DWR 223

PUBLIC HEALTH ASPECTS OF SACRAMENTO-SAN JOAQUIN DELTA WATER SUPPLIES

A Panel Report for the
California Department of Water Resources

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Members of the Scientific Panel Regarding Health Aspects of Delta Water Supplies

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I. INTRODUCTION

On August 31, 1982, Mr. Ronald B. Robie, Director, California Department of Water Resources, appointed a scientific panel to assess the health aspects of Sacramento-San Joaquin Delta water used for domestic purposes. A copy of the letter from Mr. Robie to the panel members, together with the background for the study and the original charge to the Panel, are contained in Appendix A. In essence this panel was appointed because of concerns expressed by some agencies about the quality of the raw water supplies diverted from the Delta area for domestic use. In particular, the Panel was asked to determine whether there were any health hazards that may result from use of surface water taken from the Sacramento River between Sacramento and the Delta, or from the Delta itself, particularly at the Clifton Court Forebay. Furthermore, the Panel was asked about additional treatments other than standard procedures that might be used to reduce health hazards and what their cost might be.

The Panel met on a number of occasions to discuss the issues raised. The many agencies that receive raw water from the surface waters in question were contacted for water quality information and to learn of their particular concerns. Other local, state, and federal agencies were contacted for additional water quality information they may have that could be of value in the Panel's deliberations. A list of those specifically contacted are included in Appendix B. The information obtained together with that readily available in the literature was reviewed by the Panel, and from this together with the knowledge and experience of the individual panel members, the conclusions and recommendations contained in this report were drawn.

The Sacramento-San Joaquin Delta is a complex body containing waters with great differences in quality. However, there are three main locations from which most of the surface water used as domestic water supply are taken. These are the Sacramento River near Sacramento, Rock Slough at the Contra Costa Canal, and Clifton Court Forebay where water is obtained for the State Water Project and delivered via the South Bay and California Aqueducts. The Panel specifically addressed water quality at these three locations.

From the information initially received, it became apparent that three classes of problem contaminants in water were of particular health concern to several agencies. These were sodium, asbestos, and a group of organic compounds collectively termed trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and tribromomethane). The Panel, however, did not confine its study to these three groups alone, but considered the range of chemical, physical, and biological contaminants that in general constitute health hazards to humans in the water they consume. Criteria for drinking water generally consider contaminants that affect the aesthetics of water such as taste and odor as well as substances that have a direct effect on health. However, the Panel did not address aesthetic factors in its deliberations. It is true that aesthetic factors can have health implications if consumers are driven by these factors to seek more palatable but less risk-free water. However, the time and resources for this study were insufficient for the Panel to address all quality considerations of the water supplies of concern, and so the decision was made to confine this review to contaminants that have health effects.

This report first addresses health criteria in general for drinking water and then discusses the current status of surface water in the Sacramento-San Joaquin Delta area. Finally, in response to an additional request from the Department of Water Resources, consideration was given to the high asbestos concentrations in Delta water delivered to southern California via the California aqueduct.

The Panel wishes to express its appreciation to all of the many individuals and agencies who so willingly supplied the information needed by the Panel to complete this study. We are especially grateful to B. J. Archer, William B. Mitchell, Jr., Richard Woodard, and other staff members of the Department of Water Resources who supported the Panel's study by attending meetings, and providing information, documents, and other materials for the preparation of this report.

II. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Treatment plants being supplied water from the Delta are meeting all current drinking water requirements with few exceptions. Based on the present state of knowledge and within the guidelines of the EPA interim primary drinking water regulations, conventional treatment with appropriate operation can produce drinking water that poses no known undue health hazards to the public.

2. There are areas of uncertainty that must be resolved for a full understanding of public health impacts of drinking water from the sources reviewed. These areas include the following:

   - The specific effects on public health of asbestos, sodium, and trihalomethanes in drinking water.

   - The accuracy and precision in the measurement of asbestos and trihalomethanes in water.

   - The effectiveness and reliability of treatment processes for the removal of the constituents of concern to this panel.

3. Trihalomethanes, formed as a result of disinfection of the water supplies under review, can generally be maintained within EPA drinking water requirements through appropriate operation of conventional water treatment processes. The potential for trihalomethane formation is greater in waters from Clifton Court and Rock Slough than from the Sacramento River because of greater contamination with organic carbon in the Delta.

4. The concentrations of sodium at Rock Slough and Clifton Court are sufficiently high to cause concern for the health of individuals who must limit their intake of sodium to control hypertension. The concentrations are especially high during certain times of most years and especially during droughts. The concerns are further heightened for water that has been treated by a typical home water softener.

5. Asbestos periodically occurs in relatively high concentrations in all raw waters evaluated. The source of asbestos is erosion of minerals naturally present in the drainage basin. Conventional treatment can bring about significant reductions in asbestos concentrations to near the lower limits of detection. Because of large fluctuations in concentrations of the waters reviewed and insufficient monitoring data, it cannot be assured that normal treatment will be continuously effective. Due to the

lack of definitive data on the health hazards presented by ingesting asbestos fibers, the risks posed by this uncertainty in removal cannot be evaluated at this time.

6. Considerations of public health, as affected by the quality of drinking water, have not received enough attention in decisions about the water management for the Delta, which is the source (though not always the sole source) of drinking water for approximately 15 million people.

7. The current Delta water monitoring program conducted by the Department of Water Resources was developed primarily to monitor quality from an ecological perspective specifically directed towards fishery resources and not to assess human health aspects with respect to drinking water. The program as presently constituted, while providing information for this report, is not entirely adequate to assess the present or projected suitability of these waters as a source of drinking water supply.

Recommendations

1. Considerations of public health, as affected by the quality of drinking water, should be given a much higher priority in decisions about the Delta. Following are examples of decisions that can impact the quality of drinking water:

   - How to transport water through the Delta.
   - How to solve the levee breakage problem.
   - Where to locate or relocate drinking water supply intakes.
   - What timing and magnitude of exports from the Delta should be used.
   - Setting of Delta water quality standards, in particular, revisions of Decision 1485 by the State Water Resources Control Board.

2. The Panel uniformly believed that there were public health issues of significant concern with respect to use of Sacramento-San Joaquin Delta waters as a source of drinking water supply, but were divided as to the best approach to this issue. Some felt that the long-held public health principle of obtaining drinking water from the best source available should be adhered to. Others expressed the opinion that advanced water treatment technologies could provide an adequate measure of protection. But all agreed that the public health issues should be more fully considered in future planning both by water purveyors and state authorities.

3. Data collection and analysis programs and other studies to resolve public health concerns should be actively pursued. A more comprehensive analytical framework needs to be structured for analysis of the various alternatives that may be considered to ameliorate future quality problems. Such a framework is also needed to help predict the effect of proposed system modifications on water quality at various intake

locations. This framework should provide a quantitative understanding of the system response with appropriate adjustments for any areas of uncertainty.

4a. Since trihalomethanes are suspected carcinogens, they may impose some health risk at any concentration. Thus, water purveyors should make efforts to reduce levels even below the maximum contaminant levels specified by the EPA interim primary drinking water regulations whenever economically feasible and where this will not impose other, perhaps greater, health risks.

4b. People whose dietary intake of sodium is limited (to control hypertension) should be informed by the water purveyor of the amount of sodium in water they drink if the source is Rock Slough or Clifton Court, and especially if they have a home water softener.

4c. In order to determine the degree to which conventional treatment processes are effective in removal of asbestos fibers, water purveyors should periodically monitor for asbestos fibers in both raw and treated waters.

5. Each domestic water purveyor should prepare a plan to address one or more of the following eventualities:

- More stringent requirements on the quality of drinking water.
- Worsening of raw water quality.
- Increasing demands for additional water.

The plan should include possible plant modifications and/or optimizations, use of water from a less contaminated source, provision of additional long-term storage, and/or blending.

ASBESTOS PROBLEM IN THE CALIFORNIA AQUEDUCT

Conclusion

The lack of both data and time did not allow the Panel to analyze this issue in depth. However, from the data available it is clear that the asbestos concentrations in water delivered to southern California via the California Aqueduct are unusually high. Conventional treatment with reasonable modifications will not reduce concentrations sufficiently to remove health concerns.

Recommendations

Because asbestos concentrations in the California Aqueduct are excessive such as to exceed the ability of conventional treatment plants to effectively remove these particulates, the Panel recommends the following:

- Methods other than treatment should be reviewed and considered for reducing asbestos concentrations in the water delivered by the California Aqueduct.

- Monitoring of asbestos concentrations should be continued on Aqueduct water, both above and below the Arroyo Pasajero, and in finished water derived from this source.

- The effectiveness of the project to dredge asbestos-rich sediment from the Aqueduct should continue to be monitored.

- Alternative treatment procedures to reduce asbestos concentrations should be evaluated.

III. HEALTH CRITERIA

Mankind has traditionally used sensory inputs (taste, odor and appearance) to judge water quality and continues to do so. With the studies of John Snow involving a cholera epidemic in London and the Broad Street pump, it was recognized that sensory impressions provided only a partially protective barrier and during the later part of the 19th century and the early part of the 20th century, this led to a steady shift towards reliance on scientific measurements of water quality. Initially the focus was on the microbiologic contaminants, but by the middle of the 20th century, most of the major inorganic constituents of natural and treated water systems were identified and accurately characterized. Just as the Broad Street pump shook our confidence in water quality over 100 years ago, research findings and federal agency reports in the 1960's and 1970's concerning what used to be regarded as trace levels (μg/l) of a wide variety (thousands) of organic constituents in water has stimulated a re-evaluation of water acceptability criteria.

The contaminants in drinking water that may produce adverse health effects can be classified in the following way:

1. Microbiologic agents (bacteria, viruses, pathogens)

2. Inorganics (metals, fluoride and other ions)

3. Organics (pesticides, solvents, etc.)

4. Particulates (asbestos, humics, etc.)

In considering the health hazards that could result from the use of surface water taken from the Sacramento River between Sacramento and the Delta, or from the Delta itself, the Panel reviewed available data and discussed several classes of contaminants which were considered to be potential problems related to the area such as pesticides and humics.

From these reviews and discussions, the Panel found only three contaminants to be of particular concern for detailed consideration. Thus, we have focused on the three contaminants: sodium, asbestos and the trihalomethanes (THMs), since these may be of health significance to consumers within and outside of the Delta. THMs are produced as a result of interactions between chlorine and natural organic materials present in water. Disinfectants other than chlorine have been considered by others to reduce this problem. Since adverse health effects may be associated with other disinfectants, a discussion of this issue has also been included in this Section.

Trihalomethanes (THMs)

Trihalomethanes are a group of chlorinated and brominated methanes that are formed in drinking water as a result of chlorination for disinfection purposes. Numerous studies and reports have documented their formation and the fact that at least one of these substances, chloroform, is a potential cancer causing chemical. The reader is referred to those reviews and reports for a more detailed discussion (National Research Council, 1977; Woodard and McCune, 1982; Symons et al., 1981).

The current concern about the possible adverse health effects of trihalomethanes in drinking water is based on two primary observations. The first is demonstrated existence of chloroform and other trihalomethanes (bromodichloromethane, dibromochloromethane, bromoform) in finished ground and surface waters, and the second is the findings from a 1976 National Cancer Institute bioassay in which chloroform produced tumors of the kidneys and renal pelvis in rats and liver cancers in mice (National Cancer Institute, 1976). Several epidemiological studies have reported a significant relationship between THMs in drinking water and increased mortality from cancers of the urinary and gastrointestinal organs (Buncher, 1975; Canter et al., 1978; DeRowen and Diem, 1975; Harris, 1974; Kuzma et al., 1979; Gottlieb et al., 1982). Most of these studies strongly suggest a causal relationship but are not unequivocal due to the usual problems associated with conducting epidemiological investigations (e.g., low power, confounding variables, etc.). Risk assessments of consuming water containing THMs have been discussed by the EPA (Federal Register, 1979) and in various public forums (The Brookings Institution, 1981).

Although numerous other volatile trace organics have been detected in the more recent surveys, chloroform and to a lesser extent the other trihalomethanes, dominate the frequency of detection data, and there appears to be a high correlation between the appearance of these compounds and the use of chlorine in water treatment. It should be kept in mind, however, that the compounds reported thus far in water samples are essentially from the volatile fraction only and that even when taken together, all the compounds that had been identified in any sample add up to only a small fraction of the total organic carbon known to be present. Other studies suggest that chloroform may not be the dominant reaction product and emphasize the need to look for both halogenated and non-halogenated reaction products in finished drinking water samples. The range of concentrations that have been observed for total trihalomethanes in raw water samples is substantially greater in ground water samples than in surface water samples. However, chlorination generally results in the production of much higher concentrations than found in raw water supplies.

With regard to the carcinogenicity of the trihalomethanes, it is important to recognize that such effects have been demonstrated only for chloroform, and the assumption that similar effects would be produced in rodents by chronic exposure to related halogenated compounds requires verification. In addition, there is some question regarding the interpretation of a chloroform bioassay since the studies used corn oil as the vehicle for introduction and the material was administered orally. The predictive validity of the particular mouse strain used in these experiments is currently undergoing considerable scientific scrutiny. More important, perhaps, for the health effects questioned, is the lack of information concerning the effects of chronic exposure to the nonvolatile organics in finished ground and surface water. It is important, therefore, in considering the use of additional treatment other than the standard procedures for reducing the trihalomethane content of finished water, to also consider the effect of such treatments on other organic contaminants.

The Safe Drinking Water Committee of the National Academy of Sciences - National Research Council has reviewed the health effects information related to the trihalomethanes, various alternative disinfectants (chloramine, chlorine dioxide, etc.), and the advantages and limitations of treatment methodology such as activated carbon in a series of volumes published over the last five years. Although the committee was unable to establish a causal link between THMs and an increase in cancer of the bladder or any other site after reviewing the available epidemiological data, they did recommend that strict criteria be applied when setting limits for chloroform and drinking water. In an amendment to the national interim primary drinking water regulations, the EPA has established a maximum contaminant level of 0.10 mg/l for trihalomethanes (Federal Register, 1979).

Sodium

It has long been recognized that elevated levels of sodium exist in many drinking water supplies of the United States. A 1949 survey of 150 drinking water sources serving 28% of the U.S. continental population indicated that more than a third of the sources exhibited sodium levels equal to or exceeding 20 mg/l. Subsequently, the U.S. Public Health Service surveyed 2100 water supplies affecting 50% of the U.S. population between 1963 and 1966 and found sodium levels of greater than 20 mg/l in 42% of the sources and levels of greater than 250 mg/l in 5% of the water systems. A comparable 1975 survey of 630 interstate carrier water supply systems revealed that 42% had sodium concentrations greater than 20 mg/l and 3% had levels greater than 200 mg/l.

Although attempts were made to derive a sodium standard for drinking water in the U.S. following passage of the National Safe Drinking Water Act of 1974, these were not successful due to the lack of definitive human population studies demonstrating related adverse health effects. However, the EPA has proposed (Federal Register, 1979) the requirement of monitoring of sodium levels in drinking water and subsequent public notification of the levels, and has further recommended that a level of 20 mg Na/l be used as a goal for public water systems. The American Heart Association has suggested the same level in order to afford protection to those individuals with heart or kidney disease who require a low sodium diet, and the state of Massachusetts has adopted this level as a drinking water standard for sodium.

Hypertension is the adverse health effect which is most frequently linked with excess sodium exposure and there is abundant data from animal studies which document the link between sodium intake and diastolic blood pressure. Epidemiologic studies in human populations are complicated since most of the daily sodium intake (ranging from 3 to 30 grams for adults) comes from food. It is estimated that adult humans require between 1 and 3 grams of sodium intake daily and that infants require between 0.1 and 1 gram. Drinking water containing 28 mg sodium per liter (the average value for all sources tested) would contribute, therefore, less than 5% of the total daily sodium intake. However, individuals on a restricted sodium diet (5 grams of sodium intake per day) would receive a greater fraction of their intake from their drinking water, and in those cases where the sodium content of the drinking water exceeds 20 mg/1, the contribution is likely to be significant. Sodium in finished water also presents problems for dialysis patients.

It is evident, therefore, that the potential adverse health effects of sodium intake from drinking water sources represent a greater problem for selected segments of the population than for the general population.

Asbestos

The fact that exposure to asbestos via inhalation causes numerous asbestos-related diseases such as asbestosis, bronchogenic carcinoma, and mesothelioma is well known and well documented among worker populations in the United States (Selikoff et al., 1973; National Research Council, 1977). However, it is less clear as to the risks presented upon ingestion of asbestos fibers. Attempts to demonstrate a link between ingestion of asbestos fibers in food or in the drinking water and gastrointestinal cancer or cancer at other sites have met with difficulty. Similarly, attempts to produce cancer in animals by the ingestion of asbestos either in their food or drinking water have failed to demonstrate a clear-cut cause-effect relationship.

While it has been demonstrated that animals inhaling asbestos fibers clear from the respiratory tract up to 90% of these fibers and subsequently swallow them, the evidence for increased cancer to the gastrointestinal tract remains unclear (Wagner et al., 1974). Several studies involving animal feeding experiments have not demonstrated malignant tumor development in experimental animals nor penetration of the gut wall (Gross et al., 1974; Webster, 1974), while one study has demonstrated increased incidents of lung and kidney tumors (Gibel et al., 1976). Yet, because of procedural irregularities, this study alone can not be used to state unequivocally that ingested asbestos causes an increase in malignant tumor incidence. The notion that the rat may not be the best model for studying gastrointestinal absorption and translocation of asbestos fibers has been suggested and, therefore, serves to further cloud the issue of the risks presented by ingestion. In a recently completed study by the National Toxicology Program (McConnel, 1982), hamsters and rats were fed with either amosite or chrysotile asbestos fibers mixed with the animal food (1% by weight). This dose was administered during the lifetime of the test animals (experiments began in 1978) and showed no increase in tumor incidence for the target organs studied (mesothelium, lung and intestinal tract). This feeding represented the administration of billions of asbestos fibers into the test animal's gastrointestinal tract. No measurements of fiber quantity translocating to various tissue sites were conducted, however.

Besides animal experiments, several researchers have found higher than expected incidence rates for peritoneal mesothelioma, gastric, kidney and colon cancer among workers occupationally exposed to airborne asbestos

(Selikoff et al., 1973). This suggests that in man, similar to the animal model, asbestos fibers are cleared from the respiratory tract and swallowed. The fact that asbestos fibers have been found in the urine of persons who have been drinking ulfiltered Lake Superior water in the Duluth area provides important evidence that ingested asbestos fibers do move out of the gastrointestinal tract and through the human body (Cook et al., 1974). Further studies of the Duluth population show a strong correlation between incidence of rectal cancer and asbestos ingestion from water (Mason et al., 1974). More recently, the cancer incidence rate in the San Francisco Bay Area was evaluated with regard to the concentration of asbestos in municipal water supplies. Researchers found a statistically significant association between cancers of the stomach, esophagus and pancreas and asbestos drinking water concentrations (Kanarek et al., 1980). Another study of populations in the Puget Sound region showed no correlation between increased tumor incidence and asbestos ingestion (Polissar et al., 1982). Although the epidemiological studies on the whole are equivocal, some do provide a preliminary indication that ingested asbestos may lead to risk of increased cancer.

In reviewing the results of the currently available tests in animals, the National Academy of Sciences - National Research Council, Safe Drinking Water Committee concluded that "the fundamental difficulty associated with the studies is that they seek to duplicate an effect in man by means of animal models that have neither been validated for the route of administration nor for the materials of interest." This Safe Drinking Water Committee also pointed out that the possibility of long delayed effects of mineral fiber ingestion through water cannot be ignored, and has recently reiterated its recommendation for the control of the asbestos content of finished water sources.

Review of the scientific literature leads to the conclusion that ingestion of asbestos may present an increased risk of adverse health effects and that concentrations in drinking water should be minimized where possible.

DRINKING WATER DISINFECTANTS AND DISINFECTANT BY-PRODUCTS

With the discovery that chlorination of drinking water resulted in the formation of trihalomethanes (THMs), potential cancer-causing substances, investigations into alternative treatment procedures were initiated. Three approaches have generally been presented to control THMs: treatment for removal of total trihalomethanes after formation; treatment for removal of THM precursors; and the use of disinfectants other than chlorine (Symons et al., 1981). It is this third approach that has received much scrutiny in regards to efficacy of disinfection, associated costs and possible health risks (The Brookings Institution, 1981; Clark, 1981). The possible risks to human health presented by use of these alternatives is discussed below.

The major alternatives to free chlorine disinfection include chloramines, chlorine dioxide and ozone (Symons et al., 1981). Yet, the major health effects of these disinfectants and the disinfectant by-products remain largely unknown. A review of the literature on the health effects of chloramines (Moore and Calabrese, 1980) indicates that in addition to causing hemolytic anemia in patients undergoing dialysis (Eaton et al., 1973), chloramine has been shown to be weakly mutagenic in Bacillus subtilis. Because of this weakly mutagenic effect, the National Toxicology Program is presently conducting animal bioassays to determine carcinogenicity. With regard to chlorine dioxide, this chemical is capable of oxidizing hemoglobin to methemoglobin and animal studies demonstrate chlorine dioxide induced hemolytic anemia in rats, possible antithyroid activity in monkeys, and possible spermatotoxicity in test animals (Bull, 1982). The absence of definitive studies serves only to point out the need for further investigations and does more to raise questions about the health risks involved rather than provide answers.

Therefore, because not enough is known about the various disinfectants and their by-products to assess relative health risks, it seems prudent to investigate the risks and weigh those risks against others in determining the most advantageous procedure to follow for reducing THM formation.

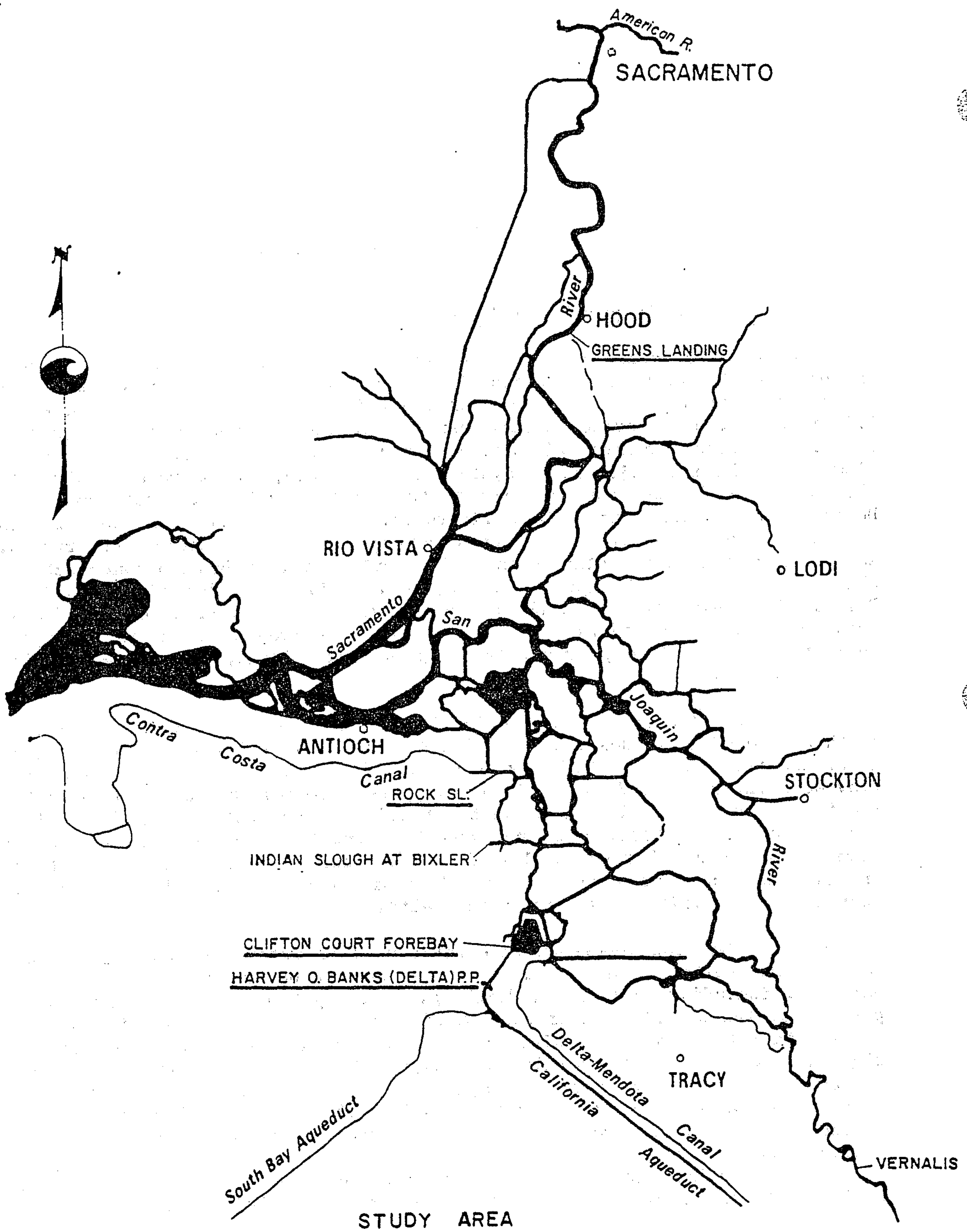
IV. CURRENT STATUS OF WATER QUALITY

A. Sacramento-San Joaquin Delta System

The Sacramento-San Joaquin Delta water system located south of Sacramento and east of San Francisco Bay constitutes one of California's most important natural resources. The system supports a unique and valuable fish and wildlife resource, and provides a large portion of the state's water for agricultural, industrial, commercial, and domestic uses. Fresh water to the Delta flows from the two major river systems in the state, the Sacramento River to the north and the San Joaquin River to the south (Figure 1). Upstream of the Delta, water is taken from these rivers for beneficial uses, and wastewaters resulting from this use are often discharged back into these same rivers. Natural runoff over undisturbed as well as cultivated lands also contributes a share of inorganic and organic material to the rivers as they flow toward the Delta. The Delta itself is the source of water for a variety of beneficial uses and like the rivers flowing into it, receives wastewaters from the recreational activities, industries, agricultural lands, and municipalities that it serves.

The Delta also acts as the collection point for water that is transported south for beneficial uses via the Delta-Mendota Canal and the California Aqueduct, and west via the South Bay Aqueduct. Fresh waters from the Delta also flow west through the San Francisco Bay system through the Golden Gate to the Pacific Ocean. In order to prevent intrusion of sea water from the Pacific Ocean into Delta waters, a balance must be maintained between waters diverted from the Delta and that which flows into the Ocean. During drought conditions or low river outflows some sea water intrusion does occur, and this tends to increase the salinity of waters in the Delta.

One of the most important beneficial uses of water from the Sacramento-San Joaquin Delta system is as a source of raw water supply for domestic purposes, including cooking and drinking. This system supplies a significant portion of the domestic water used within the drainage basin and in southern California outside of the basin. Natural and human-created contaminants that flow into these waters may adversely impact the quality of water, and thus affect its fitness for human consumption. Knowledge about health effects of contaminants as well as the ability to monitor their presence has increased in recent years. This has resulted in more intense review on a national level of criteria used to judge the quality of drinking water. For similar reasons it is also appropriate at this time to review the potential health impacts of contaminants in the major raw water source for the people of California.



STUDY AREA
SCIENTIFIC PANEL REGARDING HEALTH
ASPECTS OF DELTA WATER SUPPLIES

FIGURE 1

B. Selection of Sites for Evaluation

In the charge given to the Panel, three water sources within the Sacramento San-Joaquin Delta system were specified for evaluation: (1) the Sacramento River between Sacramento and Hood; (2) Rock Slough at Contra Costa Canal Intake, and (3) the Delta at Clifton Court Forebay (Figure 1). Water quality varies considerably with time and location in the Sacramento-San Joaquin Delta area. It would be difficult within the time and resources for this study to evaluate all possible water supply intakes and thus the Panel selected the most critical locations for evaluation. Those specified within our charge appeared reasonable to the Panel since they represent the sources for most of the municipal supplies taken from the waters under evaluation. In addition, they tend to represent the range of water quality that exists within these waters.

The Sacramento River is one of the main water supply sources for the City of Sacramento. The water at this location is influenced little by the combination of agricultural, municipal, and industrial waste discharges and sea water contamination that occur in the Delta area. The Contra Costa Water District obtains Delta water from Rock Slough at the Contra Costa Canal. Clifton Court Forebay is the source of Delta water for the California and South Bay aqueducts that provide water to the Metropolitan Water District in Southern California, and more locally to the Santa Clara Valley Water District, the Alameda County Water District, and the Alameda County Flood Control and Water Conservation District - Zone 7.

C. Constituents of Health Concern

The Panel wrote to a number of purveyors of water from the Sacramento-San Joaquin Delta system and other state and federal agencies that might have information about the quality of these waters (see Appendix B). The response we received was excellent and made the task of the Panel much easier. This material was reviewed and formed the basis for our judgments about the current quality of the water under consideration. We also reviewed pertinent literature concerning the effects of contaminants of concern and methods and costs for reduction in their concentrations.

This review indicated that there were many inorganic and organic chemicals as well as biological agents present in these waters as a result of natural and human activities within the basin. However, the concentrations of most were sufficiently low so that within the limits of current knowledge, they did not appear to constitute an undue health risk to the public. In other cases, particularly with respect to biological contaminants, conventional treatment of the raw waters would render them harmless to the public. However, with the three contaminants specified to be of major concern in our charge--that is, sodium, asbestos, and trihalomethanes--the Panel shared these concerns and thus spent most of its time with their review.

D. Trihalomethanes

Trihalomethanes are formed largely as a result of interactions between chlorine, used as a disinfectant, and organic material in water. The Panel obtained data from water purveyors and from the Sanitary Engineering Section, Department of Health Services, in order to determine whether treated water taken from the Sacramento-San Joaquin Delta area was meeting the EPA interim primary drinking water regulations for trihalomethanes of 0.1 mg/l. In general, we found that they were. However, water purveyors taking raw water from the Delta at Clifton Court Forebay and Rock Slough at Contra Costa Canal frequently were just meeting the regulations. One purveyor is using chloramination in order to meet the regulations and this appeared to reduce trihalomethane formation considerably. Others were concerned over their ability to meet the regulations in the long run. Experimental programs had been carried out by several utilities in order to reduce trihalomethane concentration. It appears that with proper concern and application of techniques as outlined by the U. S. Environmental Protection Agency (Symons et al., 1981), most utilities should have little difficulty in meeting the current trihalomethane requirement.

There have been several recent studies to evaluate the potential of the waters under study for producing trihalomethanes when disinfected (Woodard and McCune, 1982; Montgomery Engineers, 1982a; Nelson and Khalifa, 1979). In such studies, an excess of chlorine is added to samples of raw or partially treated, but otherwise unchlorinated water, and the quantity of trihalomethanes formed after several days of contact is measured. The concentration produced in this manner simulates the maximum concentration that might be formed from the water and is termed the total trihalomethane formation potential (TTMFP). Trihalomethane concentrations actually produced in a water supply are generally much less than this potential. Nevertheless, the procedure allows one to evaluate a given water supply to determine whether a problem might occur. Table 1 contains a summary of data to evaluate the TTMFP at the points of interest in this study, and at a few additional locations. The Table also contains the results of analyses for total organic carbon (TOC) in the water, which is a measure of the organic content of these waters. It can be seen that the ratio of TTMFP to TOC is fairly constant, suggesting that the potential for forming trihalomethanes is directly proportional to the TOC of the waters. Similar relationships have been found from studies elsewhere (Symons et al., 1975; Singer et al., 1981; Kavanaugh et al., 1980). On this basis, the potential for formation of trihalomethanes is about the same at Clifton Court Forebay and Rock Slough, but the potential at these two sites is about twice that with Sacramento River water.

Other studies (Luong et al., 1982; Trussell and Umphres, 1978) have also indicated that the presence of bromide in the water will increase both the rate of formation and the ultimate concentration of trihalomethanes. Lange and Kawczynski (1978) demonstrated that water at Rock Slough during the drought period tended to have a higher bromide content because of intruded sea water, and this resulted in higher trihalomethane formation. Nelson and Khalifa (1980) also demonstrated the effect of Delta station location on the distribution of trihalomethanes, suggesting the effect of sea water presence.

TABLE 1. TOTAL TRIHALOMETHANE FORMATION POTENTIAL (TTHMFP) AND TOTAL ORGANIC CARBON (TOC) ANALYSES FOR SACRAMENTO-SAN JOAQUIN DELTA

	All Data Averages			Data from Montgomery Engineers, 1982		
Location	TOC mg/l[1]	TTHMFP µg/l[2]	TTHMFP/ TOC	TOC mg/l	TTHMFP µg/l	TTHMFP/ TOC
Sacramento River Hood	2.8±1.4[3] (22)[4]	176±160 (15)	63	2.2±0.3 (10)	105±31 (8)	48
Rock Slough Contra Costa Canal				4.5±0.9 (10)		
Clifton Court Forebay	4.3±1.4 (20)	358±393 (15)	83	4.8±1.0 (9)	196±40 (8)	41
<u>Other Data:</u>						
Indian Slough Bixler				4.8±1.2 (10)	224±48 (8)	47
American River	1.8±1.0			1.7±0.3 (11)	76±19 (8)	45

(1) 1 mg/l is about one part per million parts, by weight

(2) 1 µg/l is 1/1000 of a mg/l

(3) "±" indicates one standard deviation, roughly, the average difference from the average

(4) "(xx)" indicates the number of data points available to calculate the average and the standard deviation

The reason for the increased organic content in Delta waters compared with Sacramento River water is difficult to determine specifically. Agricultural drainage can contribute organic matter. Some is also contributed by municipal and industrial dischargers. An additional amount results from the growth of algae and aquatic plants in Delta waters themselves. The exact contribution from each of these sources is largely unknown. A greatly improved monitoring effort would be required to gain a better understanding of these contributions if a control strategy were contemplated.

The trihalomethanes are potential human carcinogens, and as such, present scientific opinion supports the theory that there is no safe concentration. The concentration specified in the regulations is a compromise between health risk and other factors such as treatment effectiveness. In the Panel's opinion, water purveyors on a local basis should do whatever appears economical and technically feasible within their own means to reduce the trihalomethane concentration to well below that specified by the regulations.

E. Asbestos

Asbestos is a fibrous siliceous material that is present in many surface waters in California from erosion of serpentine and amphibole materials. Chrysotile asbestos is the type most frequently found in waters here and is derived largely from the serpentine rock that is present throughout the state. Although at present there is no regulation on asbestos in drinking water, the Panel felt consideration of this issue was justified because of the relatively high concentrations in the waters under review. The Panel evaluated the limited data available from various sources on asbestos concentrations in the raw and conventionally treated water supplies in the Sacramento-San Joaquin Delta area. Results of experimental programs to optimize asbestos removal were also reviewed.

Table 2 represents a summary of asbestos concentrations measured in samples of the waters under review, and that at a few additional locations. In general, the concentration varies from one to several thousand million asbestos fibers per liter of water. While the number is large, the size of asbestos particles is very small so that even 100 million per liter in otherwise clean water would not be visible to the eye. The mass concentration that this would represent has been estimated as only 0.7 μg/l (McGuire and Cohen, 1980). Nevertheless, such a concentration could be sufficient to present a health hazard.

Except for the California Aqueduct, the number of asbestos data for a given location is quite limited. We also understand that some of the samples analyzed were taken following storms so that the data may not be representative or typical. Because of these factors, we cannot conclude whether the asbestos concentrations are nearly the same or quite different at the three locations under review. As a special issue, the Panel was asked to address the concentration of asbestos in water delivered through the California Aqueduct to southern California. Here, we can conclude that the asbestos content is significantly higher in the water in the southern half of the Aqueduct than that entering it in the north. This appears to result from

TABLE 2. ASBESTOS CONCENTRATIONS (CHRYSOTILE, MILLIONS OF FIBERS PER LITER) REPORTED AT SELECTED SITES[1,2]
1980 - 1982

	Aug. 1980	Oct. 1980	Nov. 1980	Dec. 1980	Apr. 1981	July 1981	Oct. 1981	Nov. 1981	Dec. 1981	Jan. 1982	Feb. 1982	Mar. 1982	Apr. 1982	May 1982	June 1982	July 1982
American River at Folsom				250	53			23			372				63	
Sacramento River at Sacramento	61				62		600	20		5600	429-6000				140-1300	
Delta							1500-1900									
Rock Slough								228			60				119	
Clifton Court	320						18-110	17	500		16-830		310		26-790	
Delta Pumping Plant	300					1100-1700	190			400-3200		1500	650	1300	750	800
California Aqueduct Above Arroyo Pasajero	210	1500	250		300-900		200-700	47-100	44	1200-2500	1400	510-870	820	140-550	140	53-230
California Aqueduct Below Arroyo Pasajero	5600-15,000	4800	500-1600		1500-4000		1000-2500	1300-4900	1400-4600	1300-3100	1600-6000	630-2500	340-1800	820-2200	1600-4100	1200-6400

[1] Data collected from the following sources:
- California Department of Health Services
- California Department of Water Resources
- East Bay Municipal Utilities District Water Quality Study Interim Report (Montgomery Engineers, 1982a)
- Clifton Court Water Quality Draft (Montgomery Engineers, 1982b)
- Metropolitan Water District

[2] Some of the data were taken following unusual events, such as storms, so that the degree to which they represent typical or average concentrations is not known.

continual resuspension of asbestos-laden sediment in the Aqueduct near Coalinga. Here, drainage water from Arroyo Pasajero entered the Aqueduct during a significant rainfall-runoff period and carried with it the sediment load that is now slowly being eroded from the Aqueduct bottom (McGuire and Cohen, 1980; McGuire et al., 1982a). As Aqueduct waters pass through this area, the asbestos concentration increases by one to two orders of magnitude. Time limitations, however, did not allow the Panel to review this issue in depth.

Normal treatment processes including coagulation, sedimentation, and filtration can be effective in reducing asbestos concentrations by 99 percent or more. This has been found through experimental and full scale studies on waters under consideration and elsewhere (Logsdon and Symons, 1977; McGuire et al., 1982b). From the limited data available, conventional treatment appears to be effective in reducing asbestos in the Sacramento-San Joaquin Delta waters to about 0.5 million or less fibers per liter, levels felt by the Panel to present no undue health risk to the public on the basis of information currently available.

However, due to inadequacies in available data, it is unknown whether the individual samples of Sacramento River and Delta water containing 600 to 6,000 million fibers per liter are single-day peak levels or represent values more typical of average concentrations over days or weeks. It is therefore difficult to determine whether there have existed or will continue to exist asbestos concentrations in the Sacramento-San Joaquin Delta waters that could exceed conventional treatment capabilities, thus posing a health threat to consumers of the finished water. Much more additional asbestos monitoring is needed to assure that conventional treatment is sufficient to handle the large winter and spring flows of asbestos laden water from the Sacramento and American Rivers into the Delta.

The high asbestos concentrations in water reaching southern California through the California Aqueduct are of equal concern to the Panel. Conventional treatment here does not appear as effective in reducing asbestos concentrations to less than 1 million fibers per liter. Indeed, even with carefully controlled coagulation to optimize asbestos removal, concentrations of 10 to 100 million fibers per liter might be expected in finished waters (McGuire et al., 1982b). Whether such high asbestos concentrations present a significant health risk to the public is largely unknown (National Research Council, 1977). As concluded by the National Research Council Committee, "The development of gastrointestinal cancers among the heavily exposed asbestos workers has been slow (20 to 30 yr or more), and the possibility of long-delayed effects of mineral fiber ingestion through water cannot be ignored." While that conclusion was reached several years ago, there is little new information that would tend to alter it. Thus, the Panel felt that efforts to reduce the asbestos content in waters reaching domestic consumers in southern California are justified.

F. Sodium

The average sodium concentration in waters from the Sacramento-San Joaquin Delta area varies considerably with location and time. Data was obtained by the Panel from Figure 2 and is summarized in Table 3. In the

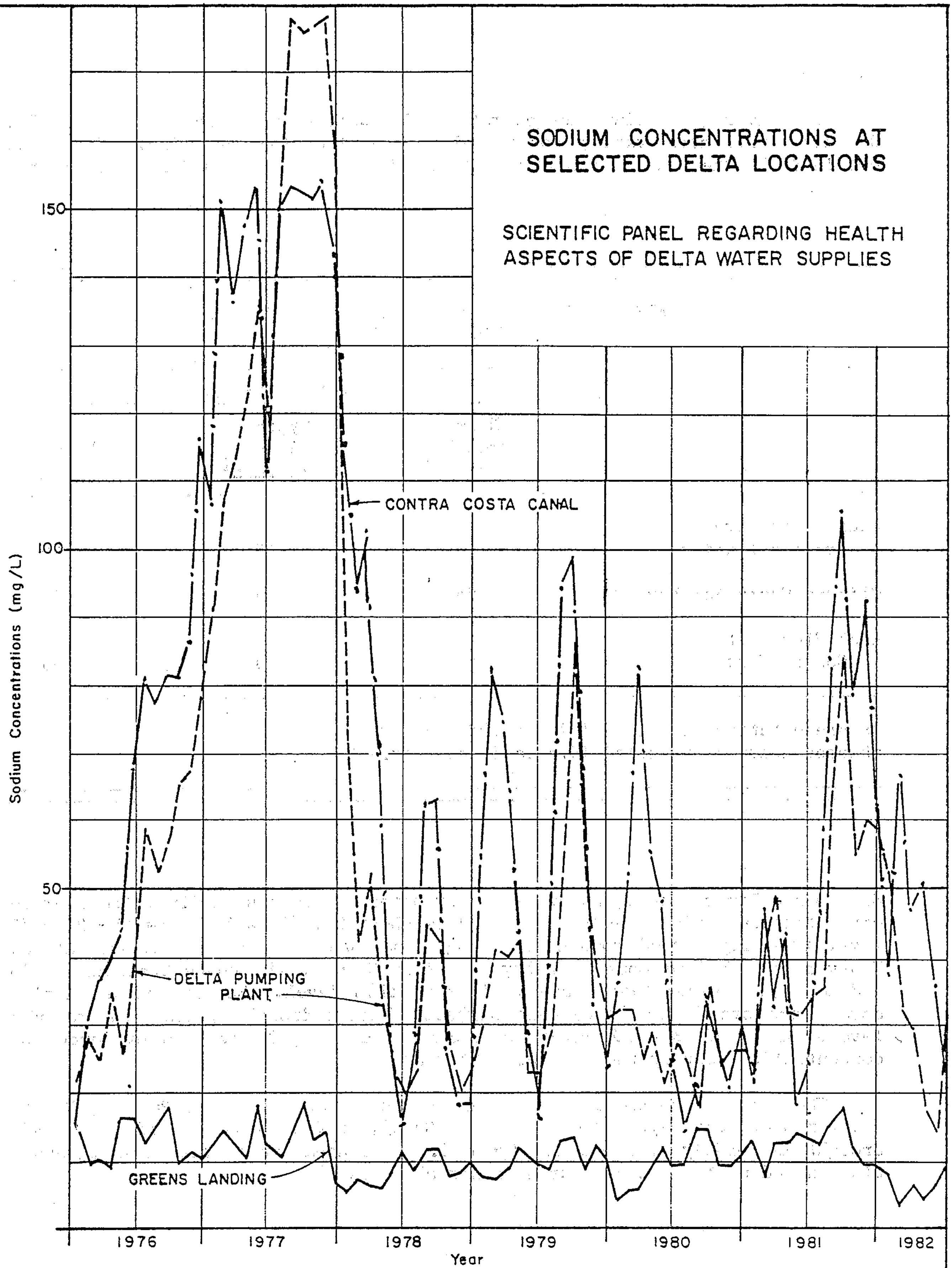
TABLE 3. SODIUM CONCENTRATIONS IN RAW WATER AT SELECTED LOCATIONS

Location	Sodium Concentration, mg/l: Non-Drought Average[1]	Typical Annual Maximum[1]	1977 Drought Maximum[2]
Sacramento River Green's Landing	9	15	20
Clifton Court Forebay	35	55	180
Rock Slough at Contra Costa Canal	50	90	165

[1]Representative of period 1978 to 1982, Figure 2
[2]Representative of period 1976 to 1978, Figure 2

Sacramento River itself, as evidenced by water at Green's Landing, the average concentration during non-drought years is about 9 mg/l, well below the 20 mg/l level that might need consideration by those with restricted sodium intake. However, at Clifton Court Forebay and Rock Slough, the concentrations of 35 and 50 mg/l, respectively, are well above this level. Maximum values during some years are 60 to 80 percent higher. During drought years, the maximum levels can reach 8 to 9 times the recommended 20 mg/l level as evidenced by concentrations during the 1977 drought year.

The large increase in sodium concentration at the Delta Pumping Plant, Clifton Court Forebay, and Contra Costa Canal, at Rock Slough, during the 1977 drought is readily apparent in Figure 2. Also apparent is the large fluctuation in sodium that occurs during a normal year.



SODIUM CONCENTRATIONS AT SELECTED DELTA LOCATIONS
SCIENTIFIC PANEL REGARDING HEALTH ASPECTS OF DELTA WATER SUPPLIES
CONTRA COSTA CANAL
DELTA PUMPING PLANT
GREENS LANDING
150
100
50
Sodium Concentrations (mg/L)
1976
1977
1978
1979
1980
1981
1982
Year

FIGURE 3

The increased sodium concentrations at Rock Slough and Clifton Court Forebay relative to the Sacramento River can result from a number of causes. Agricultural drainage and sea water intrusion are believed to be the major contributors. However, domestic and industrial discharges and evaporation can also play a part. The Panel made some attempts to determine the major sources of sodium at the various locations. However, the information about sodium concentrations in the various discharge waters was too limited as was knowledge of the relative fraction of each source in a given volume of water at any one location or time to arrive at a conclusion.

An additional increment of sodium in drinking water can result during treatment. The amount of sodium that might be added depends upon the type of treatment used; this in turn depends upon the quality of the water being treated. For the waters under review only one type of treatment adds significant amounts of sodium; this is the process of ion exchange that is common to most home water softeners. These softeners contain "resins" that release sodium in exchange for the ions that make up hardness.

Knowing the concentrations of sodium and hardness in water, it is possible to calculate the concentration of sodium that would occur after that water has been treated in a typical home water softener. Table 4 was prepared to indicate the levels of sodium expected in drinking water from the three locations if that water was softened in the home. The increase in sodium concentration over that in the absence of softening (Table 3) is significant. Even with Sacramento River water itself, the sodium concentration would then exceed 20 mg/l. It is apparent that individuals on restricted sodium diets should be cautious about drinking water that has been softened.

TABLE 4. ESTIMATED SODIUM CONCENTRATIONS AFTER TYPICAL HOME WATER SOFTENING

	Sodium Concentration, mg/l		
Location	Non-Drought Average	Typical Annual Maximum	1977 Drought Maximum
Sacramento River Green's Landing	35	45	60
Clifton Court Forebay	120	115	260
Rock Slough at Contra Costa Canal	100	155	270

The Panel felt that control of sodium is desirable as it does have health implications for some members of society. While individuals with restricted sodium intake can obtain sodium free water elsewhere, it is desirable to provide consumers with a low sodium content water. Some of the former group may not be adequately informed about the level of sodium in water, and thus may not know of the potential risk involved in drinking water from the tap. Others may find the additional cost of obtaining sodium free water beyond their economic means. Control of sodium in water is best done by controlling the source. In order to carry out an adequate source control program, better data gathering and overall analysis of this complex water system is required than is presently available. Because of the importance of such analysis in this particular case as well as in the control of water quality in general, the Panel made some effort to briefly outline the structure and data needs for such a program.

V. MONITORING NEEDS

This section addresses the data collection program and methods of data analysis with respect to the public health concerns of water quality. The Department of Water Resources has been conducting a monitoring program of water quality in the Sacramento-San Joaquin Delta area over the past few decades. These data, in conjunction with special studies by the Department and other agencies, have been most beneficial to the Panel. Without these data it would not have been possible to address our charge.

The current Delta water monitoring program conducted by the Department of Water Resources was developed primarily to monitor quality from an ecological perspective specifically directed towards fishery resources and not to assess human health aspects with respect to drinking water. The program as presently constituted, while providing some information for this report, is not entirely adequate to assess the present or projected suitability of these waters as a source of drinking water supply.

Of particular concern to the Panel are the future impacts of water demands, wastewater and agricultural discharges, and modifications in the operation of the Delta water system. The waters in this system are used at least partly as a drinking water supply by the majority of the citizens of California. The Panel has concluded that there is reason for concern about the public health implications of withdrawing drinking water from the Delta. Furthermore, it is our opinion that in the past insufficient attention has been given to the public health implications of decisions about these waters. Unless the monitoring programs and methods of analysis are modified, health issues are likely to receive insufficient attention in the future.

The need is for a monitoring program that identifies the sources of contaminants to the Delta, and how the contaminants from each source are transported through the system and affect the concentration at points of withdrawal. Needed also is information on the factors that affect the movement and fate of the contaminates in the Delta. With such information, the impact of future changes on water quality at possible points of withdrawal may be quantified.

The Panel had a general familiarity with the procedures presently used to analyze water quality and quantity in the Delta, which consist primarily of the use of mathematical and physical "models" of the Delta. The models are used to analyze historical conditions and to predict the effects of changes. The models are all mathematical with the exception of the Corps of Engineers physical model of San Francisco Bay and the Delta in Sausalito, California.

The models, which provide information on flow patterns, salinity, algal nutrients, and algal growth, only indirectly address the constituents of importance to public health. (For example, the concentration of sodium usually correlates well with salinity, so salinity model results can be somewhat useful for predicting sodium concentrations.)

One of the Panel members, Dr. Donald O'Connor, conducted preliminary work on one procedure that might be used for predicting the concentrations of sodium and trihalomethanes in the Delta, a summary of which is included in Appendix C. The following conclusions about sodium may be drawn from this analysis:

- For a given watershed, sodium concentrations in groundwater and surface water both correlate well with the concentration of total dissolved solids.

- For a given watershed, the concentrations of total dissolved solids and, therefore, of sodium correlate well with the ratio of groundwater flow to surface flow.

- The ratio of surface flow to groundwater flow can be generally correlated with total flow in a given watershed.

- Therefore, the concentration of sodium in a given watershed correlates with total flow and generally decreases as flow increases.

Similar conclusions may be drawn about trihalomethanes with the following additional considerations:

- Point discharges (wastewater treatment plants) and agricultural return may be significant sources of organic material which can be converted to trihalomethanes.

- The concentration of organic material in water is generally directly proportional to surface runoff flow.

- Therefore, at low flows the potential for trihalomethane formation is high because of the predominant effect of point sources (which tend to be constant relative to streamflow). At high flows the effect of surface runoff predominates, and the potential for trihalomethane formation is also high. At some intermediate flow, a low potential for trihalomethane formation could be expected.

This work indicates that analytical procedures (models) could be developed to predict concentrations of sodium and trihalomethanes. It is possible that analytical procedures could also be developed to predict asbestos counts.

Existing data indicate that other factors, in addition to the quality of Delta waters, affect the quality of drinking water. For example, storage or transport appears to affect all constituents of concern. Water treatment obviously has effects. The procedures for analyzing the public health effects should consider these other factors.

Particular attention should be paid to the sources of sodium, asbestos, and organic material. The analytical procedures should be able to relate the impact of each source on the quality of treated drinking water at any Delta location. Such comprehensive procedures are necessary for making rational decisions about the best way to manage the entire system to minimize public health risks.

The Panel recommends that comprehensive analytical procedures be developed to address public health concerns. The development of these procedures should build on the work already done by the Department of Water Resources and others, and consider the preliminary analysis described in this report. The monitoring program should be designed to provide data that is appropriate for the analytical procedures. The model, in turn, should be structured to incorporate and analyze the following elements:

- Location and magnitude of sources of sodium, asbestos, and organic material, including inflows to the Delta, agricultural drainage (including surface and subsurface drainage upstream of the Delta, the possibility of constructing the San Joaquin Drain, and the discharge of drainage from Delta agricultural lands), wastewater discharges, and intrusion of water from San Francisco Bay.

- Factors affecting the contributions from each important source, including stream flowrates, time of the year, levels of wastewater treatment, and reservoir release patterns.

- Variability of concentrations of each constituent at critical points in the Delta as affected by sources of each constituent and Delta flow patterns (especially Delta inflow and exports).

- Effects of Delta water quality, storage (surface and groundwater), transport, blending with other waters, and treatment on the quality of treated drinking water.

Consideration should be given to modifying the present program with respect to the number and location of sampling sites and the frequency of collection. Effort should be directed to monitoring sodium, asbestos, and organic constituents as well as other substances such as pesticides, heavy metals and other potential toxicants.

VI. TREATMENT ISSUES

A. Background

The preparation of a safe, potable, and palatable drinking water is the result of the application of a series of water treatment processes commonly referred to as "conventional treatment". A treatment plant practicing conventional treatment would include the following processes: coagulation, flocculation, sedimentation, filtration, and disinfection. Chemical additions such as: coagulants or polymers, activated carbon, lime and others are made at various points in the treatment process. Figure 3 is a generalized schematic illustrating the conventional process. The Panel considered the effectiveness of conventional processes for the removal of the three contaminants of sodium, asbestos, and trihalomethanes.

B. Sodium

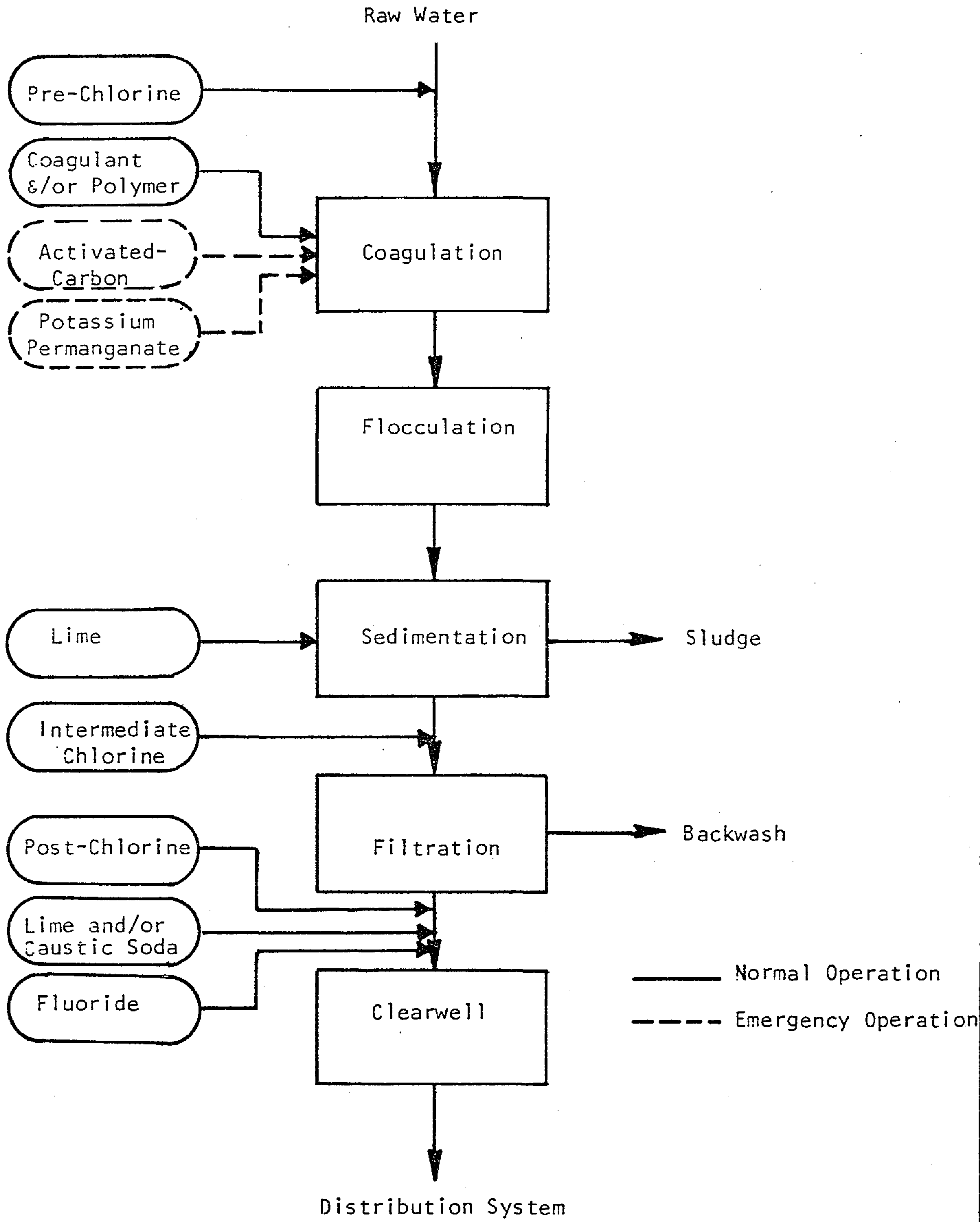
The principal source of sodium delivered in drinking water by the treatment plants in the subject area is the raw Delta water. This concentration has varied from 3 to 192 mg/l over the last 20 years. Some sodium may be added in the treatment process by the addition of sodium compounds; however, with the waters being reviewed, this is a relatively insignificant amount. Ion-exchange or lime-soda softening, which can add significant quantities of sodium to the water, is not commonly practiced here except in the case of home softeners.

Sodium compounds are generaly soluble and easily ionized, and hence sodium is not normally removed by the conventional treatment processes. Removal of sodium cannot be significantly effected by either changes in operational levels or in design factors.

No conventional treatment processes are available for the removal of sodium from drinking water. Processes that can remove sodium are distillation, reverse osmosis, ion exchange and electrodialysis. Costs of sodium removal by these processes are highly dependent on energy costs, and are estimated to range from $0.80 to $0.86 in 1980 dollars per thousand gallons using these processes (Lauch and Sorg, 1981).

C. Asbestos

Asbestos, a suspended particulate, lends itself to removal by conventional processes. Some fibers may be removed by plain sedimentation, and additional fibers by the combination of coagulant addition, flocculation, and



CONVENTIONAL WATER TREATMENT PROCESS

SCIENTIFIC PANEL REGARDING HEALTH
ASPECTS OF DELTA WATER SUPPLIES

FIGURE 2

sedimentation. Filtration effects an additional removal of fibers in the settled effluent. However, effectiveness of conventional treatment is subject to both design and operational limitations. The principal limitation is one of excessive loading occasioned by either inadequate design or excessive concentration of asbestos fiber in the raw water.

The Metropolitan Water District of Southern California (McGuire et al., 1982b) conducted a study of five large water treatment plants over a period of approximately 18 months to determine the effectiveness of asbestos fiber removal. The plants were of varied design, all utilizing flocculation, sedimentation, and filtration. In general, with optimization of operation, where influent levels exceeded approximately 500 MFL, the plants did not consistently produce an effluent with less than 1.0 MFL, although effluent turbidities were less than or on the order of 0.10 NTU.

A possible treatment alternative is the utilization of a presedimentation storage basin to reduce the asbestos load on the conventional processes. This would involve long-time storage of several months. Little information is available to judge the adequacy of other approaches.

D. Trihalomethanes

Trihalomethanes are formed during the disinfection step of water treatment when free chlorine used as a disinfectant interacts with precursor materials, e.g. TOC or organics. Changes in the point of application in the process can reduce the amount of THMs, and substitution of other chemical agents for chlorine can reduce this even further. Changes in the process to remove precursor material may also bring about reduction. However, depending on the amount of precursor material present in the raw water, the usual conventional processes may or may not be sufficient to reduce the level of THMs formed to acceptable levels.

Symons et al. (1981) noted that "for THM removal, aeration - either by diffused-air or with towers - and absorption - either by powdered activated carbon or granular activated carbon - is effective. The major disadvantage of this approach is that THM precursors are not removed by aeration. For THM precursor control, effective processes are: 1) oxidation by ozone or chlorine dioxide; 2) clarification by coagulation, settling and filtration, precipitative softening, or direct filtration; or 3) adsorption by powdered activated carbon or granular activated carbon. In addition, some modest removal or destruction of THM precursors can be achieved by oxidation with potassium permanganate, lowering the pH, or moving the point of chlorination to the clarified water."

Substitution of chloramination for direct chlorination generally has proven to be an effective alternative. The minimal equipment needs and comparable costs of application make this a preferential choice. Operational data from the Contra Costa Water District has shown successful utilization of chloramination for one year. In this plant, chlorine is used as a primary disinfectant with the addition of ammonia after filtration. Costs for this have been of the same order as direct chlorination for the preceding year (approximately $2.00 per million gallons in chemical costs). However, some concerns have been expressed over possible health risks with chloramines (see Section III), and so this approach should be used with some caution.

E. Alternatives

There are possible alternatives to treatment for reducing the levels of contamination in drinking water supplies. While not addressed at great length, the alternatives to treatment for sodium, asbestos, and THM removal are essentially the same:

- Use of alternate supplies having lower levels of contaminant
- Use of alternate supplies as a blending source to reduce contaminant concentrations
- Use of long term storage of higher quality water for either direct use or for blending during periods of unacceptable levels of quality.

VII. EFFECT OF FUTURE CONDITIONS ON THE PANEL'S CONCLUSIONS AND RECOMMENDATIONS

The Panel has concentrated on the analysis of three constituents--sodium, trihalomethanes, and asbestos--at three locations--Hood on the Sacramento River, Clifton Court Forebay, and Rock Slough at Contra Costa Canal. The analysis was based on data collected over the last few years. Therefore, the conclusions and recommendations apply to the current situation.

However, the current situation may not persist. There will be changes in the Delta. Some of these changes could impact on the Panel's conclusions and recommendations. Most of the following is conjecture based upon the Panel's analysis of the dynamics of water flow in the Delta. Although data does not exist which would allow the Panel to make more definitive conclusions, the existing data is sufficient for the Panel to reasonably state its assumptions and projections. The changes that could occur are listed below, and the possible effects of these changes are then discussed.

- Inflow to the Delta can decrease as water development takes place upstream. Exports from the Delta may increase as demands for water grow south of the Delta.
- Physical changes may be made in the Delta. Changes have been proposed to transfer larger quantities of water from north to south across the Delta than is now possible without drawing sea water in from the Bay. These changes could include modification of Delta channels or the construction of an isolated Delta water transport facility, such as the Peripheral Canal.
- Delta levees could fail, causing the flooding of Delta islands. The levee breaks may be repaired, or the islands could be left flooded.
- The San Joaquin Agricultural Drain could be built to transport subsurface agricultural drainage from the San Joaquin Valley to San Francisco Bay, probably at a point near the western boundary of the Delta.
- The Contra Costa Canal could be extended so that water would be taken from Clifton Court instead of from Rock Slough.
- Quantities of municipal, industrial, or agricultural wastewater discharged directly into the Delta or into streams that are tributary to the Delta are likely to increase.
- The possibility of accidental spills of dangerous materials into the waters under review will continue.

- Recreational activities may result in additional pollutional loads on the Delta waters.

The effect of each of these changes on the Panel's conclusions and recommendations is discussed below.

Decrease in Delta Inflow and Increase in Exports

This change may or may not have an effect on asbestos concentration at the Delta locations under review. All locations have relatively high asbestos concentrations, but the data available are insufficient to judge at which location the current concentrations are the highest. With respect to the organic precursors of trihalomethanes, they are less in the Sacramento River near Hood than at the two Delta locations. Since the sources of the increase in organic concentration in the Delta are not known, then projections about changes that would result cannot be made.

Decrease in Delta inflow or increase in exports should not affect sodium concentrations at Hood. These changes could cause an increase in sodium concentrations at Rock Slough and Clifton Court. Studies made of the increase in salinity at these two locations show dramatic (up to 250%) increase in salinity if inflow and export changes are great enough to satisfy future water demands. Sodium concentrations correlate closely with salinity. Therefore, similar increases in sodium could be expected.

The great uncertainty about the effects of such changes on water quality and on human health lend a greater degree of urgency to the recommendation that public health should receive more attention in decisions about the Delta. It also supports the Panel's recommendation for revising the water quality monitoring and data analysis programs of the Department of Water Resources.

Physical Changes to Increase the Amount of Water That Could Be Transferred across the Delta

At least two general changes are possible. One is the construction of the Peripheral Canal. The other is the widening and improvement of some Delta channels so they would carry more water from north to south across the Delta. One purpose of both changes would be to transport good quality Sacramento River water to the export pumps near Clifton Court to avoid contamination by waste discharges and sea water.

Neither of these changes would affect water quality at Hood. At Clifton Court improvement would be expected for sodium. Asbestos contamination may or may not increase while THM precursors could decrease. The change at Rock Slough is problematical and would depend upon how the overall system is operated.

There should be some improvement at Clifton Court with respect to trihalomethanes because water at Hood has about one half the organic material (that can be converted to trihalomethanes). The degree of improvement may be different with channel improvements than with the Peripheral Canal. Agricultural runoff and other inflows could have a greater impact with channel improvements. However, organic matter could increase during water passage through an unlined Peripheral Canal or areas containing peat. A better knowledge of organic material sources is necessary to be more conclusive. Data now available do not make it possible to say definitively whether asbestos levels would change or not.

Failure of Delta Levees

The immediate effect of most levee failures is to draw saline Bay water into the Delta. The general effect of this would be to increase sodium concentrations, and perhaps to aggravate the trihalomethane problem. This would occur because Bay water also contains bromine, which contributes to the formation of trihalomethanes. Also, the organic rich agricultural lands may contribute organic materials to the water.

If the levee break were such as to cause Bay water to intrude to Rock Slough or to Clifton Court, then there would be a greater problem with sodium and trihalomethanes at these locations. This conditions would persist until the Bay water could be flushed out (possibly weeks or longer).

Levee failures should not affect the quality of water at Hood.

The San Joaquin Agricultural Drain

This proposed drain would be a lined channel to carry subsurface agricultural drainage from the San Joaquin Valley to the Bay perhaps at a point near the western boundary of the Delta (Chipps Island). The drain should have no effect on water quality at Hood. Numerous studies have also indicated that there would be no significant effects at Rock Slough.

The drain may result in lower sodium concentrations at Clifton Court since the export pumps there can draw in water from the San Joaquin River. The drain would remove from the San Joaquin River some drainage waters that are high in sodium. The amount of subsurface drainage flowing into the San Joaquin River is expected to increase significantly in the future unless the drain is built.

Extending the Contra Costa Canal to Clifton Court

This is not likely to affect the quality at Hood or at Clifton Court. The water quality in the Contra Costa Canal would then be the same as that at Clifton Court. Therefore, all of the above discussion about changes in quality at Clifton Court would then apply to the quality in the Contra Costa Canal. This change would eliminate Rock Slough as a location of concern for the Panel.

Increase in Wastewater Discharges

The Panel had little data on the effects of these increases. In any event, discharges of treated industrial and municipal wastewaters are not likely to have significant impacts on health-related contaminants, especially the three constituents specifically addressed by the Panel. Agricultural runoff and drainage is likely to have more impact; for projections here, more information is needed.

Normal increases in wastewater discharges are not likely to affect the Panel's recommendations.

Accidental Spills

The area of the Delta is the site of a number of major terminals for shipment of various toxic or hazardous materials by sea, highway and rail. The area also has an extensive network of highways, railroads and deep water channels serving these terminals. In a recent study of the frequency of hazardous materials spills by the Association of Bay Area Governments (1982), the area of Contra Costa County/Solano County shoreline, extending up into the Delta, was shown to be an area of high risk in the occurrence of hazardous materials spills. Such spills could contaminate large areas of these waters because of the problem of tidal and wind movement. Because of this potential for spills and subsequent contamination, there is a need for a contingency plan to alert appropriate water supply agencies of the danger and to provide for remedial as well as preventative measures. The spills of most concern are those transportation accidents involving transportation on, over, or immediately adjacent to the waterways of the Delta and river system.

Recreational Activities

Discharges from pleasure boats are not likely to have a significant impact on water quality at the locations under study. There was insufficient data to judge whether pesticide usage in the area to control aquatic plants could become a problem; however, no available data indicated an immediate cause for concern.

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APPENDIX A

Copy of letter sent by Mr. Ronald B. Robie, Director, California Department of Water Resources, to the Panel members to provide the background and scope for this study.

STATE OF CALIFORNIA—RESOURCES AGENCY

EDMUND G. BROWN JR., Governor

DEPARTMENT OF WATER RESOURCES
P. O. BOX 388
SACRAMENTO
95802
(916) 445-9248

AUG 31 1982

Dr. Perry McCarty
Professor of Civil Engineering
Department of Civil Engineering
Stanford University
Stanford, CA 94305

Dear Dr. McCarty:

This will confirm our intention to contract for your services on a scientific panel to assess the health aspects of Sacramento-San Joaquin Delta water used for domestic purposes. Mr. Robert W. James, one of my deputies, will represent me in working with the panel.

Attached is a brief background statement indicating the reason for the panel, the charge of the panel, and a list of the panelists.

As indicated to you, the first meeting of the panel will be held on September 23 and 24, 1982. Details of the location and times will be sent to you soon along with more detailed information pertaining to panel activities and an agreement covering the terms of your participation. Should you have any questions regarding your participation as a panel member, please contact Mr. Wayne MacRostie, Chief of our Central District, or Mr. Robert L. McDonell, Chief of the Central District's Special Studies Branch. Their phone numbers are (916) 445-5631 and (916) 322-6220, respectively.

I am very pleased you are able to participate. Your considerable knowledge and expertise will be very valuable in achieving the goals of this important effort.

Sincerely,

(sgd) Ronald B. Robie

Ronald B. Robie
Director

Attachment

SCIENTIFIC PANEL ON DELTA WATER QUALITY

Delta water quality has been a subject of concern for many years. During the past year, especially, interest has focused on a drinking water standard, promulgated by the U. S. Environmental Protection Agency, establishing maximum permitted concentrations of trihalomethanes in treated water. This regulation took effect in November 1981.

In response to a concern expressed by Santa Clara Valley Water District and other State Water Project water contractors as to cost of water treatment to remove these compounds, if diversion of State Water Project supplies from Delta channels were to continue, DWR prepared a report on this subject. It included an evaluation of the effects of the then proposed Peripheral Canal on the concentration of trihalomethane precursors in the diverted raw water supplies. The three South Bay Aqueduct State Water Project water contractors and Contra Costa Water District joined to have Montgomery Engineers further investigate this matter and a draft report (now considered to be final) was prepared. East Bay Municipal Utility District has also contracted with Montgomery Engineers to sample and report upon the water qualities of a broad range of existing and potential water supply sources for the District including the Delta. This work is scheduled to be completed late in 1982.

Following the adverse vote by the California Electorate in June 1982 on Proposition 9* the Mayor of the City of San Jose expressed concern about possible health effects of South Bay Aqueduct water in view of DWR's Trihalomethane report. She requested the Governor to appoint "a Task Force of water quality experts to assess the present level of contamination of SWP water ..." She was joined in

* A referendum on Senate Bill 200 passed by the Legislature and signed by the Governor. It would have authorized construction of the Peripheral Canal, reservoirs, and other facilities to increase the SWP water supply and specified various actions to protect the Sacramento-San Joaquin Delta.

this request by State Senator Alfred E. Alquist. In response, the Director of Water Resources stated that DWR "is establishing a scientific panel to review the various aspects of the quality of water diverted from the Delta by the Department to its various customers throughout California".

Identified below are the appointed members of the panel and their charge. The panel composition and assigned tasks were determined by the Department in consultation with the State Department of Health Services and State Water Resources Control Board.

Panel Members

The membership of the Scientific Panel and their affiliation and fields of expertise are as follows:

Name	Present Position/Location	Field of Expertise
Dr. John Doull	Professor, University of Kansas Medical Center, Kansas City, KA	Toxicology
Dr. Perry McCarty	Professor, Stanford University	Waste Water Chemistry and Treatment
Dr. Donald O'Connor	Professor, Manhattan College Bronx, NY	Hydraulics and Water Qualtiy Modeling
Mr. Emanuel Pearl	Retired, (Part Time Instructor San Jose State University)	Public Health Engineering
Dr. B. J. Miller	Consultant, Water Quality and Water Resources, Oakland, CA	Water Quality
Dr. Alvin Greenberg	Chairman, Northern California Water Resources Committee, Sierra Club	Environmentalist Toxicologist
Mr. Paul DeFalco	Private Consultant, Water Pollution Control, Moraga, CA	Water Pollution

SCOPE OF STUDY
SCIENTIFIC PANEL REGARDING HEALTH ASPECTS
OF DELTA WATER SUPPLIES

1. Review the April 1982 report entitled "State Water Project Trihalomethane Study", published by the Department of Water Resources (DWR). Review other available literature and data describing quality of surface waters in Delta channels and rivers and drains tributary to the Delta. Emphasis should be placed upon constituents which may have direct health effects when present in drinking water supplies.

2. Identify and evaluate any human health hazards that may be expected from consumption of drinking water produced from these sources: 1) the Sacramento River between Sacramento and Hood; 2) Rock Slough at Contra Costa Canal Intake; 3) the Delta at Clifton Court Forebay. This evaluation should be made under the assumption modern conventional processes, including coagulation, flocculation, clarification, filtration, and disinfection, would be employed to treat the water for drinking. Emphasis should be placed on current water quality conditions at these locations, however, possible future changes may also be examined.

3. Recommend any treatment processes beyond modern conventional processes that may be required to ensure drinking water taken from the above sources attains applicable standards and guidelines for protection of human health. If additional treatment processes are recommended, provide general estimates of the incremental costs for such treatment. Alternative treatment processes beyond those recommended may be discussed without cost estimates.

4. Review DWR source water quality monitoring and control programs related to human health aspects of drinking water. Comment upon the adequacy and effectiveness of current programs and make recommendations for eliminating any perceived inadequacies in those programs.

5. Identify anticipated drinking water health effects resulting from waste discharges and accidental spills of toxic substances in the waters under consideration.

6. Provide additional comment and recommendations as desired by the panel.

APPENDIX B

Cover letter sent requesting information concerning Sacramento-San Joaquin Delta water quality and a listing of the agencies to which the letter was sent.

DEPARTMENT OF CIVIL ENGINEERING
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

PERRY L. McCARTY, Chairman
SILAS H. PALMER PROFESSOR
OF CIVIL ENGINEERING

FREDERICK EMMONS TERMAN ENGINEERING CENTER
(415) 497-3921

October 1, 1982

Dear :

The Director, California Department of Water Resources, has appointed me to serve as chairman of the Scientific Panel to Assess Health Aspects of Sacramento-San Joaquin Delta Water. As such, I am asking for information that may be useful to the Panel from agencies that use the Delta as a drinking water supply source or have been involved in investigations of Delta water quality.

The Panel will focus on human health aspects as they relate to drinking water derived from the Sacramento River between Sacramento and Hood, from the Clifton Court Forebay, or from Rock Slough at the Contra Costa Canal intake. Since our charge is to evaluate human health aspects only, we will not address problems that do not have direct health impacts. Thus, we are not considering problems primarily related to aesthetics or costs such as color, taste, or corrosion. We realize the latter may cause significant problems and may be of importance to many water consumers, but these aspects are not within the scope of our charge.

We wish to gather for review all information available that may be useful in carrying out our study whether it resulted from routine monitoring or from special studies. We wish information on all constituents of potential health concern whether they indicate a problem does or does not exist. It is important to know the extent of the data base that exists. During our preliminary briefing, we were specifically asked to consider three constituents of potential health significance. These were sodium, asbestos, and trihalomethanes. Thus, information on these would be most welcome. However, our study is not to be limited to these materials.

The Panel would be most appreciative of reports or other data that you could send to me for our review. I would also appreciate the name of an individual within your organization whom I could contact to discuss other data, information, or concerns that your organization may have about these issues. We might also discuss whether it would be appropriate for a representative from your agency to address the Panel as a whole at one of our meetings.

I would appreciate very much a prompt response to this request as our final report is due by the end of this calendar year. Thank you for your consideration.

Sincerely yours,

Mr. John DeVito
General Manager
Contra Costa Water District
P.O. Box H20
Concord, CA 94524

Mr. Timothy J. Durbin
District Chief
U.S. Geological Survey
Water Resources Division
U.S. Department of the Interior
Room W-2235, Federal Building
2800 Cottage Way
Sacramento, CA 95825

Mr. Roy E. Coverdale
General Manager
Alameda County Water District
38050 Fremont Blvd.
Fremont, CA 94537

Mr. Mun J. Mar
General Manager
Alameda County Flood Control and
Water Conservation District - Zone 7
1404 Concannon Blvd.
Livermore, CA 94550

Mr. Evan L. Griffith
General Manager
Metropolitan Water District
P.O. Box 54153
Los Angeles, CA 90054

Mr. John T. O'Halloran
General Manager
Santa Clara Valley Water District
5750 Almaden Expressway
San Jose, CA 95118

Mr. John Gaston, Chief
Sanitary Engineering Section
Department of Health Services
2151 Berkeley Way
Berkeley, CA 94704

Mr. Jerome B. Gilbert
General Manager
East Bay Municipal Utility District
P.O. Box 24055
Oakland, CA 94623

Mr. Robert Bitten, Manager
Division of Water and Sewers
City of Sacramento
927 - 10th Street
Sacramento, CA 95814

Ms. Carole A. Onorato, Chairwoman
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95814

Mr. James A. Robertson
Executive Officer
Central Valley Region (5)
3201 S Street
Sacramento, CA 95816

Mr. Michael A. Catino
Regional Director
Mid-Pacific Regional Office
Bureau of Reclamation
U.S. Department of the Interior
2800 Cottage Way, Room W1105
Sacramento, CA 95825

Mr. Leland Walton, City Manager
City of Antioch
City Hall
212 H Street
Antioch, CA 94509

Mr. Ray Cecar, City Manager
City of Stockton
Stockton, CA 95202

Mr. William Hyde
Water Quality Division
Department of Public Works
Sacramento County
9660 Ecology Ln.
Sacramento, CA 95827

Dr. Rhodes Trussell
James M. Montgomery Consulting
Engineers, Inc.
555 E. Walnut St.
Pasadena, CA 91101

APPENDIX C

MONITORING NEEDS FOR SACRAMENTO-SAN JOAQUIN DELTA SYSTEM

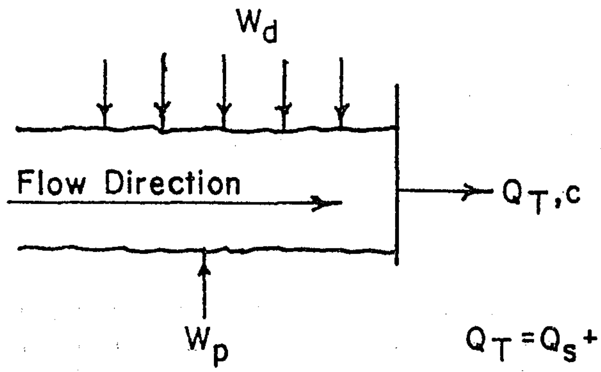
A. Introduction

Sodium is present in natural waters, both fresh and marine, and in many types of waste waters, particularly from municipal and agricultural sources. It is primarily found in ground water; its concentration in the river waters is appreciably affected by variation in runoff flow. During periods of high flow, when the surface drainage is significant, its concentration is less than during low flow when the ground water is the major component of stream flow.

Trihalomethanes are formed by the reaction of chlorine with various organic constituents in water. The source of these substances are the naturally occurring humic materials, which are introduced into water bodies from surface runoff and subsurface drainage, and organic complexes, which are present in effluents of wastewater treatment plants. It may be hypothesized, based on qualitative knowledge of the sources of these substances, that these variations are influenced by the characteristics and runoff from the contributing drainage area relative to those of effluent discharges from wastewater treatment plants.

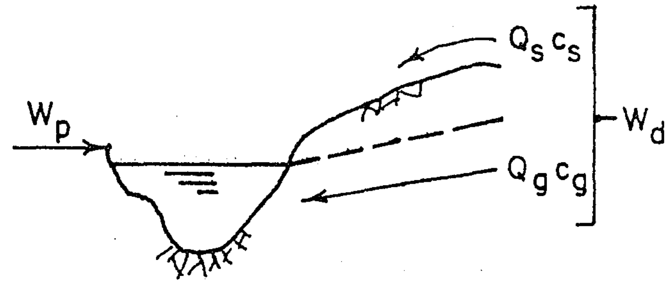
It is appropriate, therefore, to analyze the significance of each source in order to correlate the variation and magnitude of the sodium and trihalomethane concentrations in raw water. The purpose of such an analysis is to gain some insight into the natural phenomena which affect the concentrations of these substances, and thereby to provide a basis for design and operation of treatment facilities, to develop control measures to ameliorate the problem in drinking water supplies, and to project the water quality impacts of proposed changes in system operation.

The analysis is based on the identification of the sources of these materials in the surface and ground water components of runoff, in reservoir releases, and in municipal, industrial and agricultural discharges. A relationship between river flow and dissolved solids from distributed sources is developed which then may be related to the concentration of sodium. Given this relationship, i.e., between flow and the distributed sources from surface and ground water, the effect of point sources may be considered, which is relevant to the trihalomethane concentrations. A schematic diagram of the basic elements and definitions of the parameters is presented in Figure 1. The total mass rate of flux of a substance in the river flow follows from the continuity principle:



$Q_T = Q_s + Q_g$

PLAN



RIVER
CROSS SECTION

FLOW L^3/T	Q_T	= Total River Flow
	Q_s	= Surface Runoff Component
	Q_g	= Groundwater Component
CONCENTRATION M/L^3	c_s	= Concentration in Surface Runoff
	c_g	= Concentration in Groundwater
MASS (FLUX) TRANSPORT M/T	W	= Mass Rate of Transport
	W_d	= From Distributed Sources (Surface, Ground and Agriculture)
	W_p	= From Point Sources (Municipal, Industrial and Irrigation Return)

SCHEMATIC OVERVIEW
FIGURE I

$$W = W_d + W_p$$
$$= \sum qc_p + Q_s c_s + Q_g c_g \qquad (1)$$

in which:

- W_d, W_p = mass rate of transport from distributed and point sources, respectively
- q = a flow rate from a point source
- Q_s, Q_g = surface and groundwater components of runoff
- c_p, c_s, c_g = concentrations of the point source, surface runoff, and groundwater
- $\sum qc_p$ = summation of mass rates from point source

B. Sodium Flow Relation

The relation between the river flow and sodium concentration stems from the comparable relation with total dissolved solids (TDS), of which the sodium is a component. The source of these constituents in natural waters is primarily the ground water reservoir and, to a lesser extent, the surface and subsurface drainage. The ratio between the concentration of sodium and dissolved solids is approximately constant for a specific drainage area, but may vary from one region to another by virtue of differences in geochemical and hydrological characteristics of the area. Correlations between total dissolved solids and sodium are shown in Figure 2 for various locations of concern in the Sacramento-San Joaquin Delta. Since the water at the Delta pumping plant and Rock Slough are derived from both rivers, the correlation at these locations reflects those of the sources. Thus the sodium-flow correlation follows from the relationship between total dissolved solids and flow. Assuming the point sources of dissolved solids and sodium are negligible by contrast to the distributed source from the ground water inflow, Equation (1) may be re-expressed as:

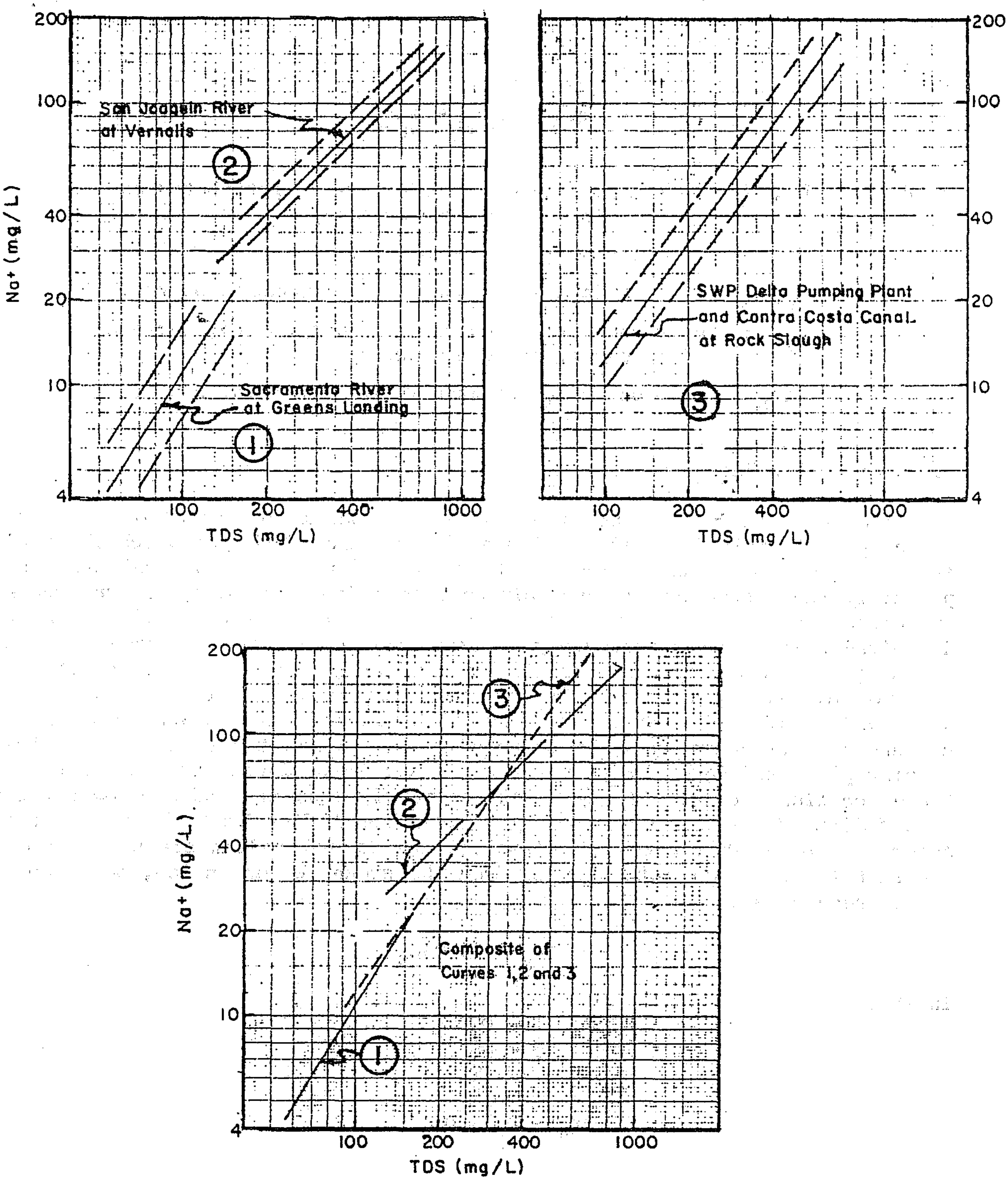
$$c = rc_g + (1-r)c_s \qquad (2)$$

in which

$$r = \frac{Q_g}{Q_T}$$

$$Q_T = Q_g + Q_s$$

Equation (2) expresses the concentration of the substance as a function of the ground and surface water concentrations and of the ratio of the ground water flow to the total flow. The concentrations, c_g and c_s, define the upper and lower limits for a conservative substance which may be expected in a fresh water stream. During the dry periods of the year, when the surface runoff is zero and stream flow is composed only of ground water (assuming no reservoir



TDS–SODIUM CORRELATIONS

FIGURE 2

releases), the concentration in the river equals that in the ground water. During the high flow period, the concentration in the river approaches that of the surface runoff, since this component is usually much greater than that of the ground water.

The crux of the analysis is, of course, the ratios of the ground water and surface water to the total river flow. These ratios vary with the magnitude of the total flow. During dry periods the surface flow is zero or a relatively small quantity, and the ground water flow is all or a large percentage of the total flow. Thus the ratio, r, equals or approaches unity for flows equal to or less than a base flow, Q_b, above which the surface component is significant. As the total river flow increases, due to surface runoff, the relative influence of the ground water component becomes less, i.e., the ground water component also increases but not as rapidly as the surface runoff.

The general nature of these relationships is shown diagrammatically on logarithmic coordinates in Figures 3A and 3B. The dashed line in Figure 3A represents a range in which both surface runoff and ground water are contributing to the total flow in the river. In many cases, however, the range may be sufficiently compressed so that a reasonable approximation is realized by the solid line, as shown. Assuming, therefore that the ground water is equal to the total river flow during periods of low runoff and may be expressed as a fractional power of the total flow during periods of high flow, the following relationships hold:

$$\text{For} \quad Q_T < Q_b, \quad Q_g = Q_T \tag{3a}$$

$$\text{and} \quad r = \frac{Q_g}{Q_T} = 1 \tag{3b}$$

$$\text{For} \quad Q_T > Q_b, \quad Q_g = bQ_T^m \quad \text{with} \quad m < 1 \tag{4a}$$

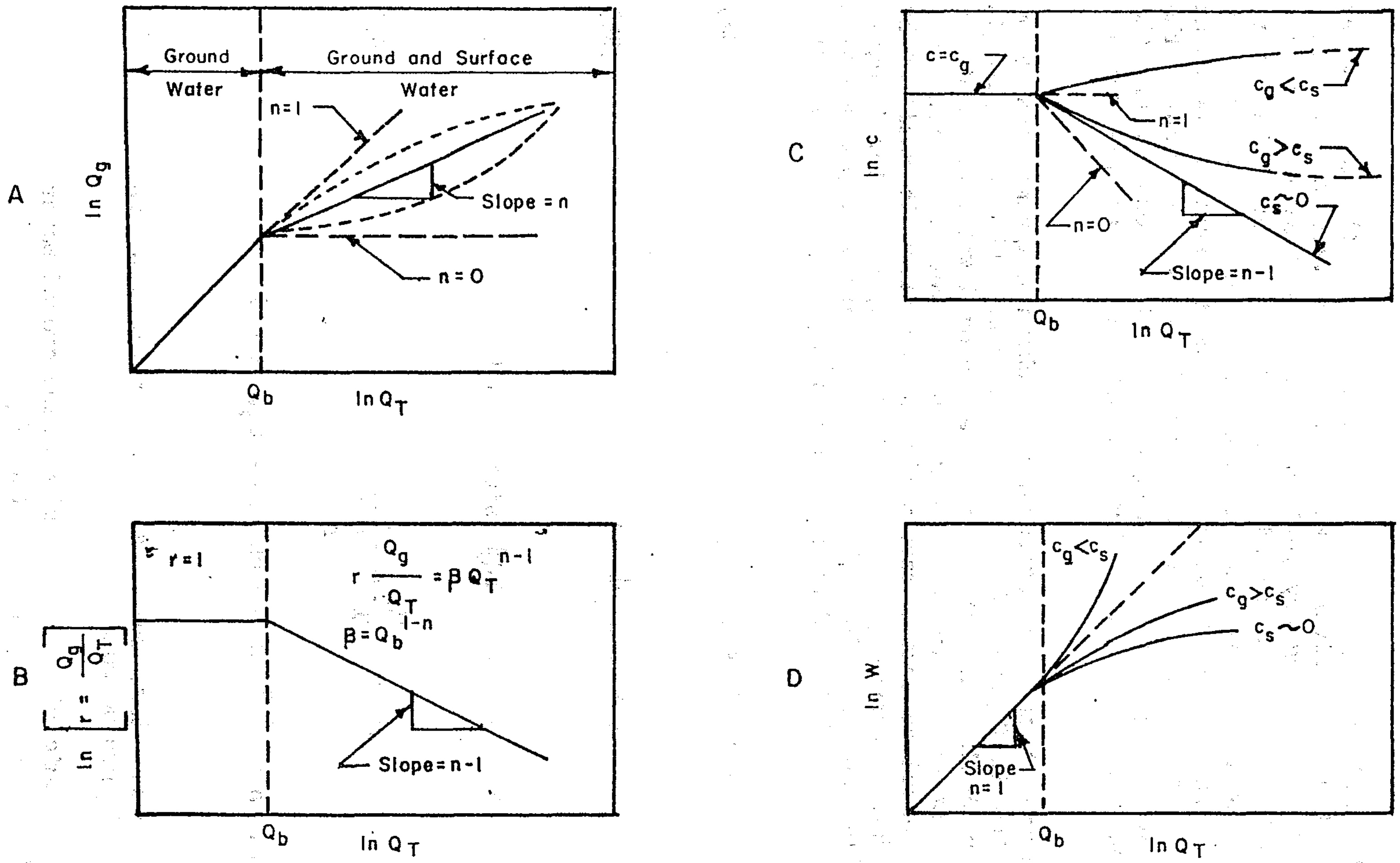
$$\text{and} \quad r = \frac{Q_g}{Q_T} = \frac{b}{Q_T^{1-m}} \tag{4b}$$

$$\text{in which} \quad b = Q_b^{1-m} \quad \text{since at} \quad Q_T = Q_b, \quad r = 1$$

with:

Q_b = the base flow, below which the river flow is totally ground water

m = logarithmic slope of the river flow-ground water relation for flows greater than Q_b



RELATIONSHIPS BETWEEN RIVER FLOW AND

A. GROUNDWATER

B. RATIO — GROUNDWATER/RIVER FLOW

C. CONCENTRATION — DISSOLVED SOLIDS

D. MASS TRANSPORT

FIGURE 3

b = a coefficient equivalent to the ground water flow component at unit river flow

The relationship between river flow, Q_T, and the ratio of river flow to the ground water component, in accordance with equations (3) and (4), are shown diagrammatically in Figure 3B.

Substitution of (3b) and (4b) in (2) yields respectively:

$$\text{For} \quad Q_T < Q_b, \quad c = c_g \tag{5a}$$

$$\text{For} \quad Q_T > Q_B, \quad c = c_s + \frac{b(c_g - c_s)}{Q^{1-m}} \tag{5b}$$

The shape of the flow-concentration relationship (Equation 5a and 5b) varies from one drainage area to another depending on the magnitudes of the surface and ground water concentrations and the ratio of the ground water to the total flow. Figure 3C indicates this relation for a surface concentration of dissolved solids, c_s, equal to zero and also for a surface concentration less than and greater than the ground water concentration, c_g. The resulting mass transport is shown in Figure 3D. Applications of the above equations are shown in Figure 4 for various rivers throughout the country.

In the Sacramento-San Joaquin Delta system, reservoir releases represent the major source of water during low flow conditions, during which the reservoir releases supplement the groundwater flow. Graphical correlations of flow with total dissolved solids and sodium are presented in Figure 5 for the Sacramento and San Joaquin Rivers, representative of the data between 1970 and 1980. The drought periods of 1976 and 1977 are specifically identified, in view of the increased concentrations during this critical period. Knowledge of the relative contribution of water from each source permits assessment of the dissolved solids and, therefore, sodium at water intake locations throughout the Delta. Indicative of such relations is the dissolved solids comparison at Vernalis (San Joaquin) and Rock Slough, as shown in Figure 6. Similar correlations may be developed for the concentration at the Delta Pumping Plant and similar comparisons for the Sacramento River.

C. Trihalomethane-Flow Relations

The above framework may be conceptually applied to the trihalomethane-flow relation. Two additional factors, however, must be considered. The first is the probable significance of the point sources of trihalomethane precursors. Since various forms of organic carbon are contributory to their formation, effluents from treatment plants which are point sources, should be included in the mass balance. Thus, Equation (1) in this case includes the W_d term, in addition to the distributed components, $Q_s c_s$ and $Q_g c_g$. Furthermore, the concentration of organic carbon may increase with the surface runoff component, by contrast to the dissolved solids and sodium, which generally decrease with higher surface flows, as indicated in the previous discussion.

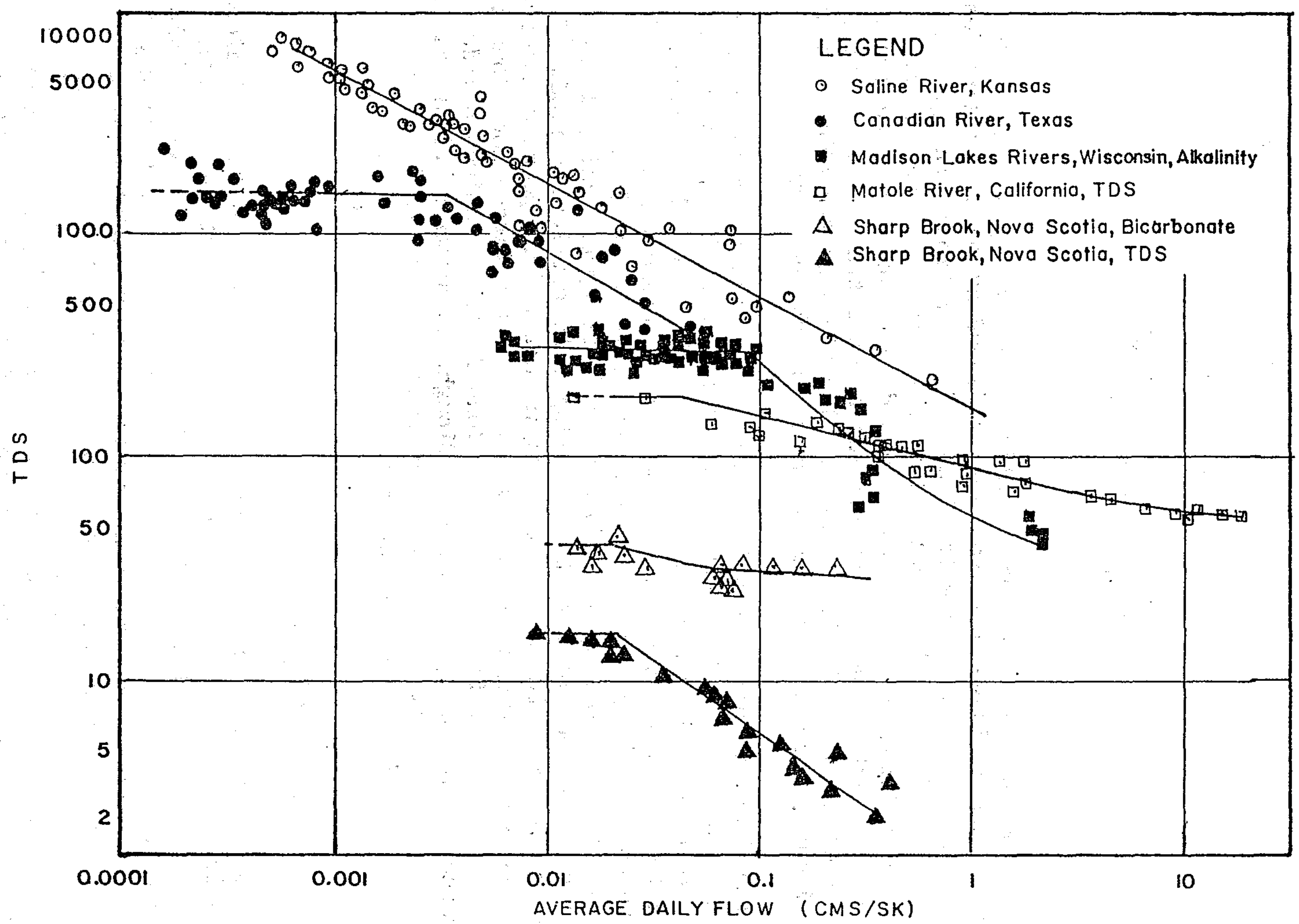
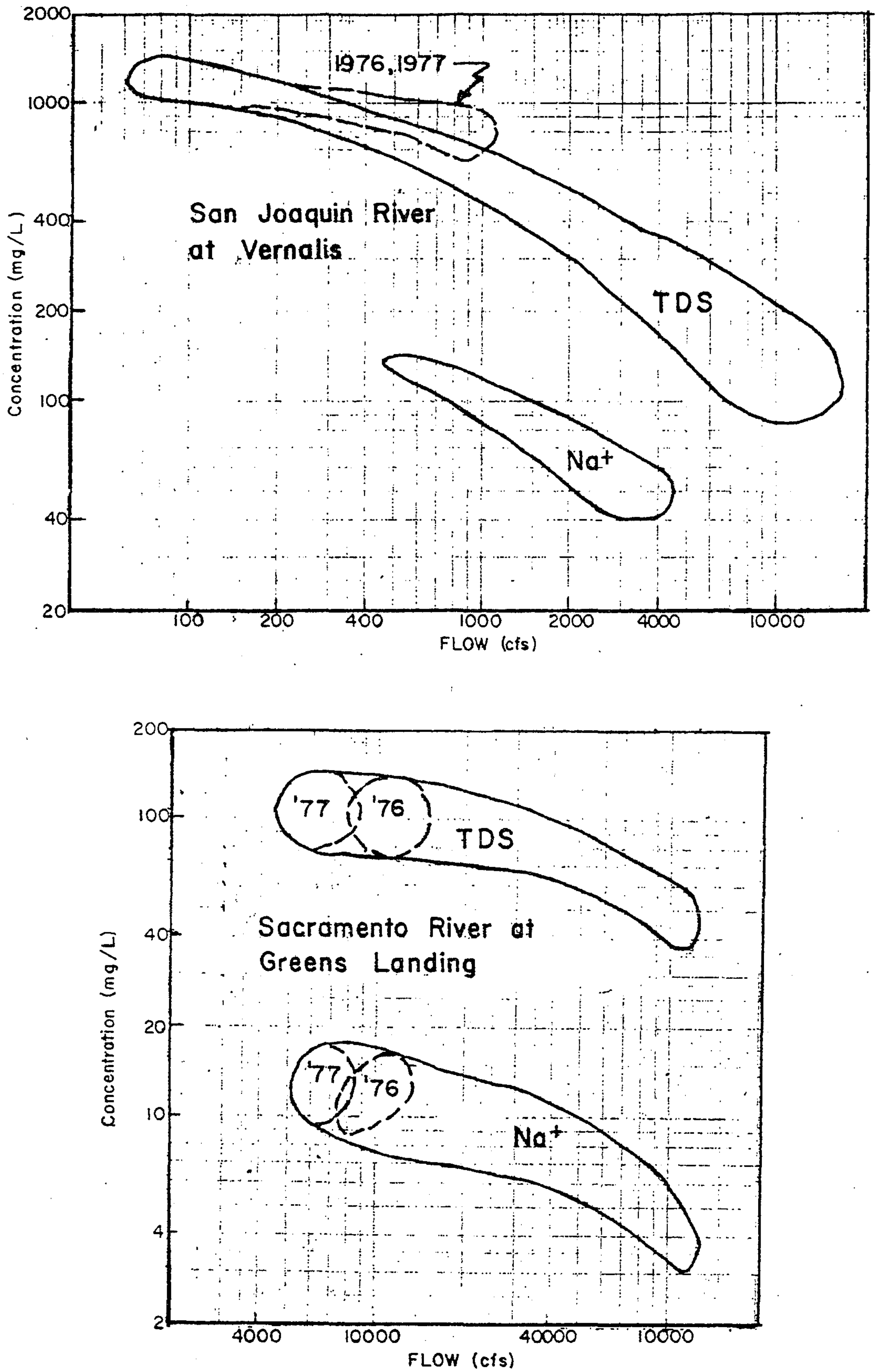

LEGEND
Saline River, Kansas
Canadian River, Texas
Madison Lakes Rivers, Wisconsin, Alkalinity
Matole River, California, TDS
Sharp Brook, Nova Scotia, Bicarbonate
Sharp Brook, Nova Scotia, TDS
TDS
10000
5000
1000
500
100
50
10
5
2
0.0001
0.001
0.01
0.1
1
10
AVERAGE DAILY FLOW (CMS/SK)

FIGURE 4



SALINITY — FLOW

FIGURE 5

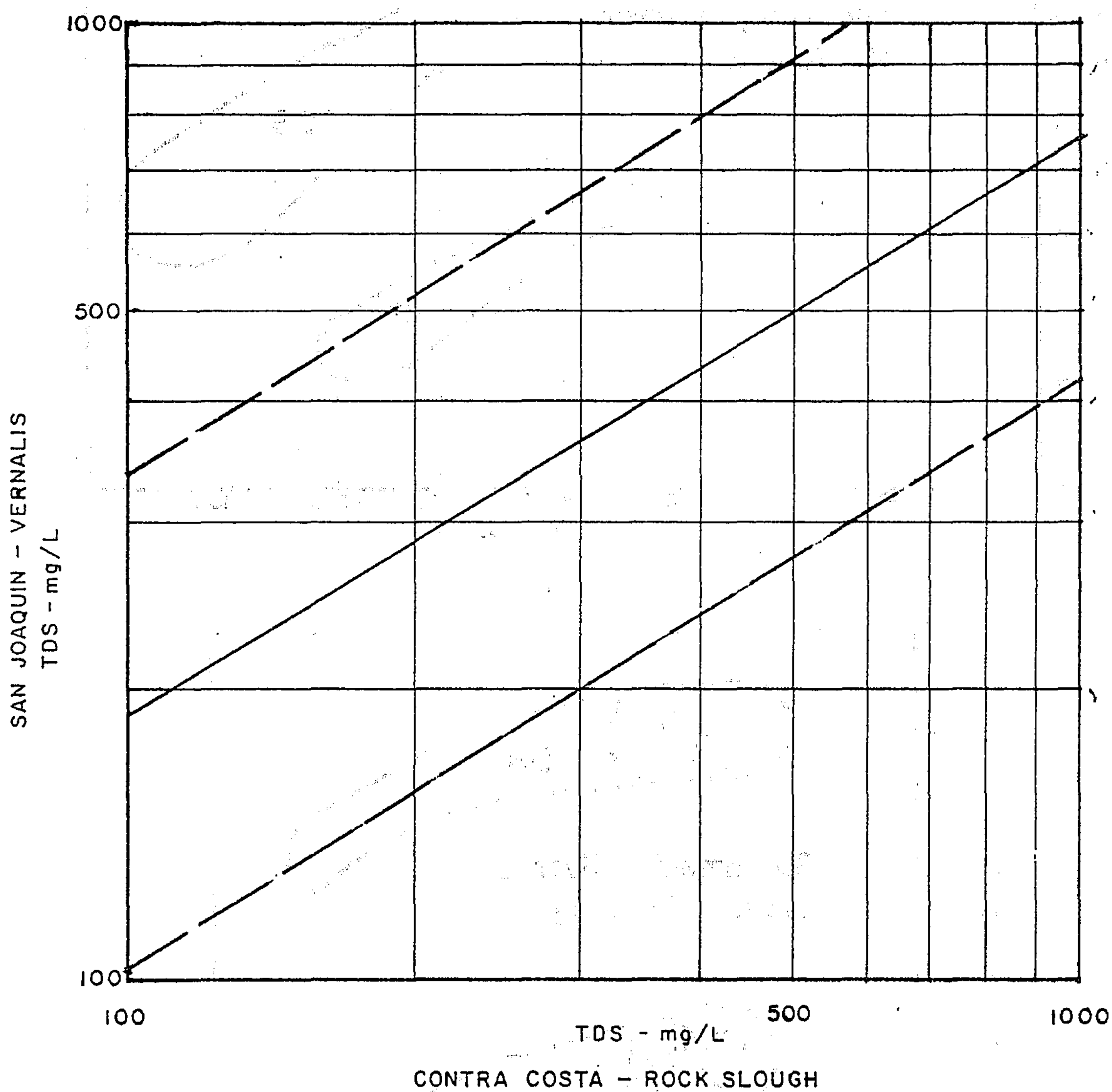
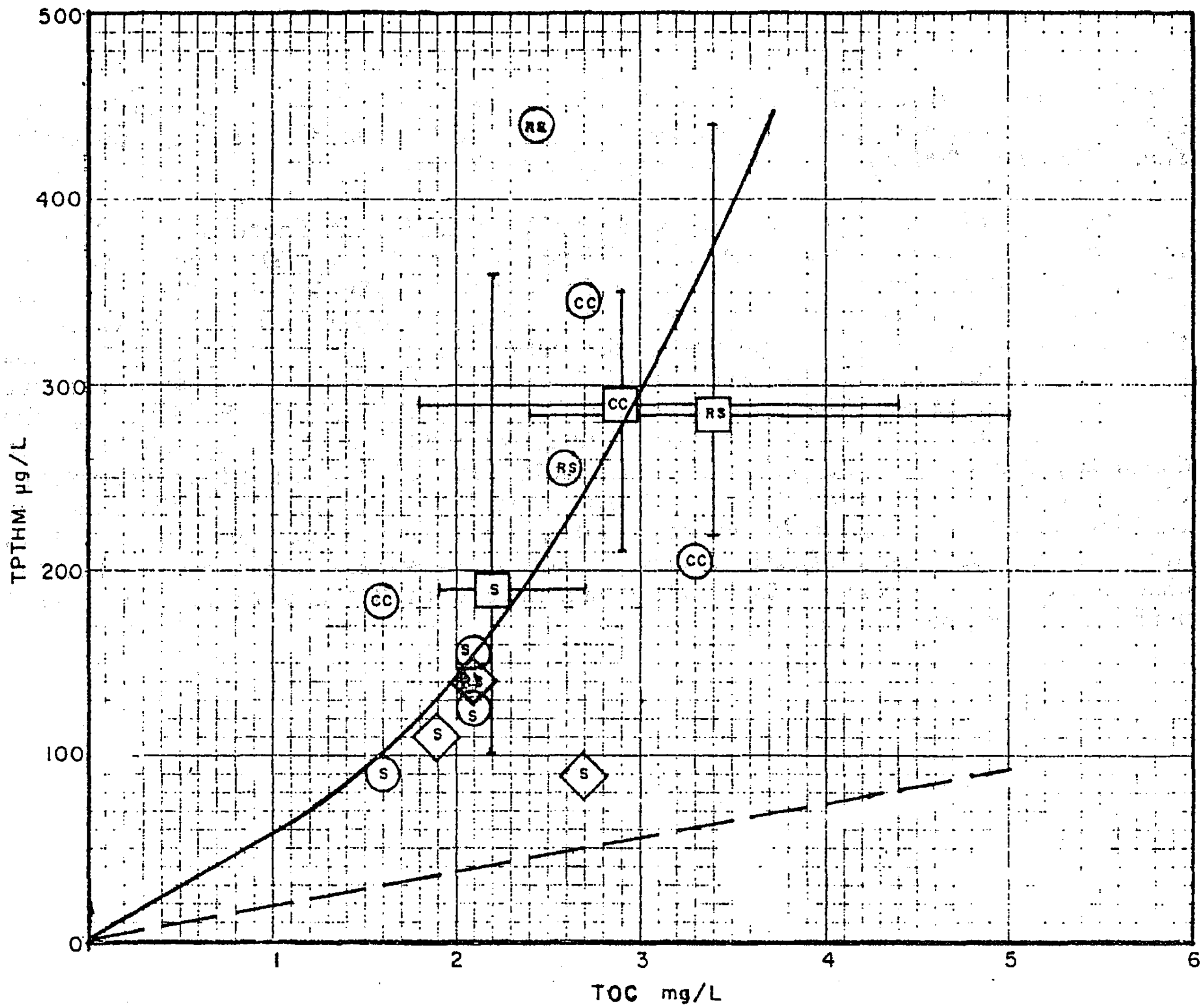
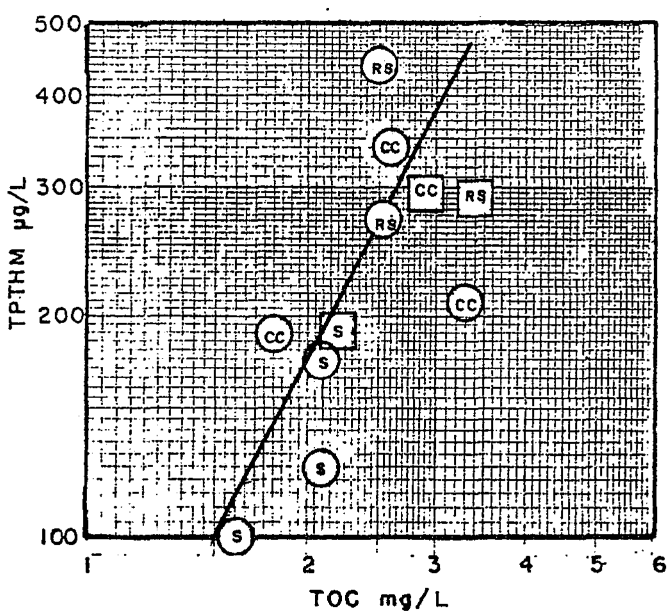

1000
500
100
SAN JOAQUIN - VERNALIS
TDS - mg/L
100
500
1000
TDS - mg/L
CONTRA COSTA - ROCK SLOUGH

FIGURE 6

Although correlations between total organic carbon and total potential trihalomethanes are weak, there are usually general trends, indicating increasing formation with TOC concentration, as shown in Figure 7.

The net effect of these two potentially significant factors modifies the flow concentration function of the TDS-sodium relation. The mass transport and concentration functions are shown in Figure 8. During low flow periods, the point sources dominate the mass transport, yielding a constant value in the limit. In high runoff periods, the effect of the interflow concentration in the surface runoff is the significant factor and the mass transport increases with flow. The concentration-flow relation follows by dividing the mass transport by the total flow. During drought periods when the sources dominate, the concentration varies inversely with flow. A minimum concentration occurs between these limits. This general pattern has been observed for various constituents, such as nutrients, in other areas of the country. Although the data on trihalomethanes in the delta waters are minimal, the few observations as summarized by Woodard and McCune (1982) are in general accord with the above hypothesis.





LEGEND

RS Rock Slough

CC Clifton Court

S Sacramento River

○ Single Analysis-1979

◇ Single Analysis-1981

□ Mean & Range

SOURCES

1. Water Quality Study November 1980
Contra Costa County Water District
James Montgomery Inc.

2. California Department of Water Resouces

FIGURE 7

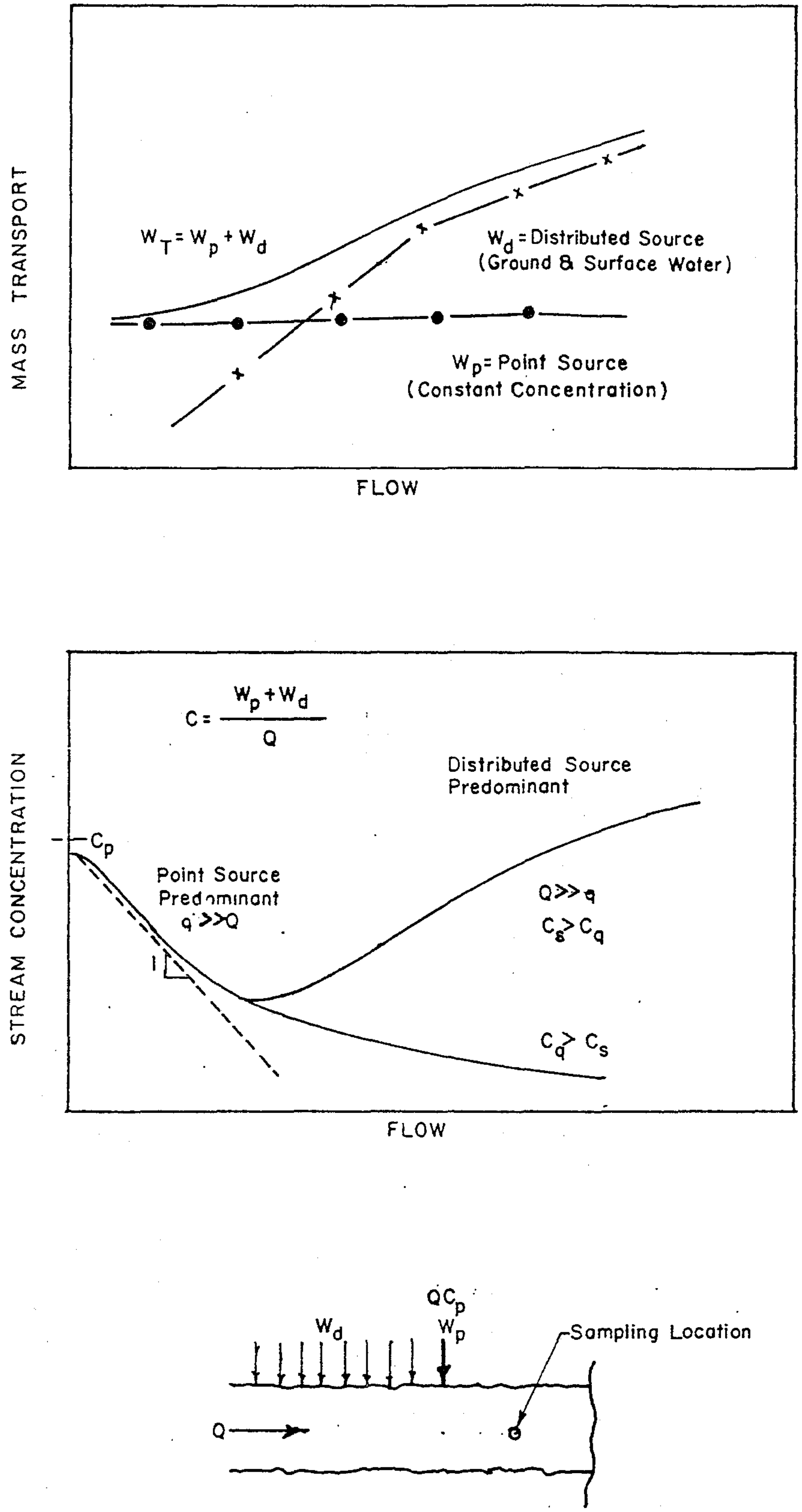

MASS TRANSPORT
$W_T = W_p + W_d$
W_d = Distributed Source
(Ground & Surface Water)
W_p = Point Source
(Constant Concentration)
FLOW
STREAM CONCENTRATION
$C = \frac{W_p + W_d}{Q}$
Distributed Source
Predominant
C_p
Point Source
Predominant
$q >> Q$
1
$Q >> q$
$C_s > C_q$
$C_q > C_s$
FLOW
QC_p
W_d
W_p
Sampling Location
Q

FIGURE 8