Attachment 8L

Groundwater Recharge Opportunities Analysis

CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE
CALIFORNIA

2012 Central Valley Flood Protection Plan

Attachment 8L: Groundwater Recharge Opportunities Analysis

June 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section states the purpose of this attachment, gives background information (including a description of planning areas, goals, and approaches) and provides an overview of the report organization.

1.1 Purpose of this Attachment

Legislative direction to improve the performance and eliminate deficiencies of State Plan of Flood Control (SPFC) facilities and to develop a prioritized list of recommended actions is described in California Water Code Section 9616. Section 9616 requires that the Central Valley Flood Protection Plan (CVFPP) shall, whenever feasible, meet multiple objectives, including each of the following:

- Identify opportunities for reservoir reoperation in conjunction with groundwater storage
- Link the flood protection system with the water supply system

This document summarizes the approach and findings of an evaluation of groundwater recharge project types and general locations that could be used to integrate groundwater recharge and groundwater storage with the flood management system for the dual benefits of increasing flood management flexibility and water supply reliability. The findings help inform the formulation and evaluation of the State's Systemwide Investment Approach presented in the 2012 CVFPP. The initial identification of opportunities is based primarily on a review of past studies and preliminary findings from flood management analyses completed for the 2012 CVFPP.

1.2 Background

Protection Act of 2008, the California Department of Water Resources (DWR) has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the SPFC, and will be updated every 5 years.

As part of development of the CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Sacramento-San Joaquin Delta (Delta).

1.3 CVFPP Planning Areas

For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

- **SPFC Planning Area –** This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010)). The State of California's (State) flood management responsibility is limited to this area.

- **Systemwide Planning Area –** This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

This analysis of potential groundwater recharge projects that could be used to integrate groundwater storage with the flood management system considered the possibility of recharging water at locations both within and outside the SPFC and Systemwide planning areas. Evaluating opportunities outside the Systemwide Planning Area was important because these areas, located farther from established surface water channels, often have greater available groundwater storage capacity, as described below.

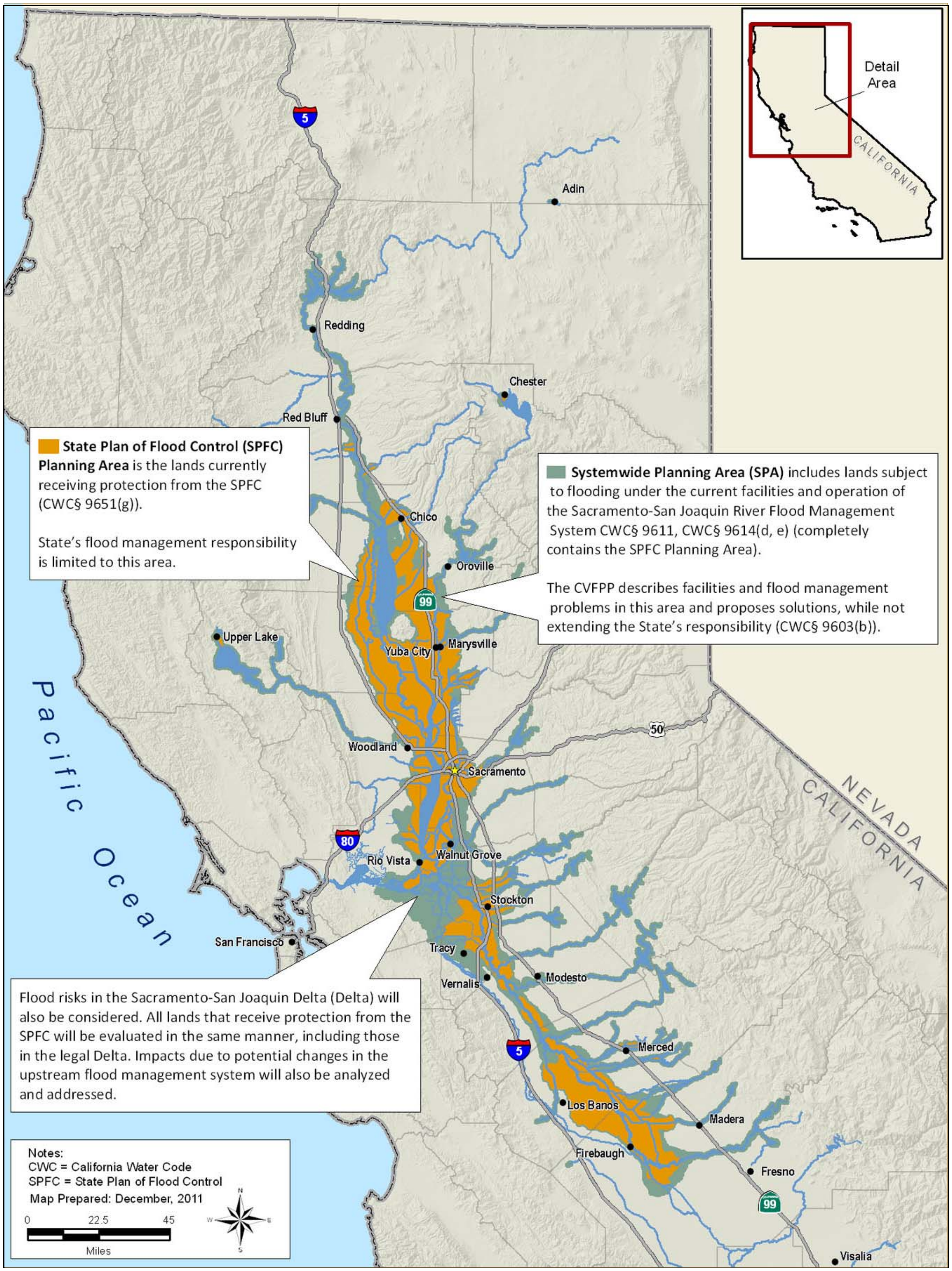

Figure 1-1. Central Valley Flood Protection Plan Planning Areas

1.4 2012 CVFPP Planning Process

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal –** Improve Flood Risk Management
- **Supporting Goals**:
  - Improve Operations and Maintenance
  - Promote Ecosystem Functions
  - Improve Institutional Support
  - Promote Multi-Benefit Projects

Integrating groundwater storage with the flood management system was identified as a potential management action that could help meet the primary goal of improving flood risk management while also providing the benefit of improved water supply reliability.

1.5 2012 CVFPP Planning Approaches

In addition to **No Project**, three fundamentally different preliminary approaches to flood management were initially compared to explore potential improvements in the Central Valley. These preliminary approaches are not alternatives; rather, they bracket a range of potential actions and help explore trade-offs in costs, benefits, and other factors important in decision making. The preliminary approaches are as follows:

- **Achieve SPFC Design Flow Capacity –** Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.
- **Protect High Risk Communities –** Focus on protecting life safety for populations at highest risk, including urban areas and small communities.
- **Enhance Flood System Capacity –** Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these preliminary approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

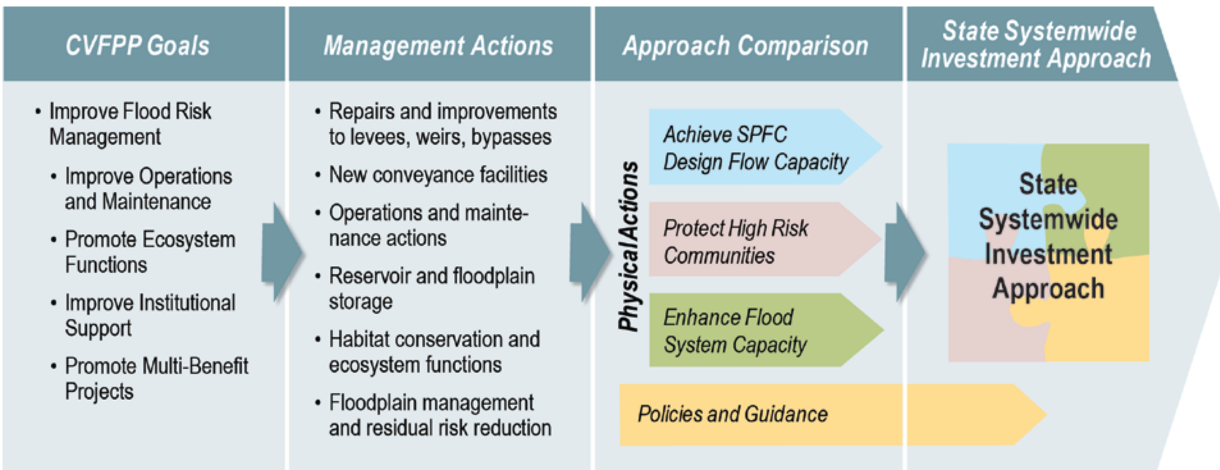

Figure 1-2. Formulation Process for State Systemwide Investment Approach

1.6 Report Organization

Organization of this document is as follows:

- Section 1 introduces and describes the purpose of this report.
- Section 2 summarizes the approach and methodologies used to evaluate groundwater storage opportunities.
- Section 3 describes the mechanisms by which groundwater recharge occurs and physical factors affecting groundwater recharge rates.
- Section 4 summarizes results for the different categories of groundwater recharge identified for this analysis.
- Section 5 describes the conclusions drawn from the analysis of groundwater storage opportunities in conjunction with flood management.

- Section 6 contains references for the sources cited in this document.
- Section 7 lists abbreviations and acronyms used in this document.

2.0 Approach and Methodology

Three categories of groundwater projects for integrating groundwater recharge with the flood management system were identified and evaluated for this attachment:

- **Category I –** Groundwater recharge projects associated with operational changes to existing reservoirs.
- **Category II –** Groundwater recharge projects associated with capturing unappropriated floodflows.
- **Category III –** Groundwater recharge projects associated with modified or new floodplain storage.

Each category was qualitatively evaluated to determine how it could serve to improve flood risk management and water supply reliability. The evaluation consisted of describing groundwater recharge mechanisms and physical factors influencing recharge (see Section 3), compiling information from prior studies of groundwater recharge in the Central Valley (see Section 4), and a basin-scale evaluation of potential recharge locations for the three groundwater project types based on historical groundwater elevation data and basin-scale soils data (see Section 4).

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3.0 Groundwater Recharge Mechanisms and Physical Factors Affecting Recharge Rates

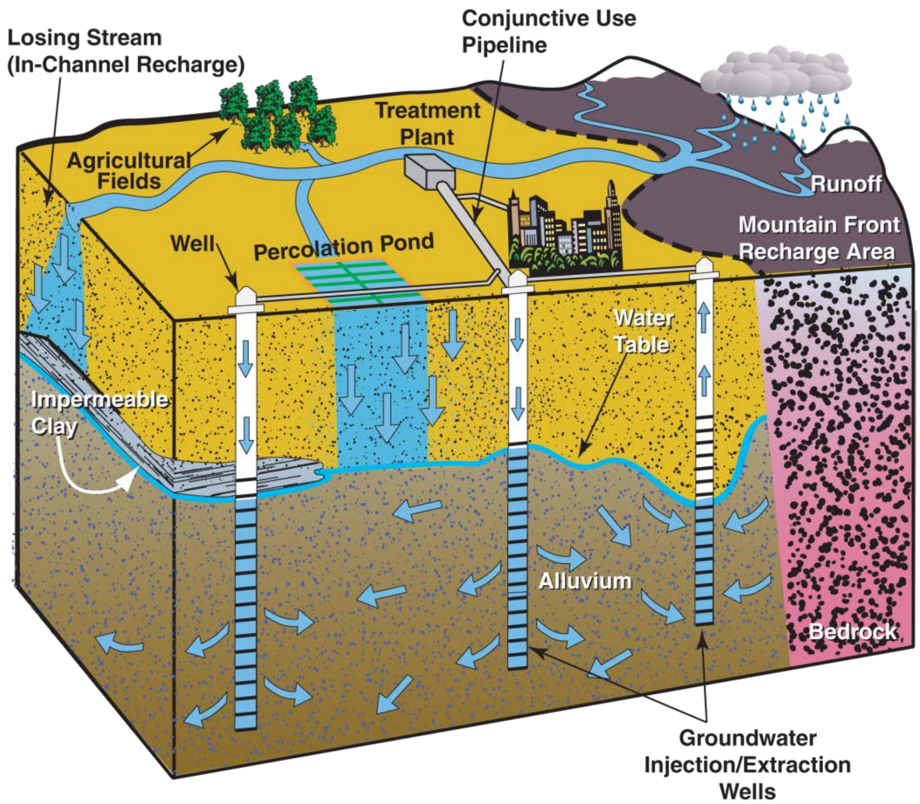
Groundwater aquifers are naturally recharged through several processes, including infiltration of precipitation falling on the land surface and infiltration of surface water (e.g., from lakes and rivers) through the unsaturated zone to the water table. In addition to natural mechanisms, managed groundwater recharge mechanisms can be applied in several forms, including the following:

- **Recharge Basins –** Water can be applied to percolation ponds, bermed and flooded fields, or excavated pits to directly recharge an underlying target aquifer (Figure 3-1).

- **Injection Wells –** Injection wells can be used to directly recharge deep or confined aquifers (Figure 3-1).

- **In-Channel Recharge –** Groundwater recharge can be enhanced by releasing greater than normal amounts of water to streams or unlined canals in locations where the stream or canal discharges to the aquifer (i.e., losing reaches) (see Figure 3-1).

- **In-Lieu Recharge –** In-lieu recharge is a special case of natural recharge. In times of surplus surface water, water users who are traditionally supplied by groundwater are instead given access to surface water. By using surface water, users allow that same amount of water to remain in storage as groundwater.



Source: Groundwater and Surface Water in Southern California: A Guide to Conjunctive Use (Association of Groundwater Agencies, 2000)

Figure 3-1. Groundwater Recharge Mechanisms

Managed groundwater recharge projects may require land acquisition, construction and maintenance of the recharge facility (recharge basins or wells), conveyance facilities to transport surface water to the facility or to users in the case of in-lieu recharge, retrieval facilities (i.e., pumping wells), and monitoring of the recharged groundwater.

Additional discussion of groundwater recharge mechanisms and requirements of managed groundwater recharge projects can be found in the *California Water Plan Update 2009* (DWR).

Several physical parameters that determine the suitability of a potential site for providing groundwater recharge benefits were identified and summarized below. Not all physical parameters are important for every recharge mechanism (e.g., the requirements for recharge basins are different than those for in-lieu recharge). Important physical parameters include the following:

- **Available Groundwater Storage Capacity –** Available storage capacity is defined as the volume of a basin that is unsaturated and capable of storing additional groundwater. It is typically computed as the product of the empty volume of the basin and the average specific yield of the unsaturated part of the basin. The available storage capacity does not include the uppermost portion of the unsaturated zone, in which saturation could cause problems such as crop root damage or increased liquefaction potential. Areas where the water table elevation has been depressed by groundwater extraction or long-term climatic conditions provide the greatest opportunities for groundwater recharge, while areas where the aquifer is relatively “full” do not. In general, aquifers in the San Joaquin Valley Groundwater Basin have larger storage capacity than those in the Sacramento Valley Groundwater Basin.

- **Suitability of Soils –** For most direct recharge methods, recharge volume is controlled by the rate at which water can infiltrate into the soil. Infiltration capacity is a measure of the volume of water that can be recharged per unit of time and is determined by soil moisture, saturated hydraulic conductivity, and moisture potential. Infiltration capacity of a basin can decrease through time due to clogging of pore space within the upper soil horizon. Routine maintenance may be required to maintain infiltration capacity at the sites.

- **Aquifer Suitability –** Water must not only migrate through the surficial soils, as described above, but it must also travel to the aquifer system that is used for regional or local groundwater supply. In the various depositional systems found in the Central Valley, there are locations where surface soils with high infiltration capacities overlie less permeable aquifer units. These less permeable units impede the flow of infiltrated water and prevent the water from reaching the target aquifer. In these cases, water infiltrates to only relatively shallow depths and then moves laterally, often discharging to downgradient surface water bodies. The degree to which water moves down through the shallow aquifers is often related to the degree of interconnectedness of coarse-grained deposits.

- **Capacity for Recovery of Recharged Groundwater –** To be considered a water supply benefit, water recharged at these facilities must be recoverable. To recover the water, a sufficient number of wells must be present near the sites to extract water from the target aquifers. Energy requirements need to be considered during planning to make groundwater costs economically viable. In general, the more transmissive an aquifer and the shallower the depth to water, the cheaper it will be to recover recharged water. Some portion of recharged water is not recoverable. Determining the percentage of recharged water that can be considered legally recoverable requires development of accounting tools, groundwater monitoring networks, and groundwater modeling tools.

- **Water Quality –** Groundwater basin water quality is an important concern for recharging groundwater that can be used later for agricultural or municipal use. Important constituents will vary based on the intended end use of the water, but can include total dissolved solids (TDS), lead, arsenic, boron, and organics. Taste of extracted water is an important concern for municipal use.

A number of other issues, including who will own the stored water and whether they have the capacity to use it locally or transfer it elsewhere, would need to be considered in ultimately assessing the viability of a site for managed groundwater recharge. These issues are described in DWR's *California Water Plan Update 2009* (see sidebar). Evaluation of these other issues was beyond the scope of this report. These issues will be a part of subsequent and more detailed evaluations that would be required to implement identified opportunities for integrating groundwater storage with the flood management system.

Issues Facing Managed Groundwater Storage

A number of issues facing managed groundwater storage were identified in the *California Water Plan Update 2009* (DWR) and those issues are summarized below:

- Uncertainty exists in the amount of surface water available for managed groundwater storage.
- Securing funding for potentially costly managed recharge activities can be difficult. The benefits of groundwater recharge activities must outweigh the associated costs.
- Uncertainty exists on the impact of groundwater pumping on surface water flows and aquatic ecosystems due to interconnectedness of hydrologic systems.
- Costs associated with siting new or enlarged recharge facilitates can be high.
- Uncertainty and inconsistency can exist in the regulation of managed aquifer recharge with respect to water quality.
- The data and tools needed to develop managed groundwater storage projects are often lacking.
- Infrastructure and operational constraints sometimes make managed groundwater storage difficult.
- Degradation of groundwater quality can be a concern if the recharged water is not of good quality.
- Managed groundwater recharge projects can have environmental impacts such as disturbing natural habitat.
- Uncertainty exists with respect to the impact that climate change may have on surface water flows and the water that could be available for managed groundwater storage projects.

4.0 Results

Information from previous studies of groundwater recharge in the Central Valley was compiled to inform the discussion of groundwater recharge in the context of flood management. The review focused on basin-scale studies and selected site-specific studies, although this review was not intended to include every historical groundwater recharge study for the Central Valley. One of the primary historical documents used was the *Hydrogeologic Suitability of Potential Groundwater Banking Sites in the Central Valley of California* study (Purkey and Thomas, 2001). This study documented a screening process to identify suitable sites throughout the Central Valley for groundwater recharge via recharge basins; several of those sites are summarized in Table 4-1. A subset of the sites evaluated in the 2001 Purkey and Thomas study were also used for the *Conjunctive Use for Flood Protection* study (USACE, 2002a), which evaluated conjunctive use of surface water reservoirs and groundwater aquifers for the purpose of increased flood protection. While the 2001 Purkey and Thomas study and the 2002 U.S. Army Corps of Engineers (USACE) study both focused on groundwater recharge in conjunction with changes in existing reservoir operations, the sites these two studies evaluate could also be applicable for storing floodflows as long as the necessary conveyance facilities exist or could be constructed.

4.1 Review of Groundwater Recharge Potential In the Central Valley

Two figures (4-1 and 4-2) were prepared to aid in visualizing potential groundwater recharge project opportunities in the Sacramento Valley and San Joaquin Valley, respectively. The figures show the locations of selected sites from the 2001 Purkey and Thomas study, as well as the locations of several other existing or potential groundwater recharge sites. The figures also show the locations of existing or potential in-lieu recharge areas and locations of potential modified or new floodplain storage. These sites are evaluated by presenting them in relation to suitability of soils and available groundwater storage capacity, two of the five important physical factors. These two important physical factors were used to screen potential opportunities for groundwater recharge in conjunction with the flood management system. The other three important physical factors – aquifer suitability, capacity for recovery of recharged groundwater, and water quality – were addressed qualitatively on a case-by-case basis (see Table 4-1).

Figures 4-1 and 4-2 include information on the hydrologic soil grouping of surface soils, as indicated from the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) Database. Surface soils in the STATSGO dataset are placed in one of four hydrologic groupings based on estimates of runoff potential. These hydrologic groupings are indicative of suitability of soils for groundwater recharge. The hydrologic soil groups are defined by NRCS as follows:

- **Group A –** Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

- **Group B –** Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

- **Group C –** Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils with a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

- **Group D –** Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays with a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

The hydrologic soil groupings, as plotted in Figures 4-1 and 4-2, are highly generalized (i.e., they are intended for basin-scale studies). Site-specific studies on infiltration rates will be needed in the feasibility study phase of a project before implementation. The brown shaded areas in Figures 4-1 and 4-2 represent the two hydrologic soil groupings (Groups A and B) with the greatest anticipated infiltration rates.

Figures 4-1 and 4-2 also show representative depth-to-water symbols for several sites. Depth to water is indicative of available groundwater storage capacity in unconfined aquifers, and was determined from measurements available in the DWR Water Data Library database. The methodology for determining representative depth to water was to use data for all groundwater wells in a 4-mile-square centered on the site. Historical depth to water was averaged for each well in the square, and individual well averages were averaged to form an aggregate average depth to water for each project site. Wells with no monitoring data after 2000 were not used for the calculations. It should be noted that this methodology could be improved with additional monitoring data, or with more specific information about screen intervals for the wells used. However, this information is not often readily available for older wells. The figures show that generally more groundwater storage space is available in the San Joaquin Valley than the Sacramento Valley. The figures do not show potential or actual recharge opportunities in the Tulare Basin. Purkey and Thomas (2001) found that sites in the Tulare Groundwater Basin generally had greater storage capacities than other locations in the Central Valley.

One potential improvement for future studies would be to develop a Central-Valley-wide surface representing depth to water. This depth-to-water surface could be a widely distributed indicator for available storage capacity, compared to the point measurements calculated for this evaluation. However, development of such a surface would require an adequate distribution of groundwater monitoring locations and a relatively contemporaneous depth-to-groundwater data set, and may require application of professional judgment thresholds (e.g., excluding water level data from wells screened below a certain depth).

Following is a summary of evaluation results for each category of opportunities for integrating groundwater recharge with the flood management system.

4.2 Category I. Groundwater Recharge Projects Associated with Operational Changes to Existing Reservoirs

Operational rules for reservoirs can be changed to increase flood pools (i.e., reservoir storage space available to capture upstream floodwater), thereby providing increased downstream flood protection. The practical impact of such a change would be increased releases from the reservoir before flood season. Changing reservoir operations in this way could be done in conjunction with coordinated groundwater recharge activities to store released water in subsurface aquifers. Reservoir storage previously reserved for water supply would be transferred to a groundwater aquifer, making that space available for flood operations. The *Conjunctive Use for Flood Protection* study (USACE, 2002a), which was completed for the *Sacramento and San Joaquin River Basins Comprehensive Study* (Comprehensive Study) (USACE, 2002b) identified up to 400 thousand acre-feet (TAF) of additional flood storage space, which was termed the Conjunctive Use pool, in the Sacramento Valley and 343 TAF in the San Joaquin Valley. For the Sacramento Valley, New Bullards Bar, Oroville, and Folsom Reservoirs were studied and for the San Joaquin Valley, Friant Dam/Millerton Lake, New Don Pedro Reservoir, and New Exchequer Dam/Lake McClure were studied. Although groundwater recharge for the Comprehensive Study was assumed to occur through direct methods such as recharge basins, recharge could also be implemented via injection wells or in-lieu methods.

A decision or recommendation to change reservoir operations for flood control benefits would need to be made with the understanding of the impact of such a change on water supply, water quality, environmental flow requirements, and contracted water delivery requirements. Because of the complexity of the operational decisions this would entail, this evaluation does not further analyze groundwater recharge benefits associated with changes in reservoir operations. DWR's ongoing System Reoperation Study can appropriately evaluate potential flood management benefits that might accrue from changes in reservoir operations.

4.3 Category II. Groundwater Recharge Projects Associated with Capturing Unappropriated Floodflows

Floodflows can be directly diverted from rivers to provide water supply benefits. The benefits may be immediate (i.e., diverting water directly for consumptive use) or deferred (i.e., groundwater recharge actions that allow the water to be extracted and used at a later time). This category of opportunities is largely locally driven with potential support provided by State and federal agencies. An example source of water for these activities is water released from federal storage facilities pursuant to Section 215 of the Reclamation Reform Act. Section 215 water is nonstorable and is made available on an annual basis to downstream users for reduced prices when certain conditions (e.g., heavy rainfall, snowmelt) result in larger than normal river flows. One potential limitation of using floodflows for consumptive use is the high sediment load that is sometimes present; this is generally of greater concern for municipal types of use than for agricultural use. One example of water directly using floodflows is the Friant Division contractors, who can accept Section 215 water released from Millerton Lake and convey the water using the Madera and Friant-Kern canals.

Deferred benefit opportunities could include many of the ongoing in-lieu and managed groundwater recharge projects in the Central Valley, as shown in Figures 4-1 and 4-2. Although not all of these projects, or potential recharge sites, were initiated with the purpose of capturing floodflows, they could be modified to accept floodflows if sufficient conveyance capacity were available. A few examples of these projects are briefly summarized below:

- **Sacramento Groundwater Authority Banking and Exchange Pilot Program –** In 1999/2000, a pilot study was conducted among the Sacramento Groundwater Authority (SGA), Sacramento Area Flood Control Agency (SAFCA), and the U. S. Department of the Interior, Bureau of Reclamation, to exercise the groundwater storage potential of the region and investigate the mechanics of a large-scale banking and exchange program. In this pilot study, SAFCA diverted and stored (banked) 2,100 acre-feet of water in the basin. The following year, surface water in the amount of 1,995 acre-feet was made available by exchange through the extraction of groundwater in-lieu of diverting a Central Valley Project supply from Folsom Lake (MWH, 2002).

- **Farmington Groundwater Recharge Program –** One example of a project with federal partnership is the Farmington Groundwater Recharge Program that began in 2001. USACE has partnered with Stockton East Water District to store up to 35,000 acre-feet per year of flood flows in local aquifers via direct recharge methods. This recharge water is intended to help arrest the overdraft condition of the Eastern San Joaquin Groundwater Basin and increase water supply reliability to the region (http://www.farmingtonprogram.org/) (see Farmington in Figure 4-2).

- **Madera Irrigation District Water Supply Enhancement Project –** The proposed Madera Irrigation District Water Supply Enhancement Project would create a water bank to recharge groundwater at natural swales and constructed recharge basins. The purpose of the project is to increase water supply reliability, reduce aquifer overdraft, reduce groundwater pumping costs, increase the quality of groundwater, and encourage conjunctive use projects (Reclamation, 2011) (see Madera Ranch in Figure 4-2).

- **Kern Water Bank –** The Kern Water Bank Authority, a Joint Powers Authority created in 1995, operates the Kern Water Bank. The Kern Water Bank occupies approximately 30 square miles of the southwestern San Joaquin Valley southwest of Bakersfield on the Kern River alluvial fan. The Kern Water Bank is capable of storing over 1 million acre-feet (MAF) on a long-term basis, and has stored approximately 1.7 MAF since the beginning of the water banking program. Approximately 240,000 acre-feet per year can be withdrawn using water supply wells located throughout the water bank. The well system is connected to the Kern Water Bank Canal, California Aqueduct, and Cross Valley Canal (http://www.kwb.org/).

Several additional potential project locations are shown in Figures 4-1 and 4-2, including groundwater banking sites that were identified in *The Hydrogeologic Suitability of Potential Groundwater Banking Sites in the Central Valley of California* study by Purkey and Thomas (2001).

4.4 Category III. Groundwater Recharge Projects Associated with Modified or New Floodplain Storage

Category III opportunities encompass any incidental groundwater recharge associated with potential floodplain storage or any actions designed to enhance groundwater recharge for water supply benefits as a result of floodplain storage. Inundation of floodplain storage areas would typically occur relatively infrequently and for short durations. Potential floodplain storage areas could include areas where levees are set back, designated flood easements, potential bypass expansion areas, and areas where titles are purchased for permanent floodplain storage facilities.

In addition to inundation frequency and duration, the water supply benefit associated with this category is directly related to the physical properties that govern the volume and rate at which water can be infiltrated through the soil and into the target aquifer. These properties include soil permeability (both at land surface and throughout the entire unsaturated zone) and water tables that are low enough to provide storage space for recharged water.

Soil hydrologic classifications and depth-to-groundwater conditions shown in Figures 4-1 and 4-2 allow for an initial screening for evaluating recharge potential at locations where potential floodplain storage may occur. As shown in Figure 4-2, some areas have potentially permeable soils along the San Joaquin River between its confluence with the Merced River and confluence with the Stanislaus River. However, the depth-to-groundwater is shallow, suggesting little capacity for storing groundwater through artificial recharge. Additional analysis may be required to evaluate specific groundwater recharge sites that are collocated with potential floodplain storage areas because the data evaluated for this attachment do not contain sufficient detail to determine site-specific soil properties.

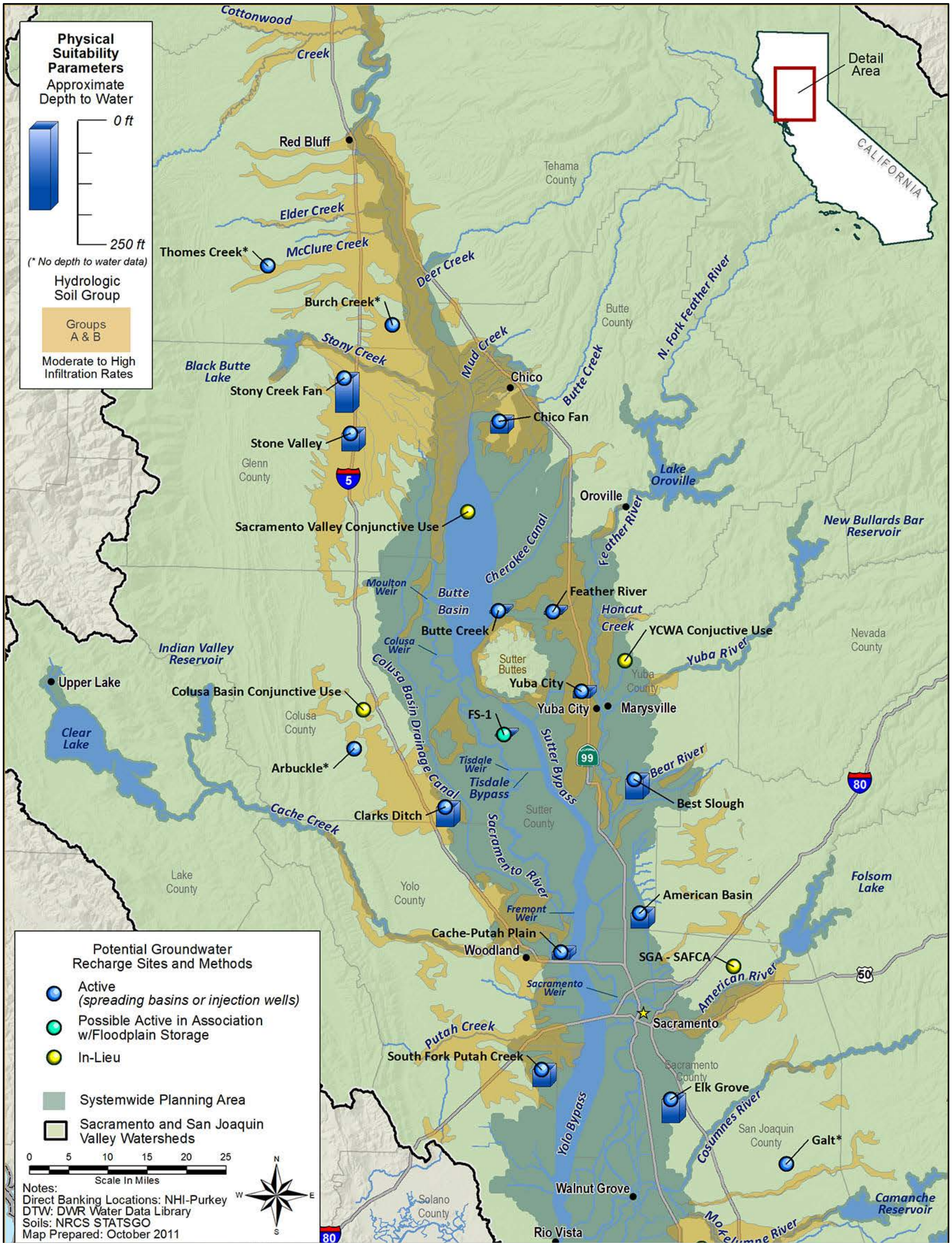


Figure 4-1. Groundwater Recharge Opportunities Identified in Sacramento Valley

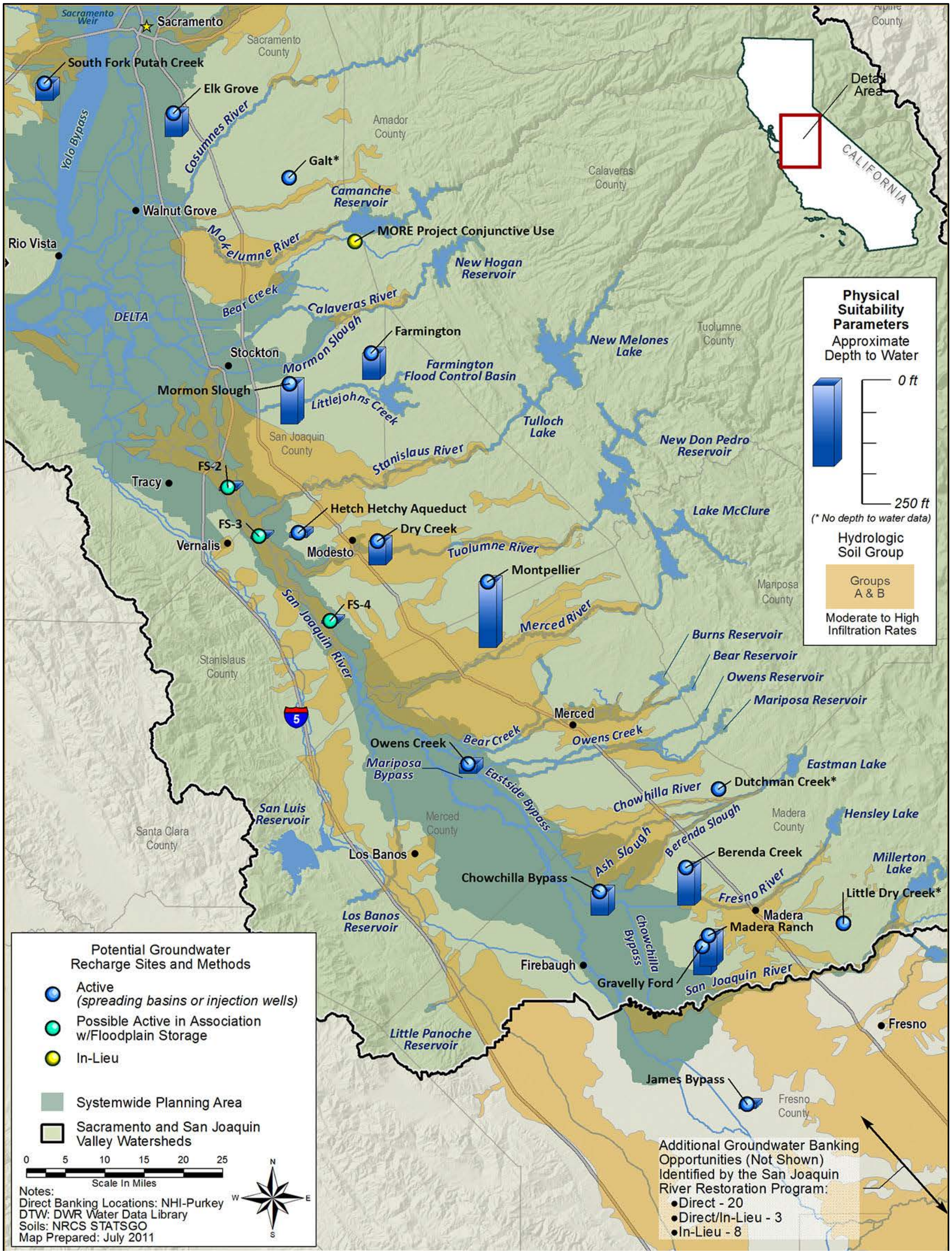


Figure 4-2. Groundwater Recharge Opportunities Identified in San Joaquin Valley

Table 4-1. Survey of Potential Groundwater Recharge Projects and Sites in Central Valley

Site Name	Location Description	Recharge Mechanism	Distance From River (miles)	Available Storage Volume/Capacity	Water Quality	Soil Suitability	Aquifer Suitability	Groundwater Extraction Facilities	Project Status	Opportunity for Integration with Flood Management
Sacramento Valley System										
Sacramento Valley Conjunctive Use Program	Northern Sacramento Valley	In Lieu	N/A	Storage capacity is relatively small (i.e., basin is generally full); basin would need to be exercised to create storage	Unknown	N/A	N/A	Depends on program implementation	Feasibility Study	Limited by full aquifer, high cost to implement
Yuba County Water Agency Conjunctive Use Programs	Yuba County/Yuba groundwater subbasins	In Lieu	N/A	Yuba groundwater subbasins are generally full as a result of historical surface water deliveries	Generally very good	N/A	N/A	Yes	Groundwater basin is being exercised through groundwater substitution transfers	Limited; no additional flood storage operations have been identified at New Bullards Bar Reservoir
SGA-SAFCA	Sacramento area	In Lieu	N/A	Approximately 500 TAF total available storage space		N/A	N/A	Yes	Pilot/ Implementation Phase	Successful pilot test of integrated groundwater banking and flood operations
Colusa Basin Conjunctive Use Opportunities	Western Sacramento Valley	Direct Recharge, In Lieu	N/A	Unknown	Unknown	Some good site-specific soil permeability corresponding to alluvial fan deposits associated with western foothill streams	N/A	Depends on program implementation	Conceptual	Limited by full aquifer, high cost to implement, limited public acceptance
San Joaquin Valley System										
Mokelumne River Regional Water Storage and Conjunctive Use Project	San Joaquin County	In Lieu and/or Direct Recharge	Varies, in vicinity of Mokelumne River	Program is targeting as much as 157 TAF/year of new water supply to help arrest groundwater overdraft and increase water supply reliability	One project goal is to reduce saline water intrusion in the basin	N/A	This site is located in an area of overdraft conditions, making it suitable for groundwater recharge and banking operations	Yes	Feasibility Study	Promising physical conditions
Farmington Groundwater Recharge Program	Eastern San Joaquin County	Direct Recharge	Varies, in vicinity of Calaveras River	Program is targeting as much as 35 TAF/year in groundwater recharge	One objective of the project is to establish a barrier to saline water intrusion	Pilot studies at several sites have demonstrated suitable soil conditions	Project is located near areas of overdraft	Yes	Pilot/ Implementation Phase	Pilot studies demonstrated feasibility of recharging target aquifer
Hetch Hetchy Aqueduct	East of San Joaquin River, between Stanislaus and Tuolumne Rivers	Possible Floodplain Storage, Direct Recharge	3 miles to Tuolumne River; 3.5 miles to San Joaquin River	Groundwater elevations are high in this area; Purkey and Thomas (2001) identified a maximum of 0.01 MAF of storage space (based on fall 1997 water levels) beneath this 4 mi2 hypothetical basin; Conjunctive Use for Flood Protection study (USACE, 2002a) calculated a range of storage capacity from 0.3 to 1.6 TAF/mi2 of recharge area	Water quality in this area is generally very good (Purkey and Thomas, 2001)	Good site-specific soil permeability, little to no hardpan. Conjunctive Use for Flood Protection study (USACE, 2002a) assumed Kv = 0.8 ft/d.	This site is located in the Modesto geologic formation, which Purkey and Thomas (2001) ranked as a medium formation for groundwater recharge; paleosols were absent and permeability was moderate	Depends on program implementation	Conceptual	Low unless conjunctive use of groundwater creates storage space

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Table 4-1. Survey of Potential Groundwater Recharge Projects and Sites in the Central Valley (contd.)

Site Name	Location Description	Recharge Mechanism	Distance From River (miles)	Available Storage Volume/Capacity	Water Quality	Soil Suitability	Aquifer Suitability	Groundwater Extraction Facilities	Project Status	Opportunity for Groundwater Recharge with Flood Management
Dry Creek	East of Modesto	Direct Recharge	1 mile to Tuolumne River	Purkey and Thomas (2001) identified a maximum of 0.02 MAF beneath this 4 mi^2 hypothetical basin; *Conjunctive Use for Flood Protection* study (USACE, 2002a) calculated a range of storage capacity from 6.6 to 12.7 TAF/mi^2 of recharge area	Good basin and site-specific water quality (Purkey and Thomas, 2001)	Good site-specific soil permeability, little to no hardpan; *Conjunctive Use for Flood Protection* study (USACE, 2002a) assumed Kv = 1 ft/d	This site is located in the Modesto geologic formation, which Purkey and Thomas (2001) ranked as a medium formation for groundwater recharge; paleosols were absent and permeability was moderate	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
Montpellier	East of Turlock	Direct Recharge	5.5 miles to Tuolumne River, 8.5 miles to Merced River	Purkey and Thomas (2001) identified a maximum of 1.04 MAF beneath this 4 mi^2 hypothetical basin; *Conjunctive Use for Flood Protection* study (USACE, 2002a) calculated a range of storage capacity from 19.1 to 26.4 TAF/mi^2 of recharge area	Relatively good basin and good site-specific water quality (Purkey and Thomas, 2001)	Good site-specific soil permeability, little hardpan; *Conjunctive Use for Flood Protection* study (USACE, 2002a) assumed Kv = 1 ft/d	Located in Tulare geologic formation, which has similar characteristics to, but is somewhat thinner than, Modesto Formation noted above	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
Owens Creek	East of San Joaquin River between the Merced and Chowchilla rivers	Direct Recharge	3 miles to San Joaquin River	Purkey and Thomas (2001) identified a maximum of 0.79 MAF beneath this 4 mi^2 hypothetical basin; *Conjunctive Use for Flood Protection* study (USACE, 2002a) calculated a range of storage capacity from 1.3 to 4.5 TAF/mi^2 of recharge area	Purkey and Thomas (2001) noted good water quality in the Merced basin, but poor water quality at this specific site, particularly in regard to high TDS	Low site-specific soil permeability, little to no hardpan; *Conjunctive Use for Flood Protection* study (USACE, 2002a) assumed Kv = 0.2 ft/d	This site is located in the Modesto geologic formation, which Purkey and Thomas (2001) ranked as a medium formation for groundwater recharge; paleosols were absent and permeability was moderate	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
Chowchilla Bypass	Northeast of Fresno River upstream from confluence with San Joaquin River	Direct Recharge	1.5 miles to Fresno River	Purkey and Thomas (2001) identified a maximum of 0.32 MAF beneath this 4 mi^2 basin; also noted condition of overdraft that could be slowed or reverse through groundwater recharge; *Conjunctive Use for Flood Protection* study (USACE, 2002a) calculated a range of storage capacity from 6.6 to 12.5 TAF/mi^2 of recharge area	Purkey and Thomas (2001) ranked the Chowchilla basin low for water quality, primarily because of elevated lead concentrations; site-specific water quality was mediocre	Moderately low site-specific soil permeability, some hardpan; *Conjunctive Use for Flood Protection* study (USACE, 2002a) assumed Kv = 0.5 ft/d	This site is located in the Modesto geologic formation, which Purkey and Thomas (2001) ranked as a medium formation for groundwater recharge; paleosols were absent and permeability was moderate	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
Gravelly Ford	East and north of San Joaquin River, upstream from Mendota Pool	Direct Recharge	6.5 miles to San Joaquin River	Purkey and Thomas (2001) identified a maximum of 3.61 MAF beneath this 4 mi^2 hypothetical basin; *Conjunctive Use for Flood Protection* study (USACE, 2002a) calculated a range of storage capacity from 14.7 to 16.7 TAF/mi^2 of recharge area	Overall water quality in the Madera basin is mediocre (Purkey and Thomas, 2001), primarily concern is elevated lead; site-specific water quality was good	Moderately low site-specific soil permeability, little hardpan (Purkey and Thomas, 2001); May be other sites in this area with better soil conditions; *Conjunctive Use for Flood Protection* study (USACE, 2002a) assumed Kv = 1 ft/d	This site is located in the Modesto geologic formation, which Purkey and Thomas (2001) ranked as a medium formation for groundwater recharge; paleosols were absent and permeability was moderate	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics

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Table 4-1. Survey of Potential Groundwater Recharge Projects and Sites in the Central Valley (contd.)

Site Name	Location Description	Recharge Mechanism	Distance From River (miles)	Available Storage Volume/Capacity	Water Quality	Soil Suitability	Aquifer Suitability	Groundwater Extraction Facilities	Project Status	Opportunity for Groundwater Recharge with Flood Management
Madera Irrigation District Water Supply Enhancement Project	Madera/Fresno area	Direct Recharge	6.5 miles to San Joaquin River	Maximum recharge and recovery capacity of 55 TAF annually; approximately 400 TAF available storage capacity beneath Madera Ranch	Improvement of groundwater quality is one of stated goals of project			Construction of recovery facilities was included in the description of project alternatives in environmental documentation	Record of Decision signed August 2011	Promising physical conditions; environmental documentation noted the ability for the district to take Friant Section 215 Water
Little Dry Creek	North of the San Joaquin River, downstream from Friant Dam	Direct Recharge	5 miles to San Joaquin River	Purkey and Thomas (2001) identified a maximum of 4.37 MAF beneath a 4 mi2 hypothetical basin; also noted condition of overdraft that could be slowed or reversed through groundwater recharge; Conjunctive Use for Flood Protection study (USACE, 2002a) calculated a range of storage capacity from 32.1 to 47.6 TAF/mi2 of recharge area.	Overall water quality in the Madera basin is mediocre (Purkey and Thomas, 2001); primarily concern is elevated lead; site-specific water quality was good	Medium site-specific soil permeability, little hardpan; Conjunctive Use for Flood Protection study (USACE, 2002a) assumed Kv = 1.0 ft/d	Located in Tulare geologic formation, which has similar characteristics to, but is somewhat thinner than, Modesto Formation noted above	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
James Bypass	Madera/Fresno area	Direct Recharge	14 miles from San Joaquin River	Purkey and Thomas (2001) identified a maximum of 6.13 MAF beneath this 4 mi2 hypothetical basin; also noted condition of overdraft that could be slowed or reversed through groundwater recharge; Conjunctive Use for Flood Protection study (USACE, 2002a) calculated a range of storage capacity from 24.0 to 37.8 TAF/mi2 of recharge area			Purkey and Thomas (2001) ranked the Alluvial Fan Deposits beneath this site low in their Geology Sub-Index	Depends on program implementation	Conceptual	Identified in basin-scale study as having suitable recharge characteristics
Projects off the Friant-Kern Canal and Madera Canal	Friant Service area	Direct Recharge, In Lieu	N/A	Site-specific	Site-specific	Site-specific	Site-specific	Site-specific	Projects range from initial planning to implementation	Modeling indicates water is available and contractors have identified specific in-lieu and direct recharge opportunities

Key:
DWR = California Department of Water Resources
ft/d = feet per day
Kv = saturated vertical hydraulic conductivity
MAF = million acre-feet
mi^2 = square mile
N/A = not applicable
SAFCA = Sacramento Area Flood Control Agency
SGA = Sacramento Groundwater Authority
TAF = thousand acre-feet
TDS = total dissolved solids

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5.0 Conclusions

Analysis of groundwater recharge opportunities that may be compatible with flood management in general, and the 2012 CVFPP in particular, has identified the following conclusions:

- Groundwater recharge associated with potential floodplain storage or increase in stream-channel area is limited in the Sacramento and San Joaquin flood management systems. Groundwater levels near the mainstem rivers are relatively high, which limits the amount of water that could be stored. Additionally, frequency and duration of inundation in these areas will be limited. Some in-channel groundwater recharge would occur during flooding, but construction of artificial recharge facilities is not recommended to increase recharge potential. Implementation of the State Systemwide Investment Approach, described in Section 3 of the 2012 CVFPP, would result in expansion and extension of the bypass system and levee setbacks. Those actions would create additional opportunities for in-channel and floodplain groundwater recharge.

- Opportunities for capturing floodflows and recharging them into groundwater aquifers by direct recharge methods are limited in the Sacramento Valley because the groundwater basin, with a few exceptions, is relatively full. The use of floodwater for recharge has been practiced for many years in the San Joaquin Valley, where historical groundwater extraction has created depressions in the groundwater table that provide opportunities to store water. Rates of groundwater recharge are typically low relative to large floodflows, and capturing those floodflows for groundwater recharge purposes would have only a small impact on lowering flood stage and flood risk. As noted above, managed groundwater storage projects are usually initiated at the local level for water supply benefits. Therefore, from the perspective of the State's investment in flood management, it may make sense to support these projects (e.g., through Integrated Regional Water Management programs) but it is not the State's responsibility to initiate and lead these types of groundwater recharge programs.

- Groundwater recharge as a component of conjunctive use with changes in existing reservoir operations continues to be a potential option to increase flood protection. Recharge in association with changes in existing reservoir operations could benefit flood protection in both the

Sacramento and San Joaquin valleys. However, changes in existing reservoir operations have implications beyond flood management, including potential impacts on water supply, water quality, environmental flow requirements, and contracted water delivery requirements. Any recommendation to change existing reservoir operations in conjunction with managed groundwater storage needs to be made with an understanding of those potential impacts. DWR's ongoing System Reoperation Study is an appropriate venue for this analysis. If this DWR study does find that managed groundwater storage should be implemented with changes in existing reservoir operations, a more detailed, site-specific analysis of sites identified here and in previous reports could be initiated.

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USACE. *See* U.S. Army Corps of Engineers

7.0 Acronyms and Abbreviations

Board	Central Valley Flood Protection Board
Comprehensive Study	Sacramento and San Joaquin River Basins Comprehensive Study
CVFPP	Central Valley Flood Protection Plan
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
MAF	million acre-feet
NRCS	Natural Resources Conservation Service
SAFCA	Sacramento Area Flood Control Agency
SGA	Sacramento Groundwater Authority
SPFC	State Plan of Flood Control
STATSGO	State Soil Geographic
TAF	thousand acre-feet
TDS	total dissolved solids
USACE	U.S. Army Corps of Engineers

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