EXECUTIVE SUMMARY

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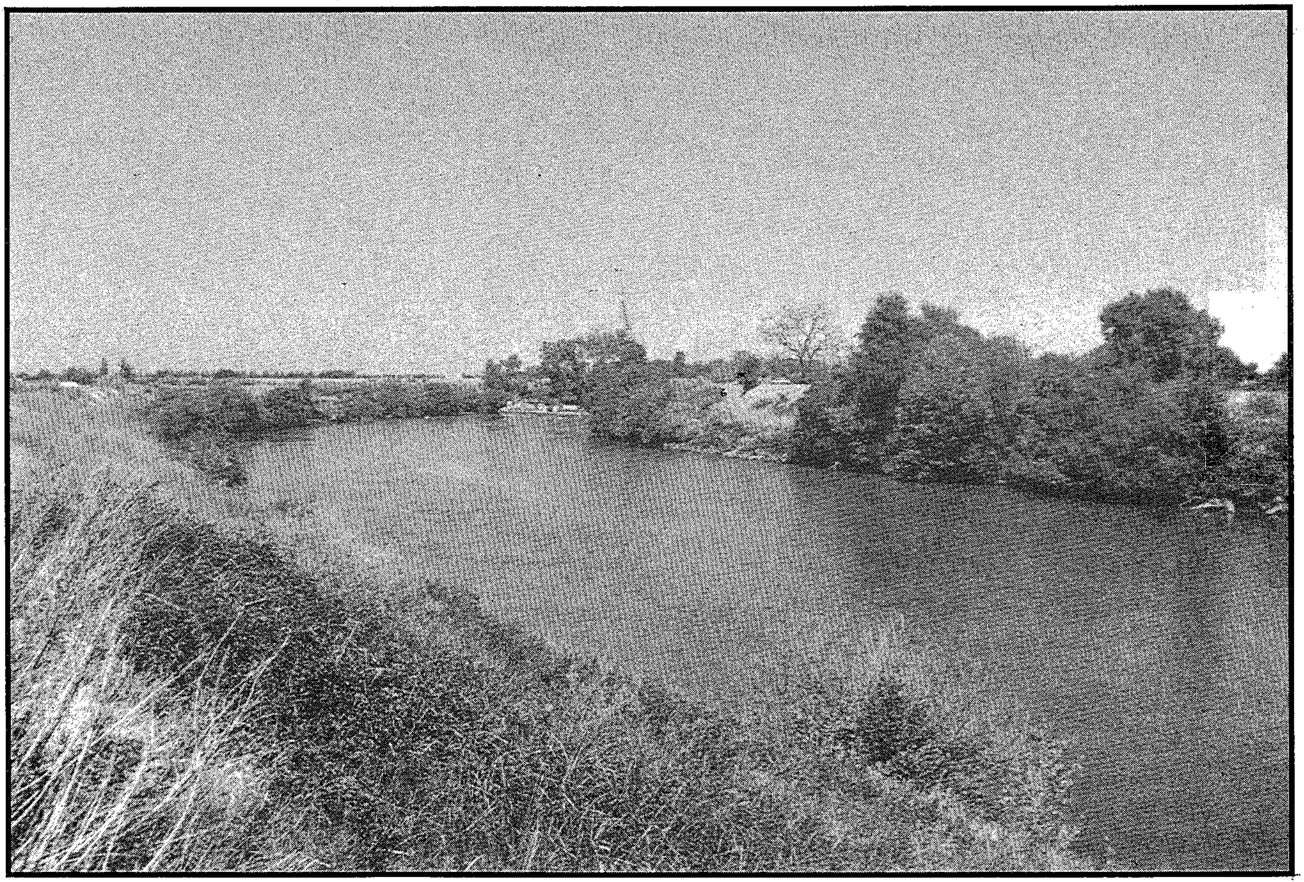
State of California
The Resources Agency
Department of Water Resources
Division of Local Assistance

FIVE-YEAR REPORT OF THE MUNICIPAL WATER QUALITY INVESTIGATIONS PROGRAM

Summary and Findings
During Five Dry Years
January 1987-December 1991

NOVEMBER 1994



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Cover photo is a waterway in the Sacramento-San Joaquin Delta near Staten Island. Photo courtesy of the *Department of Water Resources*.

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FOREWORD

In 1990 the Department of Water Resources consolidated its drinking water quality studies in the Sacramento-San Joaquin Delta. The Intergency Delta Health Aspects Monitoring Progam (1983-89), the Delta Islands Drainage Investigation (1986-89), and ancillary studies were combined into the Municipal Water Quality Investigations (MWQI) Program.

The program's major goal is to assist water agencies in protecting and improving Delta drinking water supplies and to guide research into methods of water treatment. To achieve this, program staff examine the major sources and causes of water quality changes in the Delta that affect drinking water quality. Key Delta channel and river stations and agricultural drains are monitored for contaminants such as pesticides, arsenic, selenium, sodium, and trihalomethane formation potential.

Californians experienced a six-year drought starting in 1987 that resulted in severe water shortages to some communities. As a result, water agencies implemented water conservation programs and emergency contingency plans. With less river flow into the Delta, sea water intrusion was more extensive. Delta farming changed in 1991 with less crop acreage than previous years. Delta farmers sold about half of their water allocation to the State Water Bank to help maintain domestic supplies, and about one-third of the Delta acreage was not farmed. Therefore, water quality conditions observed in the Delta represented rare and extreme dry weather hydrology.

This report presents the findings from monitoring water quality changes in the Delta during January 1987 to December 1991, a period of five consecutive dry years.

For further information on the Municipal Water Quality Investigations Program, contact Rick Woodard of the Division of Local Assistance, Department of Water Resources, at (916) 327-1636. Limited copies of this report can be obtained at no charge from Bulletins and Reports, Department of Water Resources, Post Office Box 942836, Sacramento, California 94236-0001, phone:(916) 653-1097.

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Chapter 1. EXECUTIVE SUMMARY

Municipalities taking water from the Sacramento-San Joaquin Delta are currently faced with an array of challenges. Besides having to compete for increasingly scarce water supplies, new State and federal drinking water regulations are requiring increasing levels of treatment. The cost of treating Delta waters to meet some anticipated new standards could be staggering. For this reason there is great interest in gathering water quality information from the Delta to assist in water treatment and water supply planning and research.

Under the Department of Water Resources' Municipal Water Quality Investigations (MWQI) Program, the quality of the Delta's drinking water supplies has been monitored since 1982. Over 70 sites are sampled, many of which are sampled each month, and special studies are conducted to gather information for the use of municipalities taking water from the Delta, and for planning activities within the Department. The monitoring stations include agricultural drainage discharge sites, major river channels and sloughs, estuarine locations, and water intakes or diversions (Figures 1.1 and 1.2).

Monitoring is vital for water resources planning and water quality research, especially in view of changing environmental and drinking water regulations.

Special emphasis has focused on identifying the sources and processes that enhance the formation of disinfection by-products in treated Delta water supplies. Disinfection, which is critical to protect against microbial disease, also produces chemical by-products that may pose other health risks such as cancer. Trihalomethanes (THMs) are some of the types of disinfection by-products (DBPs) that can be formed.

Until recently, trihalomethanes were the only regulated DBPs (0.100 mg/L), and chlorine and chloramines were the preferred disinfectants of choice because of lower costs and high effectiveness in controlling bacterial growth in the water distribution system. However, new U.S. Environmental Protection Agency regulations, which take effect in 1998 and referred to as the Disinfectants-Disinfection By-Products or D-DBP rule, have caused water utilities to initiate research on water treatment technologies such as ozonation and granular activated carbon filtration, and to expand their chemical testing for additional DBPs.

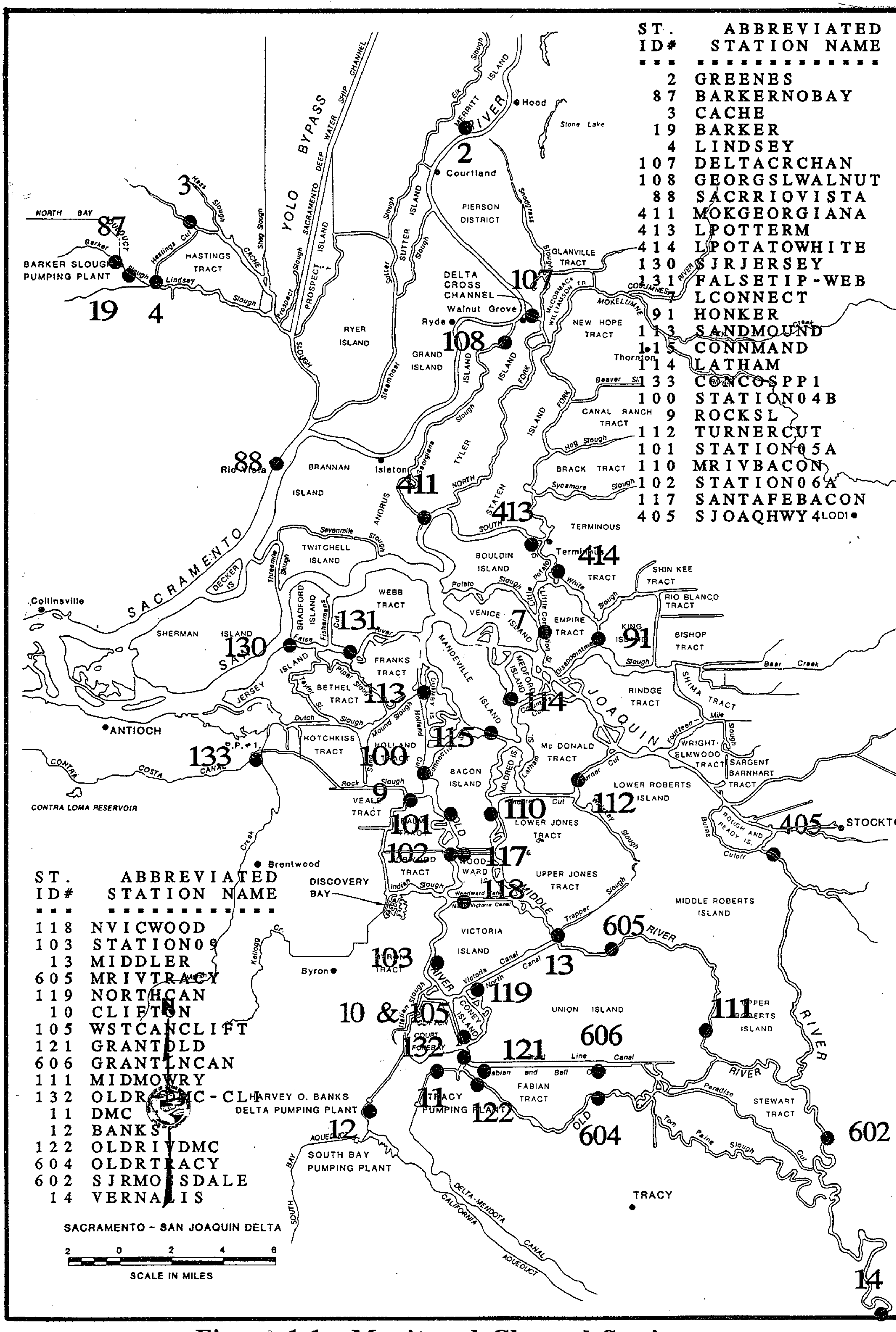


Figure 1.1. Monitored Channel Stations

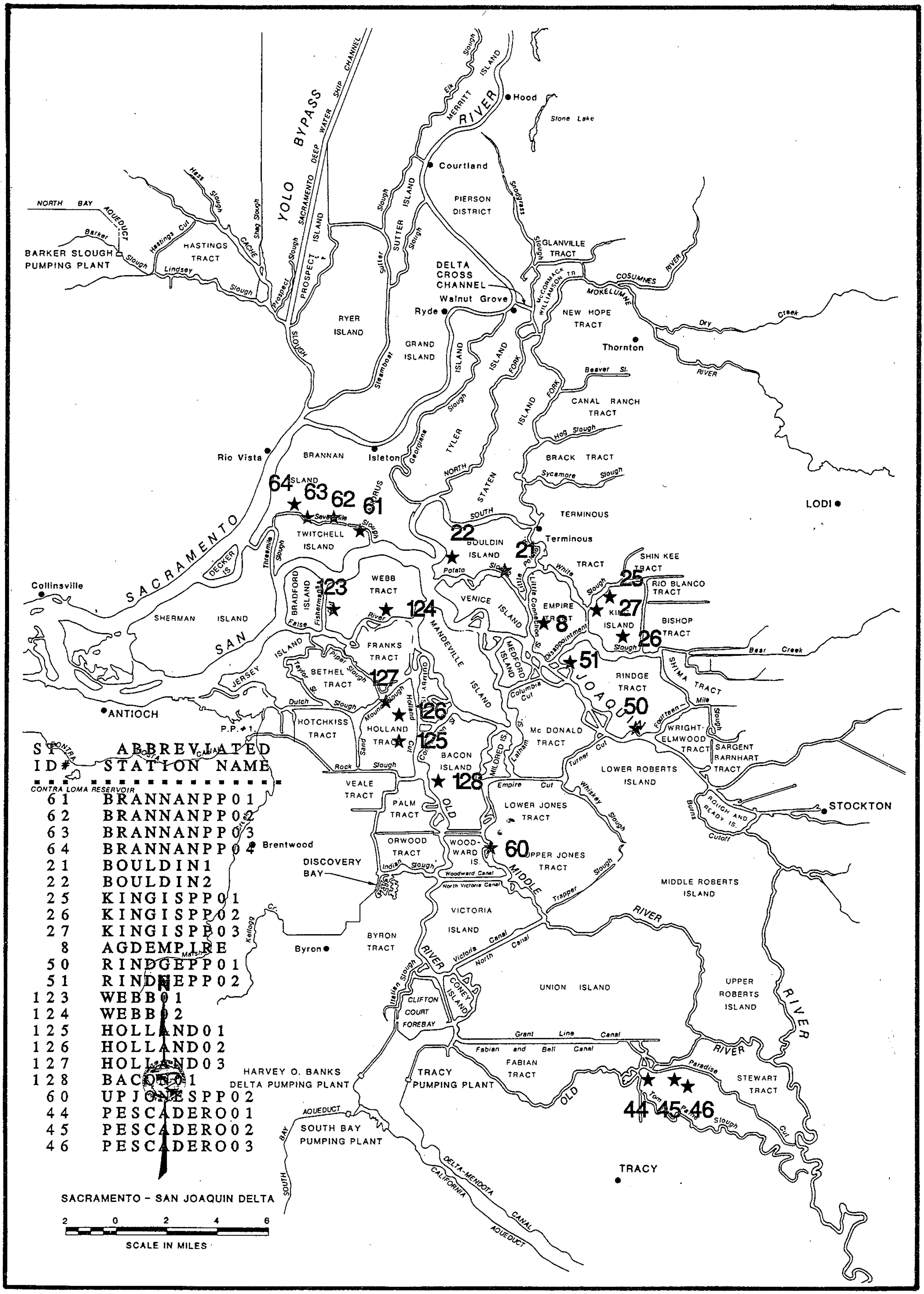


Figure 1.2. Monitored Agricultural Drainage Pump Stations

While control of DBPs is important, water purveyors must also consider that the primary thrust of disinfection is to control waterborne disease. Recent outbreaks in Milwaukee, Wisconsin, and Washington, DC, have demonstrated that, in relatively unprotected watersheds, like the Delta, disease is a considerable threat. Purveyors are, therefore, faced with maintaining a delicate balance of maintaining adequate disinfection while limiting formation of unwanted byproducts. Because Delta waters have elevated concentrations of organic matter and bromides, which contribute to formation of DBPs, finding an appropriate balance between these competing factors is especially difficult.

The new D-DBP rule has two stages. Stage 1, effective June 1998, will lower the total THM standard from 0.100 mg/L to 0.080 mg/L. Limits will be set for other DBPs including bromate (0.010 mg/L), chlorite (1.0 mg/L), and the sum total concentration of five specified haloacetic acids, referred to as the "HAA5" (0.060 mg/L). Limits for the disinfectant residuals of chlorine, chloramines, and chlorine dioxide must also be met.

Prior to the new rule, THMs were the only regulated DBPs.

The best available technology (BAT) for meeting the stage 1 maximum contaminant levels (MCL) for total THMs and the HAA5 are enhanced coagulation, enhanced softening, or granular activated carbon (GAC). The BAT for meeting the bromate MCL will consist of controlling ozonation. Control of the chlorine dioxide process will be the BAT for meeting the chlorite MCL. Since extensive research, retrofitting, and upgrading of treatment facilities will be needed to meet the new rule, stage 1 of the rule will not be in effect until June 1998.

Stage 2 of the D-DBP rule may, subject to renegotiation, further lower the total THM MCL to 0.040 mg/L and the HAA5 MCL to 0.030 mg/L. Stage 2 of the rule takes effect in January 2002.

Meeting DBP MCLs will, in part, depend on how well a water treatment plant can control bromide and organic matter in the water prior to adding disinfectant chemicals.

The degree of success water utilities will experience in complying with the new DBP rule will depend, in part, on how well DBP precursors (chemicals that lead to the formation of DBPs) can be reduced in the raw water supply prior to disinfection. By removing these precursors, the formation of known and unknown DBPs can be lowered. Changing or reducing the amount of disinfectants may reduce formation of some DBPs but may also raise the risk for waterborne disease outbreaks such as cholera.

The major precursors that have been identified as needing to be controlled are organic matter and bromide. Some parts of the Delta, the south in particular, have high concentrations of bromide and organic matter. Waters diverted by the State Water Project, Central Valley Project, and Contra Costa Water District are generally higher in organic matter, bromide, and other mineral salts than the waters of the northern Delta. Sea water has been traced as the major source of bromides in the southern Delta.

There are, however, many sources of organic matter. Some of them include streamside vegetation, decaying crop residues, algae, and sewage. The largest source appears to be from the region's soils. Because the Delta was once a vast tule marsh and is now mostly farm land, the soils of the region are rich in organic material from decaying marsh and crop residues.

About 260 pump stations are dispersed among 60 Delta islands and tracts that are below sea level. The pumps discharge a combination of seepage, runoff, and irrigation return water into the adjacent channels. Drain water is high in mineral salts and organic matter. The salts come from the evaporation of irrigation water. However, in some areas, such as Empire Tract, connate water from an underground marine aquifer contributes mineral salts to the drainage.

The volume and water quality of drain water that is discharged into the channels correlate with the seasonal farming activities and regional soils (Figure 1.3). There are two periods when drainage volumes are highest. In the late fall and early winter, the fields are flooded to leach out salt accumulations from the soil. This results in short periods of high drainage volume and high dissolved organic carbon (DOC) concentrations in the drainage, especially from organic soil areas.

Seasonal farming activities affect the amount of organic matter that is carried off by drain water.

High DOC and trihalomethane formation potential (THMFP) levels are associated with the organic content of the drained soils. The highest concentrations are typically found in drains located on peat organic soil areas and the lowest from mineral-type soil areas. U.S. Geological Survey studies attribute the variability in DOC at a given site to soil-water contact time, water table height, soil moisture, and temperature (Deverel and others, 1993).

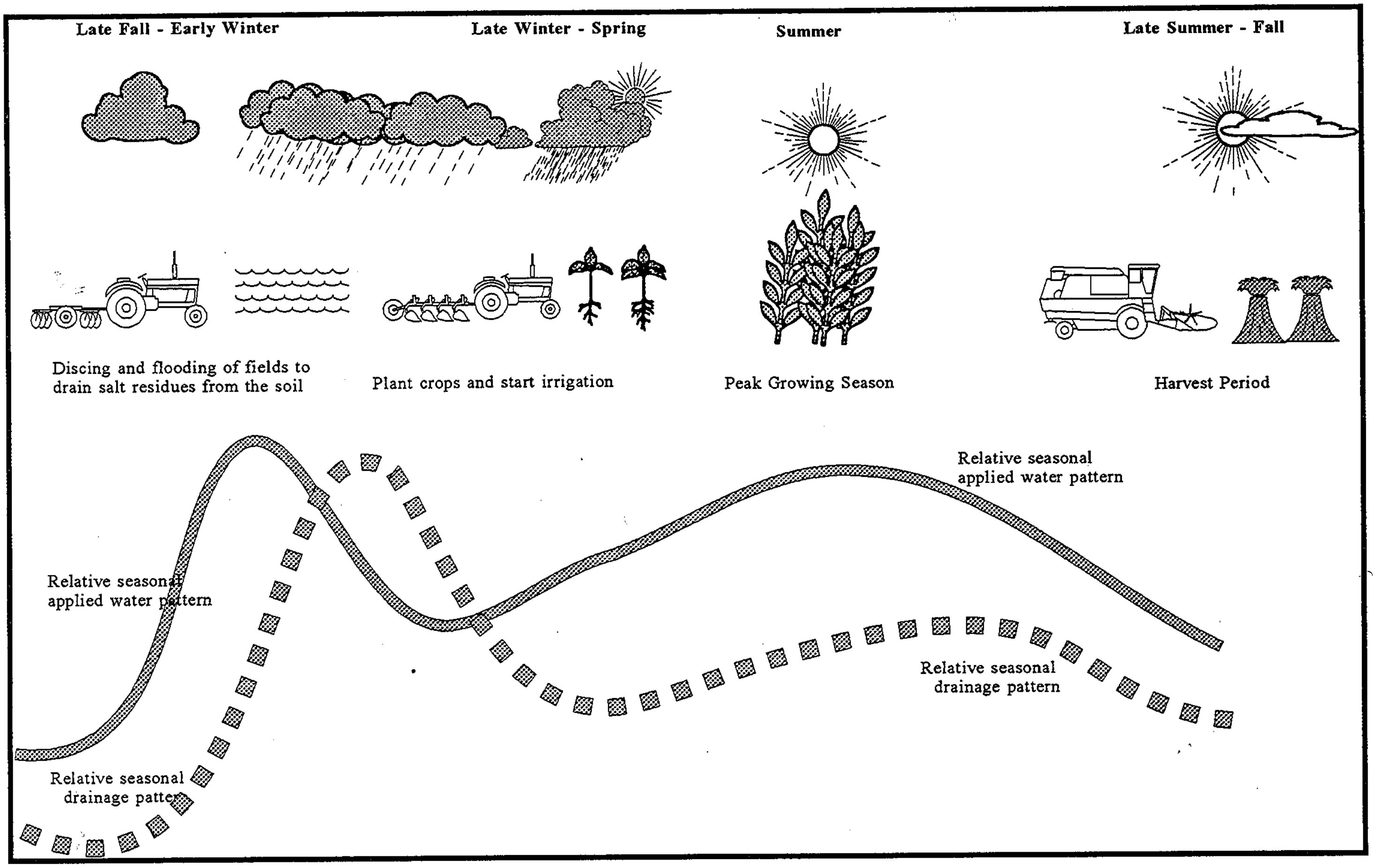


Figure 1.3. Seasonal Farming Activities in the Delta

The second peak drainage season occurs during the summer when irrigation is increased. DOC levels are relatively lower than when the fields are leached in the late fall and early winter. This may be caused by less soil to water contact time and a fluctuating lower water table that reduces the soil moisture.

Drain water has a greater tendency to form trihalomethanes and other disinfection by-products when chlorinated than nondrain water samples. This is due to the high humic content of the region's peat soil.

Humic substances form from the progressive decay of natural organic matter (Figures 1.4 and 1.5) and are considered to be the complex mixture of organic compounds that are DBP precursors. The discovery of trihalomethanes in treated drinking water resulted from a study on the effects of chlorinating humic substances (Rook, 1974).

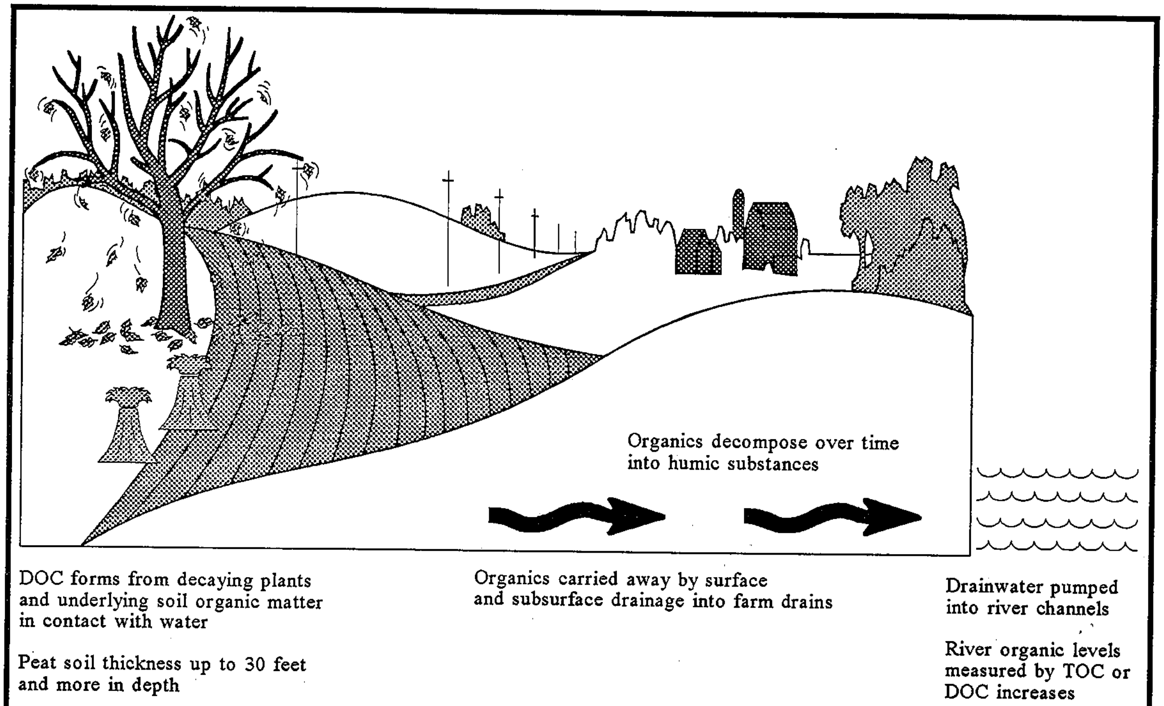


Figure 1.4. Organics From Delta Soils

The increases in DOC and THM precursor concentrations in the Delta channel waters are mostly from drainage discharges.

The high DOC and THM formation potential of Delta drain water is not surprising. Natural waters from organically enriched environments such as bogs, marshes, and wetlands are typically higher in DOC and humic content than sea water and most streams and lakes.

Based on past drainage volume estimates (1954-55) and more recent monitoring data assessments (1983-93), the increases in DOC and THM precursor concentrations in the Delta channel waters are mostly from drainage discharges. Some increases are due to activities within the channel, such as dredging, sediment leaching, and biological productivity, but they are relatively smaller than from drainage discharges. An estimate of the contribution of THMFP for Delta island drainage was published in the DWR *Delta Island Drainage Investigation Report, June 1990*.

Water quality at the intakes of the State and federal water projects generally does not resemble that of Sacramento River inflows to the Delta except when river flows are extremely high, such as during strong winter storms. During low river flows, water quality at the Tracy Pumping Plant and Clifton Court Forebay gates is affected by daily tidal excursions, Sacramento River flows that control the extent of salt water intrusion, and San Joaquin River flows entering the southern Delta.

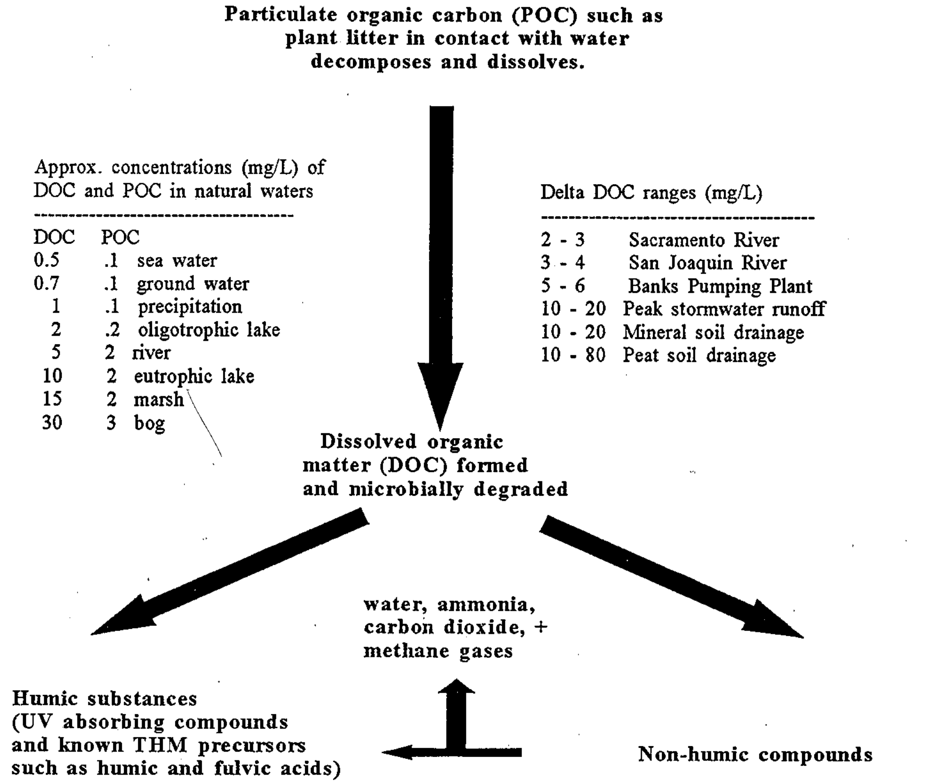
During calendar years 1987-91, most of the low San Joaquin River flows were drawn into the Delta-Mendota Canal intake. Sacramento River flows at Greenes Landing were generally ten times greater than San Joaquin inflows near Vernalis. Some of the Sacramento River flow was drawn through the central and western Delta into the State Water Project and Delta-Mendota Canal. The Sacramento River was virtually the sole fresh water source for the entire Delta.

A summary of observed EC, bromide, DOC, THMFP, and TFPC concentrations across the Delta during the five-year period are graphically summarized in notched box-and-whisker plots (Figures 1.7- 1.11). An explanation of notched box-and-whisker plots is presented in Figure 1.6.

These plots are a method for graphically showing how the data are distributed. The positions of the end points and notches give information on the extreme high and low values, the median, and the range of values by quartiles. It provides an overview as to whether the observations are widely scattered or not. The figures are useful for studying the variability of observations. The information is also useful for selecting representative data for a site.

The median electrical conductivity (EC), which is also called specific conductance, at the American River WTP intake station (AMER on Figure 1.7) was about 75 µS/cm and about 175 µS/cm at Greenes Landing (GRN). The median EC at Little Connection Slough (LCON) near Empire Tract was about 240 µS/cm. Increases in EC values were evident downstream at the other Delta stations influenced by drainage and seawater. The high EC (median 850 µS/cm) at Vernalis (VRN) reflected the upstream agricultural drainage discharges into the San Joaquin River.

Figure 1.5. The Transformation of Natural Organic Matter



Approx. concentrations (mg/L) of DOC and POC in natural waters

DOC	POC	
0.5	.1	sea water
0.7	.1	ground water
1	.1	precipitation
2	.2	oligotrophic lake
5	2	river
10	2	eutrophic lake
15	2	marsh
30	3	bog

Delta DOC ranges (mg/L)

2 - 3	Sacramento River
3 - 4	San Joaquin River
5 - 6	Banks Pumping Plant
10 - 20	Peak stormwater runoff
10 - 20	Mineral soil drainage
10 - 80	Peat soil drainage

Percent of DOC as humic substances for different water types

25%	sea water
25%	ground water
34%	lakes
47%	streams and rivers
75%	wetlands

DOC operationally defined as organic matter that passes through a 0.45 micron pore sized filter. POC is larger than 0.45 microns.

The 700 µS/cm EC median at Rock Slough near Old River (ROCK) is attributed to multiple sources, including sea water, Delta island drainage, and water from the San Joaquin River . The median EC values of water at the Banks Headworks (BANK), Clifton Court Forebay intake gates (CLIF), and DMC intake (DMC) stations were about 550 to 600 µS/cm and are attributed to mixing with lower EC water from Middle River (MIDR; median 450), which joins Old River at three canals between Bacon Island and Union Island.

Southern Delta water samples were higher in bromide than those from the northern Delta region (Figure 1.8). Bromide sources include sea water, connate water from Delta islands, and San Joaquin River basin drainage.

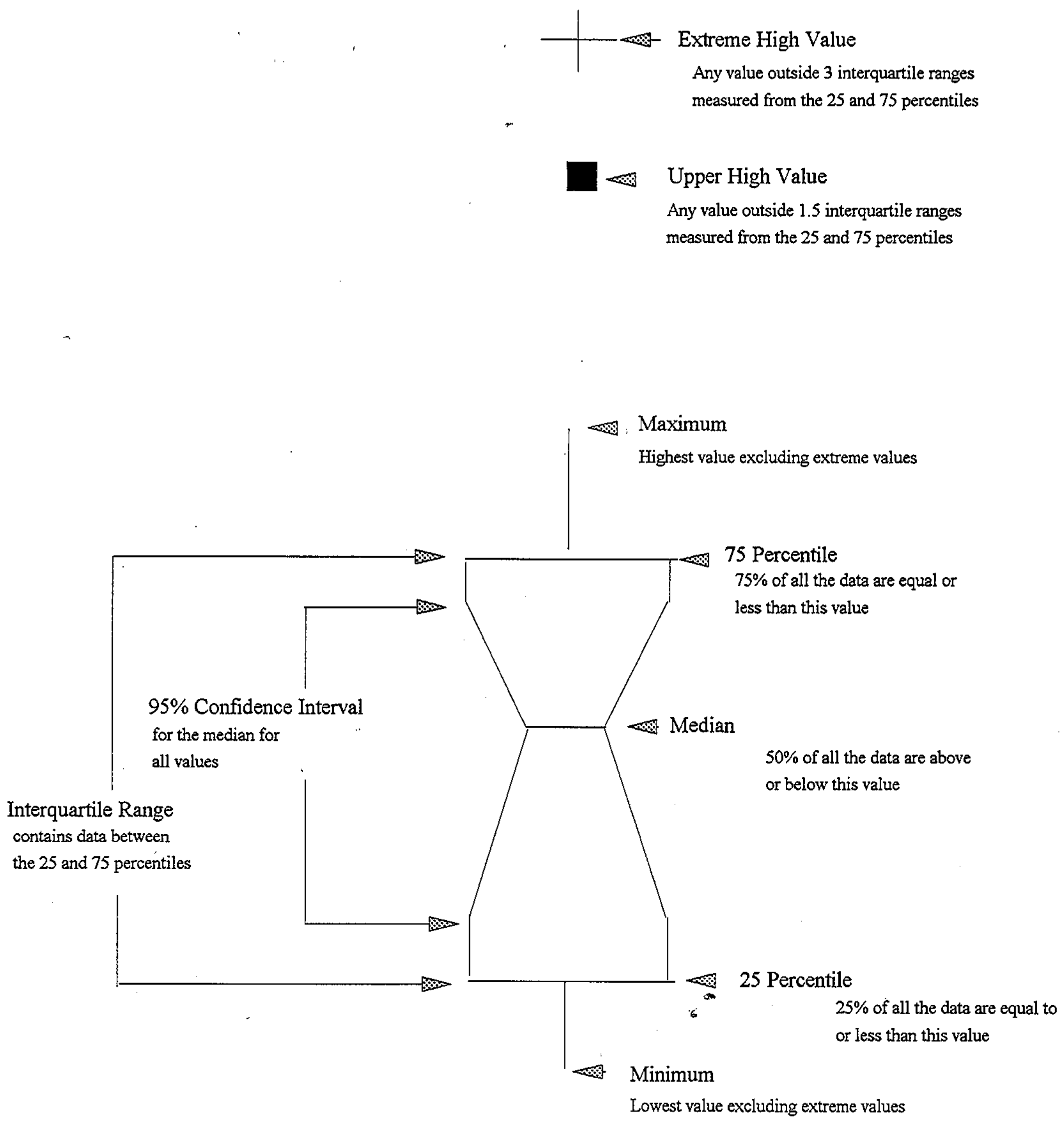
New total organic carbon (TOC) limits (2 mg/L) under the D-DBP rule will require enhanced coagulation or enhanced softening prior to disinfection for conventional water treatment plants (coagulation, flocculation, sedimentation, and filtration) and softening plants. The percent of TOC removal required by enhanced coagulation will depend on the source water TOC and alkalinity. Unfortunately, bromide, which leads to the formation of bromate and brominated THMs, will not be reduced by technologies to remove TOC. For this reason, utilities are also looking at other disinfectants such as ozone. However, there are concerns that these other disinfectants may form other DBPs that may be regulated in the near future.

TOC levels at some Delta water intakes already approach the new D-DBP rule limit and may require TOC reduction at some treatment plants

Delta TOC data are limited, but dissolved organic carbon (DOC) data are available for comparison. Past work has shown Delta DOC levels to be about the same as TOC levels. The median DOC concentrations at Greenes Landing and the American River stations were about 2 mg/L (Figure 1.9). Downstream median DOC was generally over 3 mg/L and had a wider range of concentrations. DOC usually doubles during the wet, rainy season from heavy surface runoff and drainage. Major storms can increase DOC even more during peak runoff periods.

Figure 1.6.

Guide to Notched Box-and-Whisker Plots



NOTE: Horizontal width of box is proportional to the square root of the sample size

Figure 1.7.
Delta E.C Ranges
(1987-91)

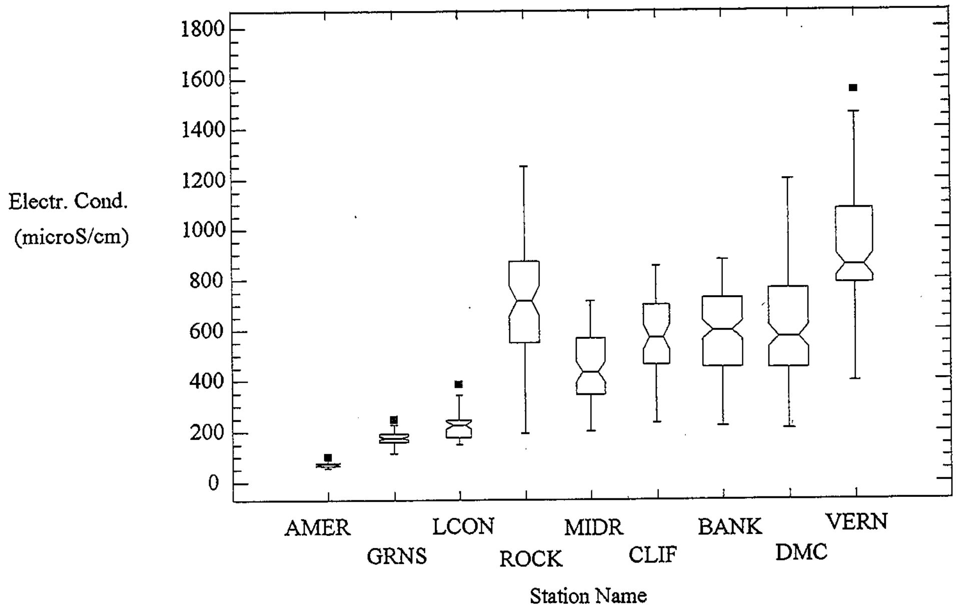
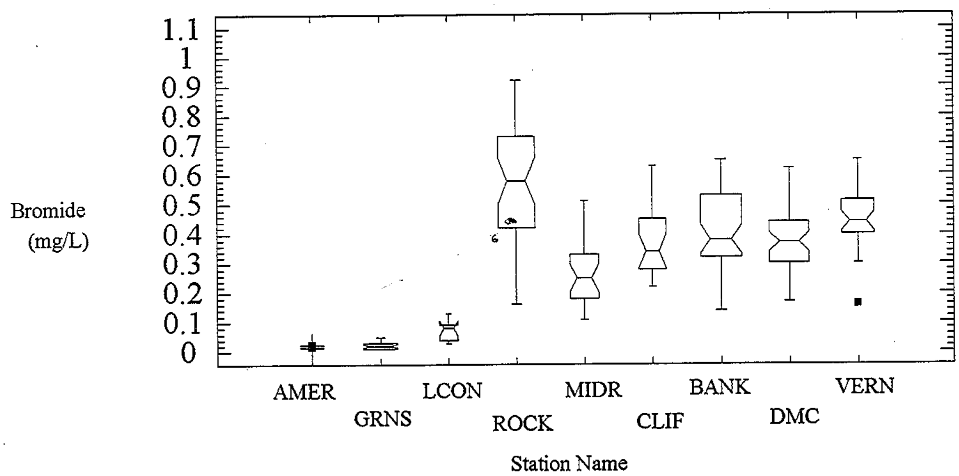


Figure 1.8.
Delta Bromide Ranges
(1990-91)



Trihalomethane formation potential, based on the DWR THMFP assay for raw water, was two to three times higher in the southern Delta than at Greenes Landing and the American River (Figure 1.10). However, these results are not comparable to the actual amount of trihalomethanes formed at a treatment plant after disinfection. Since different treatment schemes are used to limit THM formation, DWR results cannot be equated to actual THM concentrations found in tap water. The DWR raw water assay was established for comparing the THM formation potential of the variety of water types in the Delta, some of which are never used as a drinking water source (e.g., drain water, sea water).

To distinguish THMFP concentrations caused by bromide from that caused by reactive organic material, the amount of organic carbon from the THMFP concentrations was computed to yield the trihalomethane formation potential carbon (TFPC) concentration. This is a measure of how much carbon was incorporated in the trihalomethanes that were formed in the THMFP assay. The distribution pattern of Delta TFPC data was similar to the THMFP data for most stations (Figure 1.11).

The DWR THMFP assay results do not represent the amount of trihalomethanes found at the consumer's tap. It is a measure of the relative potential of different water types to form THMs. It is a tool for identifying sources of THM precursors.

Figure 1.9.
Delta DOC Ranges (1987-91)

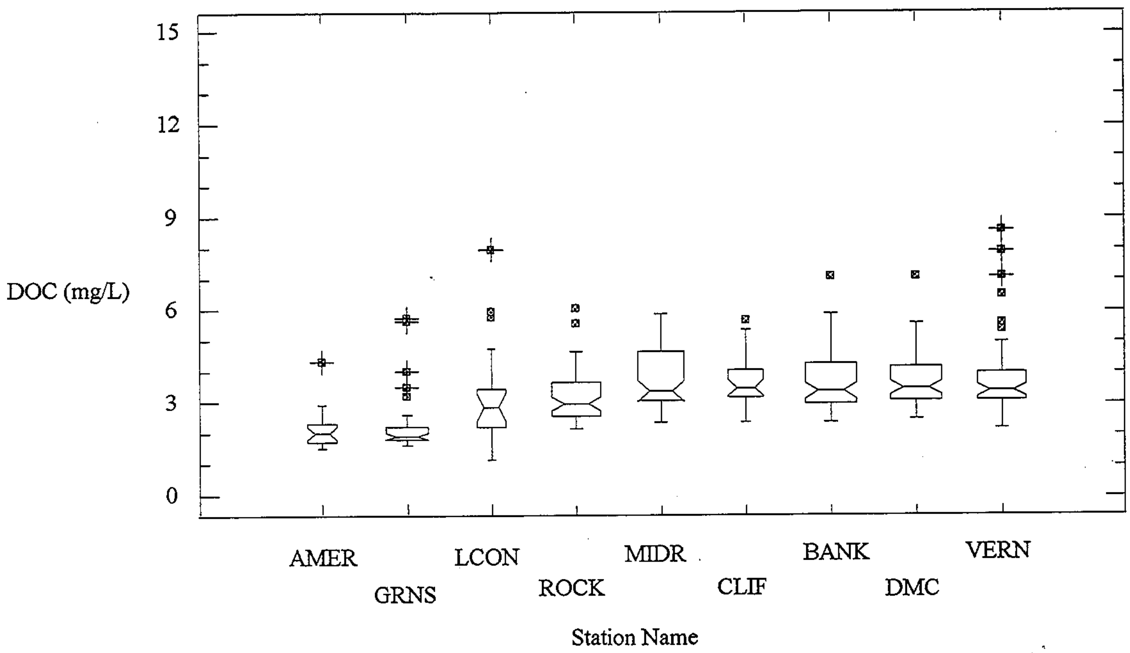
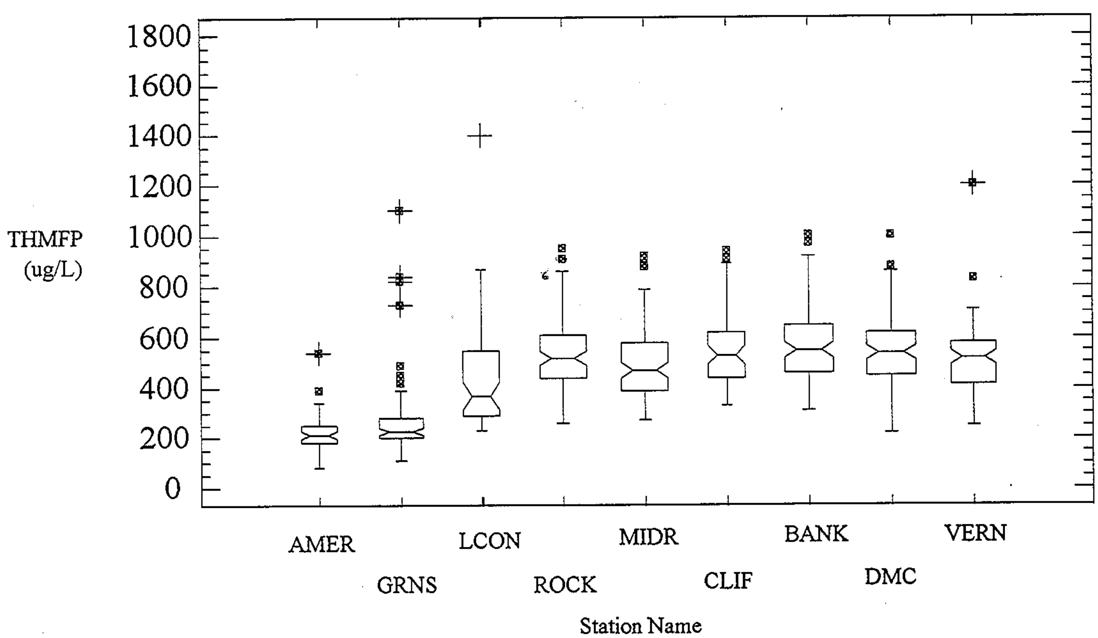


Figure 1.10.
Delta THMFP Ranges
(1987-91)



A simple accounting model was used to estimate the impact of organic carbon from drainage and nondrainage sources. Observed average DOC and TFPC concentrations were compared to predicted average values that were computed from 1954-55 drainage volume data (DWR, 1956), available water quality data, and river flow measurements. The model treated the Delta as a basin and assumed that the mathematical difference between the observed Delta concentrations and the predicted increase from drainage came from in-channel sources (e.g., algae).

Example simple model predicted estimate:

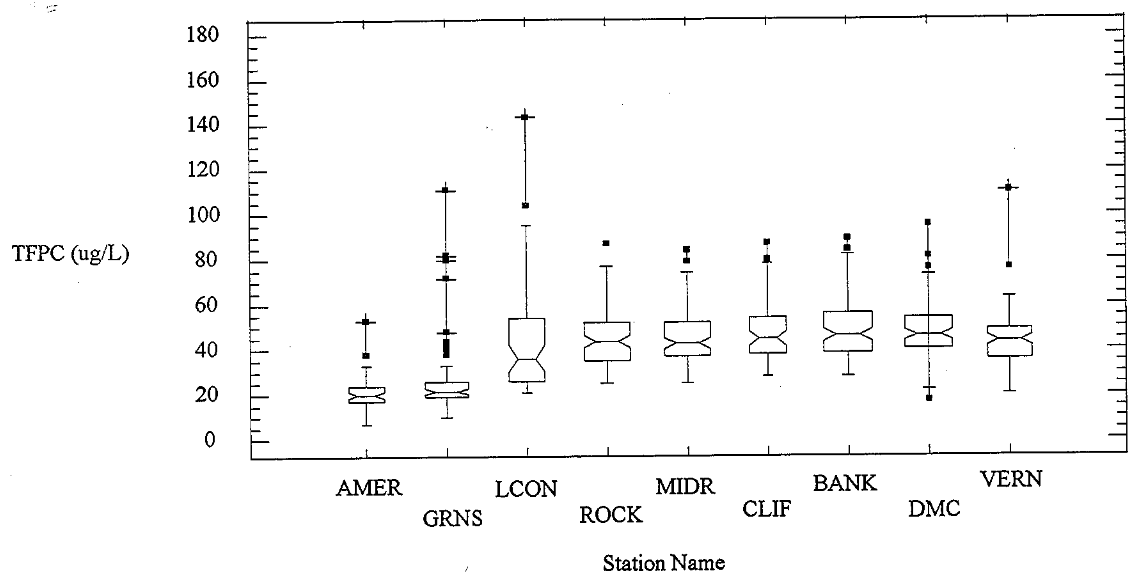
Observed Delta DOC value = 3.5 mg/L
Predicted Delta DOC value from island drainage = 3.4 mg/L
Observed river DOC inflow value = 2.5 mg/L
Therefore,
From in-channel sources = 3.5 - 3.4 = 0.1 mg/L DOC
From drainage sources = 3.4 - 2.5 = 0.9 mg/L DOC

Overall, the results showed that the impacts from drainage and in-channel sources could not be fully distinquished. The outcome of the results was affected by the drainage volume estimates and the available water quality data that served as representative monthly averages for island drain water and the Delta channels.

The model showed an average increase of 1.1 mg/L DOC in the Delta from the average river concentration of 2.5 mg/L. The model results for DOC, however, were best when the drainage volume was assumed to be 10 percent higher than the 1954-55 estimates. This could mean that current island drainage is 10 percent higher than 40 years ago or that it has remained the same but the 10 percent increase is caused by in-channel sources.

Similarly, the model accounted for a 56 percent increase in TFPC from drainage when the observed Delta TFPC was 79 percent higher. This could indicate a 23 percent increase from in-channel sources or an underestimation due to the DWR THMFP assay for drain water samples with more than 20 mg/L DOC. In all cases, the importance of gathering new drainage volume information was shown. Improvements in the simplified model are expected as new monitoring

Figure 1.11.
Delta TFPC Ranges (1987-91)



data are collected.

Revised estimates on the amount of drain water entering the channels will help assess the contribution of organics from drainage as well as from other Delta sources.

The Department's Division of Planning is using data from the MWQI Program to develop a Delta THM computer model. The model combines the Department's existing Delta Simulation Model (DSM), which mimics the complex hydrology of the estuary to predict water quality in the Delta, with a THM model component. This component uses output from the DSM and data on water treatment conditions to simulate the formation of THMs. When completed, the Delta THM computer model will assist the agency in studying proposed water management strategies such as new Delta facilities, drainage management, and regulatory actions.

Two improvements in THM precursor measurement have been initiated in recent years. A modified chemical testing procedure was developed and adopted in 1992 to improve measurement of the organic THM precursor carbon concentrations in high DOC water samples. This was needed because the original DWR THMFP assay method was shown to underestimate the precursor level in some high DOC water (above 20 mg/L) samples such as drain water. Starting in 1990, water samples were also measured for ultraviolet absorbance (UVA_{254nm}). This measurement is used as another indicator of THM precursors and correlates well with DOC for most water samples. This provides a quick and inexpensive measurement useful in assessing the THM precursor levels in the Delta.

The prediction of THM formation is now an important part of DWR's Delta modeling efforts.

Improved methods to measure the amount of THM precursor organic carbon in the Delta are being studied.

Staff of the Department's Quality Assurance and Quality Control Program participated in an analysis of the MWQI field and laboratory data. The review identified the need to establish uniform laboratory reporting procedures, routine laboratory data review protocols, and incorporation of the information in a computer database.

There continues to be significant progress in understanding the sources and nature of organic THM precursors in the Delta. Statistical analyses of the data showed some good correlations among location, soil types, and some water quality measurements such as UVA, DOC, bromide, and chloride. This information is used to develop estimates of the quality of drain water and channel water at unmonitored sites.

Planned activities include new studies to help reduce organics and bromide in Delta water supplies and to improve the monitoring and assessment methods. The following studies are planned or are in progress:

1. DWR will compare data from 1992-93 to predicted results of the mathematical relationships of UVA, DOC, and THMFP that were seen in the 1987-91 data. The information will improve modeling efforts to predict regional DOC and THMFP.

2. DWR and the U.S. Geological Survey will conduct a joint study to measure the

irrigation and drainage water quantities, quality, and power use for pumping drain water off the islands. Several islands, representative of different soil types and crop patterns in the Delta, will be studied.

3. DWR will draft proposed studies to examine the impacts of alternative land uses and changes in field irrigation and leaching practices on crop production, drainage volume, water quality, and electrical power savings.

Simple changes in land use and leaching practices need to be studied as potential methods for reducing TOC without impairment to agriculture.

4. DWR will study with the use of automated sampling devices, daily and hourly variations in water quality at channel stations affected by tides and at drainage pump stations.

5. DWR will review the need for current and future monitoring and special studies. New monitoring stations may be established at tributaries flowing into the Delta for studying upstream sources of DBP precursors.

6. DWR will continue to refine the Delta THMFP computer model.

7. DWR will collect and compare data from more water year types. The majority of water years that have been monitored since 1982 were below normal and critically dry water type years. Therefore, the 1987-91 observations and interpretations reflect an unusual period of five consecutive drought years.

8. DWR will adopt recommendations for improving the management and review of laboratory quality assurance and quality control data.

In addition to the new D-DBP rule, an Enhanced Surface Water Treatment Rule (ESWTR) and Information Collection Rule (ICR) will be issued. The EWSTR focuses on removing or inactivating disease-causing microoganisms such as *Giardia lamblia*, *Legionella*, *Cryptosporidium*, and viruses. The ICR requires gathering extensive monitoring and treatment data to establish the EWSTR and stage 2 of the D-DBP rule. The MWQI Program will work

The MWQI Program will respond to new and future data collection needs.

with the program advisors in broadening its monitoring efforts to gather needed information for these and forthcoming data collection requirements.

In summary:

- *Monitoring data from the MWQI program has been important for water resources planning and water quality research, especially in view of changing environmental and drinking water regulations.*
- *Prior to the new EPA Disinfectant-Disinfection Byproducts (D-DBP) rule, trihalomethanes were the only DBPs regulated in drinking water.*
- *Meeting the new DBP regulations will depend, in part, on how well precursors such as bromide and organic matter can be reduced in the water prior to adding disinfectant.*
- *The major Delta water supplies receive high concentrations of bromide from bay water and organics from its tributaries and from within the Delta. Most Delta soils are rich in organic matter from decomposing peat soil and crop residues.*
- *Seasonal farming activities affect the amount of organic matter leached and drained from the island soils and eventually discharged into the Delta channels.*
- *The high THM formation potential and DOC found in some parts of the Delta are typical for the area, because the Delta was a vast tule marsh prior to being reclaimed a hundred years ago.*
- *TOC reduction at some treatment plants will be required to meet the new D-DBP rule because of high TOC in some Delta water supplies.*

- *Revised estimates on the volume of drain water entering the channels will help assess the contribution of organic material from drainage as well as from other sources.*

- *DWR's Delta modeling section has developed a Delta THM computer model to assist in water resources and facilities planning.*

- *New activities focus on ways of updating drainage volume and quality estimates, refining monitoring and assessment methods, and streamlining quality assurance and quality control evaluations.*

- *The MWQI program will respond to new and future data collection requirements and needs.*