables related to how the values were estimated.

6.2. Do the study quality or valuation method affect the value obtained?

In our discussion of Fig. 1 we argued that there was little evidence of bias as a result of the quality of the studies, and our regression results largely confirm that conclusion. The coefficients on the variables indicating poor quality theory and data are both statistically insignificant, as is the coefficient indicating whether the study was published. However, the variable indicating econometric quality was strongly significant in both regressions B and C. Holding all else constant, the values from studies with poor quality econometrics average 24–50 times greater than those from those with comparatively strong econometric foundations.

Study quality also has important consequences for the confidence we place on predicted values. Using the results from model C evaluated at the

Table 2
Estimated models of the wetland valuation function[a] (log of value per acre dependent variable, standard errors in parentheses)

Variable	Mean	A	B	C
Intercept		7.945[b]	6.641[b]	7.872[b]
		(1.07)	(1.31)	(1.74)
Year	14.908	−0.052	−0.004	0.016
		(0.03)	(0.04)	(0.04)
Ln acres	9.281	−0.168[c]		−0.286[b]
		(0.10)		(0.11)
Coastal	0.431	−0.523		−0.117
		(0.71)		(0.68)
Flood	0.138	−0.358		0.678
		(1.03)		(0.77)
Quality	0.200	1.494[c]		0.737
		(0.78)		(0.75)
Quantity	0.062	0.514		−0.452
		(1.60)		(1.54)
Rec. Fish	0.354	0.395		0.582
		(0.55)		(0.56)
Com. Fish	0.277	0.669		1.360
		(0.79)		(1.01)
Birdhunt	0.400	−1.311[b]		−1.055[b]
		(0.49)		(0.52)
Birdwatch	0.277	1.704[b]		1.804[b]
		(0.52)		(0.59)
Amenity	0.154	−3.352[b]		−4.303[b]
		(0.93)		(0.95)
Habitat	0.308	0.577		0.427
		(0.56)		(0.59)
Storm	0.031	0.310		0.173
		(2.37)		(1.66)
Publish	0.769		−0.669	−0.154
			(0.72)	(0.71)
Data0	0.246		0.302	0.000
			(0.56)	(0.60)
Theory0	0.215		−1.020	−1.045
			(0.84)	(0.84)
Metric0	0.123		−4.030[b]	−3.186[b]
			(1.21)	(1.22)
PS	0.277	−2.416[b]	−2.034[b]	−3.140[b]
		(0.83)	(0.72)	(0.86)
HP	0.031		0.441	5.043[b]
			(1.02)	(1.12)
NFI	0.246		−0.724	0.273
			(0.82)	(0.90)
RC	0.277		1.376	2.232[b]
			(0.86)	(0.89)
TC	0.108		−1.196[c]	−0.341
			(0.64)	(1.05)
n	65	65	65	65
R^2		0.373	0.364	0.582

[a] Standard errors were calculated using White's (1980) correction for heteroskedasticity. All results were obtained using Shazam version 8.0 (White, 1997).

[b] Significantly different from zero at the 5% level.

[c] Significantly different from zero at the 10% level.

means of the variables the log of the wetland value predicted for a high-quality unpublished study is 5.68 with a standard error around the prediction (σ_p) of 0.61. If it is assumed that the study is published, however, σ_p falls to only 46% of the original value. For studies that are weak in the areas of theory or econometrics, σ_p increases by 1.9 or 2.1-fold, respectively. On the other hand, the impact of study's data being of poor quality is slight, leading to a 4% decline in σ_p.[7] Study quality is important not so much because it might bias results, but because high quality studies lead to a much more precise basis for prediction.

There is some evidence that the method used has a statistically significant effect on the value obtained. As in Fig. 2, in model B we find that CV tends to dominate other methods as the signs on their coefficients are either negative or statistically insignificant. However, when variables indicating the wetland services are introduced in model C, the dominance of CV disappears and the sign on HP and RC methods becomes significantly positive. Hence, relative to these methods, CV studies tend to find a lower value per acre and we cannot conclude that this method is biased relative to the TC or NFI method.[8]

6.3. Do wetlands values exhibit returns to scale?

The coefficient on LnAcres is consistently negative and statistically significant across the models reported in Table 2, indicating significant decreasing returns to scale. However, because of the double-log functional form, the scale effect is extremely small for large wetlands. From Eq. (1), the marginal effect of an increase in the size of a wetland is

$$\partial y/\partial x_a = a_a x_a^{(a_a - 1)} e^{(a_0 + a_s \cdot x_s + a_m \cdot x_m + a_0 \cdot x_0)}$$

[7] The predicted values and standard errors around the predictor were calculated following Goldberger (1991, p.175).

[8] The coefficient on the HP method should be interpreted with extra caution since it reflects only two studies in the data set that used this method.

While a negative value for a_a means that an increase in the size of a wetland pushes down the value per acre, this effect diminishes rapidly as wetland size increases. Using the coefficient from model C, a 1% increase in area leads to a 2.9% fall in value for a ten-acre wetland. This effect declines geometrically, and for a wetland of 1000 acres the elasticity is only −0.029. This confirms what we see in Fig. 4 where wetland area appears to have little impact on value per acre.

6.4. How do wetland services affect wetland value?

The final and central question that we seek to answer is how wetland services influence wetland value. The coefficients on the wetland service variables are estimates of the extent to which the presence of each service changes the value per acre. A very small coefficient on the habitat variable, for example, does not mean that this service has no value, but that the value of wetlands that provide this service are very close to the average value for all wetlands.

Most of the wetland service variables are not statistically significant. In models A and C, only the coefficient on the birdwatch variable is significant and greater than zero while those on the birdhunt and amenity variables are significant and less than zero. Hence, the data indicate that a wetland that provides bird watching opportunities is more valuable than the average wetland, while those that offer bird hunting or amenity services are less valuable.

As one would expect, based on the explanatory variables in the model, only very imprecise predictions of wetland values are possible. Using the estimates from model C, Table 3 presents the predicted values per acre for each possible single-service wetland and 90% confidence intervals around those estimates.[9] Some strong conclusions can be drawn from the results. Looking not only at the mean, but at the upper and lower bounds of the confidence interval, bird watching and commercial fishing services are among the highest three valued services while amenity services are the least valued among all wetland services. The confidence intervals are extraordinary, spanning thousands of dollars. Clearly it would be highly speculative to use of a single point from this distribution in a benefits transfer exercise.

Table 3
Predicted values per acre of single-service wetlands[a]

Service	$E[\ln y]$	90% confidence interval around $\hat{y}$ (1990 US$'s per acre)		
		Lower	Mean	Upper
Flood	5.97	89	393	1747
Quality	6.03	126	417	1378
Quantity	4.84	6	127	2571
Rec.fish	5.88	95	357	1342
Com.fish	6.66	108	778	5618
Birdhunt	4.24	25	70	197
Birdwatch	7.10	528	1212	2782
Amenity	0.99	1	3	14
Habitat	5.72	95	306	981
Storm	5.47	11	237	5142

[a] The results presented in Table 3 are obtained from model C. The predicted values are obtained at the means of year and acre variables. Except for the variables indicating the respective services, all other binary variables are set to zero so that the prediction reflects a high-quality CV study estimating consumer surplus.

7. Conclusions

We have seen that wetland valuation studies are remarkably diverse in terms of the values obtained, the wetlands evaluated, and the characteristics of the studies. Our goal in this study was to isolate the sources of the variability in the wetland value.

There is some evidence that the method employed affects the value obtained. Relative to the HP or RC methods, using the CV method tends to yield a lower estimated value while there is no statistically significant difference between the CV and the TC or NFI methods. While it is perhaps comforting that the method that is used does not appear to be a primary determinant of value, the unimportance of study quality is not so reassur-

[9] We emphasize that the values in Table 3 do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.

ing. As we saw in Fig. 1, the distribution of weak studies is quite similar to that of the values from strong studies. However, econometric quality was found to be statistically significant in Table 2, and studies with weak econometrics tended to yield higher values. Study quality also has a substantial impact on the standard error around our prediction, suggesting that quality is important for the precision of our results.

This leads us to our final point: the use of benefits transfer to estimate wetland values faces substantial challenges. From our analysis it is clear that the prediction of a wetland's value based on previous studies is, at best, an imprecise science. The need for site-specific studies remains. Part of the problem lies in the lack of uniformity across studies. A better understanding of wetland values might be achieved if future researchers follow the suggestions of David (1993) in providing more information about their studies and centralizing the supporting documentation. Until an improved foundation can be established, it is important to emphasize the enormous uncertainties that are present in benefits transfer exercises applied to wetlands. In the interim, our analysis provides some guidance as to the wetland services that are most valuable, and the potential biases of some of the valuation methods.

Acknowledgements

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Summary of Cost-Benefit Analysis

Return to Menu

Project Name: **Milliken Creek Flood Reduction Project**

Description: An in-stream impoundment dam along Milliken Creek has been identified to contribute to flooding of a neighborhood of over 50 homes. The impoundment is also a passage barrier for steelhead. The Project involves three integrated elements: 1) removal of the dam and restoration of the stream, 2) construction of a flood bypass/weir to ensure a flood detention area does not overflow into neighboring homes, and 3) minor grading/landscape improvements to ensure existing low lying properties recieve comparable level of protection as their neighbors.

Proposed project capital cost:	$ 1,763,400	[Note: construction costs which are assumed to occur in one year.]
Change in annual O&M costs:	$ 130	[Note: the change in annual O&M costs compared to without project condi
PV of future O&M costs:	$ 2,891	(at 4% discount rate over 50 years)
PV of future costs	$ 1,766,291	[Note: the sum of capital costs plus the PV of O&M costs.]

Benefits

	Actual	Potential	
EAD without project	$ 145,025	$ 156,131	[Note: for stormwater projects use "Potential" damage which ignores sl
EAD with project	$ 1,677	$ 1,766	
Annual Benefit:	$ 143,348	$ 154,364	
PV of Future Benefits:	$ 3,187,881	$ 3,432,861	(at 4% discount rate over 50 years)

Cost-Benefit Analysis

	Actual	Potential	
Net Present Value (NPV)	$ 1,421,590	$ 1,666,570	(at 4% discount rate over 50 years)
Benefit:Cost Ratio	1.805	1.944	

NPV Sensitivity to Discount Rate:

	Actual	Potential
4%	$ 1,316,034	$ 1,552,680
5%	$ 853,555	$ 1,054,661
6%	$ 496,035	$ 669,667
7%	$ 214,913	$ 366,941
8%	-$ 9,751	$ 125,012

Summary of Cost-Benefit Analysis

Return to Menu

Project Name: **Milliken Creek Flood Reduction Project**

Description: An in-stream impoundment dam along Milliken Creek has been identified to contribute to flooding of a neighborhood of over 50 homes. The impoundment is also a passage barrier for steelhead. The Project involves three integrated elements: 1) removal of the dam and restoration of the stream, 2) construction of a flood bypass/weir to ensure a flood detention area does not overflow into neighboring homes, and 3) minor grading/landscape improvements to ensure existing low lying properties recieve comparable level of protection as their neighbors.

Proposed project capital cost:	$ 1,418,540	[Note: construction costs which are assumed to occur in one year.]
Change in annual O&M costs:	$ 130	[Note: the change in annual O&M costs compared to without project condi
PV of future O&M costs:	$ 2,891	(at 4% discount rate over 50 years)
PV of future costs	$ 1,421,431	[Note: the sum of capital costs plus the PV of O&M costs.]

Benefits

	Actual	Potential	
EAD without project	$ 70,068	$ 75,019	[Note: for stormwater projects use "Potential" damage which ignores sl
EAD with project	$ 3,642	$ 3,845	
Annual Benefit:	$ 66,426	$ 71,174	
PV of Future Benefits:	$ 1,477,226	$ 1,582,819	(at 4% discount rate over 50 years)

Cost-Benefit Analysis

	Actual	Potential	
Net Present Value (NPV)	$ 55,795	$ 161,388	(at 4% discount rate over 50 years)
Benefit:Cost Ratio	1.039	1.114	

NPV Sensitivity to Discount Rate:

	Actual	Potential
4%	$ 8,433	$ 110,434
5%	-$ 205,874	-$ 119,192
6%	-$ 371,544	-$ 296,705
7%	-$ 501,813	-$ 436,285
8%	-$ 605,920	-$ 547,834

2005-23

Final Report

THE COST AND EFFECTIVENESS OF STORMWATER MANAGEMENT PRACTICES

Research

Technical Report Documentation Page

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16. Abstract (Limit: 200 words)

Stormwater management practices for treating urban rainwater runoff were evaluated for cost and effectiveness in removing suspended sediments and phosphorus. Construction and annual operating and maintenance cost data was collected and analyzed for dry detention basins, wet basins, sand filters, constructed wetlands, bioretention filters, infiltration trenches, and swales using literature that reported on existing SMP sites across the United States. After statistical analysis on historical values of inflation and bond yields, the annual operating and maintenance costs were converted to a present worth based on a 20-year life and added to the construction cost. The total present cost of each SMP with the 67% confidence interval was reported as a function of the water quality design volume or, in the case of swales as a function of the swale top width, again with a 67% confidence interval. Finally, the mass of total suspended solids and total phosphorus removed over the 20-year life was estimated as a function of the water quality volume. The results can be used by planners and designers to estimate both the total cost of installing a stormwater management practice at a given site and the corresponding total suspended solids and phosphorus removal.

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THE COST AND EFFECTIVENESS OF STORMWATER MANAGEMENT PRACTICES

Final Report

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Executive Summary

Historical data has been used to compare the cost and effectiveness of several common stormwater management practices (SMP) including dry detention basins, wet detention basins, constructed wetlands, infiltration trenches, bioinfiltration filters, and sand filters. Data on construction costs and annual operating and maintenance costs have been combined to estimate the total present cost (TPC) of the SMPs in 2005 dollars as a function of water quality volume (WQV) or, in the case of swales, the swale top width. The TPC is based on 20 years of annual O&M costs which have been converted to a present value based on historical values of inflation and municipal bond yield rates.

The effectiveness of the SMPs as a function of WQV have been assessed by estimating the total amount of total suspended solids (TSS) and phosphorus (P) removed over a 20-year time period. Both the cost (*i.e.* TPC) and effectiveness (*i.e.* amount of TSS and P removed) estimates are presented with 67% confidence intervals. Also, in order to help the user incorporate land costs, typical land-area requirements for each SMP as a function of watershed area are presented.

For the six SMPs investigated, results show that, ignoring land costs, constructed wetlands are the least expensive to construct and maintain. However, since wetlands typically require more land area to be effective, land acquisition costs may result in wetlands being significantly more expensive then other SMPs that require less area. Also, the long-term capability of wetlands to remove phosphorus has been questioned by other authors.

The results presented in this report can be used by decision makers as a preliminary tool to compare SMPs in the categories of cost and impact on water quality. However, due to the wide

scatter in the original data, the confidence intervals associated with the estimates of TPC and amount of TSS and P removed also exhibit a relatively wide range.

Even with the scatter, the results can be used as a preliminary tool to compare SMPs which are under consideration for a given project.

For a more complete estimate of SMP cost and effectiveness, a more rigorous and detailed comparison which involves, as a minimum, a preliminary SMP design, should be performed.

Introduction

With the implementation of the United States Environmental Protection Agency's (USEPA) National Pollution Discharge Elimination Systems (NPDES) Phase I and II programs, strong interest has developed in the area of water quality treatment of stormwater runoff. While little is known about the cost effectiveness of available stormwater treatment technologies, called Stormwater Management Practices (SMPs) in this report, municipal agencies are now, or soon will be, required to meet certain pollutant removal criteria based on the Phase I and II regulations.

Of primary concern are nutrients such as phosphorus (P) and nitrogen (N), which are just one of the pollutant categories being targeted for removal from stormwater runoff. Excess nutrients can initiate large algae blooms that generate negative aesthetic and eutrophic conditions in receiving lakes and rivers (USEPA, 1999a). In inland water bodies phosphorus is typically the limiting nutrient (Schindler, 1977) and can be contributed to stormwater from various sources such as fertilizers, leaves, grass clippings, etc. (USEPA, 1999a). Another pollutant of primary concern in stormwater is dirt, sand, and other solid particles which are commonly quantified by measuring the Total Suspended Solids (TSS) of a water sample. TSS can severely and negatively impact an aquatic environment. The solids increase turbidity, inhibit plant growth and diversity, affect river biota and reduce the number of aquatic species (Shammaa *et al*., 2002). Also, organic suspended solids can be biologically degraded by microorganisms in a process which consumes oxygen, which is important to the aquatic biota.

With total suspended solids and phosphorus a primary concern of most stormwater management plans, and with little known about the cost effectiveness of available stormwater treatment options, this report seeks to fill a need by developing both a cost-comparison tool

(based on total construction cost not including land acquisition) and an effectiveness comparison tool (based on pounds of total suspended solids and phosphorus removed) for common SMPs. The method is based on published, credible information of existing SMPs relating to their construction and annual operating and maintenance (O&M) costs and their ability to remove TSS and P from stormwater runoff. The goal of the report is to provide planners and engineers with a pre-feasibility tool that can be used to compare the costs and impact on water quality of available SMPs.

Literature Review

Phosphorus can occur in both dissolved and particulate form in stormwater runoff. The dissolved fraction is often in the form of phosphates (PO_4^{3-}) (Jenkins *et al*., 1971) which undergo hydrolysis in water to form H_3PO_4 (pH<2.16), $H_2PO_4^-$ (2.16 < pH < 7.20), HPO_4^{-2} (7.20 < pH < 12.35), or PO_4^{-3} (12.35 < pH). Dissolved phosphorus is usually and somewhat arbitrarily defined as that portion which can pass through a 0.45 micron filter. Solid or particulate phosphorus, defined as that portion which is retained by a 0.45 micron filter, can originate from grass clippings, leaves, animal waste or any other solid organic matter and may also be included as part of the TSS.

The Water Environment Federation in conjunction with the American Society of Civil Engineers (WEF and ASCE, 1998) site a USEPA (1983) publication that reports the expected event mean concentrations for total and dissolved phosphorus in urban runoff as 0.33 mg/L and 0.12 mg/L, respectively. A more recent report (Brown *et al.*, 2003) based upon three different studies that incorporated data from approximately 500, 107, and more than 3,783 storm events, respectively, claims that a total phosphorus concentration of 0.3 mg/L is adequate to describe

both new and old urban development stormwater runoff. Brezonik and Stadelmann (2002) investigated urban runoff in the Twin Cities Metropolitan Area (Minneapolis and St. Paul, MN) and found that event mean concentrations for total and dissolved phosphorus varied as a function of climatic season as follows: 1.37 and 0.37 mg/L for winter, 0.85 and 0.53 mg/L for spring, 0.59 and 0.21 mg/L for summer, and 0.55 and 0.21 mg/L for fall. It must be noted that the values used to calculate average values often varied widely. Based on the wide scatter of data it can be concluded that phosphorus concentrations may vary widely both from site to site and at one location from one storm event to another.

The literature contains little information regarding typical size distributions of solids in stormwater runoff. However, one report published by California State University Sacramento (2002) reported size distributions recorded over a two-year span for highway runoff in the Lake Tahoe basin. The runoff analyzed upstream of any treatment system was reported to have the grain size distribution shown in Table 1 and Figure 1 (Note: Mass finer should decrease with decreasing grain size thus there appears to be a mistake in the values reported for grain sizes of 0.0328 and 0.0196 mm).

Ghani *et al.* (2000) also report grain size distributions of sediment in urban runoff for five cities in Malaysia with average d_{50} values (mm) of 0.6, 0.9, 0.8, 0.6, and 0.7. These values are similar to the d_{50} observed in the Lake Tahoe basin which, by interpolating values in Table 1, can be estimated to be 0.67 mm.

Grain Size (mm)	Mass Finer (%)	Grain Size (mm)	Mass Finer (%)
12.7	97.70	0.15	10.22
9.525	97.33	0.075	5.16
4.75	95.49	0.0716	0.80
2.36	91.25	0.051	0.73
2	84.12	0.0328	1.23
1.18	74.23	0.0196	1.06
0.85	56.84	0.0141	0.53
0.6	47.58	0.0102	0.45
0.425	30.78	0.0055	0.33
0.3	21.24	0.0024	0.20

Table 1. Grain size distribution of highway stormwater runoff in Lake Tahoe Basin.

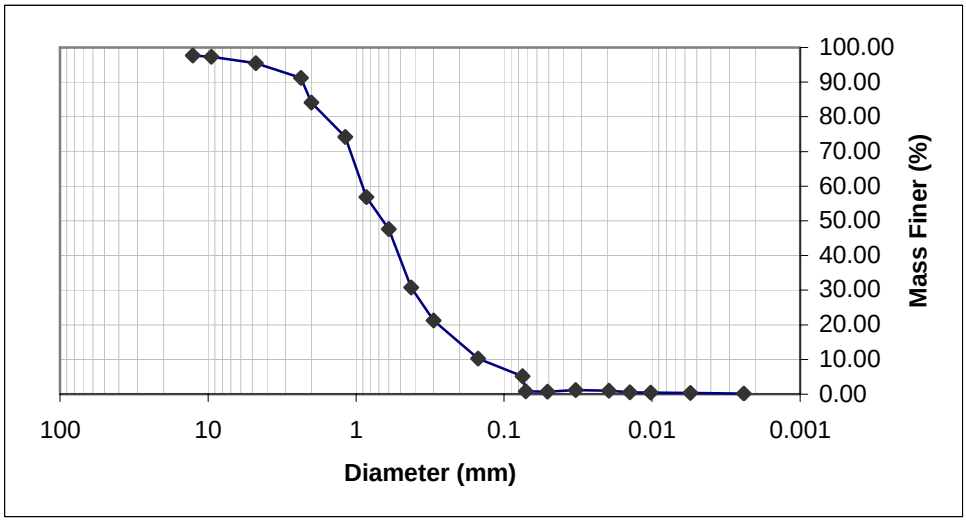

Figure 1. Grain size distribution of highway stormwater runoff in Lake Tahoe basin.

Removal of TSS and phosphorus from water may be achieved by a handful of different mechanisms. Much of the particulate or solid phosphorus can be removed via settling or mechanical filtration such as that which occurs in sand filters and when stormwater flows through adequately spaced and selected vegetation. As with particulate phosphorus, TSS levels may be reduced by settling and/or filtration.

To remove dissolved phosphorus from stormwater, the phosphorus must be converted, by means of a chemical reaction or adsorption, to a solid phase and removed as particulate (Jenkins *et al*., 1971). In wastewater treatment applications, where ambient conditions can be more readily controlled, bacteria have been employed to convert dissolved phosphorus to the

particulate phase. While the use of bacteria in stormwater treatment may be difficult, the use of wetland plants has rapidly become a commonly used process to remove both particulate and dissolved phosphorus. The plants filter TSS and particulate phosphorus out of the water while their roots absorb dissolved phosphorus. Both forms of phosphorus eventually end up in the sediments or plant matter. Once the plants have reached their capacity with regards to phosphorus, the wetland needs to be rehabilitated (typically dredged) in order to prevent the system from becoming a phosphorus source.

In an attempt to keep costs low, current SMPs typically do not include the construction of a treatment facility or a mechanical treatment process such as is commonly found in wastewater treatment plants. For example, some of today's most common SMPs include dry detention basins, wet/retention basins, constructed wetlands, infiltration practices, sand filters, grassed/vegetative swales, and filter strips, all of which will be defined and discussed below. Alternative options for low-cost solutions to pollutant removal may involve slight alterations to these common techniques to improve water quality treatment without significantly increasing construction or maintenance costs. For example, additional media such as limestone or steel wool has been added to sand filters to enhance dissolved phosphorus removal by precipitation and/or adsorption.

A report by Schueler *et al*. (1992) which summarizes studies that have determined removal efficiencies for several stormwater management practices and pollutants of concern is included in Appendix A. This collection illustrates the wide variability in pollutant removal effectiveness typically observed with SMPs.

The USEPA (1999) reported phosphorus removal efficiencies for several stormwater management practices as shown in Table 2. Also included are the minima and maxima data

related to each median value, illustrating the range with which phosphorus removal efficiencies have been reported. In fact, every median reported came from a data set that included negative removal efficiencies indicative of phosphorus contributions to the effluent. Some of the most common SMPs, including those of Table 2, are explained in more detail below.

TYPE	Typical Phosphorus Removal (%)[1]	Median Removal Efficiency (%)			No. of Observations (respectively)
		Total	Dissolved	Ortho-	
Dry Detention Basin	15 - 45				
Wet/Retention Basins	30 - 65	46[3]	34[3]		44, 20
Constructed Wetlands	15 - 45	46[2]	23[2]	28[2]	37, 12, 7
Infiltration Basins	50 - 80	65[3]			5
Infiltration Trenches/Dry Wells	15 - 45				
Porous Pavements	30 - 65				
Grassed Swales	15 - 45				
Vegetated Filter Strips	50 - 80	15[3]	11[3]		18, 8
Surface Sand Filters	50 - 80	45[3]	-31[3]		15, 2
Other Media Filters	< 30				

Table 2. Expected phosphorus removal.

Sources: [1]modified from USEPA (1993), [2]Strecker (1992), [3]Brown and Schueler (1997)

To aid in evaluating the efficiency of stormwater management practices, the American Society of Civil Engineers (ASCE) and the USEPA have developed a website, www.bmpdatabase.org, which contains data regarding SMPs throughout the country. A team of stormwater experts have evaluated over 800 bibliographic sources and posted credible information from full and pilot scale and monitoring studies regarding the efficiency of scores of SMPs. They continue to review submissions and recent studies for incorporation into the database to provide the most accurate, relevant, and current information.

To better understand the cost-effectiveness of today's SMPs and to enable planners and engineers to make wise choices with limited resources, these SMPs must be reviewed for both

their cost and contaminant removal potential and then compared amongst each other. While the final objective of this report is to provide such a comparison, a review and discussion of some common SMPs is presented below.

Dry Detention Basins

Definition: "Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems do not retain a significant permanent pool of water between rainfall events." (USEPA, 1999a)

The primary function of dry detention basins is to reduce the risk of flooding by attenuating the peak storm flow rate by temporarily storing the runoff and releasing it through outlet structures. Compared to other SMPs, dry detention basins typically provide less water quality treatment. While properly designed detention basins can remove large solid particles via settling they often do not detain runoff long enough to allow finer particles to be removed. As the detention time of the basin is increased, however, the amount of solids removed will also increase. Also, dry detention basins may require frequent cleaning to reduce re-suspension during subsequent rainfall events (USEPA, 1999a). Of the phosphorus removed by a dry detention pond, most occurs by means of gravity settling of particulate phosphorus in the pond. Thus dry ponds usually remove little, if any, dissolved phosphorus.

Wet/Retention Basins

Definition: "Retention systems capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems therefore maintain a significant permanent pool volume of water between runoff events." (USEPA, 1999a)

Also termed wet ponds in some contexts, these basins are similar to dry detention ponds except the outlet structure is set at a higher elevation to create a permanent pool within the pond. Retention basins utilize gravity settling as the major removal mechanism but nutrient and organic removal can be achieved through aquatic vegetation and microorganism uptake. Figure 2 below shows a cross section of a retention pond illustrating this type of outlet structure.

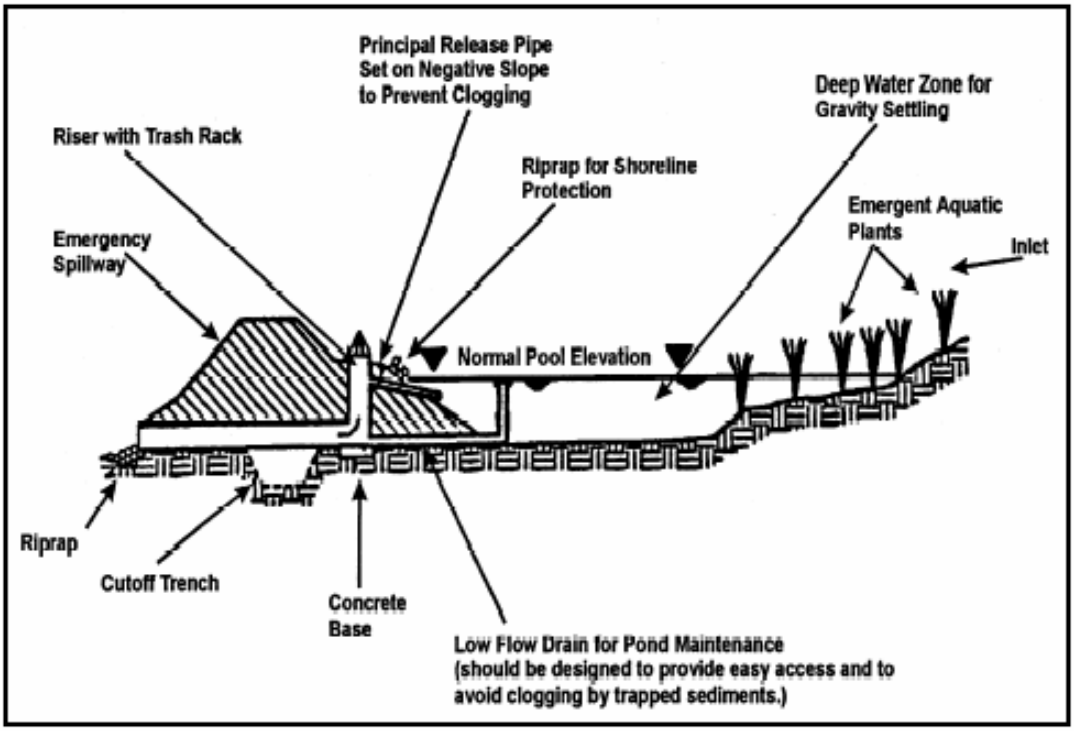

Figure 2. Retention basin cross section.

Source: Barr Engineering Company, 2001.

Limitations of these systems are typically related to retention time. During high flows, or freezing weather (when the permanent pool is frozen or covered with ice) influent runoff can short-circuit through the retention system and reduce the effectiveness of the sedimentation mechanism. Pond characteristics can also affect the removal efficiency. Changes in pH or hardness can alter the solubility of many contaminants and thus release them to the effluent (USEPA, 1999a). Another possible limitation of retention systems is high temperature effluent.

The water in the pond may absorb enough solar energy to significantly increase the temperature of the effluent which may adversely impact fish and other aquatic species in the receiving waters.

Constructed Wetlands

Definition: "Constructed wetland systems are similar to retention and detention systems, except that a major portion of the SMP water surface area (in pond systems) or bottom (in meadow-type systems) contains wetland vegetation. This group also includes wetland channels." (USEPA, 1999a)

Constructed wetlands are similar to dry basins in that they release inflow much more slowly as effluent. They also resemble wet/retention basins in that, although they are shallower, they typically hold a permanent pool of water to maintain wetland vegetation. Whereas dry detention basins are typically designed to release the entire stormwater inflow within 24 to 48 hours, constructed wetlands can take several days or more to release runoff events. Figure 3 shows one potential design of a constructed wetland system, although several configurations and systems are identified as constructed wetlands.

Constructed wetlands allow for more removal mechanisms than detention basins and longer contact times than retention basins; therefore they are capable of removing more pollutants such as nutrients and organics. Unlike dry detention basins, constructed wetlands, if designed properly, do not allow for re-suspension of particles and contaminants. However, a major drawback of constructed wetlands is the large space they require. Constructed wetlands typically require large areas to allow for adequate storage volumes and long flow paths. As a result wetlands are often impractical in urban and suburban areas where land costs are high. Another limitation of constructed wetlands (perhaps retention systems also) is nuisance fowl and insects as wetlands can provide breeding grounds for mosquitoes and other pests.

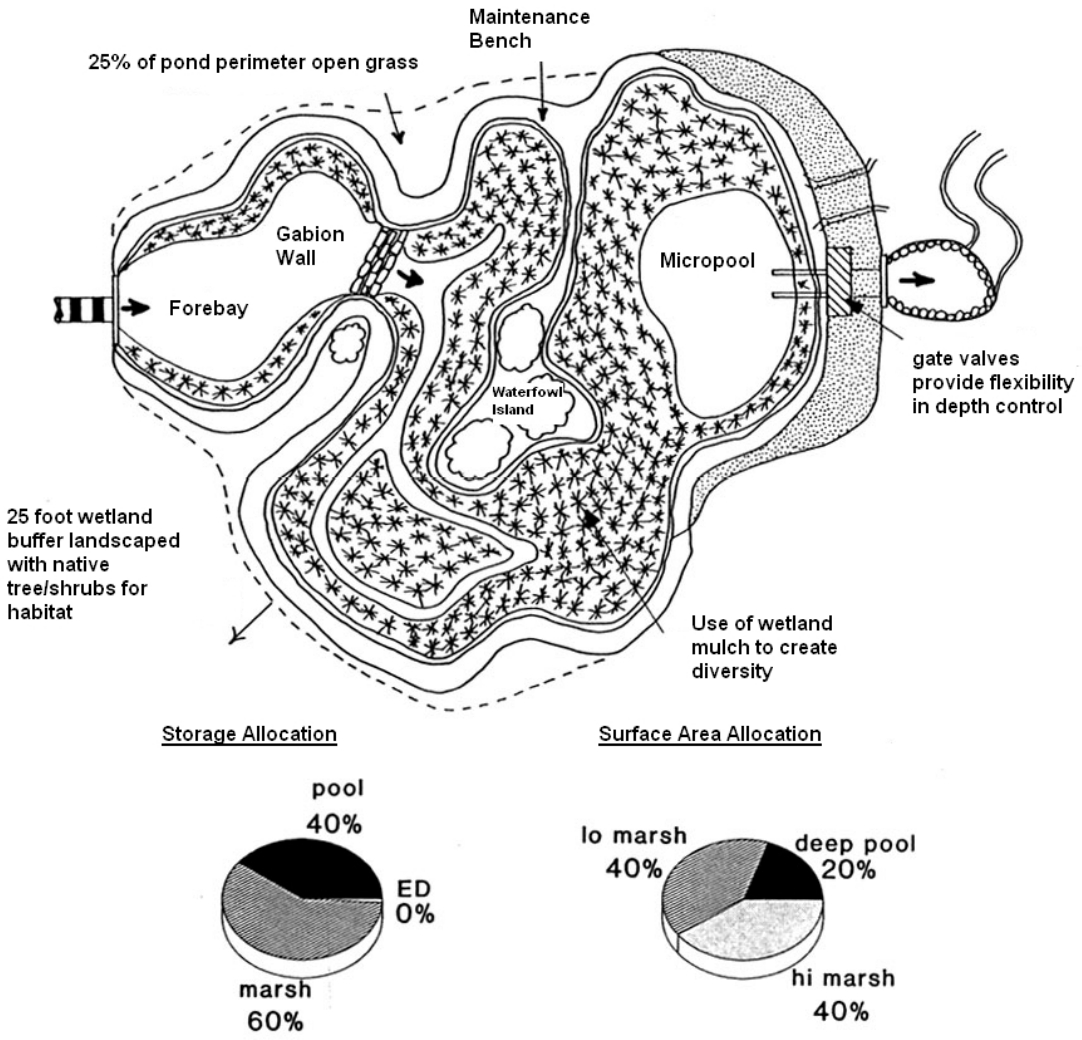

Figure 3. One example of a constructed wetland system.

Source: Barr Engineering Company, 2001.

As with any SMP, constructed wetlands require regular maintenance to remain effective. Faulkner and Richardson (1991) attributed a significant reduction in nutrient removal to the wetland vegetation reaching maximum density. Thus, wetlands plants may have to be harvested to remove overabundant vegetation. Furthermore, overabundant and decaying vegetation can deposit large amounts of soluble and particulate phosphorus into the wetlands system; typically more than the living vegetation can uptake. This can result in an addition of phosphorus to the system. However it is questionable if harvesting plants will adequately remove phosphorus

because in studies where vegetation has been harvested in an attempt to remove phosphorus, only minimal amounts of phosphorus have been recovered (Kadlec and Knight, 1996). These factors may make it difficult for constructed wetlands to be a long-term cost-effective quality control technique.

As with other SMPs, removal efficiencies of TSS and P for constructed wetlands vary widely among monitoring studies. This may be partly attributed to the fact that constructed wetlands can lose their capacity to remove phosphorus over time (Oberts, 1999). Even when phosphorus removal occurs, wetlands usually remove a significantly higher fraction of TSS than phosphorus.

Infiltration Practices

Definition: "Infiltration systems capture a volume of runoff and infiltrate it into the ground" (USEPA, 1999a). Any technique that does not discharge effluent to surface waters, or reduces total discharge, can be categorized as an infiltration practice. Infiltration practices encompass a number of techniques utilized for the treatment of stormwater runoff. Most infiltration practices require some form of pretreatment along with frequent maintenance to prevent blockage and ensure proper operation of the system.

The removal performance of infiltration practices has not been thoroughly reported. The difficulty in determining the quality of the effluent is most likely the chief reason for this lack of information. The data regarding infiltration practices that is available varies drastically due to many factors such as varying soil conditions, influent water quality, depth to water table, degree of pretreatment, maintenance protocols, etc. In areas with highly permeable soil, poor quality effluent may not receive adequate contact time and may be released to aquifers with little or no treatment (USEPA 1999a). It is also very difficult to monitor the effluent of infiltration practices

and confidently report that the findings are solely attributed to the infiltration system itself. Four common infiltration practices are discussed below.

Infiltration Basins

Infiltration basins are similar to detention or retention basins in design and appearance, but do not use an outlet structure to convey effluent, except when the runoff volume is too large and cannot be stored in the basin. These basins release treated water directly to the groundwater after filtration through the basin media which may be comprised of the existing soil and/or a specified filtration media introduced during construction. As mentioned previously, an overflow outlet to a receiving water body is usually installed to discharge the excess water volume of large storms.

Infiltration Trenches

Infiltration trenches can be thought of as constructed channels filled with filtration media or soil which allows for the infiltration of stormwater. These trenches are often placed around the perimeter of parking lots or other structures to treat the runoff generated by the site. With sufficient sizing and properly designed flow regulators (typically check dams), infiltration trenches can infiltrate a large portion of the runoff. Figure 4 shows an example of a typical infiltration trench design.

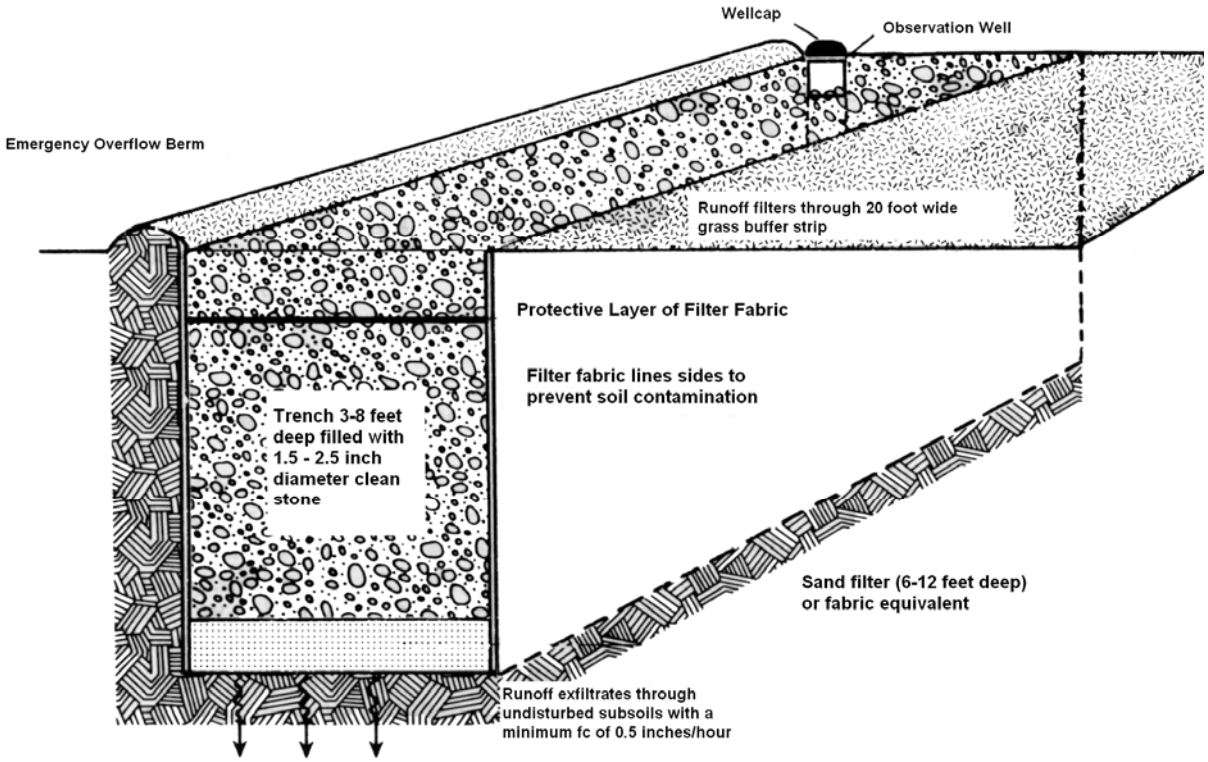

Figure 4. Infiltration trench design.

Source: Barr Engineering Company, 2001.

Bioretention

While not specifically defined by the USEPA, bioretention systems are essentially landscaped depressions to which stormwater runoff is diverted and stored. Once in the depression, the landscaped trees, shrubs, and other vegetation help to remove the water through uptake, while the runoff infiltrates into the soil below. The underlying soil may consist of the original soil or it may be non-native soil such as sand that is installed during construction. Also, depending on the permeability of the underlying soil, a bioretention system may include a perforated underdrain which collects and removes infiltrated water.

Bioretention systems are rapidly gaining in popularity because it is assumed they incorporate the best of vegetative systems and filtration systems. However, their impact on water quality is neither well known nor documented.

Porous Pavements

Definition: "Porous pavement systems consist of permeable pavements or other stabilized surfaces that allow stormwater runoff to infiltrate through the surface and into the groundwater." (USEPA, 1999a)

Porous pavement comes in many forms, some of which are commercially available. Unlike typical asphalt or concrete pavements, porous pavements allow runoff to seep through the pavement surface which reduces the amount of runoff. Porous pavements are categorized as an infiltration practice because they allow runoff to infiltrate into the underlying soil.

Limitations of porous pavements are similar to other infiltration practices and usually involve maintenance and clogging issues. Porous pavements typically contain small voids (or seams between bricks) that can become clogged with sediments. Frequent surface vacuuming or flushing is usually required to keep porous pavements free of sediments and other debris, allowing prompt infiltration of surface runoff.

Water quality treatment of runoff by porous pavements is similar to that of other infiltration practices. The porous pavement itself provides little actual removal while the infiltration of the runoff to receiving groundwater can remove significant amounts of contaminants.

Sand Filtration

Definition: Sand filtration systems utilize granular media to filter stormwater runoff that is collected and discharged as effluent to other treatment systems or directly to receiving waters. Those called "Austin" sand filters appear much like a dry detention basin but include built-in sand filled areas that filter the water and release it to an underdrain. The "Delaware" sand filters are usually smaller, low retention filters that can be placed underground in concrete chambers and are typically designed to capture and treat only the first portion (often called the "first flush") of most runoff events.

Herrera Environmental Consultants (1995) performed a study which showed that sand filters provide little (*i.e.* 20 - 50 % total, 5 - 30 % soluble) capacity for phosphorus removal compared to other SMPs. Anderson *et al*. (1985) monitored several water-quality parameters of more than a dozen intermittent sand filters for the USEPA. Their results also concur that a pure sand-filter media provides "only limited removal of phosphorus" (Anderson, 1985).

Harper and Herr (1993) performed pilot-scale and full-scale monitoring studies in Florida for the removal of several water quality contaminants. It was estimated that typical sand filters remove approximately 40 to 50 percent particulate and total phosphorus, but at most only five percent soluble phosphorus. Another sand filter utilizing a silica sand media exhibited better results for soluble and total phosphorus (35 and 55 percent, respectively) but also contributed particulate phosphorus to the effluent. Harper and Herr acknowledged that the silica sand was considerably coarser than the typical sand media used in their other experiments. Harper and Herr (1993) also conducted experiments comparing sod coverings placed on top of sand filters. Four types of sod were tested in a fashion similar to their previous study. It was determined that

all but one sod covering contributed dissolved phosphorus to the effluent, and removal rates for particulate or total phosphorus were at most 54 percent.

The full scale monitoring performed by Harper and Herr (1993) encompassed many water quality and quantity characteristics of a basin that incorporated both infiltration and filtration practices in what the authors deemed a "Wet detention basin." By performing a mass balance on the pond it was determined that the pond removed roughly 30 to 40 percent of the ortho-phosphorus, 80 percent of the particulate phosphorus, and 60 percent of the total phosphorus over the six month monitoring period. However, the configuration of the pond created a permanent pool of water which allowed for algae growth. Harper and Herr (1993) attribute the high removal rates of ortho-phosphorus to algae uptake by the biomass that developed within the pond and the particulate phosphorus removal to filtration processes.

Bell *et al*. (undated) conducted an assessment of Delaware (also referred to as intermittent) sand filters for their removal efficiencies of several pollutants found in urban stormwater runoff. The study was based on the monitoring of an existing sand filter constructed in Northern Virginia (pg. 5-1) over the course of 20 storm events during the summer of 1994. Among many other pollutants, Bell *et al*. reported removal rates of up to 90 percent for phosphorus (pg. 5-20) and suggested that their results "may not reflect the true potential of intermittent sand filter BMPs." Even though average removals of 60 to 70 percent were reported, an analysis of the filter media revealed constituents of iron (3000 mg/kg), calcium (4-6 mg/kg), and aluminum (2900 mg/kg). Based on evidence provided by Baker *et al*. (1997) and Anderson *et al*. (1985), it can be postulated that these "involuntary" additives affected the removal efficiencies of the sand filters assessed by Bell *et al.* (undated).

Other additives such as peat or compost have been studied for their effectiveness at removing contaminants from stormwater runoff. Farnham and Noonan (1988) conducted a study of peat-sand combination filter efficiencies and reported a direct relationship between phosphorus removal efficiency as percent removal and input phosphorus concentration. Galli (1990) also suggested the use of a peat-sand filter for urbanized runoff treatment and predicted 70 percent removal of total phosphorus for peat species that contain minimal, if any, phosphorus content. The USEPA monitored a filter built to Galli's design specifications and reported instances of both phosphorus removal and phosphorus addition through leaching of the media into the water (USEPA, 1999a, pg. 5-80, 5-81). Other sources (Koerlsman *et al*., 1993) have also reported peat as a source of phosphorus when used as filter media. Stewart (1992) reported that a leaf compost filter can also leach phosphorus into stormwater effluent (Section 3, Table 12).

Vegetated Systems

Definition: "Vegetated systems such as grassed swales and filter strips are designed to convey and treat either shallow flow (swales) or sheet flow (filter strips) runoff." (USEPA, 1999a)

Vegetated systems are a special application of infiltration practices that utilize vegetated cover for two purposes. Vegetated cover on sloped applications slow the overland flow to allow greater opportunity for infiltration into the soil while also providing an opportunity for nutrient uptake through the root system. Vegetated systems suffer the same monitoring difficulties as other infiltration practices, and can be more difficult to maintain. As with infiltration trenches and basins, vegetated systems can become clogged with particles and debris in the absence of proper pretreatment and maintenance. In some cases the sediment deposits can begin to choke

out the vegetated cover and create an erodible surface capable of contributing sediment and other pollutants directly downstream.

Commercial Products

Commercially available products include, but are not limited to, DrainPac™, HydroKleen™, StormTreat™ System, BaySaver™, Stormceptor®, Vortechs ™, Downstream Defender®, Continuous Deflective Separation (CDS®), and StormFilter™. Other commercially available products are available and new products will almost certainly be introduced in the future. Brueske (2000) performed a review of several commercial products, however an unbiased review of the performance of these products can be difficult to obtain and reported removal rates must be used with caution. The relatively small size of the commercial products (as compared to wet basins, wetlands, detention ponds, etc.) may result in their long-term effectiveness being much lower than reported. For example, one product with a reported TSS removal rate of over 80% was field tested and found to remove only about one-third of the sediment load and 19 percent of total phosphorus (Waschbusch, 1999).

Review Summary

The ability of SMPs to remove TSS and phosphorus effectively is dependant on many factors and can occur by various mechanisms. Many researchers have studied SMPs for their capability to remove TSS and phosphorus and some have investigated the mechanisms by which removal occurs. Designers, planners, and other decision makers have little guidance that incorporates this information in combination with SMP costs to aid them in the selection of a SMP. Comparisons of the cost-effectiveness of SMPs are, at best, rare and yet decision makers are continually forced to spend limited resources on technologies whose costs and benefits are

not well understood. A comparison of this nature would enable decision makers to better appropriate limited resources as they strive to meet federal regulations by improving the water quality of stormwater effluent.

This report helps fill a critical knowledge gap by quantitatively comparing the cost and effectiveness of several of the most common SMPs for which reliable data was available. More direct comparisons, however, are needed, including comparisons with and between commercial products.

Cost Estimation

Based on published cost data of actual SMPs a method, which is described below, was developed that will enable designers and planners to make estimates of the Total Present Cost (TPC) of various SMPs if the size of the SMP is known. In this report, the TPC is defined as the present worth of the total construction cost of the project plus the present worth of 20 years of annual operating and maintenance (O&M) costs. The values reported do not include costs of pretreatment units (which may be required), design or engineering fees, permit fees, land costs, or contingencies, etc.

Water Quality Volume

The costs of SMP projects are usually reported along with the corresponding watershed size (usually in acres or square feet) and/or the water quality volume (WQV) for which the SMP was designed. The water quality volume is often defined as the volume (typically in acre-feet or cubic feet) of runoff that the SMP is designed to store and treat.

Claytor and Schueler (1996) calculate the WQV (ft^3) for a particular precipitation amount as:

$$WQV = \left(\frac{43560}{12}\right) * P * R_V * A \quad (1)$$

where: P = Precipitation depth (inches)

R_V = Ratio of runoff to rainfall in the watershed

A = Watershed area (acres), and the constants are conversion factors.

The ratio of runoff to rainfall, R_V, has the most uncertainty of the parameters in Equation 1. For this analysis, a relatively simple relationship was used (Claytor and Schueler, 1996; Young et al., 1996)

$$R_V = 0.05 + 0.009 * (I) \quad (2)$$

where I is the percent (0-100) of the watershed that is impervious. Equation 2 indicates that, for a 100% impervious watershed, 95% of the rainfall becomes runoff.

Total Construction Costs

Values of total construction costs of SMPs throughout the United States were collected from published literature. Although data was collected on many SMP technologies, sufficient data to perform a cost analysis could be found for only dry detention basins, wet/retention basins, constructed wetlands, infiltration trenches, bioinfiltration filters, sand filters, and swales. All data were adjusted to reflect costs in Minnesota by means of 'Regional Cost Adjustment Factors' as reported by the United States Environmental Protection Agency (USEPA, 1999a) and were also adjusted to year 2005 dollars using an annual inflation rate of 3 percent. A value of 3 percent was chosen after an analysis of building cost indexes for the past 11 years (Turner Construction, 2004) revealed that the average annual inflation was 3.26 percent with a range from 0.3 to 5.4 percent.

The cost data which was collected was usually reported in conjunction with the watershed area and/or the water quality volume (WQV) for which the particular SMP was designed. When the cost data was converted to unit construction costs, defined as the total construction cost per acre of watershed or per cubic foot of WQV, the data, in all cases except for bioinfiltration filters, exhibited an Economy of Scale. In other words, when the unit construction cost was plotted versus the size (*i.e.* watershed area or WQV), the unit cost tended to decrease as the size increased. As mentioned, the only exception to this trend was bioinfiltration filters which exhibited a slight increase in unit cost with increasing size.

When comparing unit-cost data based on watershed area and WQV, the data based on WQV was, in most cases, observed to have less scatter as quantified by the standard error of the y-estimate. Thus, in order to provide for as much consistency as possible while minimizing scatter overall, WQV-based unit construction costs were selected for use over watershed area based unit construction costs. However, there was insufficient data to allow for a WQV-based approach when considering grassed/vegetative swales. Furthermore, basing a cost analysis of a swale, which is usually designed for a peak flow rate and could have a wide variety of lengths, on watershed area or WQV does not make intuitive sense. Instead, projected cost estimates per linear foot of swale as a function of geometry were collected and analyzed. Using these data, the cost per linear foot of a grassed/vegetative swale was found to be a function of the top width of the swale. Thus, a second method, used only to estimate the construction costs of swales, was developed and is based on construction cost per linear foot as a function of swale top width.

Figures 5 through 11 below show the unit construction cost data analyzed in graphical form. Also shown is the dashed, best-fit line through the data and the 67% confidence interval as shown by solid lines on either side of the best-fit line. The 67% confidence interval shows the

bounds that will, on average, contain 67% of the data. In other words, one-third of the data could fall outside of the 67% confidence interval. If there is sufficient data (~20) and the distribution is, in this case, truly log-normal, then one-third of the data will fall outside of the 67% confidence interval. The data originating from Brown and Schueler (1997) were read graphically whereas the values from SWRPC (1991), Caltrans (2004), and ASCE (2004) were given in tabular form. The data from Caltrans (2004) was collected by means of a survey distributed by Caltrans to other agencies throughout the country. It should be noted that the total construction costs of SMPs installed by Caltrans were also available but these values were omitted from this

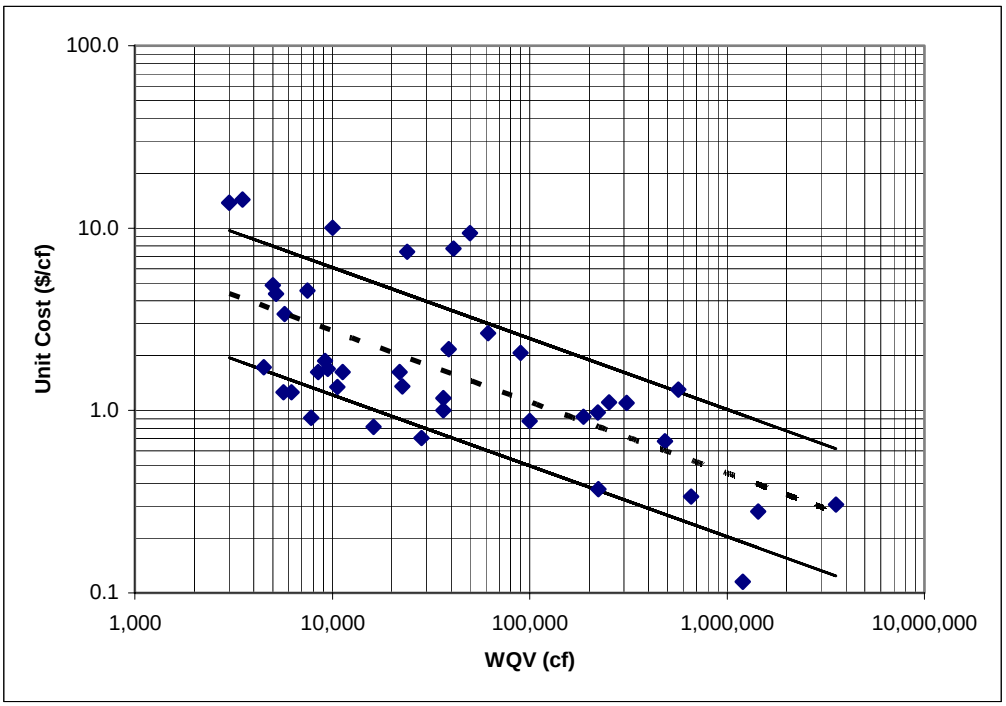

Figure 5. Unit construction costs of dry detention basins.

(Data from Brown and Schueler, 1997; ASCE, 2004; Caltrans, 2004)

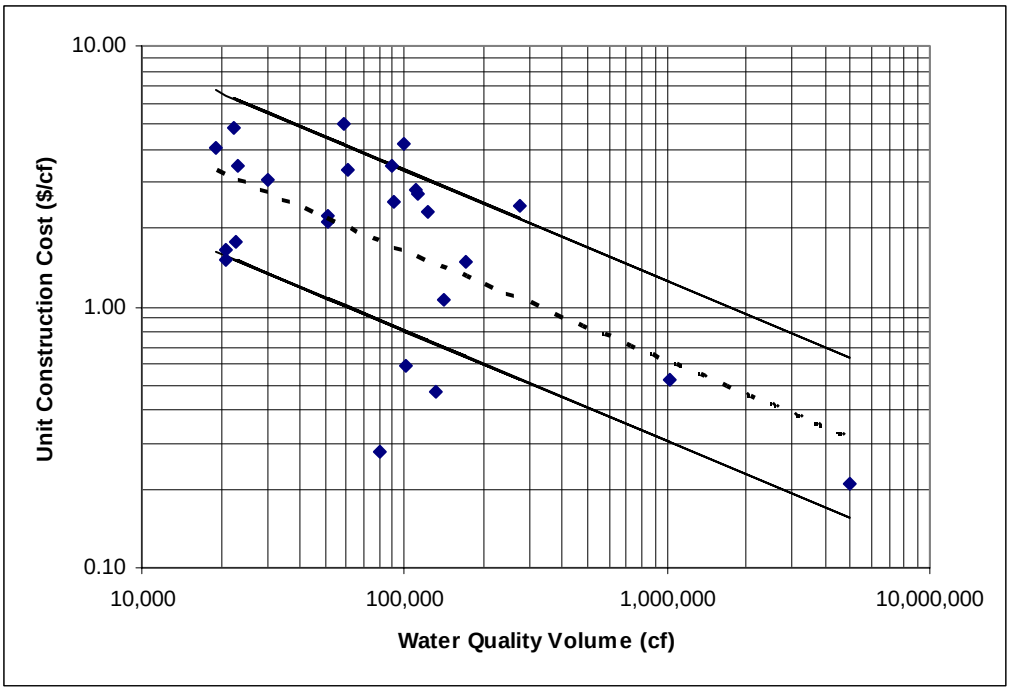

Figure 6. Unit construction costs of wet basins.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

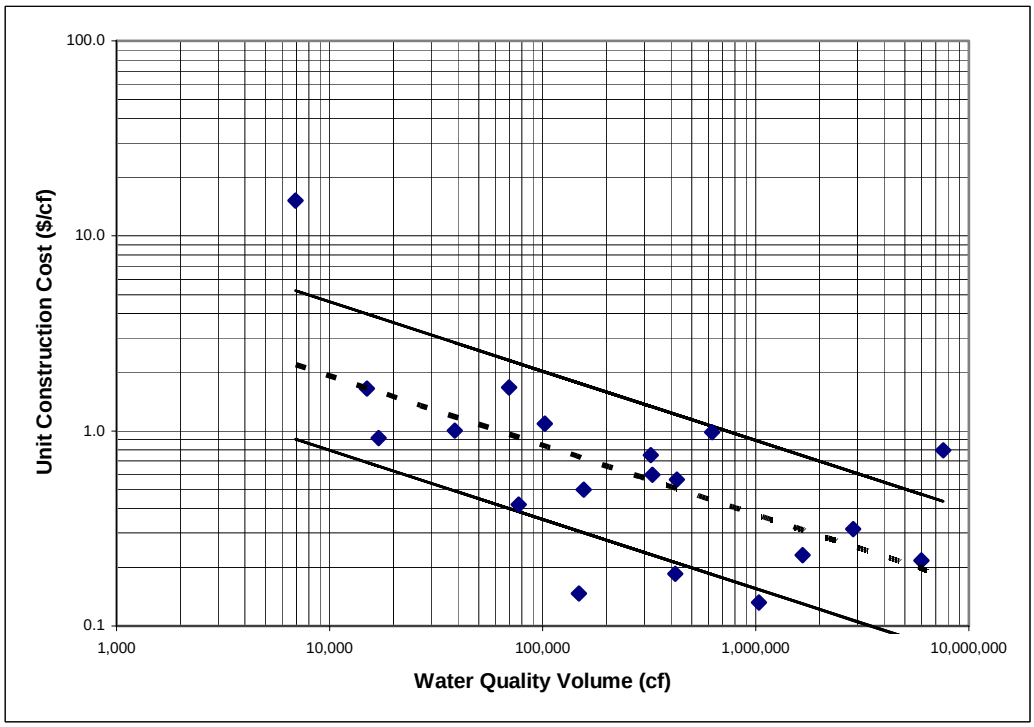

Figure 7. Unit construction costs of constructed wetlands.

(Data from Brown and Schueler, 1997, Caltrans, 2004; ASCE, 2004)

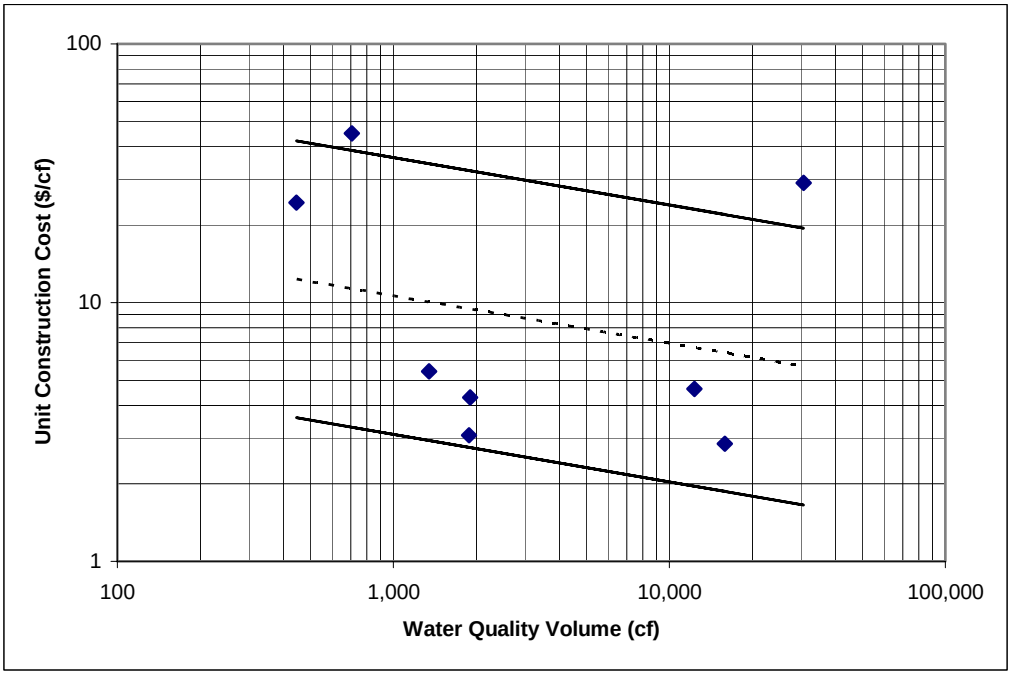

Figure 8. Unit construction costs of infiltration trenches.

(Data from Caltrans, 2004)

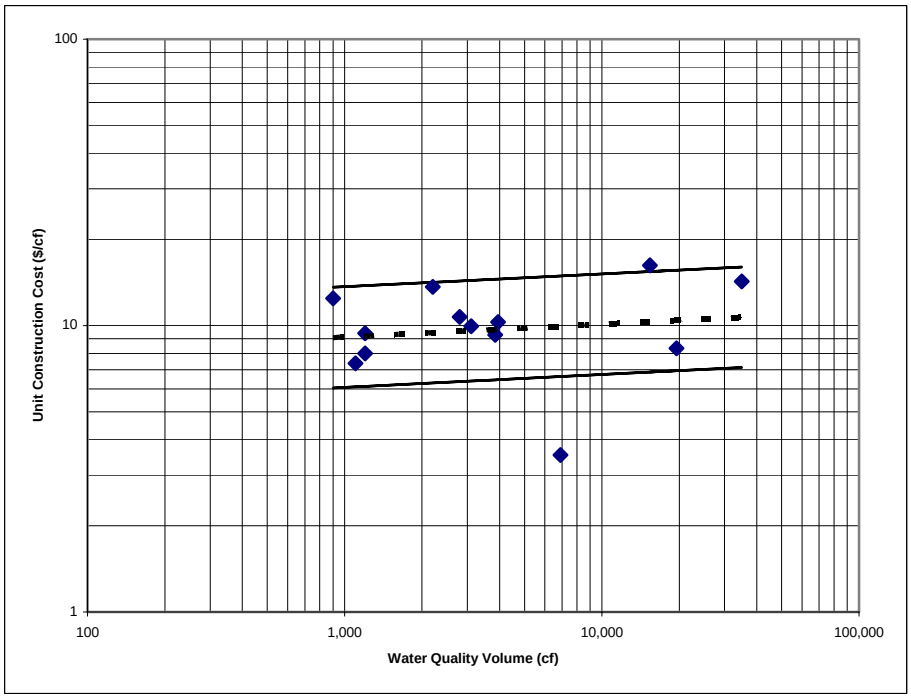

Figure 9. Unit construction costs of bioinfiltration filters.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

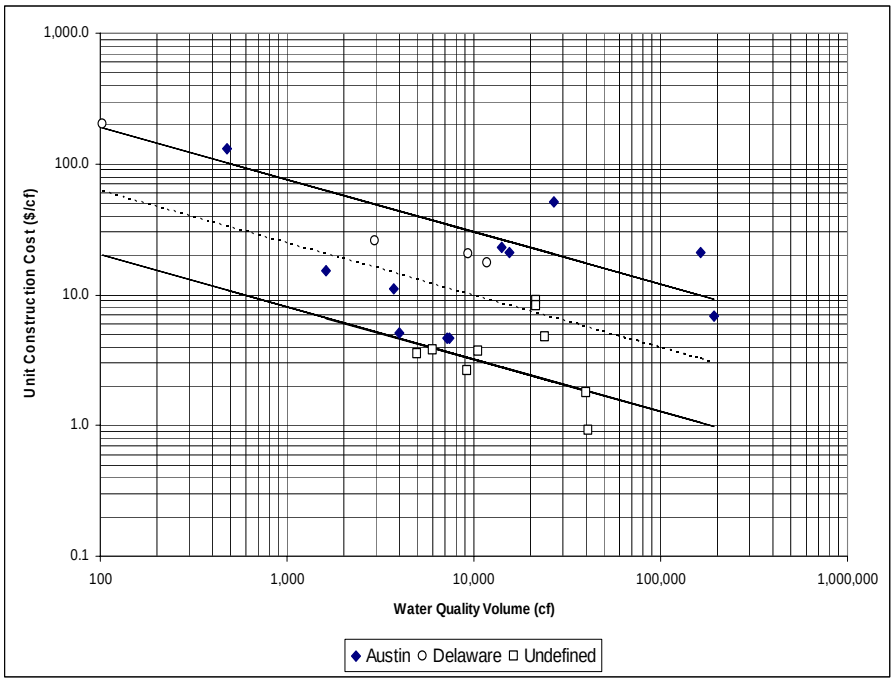

Figure 10. Unit construction costs of sand filters.

(Data from Brown and Schueler, 1997; Caltrans, 2004)

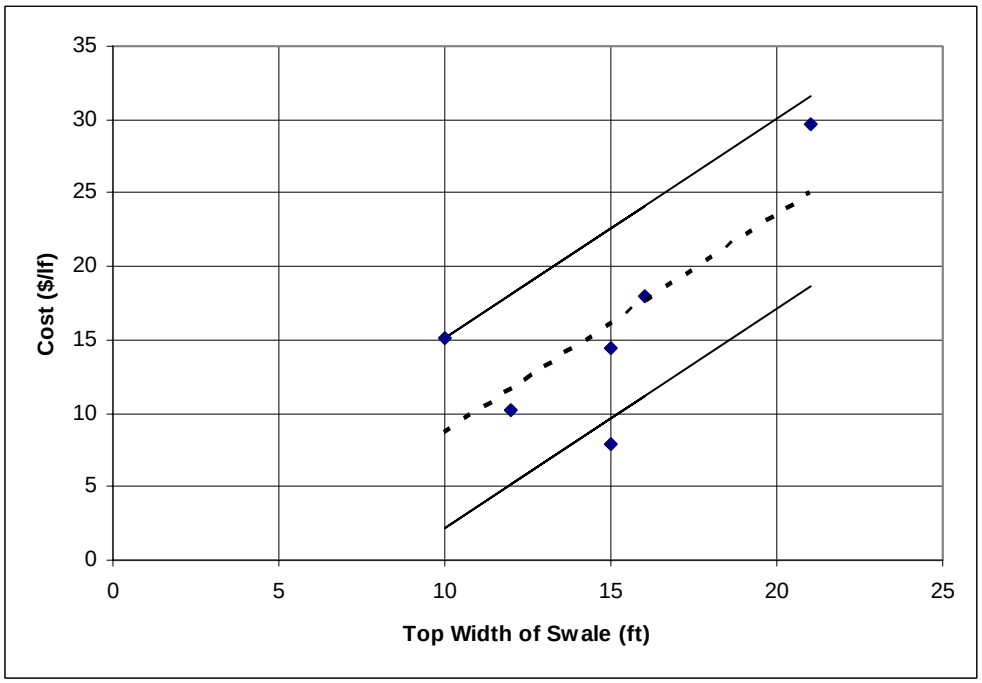

Figure 11. Unit construction costs of grassed/vegetative swales.

(Data from SWRPC, 1991)

analysis because their costs were typically about ten times higher than similarly sized projects constructed by other agencies. Caltrans attributed these high costs to the fact that their projects were retrofits and were not installed as part of larger construction projects.

Of the data collected for sand filters, some contained information on the type of sand filter (*e.g.* Austin or Delaware) while other data included no such description. Interestingly, when analyzing the sand-filter data for unit costs, there was essentially the same amount of scatter when the data of each sand-filter type was analyzed alone as there was when all sand-filter data was combined and analyzed together. This suggests that sand-filter unit-construction costs are independent of the type of filter and, as a result, cost estimates developed herein do not differentiate between sand-filter types. Figure 10 does differentiate between the Austin, Delaware, and undefined data by the data marker but, since no trend was observed for individual filter types, the best-fit line is drawn through the combined data.

The uncertainty observed in the data for all SMPs is most likely due to several factors such as design parameters, regulation requirements, soil conditions, site specifics, etc. For example, variable design parameters that would affect the total construction cost include pond side slopes, depth and free board on ponds, total wet pond volume, outlet structures, the need for retaining walls, etc. Site specific variables include clearing and grubbing costs, fencing around the SMP, etc. Due to the wide number of undocumented variables that affect the data, this scatter would be extremely difficult, if not impossible, to minimize.

Later in this report the data shown in Figures 5 through 11 will be combined with annual O&M cost data to estimate the TPC of each SMP as a function of size. After a discussion of typical land-area requirements, the methods and data used to incorporate O&M costs into this analysis are described.

Land-Area Requirements

An important cost of any SMP is that of the land area on which the SMP will be located. For urban areas, in which land is typically at a premium, this cost can be relatively large. On the contrary, in more open, rural areas, land costs might be a very small percentage of the total project costs. Due to the extreme range of land costs and variability from site to site, no attempt was made to incorporate this cost into the Total Present Cost analysis. However, the land area requirements, and therefore the associated land costs, of each SMP technology can vary dramatically and would, in many scenarios, have a significant impact on the total cost of a project. For example, a sand filter placed underground, below a parking lot would, in effect, require no additional land area. However, a constructed wetland designed to treat the same volume of runoff as the underground sand filter would require significant additional land area that may preclude the use of wetlands. Given the variability of land costs and the variety of potential SMPs that could be used, the impact of land costs must be done on an individual, case-by-case basis. Table 3, which lists typical SMP land-area requirements for effective treatment, is presented to assist designers and planners in making such a comparison. Values reported in Table 3 by Claytor and Schueler (1996) are for the general category of SMP system and may include more than one specific type of SMP. For example, their pond category may include both wet and dry ponds. Table 4 lists wet pond areas required for control of particles that are 5 and 20 microns in size as reported by Pitt and Voorhees (1997). If the land costs in the locale of a particular project are known, these costs can be combined with the information presented in the tables to estimate a range of possible land area costs associated with each SMP under consideration. This information is intended to give only a possible range of land area costs. For more accurate land area cost estimates, a preliminary SMP design should be performed.

SMP System	SMP Area (% of Impervious Watershed) From USEPA, 1999.	SMP Area (% of Watershed) From Claytor and Schueler (1996) Except as noted.
Bioretention	5	--
Wetland	3 - 5	3 - 5
Wet/Retention Basin	2 - 3	--
Sand Filter	0 - 3	--
Dry Det Basin	--	0.5 - 2.0 (UDFCD, 1992)
Infiltration Trench	2 - 3	--
Filter Strips	100	--
Swales	10 - 20	--
Pond	--	2 - 3
Infiltration	--	2 - 3
Filter	--	2 - 7

Table 3. Reported SMP land area requirements for effective treatment.

Land Use	5 micron control	20 micron control
100% Paved	3.0	1.1
Freeways	2.8	1.0
Industrial	2.0	0.8
Commercial	1.7	0.6
Institutional	1.7	0.6
Residential	0.8	0.3
Open Space	0.6	0.2
Construction	1.5	0.5

Table 4. Typical land area requirements (% of total watershed) for wet ponds (i.e. basins).

(Pitt and Voorhees, 1997)

Operating and Maintenance Costs

Over the lifetime of a SMP, the operating and maintenance costs can be a significant expense that must be considered when selecting a treatment method. However, no data was found that documented actual O&M costs of existing SMPs. At best, available data consisted only of expected or predicted O&M costs of recently constructed SMP projects. Often times, general guidelines of estimated annual O&M costs were presented as a percentage of the total

construction cost. For example, the USEPA (1999a) gives a summary of typical SMP annual O&M costs as shown in the middle column of Table 5. Also included in the right column of Table 5 is the range of the authors' collection of predicted O&M costs as a percent of the construction cost.

Ideally the estimate of TPC would be based on actual O&M costs of existing SMPs but, as mentioned above, estimated annual O&M costs were the only available data. When this data was evaluated to determine how the estimated O&M costs compared to those summarized by the USEPA, a trend was observed for all SMPs except infiltration trenches in which the annual O&M cost as a percentage of the construction cost decreased with increasing construction cost. The collected annual O&M cost data are shown as log-log plots in Figures 12 through 18. As with the construction cost data, the best-fit line through the data and the 67% confidence interval are shown.

SMP	Summary of Typical AOM Costs (% of Construction Cost) (USEPA, 1999A)	Collected Cost Data: Estimated Annual O&M Costs (% of Construction Costs)
Retention Basins and Constructed Wetlands	3%-6%	--
Detention Basins	<1%	1.8%-2.7%
Constructed Wetlands	2%	4%-14.1%
Infiltration Trench	5%-20%	5.1%-126%
Infiltration Basin	1%-3% 5%-10%	2.8%-4.9%
Sand Filters	11%-13%	0.9%-9.5%
Swales	5%-7%	4.0%-178%
Bioretention	5%-7%	0.7%-10.9%
Filter Strips	$320/Acre (maintained)	--
Wet Basins	Not Reported	1.9%-10.2%

Table 5. Typical annual O&M costs of SMPs.

In the following section the annual O&M costs will be combined with the unit construction costs to develop an estimate for the Total Present Cost of each SMP as a function of WQV or, in the case of swales, as a cost per linear foot as a function of swale top width.

Total Present Cost

If an estimate of the total construction cost of a SMP were desired, the data presented in Figures 5 through 10 could be used in a stand-alone manner simply by multiplying the unit construction cost ($/ft^3) by WQV (ft^3). The construction cost of swales could also be easily estimated by multiplying the unit cost ($/ft) by the swale length (ft). However, a more practical estimate is that of the total costs needed to not only construct but also to maintain and operate the SMP. Rather than provide one estimate for total construction cost and another estimate for annual O&M expenditures, the data presented in the previous two sections will be combined in

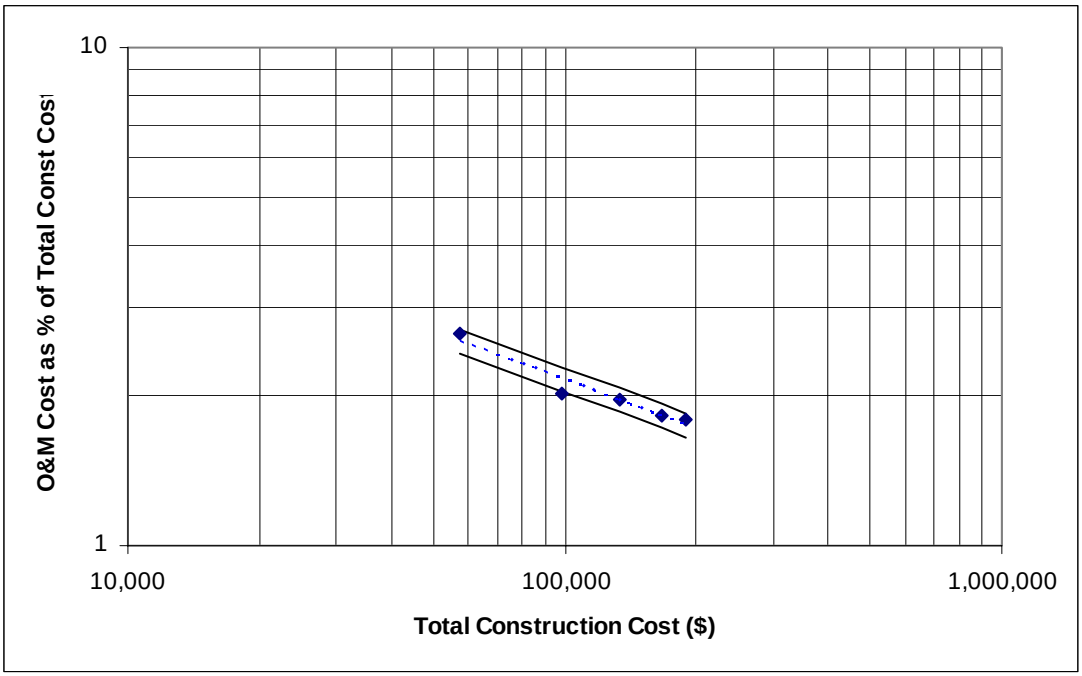

Figure 12. Annual O&M costs of dry detention basins.

(Data from Landphair, *et al*, 2000)

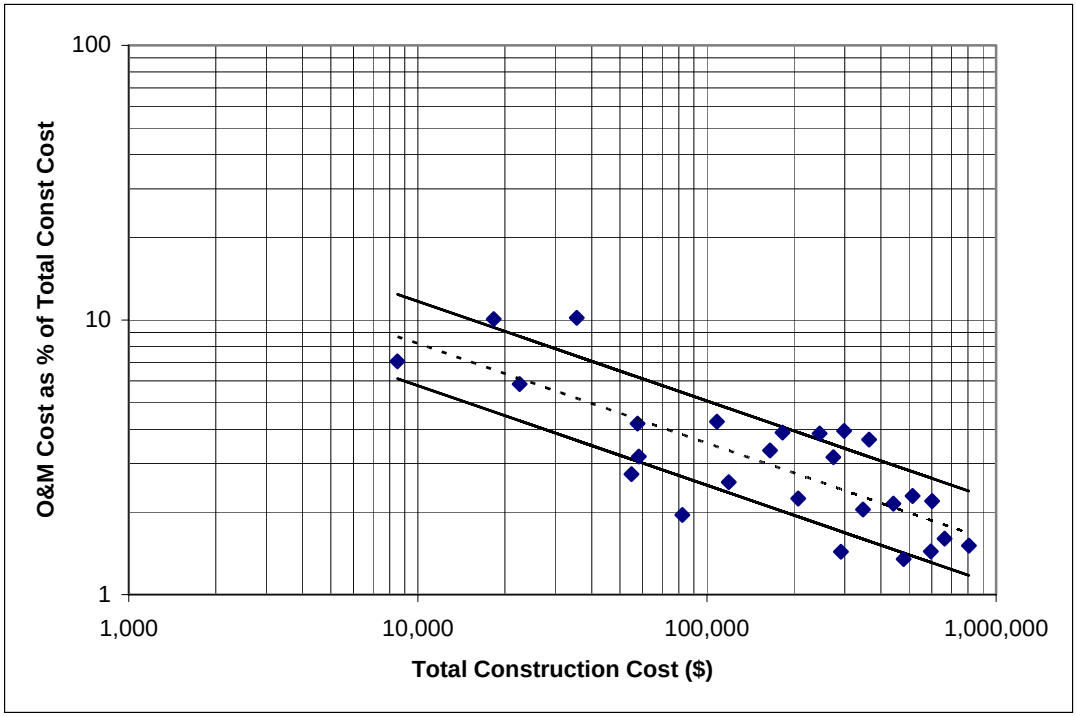

Figure 13. Annual O&M costs of wet basins.

(Data from SWRPC, 1991; Wossink and Hunt, 2003)

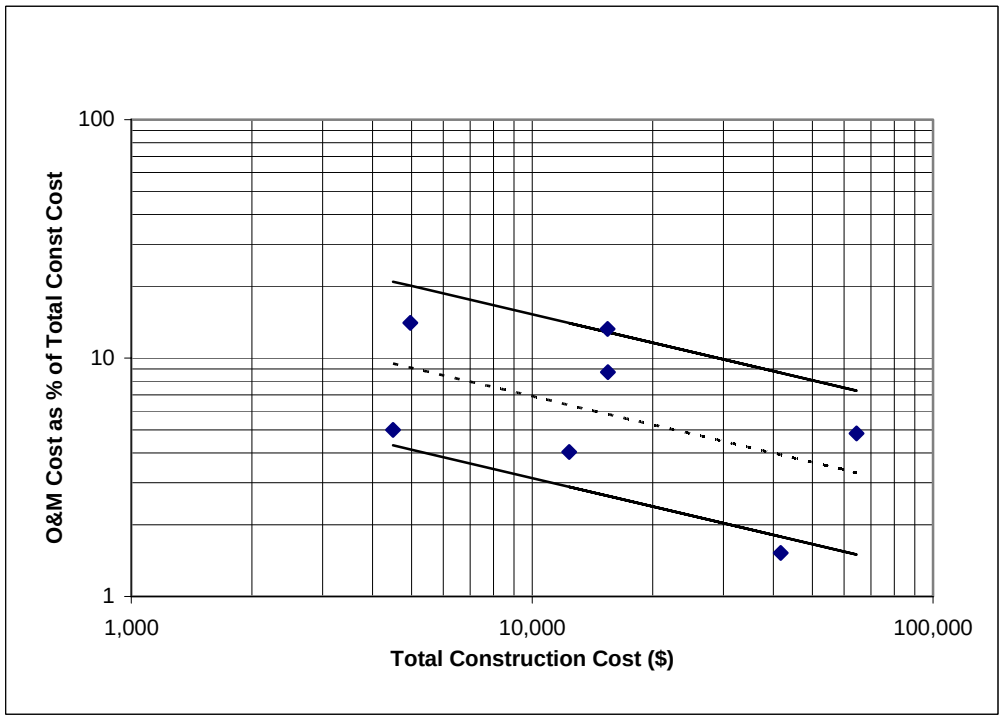

Figure 14. Annual O&M costs of constructed wetlands.

(Data from Wossink and Hunt, 2003)

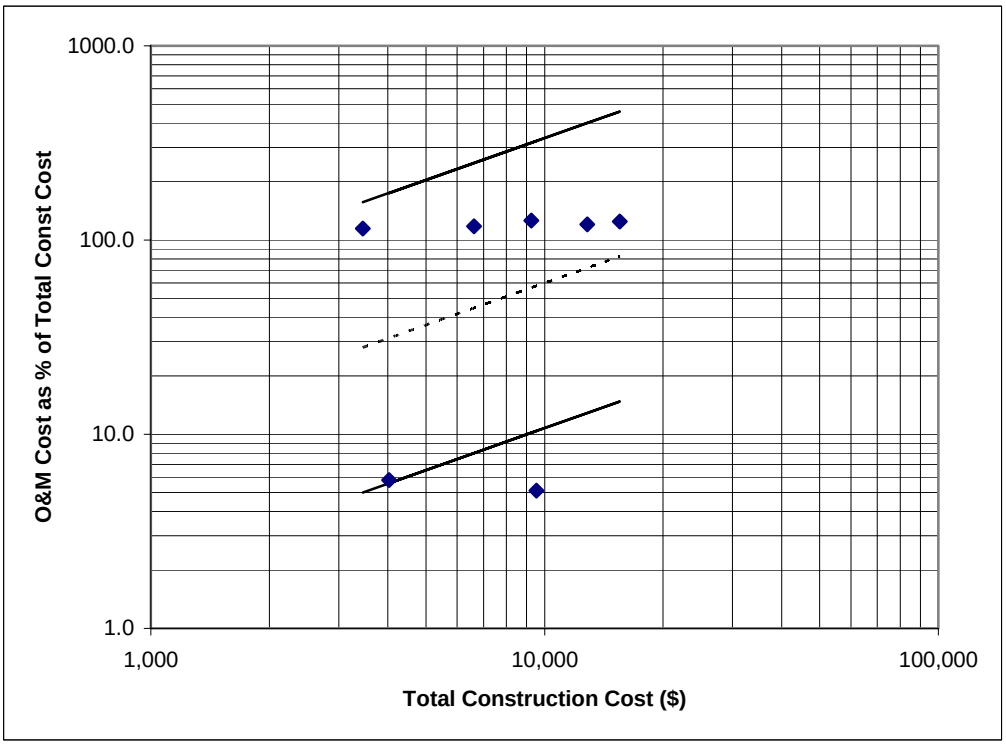

Figure 15. Annual O&M costs of infiltration trenches.

(Data from SWRPC, 1991; Landphair, *et al*, 2000)

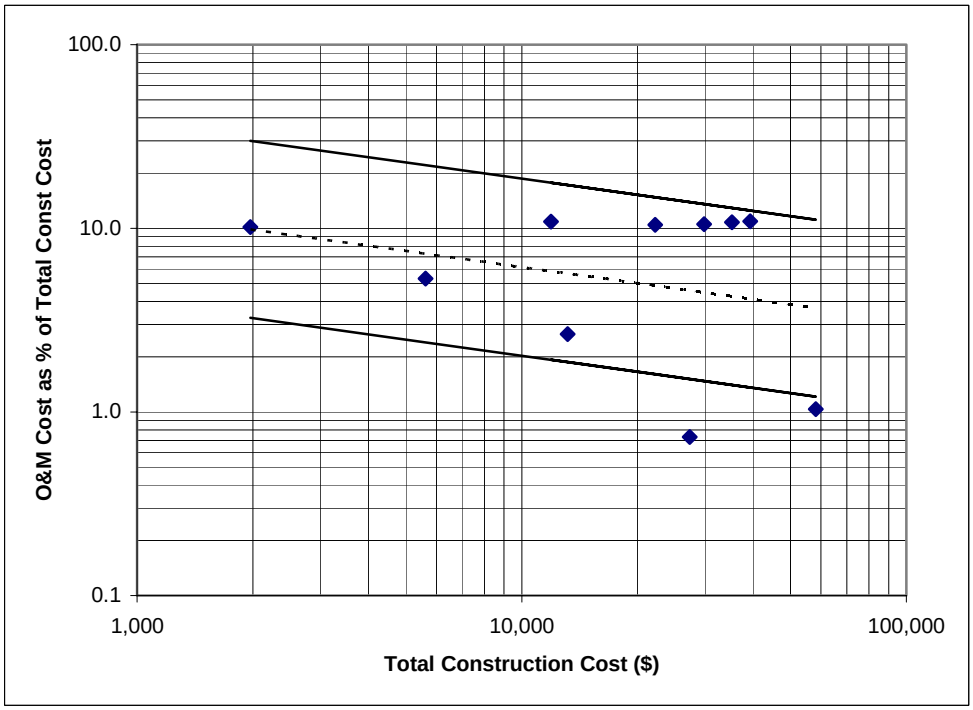

Figure 16. Annual O&M costs of bioinfiltration filters.

(Data from Landphair, *et al*, 2000; Wossink and Hunt, 2003)

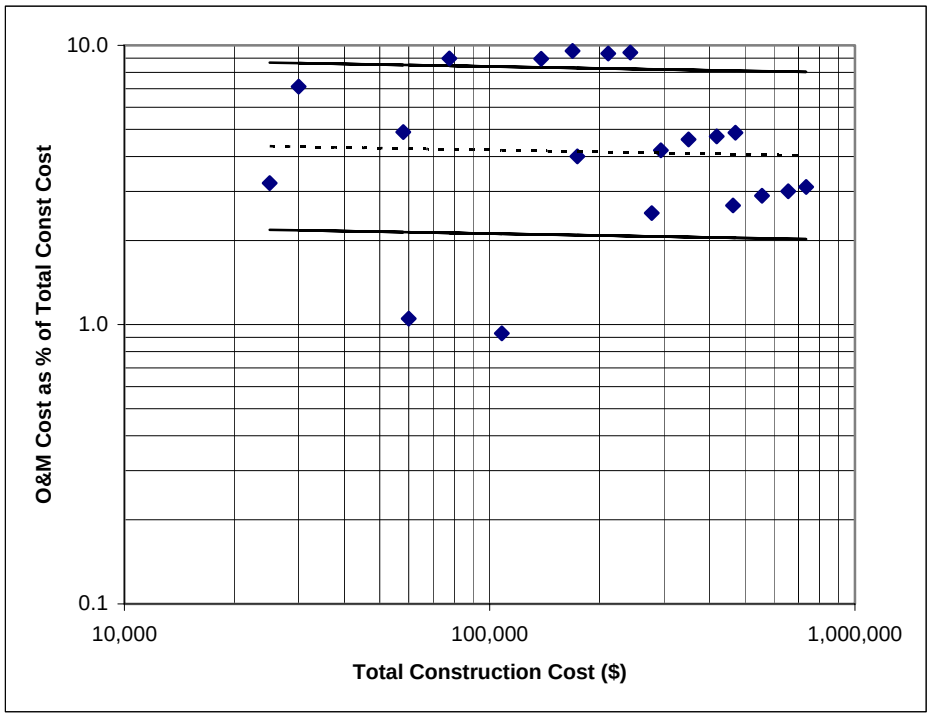

Figure 17. Annual O&M costs of sand filters.

(Data from Landphair, *et al*, 2000; Wossink and Hunt, 2003)

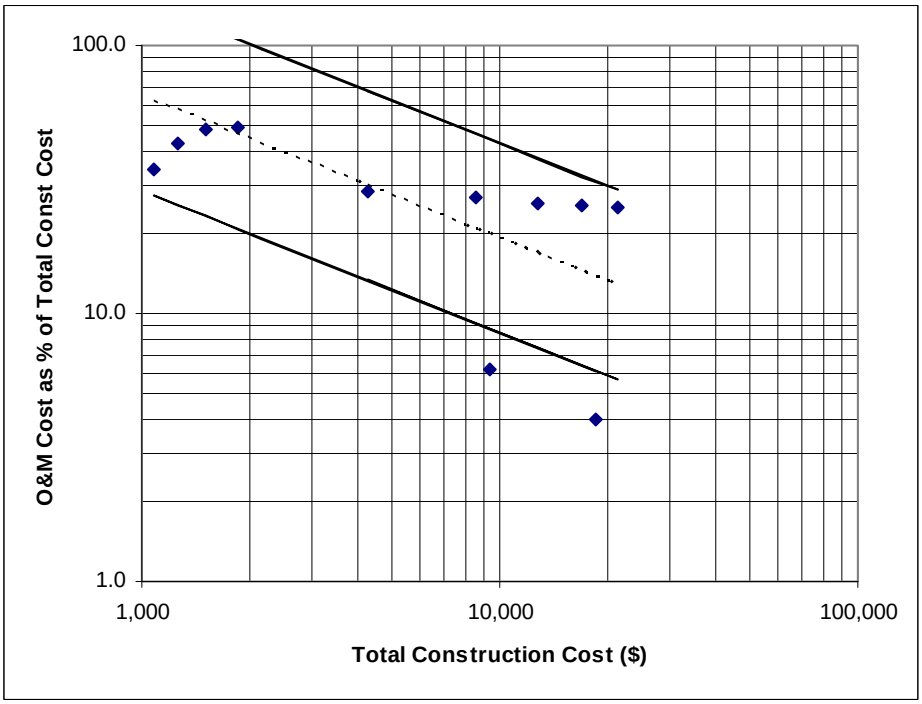

Figure 18. Annual O&M costs of grassed/vegetative swales.

(Data from Landphair, *et al*, 2000; SWRPC, 1991)

order to estimate the Total Present Cost (TPC) of each SMP as a function of size. As previously defined, the TPC is the sum of the total construction cost and the equivalent present cost of 20 years of annual O&M expenses. For each SMP, the TPC is estimated as a function of size (*i.e.* WQV or swale top width).

The Total Present Cost with a 67% confidence interval for six of the seven SMPs was estimated as a function of water-quality volume (WQV). Also, the total present cost of a 1000' long grassed/vegetative swale was estimated as a function of the swale top width. The TPC estimates incorporate the total construction cost data and annual O&M cost data presented in the previous sections. In this estimate, the annual O&M costs are converted to an equivalent present cost using historical data on the rates of municipal bond yields and inflation. The analysis method and the results for each of the seven SMPs are presented below.

In order to estimate the TPC of each SMP the total construction cost was calculated as a function of size (*i.e.* WQV or swale top width) by multiplying the corresponding unit construction cost by WQV or, in the case of swales, by the swale length. Using these values of total construction cost and the annual O&M cost data best-fit line, the annual O&M cost was estimated for each WQV or swale top width. For example, for a dry detention basin, the unit construction costs for a range of WQVs were calculated from the best-fit line shown in Figure 6. The total construction costs were then estimated by multiplying the unit construction costs by the corresponding WQV. The annual O&M costs (as a percentage of construction cost) were then estimated using the best-fit line of Figure 12. Next, the value of the annual O&M cost estimates were calculated by multiplying each percentage (as found from the best-fit line) by the corresponding total construction cost. Finally, the annual O&M costs for a 20-year period were

converted to an equivalent present cost (based on historical values of interest and inflation rates as described below) and added to the total construction cost.

Before the conversion of the annual O&M costs to an equivalent present cost is described, it must be noted that the annual O&M costs for infiltration trenches and grassed/vegetative swales were estimated in a different manner than described above. All but two of the O&M data points for these two SMPs (shown in Figures 15 and 18) were from Landphair, *et al* (2000) whose estimates ranged from 115 percent to 126 percent for infiltration trenches and 25 percent to 178 percent for grassed/vegetative swales. Since these values comprised most of the data and are high compared to the 5 percent to 20 percent for infiltration trenches and 5 percent to 7 percent for grassed/vegetative swales as summarized by the USEPA (1999a), a different method was applied when estimating these annual O&M costs. For infiltration trenches and grassed/vegetative swales, average values of the annual O&M cost (as a percent of total construction cost) based on the USEPA summary shown in Table 5 were assumed. Thus, annual O&M costs for infiltration trenches and grassed/vegetative swales were not determined from the best-fit line through the data, but rather assumed to be 12 percent (± 7%) and 6 percent (± 1%), respectively. Other than these assumptions, the TPC analysis for these two SMPs was identical to the others.

Returning to the method used to convert the annual O&M costs to an equivalent present cost and having obtained an annual O&M cost estimate, it was assumed that these costs would be incurred for 20 years. Based on this assumption, 20 years of annual O&M costs were converted to an equivalent present O&M cost using the time value of money and historical values of interest and inflation rates. Given an interest rate and inflation rate, the equivalent present cost

of the 20-year annual O&M costs can be computed by an equation modified from Collier and Ledbetter (1988) which is:

$$P = C_{OM}\left[\frac{\left(\frac{1+r}{1+i}\right)^{n} - 1}{r - i}\right] \tag{3}$$

Where: P = Equivalent present cost of 20-years of annual O&M costs

C_{OM} = annual O&M cost

r = inflation rate

i = interest rate

n = number of years (*i.e.* 20)

Equation 3 may be rewritten as:

$$P = C_{OM}[E] \tag{4}$$

where: $$E = \left[\frac{\left(\frac{1+r}{1+i}\right)^{n} - 1}{r - i}\right]$$

Using average annual Aaa municipal bond yield rates (Mergent, Inc., 2003) for interest rate values and historical Consumer Price Index (CPI) based inflation rates (Fintrend.com, 2004), the value of E was calculated for each year from 1944 through 2002. Since this analysis is based on a 20-year time span, the running 20-year average value of E was calculated for each year from 1963 through 2002. The running 20-year average values are shown in Table 6 and resulted in an overall average value of 18.68 +/- 2.29 (67% confidence interval). Returning to the example and using a value of 18.68 for E, the present equivalent cost of 20 years of annual O&M expenses were calculated over the range of WQVs and added to the corresponding total construction cost

to give the Total Present Cost (TPC) in 2005 dollars as a function of WQV. The uncertainties associated with the 67% confidence intervals of the unit construction costs, annual O&M costs as a percent of the construction cost, and inflation and interest rates (*i.e.* E) were incorporated into the TPC as described by Kline (1985).

Year	20-yr running Avg. E	Year	20-yr running Avg. E	Year	20-yr running Avg. E	Year	20-yr running Avg. E
1963	23.94	1973	17.55	1983	20.22	1993	18.23
1964	23.73	1974	18.25	1984	19.98	1994	17.41
1965	23.46	1975	18.68	1985	19.75	1995	16.91
1966	22.28	1976	18.74	1986	19.46	1996	16.74
1967	19.17	1977	18.82	1987	19.27	1997	16.36
1968	18.38	1978	19.02	1988	19.01	1998	15.93
1969	18.55	1979	19.80	1989	18.83	1999	15.12
1970	18.53	1980	20.56	1990	18.73	2000	14.32
1971	17.56	1981	20.66	1991	18.62	2001	14.12
1972	17.35	1982	20.46	1992	18.53	2002	14.27

Table 6. Yearly 20-year running average values of E.

(average of values shown is 18.68±2.29).

This method propagates the uncertainty found in each of the three above-mentioned variables (*i.e.* unit construction costs, annual O&M costs, and E) and determines the resulting uncertainty on the total present cost. Kline (1985) discusses two methods of calculating this uncertainty propagation; the first being a direct analytical solution and the second method being an approximate perturbation method. Since the unit-construction cost data is linear on a log-log plot, the linear regression through the data which gave the best-fit line was performed on the log of the unit construction costs and log of the water quality volume. Therefore, the corresponding uncertainty was also based on the log of the data and the uncertainty of the unit-cost values was estimated from this uncertainty. More specifically, the uncertainty of the unit-construction costs was estimated by raising 10 to the α power where α equals the uncertainty on the log of the data. This estimation dictated that the perturbation method be employed rather than the direct analytical solution.

The Total Present Cost (with 67% confidence interval), excluding land costs, of each SMP is shown on log-log plots as a function of WQV or swale top width in Figures 19 through 25. The range of water quality volumes for each SMP shown in these figures corresponds to the range for which construction cost data was obtained. These figures are based on historical data and are intended to be used for comparative purposes only. They are not intended to estimate costs associated with specific SMPs nor should cost be the only factor considered when selecting a SMP.

Effectiveness of Contaminant Removal

Undoubtedly an estimate of the total cost of a SMP can be a valuable aid during the planning and selection process. However, an inexpensive SMP that has minimal impact on water quality would be of little value. Thus, knowledge of the impact or effectiveness a particular

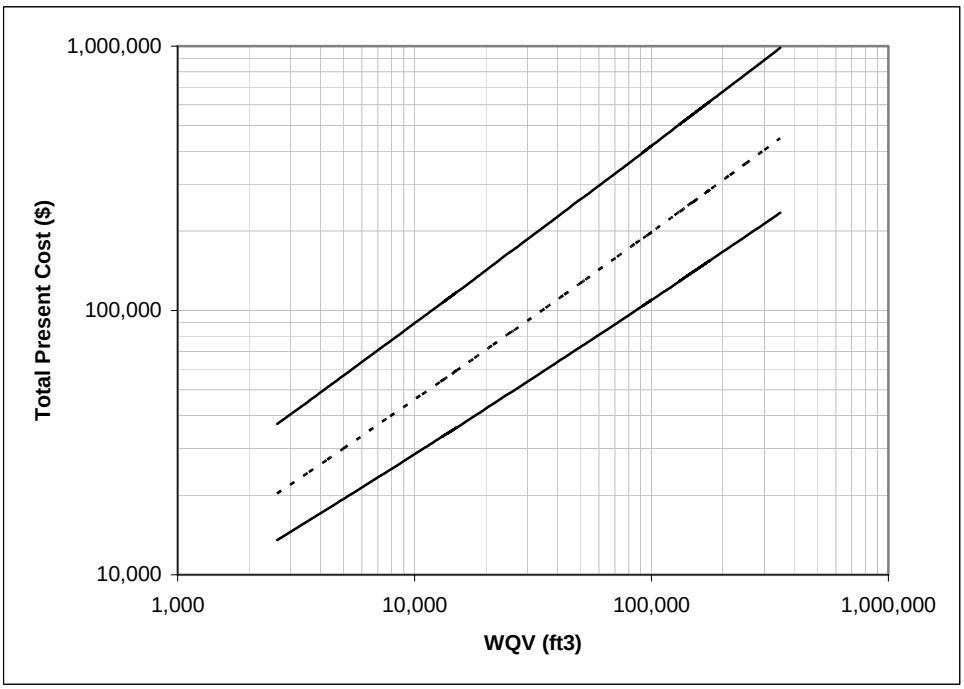

Figure 19. Total Present Cost (TPC) of dry detention basins with 67% CI. Land costs are excluded and need to be determined separately.

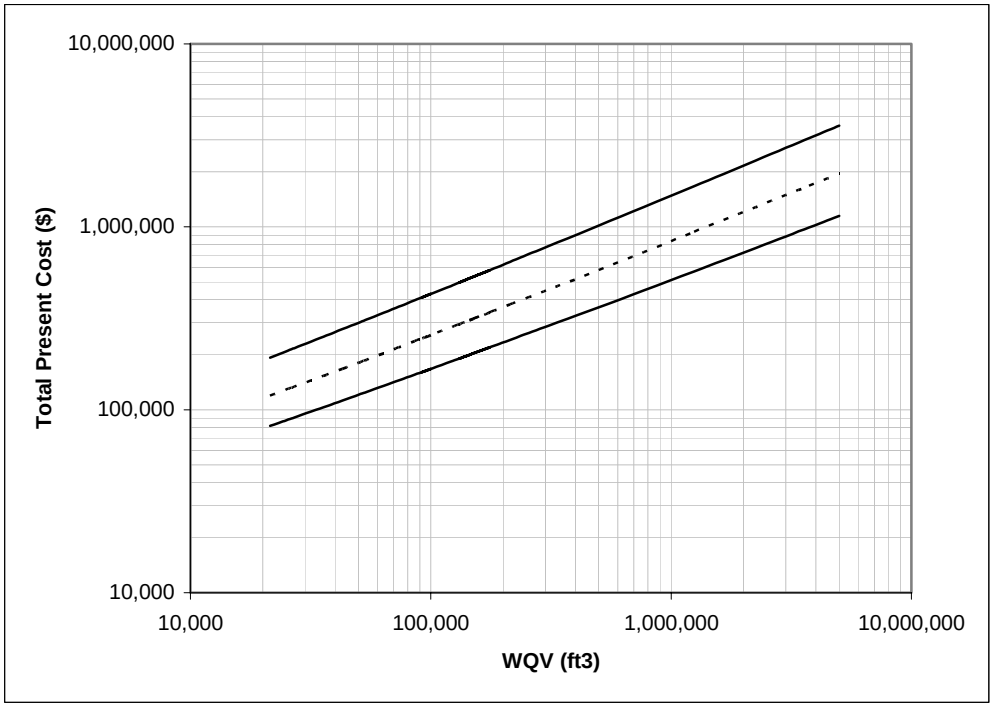

Figure 20. Total Present Cost (TPC) of wet basins with 67% CI. Land costs are excluded and need to be determined separately.

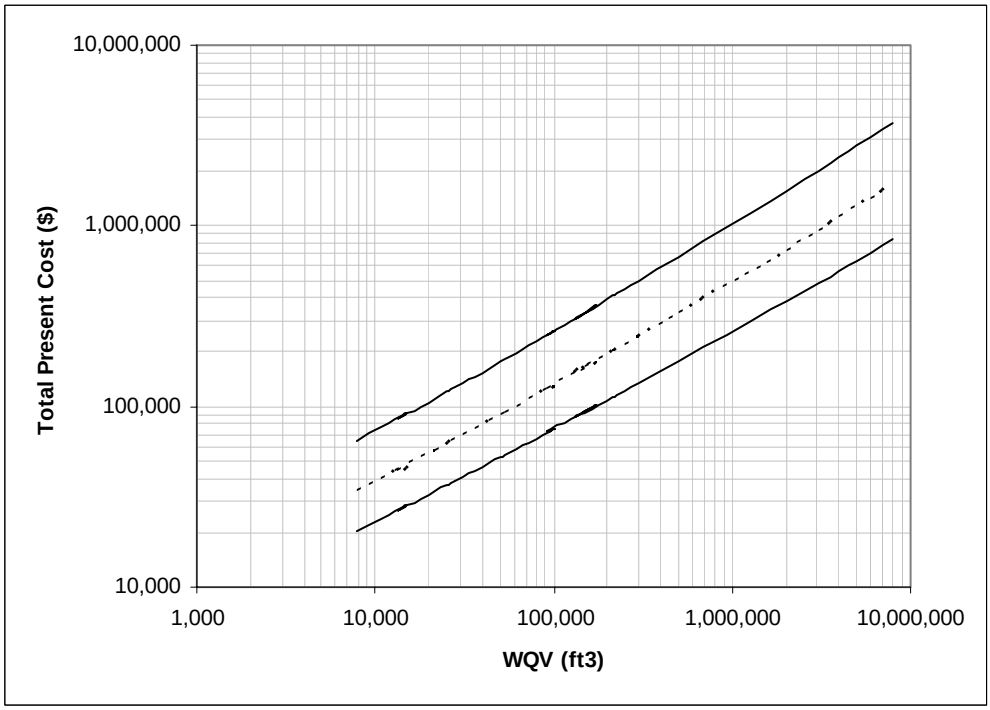

Figure 21. Total Present Cost (TPC) of constructed wetlands with 67% CI. Land costs are excluded and need to be determined separately.

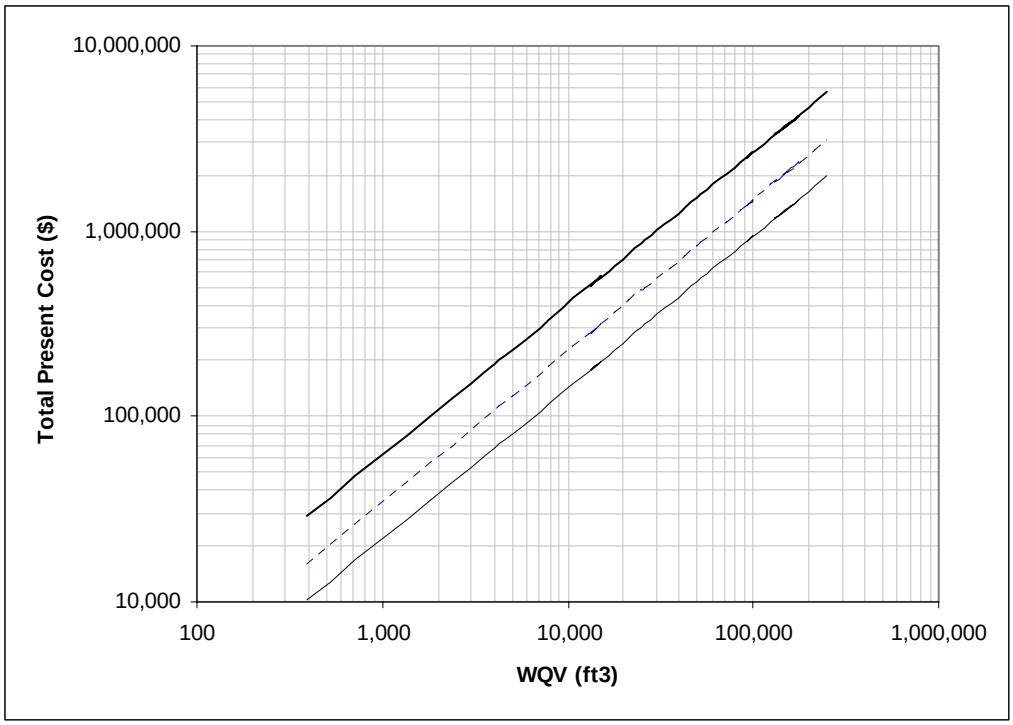

Figure 22. Total Present Cost (TPC) of infiltration trenches with 67% CI. Land costs are excluded and need to be determined separately.

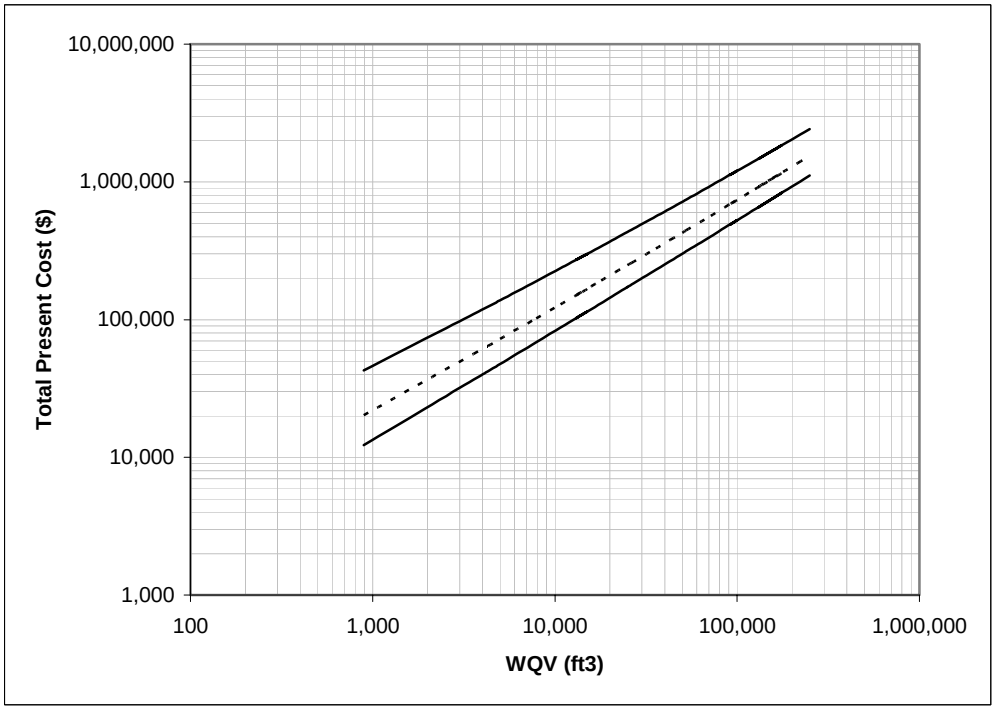

Figure 23. Total Present Cost (TPC) of bioinfiltration filters with 67% CI. Land costs are excluded and need to be determined separately.

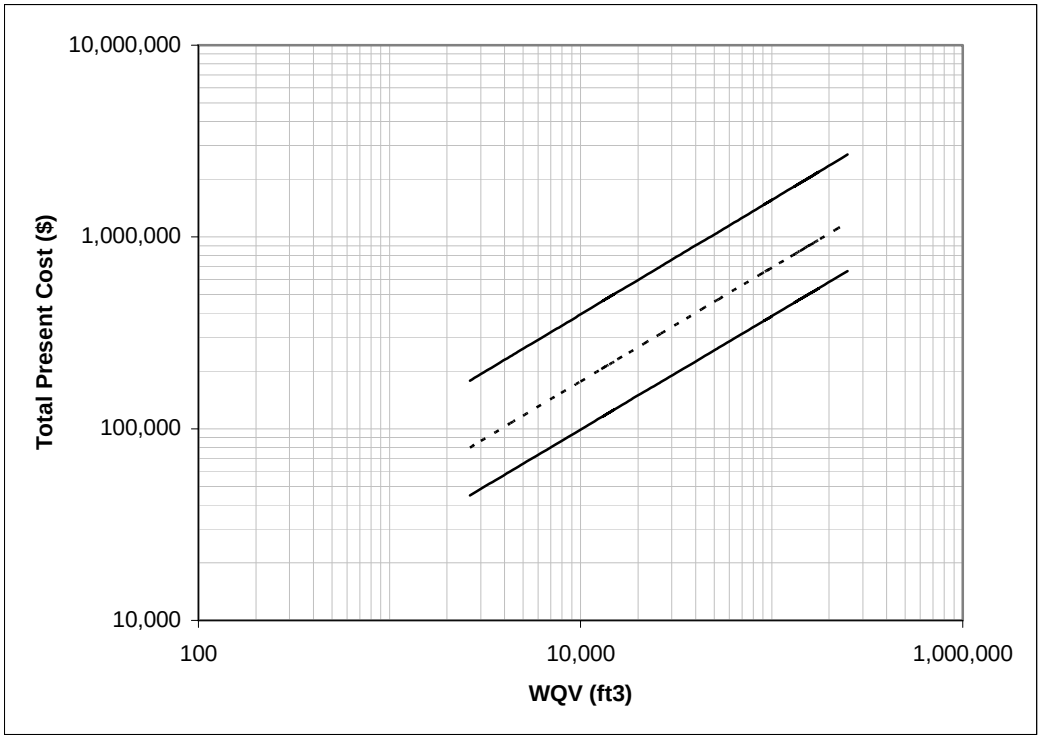

Figure 24. Total Present Cost (TPC) of sand filters with 67% CI. Land costs are excluded and need to be determined separately.

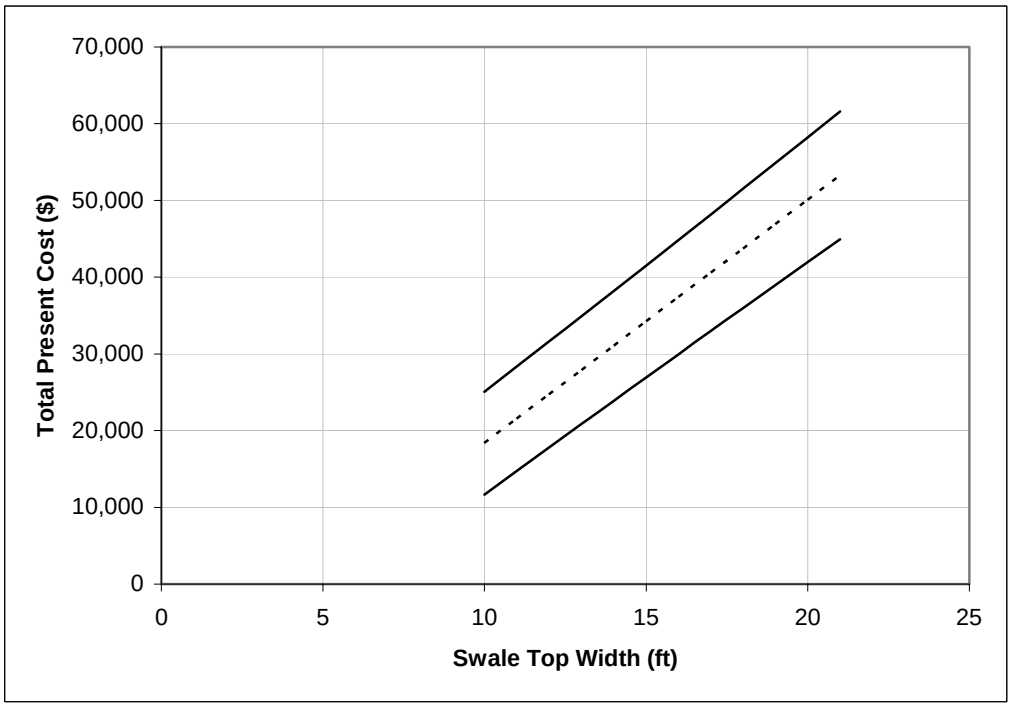

Figure 25. Total Present Cost (TPC) of 1000' long grassed/vegetative swales with 67% CI. Land costs are excluded and need to be determined separately.

SMP will have on water quality is just as important as the cost. In an effort to provide information in this area, an analysis was performed in which the total amount of TSS and phosphorus removed over a 20-year span was estimated as a function of water-quality volume. In this analysis the amount of TSS and P removed is considered to be a function of the fraction of stormwater runoff that will be treated by the SMP, the pollutant load which reaches the SMP, and the removal performance of the SMP itself. Of course, some of the variables listed above depend on other variables such as watershed area, impervious area, rainfall amounts, etc. All of these variables and the analytical method which was used to incorporate them into the estimate of total pollutant load removal is described and discussed below.

Runoff Fraction Treated

Most SMPs are designed for a particular rainfall depth used to estimate a water-quality volume or, in the case of swales, filter strips, and similar SMPs, a peak flow rate. The WQV or peak flow rate is used to size the SMP. Since an SMP is designed for a finite value of rainfall and/or runoff, there is always the chance that a given storm will produce more runoff than the unit was designed to store and/or treat. When that happens, a portion of the runoff bypasses the SMP or is discharged from the SMP via an overflow outlet and receives no treatment. In order to account for this untreated fraction of the runoff, a statistical analysis was performed on historical rainfall data in the Twin Cities. Given the design rainfall depth, the process, as described below, can be used to estimate the fraction of stormwater runoff that will be bypassed or exit the SMP without treatment.

Since design recommendations for SMPs usually state that the devices should be designed to drain in two days, two-day running sum precipitation amounts in the Twin Cities were calculated and analyzed from 1950 through 2003. For example, if the precipitation depths

measured on four consecutive days were 0.21 in., 0.13 in., 0.35 in., and 0.07 in., the data would be combined into two-day precipitation amounts of 0.34 in., 0.48 in., and 0.42 in., respectively. Using the combined data, a two-day running sum (R_S) histogram was generated using 0.10 inch increments from zero to four inches, with the last bin including any two-day sum that was greater than or equal to four inches. Of the 9,720 non-zero entries, five fell into the latter category, with the largest having a value of 10.00 inches. Columns 1 through 4 of Table 7 show the histogram in tabular form along with the frequency and cumulative frequency distributions. Subtracting the cumulative frequency from 1.00 and multiplying by 100 gives the percent exceedance as shown in column 5 and plotted in Figure 26.

Thus Table 7 and/or Figure 26 can be used to determine the fraction of two-day precipitation events that exceeded a particular precipitation depth. For example, based on Figure 26, a two-day rainfall depth of 1.00 inch was exceeded approximately 7 percent of the time over the 54-year period analyzed. Alternatively, using Table 7 and linearly interpolating between 7.43% and 6.24% gives a value of 6.84% exceedance for a precipitation depth of one inch. Furthermore, if an SMP were designed for a precipitation depth of 1.00 inch, the graph area that is both under the curve **and** below the horizontal line that corresponds to an abscissa value of 1.00 inch divided by the total area under the curve, equals the fraction of the two-day summed precipitation amounts that were below the 1.00 inch design storm depth. The values of the graph area, cumulative area, and percent of total area corresponding to each precipitation depth have been calculated and are shown in columns 6, 7, and 8, respectively, of Table 7. Due to infiltration and other abstractions of the stormwater which occur as the runoff makes it way to the SMP, this ratio is not exactly the fraction of runoff that would be treated by the SMP. That

(1) Range (in.)	(2) # of events	(3) Frequency	(4) Culm. Frequency	(5) % exceedance	(6) Area (in)	(7) Culm. Area (in)	(8) % of Total Area	(9) Rainfall Depth (in)
				100.00			0.00	0.00
0<Rs<0.1	4037	0.41533	0.41533	58.47	3.962	3.962	13.88	0.05
0.1<=Rs<0.2	1599	0.16451	0.57984	42.02	5.024	8.986	31.48	0.15
0.2<=Rs<0.3	965	0.09928	0.67912	32.09	3.705	12.691	44.45	0.25
0.3<=Rs<0.4	683	0.07027	0.74938	25.06	2.858	15.549	54.46	0.35
0.4<=Rs<0.5	501	0.05154	0.80093	19.91	2.248	17.797	62.34	0.45
0.5<=Rs<0.6	377	0.03879	0.83971	16.03	1.797	19.594	68.63	0.55
0.6<=Rs<0.7	276	0.02840	0.86811	13.19	1.461	21.055	73.75	0.65
0.7<=Rs<0.8	250	0.02572	0.89383	10.62	1.190	22.245	77.92	0.75
0.8<=Rs<0.9	171	0.01759	0.91142	8.86	0.974	23.219	81.33	0.85
0.9<=Rs<1.0	139	0.01430	0.92572	7.43	0.814	24.033	84.18	0.95
1.0<=Rs<1.1	115	0.01183	0.93755	6.24	0.684	24.717	86.58	1.05
1.1<=Rs<1.2	99	0.01019	0.94774	5.23	0.574	25.290	88.59	1.15
1.2<=Rs<1.3	98	0.01008	0.95782	4.22	0.472	25.763	90.24	1.25
1.3<=Rs<1.4	65	0.00669	0.96451	3.55	0.388	26.151	91.60	1.35
1.4<=Rs<1.5	58	0.00597	0.97047	2.95	0.325	26.476	92.74	1.45
1.5<=Rs<1.6	46	0.00473	0.97521	2.48	0.272	26.748	93.69	1.55
1.6<=Rs<1.7	34	0.00350	0.97870	2.13	0.230	26.978	94.50	1.65
1.7<=Rs<1.8	*27*	0.00278	0.98148	1.85	0.199	27.177	95.20	1.75
1.8<=Rs<1.9	*20*	0.00206	0.98354	1.65	0.175	27.352	95.81	1.85
1.9<=Rs<2.0	18	0.00185	0.98539	1.46	0.155	27.507	96.35	1.95
2.0<=Rs<2.1	18	0.00185	0.98724	1.28	0.137	27.644	96.83	2.05
2.1<=Rs<2.2	16	0.00165	0.98889	1.11	0.119	27.764	97.25	2.15
2.2<=Rs<2.3	14	0.00144	0.99033	0.97	0.104	27.868	97.62	2.25
2.3<=Rs<2.4	16	0.00165	0.99198	0.80	0.088	27.956	97.93	2.35
2.4<=Rs<2.5	9	0.00093	0.99290	0.71	0.076	28.032	98.19	2.45
2.5<=Rs<2.6	9	0.00093	0.99383	0.62	0.066	28.098	98.42	2.55
2.6<=Rs<2.7	10	0.00103	0.99486	0.51	0.057	28.155	98.62	2.65
2.7<=Rs<2.8	8	0.00082	0.99568	0.43	0.047	28.202	98.79	2.75
2.8<=Rs<2.9	8	0.00082	0.99650	0.35	0.039	28.241	98.92	2.85
2.9<=Rs<3.0	8	0.00082	0.99733	0.27	0.031	28.272	99.03	2.95
3.0<=Rs<3.1	5	0.00051	0.99784	0.22	0.024	28.296	99.12	3.05
3.1<=Rs<3.2	5	0.00051	0.99835	0.16	0.019	28.315	99.18	3.15
3.2<=Rs<3.3	2	0.00021	0.99856	0.14	0.015	28.331	99.24	3.25
3.3<=Rs<3.4	2	0.00021	0.99877	0.12	0.013	28.344	99.28	3.35
3.4<=Rs<3.5	2	0.00021	0.99897	0.10	0.011	28.355	99.32	3.45
3.5<=Rs<3.6	0	0.00000	0.99897	0.10	0.010	28.365	99.36	3.55
3.6<=Rs<3.7	2	0.00021	0.99918	0.08	0.009	28.375	99.39	3.65
3.7<=Rs<3.8	2	0.00021	0.99938	0.06	0.007	28.382	99.42	3.75
3.8<=Rs<3.9	1	0.00010	0.99949	0.05	0.006	28.388	99.44	3.85
3.9<=Rs<4.0	0	0.00000	0.99949	0.05	0.005	28.393	99.45	3.95
4.0<=Rs	5	0.00051	1.00000	0.00	0.156	28.548	100.00	10.00

# of Events= 9720 **Total Area= 28.548**

Table 7. Statistical analysis of historical 2-day precip. amounts at the MPLS-St. Paul airport.

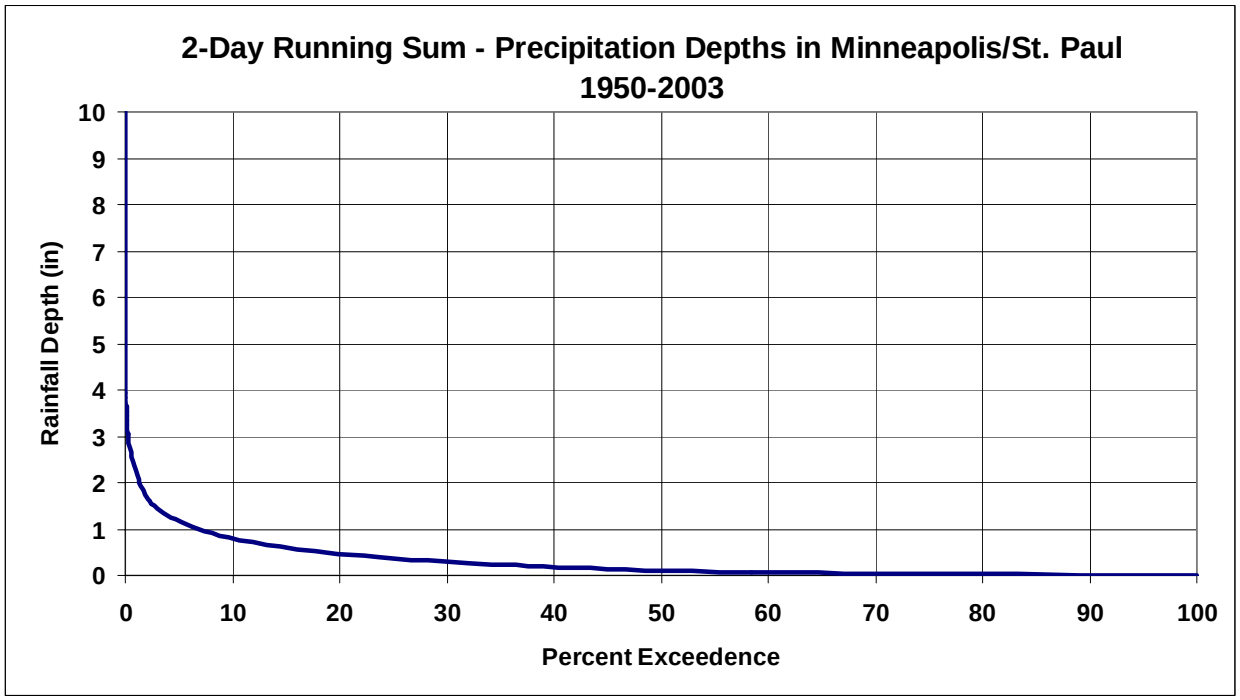

Figure 26. Exceedance probabilities of two-day precipitation depths in the Twin Cities.

would only be the case if 100 percent of the precipitation were to reach the SMP as runoff. However, the percent of total area values shown in column 8 can be used as an approximate estimate of the fraction of runoff that would be treated by an SMP designed for the corresponding rainfall depth in column 9. For example, based on columns 8 and 9 of Table 7, if an SMP was designed for a precipitation depth of 2.25 inches, it could be estimated that, based on historical data, the SMP would treat 97.62 percent of the stormwater runoff over time.

For the purposes of this report it was assumed that all SMPs would be designed for a precipitation depth of 1.45 inches which is approximately the three-month, 24-hour storm for the Twin Cities metro region (Huff and Angel, 1992). As shown in Table 7, a depth of 1.45 inches corresponds to approximately 93 percent of the area under the curve. As discussed above, it was estimated that 93 percent of all stormwater runoff will be treated by an SMP which is designed for the volume of runoff corresponding to this precipitation depth. Thus, when estimating the

total amount of TSS and P removed over 20 years, it was assumed that 93 percent of all stormwater runoff will be treated by the SMPs and the remaining 7 percent of the runoff will receive no treatment. Thus, total suspended sediment and phosphorus removal are given by:

$$\%\text{Total Removal} = 0.93 * (\%\text{Removal by SMP}) \tag{5}$$

where the "%Removal by SMP" is the removal based on inflow and treated outflow concentrations and does not consider overflow conditions. Overflow and/or bypass conditions are accounted for by multiplying the "%Removal by SMP" by 0.93.

Pollutant Loading

Several methods with a wide degree of complexity are available to estimate stormwater pollutant loads. For example, the Stormwater Management Model (SWMM) is public domain software and can be used to model single storm events or watershed basins over time. Additional methods described Young, *et al*. (1995) include regional United States Geological Survey (USGS) equations for estimation of storm loads, runoff volumes, and event mean concentrations. These equations have been developed for three regions in the United States and are based on regression analysis of nationwide data. A simplified, but less accurate, set of USGS regression equations are also available and can be used to estimate storm runoff loads and volumes. The USGS has also derived a set of equations to estimate storm mean concentrations and mean seasonal or annual loads.

The Federal Highway Administration (FHWA) has developed a method to estimate pollutant loading from highway runoff (Driscoll, *et al*., 1990). As with the USGS methods, the FHWA method is a regional method, in this case with nine regions, which involves a relatively large amount of detailed input to arrive at an estimate of annual pollutant mass loading.

The methods described above require a level of detail that is well beyond what is necessary (or perhaps possible) for the comparative purposes of this report. Thus, for this report, a modified version of a less involved method, the Simple Method, was selected to estimate pollutant loads. The Simple Method, first proposed by Schueler (1987), is widely accepted and requires only the mean annual precipitation, percent of rainfall events that produce no runoff, the drainage area, and a runoff coefficient be known. The modified Simple Method used in this report is used by the Lower Colorado River Authority (1998) and has been recommended for use by the State of Texas, Department of Transportation (Landphair, *et al*., 2000). In its modified form, the simple method is:

$$L = (0.2266) * A * R_F * R_V * C \tag{6}$$

where: L = Annual pollutant load (lb.)

A = Watershed area (acre)

R_F = Average annual rainfall (in.)

R_V = Average annual runoff coefficient (*i.e.* runoff:rainfall ratio)

C = Average annual contaminant (*i.e.* TSS & P) concentration (mg/L)

The runoff coefficient R_V, was described for water quality volume calculations and is estimated as:

$$R_V = 0.05 + 0.009 * (I) \tag{2}$$

where: I = Percent of watershed that is impervious

In order to coincide with the 20-year time span used to estimate the total present cost, the pollutant loading must also be estimated for 20 years. To accomplish this, Equation 5 must be multiplied by 20. Also, the variable R_F, must no longer be defined as the average annual rainfall but rather, the 20-year running average of annual rainfall (inches). Incorporating these small but

significant changes, the equation used to estimate the TSS and P loading over a 20-year span becomes:

$$L_{20} = 20 * 0.2266 * A * R_{F20} * R_V * C \tag{7}$$

Where: L_{20} = Estimated pollutant load over 20 years (lb.)

R_{F20} = 20-year running average of annual rainfall (in.)

and all other variables are as previously defined.

For the purposes of this report it was assumed that the watershed area A, percent impervious I, and therefore the runoff coefficient R_V, would be known without any uncertainty. To obtain an estimate of R_{F20}, a statistical analysis on historical precipitation data in Minneapolis and St. Paul from 1950 through 2003 was performed. The results showed that the 20-year running average precipitation depth is 28.44 inches +/- 1.80 inches (67% confidence interval).

In order to determine estimates of the average annual concentration of TSS and P in stormwater runoff, data was compiled from several studies and dozens of sites (Moxness, 1986; Moxness, 1987; Moxness, 1988; Driscoll, *et al*., 1990; Oberts, 1994; Barrett, *et al*., 1995; Stanley, 1996; Wu, J.S., *et al*., 1996; Sansalone and Buchberger, 1997; Barrett, *et al*., 1998; Anderle, T.A., 1999; Legret and Colandini, 1999; Waschbusch, *et al*., 1999; Carleton, *et al*., 2000; Drapper, *et al*., 2000; Brezonik and Stadelmann, 2002; Harper, *et al*., undated). Data analysis revealed that the average values of stormwater concentrations of TSS and P from sites located in the Twin Cities were essentially the same as average values of all other sites located throughout the nation and Australia. Since the data was similar, the national average values of 131 mg/L +/- 77 mg/L (67% confidence interval) for TSS and 0.55 mg/L +/- 0.41 mg/L (67% confidence interval) for total P were used. With values for R_{F20} and C estimated, the total pollutant load for TSS and P in pounds over a 20-year time frame, as estimated by Equation 7,

becomes a function of only two variables; watershed area and, with the use of Equation 2, the percent of the watershed area that is impervious.

With the selection of a storm design depth of 1.45" as previously discussed, the two remaining variables that determine the 20-year pollutant loads (*i.e.* watershed area and percent impervious) are also the same two variables that determine the WQV. Thus, for a watershed of known area and percent impervious, both the WQV and the TSS and P loads over 20 years can be estimated. In other words, for a given watershed, each value of WQV corresponds to a unique value of 20-year TSS and P loads. While pollutant loading is certainly important, the intent of this analysis is to estimate the load removed by the SMPs over a 20-year span. As with the Total Present Cost (TPC), the estimate of the pollutant load removed by each SMP will be estimated as a function of WQV. Before this analysis can be completed, however, one remaining variable, the percent of TSS and P removed by each category of SMPs, must be estimated.

Fraction of Contaminants Removed

With the fraction of runoff treated and the total 20-year pollutant load estimated, the remaining variable that must be estimated is the fraction of TSS and P removed by each type of SMP (*i.e*. "%Removal by SMP" in Equation 5). Once the removal rate of each SMP has been estimated, the total mass of TSS and P removed over the 20-year span may be estimated by multiplying the 20-year pollutant load by both the fraction of runoff treated (i.e. estimated to be 93% for a design precipitation of 1.45 inches) and the fraction of pollutant removed by the SMP. The fraction of TSS and P removed is usually reported in one of two ways; as a percent change between influent and effluent concentrations or as the percent change between the total mass load entering the SMP and the mass load exiting the SMP. Most of the data obtained were based on concentrations, however some values of reported removal rates were not clearly defined.

In order to make the estimate of SMP removal performance (*i.e.* %Removal SMP in Equation 5) as realistic as possible, published data on the performance of the various types of SMPs analyzed in this study was collected and the average removal rate with 67% confidence interval calculated. Only data from actual sites which were field tested were included. When a single site was monitored over time and had more than one removal rate reported, only the average value of the data for that site was included in the analysis.

Ideally, the estimate of total contaminant load removed over 20 years would be based on data reported as the percent of total mass load removed. However, due to limited data of this kind, this analysis combined removal rates based on mass load removed and removal rates based on the percent change in contaminant concentration between inflow to the SMP and treated outflow from the SMP. For each type of SMP the average percent removal of the combined data was calculated and assumed to be the average percent of mass load removed. When accounting for infiltration of stormwater which may occur inside some SMPs (*e.g.* wetlands, dry basins, etc.), the percent drop in the influent to effluent concentration should be smaller than the percent of mass load removed. Thus, by combining concentration-based removal rates with those based on mass loads and assuming the resulting average to be the percent of mass load removed is a conservative one.

The results are summarized in Table 8 below and the full data is included in Appendix B. Sufficient amounts of reliable data which are needed to estimate the TSS removal rate of bioretention filters and TSS and phosphorus removal rates of infiltration trenches were not available. As denoted by the asterisks in Table 8, typical values of 90 percent and 75 percent for TSS removal (for bioretention filters and infiltration trenches, respectively) as reported by the Idaho BMP Manual (undated), were used. Also assumed was the Idaho BMP Manual typical

infiltration trench phosphorus removal of 55%. The assumed values for TSS removal were either in agreement with other reported typical ranges of effectiveness, or conservative as Caltrans (2004) assumed infiltration trenches and basins remove 100 percent of TSS. Some literature, such as Caltrans (2004), have reasoned that since any water entering these SMPs is removed from the surface water, these SMPs achieve 100% removal of TSS and P. However, some dissolved contaminants may potentially reach the groundwater (MPCA, 2000) and could reenter as surface water at a later time. If this were to occur, the actual TSS and phosphorus removal of some SMPs would be less than 100%. The 67% confidence interval for these SMPs were also assumed and are denoted by an asterisk in Table 8.

SMP	%TSS Removal	TSS 67% CI	% P Removal	P 67% CI
Dry Detention Basins	53	±28	25	±15
Wet Basins	65	±32	52	±23
Stormwater Wetland	68	±25	42	±26
Bioretention Filter	90*	±10*	72	±11
Sand Filter	82	±14	46	±21
Infiltration Trench	75*	±10*	55*	±35*
Filter Strips/Grassed Swales	75	±20	41	±33

Table 8. Average percent removal rates of SMPs with corresponding confidence interval.

(* denotes assumed value)

As previously discussed, the published data used to calculate the values shown in Table 8 were reported in either percent drop in concentration between influent and effluent stormwater or percent removal of the total mass load entering the SMP. The values are based only on stormwater treated by the SMP and do not account for any portion of the flow that bypasses the SMP or exits through an overflow outlet. The confidence intervals reported in Table 8 reveal a

large amount of uncertainty in the reported data. The uncertainty is likely due to variations in design and maintenance of the SMPs. If proper maintenance is not performed, removal levels will drop. Also, parameters such as swale slope, pond and wetland residence time, etc. affect removal.

The total amount of TSS that can be expected to be removed by each SMP (except for grassed/vegetative swales) was calculated by multiplying the 20-year total TSS load by 93 percent (*i.e.* estimated percent of runoff treated) and by the corresponding removal rate as shown in Table 8. The results, with a 67% confidence interval, are shown as a function of WQV in Figures 27 through 32 below. Similarly, the amounts of phosphorus that can be expected to be removed from the various SMPs are shown in Figures 33 through 38. As with the Total Present Cost graphs, the contaminant removal estimates are shown on a log-log scale where appropriate. Also, uncertainties in contaminant concentration, 20-year running average precipitation, and percent of contaminant removal by the SMPs were incorporated by the direct analytical method described by Kline (1985).

Since swales are designed for a peak flow rate and not WQV, an estimate of the total load removed by swales over 20 years could not be estimated as a function of WQV. However, if the volume of runoff which will be treated by a swale can be estimated, the removal rates reported in Table 8 for Filter Strips/Grassed Swales may be used to estimate the corresponding total contaminant load removed.

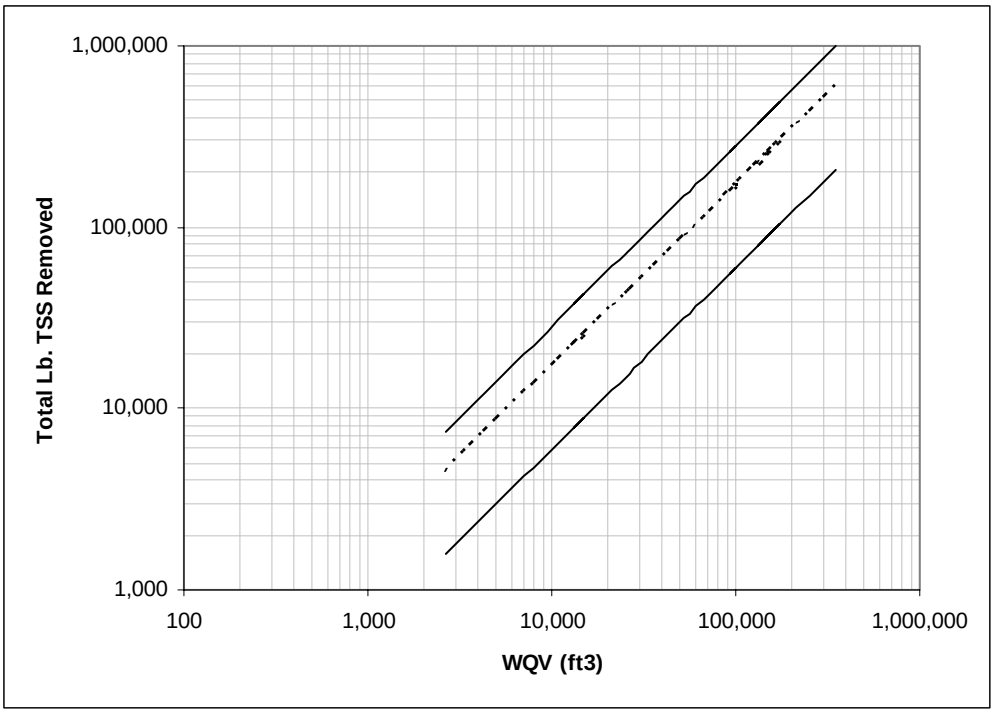

Figure 27. Estimated TSS removed in 20 years for dry detention basins with the 67% CI.

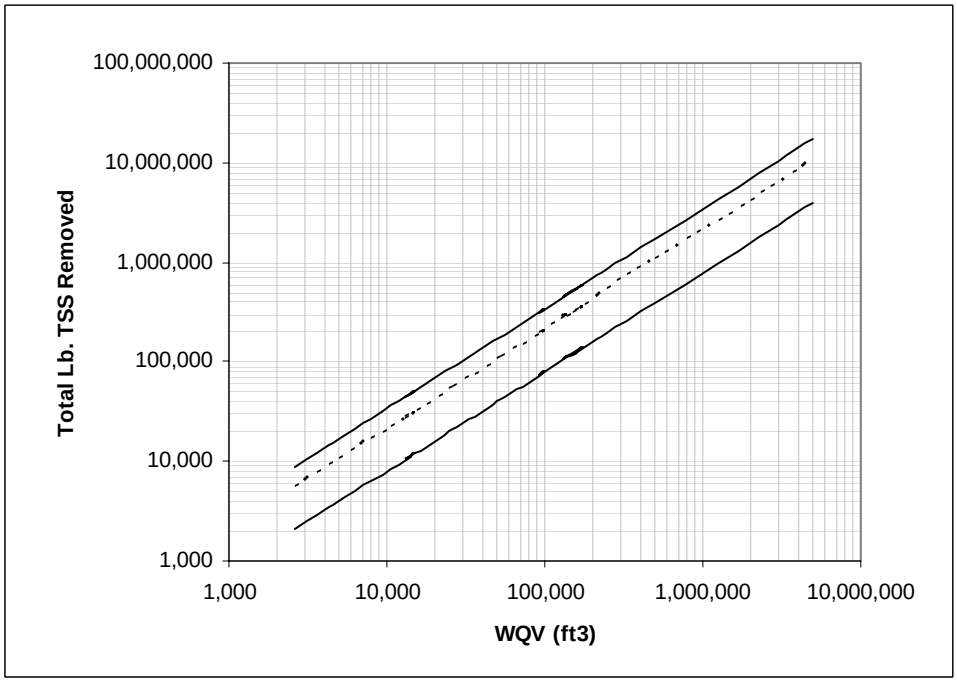

Figure 28. Estimated TSS removed in 20 years for wet basins with the 67% CI.

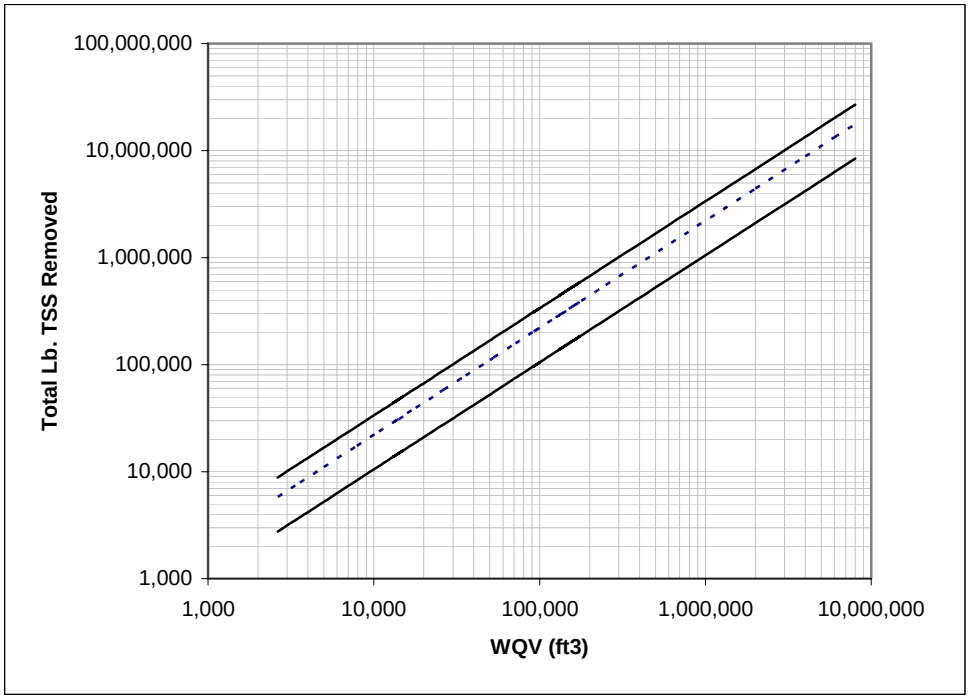

Figure 29. Estimated TSS removed in 20 years for constructed wetlands with the 67% CI.

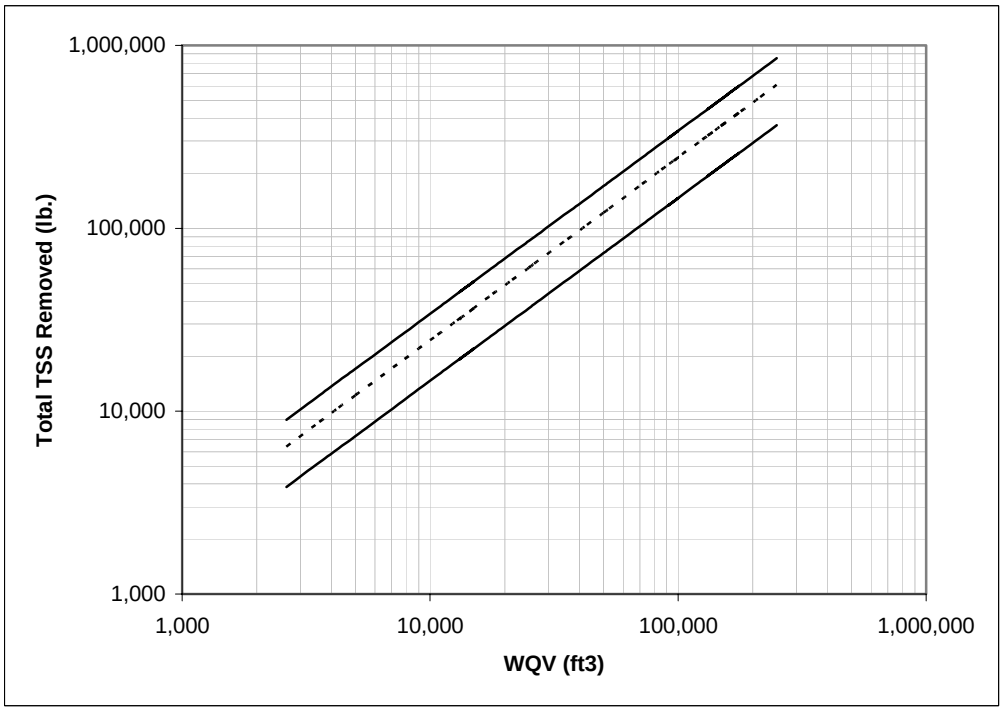

Figure 30. Estimated TSS removed in 20 years for infiltration trenches with the 67% CI.

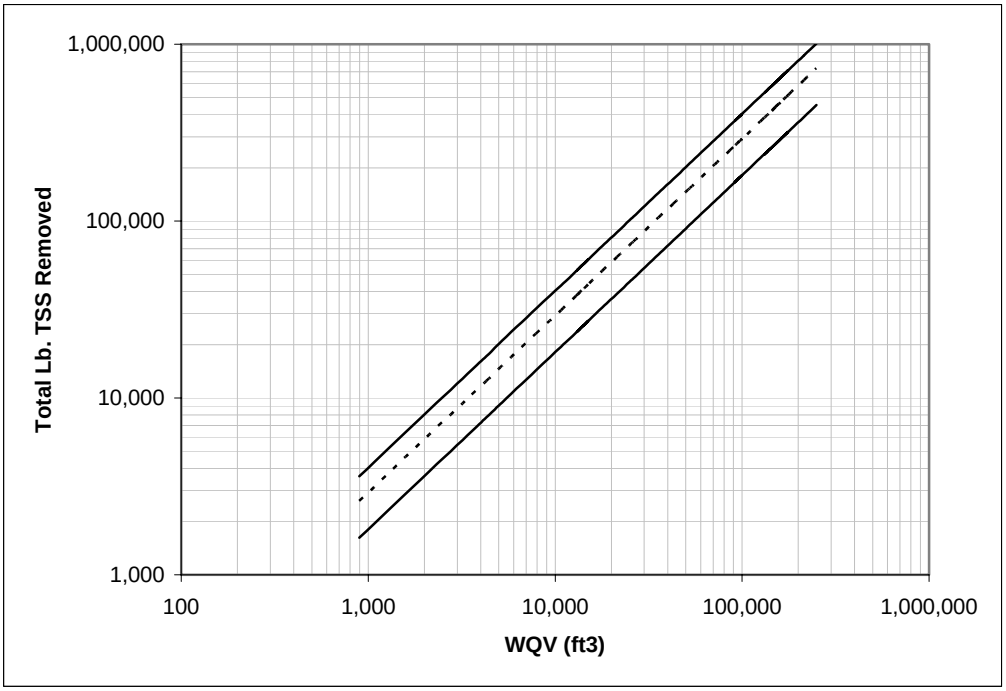

Figure 31. Estimated TSS removed in 20 years for bioinfiltration filters with the 67% CI.

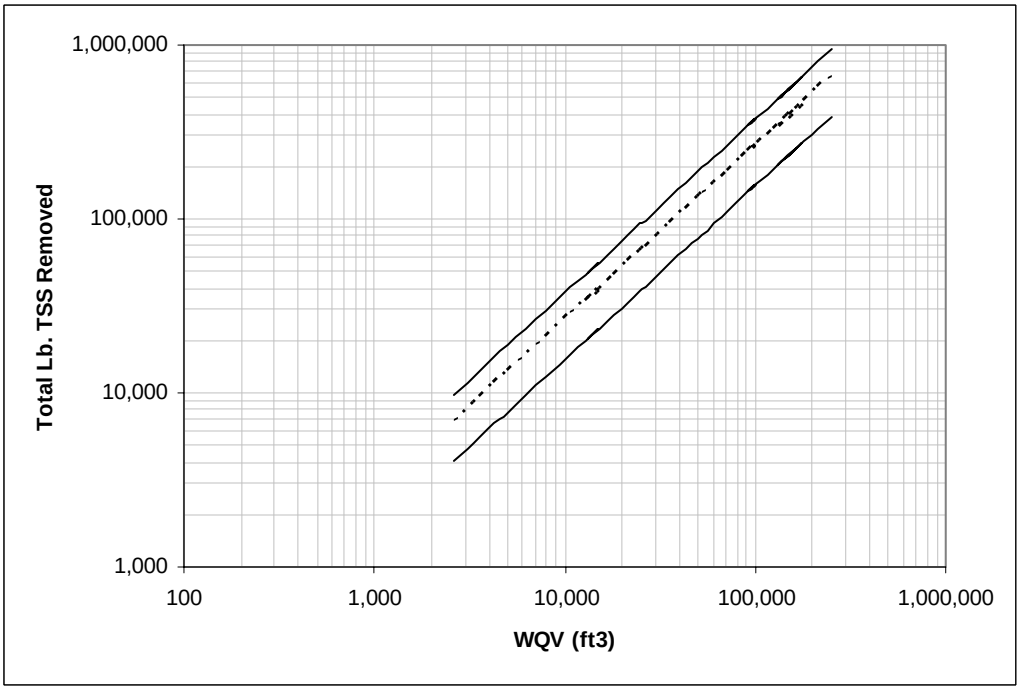

Figure 32. Estimated TSS removed in 20 years for sand filters with the 67% CI.

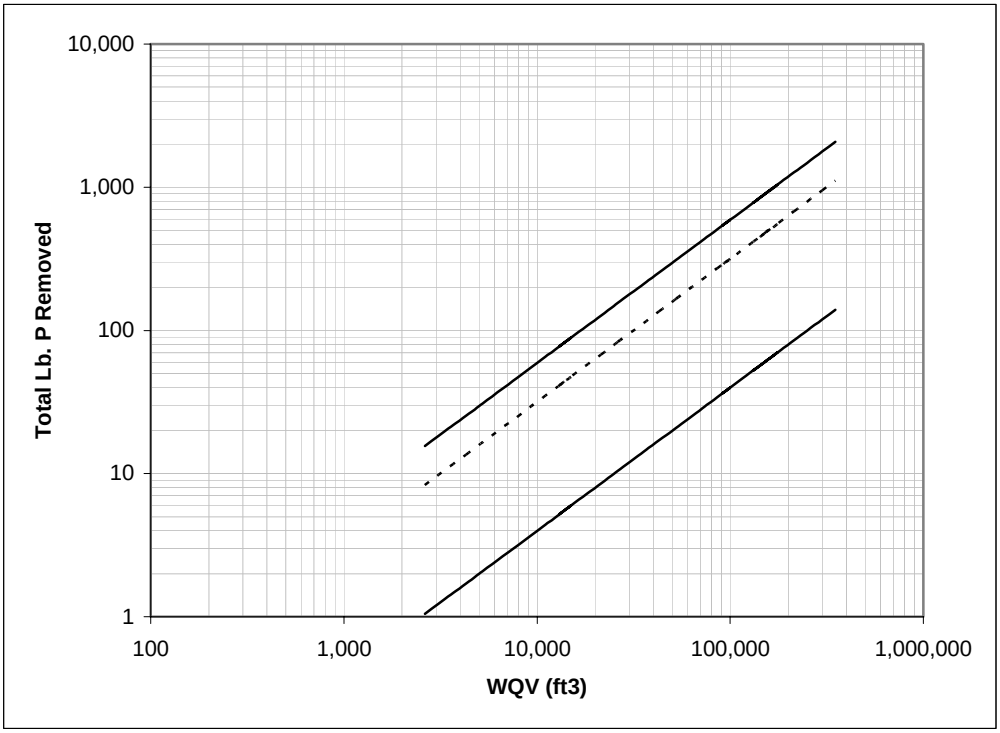

Figure 33. Estimated P removed in 20 years for dry detention basins with the 67% CI.

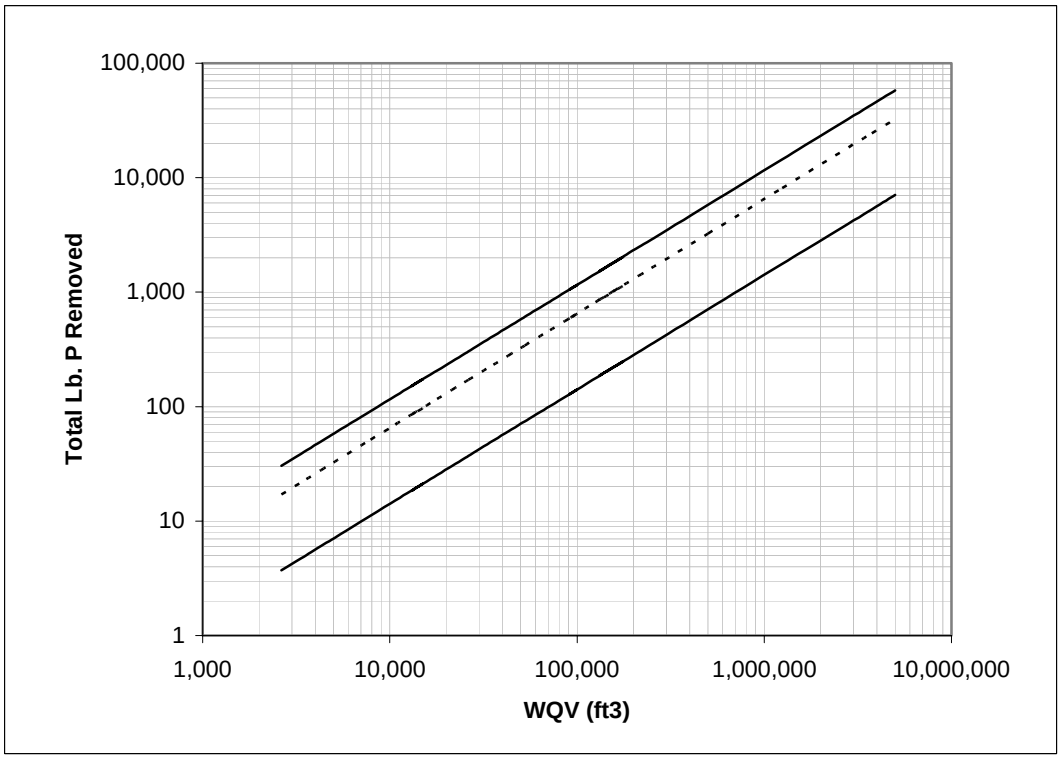

Figure 34. Estimated P removed in 20 years for wet basins with the 67% CI.

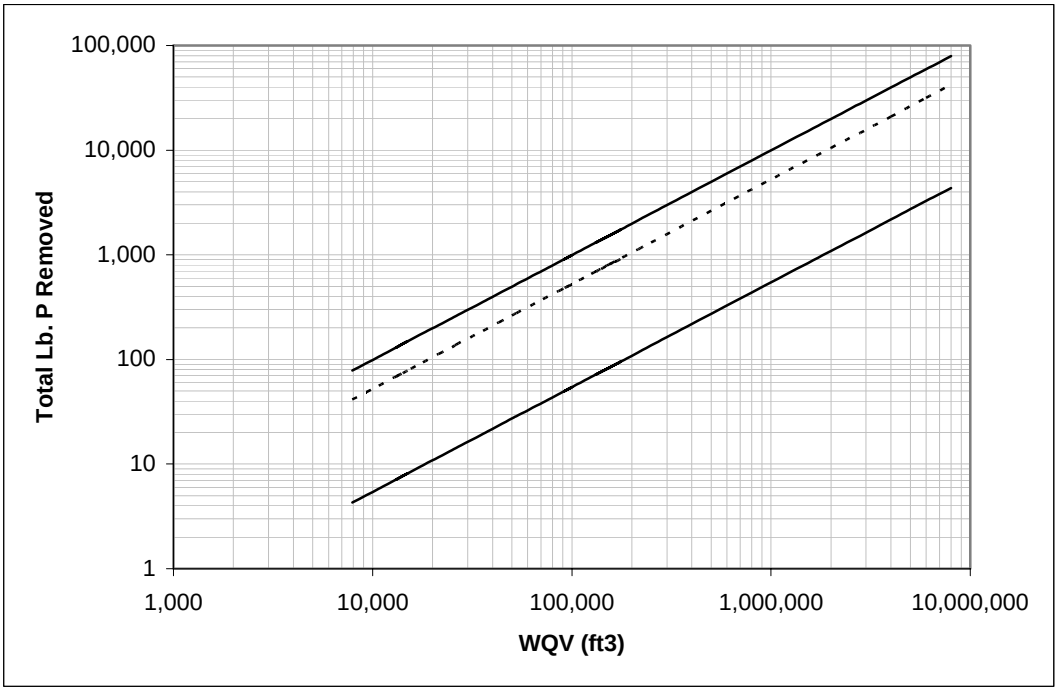

Figure 35. Estimated P removed in 20 years for constructed wetlands with the 67% CI.

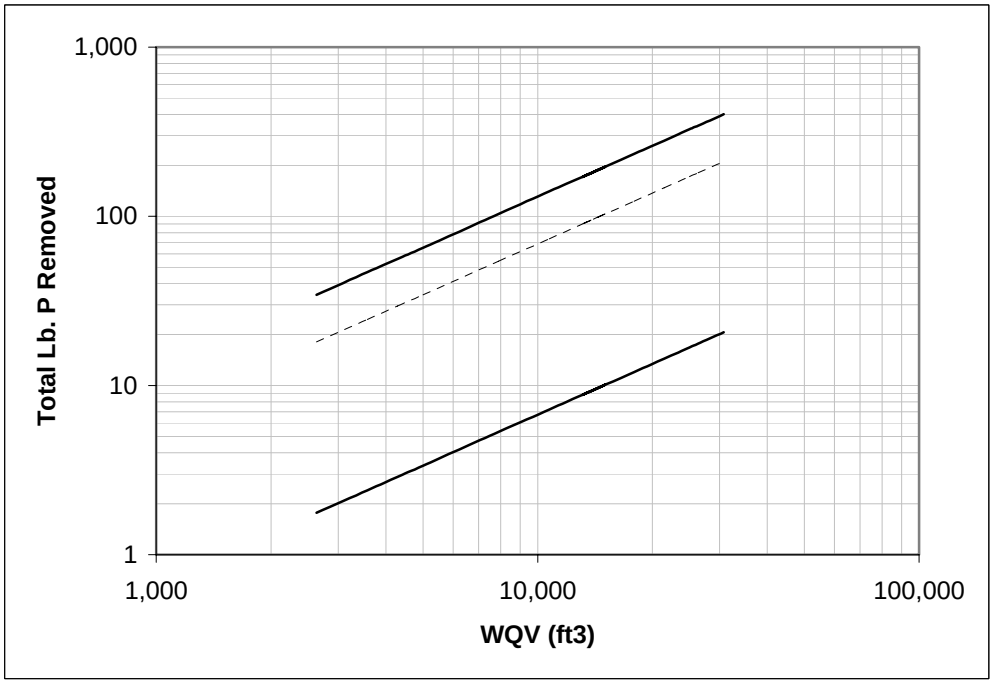

Figure 36. Estimated P removed in 20 years for infiltration trenches with the 67% CI.

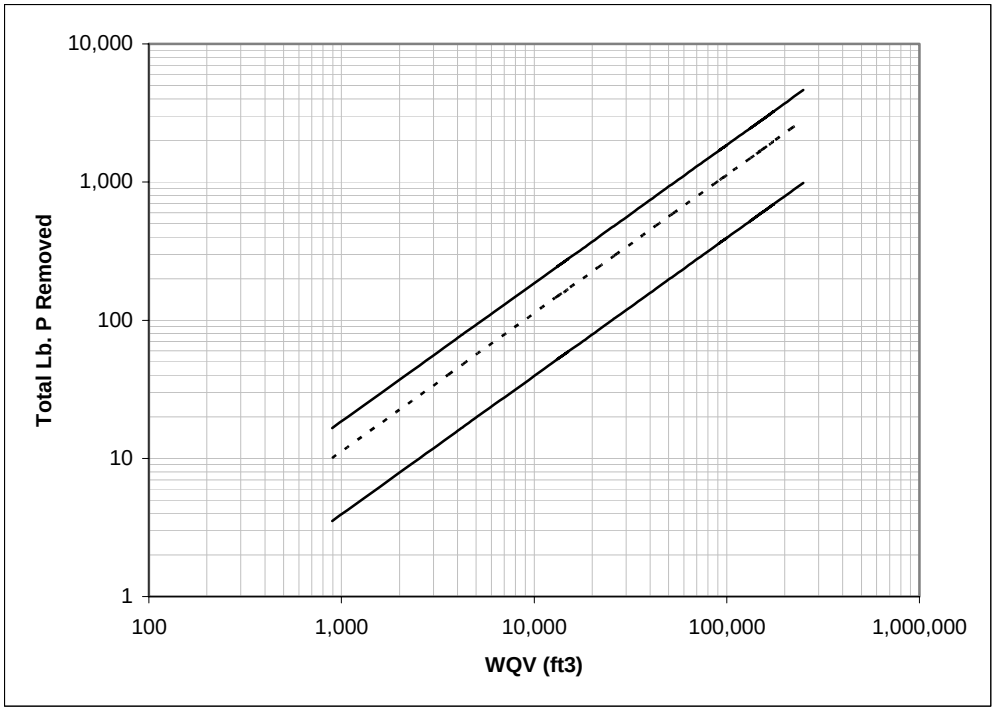

Figure 37. Estimated P removed in 20 years for bioinfiltration filters with the 67% CI.

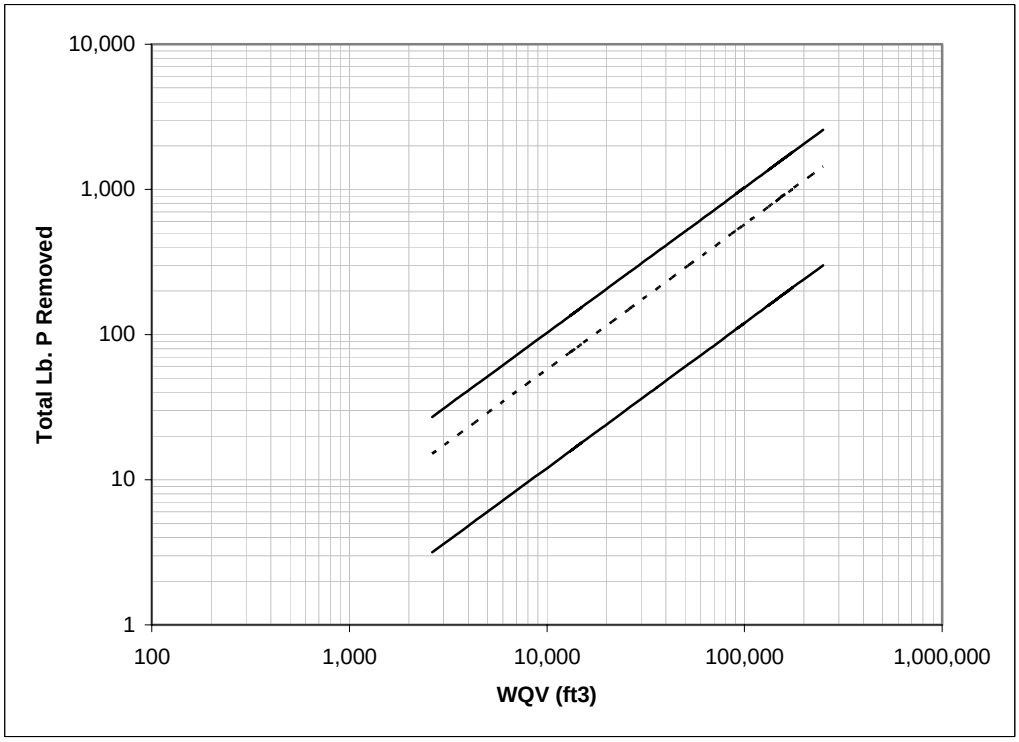

Figure 38. Estimated P removed in 20 years for sand filters with the 67% CI.

Examples

SMPs under consideration for a 50-acre watershed that is 80 percent impervious include a dry detention basin and a constructed wetland. The SMP is to be designed for a 1.45-inch precipitation depth and a comparison of the cost and effectiveness of both SMPs is desired.

Using Equations 1 and 2, the WQV can be determined as follows:

$$\mathrm{WQV} = \left(\frac{43560}{12}\right) * 1.45 * \left(0.05 + 0.009(80)\right) * 50$$

$$\mathrm{WQV} \approx 200{,}000\ \mathrm{ft}^3$$

From Figure 19, the TPC of an average dry detention basin of this size is just over $300,000 with a 67% confidence interval range of about $170,000 to $675,000. A similarly sized average wetland would, based on Figure 21, cost approximately $200,000 with a 67% confidence interval range of $110,000 to $400,000. For a comparison among all SMPs, Table 9 lists the estimated average TPC of all practices analyzed herein for various WQVs. For each SMP, TPCs are not estimated for WQVs that are outside the range of the original construction cost data. Thus some values in Table 9 do not have a cost entry.

Investigation of Table 9 reveals that, based on the collected data and in terms of TPC, wetlands are the least expensive SMP for the range of WQVs listed. This finding is somewhat similar to that of Wossink and Hunt (2003) who concluded that, in terms of construction costs, wetlands were the least expensive of four SMPs (wet ponds, constructed wetlands, sand filters, bioretention basins) for watersheds larger than 10 acres in sandy soils. Contrary to the previous conclusions, the California Stormwater Quality Association (2003) states that wetlands are relatively inexpensive but are typically 25% more expensive than stormwater ponds of equivalent volume. One must also remember that since wetlands generally require more land area, any savings in TPC may potentially be more than offset by larger land acquisition costs.

Over 20 years the estimated TSS removal and 67% confidence interval for the dry detention basin can, with the use of Figure 27, be estimated to be 344,000 pounds with a range of 120,000 pounds to 570,000 pounds. The corresponding wetland TSS removal based on Figure 29 is estimated to be 440,000 pounds with a range of 210,000 pounds to 673,000 pounds.

The phosphorus removed over 20 years can be estimated in a similar manner using Figures 33 and 35. For the dry detention basin the average P removal is approximately 630 pounds with a range of 80 to 1,200 pounds (67% confidence interval). The wetland average P removal is about 1,050 pounds with a range from about 110 pounds to about 2,000 pounds. Thus, for this watershed and design depth, the wetland, on average, would cost less to construct (not including land costs) and it would also remove more TSS and phosphorus. However, land costs must always be considered.

Focusing on associated land costs of each SMP under consideration, Table 3 can be used to estimate the range of expected land area required for each SMP. Using the values based on total watershed area and selecting the high end of each range, the dry detention basin would require 2.0 percent of the total watershed area resulting in a basin land area of 1 acre. Similarly, the wetland would require 5.0 percent of 50 acres or 2.5 acres. If land costs are known, the land areas can be used to estimate land costs associated with each SMP. For example, if land costs were $10,000 per acre, acquiring the land for the detention basin would cost an additional $10,000 and the land for the wetland would cost $25,000. The resulting total cost (now including a rough estimate for land acquisition) for the detention basin and wetland would be $310,000 and $225,000, respectively. Thus, in this relatively low land-cost scenario, the wetland would still be cheaper and more effective, on average. However, if land costs in the vicinity of the project were $250,000 per acre, an average dry detention basin would, including land, have

an estimated total cost of $550,000 and the wetland under consideration would have a total cost of $825,000. Thus, with more expensive land, wetlands are no longer the less expensive option.

	Water Quality Volume (ft^3)				
SMP	**3,000**	**10,000**	**30,000**	**100,000**	**250,000**
Dry Det. Basin	22	46	91	198	359
Wet/Ret. Basin	47	83	141	256	407
Const. Wetland	21	38	68	131	219
Infilt. Trench	84	226	554	--	--
Bioinfilt. Filter	49	122	286	--	--
Sand Filter	86	176	338	691	--

Table 9. Average Total Present Cost (in $1,000) of SMPs at varying WQVs. Land costs are excluded, and need to be determined separately.

However, wetlands are still estimated to remove more TSS and phosphorus, meaning that the parties involved would have to weigh the increased cost of the wetland against its added benefit (*i.e.* more contaminant removal). This example and the intended use for this report are preliminary in nature; to obtain a more accurate estimate of costs a more detailed design of each SMP should be completed.

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Appendix A - Pollutant Removal Capability Table: References, Notes and Notation

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS: A REVIEW

NOTE: The table below provides summary data on the pollutant removal capability of nearly sixty stormwater pond and wetland systems. Each study differs with respect to pond design, number of storms monitored, pollutant removal calculation technique, and monitoring technique, so exact comparisons between studies are not appropriate.

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
DRY ED	1	Lakeridge	VA	28	88.0	0.00	14.0	20.0	(-6.0)	10.0	9.0	(-1.0)		(-10.0)	
	2	London Commons	VA	27	11.4	0.22	A: 29.0 B: 74.0	40.0 56.0		25.0 60.0		17.0 41.0	39.0 25.0	24.0 40.0	
	3	Stedwick	MD	25	34.0	0.30	70.0	13.0		24.0		27.0	62.0	57.0	TKN: 30.0
	4	Maple Run III	TX	17	28.0	0.50	30.0	18.0		35.0	52.0	22.0	29.0	(-38.0)	TOC: 30.0 Cu: 31.0 BOD: 35.0 NH3: 55.0 FColi: 78.0
	5	Oakhampton	MD		16.8	0.50*	87.0	26.0	(-12.0)		(-10.0)				NH4: 53.5
	6	None given	KS	19	12.3	3.42	3.0	19.0	0.0		20.0	16.0	66.0	65.0	

Note: An asterisk (*) denotes an inferred value

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Note: DRY ED stands for Dry Extended Detention. Extended detention systems, as referred to in the above table are synonymous with dry detention basins, and are designed to release all runoff influent within a 24 hour period.

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET PONDS	7	Seattle	WA	5	0.75		86.7	78.4				64.4	65.1	65.2	Cu: 66.5
	8	Boynton Beach	FL	8			91.0		76.0		87.0				TKN: 58.0
	9	Grace Street	MI	18		VB/VR=.52	32.0	12.0		6.0	(-1.0)		26.0		TKN: 7.0 BOD: 3.0
	10	Pitt-AA	MI	6	4872.0	VB/VR=0.52	32.0	18.0			7.0	23.0	62.0	13.0	TKN: 14.0 BOD: 21.0
	11	Unqua	NY	8		VB/VR=3.07	60.0	45.0					80.0		TOC: 7.0
	12	Waverly Hills	MI	29		VB/VR=7.57	91.0	79.0		62.0	66.0	69.0	95.0	91.0	Cu: 57.0 TKN: 60.0 BOD: 69.0
	13	Lake Ellyn	IL	23		VB/VR=10.70	84.0	34.0					78.0	71.0	Cu: 71.0
	14	Lake Ridge	MN	20	315.0	0.08	A: 90.0 B: 85.0	61.0 37.0	11.0 8.0	41.0 24.0	10.0 17.0		73.0 52.0		TKN: 50.0 TKN: 28.0
	15	West Pond	MN	8	76.0	0.15	65.0	25.0			61.0		8.0-79.0	66.0	TOC: 19.0 TKN: 23.0 Cr: 48.0-76.0 Cd: 12.0-91.0
	16	McCarrons	MN	21	608.0	0.19	91.0	78.0		85.0		90.0	90.0		
	17	McKnight Basin	MN	20	725.0	0.22	A: 85.0 B: 85.0	48.0 34.0	13.0 12.0	30.0 14.0	24.0 11.0		67.0 63.0		TKN: 31.0 TKN: 15.0
	18	Monroe Street	WI		238.0	0.26	90.0	65.0	70.0			70.0	70.0	65.0	Cu: 75.0 FColi: 70.0 Pest: 25-50.0 Hydro: 75-90
	19	Runaway Bay	NC	5	437.0	0.33	54.0	24.0						42.0	TKN: 20.0

Note: An asterisk (*) denotes an inferred value

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
	20	Buckland	CT	7	20.0	0.40	61.0	45.0			22.0		18.0–59.0	51.0	Cd: < 0 TKN: 24.0 TOC: 33.0 Cu: 38.0
	21	Highway Site	FL	13	41.6	0.55	65.0	17.0		21.0		7.0	41.0	37.0	
	22	Woodhollow	TX	14	381.0	0.55	54.0	46.0		39.0	45.0	41.0	76.0	69.0	TKN: 26.0 NH3: 28.0 BOD: 39.0 FColi: 46.0
	23	SR 204	WA	5	1.8	0.60	99.0	91.0				69.1	88.2	87.0	Cu: 90.0
	24	Farm Pond	VA		51.4	1.13	85.0	86.0	73.0	34.0					NH3: (–107.0)
	25	Burke	VA	29	27.1	1.22	(–33.3)	39.0	77.0	32.0		21.0	84.0	38.0	
WET PONDS	26	Westleigh	MD	32	48.0	1.27	81.0	54.0	71.0	37.0		35.0	82.0	26.0	TKN: 27.0
(Cont'd)	27	Mercer	WA	5	7.6	1.72	75.0	67.0				76.9	23.0	38.0	Cu: 51.0
	28	I-4	FL	6	26.3	2.35	54.0	69.0			97.0		41.0–94.0	69.0	TOC: 45.0 TKN: 68.0 Cd: 43.0–51.0 Cu: 66.0–81.0
	29	Timber Creek	FL	9	122.0	3.11*	64.0	60.0	80.0	15.0	80.0				
	30	Maitland	FL	30–40	49.0	3.65			90.0		87.0		95.0	96.0	PP: 11.0 Cu: 77.0 NH3: 82.0
	31	Lakeside	NC	5	65.0	7.16	91.0	23.0						82.0	TKN: 6.0

Note: An asterisk (*) denotes an inferred value

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
WET ED	32	Uplands	ONT	5	860.0		82.0	69.0							FColi: 97.0
	33	East Barrhaven	ONT		2139.0	0.12	52.0	47.0							FColi: 56.0
	34	Kennedy-Burnett	ONT	6	395.0	0.62	98.0	79.0		54.0			39.0	21.0	BOD: 36.0 FColi: 99.0
STORMWATER WETLANDS	35	EWA3	IL				72.0	59.0			70.0				Fe: 48.0
	36	EWA4	IL				76.0	55.0			42.0				Fe: 43.0
	37	EWA5	IL				89.0	69.0			70.0				Fe: 50.0
	38	EWA6	IL				98.0	97.0			95.0				Fe: 92.0
	39	B31	WA	13	461.7	0.01	14.0	(-2.0)			4.0				
	40	PC12	WA	13	214.8	0.03	56.0	(-2.0)			20.0				
	41	McCarrons	MN	21	608.0	0.31	87.0	36.0		24.0		79.0	68.0		
	42	Queen Anne's	MD			0.50*	65.0	39.0	44.0	23.0	55.0				NH4: 55.0 ON: (- 5.0) PP: 7.2
	43	Swift Run	MI	5	1207.0	0.60	85.0	3.0	29.0		80.0	2.0	82.0		BOD: 4.0
	44	Tampa Office Pond	FL	3 - 8	6.3	0.61	64.0	55.0	65.0					34.0	ON: (-3.7)
	45	Highway Site	FL	13	41.6	0.81	66.0	19.0		30.0		18.0	75.0	50.0	
	46	Palm Beach PGA	FL		2340.0	2.00*	50.0	62.0			33.0				NH3: 17.0 BOD: 35.0 TOC: 10.0 TKN: 16.0
ED WETLANDS	47	Benjamin Franklin	VA		40.0	0.08	62.0	14.9	23.6		60.0			(-73.5)	Cd: (-79.8) NH3: 0.0 TKN: 4.4

Note: An asterisk (*) denotes an inferred value

Note: WET ED stands for Wet Extended Detention. Extended detention systems, as referred to in the above table are synonymous with retention basins, and are designed to store runoff until a runoff event displaces the amount of water stored.

THE POLLUTANT REMOVAL CAPABILITY OF POND AND WETLAND SYSTEMS...

TYPE	NO.	NAME	STATE	NO. OF STORMS	WATER-SHED AREA (Acres)	TREAT-MENT VOL. (In./Acre)	REMOVAL EFFICIENCY (%)								
							TSS	TP	SP	TN	NO3	COD	Pb	Zn	OTHER
ED WETLANDS (Cont'd)	48	Tanner's Lake	MN	10	413.0	0.10	A: 62.0 B: 63.0	24.0 7.0	10.0 (-14.0)	36.0 5.0	23.0 1.0		63.0 59.0		TKN: 40.0 TKN: 7.0
	49	Mays Chapel	MD		97.0	0.10*	24.0	16.0	24.0		35.0				NH3: 43.0
	50	Clear Lake	MN		1070.0	0.15*	76.0	54.0	40.0						TKN: 25.0 NH3: 55.0
NATURAL WETLANDS	51	Hidden Lake	FL		55.4	1.08*	83.0	7.0	(-109.0)	(-1.6)	80.2		54.0	40.0	ON: (-24.0) Cu: 40.0 NH3: 62.0 Cd: 70.0 BOD: 81.0
	52	Wayzata	MN		73.0	1.25*	94.0	78.0					94.0	82.0	NH3: (-44.0) Cd: 67.0 Cu: 80.0
POND/WETLAND SYSTEMS	53	Lake Munson	FL	3	23393.0		92.0	64.0		11.0	15.0	28.0	55.0	59.0	NH4: (-39.0) TKN: 11.0 NO3: 15.0 BOD: 42.0
	54	Carver Ravine	MN	15	170.0	.30*	A: 46.0 B: 20.0	24.0 1.0	21.0 1.0	15.0 (-6.0)	18.0 9.0		42.0 6.0		TKN: 14.0 TKN: (-10.0)
	55	McCarrons	MN	21	608.0	>0.50	94.0	78.0		83.0		93.0	90.0		
	56	Lake Jackson	FL		2230.0	.88*	96.0	90.0		75.0	70.0				NH4: 37.0
	57	Highway Site	FL	13	41.6	>1.35	89.0	36.0		43.0			84.0	67.0	
	58	Long Lake	ME	11	18.0	2.0*	95.0	92.0							

Note: An asterisk (*) denotes an inferred value

Note: ED Wetlands stand for Extended Detention Wetlands. Extended detention systems, as referred to in the above table are similar to wetlands, but may store stormwater runoff for a longer period than typical wetland systems. Natural Wetlands refers to systems that have been modified or utilized for stormwater treatment from natural wetlands, as opposed to constructed systems.

Appendix B – Data used to estimate average SMP effectiveness

Appendix B1 – Dry Detention Ponds

Dry Detention Ponds								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#1	77	10	0.188	0.112	87	40	Conc. Basis
Winer, Nat'l Poll. Rem. Database, 2000	#3	68	38	0.21	0.18	44	14	"
Winer, Nat'l Poll. Rem. Database, 2000	#6	98	28	0.35	0.27	71	23	"
Winer, Nat'l Poll. Rem. Database, 2000	#6	--	--	--	--	71	14	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	I5/605 Int	--	--	--	--	5	-4	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	Manchester	--	--	--	--	70	42	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	SR56/I5	--	--	--	--	43	21	"
Caltrans 2004 BMP Retrofit Pilot Program Final Report, App F	SR78/I5	--	--	--	--	55	33	"
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Maple Run III	--	--	--	--	30	18	Mass Basis
Commings, Booth, & Horner, 2000. Stormwater Pollutant Removal in two wet ponds in Bellevue, WA. Jour. Environ. Engrg, 126(4):321-330	--	--	--	--	--	61.60	20.00	"
Stanley, 1996. Pollutant Removal by a stormwater dry detention pond. Water Environ. Research, 68(6):1076-1083.	--	127	32	0.41	0.3	75	27	Conc. Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	61	"
BMP Database. Greenville Pond, Greenville, NC	--	--	--	--	--	--	27	"

Dry Extended Detention Pond (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Lakeridge, VA	--	--	--	--	14	20	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	London Commons, VA	--	--	--	--	52	48	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Stedwick, MD	--	--	--	--	70	13	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Oakhampton, MD	--	--	--	--	30	18	unknown basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Unknown	--	--	--	--	87	26	unknown basis
Pope, L..M. and L.G. Hess, Date unknown. "Load Detention Efficiencies in a Dry-Pond Basin," from Kansas State Library.	Topeka, KS	--	--	--	--	3	19	Mass Basis

Appendix B2 – Wet Basins

Wet Basins								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Uplands, Ont	--	--	--	--	82	69	Unknown Basis
"	E. Barrhaven, Ont	--	--	--	--	52	47	"
"	Kennedy-Burnett, Ont	--	--	--	--	98	79	"
Winer, Nat'l Poll. Rem. Database, 2000	#11	177	39	0.761	0.214	78	72	Concentration Basis
"	#11	--	--	--	--	60	46	Mass Basis
"	#13	61	49	0.162	0.103	20	36	Concentration Basis
"	#13	--	--	--	--	20	37	Mass Basis
"	#14	16.2	2.9	0.087	0.045	82	48	Concentration Basis
"	#15	--	--	--	--	87	79	Mass Basis
"	#16	--	--	--	--	80.00	37.00	Concentration Basis
"	#17	--	--	0.88	0.13		85	Concentration Basis
"	#18	71	12	0.232	0.112	83	52	Concentration Basis
"	#22	45	14	0.651	0.164	69	75	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#22	--	--	--	--	67	57	Mass Basis
"	#23	28	11	0.4	0.176	61	56	Concentration Basis
"	#23	--	--	--	--	71	62	Mass Basis
"	#24	131	7	0.497	0.053	95	89	Concentration Basis
"	#24	--	--	--	--	94	90	Mass Basis
"	#26	128	9	0.3	0.04	93	87	Concentration Basis
"	#27	22.8	8.9	0.095	0.077	61	19	Concentration Basis
"	#28	20.6	6.5	0.136	0.035	68	74	Concentration Basis
"	#29	7	15	0.272	0.155	-114	43	Concentration Basis

Wet Basins (cont'd)								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#29	--	--	--	--	54	69	Mass Basis
"	#30	52	23	0.3	0.4	56	-33	Concentration Basis
"	#30	--	--	--	--	65	25	Mass Basis
"	#31	47	54	0.247	0.195	-15	21	Concentration Basis
"	#31	--	--	--	--	61	45	Mass Basis
"	#38	45	19	0.17	0.12	58	29	Concentration Basis
"	#42	--	--	--	--	7	40	Concentration Basis
"	#43	--	--	--	--	80.00	80.00	Mass Basis
"	#44	--	--	--	--	75.00	22.00	Concentration Basis
"	#44	--	--	--	--	83.00	37.00	Mass Basis
"	#45	1113	63	2.91	0.27	94.34	90.72	Concentration Basis
"	#45	--	--	--	--	93.00	79.00	Mass Basis
"	#47	--	--	--	--	85.00	48.00	Mass Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#50	134	28	0.45	0.21	79.10	53.33	Concentration Basis
"	#51	--	--	0.12	0.08	--	33	Concentration Basis
"	#52	--	--	0.14	0.08	--	43	Concentration Basis
"	#52	--	--	--	--	93	45	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Wood-hollow	--	--	--	--	54	46	Mass Basis
Cazanacli, 2003. Comparing Sediment Removal Rates of Manufactured BMPs to Wet Basins. Water Resources Conf. Oct. 28, 2003. Brooklyn Park, MN		--	--	--	--	70	--	Mass Basis
Commings, Booth, & Horner, 2000. Stormwater Pollutant Removal in two wet ponds in Bellevue, WA. Jour. Environ. Engrg, 126(4):321-330		--	--	--	--	81	--	Mass Basis
Mallin, Ensign, Wheeler, Mayes, 2002. Surface Water Quality-Pollutant Removal Efficacy of Three Wet Detention Ponds. Jour. Environ Quality 31:654-660.	Ann McCrary	10.5	3.7	0.061	0.047	65	23	Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection. (Data for 4 wet ponds receiving rainfall)		--	--	--	--	78	53	Rainfall Event. Appears to be Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection. (Data for 4 wet ponds receiving snowmelt)		--	--	--	--	39	16	Snowmelt Event. Appears to be Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	76	29	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	93	73	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.		--	--	--	--	94	69	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	68	55	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	64	60	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	--	81	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	--	62	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	66	38	Concentration Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	82	91	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	60	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	85	70	Mass Basis
Harper. Pollutant Removal Efficiences for Typical Stormwater Management Systems in Florida.	--	--	--	--	--	55	65	Mass Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Lake Side Pond)	--	--	--	--	--	93	45	Concentration Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Waterford Pond)	--	--	--	--	--	41	--	Concentration Basis
Wu, J.S., R.E. Holman, and J.R. Dorney, 1996. Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. (Runaway Bay Pond)	--	--	--	--	--	62	36	Concentration Basis
BMP Database. Site: Lake Ridge Det. Pond, Woodbury, MN	--	--	--	--	--		58	Concentration Basis

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
BMP Database. Site: Lakeside Pond, Charlotte, NC.	--	--	--	--	--	--	44	Concentration Basis
	--	--	--	--	--	--		Concentration Basis
BMP Database. Site: Pittsfield Ret. Pond, Ann Arbor, MI	--	--	--	--	--	--	15	Concentration Basis
BMP Database. Site: Tampa Office Pond, Tampa, FL	--	--	--	--	--	--	77	Concentration Basis
BMP Database. Site: Traver Creek Ret. Pond, Ann Arbor, MI	--	--	--	--	--	--	40	Concentration Basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	Seattle, WA	--	--	--	--	87	78	Concentration Basis
"	Boynton Beach	--	--	--	--	91	--	"
"	Grace Street	--	--	--	--	32	12	"
"	Pitt-AA	--	--	--	--	32	18	"
"	Unqua	--	--	--	--	60	45	"
"	Waverly Hills	--	--	--	--	91	79	"
"	Lake Ellyn, IL	--	--	--	--	84	34	"
"	Lake Ridge, MN	--	--	--	--	88	49	"
"	West Pond, MN	--	--	--	--	25	--	"
"	McCarrons, MN	--	--	--	--	78	--	"

Wet Basins (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	McKnight Basin, MN	--	--	--	--	41	13	Concentration Basis
"	Monroe St., WI	--	--	--	--	65	70	"
"	Runaway Bay, NC	--	--	--	--	24	--	"
"	Buckland, CT	--	--	--	--	61	45	"
"	Highway Site, FL	--	--	--	--	65	17	"
"	Woodhollow, TX	--	--	--	--	54	46	"
"	SR204, WA	--	--	--	--	99	91	"
"	Farm Pond, VA	--	--	--	--	85	86	"
"	Burke, VA	--	--	--	--	-33	39	"
"	Westleigh, MD	--	--	--	--	81	54	"
"	Mercer, WA	--	--	--	--	75	67	"
"	I-4, FL	--	--	--	--	54	69	"
"	Timber Creek, FL	--	--	--	--	64	60	"
"	Lakeside, NC	--	--	--	--	91	23	"

Appendix B3. Constructed Wetlands

Constructed Wetlands								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#57	--	--	--	--	93	76	Mass Basis
"	#59	45	42	0.17	0.19	7	-12	Concentration Basis
"	#61	123.6	26.9	0.447	0.11	78	75	Concentration Basis
"	#61	--	--	--	--	78	79	Mass Basis
"	#62	--	--	--	--	61	33	Mass Basis
"	#62	--	--	--	--	50	28	Concentration Basis
"	#63	--	--	--	--	68	62	Mass Basis
"	#64	74.7	20.8	0.35	0.26	72	26	Concentration Basis
"	#64	--	--	--	--	96	70	Mass Basis
"	#65	--	--	--	--	66	4	Mass Basis
"	#67	134	33	0.45	0.201	75	55	Concentration Basis
Forbes, 2004 #80	--	--	--	--	--	--	9	Concentration Basis
"	--	--	--	--	--	--	16	Concentration Basis
"	--	--	--	--	--	--	21	Concentration Basis
"	--	--	--	--	--	--	47	Concentration Basis
"	--	--	--	--	--	--	62	Concentration Basis

Constructed Wetlands (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Forbes, 2004 #80	--	--	--	--	--	--	51	Concentration Basis
Bulc, 2003 #52	--	42	11	0.4	0.1	74	75	Concentration Basis
ASCE, 2002 #81	--	--	--	--	--	--	23	Concentration Basis
"	--	--	--	--	--	--	61	Concentration Basis
"	--	--	--	--	--	--	34	Concentration Basis
"	--	--	--	--	--	--	45	Concentration Basis
"	--	--	--	--	--	--	29	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	LaCosta WB	--	--	--	--	91	2	Concentration Basis
Carleton, Grizzard, Godrej, Post, Lampe, and Kenel, 2000. Performance of a constructed wetlands in treating urban stormwater runoff. Water Environ. Research 72(3):295-304.	Franklin Farms	--	--	--	--	93	76	For storms < wetland capacity. Mass Basis
"	Crestwood	--	--	--	--	58	46	Median - Mass Basis
Dierberg, DeBusk, Jackson, Chimney, Pietro, 2002. Submerged aquatic vegetation-based treatment wetlands for removing phosphorus from agricultural runoff: response to hydraulic and nutrient loading. Water Research 36.	1.5 day HRT	--	--	--	--	--	51	Concentration Basis
"	3.5 day HRT	--	--	--	--	--	73	Concentration Basis
"	7 day HRT	--	--	--	--	--	79	Concentration Basis
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection.	--	--	--	--	--	82	68	Unknown Basis

Constructed Wetlands (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Oberts, 1994. Performance of Stormwater Ponds and Wetlands in Winter. In "Watershed Protection Techniques," Vol 1(2), Center for Watershed Protection.	--	--	--	--	--	4	7	Unknown Basis
BMP Database. Site: Franklin Wood, Chantilly, VA	--	--	--	--	--	--	5	Concentration Basis
BMP Database. Franklin Wetland, Chantilly, VA	--	--	--	--	--	--	23	Concentration Basis
BMP Database. Site: Hidden River Wetland, Tampa, FL	--	--	--	--	--	--	61	Concentration Basis
BMP Database. Site: Queen Anne's Pond, Centreville, MD	--	--	--	--	--	--	34	Concentration Basis
BMP Database. Site: Swift Run Wetland, Ann Arbor, MI	--	--	--	--	--	--	45	Concentration Basis
Metropoliton Washington Council of Governments, 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.	EWA3, IL	--	--	--	--	72	59	Unknown Basis
"	EWA4, IL	--	--	--	--	76	55	Unknown Basis
"	EWA5, IL	--	--	--	--	89	69	Unknown Basis
"	EWA6, IL	--	--	--	--	98	79	Unknown Basis
"	B31, WA	--	--	--	--	14	-2	Unknown Basis
"	PC12, WA	--	--	--	--	56	-2	Unknown Basis
"	McCarrons, MN	--	--	--	--	87	36	Unknown Basis
"	Queen Anne's, MD	--	--	--	--	65	39	Unknown Basis
"	Swift Run, MI	--	--	--	--	85	3	Unknown Basis
"	Tampa Office Pond, FL	--	--	--	--	64	55	Unknown Basis
"	Highway Site, FL	--	--	--	--	66	19	Unknown Basis
"	Palm Beach, PGA, FL	--	--	--	--	50	62	Unknown Basis

Appendix B4. Bioretention Filters

Bioretention Filters								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	#93	--	--	0.52	0.18	--	65.38	Concentration Basis
Winer, Nat'l Poll. Rem. Database, 2000	#93	--	--	--	--	--	65	Mass Basis
Idaho DEQ BMP Manual (undated)	--	--	--	--	--	90	75	unknown
Caltrans 2002 as ref'd in "Bioretention TC32," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	90	76	unknown
Low Impact Development (LID) A Literature Review, EPA-841-B-00-005. USEPA, Oct. 2000	Beltway Plaza, Greenbelt, MD	--	--	--	--	--	65	unknown
Low Impact Development (LID) A Literature Review, EPA-841-B-00-005. USEPA, Oct. 2000	Peppercorn Plaza, Landover MD	--	--	--	--	--	87	unknown

Appendix B5. Sand Filters

Sand Filters								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Winer, Nat'l Poll. Rem. Database, 2000	#101	76.2	16.84	0.52	0.18	78	65	Concentration Basis
"	#101	--	--	--	--	79	66	Mass Basis
"	#102	16.1	10.3	0.08	0.06	36	25	Concentration Basis
"	#103	97.2	11.8	0.123	0.065	88	47	Concentration Basis
"	#104	204	3.5	0.356	0.126	98	65	Concentration Basis
"	#104	--	--	--	--	98	66	Mass Basis
"	#105	--	--	--	--	87	61	Mass Basis
"	#106	--	--	--	--	92	80	Mass Basis
"	--	--	--	--	--	--	--	Mass Basis
"	--	--	--	--	--	--	--	Mass Basis
"	#107	--	--	--	--	75	59	Mass Basis
"	#108	--	--	--	--	86	19	Mass Basis
"	#109	273	32	0.37	0.11	88	70	Concentration Basis
"	#110	--	--	--	--	98	61	Mass Basis
"	#111	--	--	--	--	78	27	Mass Basis
"	#112	449	112	0.4	0.14	75	65	Concentration Basis
"	#113	--	--	--	--	60	--	Mass Basis

Sand Filters (cont'd)								
Source	ID	Inflow [TSS}	Outflow [TSS]	Inflow [P]	Outflow [P]	% TSS removed	% P removed	Comment
Division, 1990 #79	--	--	--	--	--	--	0	Concentration Basis
"	--	--	--	--	--	--	45	Concentration Basis
"	--	--	--	--	--	--	59	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	E Reg MS	--	--	--	--	75	23	Concentration Basis
Glick, et al, 1998. Referenced in above report (pg 2-10)	--	--	--	--	--	89	59	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Foothill MS	--	--	--	--	86	21	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Term P&R	--	--	--	--	89	24	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	Escon MS	--	--	--	--	58	37	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	LaCosta P&R	--	--	--	--	91	30	Concentration Basis
Caltrans 2004 BMP Retrofit Pilot Program Final Report App F	SR78/I%P&R	--	--	--	--	87	29	Concentration Basis
Glick, et al, 1998. Monitoring and evaluation of stormwater quality control basins in watershed mgt: Moving from theory to	--	--	--	--	--	89	59	Concentration Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Highwood Apt	--	--	--	--	86	19	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Barton Creek Squ. Mall	--	--	--	--	75	59	Mass Basis
Environ & Conservation Services Dept. Austin TX. Removal Efficiencies of Stormwater Control Structures. May 1990.	Jollyville	--	--	--	--	87	61	Mass Basis

Appendix B6. Filter Strips/Grass Swales

Filter Strips/Grass Swales								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Barrett, Walsh, Malina and Charbeneau, 1998. Performance of Vegetative Controls for Treating Highway Runoff. Jour. Environ. Engrg. 1121-1128. US 183 median.	US 183	157	21	0.55	0.31	87	44	Concentration Basis/Grassy Median
"	MoPac expway	190	29	0.24	0.16	85	33	Concentration Basis/Grassy Median
BMP Data Base. Austin, TX. Site: Alta Vista planned development det. w/ swales	--	--	--	--	--	29	84	Concentration Basis/Grassy Median
EPA Data Base: Dayton Swale - Dayton Biofilter with grassed Swale (Site ID 1645113921)	--	--	--	0.183	0.192	--	-5	"
BMP Data Base, Seattle. Site: Dayton Biofilter-Grass Swale	--	--	--	--	--	--	-5	"
"Field Test of Grassed Swale Performance in Removing Runoff Pollution," by Jan-Tai Kuo, Shaw L. Yu et al. University of VA	Goose Creek-upper	--	--	--	--	29.7	73.4	Mass Basis/Swale
"	Goose Creek-lower	--	--	--	--	97.2	96.8	Mass Basis/Swale
"	Goose Creek-entire	--	--	--	--	94	98.6	Mass Basis/Swale
Caltrans 2002 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	77	8	Mass Basis/Dry Swale
Goldberg, 2003 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	67.8	4.5	Mass Basis/Grassed Channel
Seattle Metro & Washington Dept. of Ecology, 1992 as ref'd in "Vegetative Swale TC30," found at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	60	45	"
"	--	--	--	--	--	83	29	"

Filter Strips/Grass Swales (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Wang et al., 1981 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	80	--	Mass Basis/Dry Swale
Dorman et al., 1989 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	98	18	"
Harper, et al., 1988 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	87	83	"
Kercher et al., as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	99	99	"
Harper, et al., 1988 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	81	17	Mass Basis/Wet Swale
Koon, 1995 as ref'd in "Vegetative Swale TC30," found in CA Stormwater BMP Handbook Developement & Redevelopment at http://www.cabmphandbooks.com/Development.asp	--	--	--	--	--	67	39	"
City of Austin. 1995 (draft). Characterization of Stormwater Pollution for the Austin, Texas Area. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, Texas. As found at http://www.fhwa.	--	--	--	--	--	68	43	Concentration Basis
Yu, S.L., S.L. Barnes, and V.W. Gerde. 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Department of Transportation, Report No. FHWA/VA-93-R16, Richmond, VA. As found at http://www.fhwa.dot.gov/environment/ultraurb/3fs1	--	--	--	--	--	49	33	Mass Basis

Filter Strips/Grass Swales (cont'd)								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Yu, S.L., and R.J. Kaighn. 1995. The Control of Pollution in Highway Runoff Through Biofiltration. Volume II: Testing of Roadside Vegetation. Virginia Department of Transportation, Report No. FHWA/VA-95-R29, Richmond, VA. As found at http://www.fhwa.dot.g	--	--	--	--	--	30	0	Concentration Basis
Khan, Z., C. Thrush, P. Cohen, L. Kulzer, R. Franklin, D. Field, J. Koon, and R. Horner. 1992. Biofiltration Swale Performance, Recommendations, and Design Considerations. Municipality of Metropolitan Seattle, Water Pollution Control Department, Seattle,	--	--	--	--	--	83	29	Mass Basis
FHWA, 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032.	--	--	--	--	--	83	29	Mass Basis/200 ft swale
"	--	--	--	--	--	60	45	Mass Basis/100 ft swale
Winer, Nat'l Poll. Rem. Database, 2000	#127	--	--	--	--	67.8	4.5	Concentration Basis/Grassed Channel
Winer, Nat'l Poll. Rem. Database, 2001	#128	--	--	--	--	83	29	"
Winer, Nat'l Poll. Rem. Database, 2002	#129	--	--	--	--	60	45	"
Winer, Nat'l Poll. Rem. Database, 2003	#130	--	--	--	--	81	17	Mass Basis/Wet Swale
Winer, Nat'l Poll. Rem. Database, 2004	#131	--	--	--	--	67	39	Concentration Basis/Wet Swale
Winer, Nat'l Poll. Rem. Database, 2000	#126	--	--	--	--	80	--	Mass Basis/Dry Swale
Winer, Nat'l Poll. Rem. Database, 2000	#123	--	--	--	--	98	18	"
Winer, Nat'l Poll. Rem. Database, 2001	#124	--	--	--	--	87	83	"
Winer, Nat'l Poll. Rem. Database, 2002	#125	--	--	--	--	99	99	"

Appendix B7. Infiltration Trenches

Infiltration Trenches								
Source	**ID**	**Inflow [TSS}**	**Outflow [TSS]**	**Inflow [P]**	**Outflow [P]**	**% TSS removed**	**% P removed**	**Comment**
Winer, Nat'l Poll. Rem. Database, 2000	Study 132	--	--	0.66	0.63	--	4.5	--
Winer, Nat'l Poll. Rem. Database, 2000	Study 133	--	--	0.2	0	--	100.0	--
Winer, Nat'l Poll. Rem. Database, 2000	Study 134	--	--	0.24	0	--	84.0	--
IDAHO BMP Manual	--	--	--	--	--	90	55	--

MEMORANDUM

Date:	28 February, 2013
To:	Kristin Hathaway
Organization:	City of Oakland
From:	Erik Stromberg, ASLA
Project:	Sausal Creek Restoration Project at Dimond Park
RE:	IRWM: Basis of Cost of Avoided Projects

Kristin:

The following information has been compiled to provide the necessary backup for the cost estimates provided by RDG in Table D of the Monetized Benefit form for the IRWM grant application for the Sausal Creek Restoration Project at Dimond Park Project. Where possible, costs are taken directly from the cost estimate for the proposed Sausal Creek Restoration Project at Dimond Park (Proposed Project) completed by RDG on August 16th, 2013. All other costs are derived from our experience providing cost estimates for construction projects in the East Bay.

Avoided Capital Costs Narrative

If the Proposed Project is not constructed the following is assumed to be the most plausible alternative:

1. An 8-ft tall retaining wall system would be built at the toe of the channel on both sides to stabilize failing banks. On the right bank (viewed looking downstream) the wall would protect existing infrastructure including Canon Avenue and private structures. The wall would protect mature redwoods on the left bank. Without this work (or the work outlined in the Proposed Project) the future costs of employing emergency fixes for bank repair at Canon Avenue, or paying repair costs from private properties from failing banks or left bank trees falling across the creek on to private property are assumed to be significantly greater than the Alternative Project. As a result we are proposing the retaining wall system as an Alternative Project.

Item	*Quantity*	*Cost*	*Sub Total*
Dewatering	1 lump sum	$35,000	$35,000
Demolition of creek debris	6,000 sf	$3.50	$21,000
Clearing and grubbing	27,500 sf	0.40	$11,000
Bank Grading for walls	1,100 cy	$22	$24,200
Concrete Retaining Walls	8,800 face foot	$95	$836,000
Retaining Wall Footing	1,100 lf	$200	$220,000
Guardrails at Walls	1,100 lf	$95	$104,500

RESTORATION DESIGN GROUP, LLC

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MOUNT SHASTA
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RestorationDesignGroup.com

2. Creek bed restoration to provide scour protection for the new wall as well as a fix for the undermined concrete spillway. This work is assumed to be the same as for the Proposed Project.

Item	*Quantity*	*Cost*	*Sub Total*
Excavate (E) bed material	260 cy	$22	$5,720
Offhaul excess material	130 cy	$20	$2,600
Creek bed installation	1 lump sum	$319,800	$319,800

3. General Site work including Erosion Control, Revegetation and Irrigation. The Alternative Project footprint is 40% of the Proposed Project. The lump sum cost below is calculated as 40% of the Proposed Project.

Item	*Quantity*	*Cost*	*Sub Total*
Erosion Control, Revegetation, Irrig.	1 lump sum	$69,800	$69,800
Irrigation Point of Connection	1 lump sum	$20,500	$20,500

4. General Conditions and contingency include mobilization, demobilization, SWPPP plan preparation and implementation, staging area construction overhead and profit. This work is noted as 20% of Construction Costs. The contingency percentage is consistent with the Proposed Project cost estimate.

Item	*Quantity*	*Cost*	*Sub Total*
General Conditions	1 lump sum	$334,024	$334,024
Contingency (20%)	1 lump sum	$400,829	$400,829

5. Design and Permitting work would need to occur for this Alternative Project. These costs are estimated here using costs for the Proposed Project.

Item	*Quantity*	*Cost*	*Sub Total*
Design	1 lump sum	$260,000	$260,000
Permitting	1 lump sum	$95,000	$95,000
Construction Administration	1 lump sum	$215,000	$215,000

Total Estimated Cost: **$2,974,973**

Avoided Operations and Maintenance Costs Narrative

The largest cost in the immediate future is maintenance of the existing restroom facility. In the Proposed Project this facility is replaced so the maintenance costs in the short term would be legible. The Alternative Project described above leaves the restroom in place. Buildings of this often require plumbing repairs, painting, roof patching and replacement as well as electrical work. Any one of these tasks could

range in the 10's of thousands of dollars. This is captured in the row for year 2014 in Table D.

In addition to ongoing restroom maintenance, the existing trees are to remain in the Alternative Design. The arborist report noted several trees that are in poor condition and for the purposes of this table it was assumed that minor maintenance would be required in the year 2017 in addition to minor continued maintenance to the restroom. For a general sense of arborist services removing a large redwood could cost between $3,000 to $7,000 depending on access and size.

The Alternative Design installs 8,800 face feet of new concrete wall, which will require graffiti abatement. After 5 years of existence it was assumed that the wall would require a fresh coat of paint it was estimated that this cost would be $1.30 a square foot to remove graffiti and repaint.

Avoided Replacement Costs Narrative
There are a number of site elements that are not being updated in the Alternative Project but are in the Proposed Project. These items include park upgrades around the Scout hut and Wellington Ave Entry, as well as the installation of the new restroom. All of these items will need to be upgraded during the assumed project life of the Proposed Project.

Sincerely,

Erik Stromberg
Restoration Director

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San Francisco Bay Region
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Putting A Price On Riparian Corridors As Water Treatment Facilities

Ann L. Riley[1]

Abstract: The monetary value of natural riparian environments that provide water quality treatment functions by processing nutrients, storing sediment, moderating temperatures, and other services can be estimated by calculating the costs associated with the construction of "brick and mortar" water treatment plants built to achieve similar functions. A demonstration urban runoff treatment plant built by the City of Santa Monica provides similar water quality services as a 4,000-5,000 lineal foot riparian corridor does, and has annualized costs of approximately $1.3 million per year ($2008) over a 50-year period.

These costs can be compared to the costs of protecting and/or restoring naturally functioning riparian systems. For example, a large, federally-funded, multi-objective urban flood damage reduction project with water quality benefits has costs that are approximately $967,600 per year ($2008). Other urban stream restoration projects for 5,000 lineal feet of stream with riparian habitat can range in cost from $1,900 for fencing projects to $227,000 per year for "typical" restoration projects annualized over 50 years ($2008). While most riparian restoration projects will provide benefits over a 100 year period or in perpetuity, the life spans of the structural plants are generally much shorter, thereby requiring significant replacement costs.

If it can be demonstrated that the water quality treatment services of a "brick and mortar" plant can be equated to similar services provided by naturally functioning riparian systems, then a cost comparison between the "brick and mortar" plant is not only illustrative, but may also provide a benefit measure that can be used to evaluate the economic efficiency of proposed habitat protection and/or restoration projects.

The Policy Context

Ecologically functioning riparian environments are valued because they provide aquatic and terrestrial habitat for fish, amphibians, reptiles, mammals, and birds, and recreational and open space opportunities for the public. Yet little or no research appears to be available on the economic benefits of riparian areas to society for their water quality treatment functions. Riparian areas improve water quality by removing nutrients, improving dissolved oxygen, storing sediment and regulating temperatures among other benefits. These benefits can be achieved by protecting existing healthy riparian environments, or by restoring degraded areas into functioning ecosystems. Protection can

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be achieved by voluntary ecologically sound landowner practices, and/or through regulation, conservation easements, or fee purchase of riparian corridors. Therefore, one purpose of assigning monetary value to these natural systems is to record what society pays to prevent farming or other land uses in these areas, pass protection regulations, purchase easements or full public rights to the riparian land, and/or to restore the ecosystem.

However, in many circumstances, particularly in urban environments, the monetary costs of protecting a healthy system can be difficult to estimate. Therefore, this research focuses on putting the benefits and services of a riparian environment into perspective by describing what we need to pay if we were to substitute these naturally occurring services with a constructed plant.

Santa Monica Urban Runoff Recycling Facility

The first of its kind, state-of-the-art stormwater treatment plant located in Santa Monica, California, gives us the opportunity to compare the benefits and costs of a physical "brick and mortar" stormwater facility with the benefits and costs of naturally occurring or restored riparian environments based upon their respective abilities to affect the quality of stormwater runoff. The Santa Monica Urban Runoff Recycling Facility (SMURRF) collects polluted runoff from the Los Angeles area and reclaims it sufficiently so that it can be re-used for landscape irrigation or dual plumbing systems (Figure 1). The plant came on line in February 2001 and is located near the Santa Monica pier. The building design involved a collaboration of engineers and artists. The plant features interesting architecture, art, and on-going visitor tours with public education about urban stormwater runoff, making this interesting, pioneering engineering facility an engaging tourist attraction. There are proposals to construct similar plants at Lake Tahoe.

Figure 1: SMURRF Plant

This plant is intriguing for reasons other than its merits as a currently one-of-a kind centralized stormwater collection and treatment facility. The presence of a "brick and mortar" plant and the costs associated with its construction, operations and maintenance provides an excellent opportunity to compare its long term costs with the costs of protecting and/or restoring the treatment capabilities of a natural, functioning riparian systems. If we do allocate financial resources to protecting riparian resources or to restoring degraded waterways, this comparison gives us one method for assigning monetary benefit values for these natural system restoration projects based upon the avoided costs of more costly "brick and mortar" plants that would provide similar water quality services.

The SMURRF Plant Functions and Costs

The SMURRF Plant was constructed in 2000. In 2008 dollars, construction costs were approximately $14.8 million dollars and the annual maintenance and operations costs are about $216,900 a year; the plant treats about 320,000 gallons of runoff a day. [2] One function of the plant is to remove fine sediments from the water, which is accomplished with a rotating drum screen. A second chamber removes grit and sand. Oil and grease are then removed in a unit that aerates the water using a compressed air unit (the dissolved air flotation unit). This unit brings the oil and greases to the top so they can be skimmed off.

The next process in the plant is micro-filtration, which helps reduce the turbidity of the water by forcing the water through membranes. The membranes have to be periodically cleaned of pollutant build-up. The final step in the treatment process is to disinfect bacteria and viruses by passing the water under ultraviolet radiation lamps. The basic functions of the plant therefore are to filter sediment, reduce turbidity, trap oil and grease, and treat bacteria and viruses. Removal of sediment can also benefit removal of nutrients and other pollutants that may adhere to it. [3] A separate trash collecting unit, which cost $200,000, catches trash from about 50,000 gallons a day before it enters the plant.[4]

Comparing A Treatment Plant To A Stream

To compare the costs of a "brick and mortar" plant with the costs of protecting and/or restoring a riparian corridor, we need to identify whether the water treatment functions of the plant and the riparian corridor are similar, including an evaluation of the treatment of similar quantities and qualities of stormwater. The SMURRF plant treats approximately 320,000 gallons of water a day. The water treated is not wet weather runoff but dry weather run-off collected from about 5,100 urbanized acres. Stormwater flows from winter rainfall continue to run untreated into the ocean.[5] Theoretically, the plant could be

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[2] City of Santa Monica (2003) and Shapiro (2005) Visit the SMURFF website at: http://www01.smgov.net/epwm/smurrf/smurrf.html
[3] City of Santa Monica (2003).
[4] Shapiro (2005).
[5] Shapiro (2005).

expanded to treat wet and dry weather runoff, but for now it is assumed that the costs per gallon of either dry season or wet season runoff are comparable. It is important to keep in mind that the plant may treat runoff from 5,100 acres but only treats a small portion of the runoff from that acreage. Therefore, we cannot use as a basis of comparison the number of acres served by our “brick and mortar” plant and natural “facilities,” but we need to compare systems that can accommodate similar quantities of water. Under perfect research conditions we would collect a wide variety of water quality and sediment measurements for the same discharges in both the field conditions and the plant and compare them. This is challenging to achieve at this time, but a future research project may try to evaluate some water quality parameters at low discharges on Wildcat Creek at the project site.

A stream flowing at 1 cfs (cubic foot per second) produces a volume of water equal to 646,272 gallons per day. The 320,000 gallons treated by the plant equates to about 0.5 cfs flow per day. Using watershed and hydrologic information from a San Francisco Bay Area stream we can estimate the size of the drainage area and creek that would produce a flow of about 0.5 cfs and then evaluate the ability of a stream of this scale to treat stormwater naturally. We can also compare the costs associated with restoring a length of stream that would treat a similar average annual flow to the costs of the stormwater plant providing similar water quality services.

The San Francisco Bay Area creek we will use for a costs and benefits comparison with the plant is Wildcat Creek located in the cities of Richmond and San Pablo, and the East Bay Regional Park system in Alameda and Contra Costa Counties (Figures 2 and 3). The average discharge or average annual flow (the arithmetic mean of the daily flows for the period of the hydrologic record) of Wildcat Creek using twenty years of gage data located on the creek is approximately 7 cfs for the location we are going to evaluate on the lower portion of Wildcat Creek. This twenty-year average for the daily flow takes into account the occurrence of large fluctuations of flows during the year, including very low summer flows where the creek may dry up in places, to high flood flow events—as high as 2,000 cfs or more. Wildcat Creek drains a watershed area of about 11 square miles and the length of the creek is about 11 miles.

Figure 2: Wildcat Creek Floodplain Flows

Figure 3: Wildcat Creek Channel

The length of the Wildcat Creek stream channel is about 5,280 feet for each square mile of watershed drained, and the average daily flow from this square mile is about 0.64 cfs. Using this hydrologic information for the Wildcat Creek watershed we can estimate that a section of creek channel about 4,125 feet long comprising an area of 0.78 square miles of the lower watershed will produce a 0.5 cfs average daily flow on an annual basis. Another way to describe the scale of this watershed is as a 500-acre area. In 2000, the Wildcat San Pablo Creeks Watershed Council completed a restoration project 5,000 feet long on lower Wildcat Creek where the average daily discharge is about 7cfs. The width of the riparian corridor varies from 50 feet to 65 feet. The channel width is 10 feet and the floodplain located outside the riparian zone is maintained in grasses, shrubs, and cattails. The entire corridor is 250 feet wide. If you evaluated this reach of creek in isolation from the rest of the watershed it would produce about 0.6 cfs average daily discharge. The scale of this project and the discharges produced by this reach (if considered separated from other watershed runoff) make it a reasonable case study with which to make comparisons to the SMURRF plant which treats an average daily discharge of 0.5 cfs.

Natural Riparian Systems Functions

Research and collected field data is now available that addresses the issue of not only the water treatment functions riparian systems perform but also the area of the natural systems that produce the treatment results. A significant body of water quality research details the ability of riparian systems to store sediment, and retain and transform excess nutrients, pesticides, and toxic substances.[6] The literature represents a wide range of environmental conditions and landscapes and therefore produces a range of quantifiable findings. For example, researchers in Corvallis, Oregon found that 60 to 80 percent of the sediment generated from forest roads were captured by less than 250 feet of a healthy riparian system in point bars and pools, and their measurements indicated that stream systems could store sediment for as long as 114 years.[7] A study in the Southern Appalachian Mountains indicates that phosphorous- and nitrogen-containing compound ammonium traveled less than 65 feet downstream before being removed from the water by riparian areas.[8] First order headwater streams in the northeastern United States have been found to be responsible for 90 percent phosphorus removal.[9] A mathematical model based on research in 14 headwater streams throughout the country shows that 64 percent of inorganic nitrogen entering a small stream is transformed within 3,000 feet of stream channel.[10]

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[6] Meyer et al. 2003; Klapproth and Johnson 2000); Wenger 1999; Osborne and Kovacic 1993; Peterjohn and Correll 1984; Chagrin River Watershed Partners 2006;Perry et al 1999; Mayeret.al 2005

[7] Meyer et al. 2003.

[8] Meyer et al. 2003.

[9] Meyer et al. 2003.

[10]Naiman et al. 1997.

In general, riparian areas are found to be efficient at processing organic matter and sediments, and sediment bound pollutants carried in surface runoff are deposited effectively in riparian forests and floodplain areas. The finer sediments are removed from runoff as a result of deposition and erosion, infiltration, dilution, and adsorption/desorption reactions with woodland soil and litter.[11] Riparian systems are known to have significant impacts on water temperatures and microclimates.[12]

Scientist have described how the oxidized hyporheic water from the stream bed mixes with the interstitial water flowing from riparian zones, which reduces the transfer of inorganic nitrogen and phosphorous to stream water. Ecological process that occur in the hyporheic zones have strong effects on water quality in which bacteria, fungi, and other microorganisms living in stream bottoms consume nutrients and convert them to less harmful, more biologically beneficial compounds. [13] Riparian areas and their floodplains have been measured to remove 80 to 90 percent of the sediments contributed by agricultural areas.[14] Plant uptake can be an important mechanism for nutrient removal in riparian forests in both intermittent and perennial streams.[15] The width and length of riparian corridors needed to act as chemical filters for nitrogen varies by stream environment, but researchers have found that riparian areas as narrow as 48 feet were effective in removing it.[16] A project involving fencing a 5000 lineal foot corridor that is 45 feet wide and planting some willow posts resulted in downstream benefits with a measured significant increase in benthic insect taxa richness and increase of the presence of family taxa typically not found in polluted and degraded conditions.[17] Even smaller headwater areas have been found to rapidly take up and transform nutrients within just hundreds of lineal feet.[18]

Researchers have also found that the loss of riparian areas to clearing and channelization not only equates to a loss of these treatment functions but may also result in the disturbance of areas that have served as nutrient sinks for sediment and sediment associated nutrients, which then causes the export of the nutrient sink accumulated over many years.[19] Removal of wooded areas and the subsequent changes in the peak discharges and shortening of runoff lag time typically results in geometric increases in sediment loads being transported by streams.[20]

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[11] Bhowmilk et al. 1980;Lowrance et al 1984; Lowranceet al 1986
[12] Naiman et al.1997;
[13] Naiman 1997;Korum 1992
[14]Cooper et al. 1987.
[15] Karr and Schlosser 1978.

[16] Cooper et al. 1986.
[17] SFBRWQCB 2007
[18] Peterson, et.al 2001
[19] Kuenzler et al. 1977.
[20] Leopold 1981.

Research also indicates that healthy aquatic systems can transform animal waste and chemical fertilizers into less harmful substances. Vegetated buffers and protected riparian areas with contiguous riparian corridors have been shown to be effective in reducing pathogens such as coliform and cryptosporidium parvuum.[21]

Comparing Costs: SMURFF vs. Habitat Restoration Projects

If it can be demonstrated that the water quality treatment services of a "brick and mortar" plant can be equated to similar services provided by naturally functioning riparian systems, then a cost comparison between the "brick and mortar" plant is not only illustrative, but may also provide a benefit measure that can be used to evaluate the economic efficiency of proposed habitat protection and/or restoration projects. For this research, we will compare the costs of the SMURFF stormwater treatment plant with a Wildcat Creek multi-objective project in the Bay Area as well as other restoration projects. The critical underlying assumption is that the restoration projects provide similar water quality treatment services as the SMURFF plant. The following assumptions were used to perform the cost comparisons:

- 50 year analysis period and
- 6% discount rate

SMURFF. The SMURFF plant was constructed in year 2000 at a cost of about $12 million (including land costs). The City Engineer's best estimate on the life of this plant is twenty years, based on the technology becoming obsolete by that time, although she cautions that breakdowns and replacements of machinery are inherent in the use of the new technology. The plant construction and land costs converted to 2008 dollars are $14.8 million.[22] Annual maintenance costs are now approximately $216,900 per year. Because the plant's life is shorter than the 50-year analysis period, replacement costs ($5,000,000) were included for each 20 year period to account for significant machinery and equipment replacement. Therefore, the SMURRF construction and operations and maintenance costs annualized over this length of time are about $1.3 million per year for the treatment of 0.5 cfs per day.

Wildcat Creek. Between 1986 and 1989, the Army Corps of Engineers, in partnership with Contra Costa County, constructed a multi-objective flood damage reduction project which included acquisition of the 250-foot-wide-corridor, and creation of a floodplain, vegetated corridor, and stream channel within the 250-foot-wide-corridor over 10,000 lineal feet. Objectives of the project were to provide for a naturally functioning bankfull stream channel and adjacent floodplain, and protection of a riparian corridor. In 2008 dollars, the total construction costs for 10,000 lineal feet was about $26.7 million, and land costs and relocation costs were about $3.7 million for a total project cost of about $30.4 million. The annual maintenance cost expended by the county for this project area and staff support for the watershed council, which oversees the long tem management of

[21] Meyer et al. 2003; Tate, et al. 2004; Tate 1978; Balance Hydrologics 2007.
[22] Higbee 2007.

the project area, is approximately $9,000 per year. Army Corps projects represent the high end of costs for stream and river restoration work; the costs in this case equated to about $2,700 per lineal foot. To make this project comparable to the SMURFF plant, a length of 5,000 should be used, or about half the size of the Army Corps project. Thus, the costs of this project were halved which results in annualized costs over a fifty year period of approximately $967,600 per year.

The Army Corps project should have similar water quality treatment capacities as the SMURRF plant in respect to sediment removal, nutrient absorption, and breakdown of grease and oils, as described above. This riparian area also has the inherent capacity to reduce bacteria and viruses. The ultraviolet light treatment for pathogens is likely a more consistently reliable treatment for the latter; therefore, this may be the one area in which natural riparian system do not have equal treatment capacity. However, the primary objective of this project is flood damage reduction, and water quality benefits would be incidentally related to the creation of a vegetated floodplain corridor. Thus, it is unfair to compare the total cost of the Army Corps project with the SMURFF plant because many of these project costs should be allocated to the flood damage reduction objective, and such a cost allocation was not performed. However, even without a water quality cost allocation, the annualized cost of the Wildcat Creek project ($967,600) is less than the SMURFF plant ($1.3 million per year).

In 2000, the Wildcat-San Pablo Creeks Watershed Council implemented a 5,000-lineal-foot project along a reach in the same corridor to bring the project into conformance with the latest in geomorphic and engineering design knowledge and to provide a stream system with improved environmental values that could better maintain itself in an equilibrium condition. This project restored the stream channel to new dimensions, increased its sinuosity, and increased the average width of the riparian corridor from 30 to 55 feet. The 2000 project represents a major design and construction effort of the county and a non-profit organization; however, the project represents the lower end of the costs spectrum for restoration work at only $23 per lineal foot, for a total cost of $116,600 ($2008). The Army Corps did provide a design document that helped validate the restoration design prepared by the non-profit organization. If the cost of that document is included, the cost of this restoration project is increased to $239,300, with a per lineal foot cost of $48 (2008 dollars). The annualized cost of this restoration project for a fifty-year period is $19,700 per year including maintenance costs (in 2008 dollars). If we add in the original land acquisition costs included in the earlier Corps project, the average annual cost increases to $253,600 and the cost per lineal foot to $785 (in 2008 dollars). Thus, the Wildcat Creek case allows us to compare very high and low range costs associated with stream restoration projects that occurred along the same reach of channel at different times.

Fencing/Easement/Restoration Projects.

Protecting With Easements and Fencing

The restoration of degraded riparian corridors is a relatively expensive method of attaining their benefits compared to the more cost effective method of retaining the benefits through the protection of stream and floodplain corridors. Two of the most

effective and commonly used methods to protect and or restore streams are to fence out livestock and/or purchase conservation easements to remove riparian corridors from grazing or other agricultural uses. Only very limited cost information is available for purchase of conservation easements to protect riparian resources in the San Francisco Bay Area. The Napa Valley Regional Natural Resources Conservation Service office located in an agrarian region contiguous with the more urban part of the San Francisco Bay Area, reports that it is exceedingly rare for the federal wetland and floodplain reserve programs to be used to acquire easements in the more urbanized coastal, high value urban and agricultural lands. This rarity of conservation easements is a result of the fact that most of the Bay Area landowners generally want in-fee purchase for the total land values, and land trusts are reticent to accept the maintenance and management costs associated with conservation easements for relatively small linear tracts of property characteristic of riparian corridors as opposed to the advantages of purchasing large parcels of property for open space and wildlife refuges. The U.S. Department of Agriculture reports that its wetland reserve program was used once in the past decade in the Bay Area in partnership with Marin Audubon Society in east Marin County, where the easement price was capped at $5,000 an acre. Most wetland reserve programs are capped at $3,000 per acre federal acquisition costs, but coastal counties in California are allowed a $5,000 cap. In Stanislaus County (inland from the Bay Area) easements purchased in 1999 along the Tuolumne River required a combination of funding sources to cover costs as high as $4,000 an acre.[23] If the per acre cost of $5,000 is applied to a 150-foot-wide riparian corridor it puts the cost of a riparian easement at $86,000 for 5,000 lineal feet of stream. Fencing costs to protect riparian corridors can typically range from $19,000 to $26,000 for a 5,000-foot length of creek (including both banks).[24] A fencing cost of $26,000 results in an annualized cost of about $1,900. The costs estimates in this paper focus on the costs of both in-fee acquisition of land and restoring a 5,000 foot riparian corridor in urban western Contra Costa County and represent low, moderate and high costs associated with an urban environment.

Typical Restoration Costs

The above costs provide actual figures for expensive and low cost projects; therefore, it is also useful to estimate costs that better represent average costs for stream restoration projects. Based on the experience of the author, who is involved in implementing stream restoration projects and comparing costs with other practitioners, a reasonable average lineal foot cost for a project of this scope conducted in 2008 in the San Francisco Bay Area would range between $300 and $700. Using the higher average value of $700 per lineal foot, a reasonable capital cost estimate for a “typical” 5,000-foot riparian restoration project in the median range would be $3.5 million. Adding in average annual maintenance costs of $5,000 per year brings the annualized costs over a fifty-year period to $227,000 per year.

Thus far, we have established that our total project cost comparisons on an annualized basis are $1.3 million per year for the SMURRF plant, and the restoration projects have a wide range of annual costs, from $967,600 for a large multi-objective federal project to

[23] Blake 2008 and Fourkey 2008.
[24] Blake 2008.

$227,000 for "typical" restoration projects and $1,900 for fencing projects. Research indicates that the wide riparian and floodplain corridor and project length of the Wildcat creek case should be more than adequate to insure equivalent water treatment functions and benefits as the plant except possibly virus control. The reason we evaluated a 5,000 foot restoration corridor on Wildcat Creek is that this length of corridor, if it was viewed in isolation from the rest of the watershed, would produce approximately an equivalent average daily flow of about 0 .6 cfs compared to the SMURRF plant average daily discharge of 0.5 cfs. However, we do have to recognize that we are probably not comparing equivalent water treatment functions because the average daily discharge that flows through this restored section of Wildcat Creek—because it is part of a larger watershed—is closer to 7 cfs, as opposed to the 0.5 cfs treated by the plant. Again it is reasonable to assume that the riparian corridor is affecting the quality of the total average daily 7 cfs. We could correct for the equivalent costs for "treatment" of 0.5 cfs by proportionately lowering the costs to approximate the costs per cfs treated. For example the treatment by a riparian system of 7 cfs average annual flow comes at a cost of $877,200 for the large, multi-objective federal project and therefore, theoretically, the costs for treating only 0.5-0.6 cfs would be about $63,000.

Multiple Benefits

This analysis so far restricts itself to only the comparable water treatment functions of the riparian system and the SMURRF plant. However, there are additional benefits of both the SMURRF Plant and the riparian systems that should be recognized and these can be described in either qualitative or quantitative terms.

The SMURRF plant also serves as a public education facility in which visitors can tour the plant and read interpretive displays about the plant and stormwater management. City records indicate that the plant averages about 230 visitors a year.[25] Some of the water treated by the SMURRF plant is sold to customers, including the City of Santa Monica, for landscape irrigation and use in dual plumbing systems. Currently the water supplied by the plant is used in the new dual- plumbed Santa Monica Public Safety Building housing the police and fire departments, and the water is used to irrigate the grounds of the civic center parking structure, city parks, and cemetery, and Caltrans applies it to Santa Monica freeway landscaping. The income receipts for this water use currently total $32,000 a year based on 2003-2004 records.[26] New water customers just now hooking up include a state-of-the art Rand Corporation Building and a commercial building known as The Water Gardens, which will be dual plumbed. It is estimated that this may increase the use of the water from the plant by 20 percent; therefore, receipts in the next few years could reasonably expect to increase to almost $40,000 annually. Unused flows return to the regional sewage treatment plant. It is very hard to predict future demand for the water cleaned by the plant because high volume estimates would be based on demand for newly constructed dual plumbing systems. The city water resources engineer's best estimate of a potential full use annual income if there is a demand for the full 230,000

[25] Higbee 2005.
[26] Lowell 2005.

gallons a day (based on a three tier pricing rate structure) is about $390,000 per year by 2016.[27] If we apply some optimistic assumptions about increasing demand over time for the water supply created by the plant, which includes a demand for the full amount treated by 2016, the plant will bring in an average annual income, based on a plant life of twenty years, of about $150,000 per year. (The plant may reasonably bring in total revenue of about $3,000,000 during its life span.) This benefit helps offset the annual maintenance costs of $216,900 ($2008) which lowers the total annualized costs of the plant to about $1.1 million a year.

The Wildcat Creek restoration project has enabled an adjacent regional trail to be developed, and the project serves as a part of the educational opportunities for a very disadvantaged elementary school serving an impoverished community located next to the creek. The creek restoration area is also the focus for a Richmond High School environmental education program that serves about 25 students a year. The elementary school located next to the restored creek banks serves about 307 students a year. The project also serves as an anadromous steelhead (a threatened species) fisheries habitat restoration project and supports habitat and protection for the endangered California clapper rail and salt marsh harvest mouse. It is known that the restored riparian system offers habitat for mammals, raptors and other birds, and a range of aquatic organisms. One of the important objectives of the restoration project is to protect 200 acres of high quality brackish marsh from degradation by sedimentation. Environmental organizations hold regularly scheduled birding and wildlife hikes along the creek. The restored creek serves as the location for an on-going inner city youth environmental stewardship, training, and employment program that has involved an average of another 15 students on an annual basis for the past ten years, and there are varying numbers of community based water quality monitoring volunteers. This particular program has attracted over $200,000 in grants and donations to the community's desperately needed youth programs in a ten-year period.

Water Quality Program Policy Implications

Water quality programs have followed a logical progression from the first emphasis on the treatment of "point pollution" discharges from sewage treatment plants and industrial facilities. The second generation of water quality programs has focused on the avoidance and treatment of polluted runoff from "non-point" sources. The U.S. Environmental Protection Agency has identified six categories of non-point sources of polluted runoff including: urban properties and streets; farm fields, pastures and operations; forestry activities; marinas and recreational boating; hydromodifications of streams such as channelization, bank stabilization projects and stormwater discharge increases; and alteration of wetland and riparian areas. The three strategies applied to managing non-point sources pollution are prevention of pollution at the source, control and reduction of unavoidable runoff, and cleanup and remediation of pollutants that remain. Best management practices including environmentally sensitive land use and development site plans, and stormwater catchment and detention and filtering systems are common

[27] Lowell 2005.

examples of source control and remediation. Protecting riparian areas, of course, directly addresses the avoidance of pollution from environmentally damaging hyrdomodifications and alterations of wetland areas. The evaluation most often missing from this non-point source management model is the recognition of the role of natural riparian areas to serve as part of the remediation system for runoff that escapes catchment and or detention near its source. This gives added value to riparian areas of not only addressing a part of the strategy to avoid degradation but also pro-actively remediating the impacts of various causes of non-point source pollution. A possible practical application of this information could be to assign water quality credits for meeting TMDL requirements in a watershed through the implementation of stream protection and restoration projects.

Current water quality budgets and priorities should evaluate the expenditures that have gone into treatment plants in the past and the expenditures that could occur in the future with mechanical stormwater treatment facilities, and use this evaluation as a budgeting framework for addressing the next generation of treatment systems. The comparisons described here indicate that projects designed to restore degraded stream environments as fully functioning water treatment systems (which provide a significant range of other environmental benefits) can have a wide range of annual costs, from $967,600 for a large multi-objective federal project to $227,000 for “typical” restoration projects but involve discharge amounts much greater than those addressed by a treatment plant. More attention could be given to the purchase of riparian easements for unprotected riparian corridors in suburban and urban areas to provide cost-effective long term benefits as part of a protection program which supplements regulatory programs. The costs of these alternatives can be compared to the annual cost of the stormwater treatment plant of around $1.3 million for a system that treats a fraction of the amount of water and that has inherent limitations on additional environmental benefits. This represents a substantial magnitude in cost differences while the benefits of riparian environmental protection or restoration should be viewed as a more sustainable approach for attaining many more benefits through time.

Comparison of Project Costs (2008 Dollars)

US Army Corps of Engineers Wildcat Creek Project	**Wildcat-San Pablo Creeks Watershed Council Wildcat Creek Project**	**SMURRF Plant**
1986 U.S. Army Corps of Engineers multi-objective flood damage reduction project of 10,000 foot length Estimated construction costs: $26,673,400 Estimated permanent rights of way and relocation costs for $3,687,700 Total project costs: $30,361,100 Design and construction per lineal foot: $2,700 Average Annual Maintenance costs: $9,000 These costs were reduced by 50% to be comparable with a stream length (5,000 feet) that would provide similar water quality benefits.	2000 Watershed Council Restoration Project (executed by Contra Costa County and a non-profit). Channel excavation and partial revegetation for 5,021 feet of project channel Costs: $116,600 for design and construction by the watershed council $127,700 Army Corps planning Total Cost: $239,300 Design and construction per lineal foot including Army Corps planning; $48 Average Annual Maintenance including management of the watershed council: $4,500.	Constructed in 2000. Values provided by City of Santa Monica Construction costs: $14,761,900 Land Costs: The land used for construction of the SMURRF plant was in city ownership and is an odd shaped parcel, which made it infeasible to develop. The Los Angeles Assessors' office values the parcel of land, 2,783 sq. ft at $33,300. . Average Annual Management costs: $216,900
Total Annual Average Cost for 5,000 length project $967,600	**Total Average Annual Costs $19,700** **With Corps land purchase & relocation costs: $253,600**	**Total Average Annual Cost $1,283,800**

Data from:

- Contra Costa County Wildcat and San Pablo Creeks Project Cost Summary
- 1985 U.S. Army Corps of Engineers Design Memorandum for the Wildcat- San Pablo Creeks Flood Control Project, Richmond, Contra Costa County, Calif.
- City of Santa Monica
- Cost annualization computed over a fifty year analysis period with a 6% discount rate (Capital Recovery Factor = 0.06344)

Comparison of Projects Benefits

Summary of Benefits of the Wildcat Creek Project	**Summary of Benefits of the SMURRF Project**
• 6.9 acres of high quality riparian corridor with a diversity of species and forest tiers to support wildlife habitat • 5,000 lineal feet of fish habitat and habitat for other aquatic species • Water quality functions: sediment collection and storage; nutrient uptake and conversion; bacteria reduction • Watershed Council conducts biannual community sponsored program of trash clean up • Water quality functions for average annual flows and greater magnitude flows • Flood storage and conveyance sufficient to protect the surrounding community from the damages associated with the one in one hundred year flood. Estimated average annual savings from avoided flood control damages calculated by the Army Corps of Engineers in 1986 for the period 1988-2088 is $1,498,000 ($2008). • Active, hands-on environmental education experiences including water quality monitoring, and cleanup and revegetation projects for 340 plus elementary school students and other local public schools and community members • Youth training and employment projects (ten year program attracted more than $200,000 to community youth programs) • Riparian corridor bird habitat and bird watching for hikers who use the creekside trail. (The Sierra Club, schools and other organizations sponsor hikes.) • Riparian corridor and floodplain protect 250 acres of downstream brackish and saltwater wetlands and San Francisco Bay water quality. • Endangered species habitat	• 1,200 sq.ft. educational facility for the public. Visitors recorded averaged 230 annually • Partial trash collection • Treatment of low-flow dry weather runoff • Water Quality functions: sediment removal; nutrient removal to a water treatment plant for further treatment; bacterial treatment, and virus control • Protection of the Santa Monica beach and the surfers and other public who frequent the ocean in the area • Income from the sale of recycled water averages $153,000 a year. • Water conservation for avoidance of use of equivalent potable supplies.

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ANALYSIS

The economic value of wetland services: a meta-analysis

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Abstract

The number of studies quantify the value of wetlands and the services provided by these ecosystems is rapidly expanding. The time is ripe for an assessment of what has been learned from this literature. Using results from 39 studies, we evaluate the relative value of different wetland services, the sources of bias in wetland valuation and the returns to scale exhibited in wetland values. While some general trends are beginning to emerge, the prediction of a wetland's value based on previous studies remains highly uncertain and the need for site-specific valuation efforts remains large. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

The valuation of wetlands' ecological services is a relatively recent phenomenon. Historically, wetlands were viewed as a waste of valuable land that could only be 'improved' through drainage and destruction of the wetland (Mitsch and Gosselink, 1986). Today, while there is now widespread recognition that wetlands provide valuable ecological services, there remain substantial debates over whether particular areas are in their highest economic use as wetlands, and to what extent public and private resources should be used for their protection and restoration. Hence, there is a growing need to quantify the value of wetland services.

The services provided by wetlands include habitat for species, protection against floods, water purification, amenities and recreational opportunities. Because these services typically have no market price, a measure of their values can only be obtained through non-market valuation techniques. Many wetland valuation studies have been conducted and the range of the estimates is remarkable. A recent review by Heimlich et al. (1998) lists 33 studies over the last 26 years with per acre values ranging from US$0.06 to US$22050. Even within the same study looking at a single ecosystem function, Batie and Wilson (1978) find values per acre that differ by two orders of magnitude from one site to another.

The purpose of this paper is to assess whether any systematic trends can be distilled from the

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breadth of wetland valuation studies conducted to date, and to shed light on what factors determine a wetland's value. We maintain an assumption that there exists an unobserved valuation function that determines a wetland's value given its physical, economic and geographic characteristics. After reviewing 46 studies, data from 39 wetland valuation studies were identified that had sufficient commonalties to allow inter-study comparisons. We used two techniques to learn about the valuation function, both of which can be broadly described as meta-analysis since many studies are used to identify general relationships. The first method that we employ uses bivariate graphical and standard techniques. This gives us both an indication of the extent to which particular characteristics influence wetland values while also portraying the full distribution of the data. The second technique is more standard, using a multivariate regression of wetland values on the characteristics of both the wetlands and the studies. Together, these two techniques provide a richer basis from which we can draw lessons on the factors determining wetland value.

There are numerous reasons why understanding the value of wetland services might be useful. The most obvious is that if the value of these services were known, benefits transfer efforts could be substantially improved. As Deck and Chestnut (1993) point out, benefits transfer may play a variety of different roles, ranging from an attempt to place a precise value on a particular resource to providing information that feeds into the process of building support for projects already implemented. While benefits transfer is rarely suitable for the former case, it might often be appropriate for the latter. Another form of benefits transfer is the use of estimated values to predict the aggregate value of similar systems nationally or globally. Such estimates can be useful in setting national priorities or the evaluation of policies with impacts that are national or global. Costanza et al. (1997), for example, placed a value on the entire globe's ecosystems. While such expansive efforts may be overambitious, the aggregate numbers do help to get the attention of policy makers and the public.

Estimates of the value of a wetland can also influence site-specific valuation efforts in two ways. First, they might provide Bayesian priors that might be formally incorporated into the valuation exercise. Secondly, they may give researchers a sense of where the values at stake are likely to be of greatest social importance and might, therefore, influence where detailed studies are carried out.

The paper is organized as follows. In the next section we provide a brief overview of the economics of wetland valuation. We survey the ecological functions and economic services provided by these areas, the basis for their valuation and the techniques that are used to place an economic value on wetlands. Section 3 provides a brief summary of meta-analysis as a tool. In Sections 5 and 6 we explore the trends in the data, identifying the sources of variability in wetland values. We conclude by reflecting on the implications of our analysis both for our understanding of wetland values and for future research.

2. The value of wetland functions

2.1. Wetland functions and services

While an inclusive definition of wetlands is difficult to state, they are generally characterized as being moist during an extended period each year with soils, plants and animals that are distinct from their aquatic and terrestrial neighbors. These transition areas are highly diverse, ranging from coastal mangroves that are inundated with water most of the year to areas that are moist for only a few months during the year. Partly because they share features of both terrestrial and aquatic systems, wetlands are remarkably productive.

In assessing the value of wetlands, it is useful to distinguish the systems' ecological functions from the associated services that are directly valued by humans (Costanza et al., 1997). Larson et al. (1989) list 17 services and functions provided by the world's ecosystems (Table 1). In our data set, the services were grouped into ten categories as indicated in the table. The measurement of the value of these services varies substantially both in

Table 1
Wetland functions, the associated economically valuable goods and services and the names of variables that capture the presence of these in the data[a]

Function	Economically valuable good(s) and/or service(s) (variable names)	Technique(s) typically used to quantiiy the value of the service(s)
Recharge of ground water	Increased water quantity (quantity)	Net factor income or replacement cost
Discharge of ground water	Increased productivity of downstream fisheries (com.fish)	Net factor income, replacement cost or travel cost
Water quality control	Reduced costs of water purification (quality)	Net factor income or replacement cost
Retention, removal and transformation of nutrients	Reduced costs of water purification (quality)	Net factor income or replacement cost
Habitat for aquatic species	Improvements in commercial and/or recreational fisheries either on or offsite (com.fish and rec.fish). Nonuse appreciation of the species (habitat)	Net factor income, replacement cost, travel cost or contingent valuation
Habitat for terrestrial and avian species	Recreational observation and hunting of wildlife (birdwatch & birdhunt). Nonuse appreciation of the species (habitat)	Travel cost or contingent valuation
Biomass production and export (both plant and animal)	Production of valuable food and fiber for harvest (birdhunt & com. fish)	Net factor income
Flood control and storm buffering	Reduced damage due to flooding and severe storms (flood)	Net factor income or replacement cost
Stabilization of sediment	Erosion reduction (storm)	Net factor income or replacement cost
Overall environment	Amenity values provided by proximity to the environment (amenity)	Hedonic pricing

[a] The first two columns are adapted from Larson et al. (1989).

the methods that are used and the economic theory that underlies the valuation exercise. The most common methods for measuring the economic value of these services are also presented in the table. Though not indicated in the table, the contingent valuation method can, in principle, be used to measure the value of all these services.

2.2. The valuation of wetland services

The economic value of resources such as wetlands is equal to the benefits (net of costs) that these systems provide to humans (Freeman, 1993). Four methods are listed in Table 1 as commonly used to place a value on wetlands. The net factor income (NFI) method is most appropriate when the wetland provides a service that leads to an increase in producer surplus. In the NFI method the physical relationship between wetland area and the economic activity is estimated. It is then possible to identify the increase in producer surplus associated with the wetland's area. In practice, it is often assumed that demand is perfectly elastic so that the impact of the wetland on consumer surplus can be ignored. Other times the producer surplus that is generated by a wetland is estimated using the replacement cost (RC) method. This approach values the wetland's service based on the price of the cheapest alternative way of obtaining that service. For example, the value of a wetland in the treatment of wastewater might be estimated using the cost of chemical or mechanical alternatives. As noted by Anderson and Rockel (1991), the replacement cost method is actually an upper bound on the true value since the producer may not choose to actually use that alternative considered.

Non-market values can be measured using travel cost (TC), contingent valuation (CV), or hedonic pricing (HP) methods. There is, however, substantial variability within each of these approaches, much more than can be discussed here (Freeman, 1993), and the literature is filled with reasons why results might be biased or otherwise

deficient. While in principle each method can give a correct estimate of economic value, it is easy to misuse the method and obtain results that may have little relation to the true value.

Some wetland values are obtained using methods that do not estimate economic surplus and, therefore, lack a foundation in standard economic theory. Of the studies identified in our review of the literature, two values were estimated using energy analysis in which the value is based on the gross primary production of the ecosystem, and five values were obtained using the market value of the products extracted. These methods have been strongly criticized (Anderson and Rockel, 1991). Energy analysis equates the energy embodied in a wetland's biota with the energy purchased in fossil fuels. Since the correlation between energy content and consumer preferences is quite weak, the technique is a poor predictor of economic value. The market value technique is also flawed since it cannot capture consumer surplus and can lead to over-estimate producer surplus if cost of extracting the valued products is not subtracted.

3. Meta-analysis as a tool in understanding non-market valuation

First used by psychologists (Glass, 1976; Schmidt and Hunter, 1977), meta-analysis has proved to be a useful tool for synthesizing the results of numerous studies. The method has recently gained attention in economics as a way to appreciate numerous studies that have placed economic values on environmental goods and services (see Brouwer (2000) for a review). The central advantage of meta-analysis is that it provides a rigorous statistical synthesis of the literature that cannot be achieved using more qualitative analysis.

There are two main types of meta-analyses: those that use the actual data from multiple studies, and those that use the results of multiple studies. It is the later method that has been applied to interpret valuation studies. Brouwer lists ten studies that have used meta-analysis to study valuation efforts. Smith and Kaoru (1990) were the first to use meta-analysis in the context of nonmarket valuation, looking at values placed on outdoor recreation. Since then, meta-analysis has been used to study air pollution, recreational fishing, visibility, health risks, endangered species and wetlands.[1]

The basic approach used in most valuation meta-analyses is the same. A set of studies is selected yielding a number of values that become the dependent variable. The independent variables are the characteristics of each study and study site. If a single study reports numerous values, then several data points are obtained. Meta-analysis allows the evaluation of the effect of changes in the underlying environmental attribute on value. Such analysis is usually not possible in the context of a single study since most such attributes are held constant.

A good example of the benefits of meta-analysis is seen in Smith and Osborne's (1996) analysis of the value of improvements in visibility. Since visibility varies continuously from zero to one, the authors are able to estimate the marginal benefit of improvements in visibility. One of the most significant limitations of meta-analysis, however, is the lack of comparability across studies (van den Bergh and Button, 1997). Characteristics of the resource being valued are often presented in such diverse fashion that the best that the analyst can do is to use a binary variable to indicate whether an attribute is reflected in each value. Boyle et al. (1994), for example, have no data on the level of cancer risk in each of their eight studies, only an indication of whether such a risk was mentioned in the study. Similarly, in this study wetland services are captured using qualitative variables.

Brouwer et al. (1997) is, to our knowledge, the only other attempt to carry out meta-analysis of wetland valuation studies. In their work, only contingent valuation studies are considered. This narrow focus allowed the authors to develop a

[1] The analysis of wetlands by Brouwer et al. (1997) looked at WTP estimates from CV studies and used a more expansive interpretation of 'wetlands' than we retain in this paper. Hence, their results are not directly comparable to the results here.

rich set of variables characterizing the qualities of the studies. However, this is also a limitation in that it eliminates any variability associated with valuation method and reduces the variability in services that can be considered. In the next section we discuss how we attempted to overcome these limitations in our data.

4. The wetland valuation data

After a lengthy review of the literature, we identified 39 studies that contained sufficient data to allow inter-study comparisons. Many other studies were identified but could not be used. The values are taken from published reports, 'gray' literature, and theses.[2] Because of our desire to synthesize wetland values from all different services, we use annual value per acre in 1990 US dollars. This distinguishes our work from other meta-analyses which typically use willingness to pay (WTP) per person (e.g. Brouwer et al., 1997). WTP per person is not applicable here because some methods (e.g. NFI) do not lead to a WTP per person measure. On the other hand, if WTP per person is available, then value per acre can be calculated with knowledge of the relevant population and the wetland's size. When capitalized values were reported, they were annualized assuming constant value per year and using discount factors provided in the studies or a 6% rate in the two studies that did not state a discount rate.

In our analysis we assume that a wetland's value is a function of the system's ecological characteristics and its socio-economic environment. Each wetland in our data is interpreted as a (not necessarily random) draw from the population of all wetlands. We assume that there exists a true public WTP at a given moment for a particular wetland. While this true WTP cannot be observed directly, it can be estimated using the methods discussed above. Seen in this way, there are two sources of variability in the wetland values: variation due to differing characteristics of the wetlands, i.e. along the function; and variation due to error in the estimation of the true value, i.e. deviations from the function.

Of course, the wetlands that have been valued were almost certainly not chosen at random from the total population. First there is the problem of selection bias. It seems likely that wetlands that are considered valuable a priori are much more likely to be studied and valued. This need not lead to errors in our estimation of the valuation function if all important variables are accurately measured, but given the limitations in the available data, the likelihood of such bias should be taken into account in benefits transfer exercises or any other attempt to extrapolate estimated values. Similarly, the fact that many of the studies have been filtered by the peer review process might have excluded some estimates. Good estimates that are either not statistically different from zero or are much higher than anticipated may not be published.

The values in our data are also not independent draws. Numerous studies generate multiple measures of wetland value, so that, as pointed out by Smith and Kaoru (1990), the data have panel characteristics. Furthermore, researchers who work closely together are likely to share practices that differ in important ways from others. Finally, since there has no doubt been learning over time, both in terms of methodology and the values that are reasonable, the data also probably suffer from some autocorrelation.

5. Bivariate meta-analysis

Using the available data, we now evaluate the sources of variation in estimates of wetland value. Two complementary techniques are used. In this section we explore some of the relationships in the data using graphical presentation and bivariate statistics. The advantage of this analysis is that it allows us to present the full data set graphically, making possible a richer appreciation of the data. However, the bivariate analysis ignores interactions between explanatory variables. Hence, a second and more standard technique is also used,

[2] The complete data set, including a description of each study and an explanation of the interpretations of the data that were made is available from the authors on request or via the internet at http://ageco.tamu.edu/faculty/woodward/.

that of estimating a valuation function using multivariate regression techniques.

5.1. Variation due to measurement error or bias

As noted above, there are two types of variation with which we are concerned, deviations from the valuation function due to bias or errors in estimation, and variations along the valuation function attributable to different wetland characteristics. We begin by looking at sources of systematic error because of study weaknesses and bias because of the valuation method used.

One might expect study quality to affect estimates of wetland value. Attention to this issue is potentially important because there is substantial variability in the quality of wetland valuation studies. While some studies are characterized by sound theoretical foundations and state-of-the-art econometric methods, others are crippled by faulty logic, poor data or incorrect economic analysis.

The weakness of many wetland valuation efforts is widely recognized. In their review of wetland valuation studies, Anderson and Rockel (1991) found only five studies that they deemed credible enough to list in their summary table. However, while it may appear obvious that only high quality analyses should be used in meta-analysis, it is also clear that the evaluation of quality is likely to be quite subjective. The problem of subjectivity is particularly problematic in wetland valuation studies because few efforts satisfy the highest standards of quality, in large part because of data limitations. In CV studies, for example, strict adherence to the guidelines of the NOAA panel (Arrow et al., 1993) is often impossible because of budgetary restrictions. Hence, there is a great deal of subjectivity in assessing how good is good enough.

As Cooper (1989, p. 67) points out, "The decision to include or exclude studies on an a priori basis requires the reviewer to make an overall judgment of quality that is often too subjective to be credible." He argues that it makes more sense to enumerate characteristics of each study and then evaluate whether 'good' methods lead to different results than 'bad' methods. "When no difference is found it is sensible to retain the 'bad' studies because they contain other variation in methods (such as different samples and locations) that, by their inclusion, will help answer many other questions surrounding the problem area."

Following Cooper's advice, some meta-analyses include objective indicators of study quality such as response rate or study format (Brouwer et al., 1997; Loomis and White, 1996). Given the diversity of studies considered in our analysis, no standard objective indicator of quality was available; only a subjective assessments of study quality could be used. Each study was ranked on a scale of 1–3 in four categories: the apparent quality of the data, the theoretical consistency of the methodology, econometric techniques and statistical certainty. A study was given a rank of 1 if we felt that this feature of the study made the results highly questionable. Studies with a 1 in any of the quality categories are called 'weak' in the figures and econometric analysis below.[3] A 'weakness' in a study should not be interpreted as a condemnation since valuation may not have been the authors' primary objective or data limitations may have been prohibitive.

On average, the weak and strong studies do not yield statistically different values. Excluding the highest value in our data set, the average of the weak studies is US$986 per acre versus US$915 for the strong studies.[4] When looking at the complete distribution of these studies however, there do appear to be some systematic differences two sets of values. Fig. 1 plots the rank of both the weak and the strong studies in their respective

[3] For studies that are also evaluated by Anderson and Rockel (1991) our critique was generally consistent. Some studies which we ranked as a 2 were questioned, but did not appear to be completely rejected by Anderson and Rockel.

[4] The highest value from the Amacher et al. (1989) study is excluded as it is over 60 times the second largest value. After excluding this value, the mean of the weak studies is not significantly different from the mean of the strong studies at the 10% level. This value, one other value estimated using energy analysis and five values estimated using the market value of the output are excluded from the econometric analysis below.

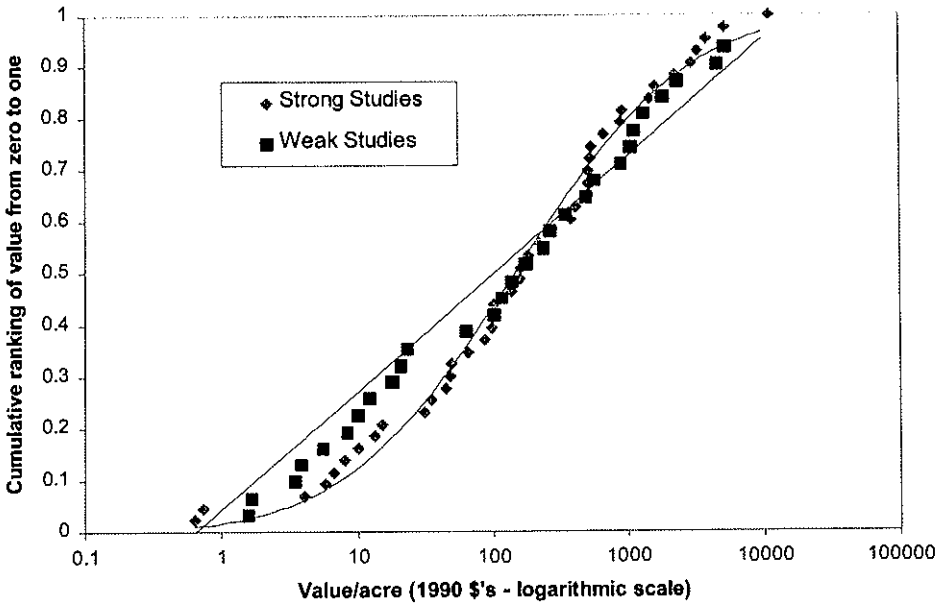

Fig. 1. Cumulative distributions of wetland values broken down by study quality.

categories on the vertical axis, against the estimated values per acre on the horizontal axis. The solid lines in the figure represent cumulative distribution functions (cdfs) of distributions from which the data appear to be drawn. While the distribution of the strong data closely resembles a log normal distribution, the weak data seem to be drawn from a uniform distribution. There is also slightly less variance in the strong studies, indicating that the lack of quality may not bias the estimated value, but it might have implications for the accuracy of the predictions. This result is confirmed in the multivariate analysis below. Nonetheless, we do not find the kind of dramatic difference between the two groups that would justify discarding the weak studies from the data set.

Another potential reason that the estimated value may deviate from the valuation function might be bias due to the method that was used in the study. In principle, if two methods seek to estimate consumer surplus from the same wetland then they should yield similar values. If there is no systematic difference between two techniques, then they are said to satisfy the criterion of convergent validity. Numerous studies have tested the convergent validity of CV analysis relative to other methods (e.g. Carson et al., 1996).

Fig. 2 presents the distributions of the values taken from the four primary methods used to measure wetland values. The means of the values from these methods vary from a low of US$198 for the travel cost method to a high of US$1555 for the replacement cost method. However, because of the substantial variability in the data, none of the means are statistically different from each other. Still, some patterns are evident. At one extreme, the net-factor input method is a lower bound on the distribution of values. At the other extreme, the distribution of values obtained using CV nearly stochastically dominates the distributions of values from the other three methods. These findings do not necessarily indicate biases in these techniques. Because of the small sample size we cannot statistically reject the hypothesis that the distributions are the same. Moreover, different methods are used to value different services. It may be that CV is used for high-value services while the NFI method is used for low-value services. Hence, the question of whether the method itself is a source of bias can only be explored using multivariate analysis.

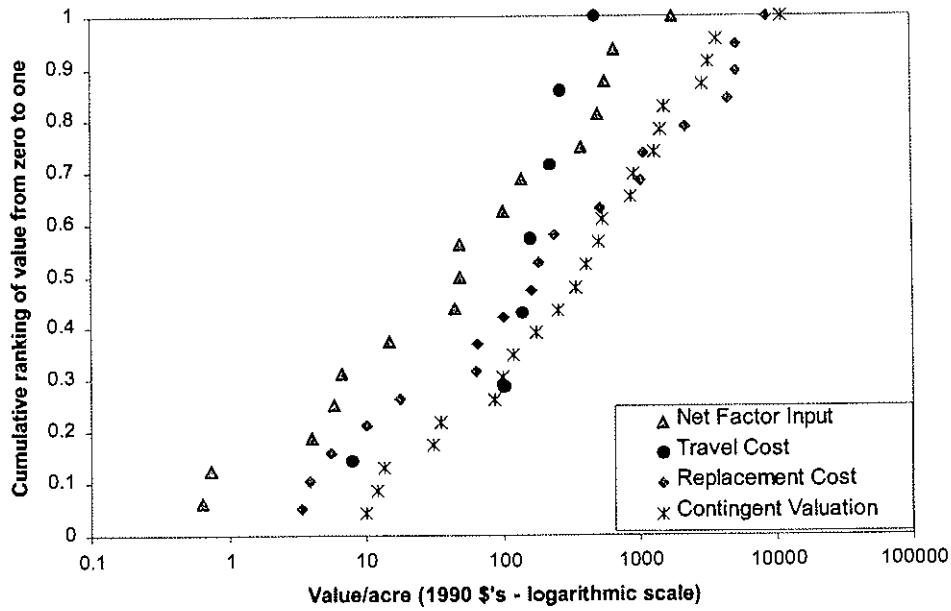

Fig. 2. Cumulative distributions of wetland values broken down by valuation method.

5.2. Variation in value due to wetland characteristics

We now turn an initial analysis of the sources of variation in the valuation function. Ten variables were defined indicating whether a particular wetland service was reflected in each study. These are listed in Table 1. Identifying the services reflected in a study often involves some subjectivity, particularly in CV studies since respondents might be aware of services other than those about which they had been explicitly asked in the survey.[5]

A relatively weak hypothesis would be that increasing the number of services considered in a valuation exercise would tend to increase a wetland's estimated value. This relationship is presented in Fig. 3. While almost two-thirds of the studies measured the value of only one wetland service, more than 30% of the studies measured three or more services. Contrary to our hypothesis, there is no noticeable relationship between the value of a wetland and the number of services valued. The correlation between estimated value per acre and the number of services is only 0.10 and, based on the Spearman rank criterion, the hypothesis of no correlation cannot be rejected at the 10% level.

In addition to being affected by wetland services, one might also expect the value per acre to be a function of the wetland's area. In this case there is no clear a priori expectation as to the form that such a relationship might take. Economic intuition would suggest that the marginal value of each acre would tend to decline. On the other hand, based on ecological principles of functional interdependence, one might expect that larger wetlands would provide a richer and more valuable set of services. This relationship is plotted in Fig. 4. There is no apparent relationship between wetland area and value in the figure and, once again, the hypothesis of no significant correlation cannot be rejected at the 10% level.

Our analysis to this point is quite inconclusive. There is some evidence that CV studies tend to yield greater values than any other method, but no visible relationship between value per acre and either the number of services or the size of the wetland. However, while we find the bivariate

[5] In a few instances authors were contacted to assist us in obtaining the most accurate interpretation possible.

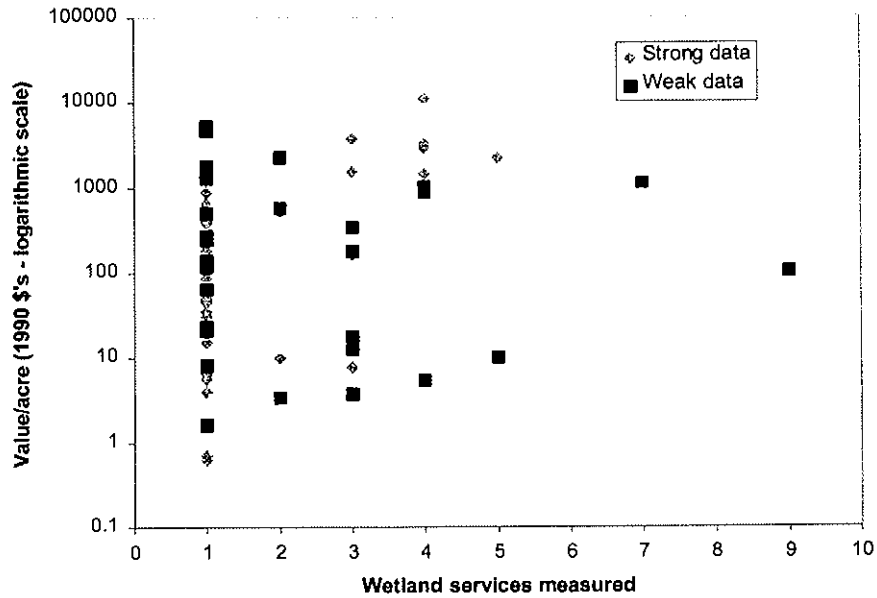

Fig. 3. Wetland values and the number services present.

analysis useful, it cannot distinguish how multiple factors might be interacting to influence wetland value. In the next section we attempt to tease out more understanding of the wetland valuation function using multivariate regression analysis.

6. Multivariate meta-analysis of wetland values

In this section we estimate a parametric specification of the valuation function using the data discussed above. After excluding incomplete observations and values based on either energy analysis or the market value methods, the 65 observations of wetland values were obtained.

6.1. The estimated model and results

The dependent variable in all regressions is the natural log of the value per acre of wetland converted to 1990 dollars, the mean of which is 4.92. In addition to the variables discussed above representing services, area and study quality, we included variables indicating date of the study (1960 = 0), year; whether the wetland was a coastal wetland, coastal; whether the value was an estimate of producer's surplus, PS; and whether the results had been published, published. The variables data0, theory0 and metric0, are dummy variables set at one if the data, theory or econometrics used in the study were deemed highly questionable.[6]

We should recognize that there are certainly important variables that determine a wetland's value that are omitted from our model. Characteristics of the population near a wetland are particularly likely to influence the value placed on the area. However, such data could not be identified in most of the studies; we were unable to include any such variables in our model. While the absence of these variables no doubt greatly diminishes the explanatory power of our analysis, it need not bias the estimated coefficients if these variables are uncorrelated with the included set (Kennedy, 1986).

Our econometric model is based on a maintained hypothesis that measured wetland value

[6] Since only two studies were deemed weak based on statistical significance, and many studies did not report sufficient information to gauge the statistical accuracy of their estimates, this variable was excluded from the econometric analysis.

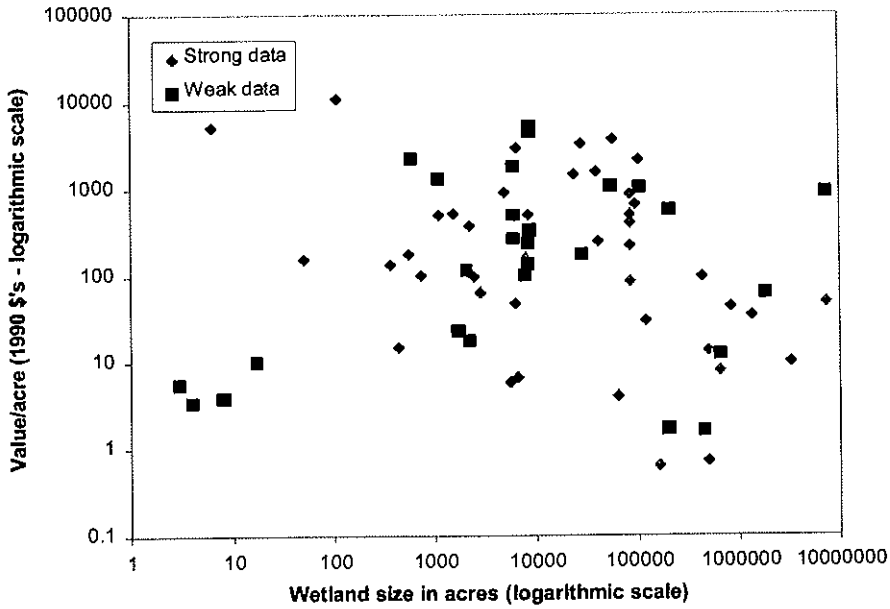

Fig. 4. Wetland area and values.

per acre, y, is a function of the services provided, $\mathbf{x}_s$, the methodology used, $\mathbf{x}_m$, the acres of the wetland x_a, other variables describing the study including year and location, $\mathbf{x}_0$, and a constant term. The fit was substantially improved by using the logs of both the per-acre value and the acres. Hence, the estimated linear model is

$$\ln(y) = a + b_a \ln(x_a) + \mathbf{b}_s'\mathbf{x}_s + \mathbf{b}_m'\mathbf{x}_m + \mathbf{b}_0'\mathbf{x}_0 \qquad (1)$$

where a is the constant term and the b's are the estimated coefficients on the respective explanatory variables.

The results of several regressions are presented in Table 2. In each case the hypothesis of homoskedasticity was rejected at the 5% significance level using the BPG test. Accordingly, the standard errors were estimated using White's (1980) correction. Model A presents the estimated coefficients of a model in which it is assumed that the variability in the values is solely a function of the physical characteristics of the wetland systems, ignoring any systematic variation due to the way that the values were estimated. Model B takes the opposite approach, explaining the values based solely on the methods used to measure those values and the quality of the studies. Model C combines both the characteristics of the sites and variables related to how the values were estimated.

6.2. Do the study quality or valuation method affect the value obtained?

In our discussion of Fig. 1 we argued that there was little evidence of bias as a result of the quality of the studies, and our regression results largely confirm that conclusion. The coefficients on the variables indicating poor quality theory and data are both statistically insignificant, as is the coefficient indicating whether the study was published. However, the variable indicating econometric quality was strongly significant in both regressions B and C. Holding all else constant, the values from studies with poor quality econometrics average 24–50 times greater than those from those with comparatively strong econometric foundations.

Study quality also has important consequences for the confidence we place on predicted values. Using the results from model C evaluated at the

Table 2
Estimated models of the wetland valuation function[a] (log of value per acre dependent variable, standard errors in parentheses)

Variable	Mean	A	B	C
Intercept		7.945[b]	6.641[b]	7.872[b]
		(1.07)	(1.31)	(1.74)
Year	14.908	−0.052	−0.004	0.016
		(0.03)	(0.04)	(0.04)
Ln acres	9.281	−0.168[c]		−0.286[b]
		(0.10)		(0.11)
Coastal	0.431	−0.523		−0.117
		(0.71)		(0.68)
Flood	0.138	−0.358		0.678
		(1.03)		(0.77)
Quality	0.200	1.494[c]		0.737
		(0.78)		(0.75)
Quantity	0.062	0.514		−0.452
		(1.60)		(1.54)
Rec. Fish	0.354	0.395		0.582
		(0.55)		(0.56)
Com. Fish	0.277	0.669		1.360
		(0.79)		(1.01)
Birdhunt	0.400	−1.311[b]		−1.055[b]
		(0.49)		(0.52)
Birdwatch	0.277	1.704[b]		1.804[b]
		(0.52)		(0.59)
Amenity	0.154	−3.352[b]		−4.303[b]
		(0.93)		(0.95)
Habitat	0.308	0.577		0.427
		(0.56)		(0.59)
Storm	0.031	0.310		0.173
		(2.37)		(1.66)
Publish	0.769		−0.669	−0.154
			(0.72)	(0.71)
Data0	0.246		0.302	0.000
			(0.56)	(0.60)
Theory0	0.215		−1.020	−1.045
			(0.84)	(0.84)
Metric0	0.123		−4.030[b]	−3.186[b]
			(1.21)	(1.22)
PS	0.277	−2.416[b]	−2.034[b]	−3.140[b]
		(0.83)	(0.72)	(0.86)
HP	0.031		0.441	5.043[b]
			(1.02)	(1.12)
NFI	0.246		−0.724	0.273
			(0.82)	(0.90)
RC	0.277		1.376	2.232[b]
			(0.86)	(0.89)
TC	0.108		−1.196[c]	−0.341
			(0.64)	(1.05)
n	65	65	65	65
R^2		0.373	0.364	0.582

[a] Standard errors were calculated using White's (1980) correction for heteroskedasticity. All results were obtained using Shazam version 8.0 (White, 1997).

[b] Significantly different from zero at the 5% level.

[c] Significantly different from zero at the 10% level.

means of the variables the log of the wetland value predicted for a high-quality unpublished study is 5.68 with a standard error around the prediction (σ_p) of 0.61. If it is assumed that the study is published, however, σ_p falls to only 46% of the original value. For studies that are weak in the areas of theory or econometrics, σ_p increases by 1.9 or 2.1-fold, respectively. On the other hand, the impact of study's data being of poor quality is slight, leading to a 4% decline in σ_p.[7] Study quality is important not so much because it might bias results, but because high quality studies lead to a much more precise basis for prediction.

There is some evidence that the method used has a statistically significant effect on the value obtained. As in Fig. 2, in model B we find that CV tends to dominate other methods as the signs on their coefficients are either negative or statistically insignificant. However, when variables indicating the wetland services are introduced in model C, the dominance of CV disappears and the sign on HP and RC methods becomes significantly positive. Hence, relative to these methods, CV studies tend to find a lower value per acre and we cannot conclude that this method is biased relative to the TC or NFI method.[8]

6.3. Do wetlands values exhibit returns to scale?

The coefficient on LnAcres is consistently negative and statistically significant across the models reported in Table 2, indicating significant decreasing returns to scale. However, because of the double-log functional form, the scale effect is extremely small for large wetlands. From Eq. (1), the marginal effect of an increase in the size of a wetland is

$$\partial y/\partial x_a = a_a x_a^{(a_a - 1)} e^{(a_0 + a_s \cdot x_s + a_m \cdot x_m + a_0 \cdot x_0)}$$

[7] The predicted values and standard errors around the predictor were calculated following Goldberger (1991, p.175).

[8] The coefficient on the HP method should be interpreted with extra caution since it reflects only two studies in the data set that used this method.

While a negative value for a_a means that an increase in the size of a wetland pushes down the value per acre, this effect diminishes rapidly as wetland size increases. Using the coefficient from model C, a 1% increase in area leads to a 2.9% fall in value for a ten-acre wetland. This effect declines geometrically, and for a wetland of 1000 acres the elasticity is only −0.029. This confirms what we see in Fig. 4 where wetland area appears to have little impact on value per acre.

6.4. How do wetland services affect wetland value?

The final and central question that we seek to answer is how wetland services influence wetland value. The coefficients on the wetland service variables are estimates of the extent to which the presence of each service changes the value per acre. A very small coefficient on the habitat variable, for example, does not mean that this service has no value, but that the value of wetlands that provide this service are very close to the average value for all wetlands.

Most of the wetland service variables are not statistically significant. In models A and C, only the coefficient on the birdwatch variable is significant and greater than zero while those on the birdhunt and amenity variables are significant and less than zero. Hence, the data indicate that a wetland that provides bird watching opportunities is more valuable than the average wetland, while those that offer bird hunting or amenity services are less valuable.

As one would expect, based on the explanatory variables in the model, only very imprecise predictions of wetland values are possible. Using the estimates from model C, Table 3 presents the predicted values per acre for each possible single-service wetland and 90% confidence intervals around those estimates.[9] Some strong conclusions can be drawn from the results. Looking not only at the mean, but at the upper and lower bounds of the confidence interval, bird watching and commercial fishing services are among the highest three valued services while amenity services are the least valued among all wetland services. The confidence intervals are extraordinary, spanning thousands of dollars. Clearly it would be highly speculative to use of a single point from this distribution in a benefits transfer exercise.

Table 3
Predicted values per acre of single-service wetlands[a]

Service	$E[\ln y]$	90% confidence interval around $\hat{y}$ (1990 US$'s per acre)		
		Lower	Mean	Upper
Flood	5.97	89	393	1747
Quality	6.03	126	417	1378
Quantity	4.84	6	127	2571
Rec.fish	5.88	95	357	1342
Com.fish	6.66	108	778	5618
Birdhunt	4.24	25	70	197
Birdwatch	7.10	528	1212	2782
Amenity	0.99	1	3	14
Habitat	5.72	95	306	981
Storm	5.47	11	237	5142

[a] The results presented in Table 3 are obtained from model C. The predicted values are obtained at the means of year and acre variables. Except for the variables indicating the respective services, all other binary variables are set to zero so that the prediction reflects a high-quality CV study estimating consumer surplus.

7. Conclusions

We have seen that wetland valuation studies are remarkably diverse in terms of the values obtained, the wetlands evaluated, and the characteristics of the studies. Our goal in this study was to isolate the sources of the variability in the wetland value.

There is some evidence that the method employed affects the value obtained. Relative to the HP or RC methods, using the CV method tends to yield a lower estimated value while there is no statistically significant difference between the CV and the TC or NFI methods. While it is perhaps comforting that the method that is used does not appear to be a primary determinant of value, the unimportance of study quality is not so reassur-

[9] We emphasize that the values in Table 3 do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.

ing. As we saw in Fig. 1, the distribution of weak studies is quite similar to that of the values from strong studies. However, econometric quality was found to be statistically significant in Table 2, and studies with weak econometrics tended to yield higher values. Study quality also has a substantial impact on the standard error around our prediction, suggesting that quality is important for the precision of our results.

This leads us to our final point: the use of benefits transfer to estimate wetland values faces substantial challenges. From our analysis it is clear that the prediction of a wetland's value based on previous studies is, at best, an imprecise science. The need for site-specific studies remains. Part of the problem lies in the lack of uniformity across studies. A better understanding of wetland values might be achieved if future researchers follow the suggestions of David (1993) in providing more information about their studies and centralizing the supporting documentation. Until an improved foundation can be established, it is important to emphasize the enormous uncertainties that are present in benefits transfer exercises applied to wetlands. In the interim, our analysis provides some guidance as to the wetland services that are most valuable, and the potential biases of some of the valuation methods.

Acknowledgements

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Avoided Costs (D3, Table D)

Item	Quantity	Unit	Unit Cost	Capital Cost	References
Tank, 140,000 gallon	1	LS	$ 87,352	$ 87,400	Quote for bolted steel tank is $92,632, Accelerated Environmental Services, 01/25/13. Costs escalated to 2012 dollars using DWR factor of 0.943.
WTP, 200 gpm	1	LS	$ 1,228,790	$ 1,228,790	Lake Berryessa Resort Improvement District bid prices, 2009. Costs of $1,193,000 escalated to 2012 dollars using DWR factor of 1.03.
Pipeline, 4" HDPE	9610	LF	$ 30	$ 288,300	Estimated unit cost of $30/LF from Pipeline Cost Calculations (rounded up to nearets 10). Distance is from new well/tank site to Lake Lucerne (1.82 mi).
Pump Station, 200 gpm	1	LS	$ 125,000	$ 125,000	
Total				$ 1,729,000	

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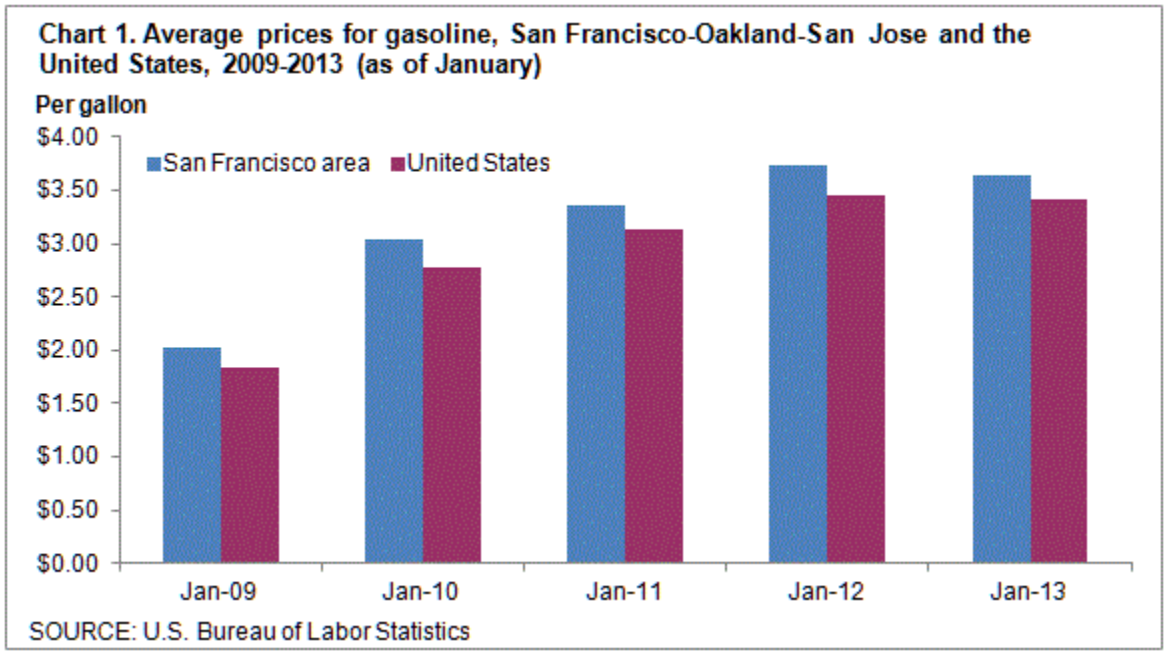
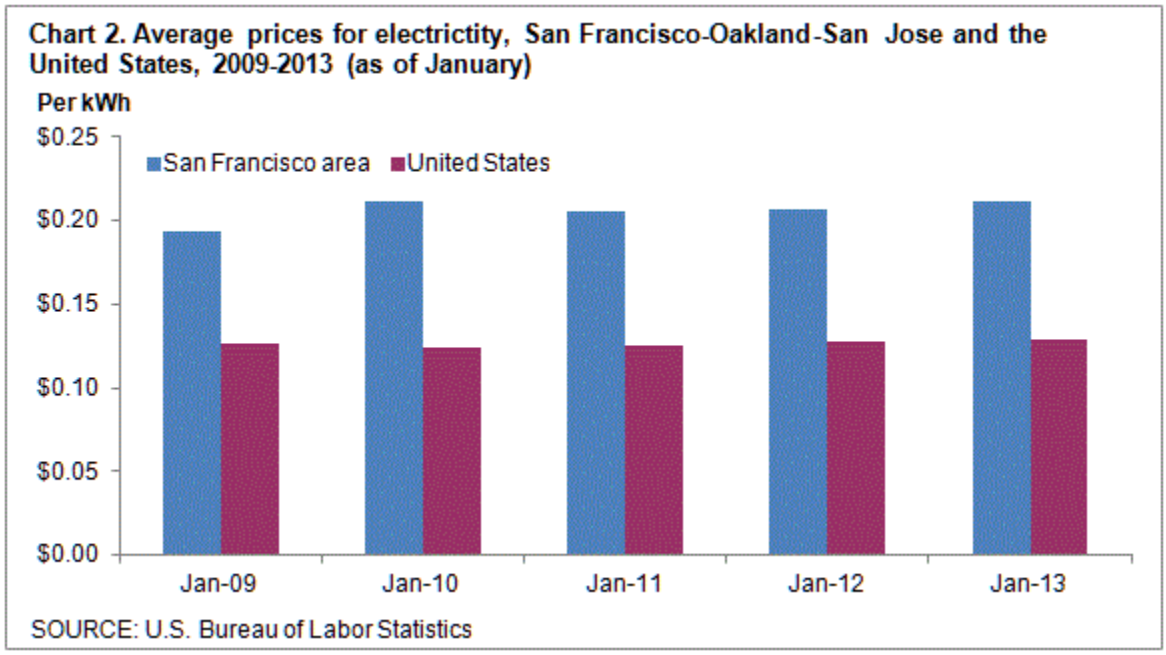
AVERAGE ENERGY PRICES, SAN FRANCISCO AREA–JANUARY 2013

Gasoline prices averaged $3.646 a gallon in the San Francisco area in January 2013, the U.S. Bureau of Labor Statistics reported today. Regional Commissioner Richard J. Holden noted that area gasoline prices were down 9.0 cents compared to last January when they averaged $3.736 per gallon. San Francisco area households paid an average of 21.2 cents per kilowatt hour (kWh) of electricity in January 2013, up from 20.7 cents per kWh in January 2012. The average cost of utility (piped) gas at $1.079 per therm in January was less than the $1.148 per therm spent last year. (Data in this release are not seasonally adjusted; accordingly, over-the-year-analysis is used throughout.)

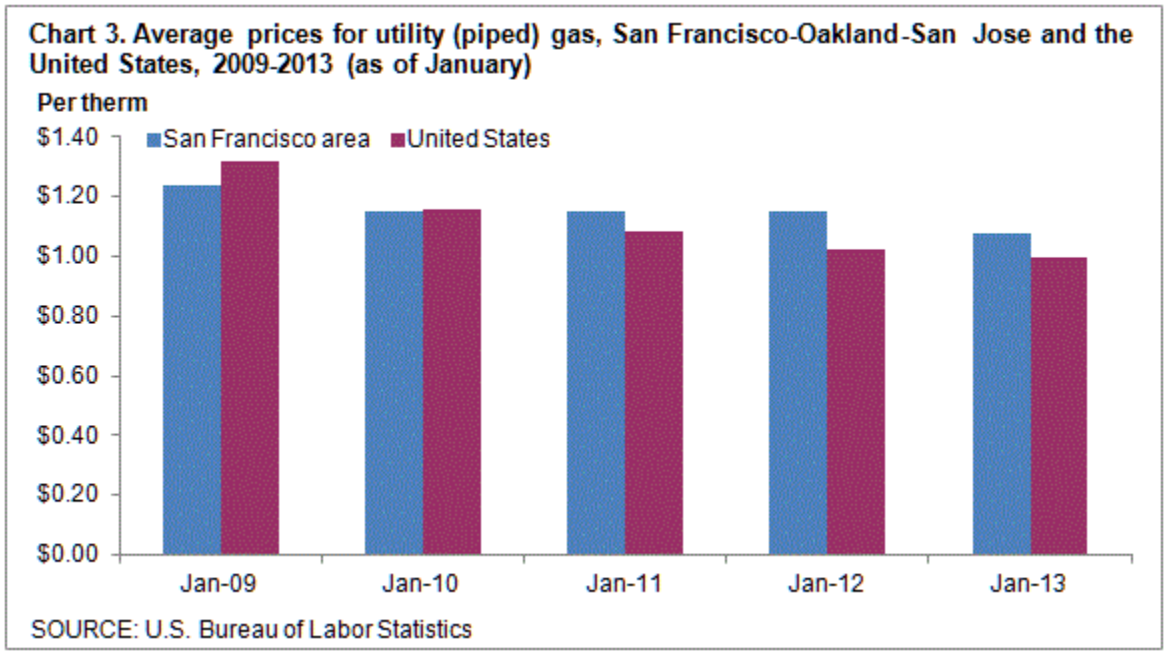
At $3.646 a gallon, San Francisco area consumers paid 7.0 percent more than the $3.407 national average in January 2013. A year earlier, consumers in the San Francisco area paid 8.4 percent more than the national average for a gallon of gasoline. The local price of a gallon of gasoline has exceeded the national average by more than six percent in the month of January in each of the past five years. (See chart 1.)



The 21.2 cents per kWh San Francisco households paid for electricity in January 2013 was 64.3 percent more than the nationwide average of 12.9 cents per kWh. Last January, electricity costs were 61.7 percent higher in San Francisco compared to the nation. In each of the past five years, prices paid by San Francisco area consumers for electricity exceeded the U.S. average by at least 53 percent in the month of January. (See chart 2.)



Prices paid by San Francisco area consumers for utility (piped) gas, commonly referred to as natural gas, were $1.079 per therm, or 8.3 percent above the national average in January 2013 ($0.996 per therm). A year earlier, area consumers paid 12.4 percent more price per therm for natural gas compared to the nation. In the past three years, the per therm cost for natural gas in January in the San Francisco area has been above the U.S. average. (See chart 3.)



The San Francisco-Oakland-San Jose, Calif. metropolitan area consists of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties in California.

Technical Note

Average prices are estimated from Consumer Price Index (CPI) data for selected commodity series to support the research and analytic needs of CPI data users. Average prices for electricity, utility (piped) gas, and gasoline are published monthly for the U.S. city average, the 4 regions, the 3 population size classes, 10 region/size-class cross-classifications, and the 14 largest local index areas. For electricity, average prices per kilowatt-hour (kWh) and per 500 kWh are published. For utility (piped) gas, average prices per therm, per 40 therms, and per 100 therms are published. For gasoline, the average price per gallon is published. Average prices for commonly available grades of gasoline are published as well as the average price across all grades.

Price quotes for 40 therms and 100 therms of utility (piped) gas and for 500 kWh of electricity are collected in sample outlets for use in the average price programs only. Since they are for specified consumption amounts, they are not used in the CPI. All other price quotes used for average price estimation are regular CPI data.

With the exception of the 40 therms, 100 therms, and 500 kWh price quotes, all eligible prices are converted to a price per normalized quantity. These prices are then used to estimate a price for a defined fixed quantity.

The average price per kilowatt-hour represents the total bill divided by the kilowatt-hour usage. The total bill is the sum of all items applicable to all consumers appearing on an electricity bill including, but not limited to, variable rates per kWh, fixed costs, taxes, surcharges, and credits. This calculation also applies to the average price per therm for utility (piped) gas.

Information from this release will be made available to sensory impaired individuals upon request. Voice phone: 202-691-5200, Federal Relay Services: 800-877-8339.

Table 1. Average prices for gasoline, electricty, and utility (piped) gas, San Francisco-Oakland-San Jose and the United States, January 2012-January 2013, not seasonally adjusted

Year and month	Gasoline per gallon		Electricity per kWh		Utillity (piped) gas per therm	
	San Francisco area	United States	San Francisco area	United States	San Francisco area	United States
2012						
January	$3.736	$3.447	$0.207	$0.128	$1.148	$1.021
February	4.040	3.622	0.207	0.128	1.187	0.986
March	4.375	3.918	0.209	0.127	1.055	0.978
April	4.230	3.976	0.209	0.127	1.197	0.951
May	4.331	3.839	0.220	0.129	1.224	0.907
June	4.012	3.602	0.220	0.135	1.345	0.927
July	3.804	3.502	0.218	0.133	1.385	0.943
August	4.136	3.759	0.218	0.133	1.369	0.960
September	4.201	3.908	0.218	0.133	1.320	0.953
October	4.476	3.839	0.218	0.128	1.273	0.962
November	3.832	3.542	0.207	0.127	1.190	0.994
December	3.563	3.386	0.207	0.127	1.140	1.004
2013						
January	3.646	3.407	0.212	0.129	1.079	0.996