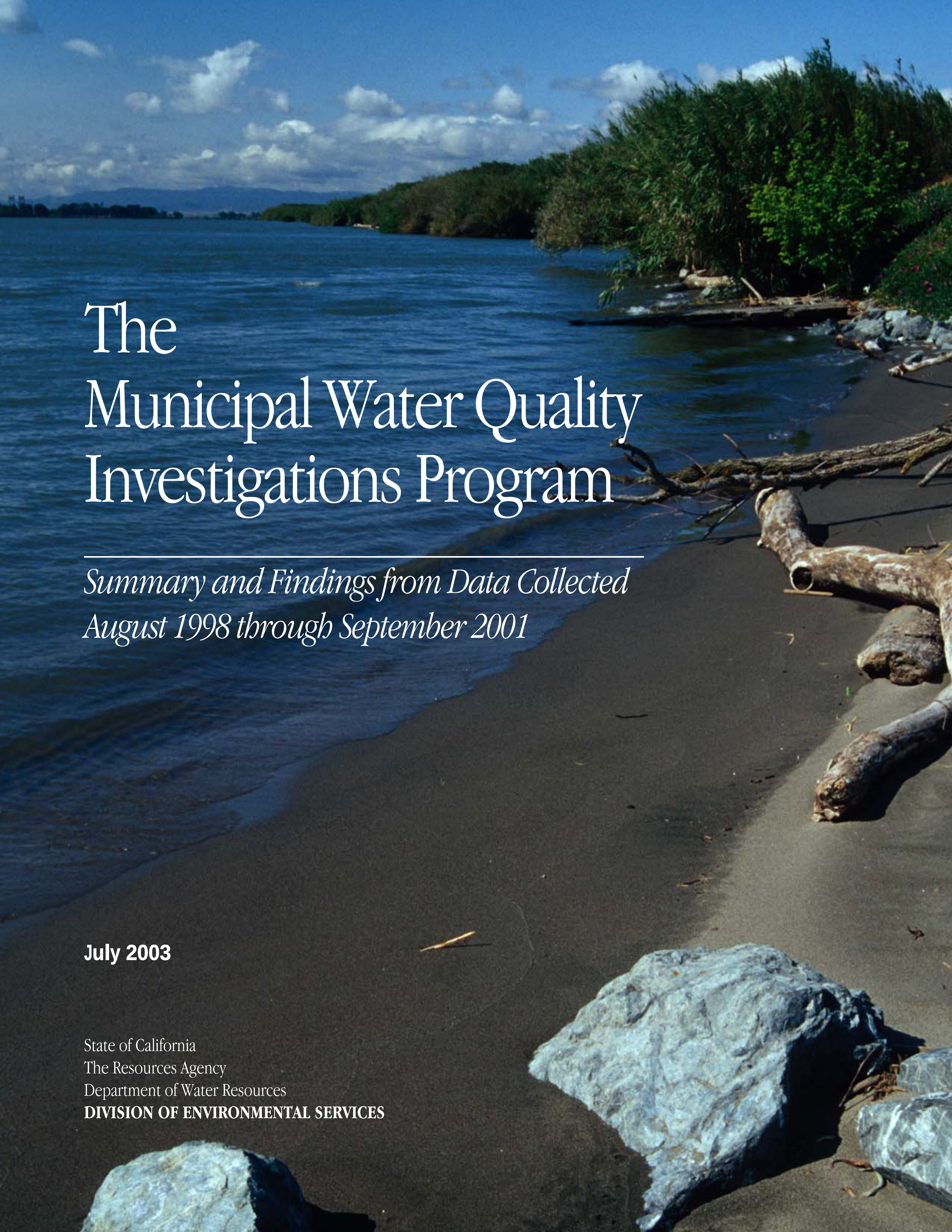

The Municipal Water Quality Investigations Program

Summary and Findings from Data Collected August 1998 through September 2001

July 2003

State of California
The Resources Agency
Department of Water Resources
DIVISION OF ENVIRONMENTAL SERVICES

State of California
The Resources Agency
Department of Water Resources
Division of Environmental Services

The Municipal Water Quality Investigations Program Summary and Findings from Data Collected August 1998 through September 2001

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Gray Davis
Governor
State of California

Mary D. Nichols
Secretary of Resources
The Resources Agency

Michael J. Spear
Interim Director
Department of Water Resources

If you need this publication in an alternate form, contact the Municipal Water Quality Investigations Program at the Division of Environmental Services or the Department's Office of Water Education at 1-800-272-8869.

Foreword

Water in the Sacramento-San Joaquin Delta (the Delta) is a major source of drinking water for two-thirds of California's population. Delta waters originate mostly from precipitation in the Sierra, the Cascade Range, and the watersheds of the Sacramento and San Joaquin valleys. Water from the Sierra and in the storage facilities outside the Delta are of high quality. When water traverses the complex Delta to diversion points, drinking water quality degrades.

Municipal Water Quality Investigations (MWQI), a program within the Division of Environmental Services of the California Department of Water Resources, is the only state program whose primary mission is to investigate and protect Delta drinking water quality. Since 1983, MWQI has been conducting comprehensive and systematic monitoring at various points near and within the Delta along the water transport path to the diversion locations.

This report summarizes and interprets MWQI monitoring data collected from August 1998 through September 2001 from 14 MWQI sampling stations. Major water quality constituents examined in this report include organic carbon, bromide, salinity, regulated organic and inorganic constituents in drinking water, and a few unregulated constituents of current interest. In addition to presenting the basic summary statistics, this report also discusses seasonal and spatial patterns, differences among stations, and sources of some constituents.

This and other MWQI reports are available online at the MWQI web site: http://www.wq.water.ca.gov/mwq/index.htm. For further information about the MWQI program, please visit its website or contact Richard S. Breuer, Program Manager, (916) 651-9687, or send your request to: P.O. Box 942836, Sacramento, CA 94236-0001.

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Casitas Municipal Water District
Castaic Lake Water Agency
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City of Yuba City
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Contra Costa Water District
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Napa County Flood Control and Water Conservation District
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San Bernardino Valley Municipal Water District
San Gabriel Valley Municipal Water District
San Gorgonio Pass Water Agency
San Luis Obispo County Flood Control and Water Conservation District
Santa Clara Valley Water District
Solano County Water Agency
Tulare Lake Basin Water Storage District

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Executive Summary

Purpose

The purpose of this report is to summarize and interpret water quality data collected near or in the Sacramento-San Joaquin Delta (the Delta) from August 1998 through September 2001. The Municipal Water Quality Investigations (MWQI) program of the California Department of Water Resources (DWR) provides Delta source water quality information to the State Water Contractors through continuous monitoring at selected sites. Among the many State and local agencies that are monitoring the Delta and its tributaries, MWQI conducts the only monitoring program whose primary mission is to investigate quality of source waters in the Delta. Since 1983 MWQI has been conducting comprehensive and systematic source water monitoring at export and diversion stations within the Delta, various sites along Delta tributaries, and urban and agricultural drainage canals within or near the Delta. MWQI regularly prepares annual or multi-year data summary reports. The previous annual report summarized data collected through July 1998.

Background

Rivers and channels of the Delta are a major source of drinking water for more than 22 million people in California. Delta waters originate mostly as precipitation in the Sierra, the Cascade Range, and in the watersheds within the Sacramento and San Joaquin valleys. In these areas, precipitation is unevenly distributed throughout the year with most of the annual precipitation occurring from November through April (wet months). Water from the wet months must be stored outside the Delta and transported through the Delta before it is exported or diverted. The quality of the water often deteriorates as water traverses the complex Delta tributaries and channels, especially during dry and critical water years when annual precipitation is low.

In addition to uneven distribution and limited amounts of rainfall, other factors and sources can degrade Delta water quality: infiltration of seawater with high salinity and bromides, releases of organic carbon from peat soils of the Delta islands, phytoplankton growth and decay in rivers and channels, agricultural practices and drainage discharges, urban runoff and discharges, and recirculation of Delta waters through the San Joaquin Valley.

The Delta is highly complex and variable, and water operations in the Delta are constrained by competing interests. Accordingly, it will not be feasible to alter the processes and sources that degrade Delta waters in the near term. Frequent monitoring is necessary to identify water quality constraints and spatial and seasonal patterns to assist Delta water users to treat and manage their source waters. Long-term monitoring data are essential to the development, calibration, and validation of predictive computer models. These models may subsequently be used for long-term resource and facilities planning and project operations.

Scope of Report

Presented are data from 14 MWQI stations. Five of these stations monitor water quality from the San Joaquin River (SJR), the Sacramento River, and the American River as they flow into the Delta. Three of these 5 stations are on the American and Sacramento rivers at or near the north end of the Delta—American River at E. A. Fairbairn Water Treatment Plant (WTP), Sacramento River at West Sacramento WTP Intake, and Sacramento River at Hood. The E. A. Fairbairn WTP represents water quality of the American River, which is a major tributary of the Sacramento River. West Sacramento WTP Intake represents water quality of the Sacramento River before mixing with water of the American River, and the Sacramento River at Hood reflects the quality of water from the Sacramento River shortly after it enters the Delta. Two of the 5 stations are along the SJR—SJR near Vernalis and SJR at Highway 4 in the southern part of the Delta. The Vernalis station represents SJR water quality as it enters the Delta. The Highway 4 station reflects urban influence on water quality from the city of Stockton.

Six of the 14 stations are within the Delta or at diversions of the Delta. Two of the 6 stations—the Old River at Station 9 and Old River at Bacon Island—are Delta channel stations representing quality of mixed waters primarily from the SJR and Sacramento River. Water is being diverted near the Old River at Station 9 at a pumping station of the Contra Costa Water District (CCWD). Three of the 6 stations—Banks Pumping Plant, Delta-Mendota Canal (DMC) at McCabe Road, and Contra Costa Pumping Plant No. 1—are diversion stations that reflect source water quality before waters are diverted from the Delta. The Sacramento River at Mallard Island is a station at the western end of the Delta, which is most susceptible to seawater influence due to its proximity to the San Francisco and Suisun bays. CCWD also has an intake at Mallard Slough, which is near Mallard Island. CCWD only operates this intake during high Delta outflow conditions when chloride concentration is below its maximum contaminant level (MCL).

MWQI also monitors 3 drainage stations: 2 agricultural drainage stations within central Delta—Bacon Island Pumping Plant and Twitchell Island Pumping Plant—and an urban drainage site—Natomas East Main Drainage Canal (NEMDC). These stations represent water quality at agricultural and urban drainages.

Limited salinity data from DWR’s San Joaquin District and the U.S. Bureau of Reclamation (USBR) are presented in the discussions of water quality in the upper SJR south of Vernalis. Data from the USBR station at Greenes Landing on Sacramento River are also included. These data help identify sources of salinity loads.

Water quality constituents in Delta source waters are presented according to current regulatory priorities with organic carbon, bromide, and salinity addressed in individual chapters. For each constituent at each station, descriptive plots in the form of temporal graphs describe general seasonal patterns. Summary statistics that include range, median, and percentiles show general data characteristics. The Loess Smooth Procedure is often performed to show seasonality and constituent sources such as the effects of rice drainage and agricultural activity on water quality. No data on bacteria or pathogens are included in this report.

Summary of Findings

Organic Carbon

Organic carbon in the Delta and its tributaries differed both seasonally and spatially (Figure A). Median total organic carbon (TOC) for the American and Sacramento River stations north of the Delta was generally less than 2 mg/L, whereas median TOC for the 2 SJR stations ranged from 3.1 to 3.5 mg/L. The median TOC at Mallard Island was 2.5 mg/L, reflecting multiple sources of water at this station. The 2 Delta channel stations—Old River at Station 9 and Old River at Bacon Island—and the 3 diversion stations—Banks Pumping Plant, DMC, and Contra Costa Pumping Plant #1—receive water from both the SJR and the Sacramento River. Despite dilutional effects of water from the Sacramento River, median TOC for these stations was similar to that of the SJR stations, suggesting that additional sources of organic carbon exist. Agricultural drainage and in-channel phytoplankton growth and decay are sources of organic carbon.

Figure A Total organic carbon: Range, median (mg/L) (map)

Seasonal patterns of organic carbon differed between tributary stations and channels. At each tributary station, organic carbon was generally significantly higher during the wet months when there was rain in the watershed than during the dry months. Seasonal patterns at the 2 Delta channel stations and at the 3 diversion stations differed from those at SJR and the Sacramento River stations, further indicating additional organic carbon sources.

The data suggest 4 major organic carbon sources:
1) Runoff from watersheds in the Sacramento and San Joaquin valleys
2) Urban runoff and discharges
3) Agricultural drainage
4) River and channel phytoplankton production

TOC in the Delta rivers, channels, and diversion stations was high. Given the ranges of alkalinity of most Delta source waters, the Disinfectants/Disinfection Byproducts (D/DBP) Rule would require removal of approximately 25% to 35% of TOC before disinfectants may be added to water taken from the Delta diversion stations and used as a source for drinking water.

Bromide

The data suggest that bromide in Delta source waters came from seawater. Bromide concentrations were higher at stations closer to seawater influence (Figure B). The stations at the north end of the Delta are not influenced by seawater; therefore, bromide concentrations were very low.

Figure B Bromide: Range, median (mg/L) (map)

General seasonal patterns of bromide differed from those of organic carbon. Despite some variations, organic carbon generally increased during the wet months and decreased during the dry months. Bromide levels could increase both during the wet months and during the dry months due to loads from agricultural lands. In general, bromide levels appear to have been inversely related to the amount of annual precipitation. Unlike organic carbon, bromide loads do not increase with high precipitation from the Sacramento Valley; instead, the precipitation dilutes bromide concentrations. Precipitation in the San Joaquin Valley may increase loads because rain washes soil bromide to the SJR.

In addition to these general trends, the data also suggest the following:

- Urban discharges and runoff from the watersheds in the Sacramento Valley were not a significant source of bromide in Delta waters because bromide concentrations in waters of the American and Sacramento rivers and the NEMDC were low.
- Seawater influence, either directly or indirectly, increases bromide levels in waters of Delta channels, diversion stations, and the SJR. Bromide at the 3 diversion stations was high. The Contra Costa Pumping Plant #1 had the highest bromide because it is closer to Mallard Island, which is the most susceptible to seawater influence among all the stations included in this report.
- Indirect seawater influence—irrigation water, old marine deposits, and shallow groundwater in the San Joaquin Valley—increases bromide concentrations in the SJR. For years, agricultural lands in the San Joaquin Valley have been irrigated with DMC water, which contains considerable bromide. Bromide in irrigation water is concentrated and discharged to agricultural drainage canals and recirculated within Delta channels. Soils in some areas were developed from old marine deposits with high levels of bromide that may be concentrated on the soil surface and washed into the river during wet months of low to moderate rainfall. In some areas, shallow groundwater carries high levels of bromide and moves into the SJR through seepage. Therefore, bromide levels in the SJR and Delta channels were high.
- High Delta outflows lower bromide levels at seawater-affected stations such as Mallard Island and nearby stations. Freshwater outflow not only keeps seawater from entering the Delta, it also dilutes bromide already present in the waters. Therefore, bromide levels were lower during wet years when outflows were greater and significantly higher during dry or critical water years when Delta outflows were less.
- Bromide levels at western Delta stations could be higher during the wet months when Delta outflows are reduced because reservoirs are releasing less water. Reduced reservoir releases are insufficient to hold back seawater, which results in higher bromide concentrations.

Salinity

The data suggest that seawater influence was the primary source of salinity throughout the western Delta as indicated by the high median electrical conductivity (EC) and the wide EC range at Mallard Island (Figure C). Salinity at the diversion and Delta channel stations generally varied with their distance from the Mallard Island station where seawater influence was the greatest. An exception is the DMC where the SJR influence may play a major role (Figure C).

Figure C Electrical conductivity: Range, median (µs/cm) (map)

Salinity of SJR water was significantly higher than waters from the American and Sacramento rivers, partially due to discharge of recirculated irrigation water from the DMC, which is seawater-influenced.

Salinity was significantly lower at Delta channel and diversion stations than at the SJR due to the dilutional effects of water from the Sacramento River. This dilutional effect was not observed with TOC, which implies that some organic carbon was produced within the Delta.

In addition to seawater intrusion, salinity in Delta waters are affected by sources that include watershed runoff, urban discharges, and agricultural drainage. Salinity loads from the watersheds were significant during the wet months, especially after each of the first few significant rain events.

Other Constituents

MWQI monitored constituents that are known either to have adverse human health effects or to degrade taste, odor, or appearance of finished drinking water. Monitoring was primarily at the diversion stations. Of all the constituents monitored, none was found at concentrations above the State or federal MCLs (Table A). The highest concentrations of lead, selenium, chromium, arsenic, iron, manganese, copper, and zinc never exceeded the objectives specified in "Article 19 Water Quality" of the *Standard Provisions for Water Supply Contract*.

Table A Inorganic and miscellaneous constituents

Recommendations

- Increase monitoring frequency at some stations during the wet months from monthly to weekly (or biweekly at key stations) for constituents such as organic carbon, bromide, turbidity, and EC. Since November 2001, MWQI has conducted weekly sampling during the wet months at some sites.

- Replace the insufficient monthly EC and bromide data from Mallard Island with real-time data. Both constituents vary greatly within a day, and values vary depending on when samples are taken. Therefore, monthly data are limited in explaining temporal patterns of EC and bromide at this and nearby sites. MWQI recommends continuation of the monthly grab sampling at Mallard Island for constituents other than EC. An arrangement should be made with the Interagency Ecological Program of DWR to share real-time EC data with MWQI. In addition, real-time bromide monitoring capability should be explored. Commercially available bromide electrodes suffer from low sensitivity. However, real-time bromide concentrations may be reliably estimated from chloride concentrations. Sensitive electrodes for measuring the chloride ion are available.

- Discontinue monitoring for methyl tertiary-butyl ether (MTBE). During the reporting period, 650 samples were analyzed and about 25% of the samples had MTBE at or slightly above its reporting limit of 0.001 mg/L. Concentration ranged from 0.001 to 0.005 mg/L, with a median of 0.002 mg/L. Most positive finds are in waters of the Sacramento River. Considering the long distance from the Sacramento River to the diversion stations, the volatility of MTBE under Delta conditions and the disturbances of water treatment processes, and the phasing out of MTBE as a fuel additive, further monitoring of MTBE in Delta source waters is not necessary.

- Resume nutrient monitoring and study the effects of nutrients on in-channel production of organic carbon and the interrelationships between nutrient fluxes and organic carbon levels, especially during the summer months.

- Analyze grab sample TOC using the wet oxidation method unless further research proves it to be inadequate. MWQI has been using the wet oxidation method for more than a decade. The method does not fluctuate as much as the combustion method. Like the combustion method, it measures a fraction of carbon present in a sample. Current studies of the 2 methods within DWR's Office of Water Quality may provide further clarification of this issue.

- Monitor the SJR near Salt and Mud Slough and its drainage sites to understand the seasonality and to establish some ranges. This section of the river appears to contribute organic carbon, salinity, and bromide to the Delta. The monitoring could be undertaken as a special project in collaboration with DWR's San Joaquin District and in coordination with monitoring efforts of the Grassland Bypass Project.

Table A Inorganic and miscellaneous constituents

Constituents	Findings	Regulation compliance
Constituents with adverse effects on human health		
Aluminum	Detected at or above reporting limit in 17 of 69 samples (25%) collected at 2 diversion stations; range: 0.01–0.08 mg/L; median: 0.04 mg/L	Never exceeded State or federal MCL of 0.2 mg/L
Antimony, cadmium, and lead	Never detected at or above reporting limits	Never exceeded federal primary MCL
Arsenic	Detected at or above reporting limit in all 69 samples; range: 0.001–to 0.003 mg/L; median: 0.002 mg/L	Never exceeded federal MCL of 0.01 mg/L
Barium	Of 59 samples collected at diversion stations, only one sample was found at the reporting limit of 0.05 mg/L	Never exceeded federal MCL of 2 mg/L or DHS MCL of 1 mg/L
Chromium (total)	Detected at or above reporting limit in 38 of 69 samples (55%); range: 0.003–0.009 mg/L; median: 0.006 mg/L	Never exceeded federal MCL of 0.1 mg/L or DHS MCL of 0.05 mg/L
Copper	Detected at or above reporting limit in all 69 samples collected at 2 diversion stations; range: 0.001–0.007 mg/L; median: 0.002 mg/L	Never exceeded State or federal MCL of 1.0 mg/L
Mercury	Of 58 samples, one sample was found at 0.0002 mg/L	Never exceeded federal MCL of 0.002 mg/L
Nickel	Detected at or above reporting limit in 40 of 41 samples (98%); range: 0.001–0.002; median: 0.001 mg/L	Never exceeded DHS MCL of 0.1 mg/L
Nitrate+Nitrite (as N)	Detected in all 29 samples at Banks; range: 0.13–1.20 mg/L, median: 0.51 mg/L	Never exceeded DHS MCL of 10 mg/L
Selenium	Detected at or above reporting limit in 16 of 54 samples (30%); range: 0.001–0.003 mg/L; median: 0.002	Never exceeded federal MCL of 0.05 mg/L
Constituents with adverse effects on taste, odor, or appearance		
Iron	Detected at or above reporting limit in 49 of 69 samples collected at 2 diversion stations (71%); range: 0.005–0.117 mg/L; median: 0.017 mg/L	Never exceeded federal MCL of 0.3 mg/L
Manganese	Detected at or above reporting limit in 39 of 69 samples collected at 2 diversion stations (57%); range: 0.005–0.032 mg/L, median: 0.12 mg/L	Never exceeded federal MCL of 0.05 mg/L
Silver	Never detected at or above reporting limit in any of the 69 samples collected at 2 diversions stations	Never exceeded federal MCL of 0.1 mg/L
Zinc	Never detected at or above reporting limit in any of the 69 samples collected at 2 diversions stations	Never exceeded federal MCL of 5 mg/L
MTBE	Of 650 samples collected, about 25% were at or above reporting limit of 0.001 mg/L; range: 0.001–0.005 mg/L; median: 0.002 mg/L	Never exceeded DHS enforceable primary drinking water MCL of 0.013 mg/L; never exceeded DHS enforceable secondary MCL of 0.005 mg/L

MCL = maximum contaminant level

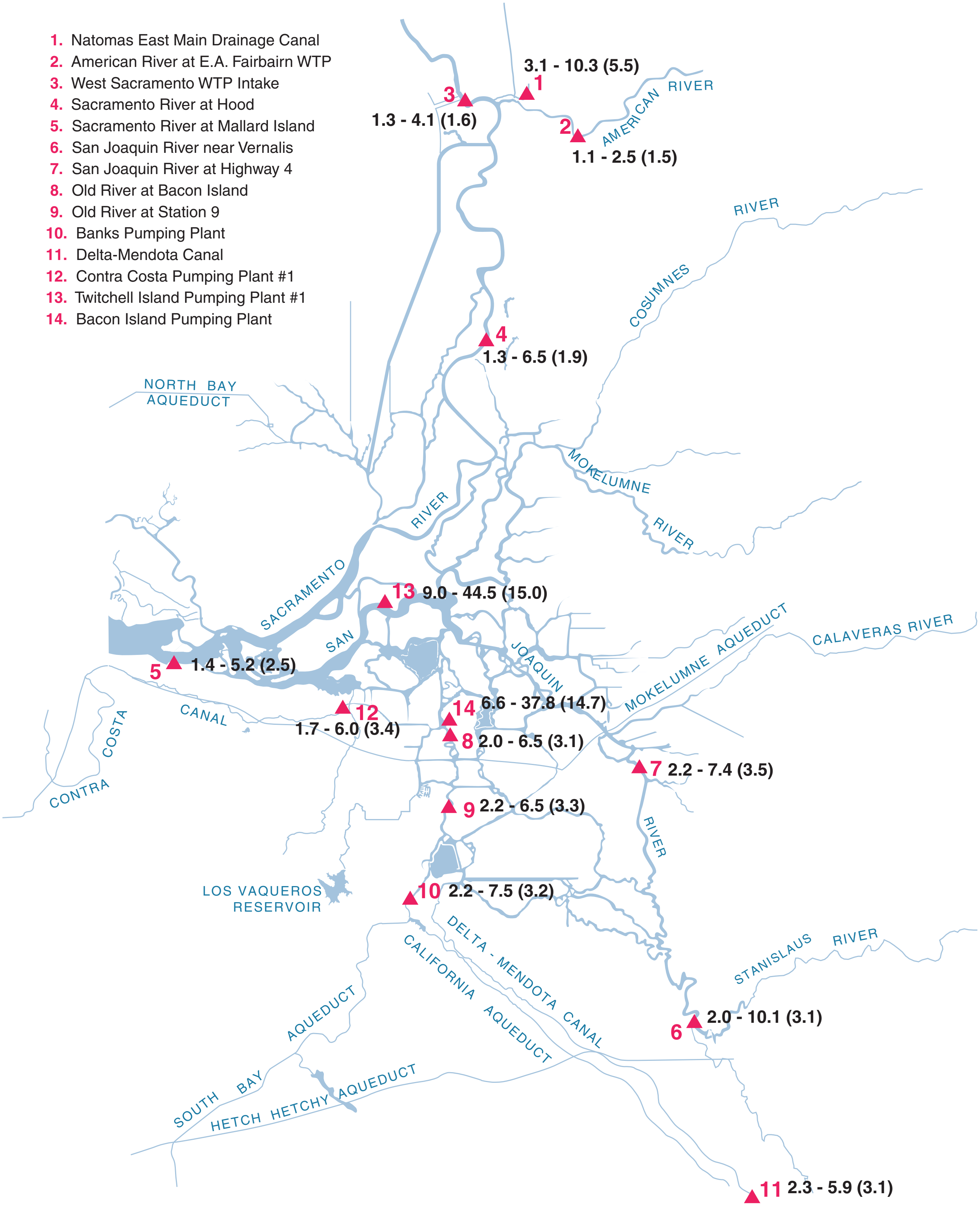


Figure A Total organic carbon: Range, median (mg/L)

Figure B Bromide: Range, median (mg/L)

1. Natomas East Main Drainage Canal
2. American River at E.A. Fairbairn WTP
3. West Sacramento WTP Intake
4. Sacramento River at Hood
5. Sacramento River at Mallard Island
6. San Joaquin River near Vernalis
7. San Joaquin River at Highway 4
8. Old River at Bacon Island
9. Old River at Station 9
10. Banks Pumping Plant
11. Delta-Mendota Canal
12. Contra Costa Pumping Plant #1
13. Twitchell Island Pumping Plant #1
14. Bacon Island Pumping Plant

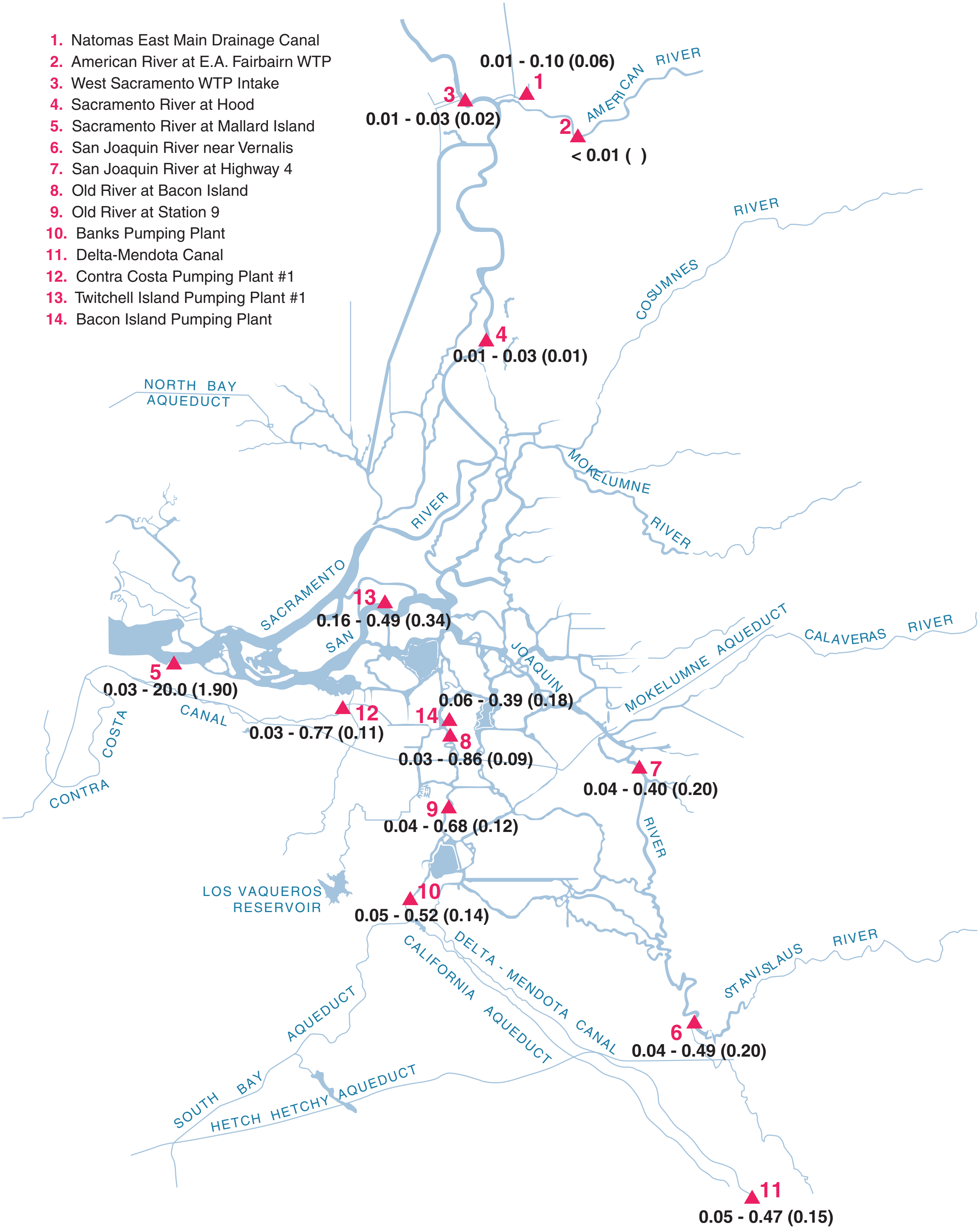
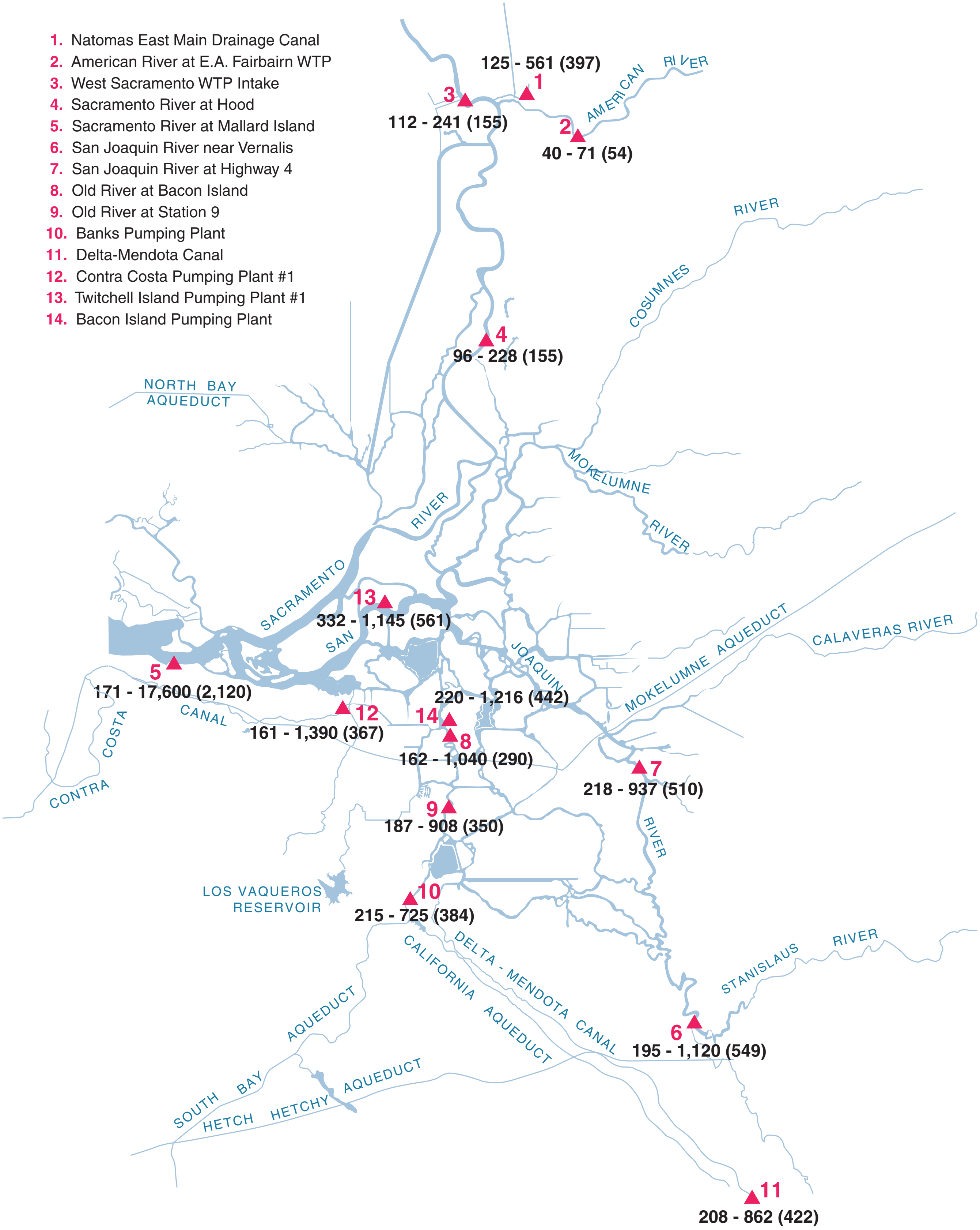


Figure C Electrical conductivity: Range, median (µS/cm)



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11. Delta-Mendota Canal
12. Contra Costa Pumping Plant #1
13. Twitchell Island Pumping Plant #1
14. Bacon Island Pumping Plant

Chapter 1 Introduction

Overview

This report summarizes and interprets monitoring data collected by the Municipal Water Quality Investigations Program (MWQI) of the Department of Water Resources (DWR) from August 1, 1998, to September 30, 2001. Data collected before August 1998 have been presented in previous reports (DWR 1994, DWR 1995a, DWR 1995b, DWR 1996, DWR 1997, DWR 2000, and Woodard 2000). Data collected after October 1, 2001, will be reported in future reports.

The MWQI program was established in 1990. It evolved from 2 earlier DWR programs, the Interagency Delta Health Aspects Monitoring Program (IDHAMP) and the Delta Island Drainage Investigation (DIDI) (DWR 1994). The IDHAMP was initiated in 1983 in response to a 1982 recommendation by a DWR scientific advisory panel. The panel was concerned about pesticides, asbestos, sodium, and trihalomethane precursors and the lack of sufficient knowledge on the quality of Delta water supplies. The DIDI program was established in 1987 to evaluate the effects of agricultural drainage on channel water quality (DWR 1994).

The program began primarily with discrete (grab) samples from which MWQI learned that Delta source waters contain elevated organic carbon, bromide, salinity, nutrients, and, possibly, bacteria and some waterborne pathogens. Drinking water regulations for these constituents became more and more stringent, which led the State Water Contractors (SWC) to place greater emphasis on source water quality control and operational mitigation (Woodard 2003 pers comm). Over the years, MWQI responded by increasing the number of grab sample monitoring stations, increasing sampling frequency, conducting special studies, and, more recently, exploring real-time monitoring capabilities at key stations.

This report presents data collected from 14 MWQI sampling stations in or near the Sacramento-San Joaquin Delta (the Delta). An extensive number of water quality constituents were analyzed for each sample, but only those constituents that are of most concern to the SWC are discussed in this report. Selection of these constituents is based on findings from previous reports and *Sanitary Survey Update Report 2001* (DWR 2001). Water quality constituents of limited concern to the SWC are discussed only for selected stations.

Major water quality constituents examined in this report include organic carbon, bromide, salinity, regulated organic and inorganic constituents in drinking water, and a few unregulated constituents of current interest. Some basic statistics are presented. Seasonal and spatial patterns, differences among stations, and sources of some constituents are also discussed. The raw data for all examined constituents are available online or on CD-ROM (see Appendix B).

Water quality at most stations is not discussed in the context of drinking water standards because source waters are not regulated to meet standards for finished drinking water. However, at some Delta diversion stations, certain constituents are discussed in the context of existing State and federal drinking water regulations and water quality objectives specified in the long-term water supply contracts between DWR and each SWC. This report does not present the details of the regulations, standards, or provisions; the regulations and standards may be found in Chapter 2 of *Sanitary Survey Update Report 2001* (DWR 2001). The *Standard Provisions for Water Supply Contract* between DWR and the SWC is available from the Project Water Contracts unit, State Water Project Analysis Office of DWR.

Interpretations presented in this report are based on either monthly or weekly grab sampling data. Results and interpretations from grab sampling data, especially monthly data, have limitations in explaining spatial and seasonal patterns in the Delta of complex hydrology. Therefore, MWQI collaborated with DWR's Modeling Section to develop computer models using grab sampling data and hydrology information, particularly at tidally influenced locations. Significant progress has been made most notably on a Delta hydrodynamics and water quality transport model (DSM2), which was validated with organic carbon data from March 1991 and December 1997. The model validation results have been presented to the SWC and are available online at http://modeling.water.ca.gov/branch/reports.html. MWQI will use modeling tools to provide more extensive interpretation of data. MWQI staff has been working on a modeling issue paper with DWR modelers, and work is ongoing in the use of models to interpret real-time monitoring data.

Monitoring Stations

General description and geographic locations of the 14 monitoring stations are presented in Figure 1-1. During the reporting period, MWQI collected samples at 12 stations; the Division of Operations and Maintenance (O&M) of DWR collected samples for MWQI at the Banks and Delta-Mendota Canal (DMC) stations. Samples were generally taken monthly; but at the Hood station on the Sacramento River and the San Joaquin River (SJR) near Vernalis station, samples were collected weekly.

Figure 1-1 MWQI monitoring stations, 1998-2001 (map)

To facilitate data presentation and comparisons, the stations were divided into six functional groups:

- American and Sacramento River stations
- San Joaquin River stations
- Delta channel stations
- Delta diversion stations
- Agricultural drainage stations
- Urban drainage station

Stations within each group are either geographically or hydrologically related, or they are the same type of station (Table 1-1). Although the Old River at Station 9 is treated as a channel station in this report, Contra Costa Water District (CCWD) has an intake very close to the station. The Mallard Island station is traditionally considered a station on the Sacramento River, but it receives water from both the SJR and the Sacramento River, and it is

Table 1-1 MWQI monitoring stations, 1998-2001

affected by water from the San Francisco and Suisun bays. CCWD has another intake at Mallard Slough, which is close to MWQI's Mallard Island monitoring station. However, CCWD operates this station only when Delta outflows are high and chloride concentrations are below regulatory limits. The Mallard Island station shows the most seawater influence of all the Delta stations. When Delta outflows are low during dry runoff years or during dry months of each year, water quality (electrical conductivity and bromide in particular) at this station reflects a mixture of fresh and marine waters and, thus, is an indicator of water quality that may be affecting the diversion stations. Therefore, water quality at this station is discussed separately throughout this report.

Definitions of Terms

This report uses certain abbreviations, acronyms, and terminology. A detailed list of abbreviations, acronyms, and terminology is in the Glossary at the back of this report. Some frequently used terms are defined here:

Water year: The period between October 1 of one calendar year and September 30 of the following calendar year is called a water year. The year number is the latter of the 2 calendar years; for example, the 1999 water year runs from October 1, 1998, to September 30, 1999.

Wet months: November 1 to April 30 of each water year

Dry months: May 1 to October 31 of each calendar year

Dry Year, Above Normal Year, and Wet Year: Runoff year types indicating low, moderately high, and high total unimpaired runoff in a watershed, respectively, as defined in http://cdec.water.ca.gov/cgi-progs/iodir/wsihist.

NEMDC: Natomas East Main Drainage Canal

Banks Pumping Plant: the Banks Pumping Plant Head-works station at the start of the California Aqueduct

Contra Costa Pumping Plant: Contra Costa Water District Pumping Plant #1

DMC: A sampling site along the Delta-Mendota Canal at mile 67.2 about 0.87 miles upstream of McCabe Road. Mile 0.00 of the DMC is at the diversion point from the Old River.

Reporting period: The period between August 1, 1998, and September 30, 2001, which is different from the "3 water years" (see below for definition).

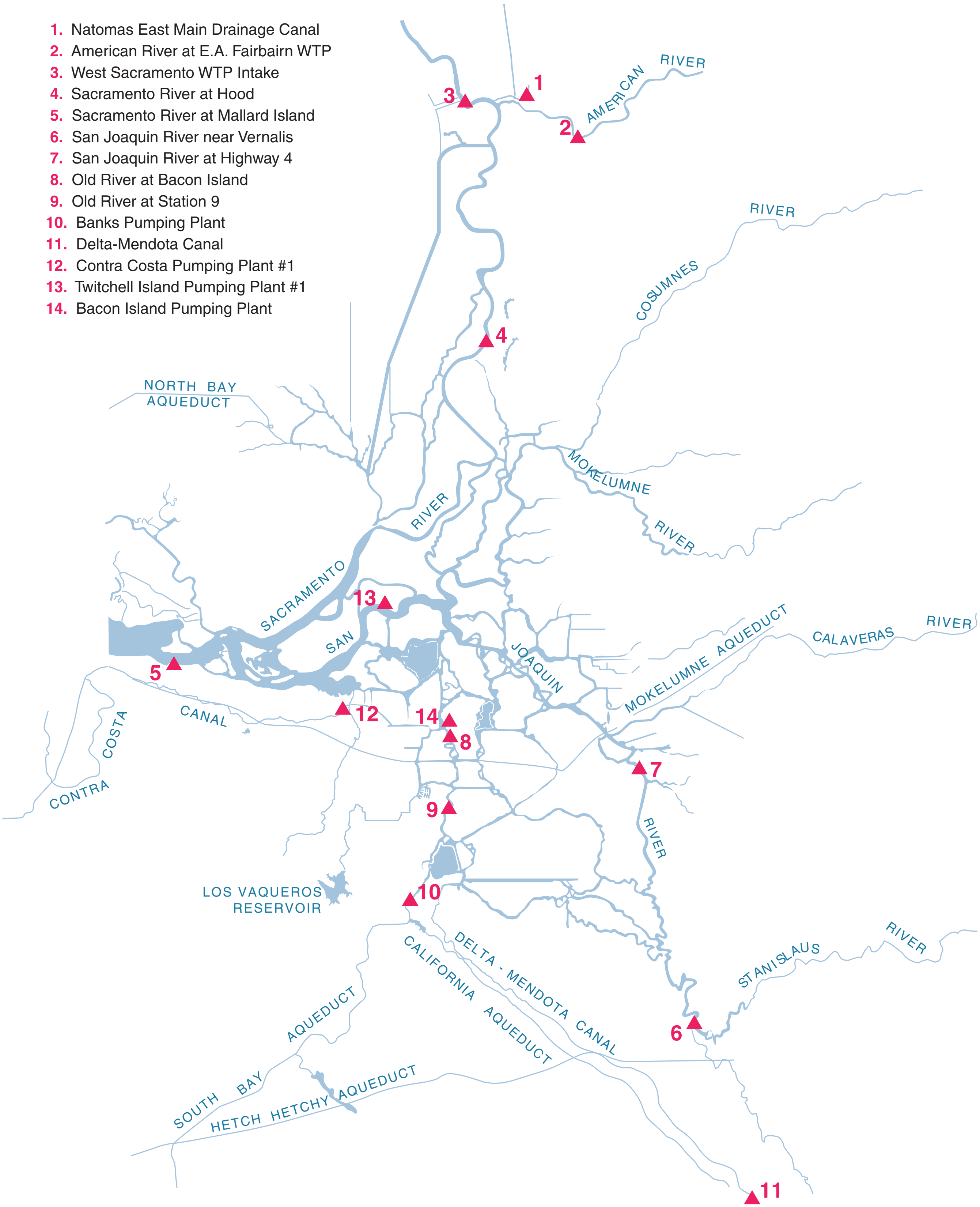
Three water years: In this report, data are often compared among water years during the "reporting period" as defined above. The "3 water years" include the 1999, 2000, and 2001 water years. "Water year" is defined above.

Table 1-1 MWQI monitoring stations, 1998-2001

Station	DWR station number	Monitoring frequency
American and Sacramento River stations		
American River at E.A. Fairbairn WTP	A0714010	Monthly
West Sacramento WTP Intake	A02104.51	Monthly
Sacramento River at Hood	B9D82211312	Weekly
Sacramento River at Mallard Island	E0B80261551	Monthly
San Joaquin River stations		
San Joaquin River near Vernalis	B0702000	Weekly
San Joaquin River at Highway 4	B9D75571196	Monthly
Delta channel stations		
Old River at Station 9	B9D75351342	Monthly
Old River at Bacon Island	B9D75811344	Monthly
Delta diversion stations		
Banks Pumping Plant	KA000331	Monthly
Delta-Mendota Canal	DMC06716	Monthly
Contra Costa Pumping Plant #1	B9591000	Monthly
Agricultural drainage stations		
Bacon Island Pumping Plant	B9V75881342	Monthly
Twitchell Island Pumping Plant #1	B9V80661391	Monthly
Urban drainage station		
Natomas East Main Drainage Canal	A0V83671280	Monthly

WTP = water treatment plant

Figure 1-1 MWQI monitoring stations, 1998-2001



Chapter 2 Data Collection and Analysis

Selection of Constituents

The following constituents are discussed in this order:

- Total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA_{254}), formation potential of trihalomethanes (THMs) and haloacetic acids (HAAs).
- Bromide.
- Salinity including electrical conductivity (EC)—also referred to as specific conductance in older publications—total dissolved solids (TDS), chloride, sulfate, sodium, calcium, and magnesium.
- pH, alkalinity, hardness, and turbidity.
- Methyl tert-butyl ether (MTBE), aluminum, copper, iron, manganese, silver, and zinc.
- Antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, and selenium.
- Ammonia, nitrate, nitrate and nitrite, Kjeldahl nitrogen, orthophosphorus, and total phosphorus.
- Boron.

Historical data and recent findings in *Sanitary Survey Update Report 2001* (DWR 2001) suggest that these constituents represent the major parameters of concern in Sacramento-San Joaquin Delta (the Delta) source waters. They directly affect the quality of finished drinking water processed from Delta source waters.

Sample Collection

The Field Support unit of the Municipal Water Quality Program Branch under the Department's Office of Water Quality sampled at 12 of the 14 stations. The Division of Operations and Maintenance of the California Department of Water Resources (DWR) collected samples at the Banks and Delta-Mendota Canal stations. Because samples from all stations cannot be collected within one day due to distances between stations and limitations in resources, the samples were collected on 3 different one-day sampling runs within one week with each sampling day covering a group of geographically close stations.

A set of sample documentation forms was generated for each site before each sample run. These forms included a Sample Submission Form and a Test Request Form, which contained site information, sample description, an automatically assigned sample number, and the requested laboratory and field tests. The forms were generated from a Field and Laboratory Information Management System (FLIMS), an automatic lab information, data tracking, and management system. Field staff also uses the FLIMS system to prepare sample containers and preservation methods. Bryte Chemical Laboratory of the Office of Water Quality supplied all necessary sampling materials to the Field Support unit and performed all the laboratory analyses included in this report. Bryte Laboratory's requirements for sample containers, preservation techniques, and sample holding times for the included constituents are summarized in Table 2-1.

Table 2-1 MWQI water sample collection and preservation

Samples were collected from each site approximately 3 feet below the surface. At stations with a sample collection platform, a stainless steel bucket was used to collect the sample. At stations without a platform, a round, 2-liter, stainless steel container attached to the end of a 15-foot extension pole was used to collect the sample; in this case, 4 or 5 subsamples were combined to make a composite sample.

All samples were prepared and filtered, when necessary, onsite in a specially equipped mobile laboratory van. Samples were preserved according to techniques listed in Table 2-1 and stored on ice inside an ice chest for transportation to Bryte Laboratory. Certain field measurements were also taken onsite, but these measurements are not included in this report. However, certain onsite measurements were useful during internal data audits when laboratory data for the same measurements seemed questionable. Large discrepancies between field and laboratory values occasionally triggered corrective action in the laboratory. Details about corrective actions made on data presented in this report are discussed in Chapter 9.

For quality control purposes, the Field Support unit regularly collects QA/QC samples according to U.S. Environmental Protection Agency QA/QC requirements. These samples often included equipment blanks, field blanks, and duplicate site samples. QA/QC samples were processed in the same manner as regular grab samples.

Laboratory Analysis

Bryte Chemical Laboratory of DWR analyzed all samples for constituents presented in this report. Bryte Laboratory is a fully certified environmental laboratory in West Sacramento. The methods and reporting limits for the included constituents are summarized in Table 2-2.

Table 2-2 Analytical methods and reporting limits for included constituents

Samples were submitted to the laboratory on the same day of collection. A Test Request Form specifying the requested analyses was submitted to the laboratory for each sample. The sample container was labeled with FLIMS-generated sample labels indicating the sample identification number and other required information. After the samples and necessary forms were cross-checked and verified, the receiving clerk at Bryte signed and dated the Test Request Forms with a copy to the sampler. All samples received by the laboratory were placed in appropriate storage cabinets for various sample types (that is, metals, standard minerals, etc.) or sent directly to the test area.

All pertinent field information—including date, time, location, sampling personnel, field measurements, requested laboratory tests, and additional information—was logged into and tracked by the FLIMS system after sample collection. Following data login, FLIMS notified laboratory personnel of the samples to be analyzed. The samples were then processed within an allowed holding time (Table 2-1). Analytical results were entered into FLIMS, which is connected to the DWR Water Data Library (WDL), the destination database for all Municipal Water Quality Investigations monitoring data.

Data Quality

Once analyses were completed, the remaining sample was kept for 30 to 60 days in storage before being discarded. The storage time is necessary for evaluating and ensuring acceptable results. Bryte Laboratory follows a set of internal QA/QC audit procedures, which include evaluation of data for blanks (laboratory and field), calibration standards, laboratory control samples, etc. The detailed QA/QC procedures and corrective actions have been described in Bryte Laboratory's latest QA technical documentation (Fong 2002). The Quality Assurance/Quality Control unit of the Municipal Water Quality Program Branch, Office of Water Quality, performs data quality checks routinely on data in WDL. Results of data quality evaluations for constituents included in this report are presented in Chapter 9.

In this report, constituents testing below their reporting limits are treated as "non-detect" and are not included in the summary statistics (discussed below). During the reporting period, occasional method changes occurred for some constituents due to adoption of improved techniques, equipment failures, or staff limitations. Constituents that may be analyzed by more than one method are shown in Table 2-2. To minimize discrepancy of data resulting from method changes, this report included data from a single method for each constituent whenever possible. For some limited number of constituents, data from different methods had to be combined. When this occurred, the data from different methods were comparable based on the comparability guidelines (Agee 2002 pers comm). All data conversions and data from more than one method are documented throughout this report.

Statistical Analysis

Statistical methods were used to show summary statistics. The focus of this report is to demonstrate the general status and trends of various constituents throughout the Delta; therefore, most data are presented using simple descriptive graphics with mostly simple summary statistics. More advanced statistical analyses were also performed to show temporal and spatial variations, constituent sources such as the effects of rice drainage and other agricultural activity on water quality at some Sacramento and San Joaquin River stations. Nonparametric statistical methods were used when parametric assumptions were not met. A statistical computing package, the SAS® System for Windows Version 8.2, was used for all statistical analyses. The SAS® System was developed and supported by SAS® Institute, Inc, Cary, NC.

Descriptive Plots

Descriptive plots are mostly in the form of temporal graphs. Monthly or weekly data are plotted with time to demonstrate general behavior of the data during the reporting period. Data interpretation based on traditional bar charts or scatter plots are not always reliable. In this report, a new statistical regression method called the Loess Smooth Procedure was used for exploratory data analysis to demonstrate seasonal trends and to compare differences among sites.

Loess stands for local regression. It implements a nonparametric method for estimating local regression for situations where there is no suitable parametric form of the regression model. The idea of local regression is that at a predictor level the regression function can be locally approximated by the value of a function in some specified parametric class and is obtained by fitting a regression line to the data points within a chosen neighborhood of a specific predictor level. Weighted least-squares is used to fit linear or quadratic functions of the predictors at the centers of neighborhoods. The radius of each neighborhood is chosen and is called the smoothing parameter. A detailed description of the procedure can be found in SAS/STAT User's Guide (SAS® Institute 1999).

One advantage of the Loess procedure is that when outliers are present the effect of these outliers on the overall regression is minimized and a robust fitting can be achieved because the overall regression is the result of local regression fittings to the centers of each individual neighborhood. The Loess smooth will not be helpful for very small data sets, but it is a useful tool for exploratory data analysis on large data sets.

The procedure is particularly useful for analysis of water quality data, which may contain outliers. No parametric regression is available for this type of water quality data. Data interpretation based on traditional bar or scatter plots are statistically unreliable. However, scatter plots smoothed by the Loess procedure provide a more statistically defensible, robust regression analysis, which provides insight into seasonal differences and demonstrates the influences of constituent sources during a given time period.

Descriptive Statistics

This report used predominantly the following summary statistics:

- Data range: data between the minimum and the maximum.
- Majority data range: data between the 5th and 95th percentiles.
- Interquartile range (IQR): data range between the 25th and the 75th percentile. The IQR is preferred over the standard deviation because it is the most commonly used resistant measure of data spread and dispersion. It measures the range of the central 50% of the data, and is not influenced at all by the 25% of the data on either end (Helsel and Hirsch 1992). The wider the IQR, the greater the dispersion of the majority of the data.
- Mean: presented mostly for historical reasons. Skewed data of wide variability such as water quality data should not be averaged because the mean is usually strongly influenced by data at both ends and is often misleading.
- Median: more resistant measure for water quality data, thus a preferred measure over the mean. When adequate this report uses the median to represent baseline levels of water quality constituents.

Nonparametric Statistical Methods

The majority of monitoring data for the included constituents was not normally distributed, thus parametric statistical methods may not be robust. In this report, 2 nonparametric tests—the Wilcoxon Rank-sum Test and the Kruskal Wallis Test—were used for comparisons among stations. These nonparametric tests are as powerful as their parametric equivalents but do not require normal data distribution.

Table 2-1 MWQI water sample collection and preservation

Determination	Container	Sample preparation	Sample size (mL)	Preservative	Holding time
Alkalinity	Polyethylene	Filtered	500	4 ^oC	14 days
Electrical conductivity (EC)	Polyethylene	Filtered	500	4 ^oC	28 days
Haloacetic acid (HAA)	Glass, amber VOA	Unfiltered	40, X 2, Teflon, no air	4 ^oC	7d ext, 21d after ext
Haloacetic acid formation potential (HAAFP)	Glass, amber VOA	Filtered	40, X 3, Teflon, no air	4 ^oC	7d ext, 21d after ext
Hardness by calculation	Polyethylene	Filtered	250	HNO_3, pH<2	6 months
Hardness, total by calculation	Polyethylene	Unfiltered	250	HNO_3, pH<2	6 months
ICP cations, dissolved - Na,Ca,Mg, K, B, Si	Polyethylene, acid washed	Filtered	250	HNO_3, pH<2	6 months
ICP cations, total - Na,Ca,Mg, K, B, Si	Polyethylene, acid washed	Unfiltered	250	HNO_3, pH<2	6 months
ICP/MS trace metals, dissolved	Polyethylene, acid washed	Filtered	500	HNO_3, pH<2	6 Months
ICP/MS trace metals, total	Polyethylene, acid washed	Unfiltered	500	HNO_3, pH<2	6 Months
IC anions - Cl, SO_4, Br, F	Polyethylene	Filtered	500	4 ^oC	28 days
Mercury by cold vapor	Polyethylene, acid washed	Unfiltered	500	4 ^oC, HNO_3, pH<2	28 days
Mercury by ICP/MS	Polyethylene, acid washed	Filtered	500	4 ^oC, HNO_3, pH<2	28 days
Nitrate, nitrite (nutrient)	Polyethylene	Filtered	250	-20 ^oC, dark	48 hours
Nitrate, nitrite (nutrient DWR Modified)	Polyethylene	Filtered	250	-20 ^oC, dark	28 days
Nitrate, nitrite (Std Mineral-IC Anions)	Polyethylene	Filtered	500	4 ^oC	48 hours
Nitrate, nitrite (Std Mineral DWR Modified)	Polyethylene	Filtered	500	4 ^oC	28 days
Nitrogen, ammonia	Polyethylene	Filtered	250	-20 ^oC, dark	28 days
Nitrogen Kjeldahl, total (TKN)	Polyethylene	Unfiltered	250	-20 ^oC, dark	28 days
Organic carbon, dissolved (DOC)	Glass, clear VOA	Filtered	40	4 ^oC, HNO_3, pH<2	28 days
Organic carbon, total (TOC)	Glass, clear VOA	Unfiltered	40	4 ^oC, HNO_3, pH<2	28 days
Orthophosphate	Polyethylene	Filtered	250	4 ^oC	48 hours
Orthophosphate DWR modified	Polyethylene	Filtered	250	-20 ^oC, dark	28 days
pH	Polyethylene	Unfiltered	250	4 ^oC	ASAP

Table continued on next page

Table 2-1 continued

Determination	Container	Sample preparation	Sample size (mL)	Preservative	Holding time
Phosphorous, total	Polyethylene	Unfiltered	250	-20 °C, dark	28 days
Solids, total dissolved (TDS)	Polyethylene	Filtered	500	4 °C	7 days
Trihalomethane (THM)	Glass, amber VOA	Unfiltered	40, X 2, Teflon, no air	4 °C, HCl, pH<2	14 days
Trihalomethane formation potential (THMFP)	Glass, amber VOA	Filtered	40, X 3, Teflon, no air	4 °C	7 days after chlorination
Turbidity	Polyethylene	Unfiltered	500	4 °C	48 hours
UVA	Polyethylene	Filtered	250	4 °C	14 days
Volatile organic analysis (MTBE, etc.)	Glass, amber VOA	Unfiltered	40, X 2, Teflon, no air	4 °C, HCl, pH<2	14 days

Note: Condensed from Appendix A, *Bryte Chemical Laboratory Quality Assurance Manual* (Fong 2002).
ext = extraction

Table 2-2 Analytical methods and reporting limits for included constituents

Constituent	Method source	Method number	Reporting limit[a]
Total organic carbon (TOC)	Std methods	5310 D, Wet oxidation, IR, automated	0.1
	EPA	415.1 Wet oxidation, IR, automated	0.1
Dissolved organic carbon (DOC)	EPA	415.1 Wet oxidation, IR, automated	0.1
Trihalomethane formation potential (THMFP)	EPA	510.1 (modified) GC, purge and trap	1
Haloacetic acids		552.2 Gas chromatography (GC)	1
UV absorbance at 254 nm	Std methods	5910 B UV-absorbing organics	0.001 cm^{-1}
MTBE	EPA	502.2 purge and trap	0.5
Bromide		300.0 ion chromatography	0.01
Electrical conductivity	Std methods	2310 B Wheatstone Bridge	1 µS/cm
	EPA	120.1 Wheatstone Bridge	1 µS/cm
Total dissolved solids (TDS)	Std methods	2540 C Gravimetric, dried at 180° C	1
	EPA	160.1 Gravimetric, dried at 180° C	1
Chloride	Std methods	4500-Cl-E Colorimetric, Ferricyanide	1
Sulfate		375.2 Colorimetric, Methythymol Blue	1
		300.0 Ion Chromatography	1
Calcium	EPA	215.1 AA Flame	1
		200.7 ICP	1
Magnesium		242.1 AA Flame	1
		200.7 ICP	1
Sodium		273.1 AA Flame	1
		200.7 ICP	1
pH	Std methods	4500 H^+ Electrometric	0.1 pH unit
	EPA	150.1 Electrometric	0.1 pH unit
Alkalinity	Std methods	2320 B Titrimetric	1
	EPA	310.1 Titrimetric	1
Hardness	Std methods	2340 B total by calculation	
Turbidity		2130 B Nephelometric	1 NTU
	EPA	180.1 Nephelometric	1 NTU

a. Unit is mg/L unless otherwise indicated.

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Table 2-2 continued

Constituent	Method source	Method number	Reporting limit[a]
Aluminum	EPA	200.7 ICP	0.05
		200.8 ICP/MS	0.01
		200.9 GFAA	0.01
Antimony	EPA	200.7 ICP	0.025
		200.8 ICP/MS	0.001
Arsenic	Std methods	3114, AA gaseous hybride	0.001
	EPA	200.7 ICP	0.05
		200.8 ICP/MS	0.001
Barium	EPA	200.7 ICP	0.01
		200.8 ICP/MS	0.05
		200.9 GFAA	0.05
		208.2 GFAA	0.05
Boron	USGS	I-2115-85 Colorimetric, Azomethine	0.1
Cadmium	EPA	200.7 ICP	0.01
		200.8 ICP/MS	0.001
		200.9 GFAA	0.005
		213.2 GFAA	0.005
Total chromium (all valencies)	EPA	200.7 ICP	0.02
		200.8 ICP/MS	0.005
		200.9 GFAA	0.005
		218.2 GFAA	0.005
Cobalt	EPA	200.7 ICP	0.02
		200.8 ICP/MS	0.005
		200.9 GFAA	0.005
		219.2 GFAA	0.005
Copper	EPA	200.7 ICP	0.02
		200.8 ICP/MS	0.001
		200.9 GFAA	0.005
		220.1 AA Flame	0.1
		220.2 GFAA	0.005

a. Unit is mg/L unless otherwise indicated.

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Table 2-2 continued

Constituent	Method source	Method number	Reporting limit[a]
Iron	EPA	200.7 ICP	0.025
		200.8 ICP/MS	0.005
		200.9 GFAA	0.005
		236.1 AA Flame	0.1
		236.2 GFAA	0.005
Lead	EPA	200.7 ICP	0.05
		200.8 ICP/MS	0.001
		200.9 GFAA	0.005
		239.2 GFAA	0.005
Manganese	EPA	200.7 ICP	0.01
		200.9 GFAA	0.005
		243.1 AA Flame	0.1
		243.2 GFAA	0.005
Mercury	EPA	245.1 AA, Flameless, cold vapor	0.001
Molybdenum	EPA	200.7 ICP	0.02
		200.8 ICP/MS	0.005
		200.9 GFAA	0.005
		246.2 GFAA	0.005
Nickel	EPA	200.7 ICP	0.025
		200.8 ICP/MS	0.001
		200.9 GFAA	0.005
		249.1 AA Flame	0.1
		249.2 GFAA	0.005
Selenium	Std Methods	3114B AA gaseous hydride	0.001
	EPA	200.8 ICP/MS	0.001
Silver	EPA	200.7 ICP	0.025
		200.8 ICP/MS	0.001
		200.9 GFAA	0.005
		272.2 GFAA	0.005

a. Unit is mg/L unless otherwise indicated.

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Table 2-2 continued

Constituent	Method source	Method number	Reporting limit[a]
Zinc	EPA	200.7 ICP	0.02
		200.8 ICP/MS	0.005
		200.9 GFAA	0.005
		289.1 AA Flame, Direct	0.1
		289.2 GFAA	0.005
Ammonia	Std methods	4500-NH_3 B, G Automated Phenate	0.01
	EPA	350.1 Automated Phenate	0.01
Total Kjeldahl nitrogen	EPA	351.2 Colorimetric, semi-automated	0.1
Nitrate	Std methods	4500-NO_3-F Cd-Reduction	0.01
	EPA	353.2 Cd-Reduction, Automated	0.01
Nitrite + nitrate	EPA	353.2, Cd-Reduction, Automated	0.01
Orthophosphate	Std methods	4500-P-E Colorimetric, Ascorbic Acid	0.01
	EPA	365.1 Colorimetric, Ascorbic Acid	0.01
Phosphorus, total	EPA	365.4 Colorimetric, semi-automated	0.01

Note: Condensed from Appendix G, *Bryte Chemical Laboratory Quality Assurance Manual* (Fong 2002).

a. Unit is mg/L unless otherwise indicated.

Chapter 3 Watershed and Delta Hydrology

This chapter presents a brief overview of the hydrologic conditions in the watersheds that affect water quality in rivers and channels of the Sacramento-San Joaquin Delta (the Delta). In the following chapters, water quality at various stations is discussed in the context of Delta hydrologic conditions.

Six weather stations were selected to represent the general precipitation patterns in areas that influence the Delta. Figure 3-1 shows the locations of these stations relative to the Delta and the San Joaquin River (SJR) and Sacramento River. The 3 northern stations—Redding Fire Station, Durham, and Sacramento Executive Airport—are within the Sacramento Valley; the other 3 stations— Brentwood, Stockton Fire Station, and Madera—are in the San Joaquin Valley. Data for Redding Fire Station, Stockton Fire Station, and Sacramento Executive Airport were obtained from the Western Regional Climate Center in Reno, Nevada. Data for the remainder of the stations were from the California Irrigation Management Information System (CIMIS) of the California Department of Water Resources (DWR).

Figure 3-1 Location of selected weather stations (map)

Also presented are water outflows at 3 Delta locations and a hydrologic classification index that categorizes water-year types based on river runoff.

Precipitation

The stations within the Sacramento Valley (the northern stations) generally recorded more rainy days and more intense rain than did the stations in the San Joaquin Valley (the southern stations) during the reporting period (Table 3-1). For example, during the study period, there were 239 rainy days at the Redding station and the highest daily precipitation was 3.17 inches; whereas there were 160 rainy days at the Stockton Fire Station, and the highest daily rainfall was 1.13 inches. The southern stations recorded only a few days with more than one inch of rain; whereas the northern stations recorded several more days of heavier rainfall.

Table 3-1 Summary of daily precipitation (in inches) at six weather stations

Figure 3-2 presents the cumulated monthly precipitation for the 6 stations. Table 3-2 summarizes these data, clearly showing the differences in cumulated monthly precipitation among the stations. Monthly and total accumulated precipitation at the selected stations were lower during the 2001 water year than during the 2000 water year; monthly and total accumulated precipitation were comparable for both the 1999 and 2001 water years (Table 3-2 and Figure 3-2). Although these stations indicate a general pattern of precipitation within the contributing watersheds, they cannot be used as a reliable measure of total precipitation and runoff in these watersheds. For example, although total cumulated precipitation was the highest in the 2000 water year, runoff in the watershed was not the greatest in that water year. This is discussed in the following section, "Runoff Index."

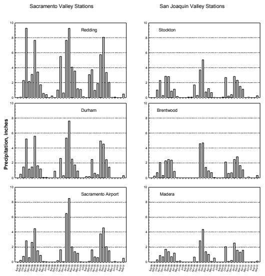


Figure 3-2 Cumulative monthly precipitation at six weather stations

Table 3-2 Summary of monthly precipitation (in inches) at six weather stations

Most rainfall occurred from September through April at all stations (Figure 3-2). The northern stations had considerably more rain than the southern stations during all rainy months. Rainfall during the months of

June, July, and August were negligible at all stations except for the Redding station. In some years, considerable precipitation occurred in May or June, but this was generally followed by a dry September of the same year.

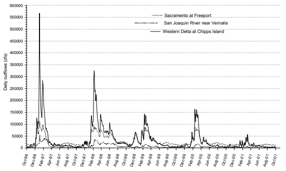
Runoff Index

The Delta receives water from the SJR and Sacramento River systems, which depend on runoff water from their watersheds. To classify runoff years, the State Water Resources Control Board developed a hydrologic index based on the amount of unimpaired watershed runoff. The definition and method of calculating the index can be found in Water Right Decision 1641, revised March 15, 2000 (SWRCB 2000).

DWR maintains a database containing hydrologic indices for the SJR and Sacramento River systems. In calculating these indices, unimpaired runoff represents the natural water production of a river basin unaltered by upstream exports, storage, or diversion to or import of water from other basins. For the Sacramento River system, the index uses the total runoff (in million acre-feet) of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. The runoff for the SJR system is the total of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and SJR inflow to Millerton Lake.

Table 3-3 summarizes year type classification. Water year 2001 was a dry year for both valleys, indicating that runoff was lower than normal. This index is not necessarily related to total rainfall at the selected stations in the 2 watersheds. Runoff into the rivers is determined not only by the amount of precipitation in the 2 watersheds but also by the precipitation in the Sierra Nevada. Total precipitation at the 6 stations was lower in the 2001 water year than it was in the 2000 water year (Table 3-2). Consequently, less water entered the river system as shown in Figure 3-3, which presents daily flows at Sacramento River at Freeport and SJR at Vernalis. The SJR outflows as measured at Vernalis were significantly lower than outflows of the Sacramento River as measured at the Freeport station (Figure 3-3). This is so because the Sacramento Valley had considerably more rain than the San Joaquin Valley during all rainy months as discussed in the previous section, "Precipitation."

Table 3-3 Hydrologic index classification based on measured unimpaired runoff at selected rivers



Source: Department of Water Resources, http://iep.water.ca.gov/dayflow/output/index.html. Accessed 12 March 2002.

Figure 3-3 Daily outflows at three Delta locations

Due to the differences in runoff among the 3 water years, water quality varied by watershed. The effect of precipitation and runoff on water quality at various stations and at the diversion pumps is discussed in later chapters.

Delta Outflows

Delta inflows mostly come from the SJR and Sacramento River systems. Water inflows to these rivers come from their major tributaries, reservoirs, and drainage canals within their watersheds. A proportion of the water within the Delta is diverted through the State Water Project, Contra Costa Pumping Plant, Central Valley Project (CVP), the North Bay Aqueduct, the CVP's Tracy Pumping Plant, and Contra Costa Water District's intake at Rock Slough (Contra Costa Pumping Plant #1), Old River at Station 9, and Mallard Slough. The remaining water is allowed to continue as Delta outflows into the San Francisco and Suisan bays at the western end of the Delta to help maintain marine ecosystems. The outflows also help control seawater influence in the western Delta by holding back the daily tides. Therefore, a steady Delta outflow is necessary to preserve the quality of source waters in the Delta.

The Interagency Ecological Program of DWR routinely calculates the daily outflows at Chipps Island at the western end of the Delta. This daily outflow is often referred to as net total outflow of the Delta. Figure 3-3 presents the calculated Delta outflows and inflows at SJR and Sacramento River from water years 1997 to 2001. Delta inflows and outflows varied widely among water years and within each water year. During the reporting period, Delta outflows were highest in the 1998 water year and lowest during the 2001 water year. Outflow patterns were similar in the 1999 and 2000 water years (Figure 3-3). Low Delta outflows in water year 2001 were attributable to significantly less runoff that year within major watersheds (Table 3-3). The reduced Delta outflows during the 2001 water year adversely affected water quality at various stations, particularly those in the western and central Delta. Water quality at these stations with respect to changes in Delta outflow are discussed in following chapters.

Table 3-1 Summary of daily precipitation (in inches) at six weather stations

Station	Reporting days	Days rained	Range	Mean	Median	Days of varying intensity >= 0.1	>= 0.5	>= 1	>= 2
Sacramento Valley									
Redding Fire Station	1,157	239	0.01–3.17	0.40	0.19	161	68	26	3
Durham	1,157	192	0.01–1.74	0.30	0.17	119	39	9	0
Sacramento Executive Airport	1,157	175	0.01–2.99	0.29	0.16	109	39	8	1
San Joaquin Valley									
Stockton Fire Station	1,157	160	0.01–1.13	0.23	0.12	92	25	3	0
Brentwood	1,157	205	0.01–1.78	0.17	0.08	97	18	2	0
Madera	1,157	157	0.01–1.39	0.17	0.08	75	16	1	0

Table 3-2 Summary of monthly precipitation (in inches) at six weather stations

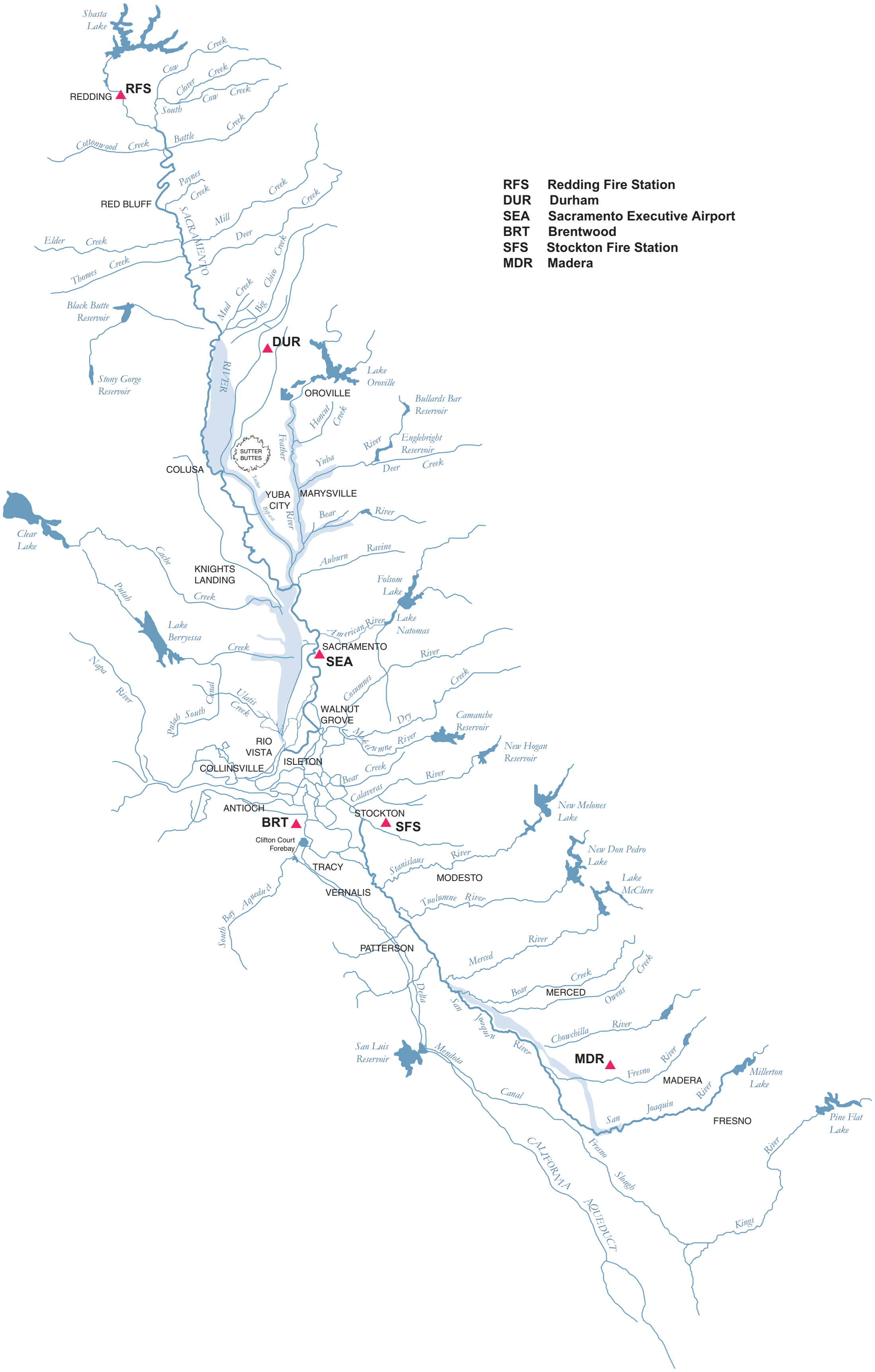
Station	Cumulated monthly precipitation Range[b]	Mean[b]	Median[b]	Cumulated precipitation during each water year[a] 1999	2000	2001
Sacramento Valley						
Redding Fire Station	0.03–9.29	2.96	2.11	30.90	37.24	26.43
Durham	0.08–7.63	2.07	1.45	18.85	21.44	17.20
Sacramento Executive Airport	0.03–8.49	1.75	1.17	13.75	21.57	15.33
San Joaquin Valley						
Stockton Fire Station	0.03–5.07	1.31	0.95	11.55	13.64	11.41
Brentwood	0.01–4.69	1.33	0.89	11.19	12.44	11.94
Madera	0.02–4.36	1.05	0.79	7.05	10.89	9.44

a. Water year runs from October 1 to September 30; for example, the 1999 water year runs from 1 October 1998 to 30 September 1999.
b. Calculated with data from wet months only.

Table 3-3 Hydrologic index classification based on measured unimpaired runoff at selected rivers

Water year	Sacramento Valley	San Joaquin Valley
1997	Wet	Wet
1998	Wet	Wet
1999	Wet	Above normal
2000	Above normal	Above normal
2001	Dry	Dry

Figure 3-1 Location of selected weather stations



RFS	Redding Fire Station
DUR	Durham
SEA	Sacramento Executive Airport
BRT	Brentwood
SFS	Stockton Fire Station
MDR	Madera

Figure 3-2 Cumulated monthly precipitation (in inches) at six weather stations

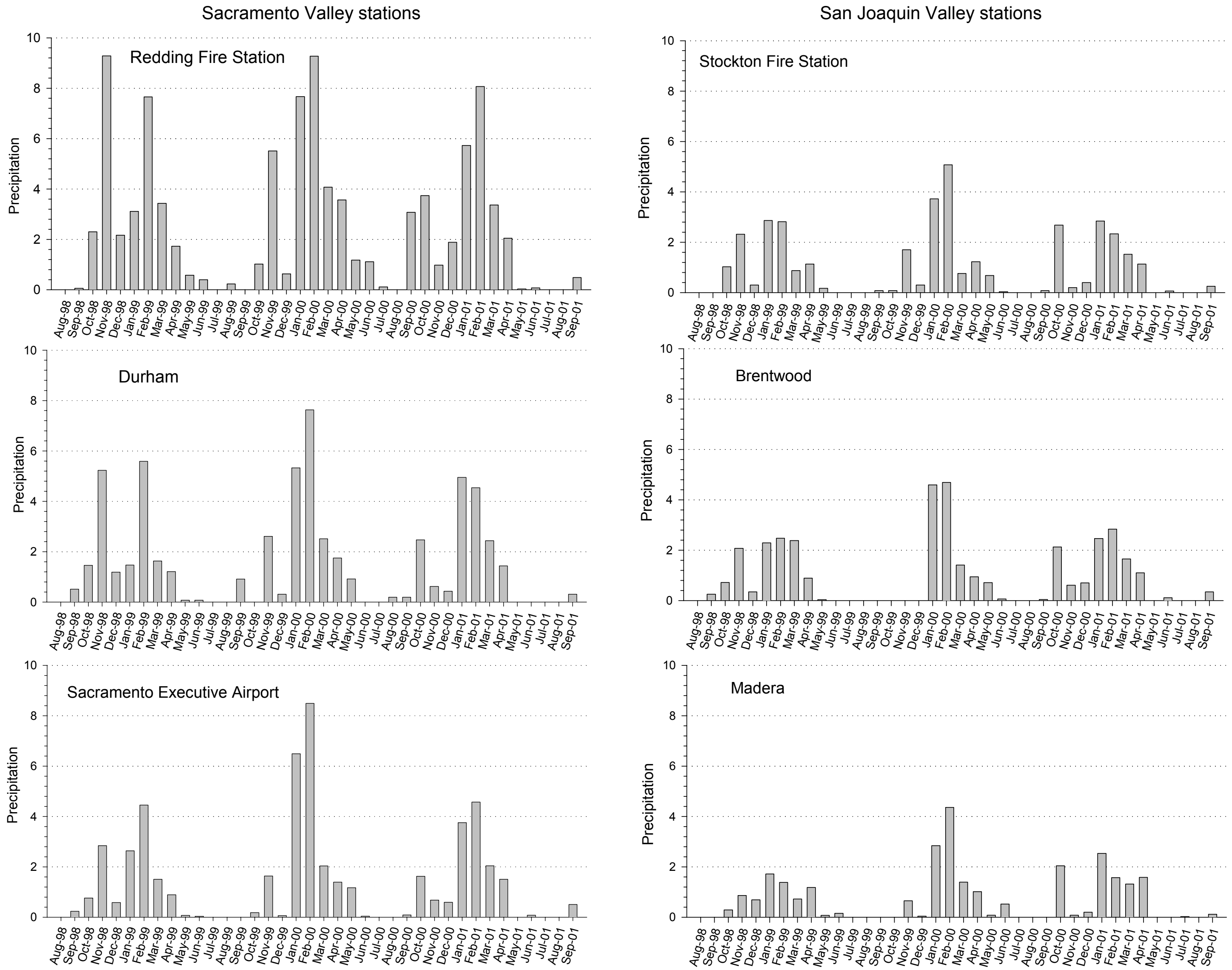
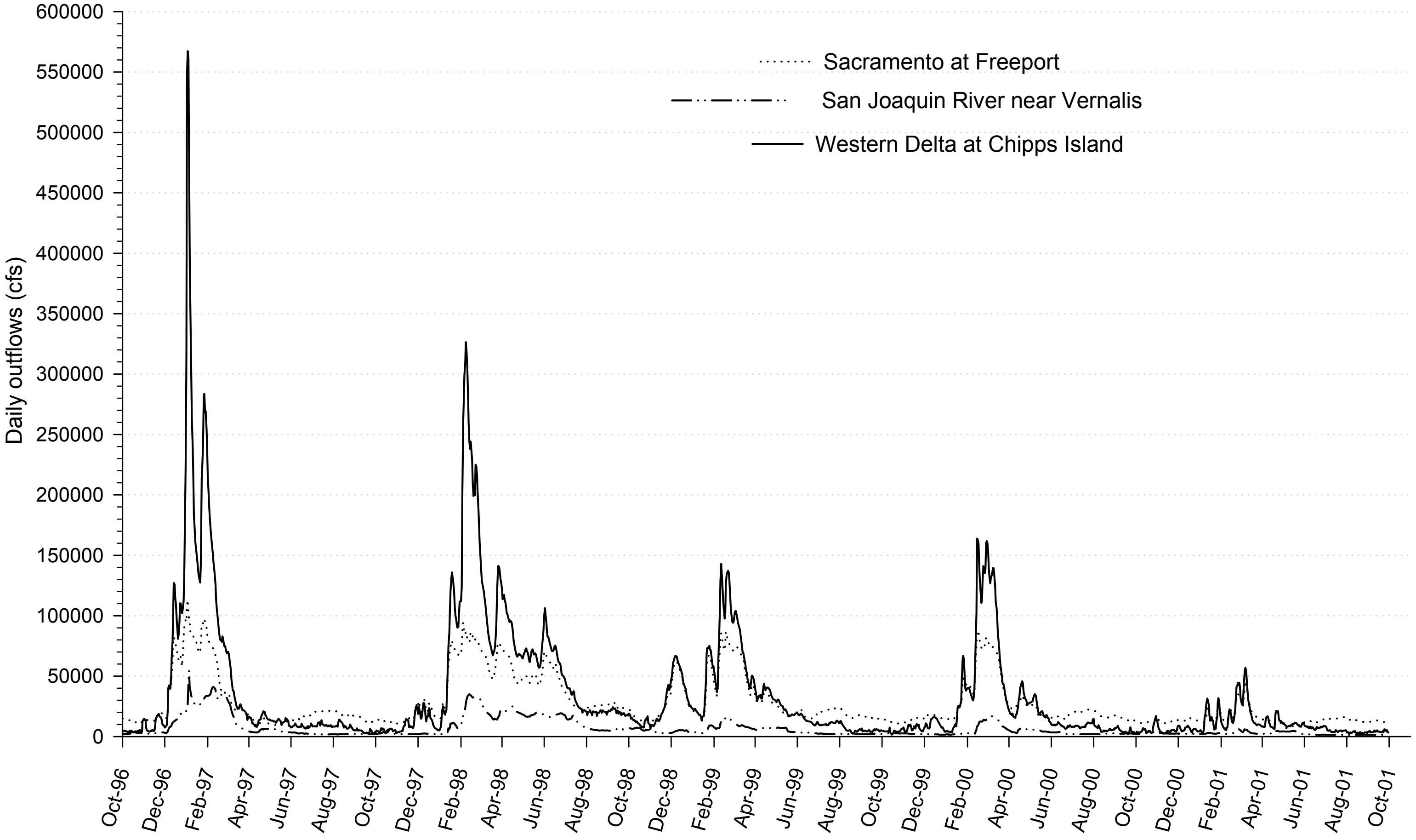


Figure 3-3 Daily outflows at three Delta locations



Source: Department of Water Resources, http://iep.water.ca.gov/dayflow/output/index.html. Accessed 12 March 2002.
cfs = cubic feet per second

Chapter 4 Organic Carbon

Overview

This chapter summarizes organic carbon data collected from 14 monitoring stations in or near the Sacramento-San Joaquin Delta (the Delta) from August 1, 1998, to September 30, 2001. The Municipal Water Quality Investigations Program (MWQI) monitors both total organic carbon (TOC) and dissolved organic carbon (DOC). Since 1986, TOC and DOC have been determined by a chemical oxidation method (wet oxidation). From November 2000 through August 2001, TOC was determined by a new combustion method. The method changed because the combustion method measured more TOC than did the wet oxidation in waters containing high particulate organic carbon. Both TOC by wet oxidation and by combustion are methods approved by the U.S. Environmental Protection Agency (EPA) for monitoring drinking water quality and are described in EPA Method 415.1.

This report presents TOC data from 725 samples collected during the reporting period. Of these, 132 samples (approximately 18%) were measured by the combustion method. TOC measured by the 2 different methods cannot be compared statistically because TOC measured by combustion is generally greater than that measured by wet oxidation. In order to include the 132 TOC analyses in this report, combustion values were converted to wet oxidation values by linear regression. A data set containing values of 260 samples analyzed for TOC by both combustion and wet oxidation were used for developing predictive regression equations. Two regression equations derived from the data set can reliably convert TOC by combustion to their TOC equivalents by the oxidation method. The methodology, derivation of regression equations, and criteria for choosing the appropriate equation are described in Appendix A. See Appendix B for information on availability of data set.

Appendix A Method for Converting TOC by Combustion to TOC by Oxidation

Appendix B Report and Data in Electronic Format

This chapter discusses the ranges and seasonality of TOC and DOC, organic carbon differences among stations, and major sources of organic carbon. Also presented is a brief discussion of potential formation of disinfection byproduct (DBP) and the relationships between organic carbon and UVA_{254} of Delta source waters.

Ranges and Seasonality of Organic Carbon at Individual Stations

American River

Monthly grab samples were collected from the American River at the E.A. Fairbairn Water Treatment Plant (WTP) (Figure 4-1). Organic carbon at this station was generally lower than 2 mg/L (Figure 4-2). Of the 36 monthly grab samples, only one sample (January 2001) had TOC and DOC of more than 2.0 mg/L (Figure 4-2).

Figure 4-1 Monitoring stations near the City of Sacramento (map)

TOC is generally higher than DOC because TOC includes organic carbon associated with particulate matter as well as DOC, but the difference was small. TOC increased during the wet months of each water year when heavy rainfall occurred and turbidity increased. When turbidity and particulate matter in the water was low during the dry months, the differences between TOC and DOC were small (Figure 4-2).

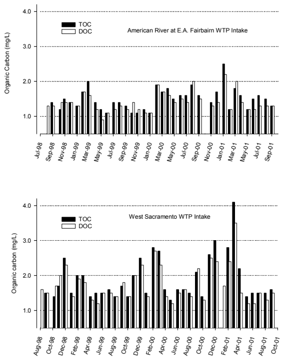


Figure 4-2 Organic carbon at the American River and West Sacramento WTP Intake

The ranges, median, mean, and the spread for both TOC and DOC at this station were similar (Table 4-1). Median concentrations of TOC and DOC were 1.5 and 1.3 mg/L, respectively (Table 4-1). Statistical analysis indicates that there was no significant difference between TOC and DOC ($p=0.081$), suggesting that organic carbon was mostly present in nonparticulate forms. American River water is low in turbidity (refer to Chapter 7), thus the differences between TOC and DOC were small.

Although TOC was generally higher during the wet months than during the dry months of each water year (Figure 4-2), seasonal differences were not statistically significant ($p=0.087$ and 0.090 for DOC and TOC, respectively). It appears that organic carbon levels from February 2000 through September 2001 were higher than those from September 1998 through January 2000. Average TOC concentrations between the 2 periods were significantly different ($p=0.02$), suggesting that average TOC was statistically higher during the latter period. This increase in organic carbon may be attributable to the lower runoff in the watershed or reduced releases from the reservoirs that supply water to the American River. The 2001 water year was classified as a dry year in terms of watershed runoff (see Table 3-3).

Table 4-1 Summary of organic carbon at 14 MWQI stations (mg/L)

Sacramento River

West Sacramento WTP Intake Station

The West Sacramento WTP Intake is about 2.5 miles upstream of the junction of the American and the Sacramento rivers (Figure 4-1). Episodic spikes and clear seasonality of organic carbon were observed (Figure 4-2). TOC and DOC were higher during the wet months than during the dry months. With the exception of September, TOC and DOC concentrations didn’t change significantly during the dry months of the reporting period (Figure 4-2). Organic carbon spikes in September were due to rice drainage to the Sacramento River (see Chapter 6, section “Agricultural Drainage to the Sacramento River”). Organic carbon during the wet months increased in each successive year of the reporting period (Figure 4-2).

The median levels of TOC and DOC were 1.6 and 1.5 mg/L, respectively (Table 4-1). Organic carbon concentrations were mostly less than 2 mg/L. Of the 38 monthly TOC and DOC measurements, 10 samples or 26% exceeded 2 mg/L. Organic carbon levels exceeded 3 mg/L only once (March 2001), probably due to high turbidity and particulate carbon following heavy rainfall. TOC and DOC fluctuated within a similar range (Table 4-1).

The Hood Station

The Hood station is on the Sacramento River shortly after the river enters the Delta (Figure 4-1); therefore, it is one of the 2 key MWQI monitoring stations where water quality is monitored weekly. As at the other stations on the American River and at this section of the Sacramento River, organic carbon concentrations at Hood are generally low and heavily influenced by rainfall events in the Sacramento Valley. Organic carbon is much higher during the wet months than during the dry months (Figure 4-3).

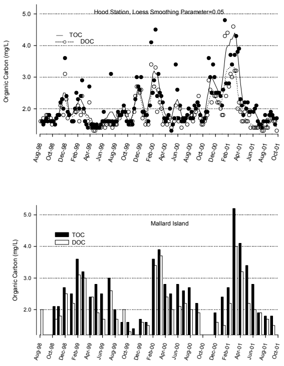


Figure 4-3 Organic carbon at Hood and Mallard Island stations

Median concentrations of TOC and DOC were 1.9 and 1.7 mg/L, respectively (Table 4-1). TOC varied from 1.3 to 6.5 mg/L. DOC ranged from 1.3 to 4.6 mg/L (Table 4-1). TOC was considerably higher than DOC during the wet months (Figure 4-3), suggesting that considerable particulate organic carbon was present during rainfall periods.

Compared with monthly sampling at nearby stations (Figure 4-2), weekly sampling reveals more detailed changes of organic carbon. With the help of the Loess smoothing procedure, the data showed that organic carbon concentrations dropped to their regular levels between rainfall events during the wet months (Figure 4-3). For example, there was no rain during extended periods in January 1999, January 2000, and January 2001 (see Appendix B for raw data), and organic carbon returned to about its baseline level (Figure 4-3). The fall of elevated organic carbon levels to their baseline levels suggests that high organic carbon levels are transitory.

As with the West Sacramento WTP Intake station, organic carbon at Hood increased slightly each September (Figure 4-3). The TOC increases in September were perhaps due to rice drainage into the upper Sacramento River. The effects of rice drainage are discussed in more detail in Chapter 6.

High organic carbon was also found at the Hood Station during June and July (Figure 4-3). This perhaps was due to irrigation discharges from rice fields and row crops (Rich Breuer 2002 pers comm). Approximately half a million acres of rice is grown in the Sacramento Valley. Herbicides are usually applied in April and May. A one-month embankment of the rice fields is required to ensure a good kill of weeds following herbicide application to the rice field. At the end of the embankment, irrigation water is discharged to the Sacramento River in June and July (Rich Breuer 2002 pers comm), thus increasing organic carbon levels.

Mallard Island Station

Water at the Mallard Island station is a mixture from several sources including the San Joaquin River (SJR) and the Sacramento River, the San Francisco Bay, and drainage from in-Delta islands. As at the upstream stations on the Sacramento River, organic carbon levels at Mallard Island were affected seasonally, but the magnitude and seasonality pattern were different. The highest organic carbon spikes were observed in water year 2001, a dry year in which daily outflows in the Delta also were the lowest during the reporting period (Figure 4-3).

Median TOC and DOC concentrations were 2.5 and 2.0 mg/L, respectively, which were considerably higher than those at the upstream Sacramento River stations (Table 4-1). TOC varied from 1.4 to 5.2 mg/L; DOC, from 1.1 to 4.0 mg/L (Table 4-1). The median TOC was 25% higher than median DOC. The higher TOC levels indicate that considerable quantities of particulate organic carbon were present (Figure 4-3).

San Joaquin River

San Joaquin River near Vernalis

The SJR near Vernalis station represents the point where the SJR enters the Delta. As at the Hood station on the Sacramento River, water quality near Vernalis was monitored weekly. Organic carbon concentrations were generally between 2 and 6 mg/L, but occasionally were higher than 8 mg/L during the wet months (Figure 4-4). The median concentrations of TOC and DOC were 3.1 and 2.8 mg/L, respectively (Table 4-1). The average and median TOC were slightly higher than those for DOC.

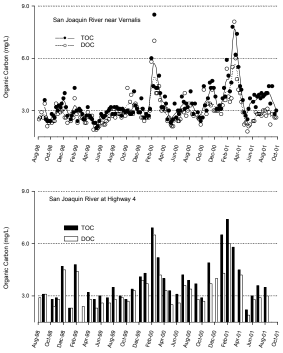


Figure 4-4 Organic carbon at two San Joaquin River stations

Organic carbon spikes occurred during the wet months of each water year. Organic carbon concentrations appear to have been higher during dry runoff years than during wetter runoff years during the reporting period (Figure 4-4). The 1999 and 2000 water years were classified as above-normal runoff years, whereas the 2001 water year was a dry year. Organic carbon levels during the wet months of the 2001 water year were higher than those of the 1999 and 2000 water years (Figure 4-4). The relatively lower organic carbon levels during the 1999 and 2000 water years were probably attributable to high runoff during the 1997 and 1998 water years, which were wet years in the San Joaquin Valley.

Although rain events in the watershed increased organic carbon levels during the wet months, such elevated carbon levels were temporary with organic carbon concentrations returning to regular levels after extended non-rainy winter months (Figure 4-4). Baseline organic carbon concentrations do not appear to have increased with time despite the differences among water years.

Agricultural drainage enters the SJR from May to October of each year and increases organic carbon concentrations (Figure 4-4). During the dry months the lowest organic carbon was observed in May and October when agricultural drainage was less (Figure 4-4).

San Joaquin River at Highway 4

Organic carbon at the Highway 4 station varied generally between 2 and 6 mg/L and rarely exceeded 6 mg/L (Figure 4-4). TOC ranged from 2.2 to 7.4 mg/L, and DOC from 1.9 to 6.5 mg/L (Table 4-1). The median concentrations of TOC and DOC were 3.5 and 2.9 mg/L, respectively (Table 4-1 and Figure 4-4), and these levels do not appear to have increased with time during the reporting period (Figure 4-4). Both average and median TOC were significantly higher than DOC (p=0.016), suggesting that considerable particulate organic carbon and higher turbidity were present at this station.

As at the other stations, organic carbon spikes occurred during wet months of each water year. The general trend of carbon levels during the wet months was similar to that observed at the Vernalis station; that is, organic carbon levels during the wet months were higher during the dry year (water year 2001) than during above normal years (water years 1999 and 2000) (Figure 4-4).

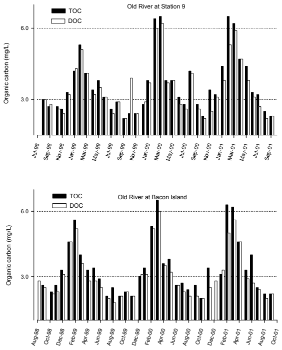


Figure 4-5 Organic carbon at two Old River stations

Delta Channel Stations

Old River at Station 9

Although TOC was occasionally much higher than DOC such as during February 2001, TOC and DOC differed only slightly (Figure 4-5). This suggests that most organic carbon was in dissolved form. The ranges for TOC and DOC were from 2.2 to 6.5 and 2.2 to 6.2 mg/L, respectively (Table 4-1). The median levels of TOC and DOC were 3.3 and 3.1 mg/L, respectively.

Although TOC at Station 9 comes from multiple sources, including the SJR and Sacramento River, seasonality was similar to that at the Vernalis and Highway 4 stations, reflecting some influence of high TOC water from the SJR. Unlike the Vernalis and Highway 4 stations on the SJR, variations in organic carbon concentrations during wet months were small among water years (Figure 4-5). At the Vernalis and Highway 4 stations, organic carbon in water year 2001 (a dry runoff year) was much higher than during the previous 2 water years (Figure 4-4), whereas at Station 9, only slight increases were observed between the 1999 and 2000 water years, and little difference was found between the 2000 and 2001 water years (Figure 4-5).

Old River at Bacon Island

The ranges and seasonality of organic carbon at the Bacon Island station were similar to those at Station 9 (Figure 4-5), and TOC at the stations did not differ statistically (p=0.238). TOC and DOC varied from 2.0 to 6.5 mg/L and 1.8 to 6.0 mg/L, respectively (Table 4-1). The median concentrations of TOC and DOC were 3.1 and 2.8 mg/L, respectively. The baseline levels of organic carbon did not increase with time during the reporting period (Figure 4-5). Seasonality of organic carbon was the same as at Station 9, and was relatively independent of runoff from the SJR and Sacramento River watersheds.

Ranges and Seasonality of Organic Carbon at Diversion Stations

Banks Pumping Plant

TOC was analyzed monthly at Banks Pumping Plant during most of the reporting period; DOC analysis did not begin until February 2000 despite the fact that samples for DOC had been collected. Similar to those at the Old River stations, TOC and DOC levels at Banks Pumping Plant were not significantly different (p=0.622) during the period when both TOC and DOC were analyzed. In November and December 2000 and March 2001, however, TOC was much higher than DOC (Figure 4-6).

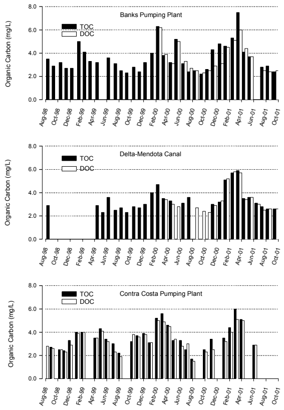


Figure 4-6 Organic carbon at three Delta diversion stations

The ranges for TOC and DOC were 2.2 to 7.5 mg/L, and 2.3 to 6.2 mg/L (Table 4-1). The median TOC and DOC levels were 3.2 and 3.1 mg/L, respectively (Table 4-1). TOC and DOC concentrations do not appear to have increased at Banks with time (Figure 4-6), which was similar to what occurred at Old River at Bacon Island. The general seasonality does not appear to have been as dependent on watershed runoff at either of these stations as at the Vernalis and Highway 4 stations. For example, runoff was least in the Sacramento and San Joaquin valleys during the 2001 water year, but organic carbon at Banks and Old River at Bacon Island was not much higher during the 2001 water year than during the 2 previous water years (Figure 4-5 and Figure 4-6).

Organic carbon was higher during the wet months than the dry months of each water year (Figure 4-6). The increase in organic carbon during the wet months was attributable to increased loads from contributing watersheds. Organic carbon in inflow waters to the Banks station increased during the wet months, but fresh water flow did not dilute organic carbon in the water because the dams and reservoirs released less water during the winter.

Delta-Mendota Canal

Although samples were collected monthly at the Delta-Mendota Canal (DMC) during the reporting period, DOC was not analyzed until March 2000. TOC and DOC ranged from 2.3 to 5.9 mg/L and from 2.3 to 5.8 mg/L (Table 4-1). Although DOC data were not available for the entire reporting period, TOC and DOC levels were not significantly different (p=0.703) during the period when both TOC and DOC were analyzed (Figure 4-6), suggesting that organic carbon was primarily in dissolved form.

The median concentrations of TOC and DOC were 3.1 and 3.0 mg/L, respectively (Table 4-1). For the same reasons as at the Banks stations, organic carbon was higher during the wet months than during the dry months of each water year (Figure 4-6). Despite such seasonal fluctuations, organic carbon concentrations do not appear to have increased with time.

Contra Costa Pumping Plant

Samples were collected monthly at the pumping outlet of the Contra Costa Pumping Plant. During the period when samples were analyzed for both TOC and DOC, TOC and DOC concentrations were not significantly different (p=0.526), suggesting low particulate organic carbon in the water.

TOC ranged from 1.7 to 6.0 mg/L; DOC, from 1.5 to 5.1 mg/L (Table 4-1). The median levels were 3.4 and 3.2 mg/L for TOC and DOC, respectively (Table 4-1). As at all other Delta stations, organic carbon at the Contra Costa Pumping Plant was higher during the wet months than during the dry months (Figure 4-6). Neither TOC nor DOC appears to have increased with time during the reporting period.

The seasonality patterns of organic carbon at this station resemble those at the Old River stations (Bacon Island and Station 9) and appear to have been less dependent on runoff patterns in the contributing watersheds than were the Vernalis and Highway 4 stations. The increase in organic carbon during the wet months is attributable to the same reasons as at Banks Pumping Plant.

Organic Carbon Differences among Stations

This section compares organic carbon at various monitoring stations. Analysis was primarily on TOC because DOC data were not available at all stations for the reporting period. Comparisons were primarily based on geography and hydrologic connections. Although the Mallard Island station is considered a Sacramento River station, it receives water from multiple hydrologic sources including the Sacramento River, SJR, and the San Francisco Bay.

Sacramento River Stations

West Sacramento WTP Intake vs. Hood

The West Sacramento WTP Intake and the Hood stations are approximately 24.6 miles apart along the Sacramento River near the City of Sacramento (Figure 4-1). Between the 2 stations, the American River joins the Sacramento River. Relatively higher quality water from the American River merges with water from the upstream Sacramento River. The Natomas Main Drain and the Natomas East Main Drainage Canal (NEMDC) both discharge to the Sacramento River in this section. Two wastewater treatment plants (WWTPs) also discharge wastewater within this section of the Sacramento River (Figure 4-1).

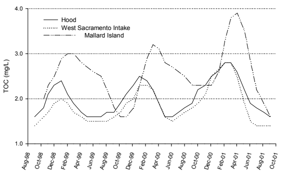


Figure 4-7 Monthly TOC at three stations sampled at the same time interval

The seasonality between the 2 stations was similar as indicated by the Loess smoothing of the TOC data (Figure 4-7). Although both the average and median TOC and DOC concentrations at the Hood station were slightly higher than those at the West Sacramento WTP Intake (Table 4-1), the Wilcoxon Rank-sum test suggests that TOC at the stations was not significantly different (p=0.10). The freshwater inflows from the American River may have diluted wastewater discharges from the 2 WWTPs before water reached the Hood station; therefore, average TOC at both stations was not statistically different. The different sources and factors that affect these stations are discussed in section “Sources of Organic Carbon in Delta Waters” of this chapter.

West Sacramento WTP Intake vs. Mallard Island

Although TOC concentrations at the West Sacramento WTP Intake and Mallard Island stations appear tied to rainfall events in their respective watersheds, the 2 stations differed in TOC peak times. The highest TOC levels at the West Sacramento WTP Intake occurred from December to March of each water year, which was parallel to rainfall events in the area. The highest TOC concentration at Mallard Island occurred from February through April (Figure 4-7). TOC peak times between the 2 stations appear to have been offset by approximately one month. Average and median TOC levels at Mallard were much higher than at the West Sacramento WTP Intake station (Table 4-1). These differences were highly significant ($p<0.0001$).

Higher TOC at the Mallard Island station may be attributable to a variety of reasons. There are many agricultural drainage sites between West Sacramento WTP Intake and Mallard Island along the Sacramento River. Mallard Island receives water from both the SJR and Delta channels, which contain higher organic carbon than water from the upper Sacramento River. In-channel production and Delta agricultural drainage returns may also increase TOC at Mallard Island.

Hood vs. Mallard

TOC concentrations at Mallard Island also were significantly higher ($p=0.002$) than at Hood (Figure 4-7). Peak TOC levels at Hood occurred earlier than at Mallard Island each water year (Figure 4-7). The differences in TOC concentration and peak times may be explained by the same hydrologic reasons responsible for the differences between Hood and West Sacramento WTP Intake.

San Joaquin River Stations

Two stations were monitored on the SJR. The Vernalis station at the entrance to the Delta was monitored weekly, and the Highway 4 station inside the Delta was monitored monthly. The Highway 4 station receives inflows from Vernalis. Water circulation is poor at this section of the SJR. The flow pattern is complex and fluctuates around 1,000 cubic feet per second (DWR 2001), depending on the pumping activities at the State and federal pumping plants.

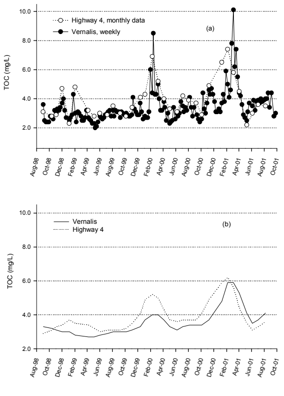


Figure 4-8 Monthly TOC at Vernalis and Highway 4

Although sampling frequencies differed between the 2 sites, seasonal patterns appear to have been similar (Figure 4-8(a)). Water quality at Highway 4 could also be influenced by inflows from the Calaveras River, but such inflows are usually much less than inflows from Vernalis. Therefore, the changes of TOC with time at Highway 4 resemble those at the Vernalis station. Differences in sampling frequency made it difficult to compare trends statistically between the stations, but the differences in TOC became clear with the Loess smoothing procedure (Figure 4-8(b)). It appears that TOC concentrations at Highway 4 were consistently higher than at Vernalis. The factors contributing to these differences are discussed in section “Urban Sources” of this chapter.

Delta Channel Stations

Delta channels, especially the Old River, provide source waters for the DMC, the California Aqueduct, and Contra Costa Water District intakes at Rock Slough and Old River near Station 9. MWQI takes monthly grab samples from 2 stations along the Old River because of its importance. The 2 sites, one at Bacon Island (Bacon) and the other at Station 9 near Highway 4, are approximately 9 miles apart. More than 10 agricultural return sites drain to this section of Old River from 5 islands/tracts: Holland, Bacon, Orwood, Woodward, and Victoria. The Woodward and North Victoria canals and Indian Slough join with this section of the river.

With a few exceptions, the temporal patterns of TOC and DOC at these 2 sites were similar (Figure 4-9). The average and median TOC levels were slightly higher at Station 9 than at Bacon Island (Table 4-1); however, the reverse trend was also true at times (Figure 4-9). Statistically, there was no significant difference in average TOC between the 2 sites (p=0.09).

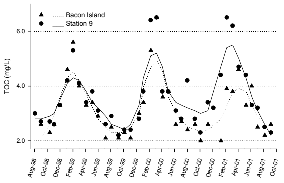


Figure 4-9 Monthly TOC at two Old River stations (Loess smoothing parameter = 0.2

Sacramento River vs. San Joaquin River

The Sacramento River at Hood and the SJR near Vernalis stations represent the condition of waters from both rivers at or near their entrance to the Delta. MWQI sampled the 2 stations weekly during the reporting period. Concentrations of TOC in the SJR were higher than those in the Sacramento River (Figure 4-10 and Table 4-1). The median TOC and DOC were 1.9 and 1.7 mg/L at Hood, and 3.1 and 2.8 mg/L at Vernalis. The Wilcoxon Rank-sum test indicates that average TOC was statistically higher at Vernalis than at Hood (p<0.001). Depending on hydrologic conditions of the Delta, organic carbon from the SJR system may dominate the river loads in the Delta. When this occurs, organic carbon in Delta waters may be significantly higher than the concentrations when the Sacramento River water is the major source.

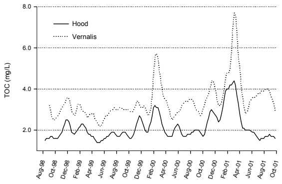


Figure 4-10 TOC: Sacramento and Hood vs. SJR near Vernalis

Organic Carbon Differences in Diversions Waters

The temporal patterns of TOC at the diversion stations were similar (Figure 4-11). Concentrations of TOC were higher during the wet months than during the dry months at all 3 stations. TOC began to increase starting in November, peaked during February and March, and started to drop in April or May. From July to November, TOC levels generally fell below 3 mg/L (Figure 4-11). Average and median TOC levels differed only slightly among the diversion stations (Table 4-1). Statistical comparisons among stations were not made due to differences in sample dates.

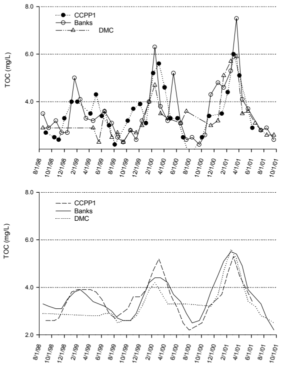


Figure 4-11 Monthly TOC at three Delta diversion stations (Loess smoothing parameter = 0.2)

Sources of Organic Carbon in Delta Waters

Agricultural Drainage Returns

There are more than 236 agricultural drainage return sites with one or more pumps within the Delta (Figure 4-12). Organic carbon content in agricultural drainage returns is invariably high; considerable organic carbon in Delta source waters may come from agricultural drainage.

Figure 4-12 Agricultural drainage returns (map)

During the reporting period, MWQI monitored 2 agricultural drainage sites—one on Bacon Island and the other on Twitchell Island. The Bacon Island Pumping Plant discharges to the Old River, and the Twitchell Pumping Plant to the SJR. Organic carbon at both agricultural drainage stations varied with the season. Concentrations were higher during the wet months than during the dry months of each water year (Figure 4-13). A statistical analysis could not be made due to incomplete data in the 2001 water year. Although organic carbon levels occasionally were as low as 5 to 6 mg/L, concentrations were higher than 10 mg/L during most of the reporting period (Figure 4-13) with average and median TOC and DOC levels varying from 12 to 15 mg/L (Table 4-1).

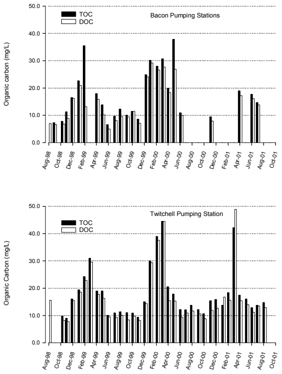


Figure 4-13 Organic carbon at two agricultural drainage stations

MWQI extensively monitored several Delta agricultural drainage sites (DWR 1990), but organic carbon loads from agricultural drainage could not be accurately estimated based on these historical data because of a lack of pumping rates. Detecting the influences of agricultural drainage returns on receiving channel waters is difficult; however, monitoring data suggest that organic carbon levels in the channels varied in response to carbon in the drainage waters as shown in Figure 4-14. Although TOC in the channel waters was much lower than in the drainage ditches, temporal changes of TOC in the channel were similar to those observed in the 2 agricultural drainage sites. Organic carbon concentrations were higher in channel waters than in waters from either the SJR or the Sacramento River. These 2 facts suggest that TOC in the channels are either due to agricultural drainage or produced by in-channel processes such as phytoplankton growth. Although MWQI does not monitor phytoplankton productivity in the Delta, nutrient-rich Delta waters are known to cause algal blooms and other aquatic growth (Chapter 8 of DWR 2001). For example, algae and other aquatic organisms often die and decay during fall in the San Luis Reservoir (Mathews 2000 pers comm). Similar decay processes in channel waters may release organic carbon fixed earlier in the season into Delta channels and increase organic carbon.

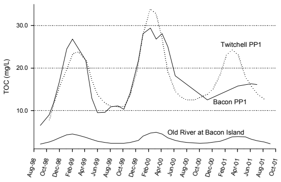


Figure 4-14 Changes in organic carbon in the Old River in response to agricultural drainage returns (Loess smoothing parameter = 0.2)

Urban Sources

Urban sources of organic carbon in the Delta include urban runoff and wastewater discharges to Delta waterways and potentially affect 3 MWQI monitoring stations: NEMDC, Sacramento River at Hood, and San Joaquin River at Highway 4.

Natomas East Main Drainage Canal

The NEMDC at El Camino Avenue in north Sacramento is an urban drainage canal that discharges water to the Sacramento River. The NEMDC relative to both the American and Sacramento rivers is shown in Figure 4-1. About half of the NEMDC watershed is densely populated, and water discharged to the canal comes from a variety of urban sources.

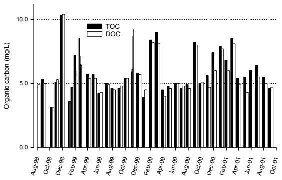


Figure 4-15 Organic carbon at the Natomas East Main Drainage Canal

Organic carbon varied around 5 mg/L during most dry months. Carbon concentrations nearly doubled during some of the wet months (Figure 4-15). The high organic carbon concentration in September 2000 was probably due to rice drainage. In September 2000, Reclamation District 1000 Pump #6 discharged rice drainage to the NEMDC (McCune 2002 pers comm). No rainfall occurred during that month according to data collected at the Sacramento Executive Airport. Median concentrations of TOC and DOC were 5.5 and 5.0 mg/L, respectively (Table 4-1). Statistical analysis indicates no significant difference between average TOC and average DOC at the site (p=0.317), suggesting that organic carbon was primarily in the dissolved form. Although rainfall during the 2001 water year was much less than in the previous 2 water years, the differences in TOC and DOC among the 3 water years were small (Figure 4-15). Statistical analysis shows that average TOC and DOC were not significantly different among the water years (p=0.386 and 0.680 for TOC and DOC, respectively).

Organic carbon concentrations at NEMDC were much higher than those in the water of the nearby Sacramento River. Organic carbon loading from discharges at this site is under investigation by MWQI.

Urban Loads between West Sacramento WTP Intake and Hood

Average and median organic carbon concentrations were slightly higher at Hood than at the West Sacramento WTP Intake (Table 4-1); however, these levels were not statistically different. Two WWTPs, the West Sacramento WWTP and the Sacramento Regional WWTP, discharge to the river between West Sacramento WTP Intake and Hood (Figure 4-1). Considerable urban runoff occurs between West Sacramento WTP Intake and Hood. These urban sources contribute significant organic carbon loads within this section of the Sacramento River.

As shown in Figure 4-1, the American River merges with the Sacramento River between West Sacramento WTP Intake and Hood. Organic carbon levels are lower in the American River than in the Sacramento River; therefore, enrichment and dilution of organic carbon occur at the same time within this section of the Sacramento River. Inflows from the American River may be high enough to dilute carbon inputs from nearby urban sources, which makes organic carbon concentrations at Hood not statistically different from those at the West Sacramento WTP Intake.

Urban Loads to the San Joaquin River as Measured at Highway 4

Organic carbon at Highway 4 was higher than at the Vernalis station (Figure 4-8a and Table 4-1). Since Vernalis is upstream from the Highway 4 site, organic carbon concentrations at both sites should be similar if there are no additional sources of organic carbon. However, the Highway 4 site receives water from various urban sources as shown in Figure 4-16, including from a major WWTP to which many canneries and other industrial facilities are connected. Wastewater discharges at the Stockton shipyard also affect water quality at this site (DWR 2001). In addition, this section of the

Figure 4-16 Organic carbon sources in the City of Stockton (map)

river receives some of the street runoff from the City of Stockton with a population of more than 250,000.

The origin of TOC at the Stockton site is multifaceted due to complex hydrology and its proximity to Delta islands. The observed higher organic carbon levels at this site over the levels at Vernalis may be due to poor circulation, wastewater discharges, urban runoff from nearby WWTPs, canneries, and the shipyard.

Although SJR at Highway 4 was the only site monitored during the reporting period, other south Delta sites are becoming more likely to be influenced by urban sources as the cities of Tracy, Manteca, and Lathrop and the east Contra Costa County area develop. These urban developments may increase discharges to Old River (Holm 2003 pers comm).

UVA_{254} and DOC Relationships

This section discusses relationships between the ultraviolet absorption (UVA) and DOC in Delta source waters. Historically, UVA is measured at a wavelength of 254 nm, and thus is commonly referred to as UVA_{254}. It is widely used in the water industry.

UVA_{254} and Organic Carbon Aromaticity

UVA_{254} has been used as a surrogate measure of organic carbon for monitoring wastewater effluents and for evaluating organic removal by coagulation in WTPs (Eaton and others 1995). More recently, aromatic compounds have been implicated as DBP precursors. UVA_{254} was used as an indicator of aromaticity of organic carbon and, subsequently, for predicting the abundances of precursors of various DBPs. However, DBP precursors are a broad range of complex molecules. Some absorb ultraviolet (UV) at 254 nm, and some do not. To date there is no sufficient evidence to suggest that all UV-active organic compounds are DBP precursors, nor is there sufficient evidence to show that UV-inactive compounds are not involved in producing DBPs. A few aromatic compounds absorb at 254 nm, most aromatic compounds (or structural relatives of benzene) absorb at 205 nm and between 255 and 275 nm. On the other hand, many nonaromatic organic species absorb at or near 254 nm. For example, the organic compound 1,3-Cyclohexadiene has a UVA maximum at 256 nm, and the maximum for a straight chain organic compound 1,3,5-Hexatriene is 258 nm. It is thus inadequate to assert that UVA_{254} measures aromaticity of organic carbon.

Ranges of UVA_{254} in Delta Waters

During the reporting period, 657 samples were collected throughout the Delta and measured for both UVA_{254} and DOC. These samples represent typical temporal and spatial variations in the Delta region. A summary of sample distribution among stations and statistics is presented in Table 4-2. Samples were collected monthly except at the Hood and Vernalis stations, where samples were collected weekly.

Table 4-2 Sample distribution and statistics at UVA_{254} and DOC during the reporting period

The UVA_{254} data ranged from 0.021 to 2.250 cm^{-1} (Table 4-2). About 2.4% of the data exceeded the recommended upper limit of 0.900 cm^{-1} (Eaton and others 1995). These values were excluded from this analysis because values above 0.9 cm^{-1} are generally not reliable and sample dilution is required. The majority (90%) of the data (excluding 5% on each end of the distribution) range from 0.034 to 0.639 cm^{-1}. The central 50% of the data (or interquartile range) was 0.050 cm^{-1} (0.051-0.101), which represents dispersion of data.

Relationships Between UVA_{254} and DOC in Delta Waters

Figure 4-17(a) describes the relationship between UVA_{254} and DOC for 641 samples with a UVA_{254} of 0.9 or less. The coefficient of determination, $r^2 = 0.944$, was highly significant ($p<0.0001$), suggesting that the regression line could account for more than 94% of the data variation. However, when data below 0.5 cm^{-1} were presented with the overall regression line, misrepresentation of data below 0.3 cm^{-1} (93% of all data) by the overall regression line became clear (Figure 4-17(b)).

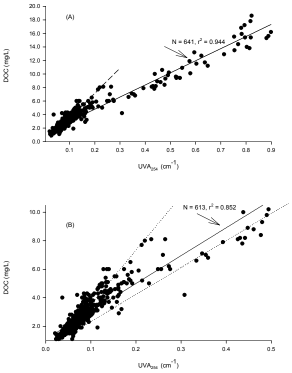


Figure 4-17 The relationship between UVA_{254} and DOC

The linear relationship between UVA_{254} and DOC diminished at the lower ranges of UVA_{254} (Figure 4-18). Figure 4-18(a) included UVA_{254} of 0.100 cm^{-1} or less, which represents 50% of the 657 samples collected during the reporting period. As shown in Figure 4-18(b), the majority of data variation cannot be accounted by the regression equation despite a high coefficient of determination (r^2). For example, a UVA_{254} of 0.08 may represent DOC from less than 2 mg/L to as much as 4 mg/L (Figure 4-18(a)); a DOC of 1.3 mg/L may result in a UVA_{254} from 0.026 to 0.038 (Figure 4-18(b)).

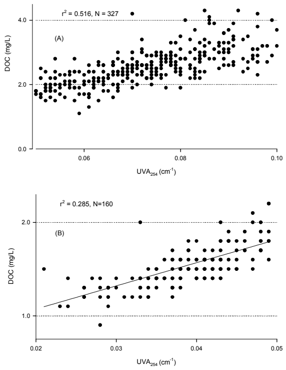


Figure 4-18 UVA_{254} and DOC relationships at low UVA_{254} ranges

The reason why a single regression line cannot be used to represent all data is that UVA_{254} varies both by site and by season. At a specific site, DOC is generally higher during the wet months than during the dry months. UVA_{254} and DOC relationships for samples collected during the dry months differed from those relationships in samples collected during the wet months, even when the samples were from the same station.

Specific UVA_{254} and DOC

UVA_{254} normalized on a carbon basis (that is, the ratio of UVA_{254} to DOC) is defined as specific UVA_{254} ($SUVA_{254}$). $SUVA_{254}$ has been used to compare organic carbon aromaticity and DBP formation potentials (DBPFP) among different sites.

Figure 4-19 describes the relationship between $SUVA_{254}$ and DOC. The regression for $SUVA_{254}$ and DOC had an r^2 of 0.353; such a regression line should not be drawn to represent the relationship because data scattering occurred. If UVA_{254} were indicative of DOC, $SUVA_{254}$ should be concentrated as a single data cluster roughly paralleling the x axis. However, 2 distinct clusters were observed, roughly above and below an $SUVA_{254}$ of 0.04. The cluster with $SUVA_{254}$ of 0.04 represented waters with relatively lower DOC. In this cluster, DOC varied from 0.9 to 8.1 mg/L, and UVA ranged from 0.021 to 0.265 cm^{-1} (Figure 4-19). More than 97% of waters in this cluster were collected from rivers or Delta channels; the remainder was waters from urban drainage. The cluster above an $SUVA_{254}$ of 0.04 represented waters of relatively higher DOC. DOC in this cluster ranged

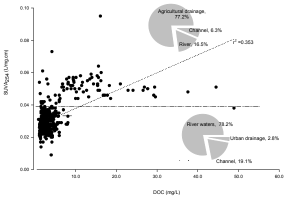


Figure 4-19 The relationship between $SUVA_{254}$ and DOC

from 1.1 to 44.5 mg/L, and UVA_{254} from 0.059 to 2.25 cm^{-1}. More than 77% of waters in this category were collected from agricultural drainage. The remainder of the samples came from rivers or Delta channels, which generally had lower DOC than the agricultural drainage sites (Figure 4-19).

Within each data cluster, there was considerable spread of $SUVA_{254}$ (Figure 4-19), suggesting that $SUVA_{254}$ varied considerably within each cluster, and $SUVA_{254}$ did not vary proportionately with DOC. Instead, $SUVA_{254}$ seemed to be site dependent. These results suggest that a single $SUVA_{254}$ was location dependent.

DBP Formation Potential of Delta Waters

Samples for DBPFP analyses were not collected regularly during most of the reporting period. This was due to concerns that DBPFP of source waters do not represent those of finished drinking waters and could be misinterpreted. The value of collecting such samples is thus questionable. MWQI discontinued monitoring DBP in July 1998. This section summarizes limited DBP data that have not been presented in previous MWQI annual reports. The data are presented simply to show general status of DBP in Delta source waters at the time the samples were collected, and they are not representative of spatial or temporal changes of DBPs in Delta waters. MWQI has no desire and makes no further effort to continue DBP monitoring. The California Department of Water Resources has presented a comprehensive analysis of DBPs of Delta waters and agricultural drainages (DWR 1990).

DBPFP at Delta Stations

Delta samples were all collected in August 1998. Two methods, one buffered and the other reactivity-based, were used to determine the formation potential of trihalomethanes (THMFP); the reactivity-based method alone was used to determine the total formation potential of 6 haloacetic acids (THAAFP). Total THMFP determined by the buffered method was consistently higher than that determined by the reactivity-based, variable chlorine dose method (Table 4-3).

Table 4-3 DBP formation potential in Delta waters

DBPFP in Delta waters varied with location. In general, Delta channels contained higher DBPFP than waters from the SJR and Sacramento River (Table 4-3). This is consistent with the fact that organic carbon concentrations were higher in channels and in agricultural drainage returns. The agricultural drainage return waters had the highest DBPFP (Table 4-3). Water from the SJR generally had higher DBPFP than water from the Sacramento and American rivers (Table 4-3). THMFP by the buffered method for the 3 samples collected at the American and Sacramento rivers averaged 160 µg/L and increased to 288 µg/L at Mallard Island, which receives water from both the SJR and the Sacramento River. Average THMFP by the buffered method for samples collected at the SJR near Vernalis was 329 µg/L (Table 4-3). THAAFP showed a pattern similar to that of THMFP (Table 4-3).

DBPFP at Diversion Stations

A limited number of monthly THMFP samples were collected and analyzed for DBPFP at the Banks Pumping Plant and the DMC at McCabe Road during the reporting period (Table 4-4 and Figure 4-20). Seasonality of THMFP at both stations was the same as that of organic carbon (Figure 4-11). At Banks THMFP ranged from 272 to 698 µg/L; THAAFP, from 84 to 271 µg/L. The median THMFP and THAAFP levels were 358 and 125 µg/L, respectively (Table 4-4). The median THMFP at the Banks station was comparable to the values obtained from waters in both the Delta channels and the SJR (Table 4-3 and Table 4-4). Comparison between Banks and DMC cannot be made because DMC data were missing from September 1998 through March 1999. However, DBPFP at DMC appears to have been similar to that at Banks when data from April 1999 through January 2000 were compared (Figure 4-20).

DBPFP Predictors

DBPFP appears to have followed the same patterns of seasonality as organic carbon. Because of a fairly small and nonrepresentative data set, relationships between DBPFP in Delta waters and potential predictors could not be reliably established. For example, samples from the Delta stations were all collected in August 1998. Continuous monthly DBPFP data were available for the Banks and DMC stations, but DOC was not measured at the same time. Instead, TOC was measured. Thus, a thorough analysis of the relationship between DBPFP and organic carbon could not be made.

Figure 4-21(a) summarizes the relationship between THMFP and both DOC and $SUVA_{254}$ for all the stations during the reporting period. No apparent strong linear relationship exists for either data set (Figure 4-21(a)). The coefficient of determination (r^2) for the regression line for THMFP and $SUVA_{254}$ was 0.454, suggesting that the regression could explain only 45% of the data variance.

Because DOC data were not available when DBPFP was measured at the diversion stations, only the relationship between DBPFP and TOC could be shown (Figure 4-21(b)). THMFP appears to have increased linearly with TOC, but such a linear relationship was weak due to data scattering. The r^2 was 0.50, suggesting that factors other than TOC were responsible for 50% of the data variance.

Although only limited data were available during the reporting period, the data seem to suggest that none of the 3 parameters—DOC, TOC, and $SUVA_{254}$—was a satisfactory predictor of DBPFP. However, a more thorough analysis should be made with a larger and more representative data set if an interest in this matter arises.

Table 4-4 Total DBP formation potential at two diversion stations

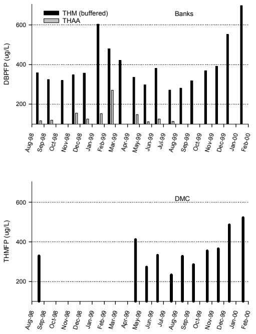


Figure 4-20 DBP formation potential at two Delta diversion stations

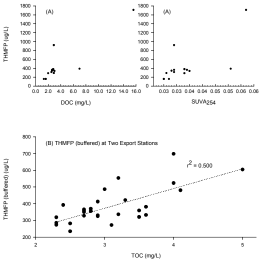


Figure 4-21 DBP formation potential, organic carbon, and $SUVA_{254}$ relationships

TOC and DOC Relationships

This section briefly summarizes the relationship between TOC and DOC. By definition, DOC is a fraction of TOC and should not be higher than TOC; therefore, samples having a DOC/TOC ratio greater than one were not included in this analysis.

A total of 669 samples collected throughout the Delta were analyzed for both TOC and DOC. DOC in all samples was measured by the oxidation method. TOC in 475 samples was analyzed by the oxidation method (TOC_{ox}), and TOC in the remaining 194 samples was measured by the combustion method (TOC_{cmbst}). Because TOC_{ox} and TOC_{cmbst} are not comparable, their relationships with DOC are presented separately.

A strong linear relationship existed between TOC_{ox} and DOC (Figure 4-22(a)). Of the 475 samples included in the analysis, only a few deviated significantly from the regression line. Most of the data could be described by the equation:

$$TOC_{ox} = 0.043+1.12*DOC, [r^2 =0.95]$$

A strong relationship was also found between TOC_{cmbst} and DOC, but the relationship was not as strong ($r^2 = 0.75$) as between TOC_{ox} and DOC (Figure 4-22(b)). TOC by combustion is known to be more variable than TOC by oxidation, especially for samples having high particulate matter. Therefore, the differences in their coefficients of determination (r^2) are not unusual.

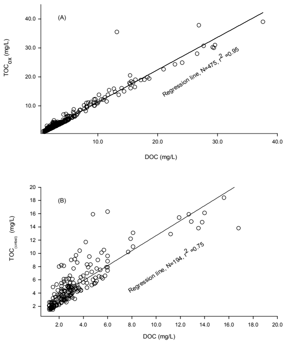


Figure 4-22 Relationship between TOC by two different methods and DOC in Delta source waters

Table 4-1 Summary of organic carbon at 14 MWQI stations (mg/L)

Station	River mileage[a]	Constituent	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
American and Sacramento River								
American River at E.A. Fairbairn WTP		TOC	36	1.1–2.5	1.1–1.9	1.3–1.6	1.5	1.5
		DOC	37	0.9–2.2	1.1–2.0	1.2–1.5	1.4	1.3
West Sacramento WTP Intake	63.2	TOC	36	1.3–4.1	1.4–2.9	1.5–2.1	1.9	1.6
		DOC	38	1.2–3.5	1.2–2.5	1.4–2.0	1.7	1.5
Sacramento River at Hood	38.6	TOC	162	1.3–6.5	1.5–3.7	1.6–2.4	2.1	1.9
		DOC	163	1.3–4.6	1.4–3.1	1.5–2.0	1.9	1.7
Sacramento River at Mallard Island	-4.1	TOC	34	1.4–5.2	1.6–4.0	1.9–2.8	2.6	2.5
		DOC	35	1.1–4.0	1.4–3.5	1.7–2.4	2.2	2.0
San Joaquin River stations								
San Joaquin River near Vernalis		TOC	156	2.0–10.1	2.4–5.1	2.8–3.8	3.4	3.1
		DOC	160	1.8–8.1	2.1–4.4	2.5–3.1	3.0	2.8
San Joaquin River at Highway 4		TOC	34	2.2–7.4	2.6–6.6	3.0–4.5	3.9	3.5
		DOC	36	1.9–6.5	2.3–4.9	2.7–3.8	3.3	2.9
Delta channel stations								
Old River at Station 9		TOC	38	2.2–6.5	2.3–6.4	2.7–4.2	3.6	3.3
		DOC	38	2.2–6.2	2.2–5.9	2.6–3.9	3.4	3.1
Old River at Bacon Island		TOC	36	2.0–6.5	2.1–6.2	2.5–3.8	3.4	3.1
		DOC	38	1.8–6.0	2.0–5.3	2.2–3.3	3.1	2.8
Diversion stations								
Banks Pumping Plant		TOC	37	2.2–7.5	2.4–5.5	2.7–4.1	3.6	3.2
		DOC	19	2.3–6.2	2.4–6.0	2.5–4.5	3.6	3.1
Delta-Mendota Canal		TOC	27	2.3–5.9	2.4–5.5	2.8–3.6	3.4	3.1
		DOC	17	2.3–5.8	2.4–5.7	2.6–3.4	3.4	3.0
Contra Costa Pumping Plant		TOC	29	1.7–6.0	2.3–5.4	2.9–4.0	3.6	3.4
		DOC	30	1.5–5.1	2.1–5.0	2.7–4.0	3.3	3.2

a. River miles from Collinsville at the junction of the Sacramento and San Joaquin rivers.

Table continued on next page

Table 4-1 continued

Station	River mileage[a]	Constituent	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
Agricultural drainage stations								
Bacon Island Pumping Plant		TOC	25	6.6–37.8	7.4–34.5	10.1–22.6	17.4	14.7
		DOC	26	5.0–29.2	6.7–27.5	8.3–18.0	14.4	12.4
Twitchell Island Pumping Plant		TOC	35	9.0–44.5	9.7–40.0	11.8–19.0	17.7	15.0
		DOC	36	7.8–48.9	8.2–39.3	10.0–16.4	16.3	13.8
Urban drainage station								
Natomas East Main Drainage Canal (NEMDC)		TOC	40	3.1–10.3	3.9–8.7	4.8–6.9	5.9	5.5
		DOC	41	3.1–10.4	4.0–8.2	4.7–6.0	5.6	5.0

Note: All statistics are calculated for positively detected samples; positive detects are samples with concentration greater than or equal to the reporting limit of 0.1 mg/L

[a] River miles from Collinsville at the junction of the Sacramento and San Joaquin rivers.

Table 4-2 Sample distribution and statistics of UVA_{254} and DOC during the reporting period

Station	Sample number	% of total
American River WTP	37	5.6
Bacon Pumping Plant 1	26	4.0
Banks Pumping Plant	9	1.4
Contra Costa Pumping Plant	30	4.6
Mallard Island	35	5.3
Natomas East Main Drainage Canal	16	2.4
Old River at Bacon Island	38	5.8
Sacramento River at Hood	159	24.2
Sacramento River at West Sacramento Intake	38	5.8
San Joaquin River at Highway 4	36	5.5
Old River at Station 9	38	5.8
Twitchell Pumping Plant	36	5.5
San Joaquin River near Vernalis	159	24.2
Total	657	100.0

Summary of statistics

Statistics	UVA_{254}	SUVA [a]
Minimum	0.021	0.009
Maximum	2.250	0.095
Mean	0.145	0.031
Median	0.073	0.029
5th percentile	0.034	0.022
95th percentile	0.639	0.052
25th percentile	0.051	0.026
75th percentile	0.101	0.033

a. Denotes specific UVA, which is the ratio of UVA_{254}/DOC.

Table 4-3 Disinfection byproduct formation potential in Delta waters

Station	Sample date	THM (B) [a]	THM (R)[b]	THAA (R) [b]	DOC	UVA_{254}
American River	08/04/1998	160	110	62	1.3	0.033
Sacramento River at Hood	08/04/1998	160	110	63	1.6	0.043
West Sacramento WTP Intake	08/04/1998	160	110	63	1.6	0.040
San Joaquin River near Vernalis	08/05/1998	314	240	79	2.5	0.073
San Joaquin River near Vernalis	08/11/1998	365	253	95	2.6	0.076
San Joaquin River near Vernalis	08/18/1998	293	248	108	2.9	0.074
San Joaquin River near Vernalis	08/25/1998	344	230	110	2.6	0.074
San Joaquin River at Highway 4	08/04/1998	919	258	115	2.9	0.085
Old River at Station 9	08/04/1998	338	266	126	3.0	0.105
Old River at Bacon Island	08/04/1998	380	218	117	2.8	0.093
Contra Costa Pumping Plant	08/05/1998	365	272	118	2.8	0.095
Sacramento River at Mallard Island	08/05/1998	288	241	72	2.0	0.066
Bacon Island Pumping Plant	08/04/1998	390	632	316	7.0	0.355
Twitchell Pumping Plant	08/05/1998	1,710	1410	665	15.6	0.889

a. THM formation potential determined by DWR modified buffered method. Method involves a fixed dose of chlorine, a 7-day buffered incubation.

b. THM and THAA formation potentials determined by the reactivity based method. Method involves variable doses of chlorine and a 7-day incubation.

Table 4-4 Total disinfection byproduct formation potential at two diversion stations

Station		Sample number	Range	Average	Median	IQR	5th-95th percentile
Banks Pumping Plant	THMFP[a]	18	272–698	395	358	321–414	280–618
	THAA[b]	13	84–271	136	125	113–148	91–201
Delta-Mendota Canal	THMFP[a]	11	234–523	357	332	306–389	254–505

a. THMFP determined by DWR modified buffered method. Method involves a fixed dose of chlorine, a 7-day buffered incubation.

b. THAAFP determined by the reactivity-based method, which involves variable doses of chlorine and a 7-day incubation.

Figure 4-1 Monitoring stations (▲) near the City of Sacramento

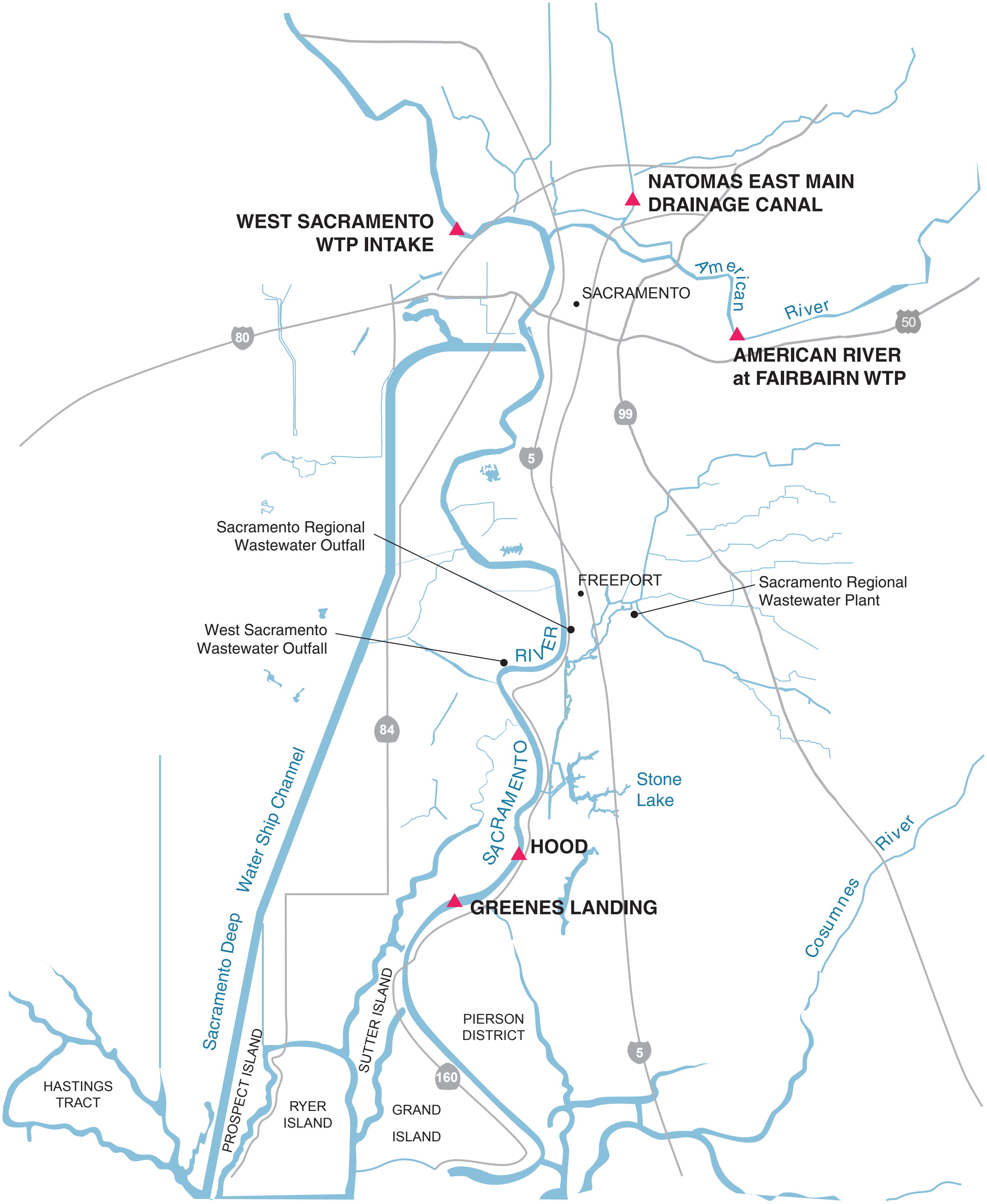
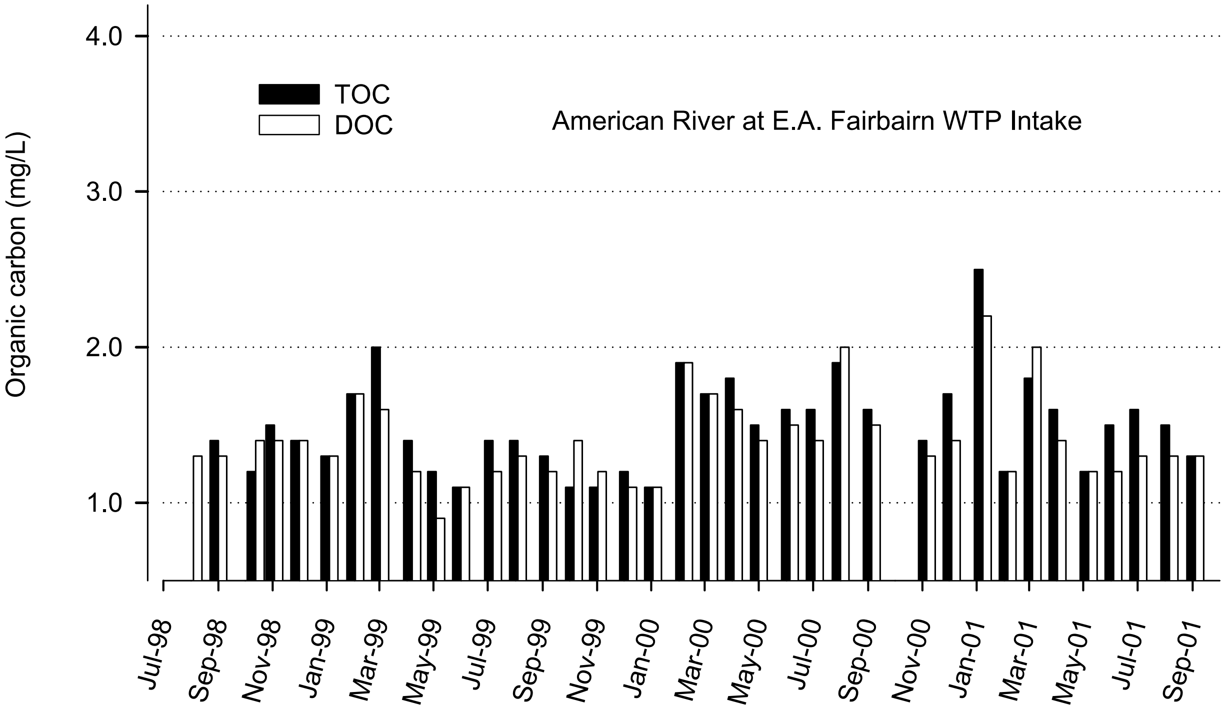


Figure 4-2 Organic carbon at the American River and West Sacramento WTP Intake



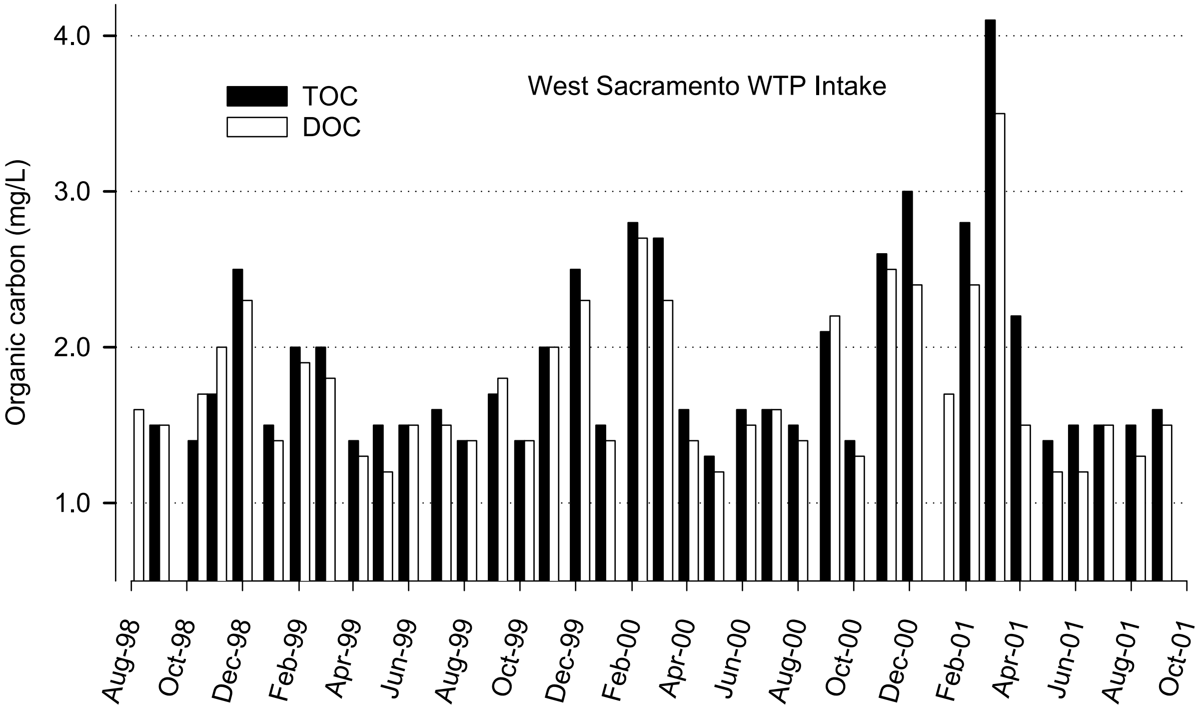
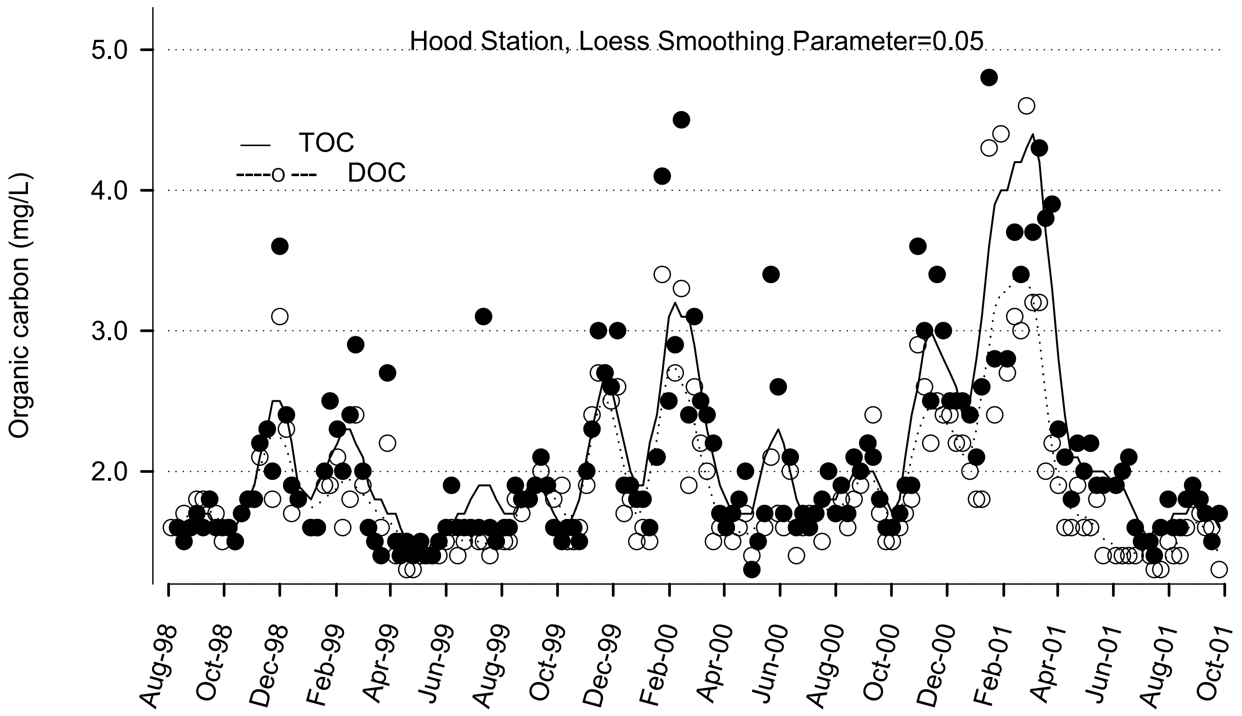


Figure 4-3 Organic carbon at Hood and Mallard Island stations



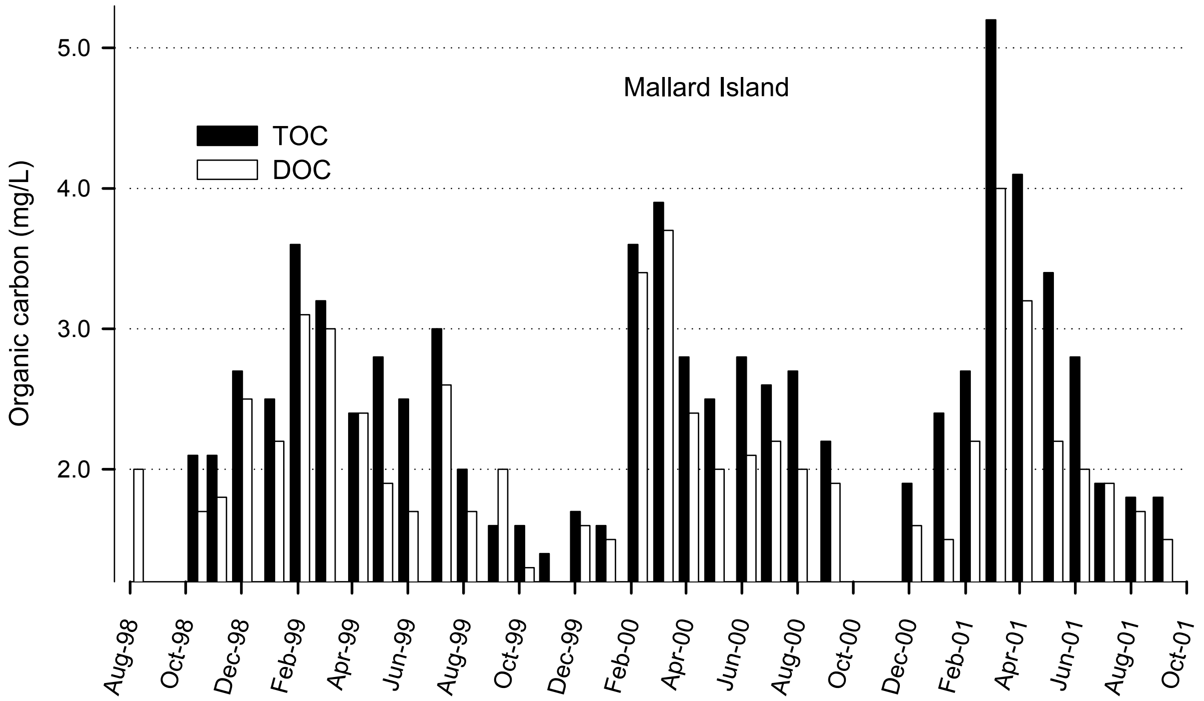
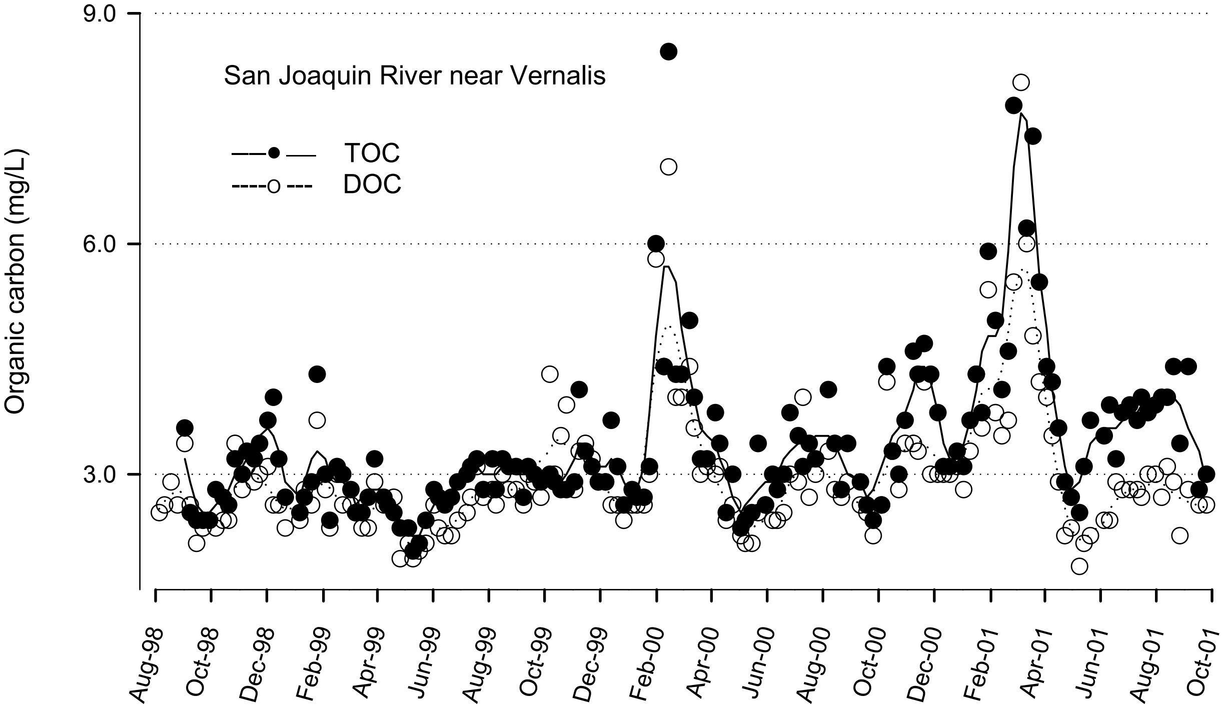


Figure 4-4 Organic carbon at two San Joaquin River stations



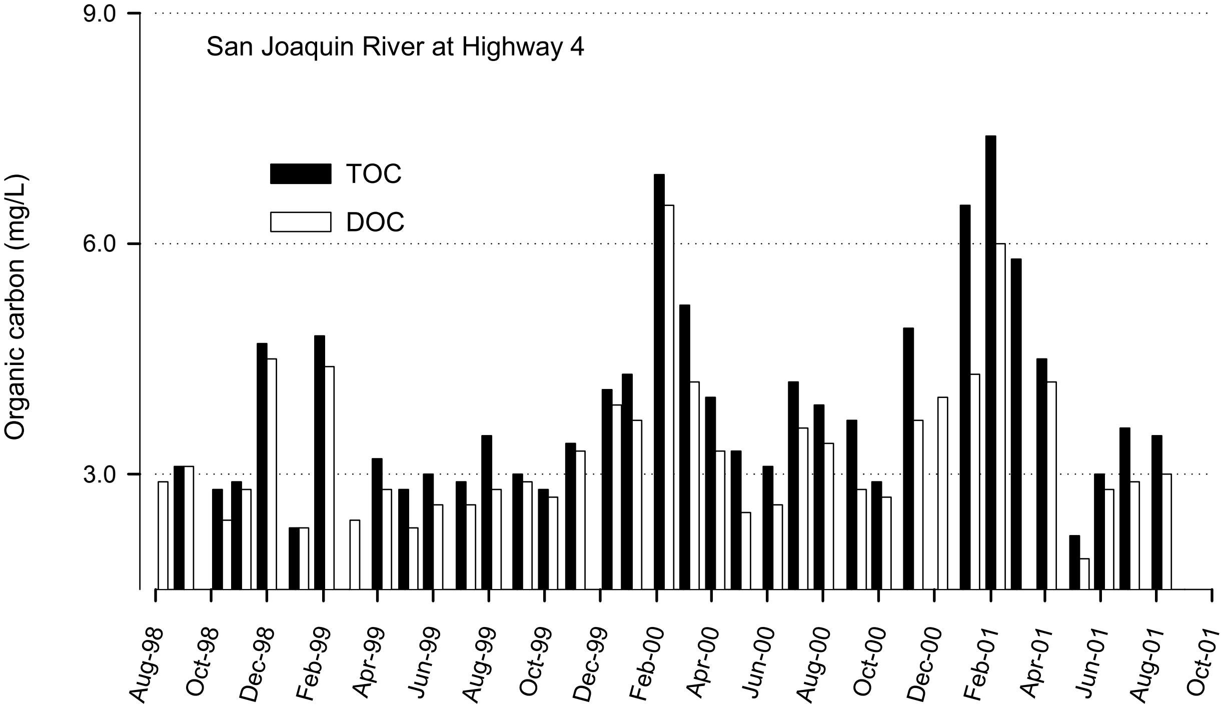
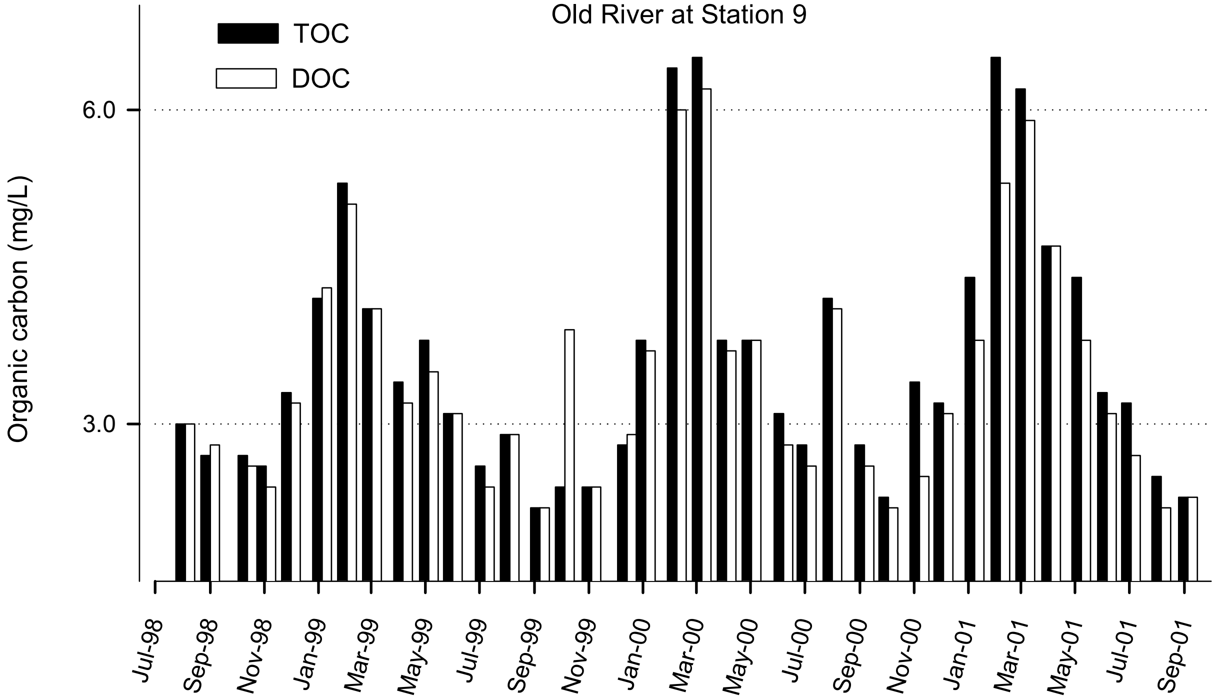


Figure 4-5 Organic carbon at two Old River stations



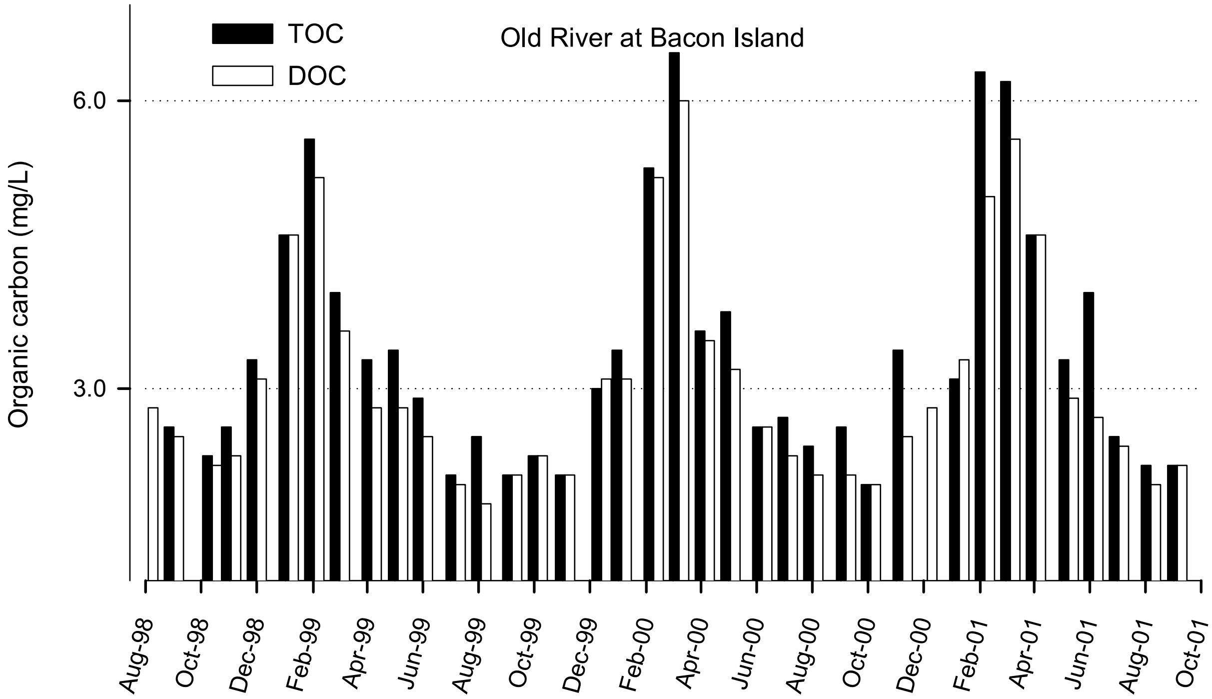
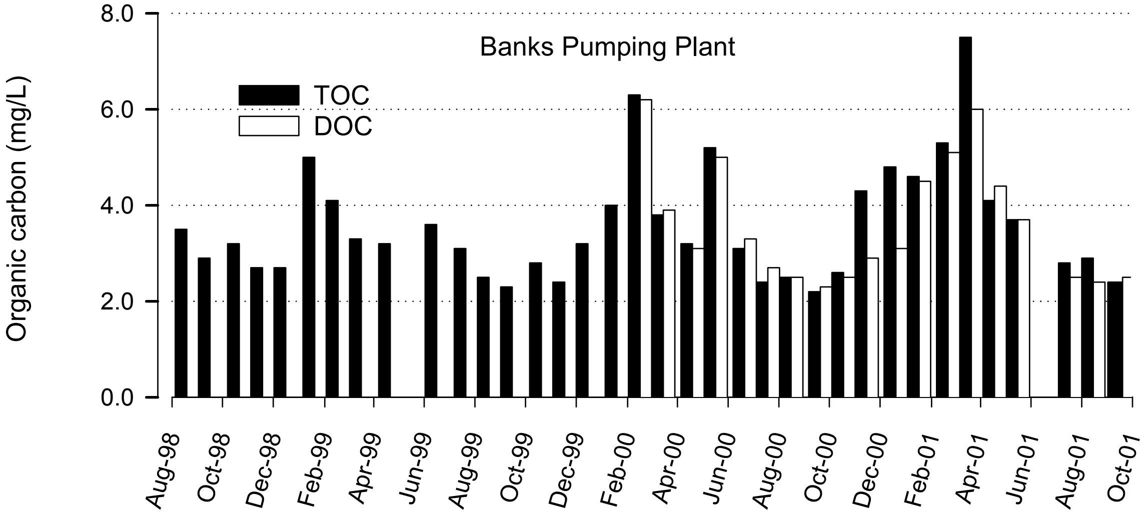
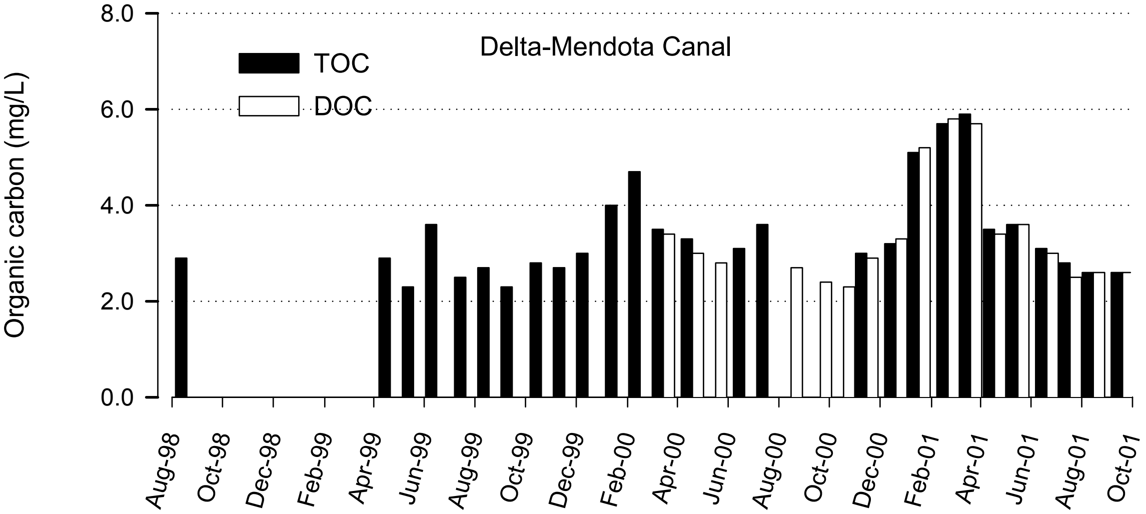


Figure 4-6 Organic carbon at three Delta diversion stations





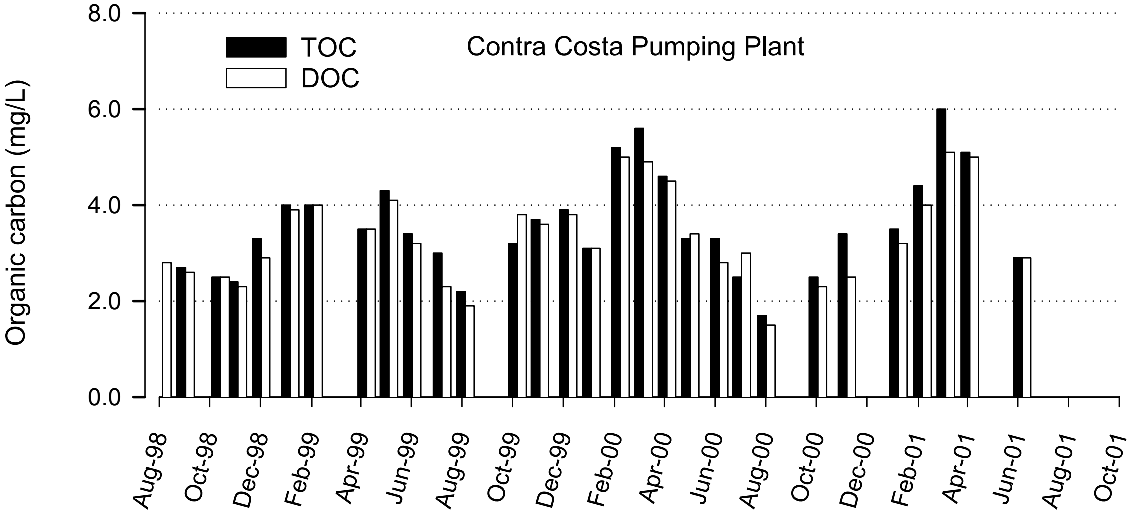


Figure 4-7 Monthly TOC at three stations sampled at the same time interval (Loess smoothing parameter = 0.2)

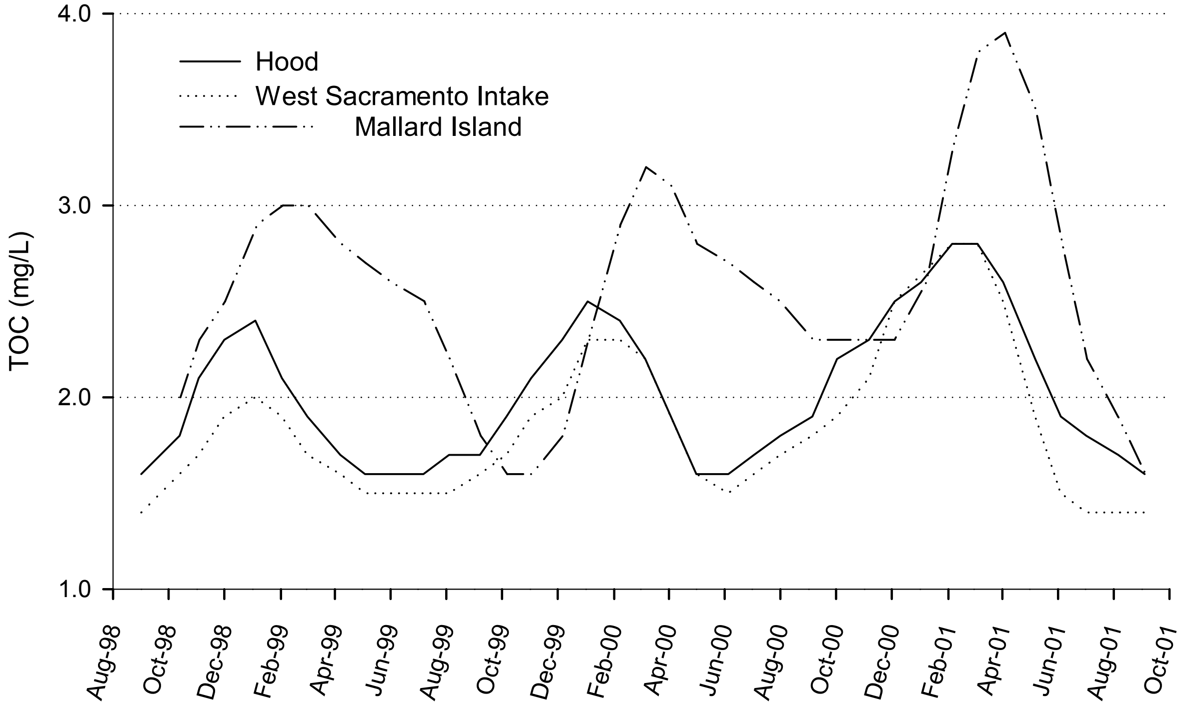


Figure 4-8 TOC at Vernalis and Highway 4

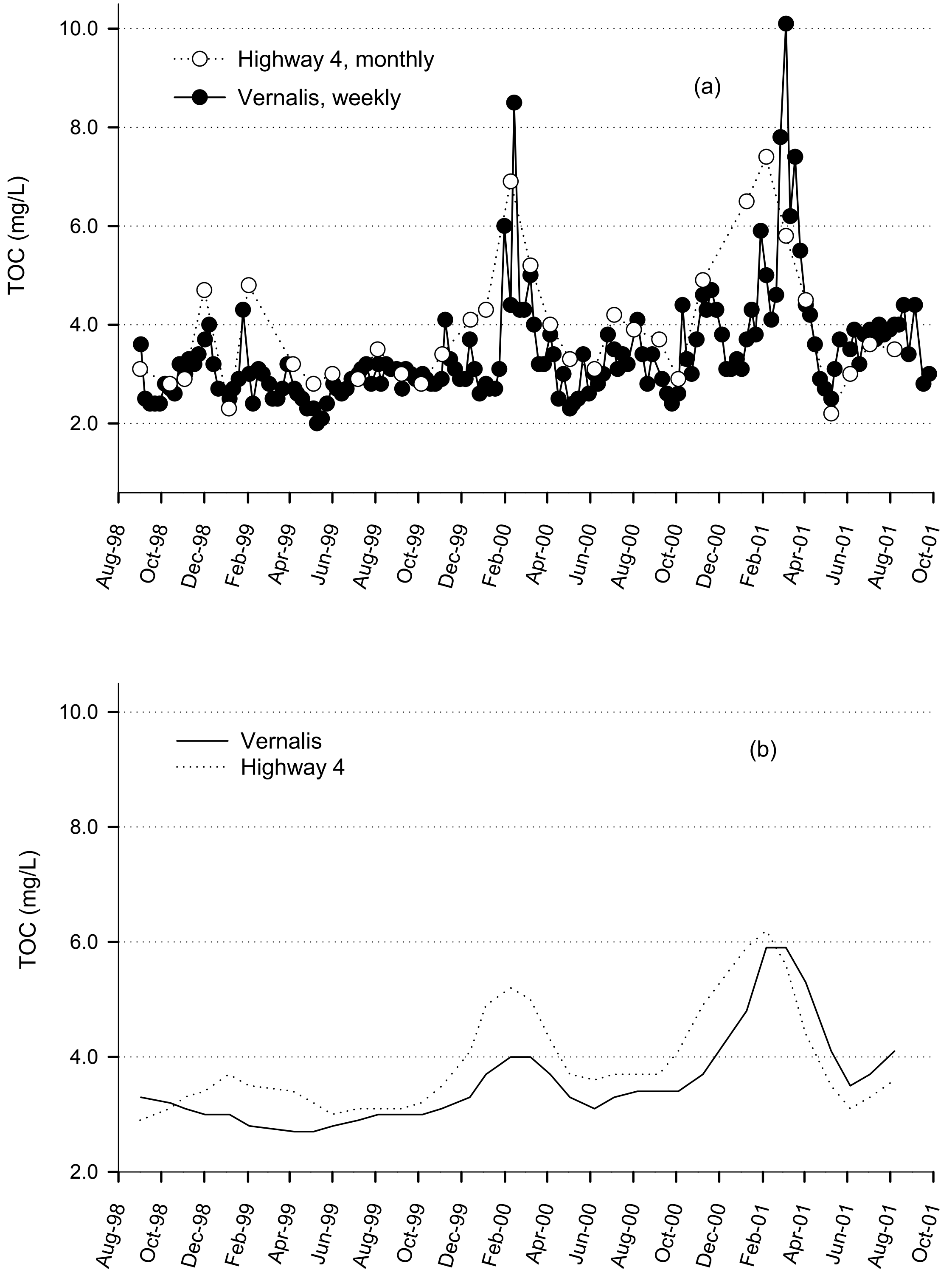


Figure 4-9 Monthly TOC at two Old River stations (Loess smoothing parameter = 0.2)

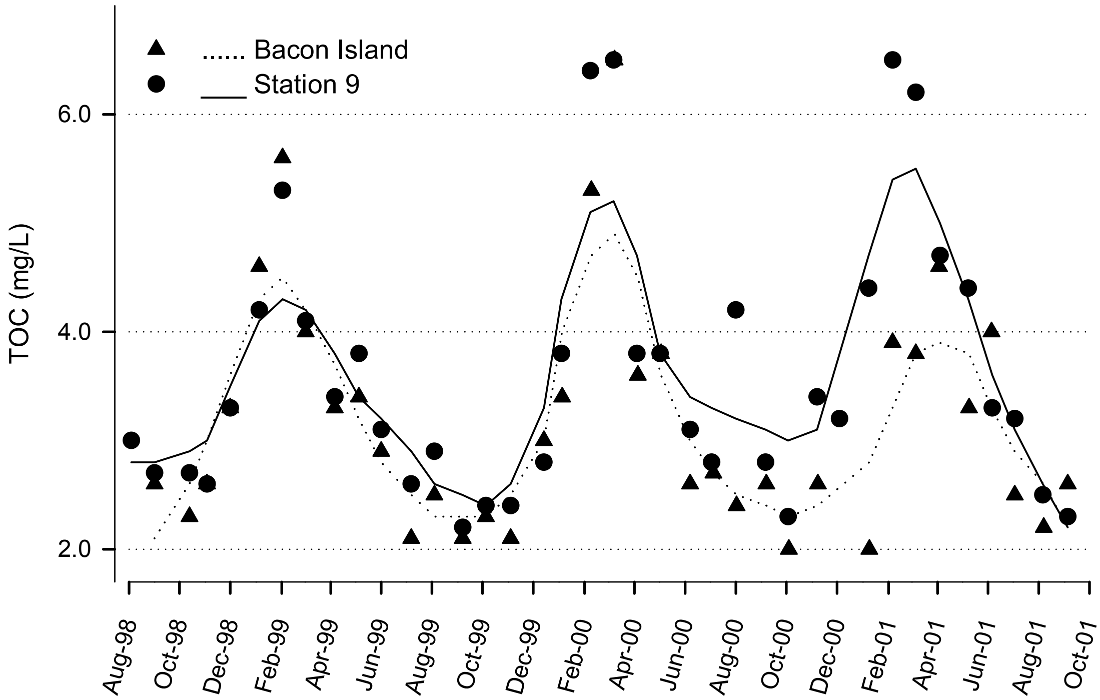


Figure 4-10 TOC: Sacramento River at Hood vs. San Joaquin River near Vernalis

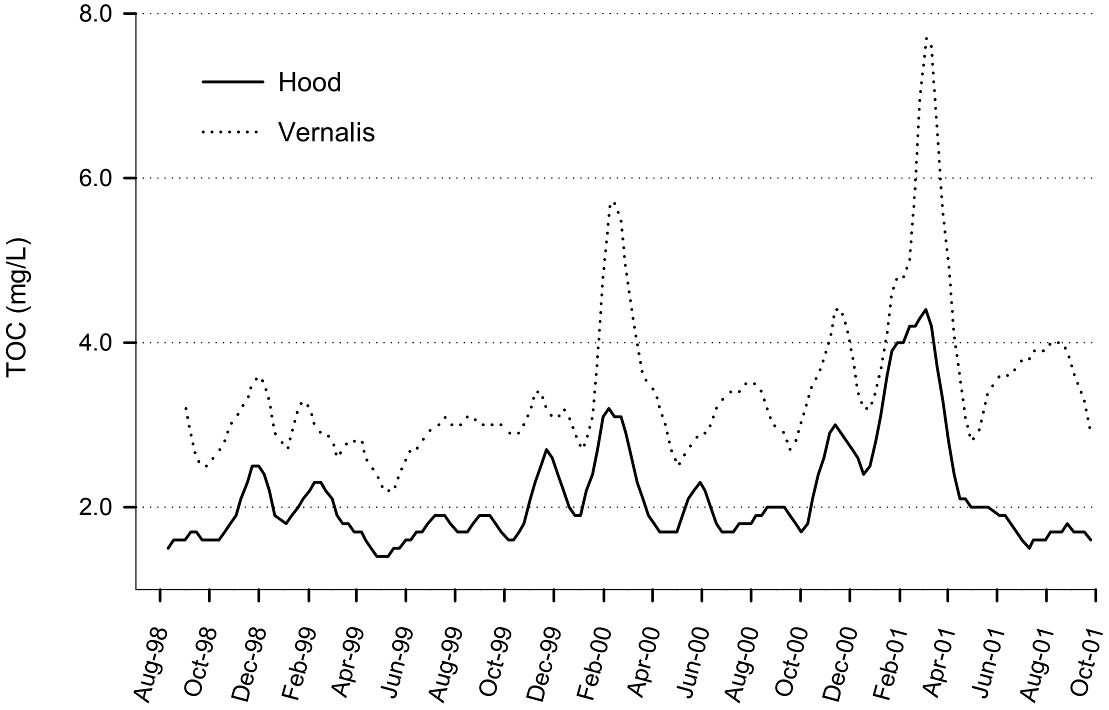


Figure 4-11 Monthly TOC at three Delta diversion stations (Loess smoothing parameter = 0.2)

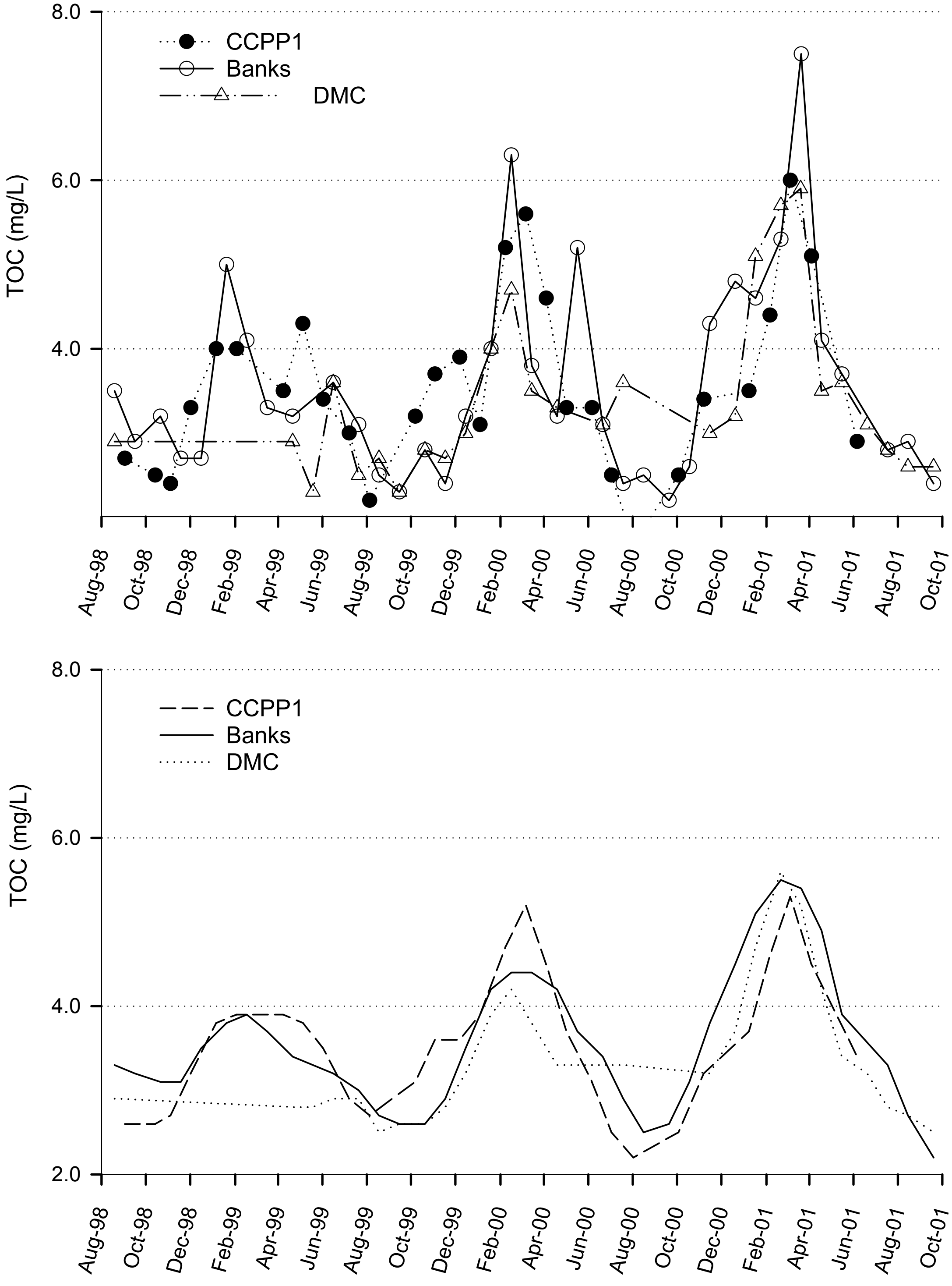
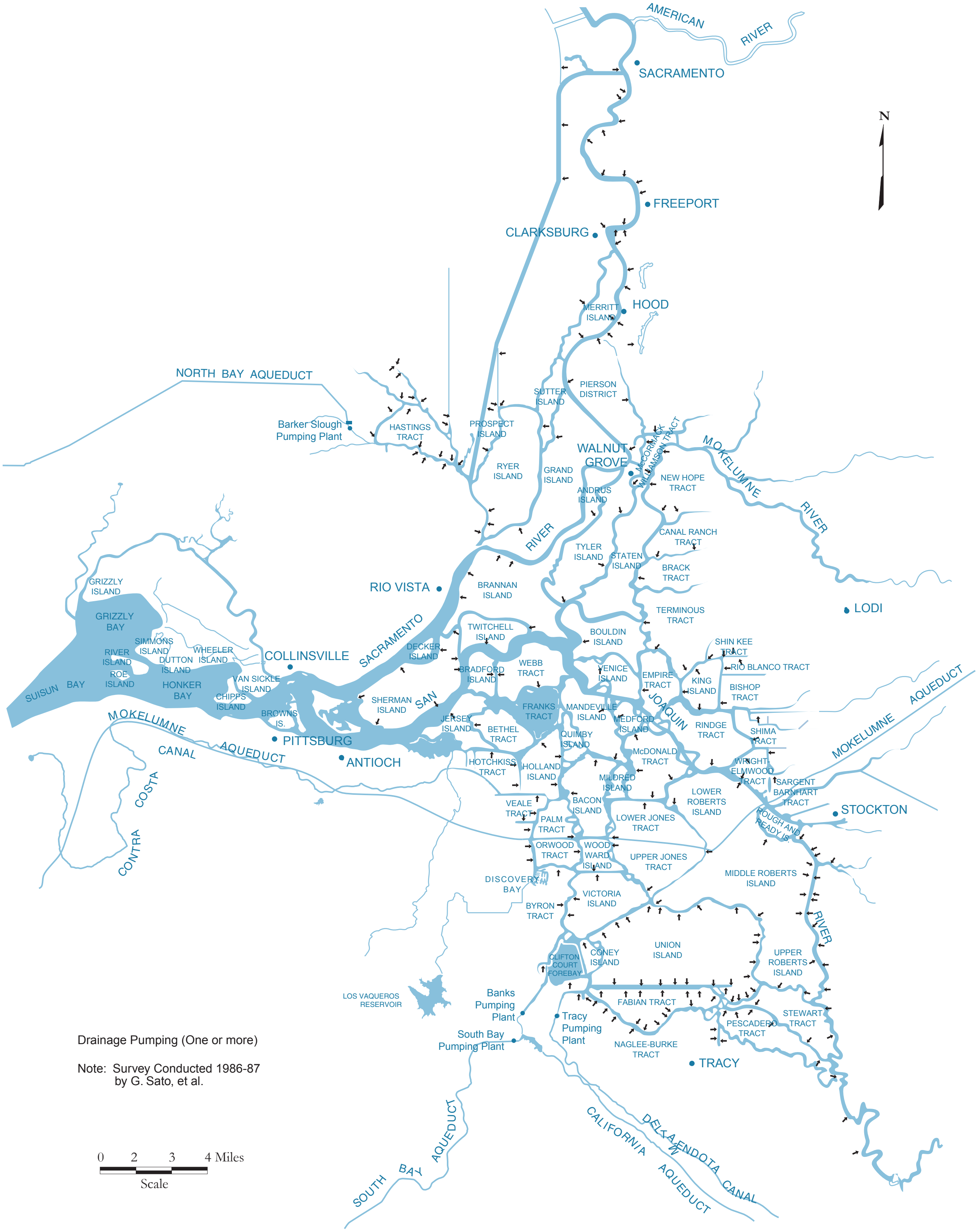
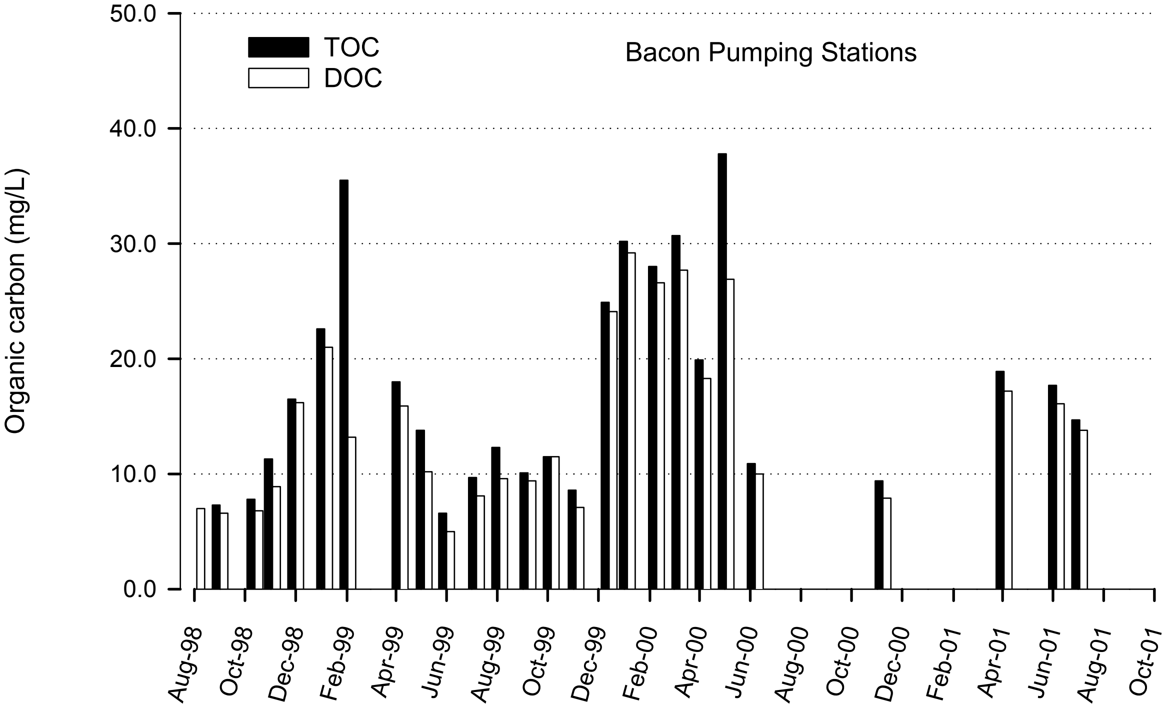


Figure 4-12 Agricultural drainage returns



Note: Survey Conducted 1986-87
by G. Sato, et al.

Figure 4-13 Organic carbon at two agricultural drainage stations



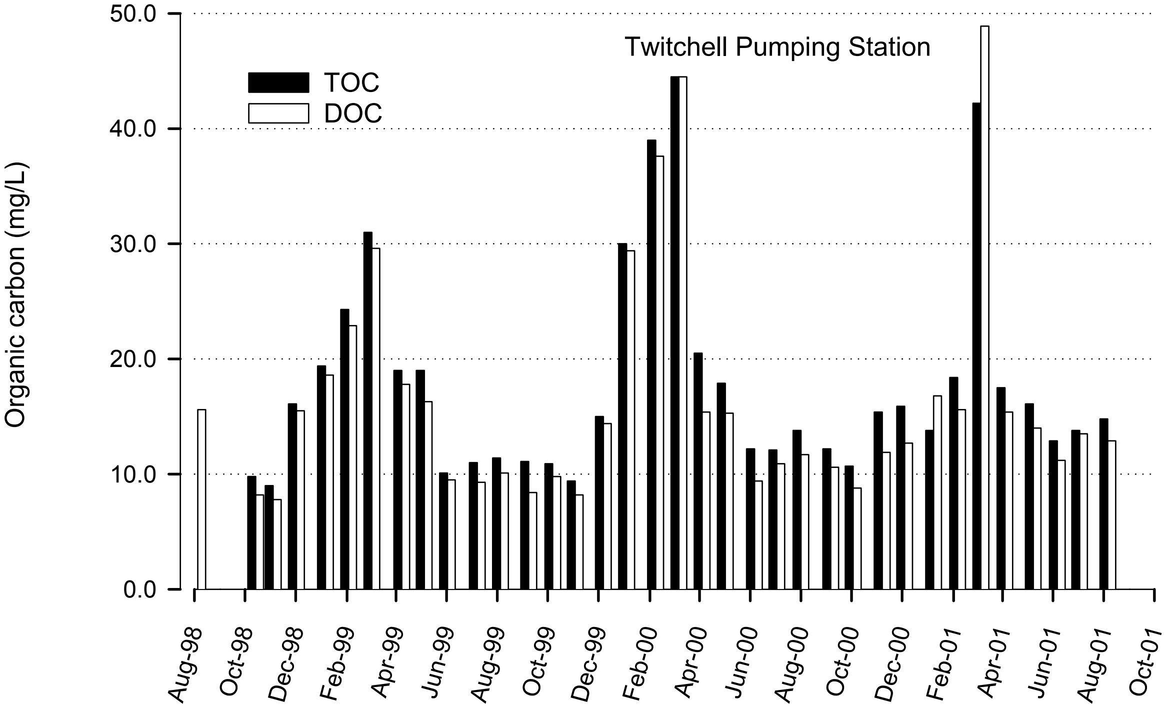


Figure 4-14 Changes in organic carbon in the Old River in response to agricultural drainage returns (Loess smoothing parameter = 0.2)

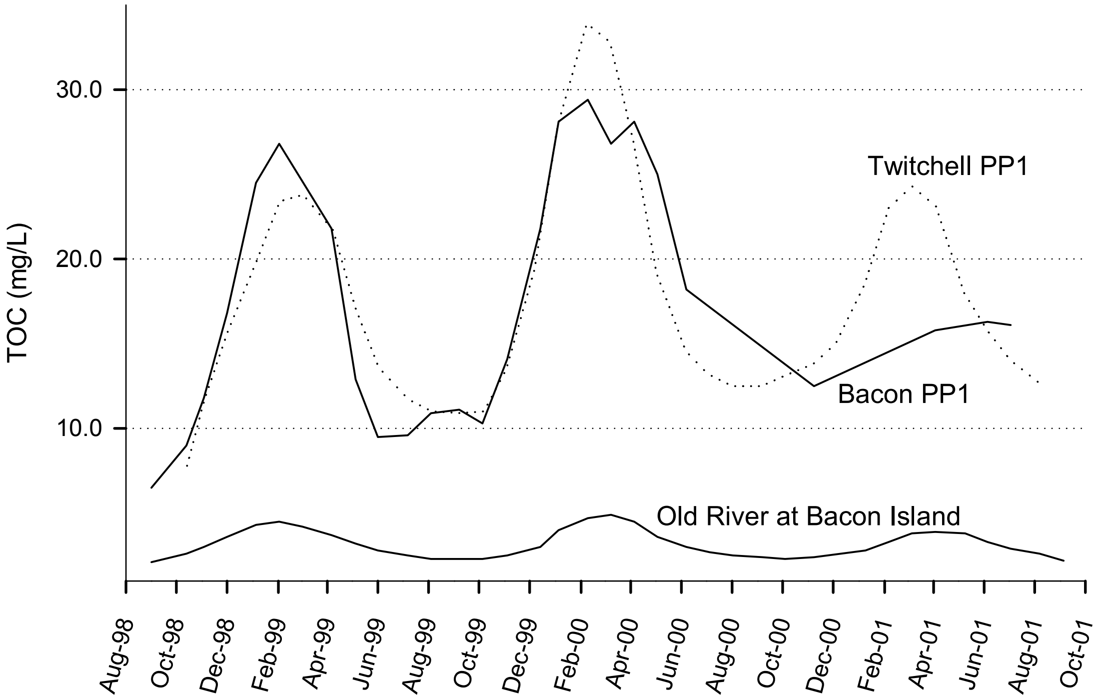


Figure 4-15 Organic carbon at the Natomas East Main Drainage Canal

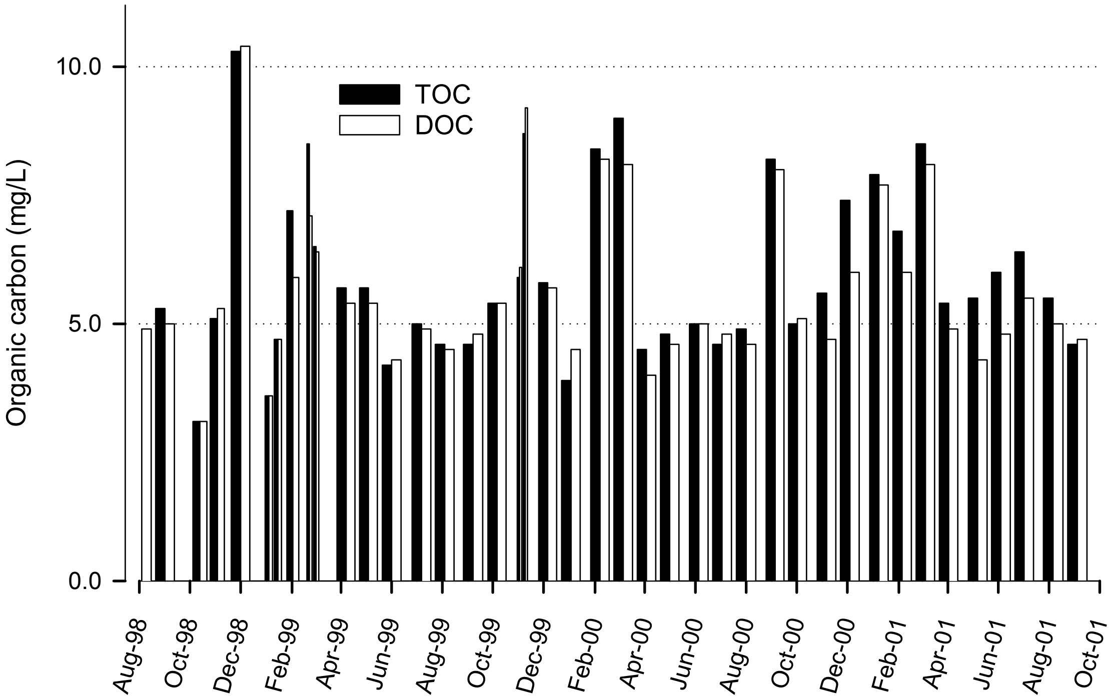


Figure 4-16 Organic carbon sources in the City of Stockton

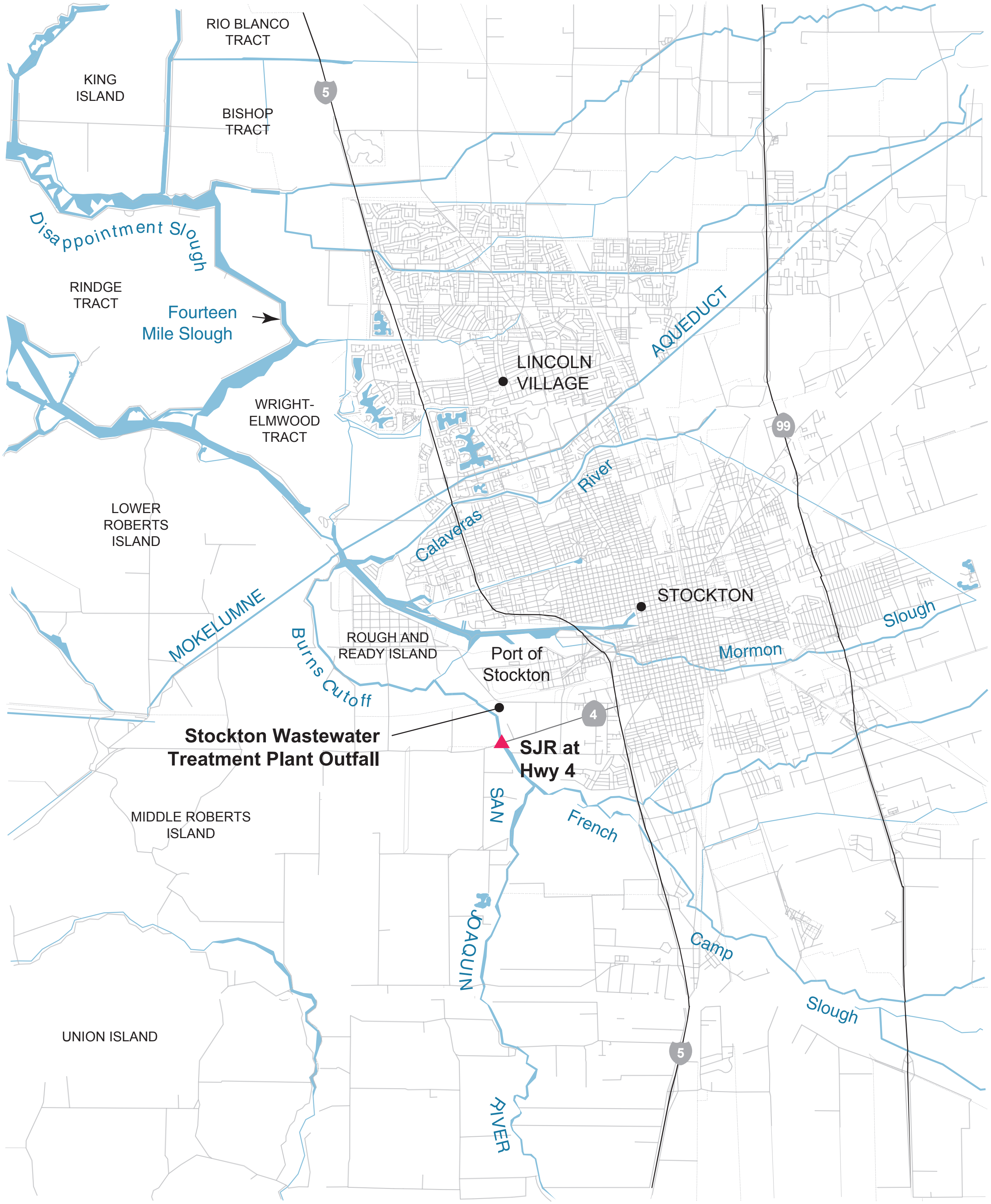


Figure 4-17 The relationship between UVA_{254} and DOC

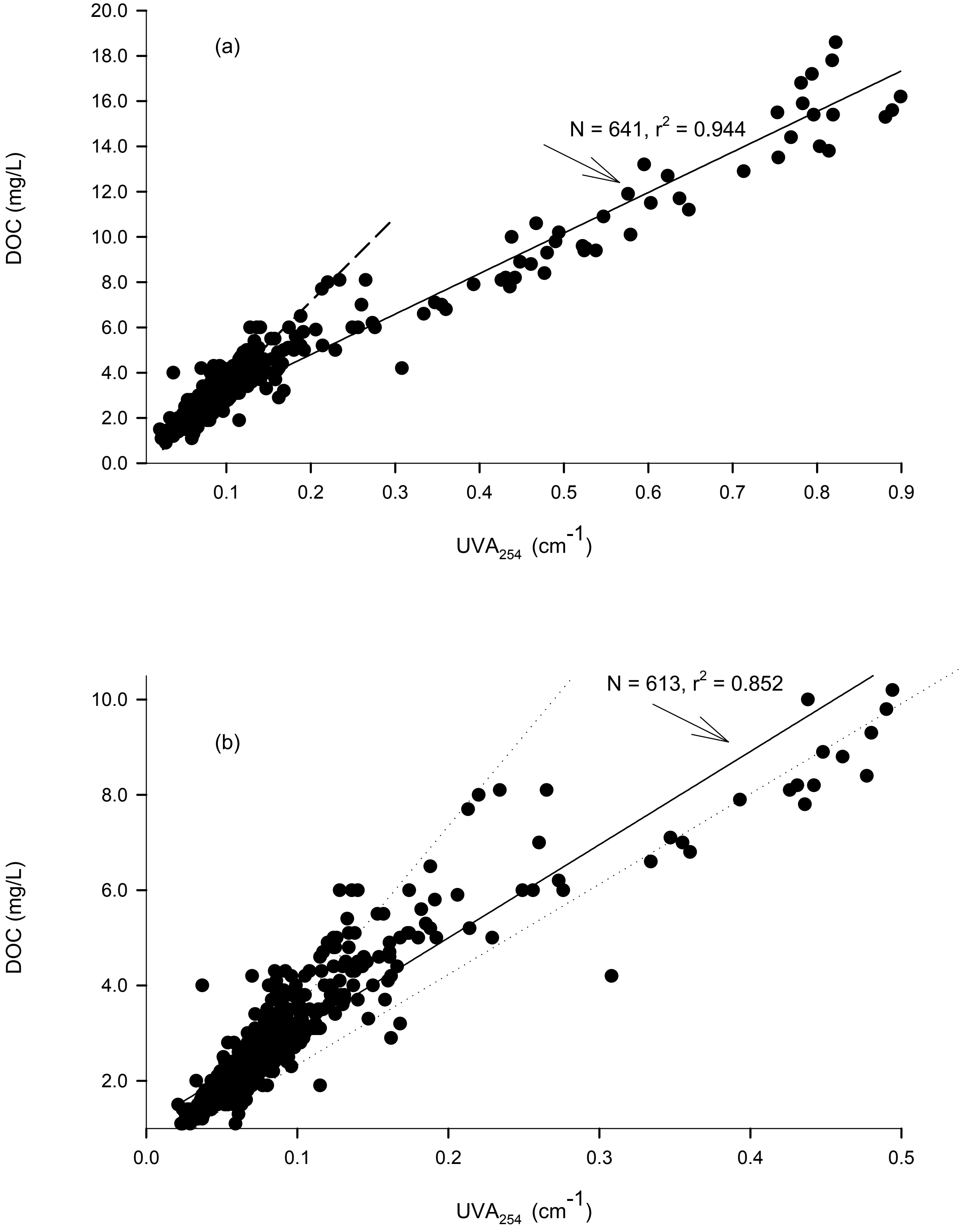


Figure 4-18 UVA_{254} and DOC relationships at low UVA_{254} ranges

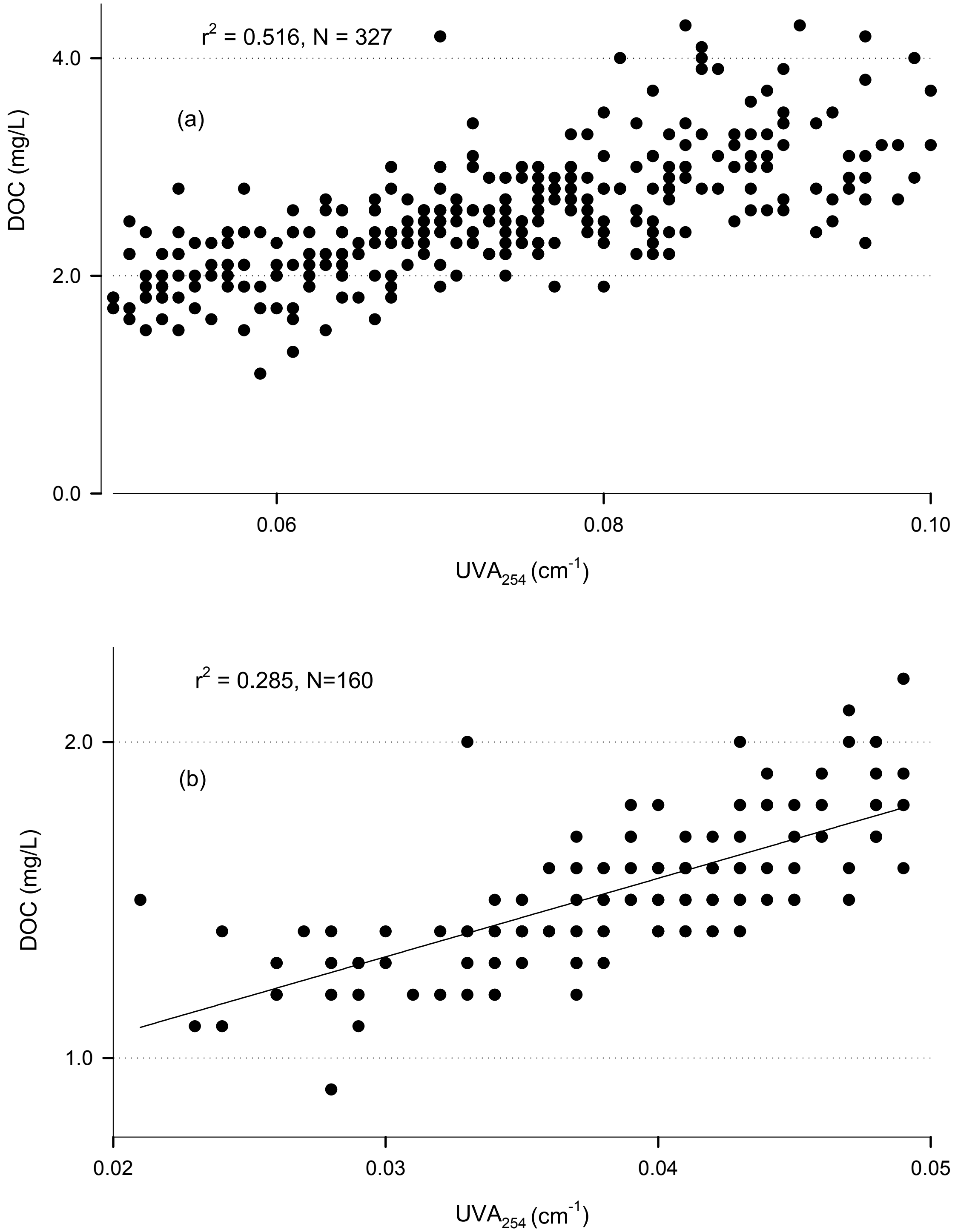


Figure 4-19 The relationship between $SUVA_{254}$ and DOC

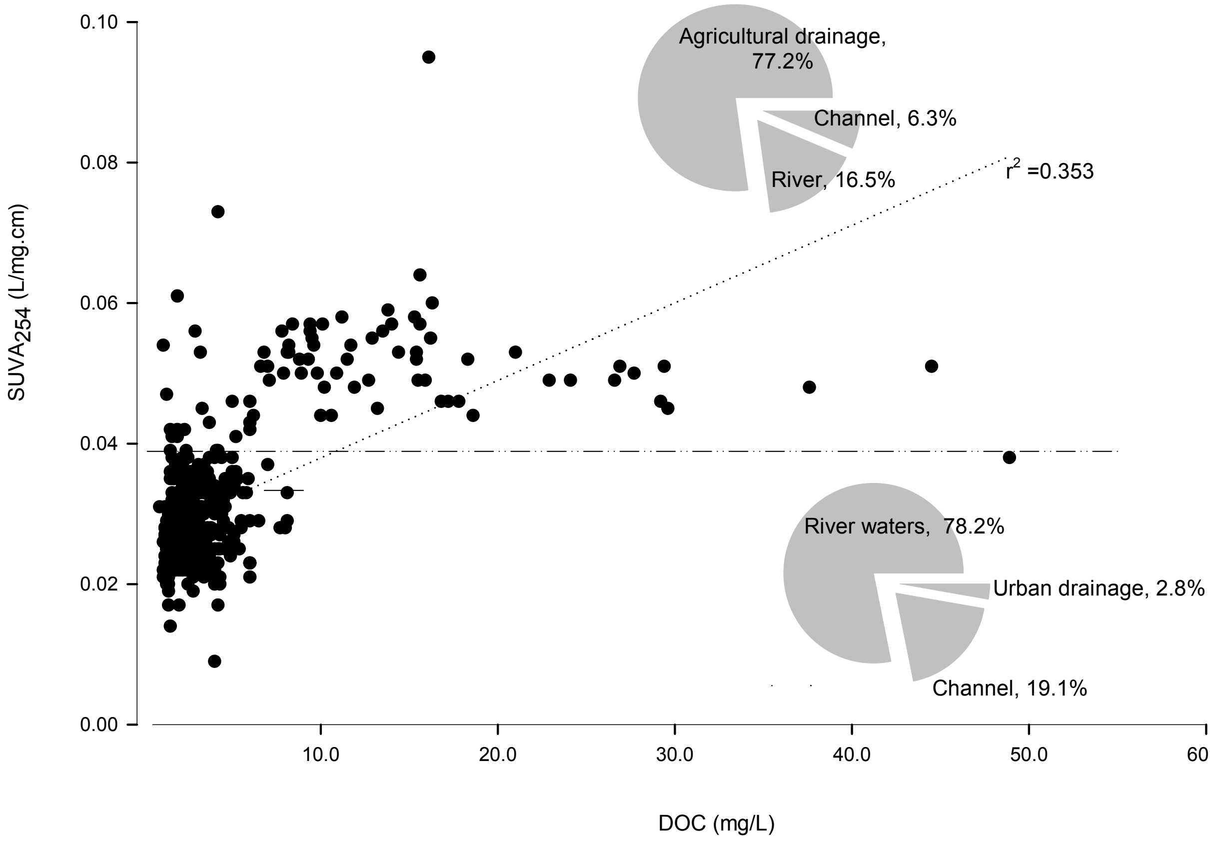


Figure 4-20 Disinfection byproduct formation potential at two Delta diversion stations

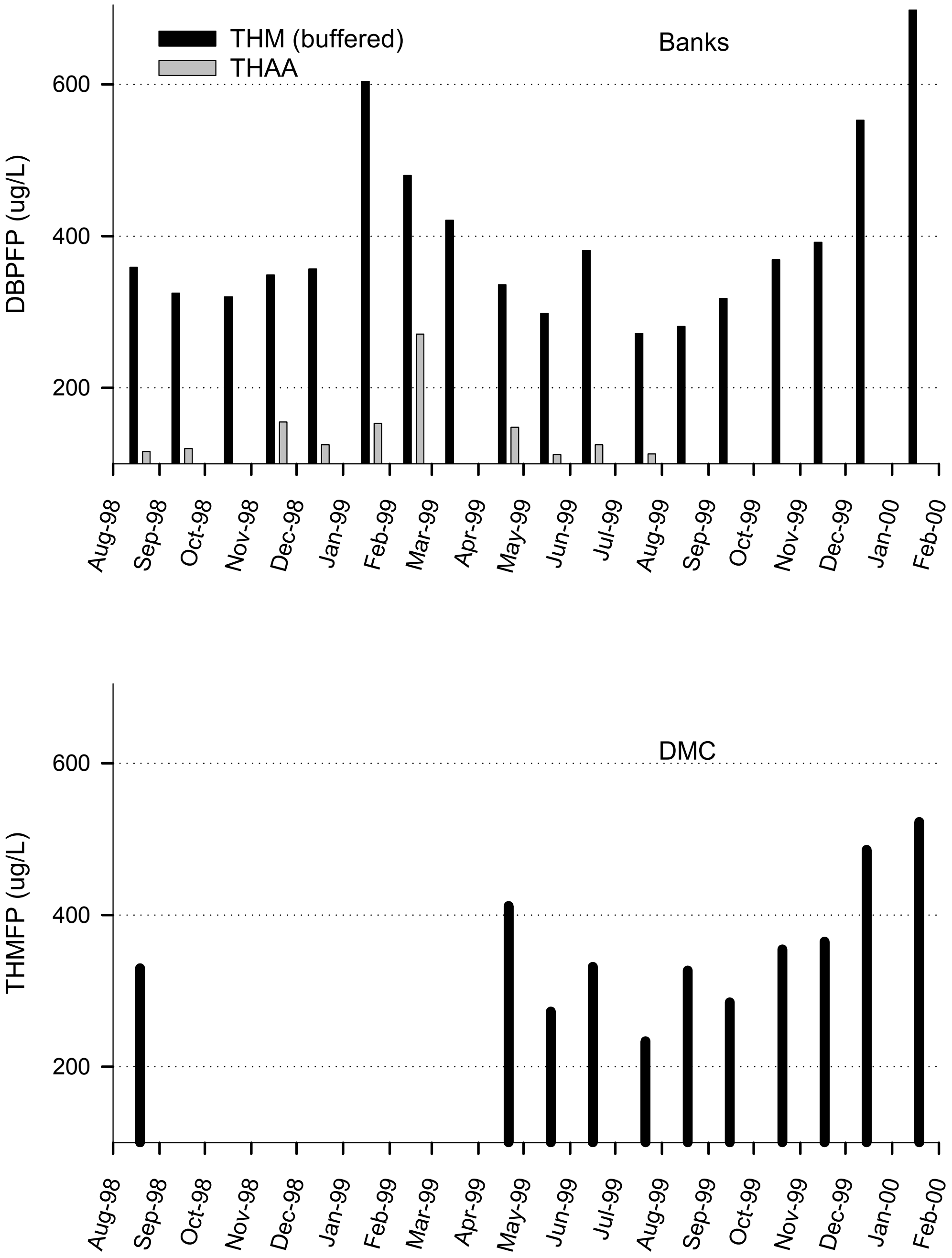


Figure 4-21 Disinfection byproduct formation potential, organic carbon, and $SUVA_{254}$ relationships

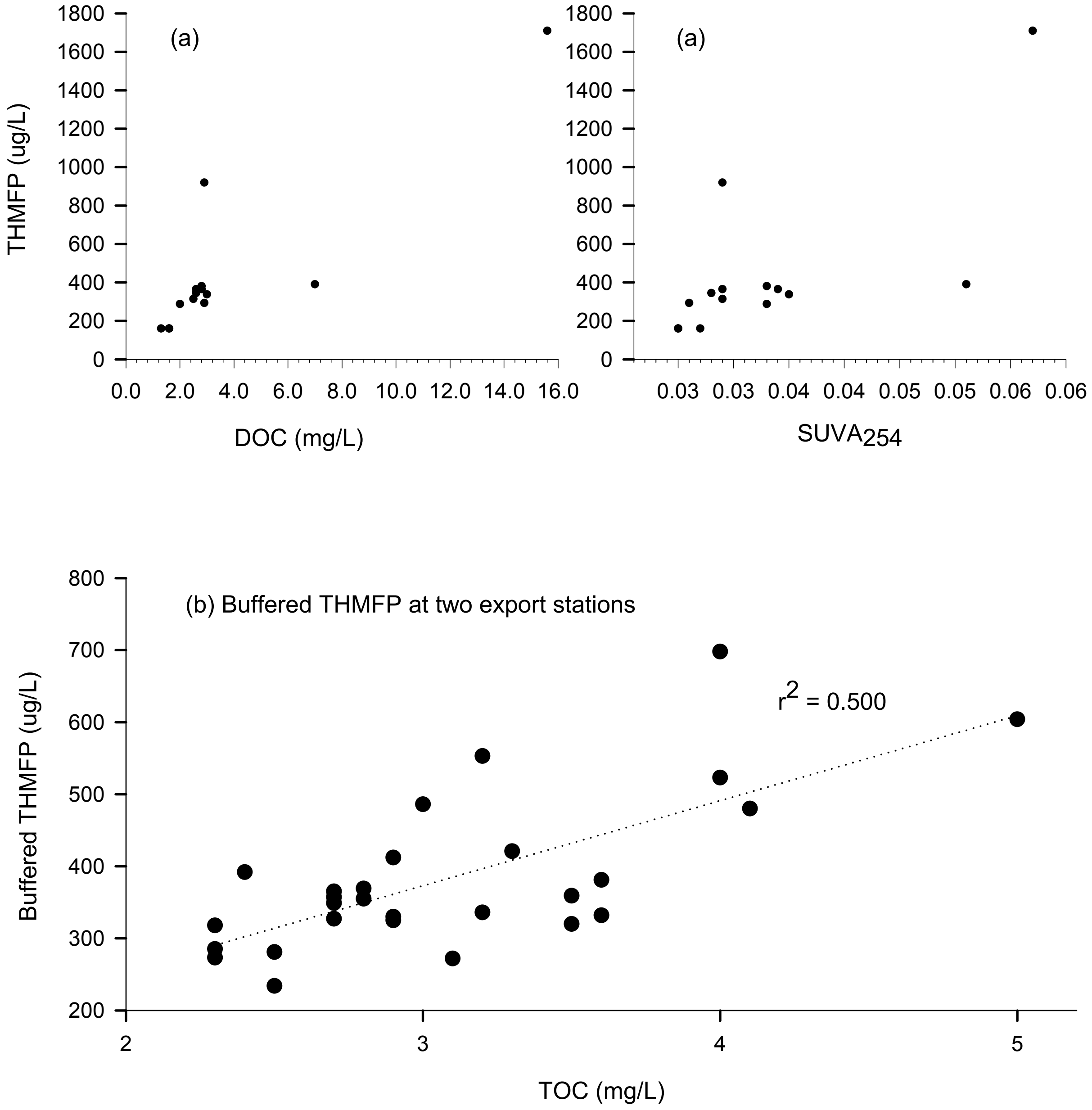
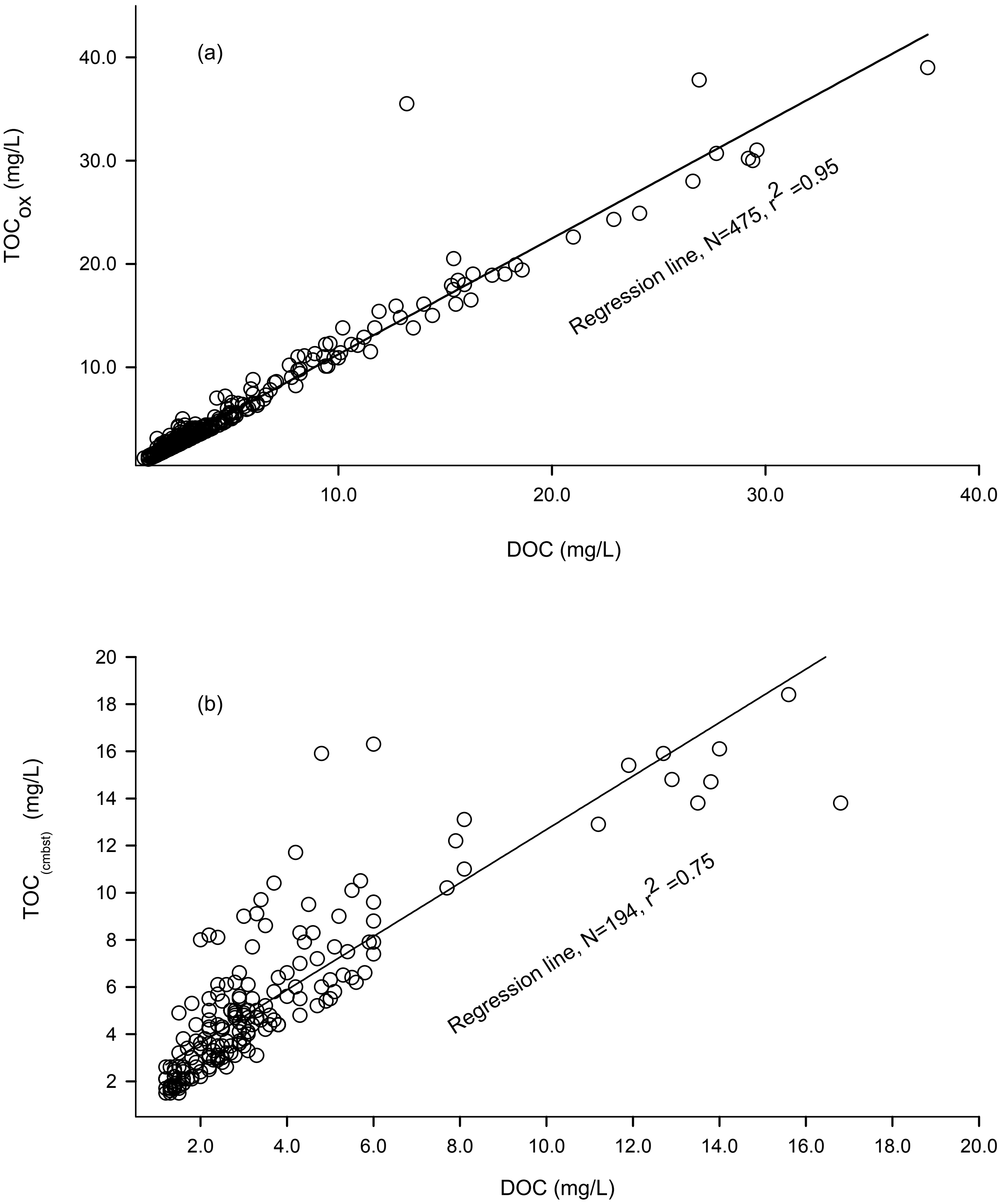


Figure 4-22 Relationship between TOC by two different methods and DOC in Delta source waters



Chapter 5 Bromide

Overview

This chapter discusses bromide data collected at 14 Municipal Water Quality Investigations Program (MWQI) monitoring stations during the reporting period. Bromide concentrations varied widely among stations depending on the geographic location and hydrologic conditions (Table 5-1). The stations could be grouped into low, medium, and high categories according to their median bromide concentrations.

Table 5-1 Summary of bromide at 14 MWQI stations

The stations having low bromide concentrations included 3 river stations—American River at E.A. Fairbairn Water Treatment Plant (WTP), Sacramento River at the West Sacramento WTP Intake, and Sacramento River at Hood. Also in this category was an urban drainage station, the Natomas East Main Drainage Canal (NEMDC). Bromide at the Sacramento River stations ranged from <0.01 mg/L to 0.03 mg/L (Table 5-1). Bromide was always below the reporting limit at the American River station. At NEMDC, bromide ranged between 0.01 and 0.10 mg/L with a median concentration of 0.06 mg/L.

Stations with medium bromide concentrations included 2 channel stations—Old River at Station 9 and Old River at Bacon Island—and 3 diversion stations—Banks Pumping Plant, Delta-Mendota Canal (DMC), and the Contra Costa Pumping Plant. Bromide levels at these stations were variable, but median concentrations of bromide ranged from 0.09 to 0.15 mg/L (Table 5-1).

Stations with high bromide concentrations included the Sacramento River at Mallard Island, San Joaquin River (SJR) near Vernalis, SJR at Highway 4, and 2 agricultural drainage stations—Bacon Island Pumping Plant and Twitchell Island Pumping Plant.

Bromide was detected in all 34 monthly samples collected from the Mallard Island station, which is close to the San Francisco and Suisun bays. Concentrations ranged from 0.03 to 20.00 mg/L at this station, which is the most widely variable among all 14 MWQI stations (Table 5-1). The median concentration was 1.90 mg/L. High bromide levels at this station were attributable to seawater influence because bromide in Delta rivers, channels, and agricultural drains was much lower than what was observed at this station.

Bromide concentrations at SJR near Vernalis and at Highway 4 were similar despite differences in sampling frequency (Table 5-1). Bromide concentrations at the 2 agricultural drainage stations were high with concentrations higher at Twitchell Island station than at the Bacon Island station.

Seasonal Variations and Differences among Stations

American River WTP and Sacramento River Stations

Bromide was not detected at the American River at E.A. Fairbairn WTP station. At the Sacramento River stations at West Sacramento WTP Intake and Hood, bromide concentrations ranged from <0.01 mg/L to 0.03 mg/L (Table 5-1). Although the West Sacramento WTP Intake station was sampled monthly and the Hood station was sampled weekly, the percentage of positive detects at the 2 stations were 71% and 75%, respectively. The ranges, data dispersion, and average concentrations were the same for both stations. Medians were also similar (0.01 and 0.02 for Hood and West Sacramento WTP Intake, respectively).

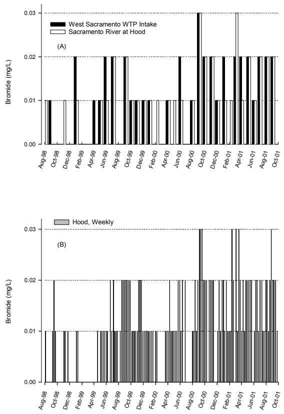


Figure 5-1 Bromide at two Sacramento River stations

Temporal patterns of bromide at both the West Sacramento WTP Intake and Hood stations were similar (Figure 5-1). Bromide concentrations were higher during the 2001 water year of low runoff than during the 1999 and 2000 water years of higher runoff. More positive samples were found during the 2001 water year than during either of the previous 2 water years (Figure 5-1). At both stations, bromide concentrations were generally higher during the dry months than during the wet months. During February and March of each year, bromide was either not detected or was lower than bromide concentrations in the dry months. Temporal patterns were similar, and the average bromide concentrations at both stations were statistically the same (p=0.708).

San Joaquin River Stations

The SJR near Vernalis was monitored weekly, and the SJR at Highway 4 was monitored monthly. Bromide concentrations at either site were seldom below the reporting limit (Table 5-1). Despite differences in sampling frequency, both average and median bromide concentrations at these stations were the same (Table 5-1). The ranges and data dispersion were also similar.

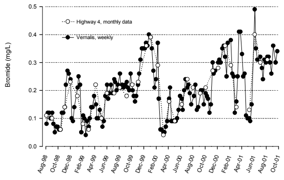


Figure 5-2 Bromide at two San Joaquin River stations

Seasonal pattern of bromide differed from that of organic carbon at these stations. Organic carbon could be high during wet months depending on rainfall events in the watershed, but generally lower and less variable during the dry months (Chapter 4). Bromide concentrations also were generally high during the wet months (Figure 5-2); however, bromide could also be high during the dry months. Bromide generally increased starting in May of each year. Bromide began to level off or decline during August or September and usually reached a low point in October. During the wet months, bromide reached its highest concentration from November through February and was lowest during the month of March. In general, bromide levels appear to be inversely related to the amount of annual precipitation during the reporting period (Figure 5-2).

Seasonal patterns of bromide in the SJR reflect the effects of both rainfall and agricultural practices in the watershed. The San Joaquin Valley is mostly irrigated agricultural land. Irrigation water for the area comes from the DMC, a Delta diversion station, and contains considerable bromide (Table 5-1); and it recirculates within the San Joaquin Valley. When irrigation water is applied, bromide concentrates on the soil surface through evapotranspiration. Following either irrigation or rainfall, runoff water carries previously accumulated bromide on the soil surface and moves into the SJR. Soils in some areas were developed from old marine deposits that contain high levels of bromide, which may be concentrated on the soil surface and washed into the river during wet months of low to moderate rainfall. In some areas, shallow groundwater also carries high levels of bromide and moves into the SJR through seepage. On the other hand, inflow water in the upstream watershed with low bromide is mostly trapped in upstream reservoirs for flood control or storage purposes during the wet months resulting in less dilution downstream; therefore, bromide concentrations in the lower part of the river are high during the wet months.

During the dry months, irrigation return waters containing high levels of bromide are discharged into the SJR. Thus, bromide concentrations generally increased during periods of peak irrigation (May through September) and decreased at the end of the irrigation season prior to increases in the wet months (Figure 5-2).

During the reporting period, the 1999 and 2000 water years were above-normal runoff years, whereas the 2001 water year was a dry year in the SJR watershed (refer to Chapter 3). The overall bromide concentrations in the 2001 water year were the highest among the 3 water years, especially during the dry months. This was attributable to irrigation returns with modest bromide concentrations and decreased inflows with low bromide levels from the tributaries on the east side of the upper SJR.

Bromide concentrations were not statistically different (p=0.71) at SJR near Vernalis and SJR at Highway 4 despite urban influence at the latter site. This suggests that urban contribution may not be a major source of bromide to the river.

Channel Stations

MWQI monitored bromide at 2 channel stations—Old River at Station 9 and Old River at Bacon Island. Bromide was always above the reporting limit (Table 5-1). Median concentrations of bromide were 0.09 mg/L at Bacon Island and 0.12 mg/L at Station 9. This difference was probably the result of Sacramento River water influence at these sites.

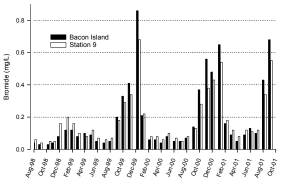


Figure 5-3 Monthly bromide concentrations at two Old River stations

Temporal changes of bromide at both stations were similar to those of organic carbon in that concentrations were higher during the wet months and remained lower and relatively unchanged during the dry months (Figure 5-3). This differed from the seasonality patterns of the 2 SJR stations. Despite increased bromide concentrations during the wet months, there was little change in bromide concentrations at either station during the dry months. Average bromide was the highest in the 2001 water year (the dry year) despite a higher bromide level in December of 1999. Statistical analysis showed no significant difference in average bromide concentrations between the 2 channel stations (p=0.343). The average and median bromide levels are presented in Table 5-1.

Diversion Stations

At the Delta diversion stations—Banks Pumping Plant, DMC, and Contra Costa Pumping Plant—median bromide levels varied from 0.11 to 0.15 mg/L. Average bromide concentrations ranged from 0.17 to 0.22 mg/L (Table 5-1). The seasonal patterns were similar for all 3 stations (Figure 5-4). In general, bromide reached its highest value from October through March of each water year. Bromide concentrations were lower from April through August (Figure 5-4). These seasonal patterns were different from those observed at the SJR stations reflecting the influences of multiple sources at the diversion pumps.

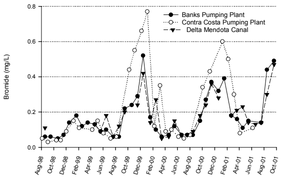


Figure 5-4 Bromide at three diversion stations

Due to differences in sampling frequency, statistical comparisons of the stations' average bromide concentrations were not possible. However, a Wilcoxon Rank-sum test of bromide levels at Banks and DMC, which were sampled on the same day, found no significant differences between average bromide levels at the 2 stations ($p=0.40$). During most of the wet months of the 2000 and 2001 water years, bromide was higher at the Contra Costa Pumping Plant than at the other 2 diversion stations (Figure 5-4); little difference was noticed during the 1999 water year.

Higher bromide at the Contra Costa Pumping Plant is perhaps due to the station's proximity to the Mallard Island station and the likely seawater influence (Figure 1-1). Seawater influence is related to Delta outflows. The 1999 water year was an above-normal year, but the 1998 water year was a wet year. Delta outflows in 1999 were the highest among the 3 water years due to carry-over water from the 1998 water year (refer to Chapter 3). Although the 2000 water year was also an above-normal year, the 1998 carry-over effect had disappeared; therefore, outflow in the 2000 water year was lower than in the 1999 water year. Delta flow was lowest in the 2001 water year, a dry year (refer to Chapter 3). Reduced outflows resulted in greater seawater influence to the western part of the Delta during the 2000 and 2001 water years. During the wet months of these water years, bromide concentrations were higher at Contra Costa Pumping Plant than at the other 2 diversion stations.

Sources of Bromide in Delta Waters

Seawater Influence

Seawater influence can occur when Delta outflows are not sufficiently strong to prevent seawater from entering the western Delta. Seawater influence often occurs during dry runoff years or during the dry months when Delta inflows from the watershed are low and while pumping at the diversion stations are high. In addition, seawater influence occurs when upper reservoirs and lakes are closed for water storage purposes or for flood control during the wet months of a water year. Seawater influences and normal tidal mixing increase bromide concentrations at the stations throughout the western Delta.

The Mallard Island station is indicative of seawater influence among the stations. Water at this station is a mixture of water from various rivers and channels in the Delta as well as water from the Bay. A total of 34 monthly samples were collected from this station during the reporting period. Bromide was always above the reporting limit (Table 5-1). Concentrations ranged from 0.03 to 20.00 mg/L, making it the most widely variable of all 14 stations (Table 5-1). The average bromide level was 4.45 mg/L. The median concentration was 1.90 mg/L. Because rivers, channels, and agricultural drains of the Delta all had substantially lower bromide levels, the high bromide at Mallard Island was attributable to seawater influence.

Bromide at the Mallard Island station was much higher during the dry water year than during the above-normal or wet years (Figure 5-5). In the 1999 water year, runoff was the highest and bromide was the lowest among the 3 water years. Of the 2000 and 2001 water years, bromide was higher in both the wet and dry months of the 2001 water year—a dry year. The 2000 water year was an above-normal year (Figure 5-5). Increases in bromide at Mallard during the 2001 water year appear to have been directly related to runoff in the contributing watersheds. As shown in Figure 3-3, Delta outflows were the highest in the 1998 water year, and the lowest during the 2001 water year. A wet year in 1998 and residual outflows from the 2 previous years, which also were wet years, contributed to the higher flows in 1998 (Table 3-3). When outflows decrease, seawater influence and thus bromide concentrations increase.

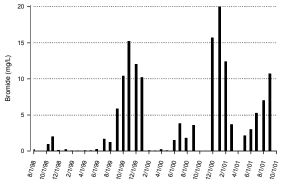


Figure 5-5 Bromide concentrations at the Mallard Island station

Recirculation of Bromide within the San Joaquin Valley

The SJR contributes significant amounts of bromide to the Delta. Both average and median bromide concentrations of the river were 0.20 mg/L (Table 5-1). Bromide levels increased during the wet months of each water year. Bromide concentrations were higher during the dry year than during the previous 2 wetter years (Figure 5-2). Bromide from seawater enters the San Joaquin Valley as irrigation water taken from the Delta (discussed in section "San Joaquin River Stations"). Bromide in the irrigation water is concentrated in the agricultural lands and returned to the Delta through the SJR. Most of the bromide in the San Joaquin Valley can be accounted for this way, but the valley also has intrinsic bromide sources, such as bromide from shallow groundwater or from soils developed from old marine deposits.

The hydrology of the Delta is complex, and the accurate percentage of SJR water at specific pumping stations at specific time periods remains unknown. A significant proportion of bromide in south Delta waters may come from the SJR.

Bromide from Delta Islands

Delta soils are peaty soils formed when the area was a tidal wetland. Bromide and salts also accumulate in Delta island soils through irrigation. Some islands have shallow groundwater, which also contributes bromide through seepage. When agricultural drainage water is pumped back into the Delta, bromide is released into Delta channels. Median bromide in agricultural drainage return waters ranged from 0.18 to 0.34 mg/L during the reporting period (Table 5-1). Bromide concentrations in drainage waters at both Bacon and Twitchell islands fluctuated but remained high throughout each water year except June through August when bromide was lower (Figure 5-6). Lower concentrations between June and August may be due to

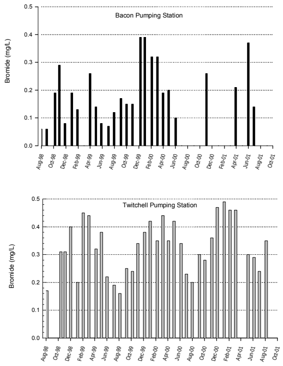


Figure 5-6 Bromide at two Delta agricultural pumping stations

high demand of crop water. Heavy and frequent watering causes irrigation water overflows, which probably dilute bromide concentrations in drainages. In contrast, bromide increased during the wet months because farmers apply water to the land specifically to leach salts including bromide, which returns to the channels during the winter. Heavy rainfall during the wet months also causes surface runoff carrying bromide accumulated during the summer to the ditches, thus bromide is higher during the wet months.

Bromide is higher at Twitchell Island than at Bacon Island. Twitchell Island is geographically closer to the seawater-affected waters of San Francisco and Suisun bays (refer to Figure 1-1), thus salinity in water of the channels near Twitchell Island is generally higher. Irrigation water for Twitchell Island primarily comes from the SJR, which contains high concentrations of bromide. In contrast, Bacon Island is irrigated with water from the Old River, which is mostly water from the Sacramento River and generally low in bromide.

Urban Drainage

Urban drainage was not a major source of bromide in Delta waters. Figure 5-7 presents available data during the reporting period at NEMDC. Bromide ranged between 0.01 and 0.10 mg/L. The majority of the data were from 0.02 to 0.09 mg/L with a median concentration of 0.06 mg/L (Table 5-1). No apparent seasonal or temporal trend was found (Figure 5-7). A comparison of bromide concentrations in the SJR near Vernalis and at Highway 4 also concluded that urban drainage was not a significant source of bromide to the SJR (see section “San Joaquin River Stations”).

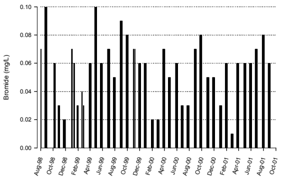


Figure 5-7 Bromide at the Natomas East Main Drainage Canal

The Relationship between Bromide and Chloride in Delta Waters

As discussed in previous sections, bromide in the Delta originates from seawater either directly or indirectly. Seawater contains approximately 65 mg/L of bromide and 19,000 mg/L of chloride; the bromide/chloride ratio in seawater is roughly 0.0034. Like chloride, bromide is conservative. This ratio should hold in Delta waters if seawater is the sole source of bromide and chloride.

Among the stations monitored, 4 stations are unaffected by seawater. These include (1) American River at E.A. Fairbairn WTP, (2) Sacramento River at West Sacramento WTP Intake, (3) Sacramento River at Hood, and (4) NEMDC. At the 2 Sacramento River stations, a total of 145 samples had both bromide and chloride at or above their respective reporting limits (Figure 5-8(a)). The relationship between bromide and chloride at these 2 stations was weak (r^2=0.333), probably due to the mostly low bromide levels near the reporting limit. At NEMDC both bromide and chloride were detected at or above their reporting limits in all 41 monthly samples, but the relationship between bromide and chloride also was weak (Figure 5-8(b), r^2=0.284). The majority of data suggests that bromide did not increase with the increase of chloride. The NEMDC collects urban drainage from the Roseville area and much of the Sacramento area north of the American River. High chloride concentrations were probably attributable to use of chlorine products in urban areas. Because bromide is seldom used in urban

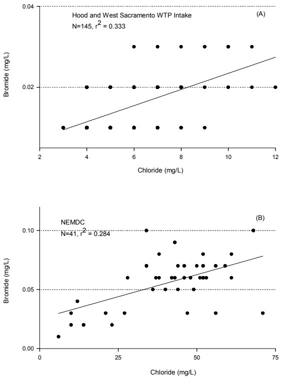


Figure 5-8 Bromide and chloride relationship at three stations

areas, a linear relationship between bromide and chloride should not be expected at NEMDC. Due to lack of either positive detects or a reliable linear relationship, data from these 4 stations were not included in the analysis of the relationship between bromide and chloride in seawater-influenced stations.

A total of 427 samples were collected from the remaining 10 stations, 2 of which were agricultural drainage stations. A strong linear relationship existed between bromide and chloride (Figure 5-9). This relationship may be described by this linear regression equation:

$$\text{bromide} = 0.0035 * \text{chloride} - 0.019, \; [\, r^2 = 0.996, \; p < 0.0001]$$

Thus, the bromide/chloride ratio in Delta waters is 0.0035, which is close to the ratio found in seawater. This analysis confirms that the source of bromide in the Delta is seawater. The above equation suggests that bromide concentrations at the 10 seawater-influenced stations may be estimated by multiplying the concentration of chloride with an empirical constant of 0.0035, as the regression intercept is negligible.

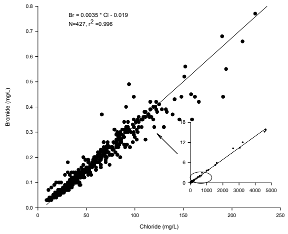


Figure 5-9 The relationship between bromide and chloride at 10 stations

Table 5-1 Summary of bromide at 14 MWQI stations (mg/L)

Station	Positive detects/ Sample number[a]	Range	Majority data range	Data dispersion (IQR)	Average	Median
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	0/37	<0.01				
West Sacramento WTP Intake	27/38	0.01–0.03	0.01–0.02	0.01–0.02	0.02	0.02
Sacramento River at Hood	118/158	0.01–0.03	0.01–0.03	0.01–0.02	0.02	0.01
Sacramento River at Mallard Island	34/34	0.03–20.00	0.03–15.38	0.21–6.72	4.45	1.90
San Joaquin River stations						
San Joaquin River near Vernalis	157/159	0.04–0.49	0.06–0.37	0.12–0.26	0.20	0.20
San Joaquin River at Highway 4	36/37	0.04–0.40	0.06–0.37	0.14–0.27	0.20	0.20
Delta channel stations						
Old River at Station 9	38/38	0.04–0.68	0.05–0.54	0.07–0.22	0.18	0.12
Old River at Bacon Island	38/38	0.03–0.86	0.04–0.65	0.05–0.21	0.19	0.09
Diversion stations						
Banks Pumping Plant	37/37	0.05–0.52	0.06–0.45	0.07–0.21	0.17	0.14
Delta-Mendota Canal (DMC)	29/29	0.05–0.47	0.06–0.40	0.11–0.24	0.18	0.15
Contra Costa Pumping Plant	30/30	0.03–0.77	0.04–0.63	0.07–0.35	0.22	0.11
Agricultural drainage stations						
Bacon Island Pumping Plant	26/26	0.06–0.39	0.06–0.39	0.12–0.26	0.19	0.18
Twitchell Island Pumping Plant	35/36	0.16–0.49	0.19–0.46	0.25–0.41	0.33	0.34
Urban drainage station						
Natomas East Main Drainage Canal (NEMDC)	41/41	0.01–0.10	0.02–0.09	0.04–0.07	0.06	0.06

Note: All statistics are calculated for positively detected samples; positive detects are samples with concentration greater than the reporting limit of 0.01 mg/L.

a. Positive detects are samples with concentration greater than the reporting limit of 0.01 mg/L.

Figure 5-1 Bromide at two Sacramento River stations

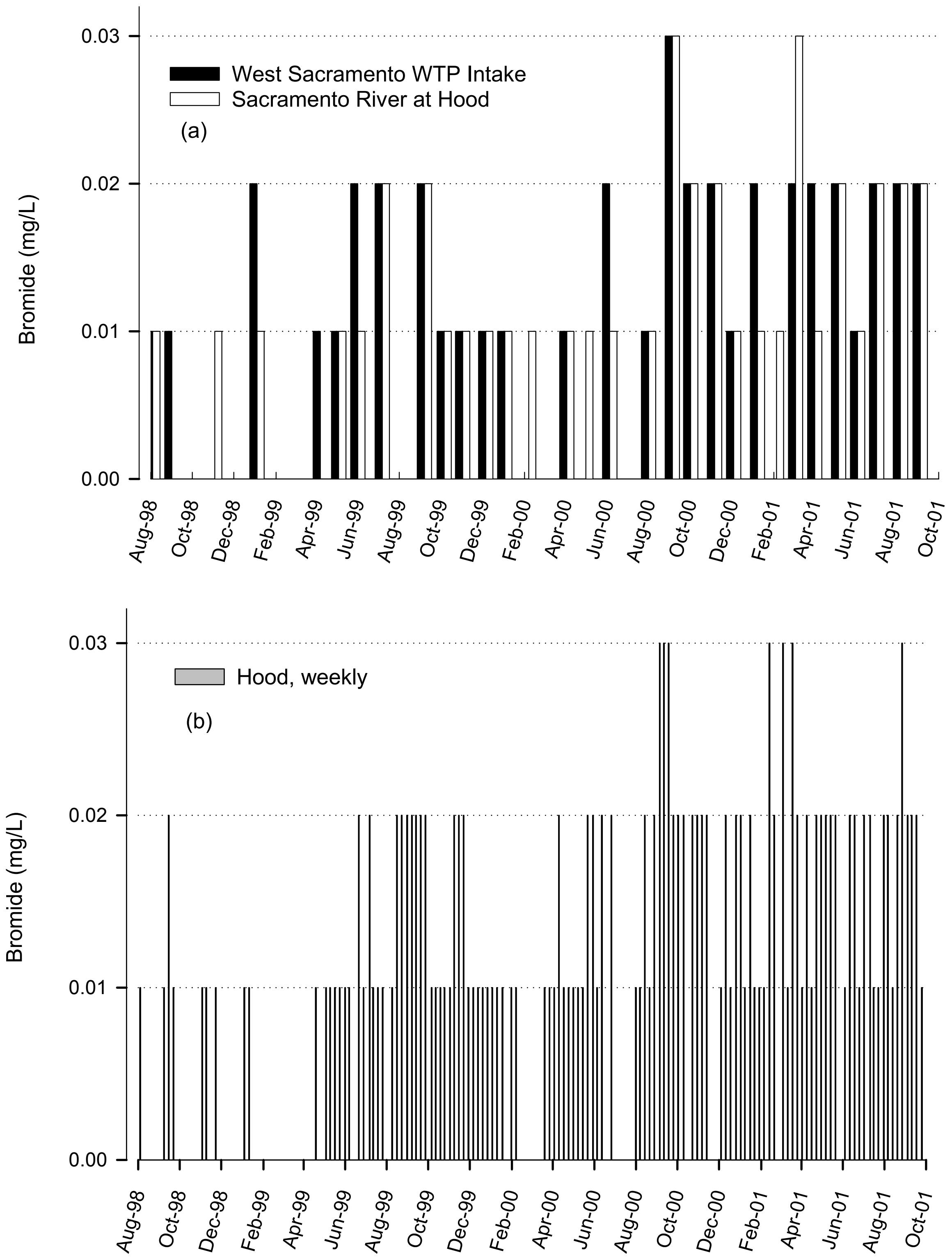


Figure 5-2 Bromide at two San Joaquin River stations

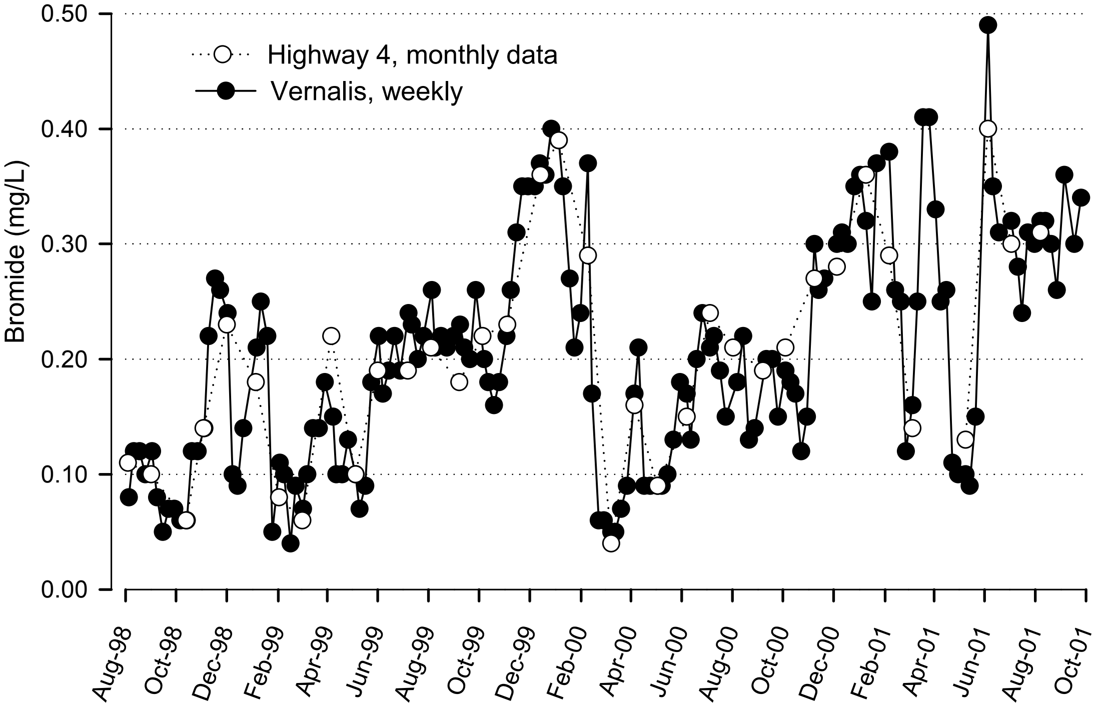


Figure 5-3 Monthly bromide concentrations at two Old River stations

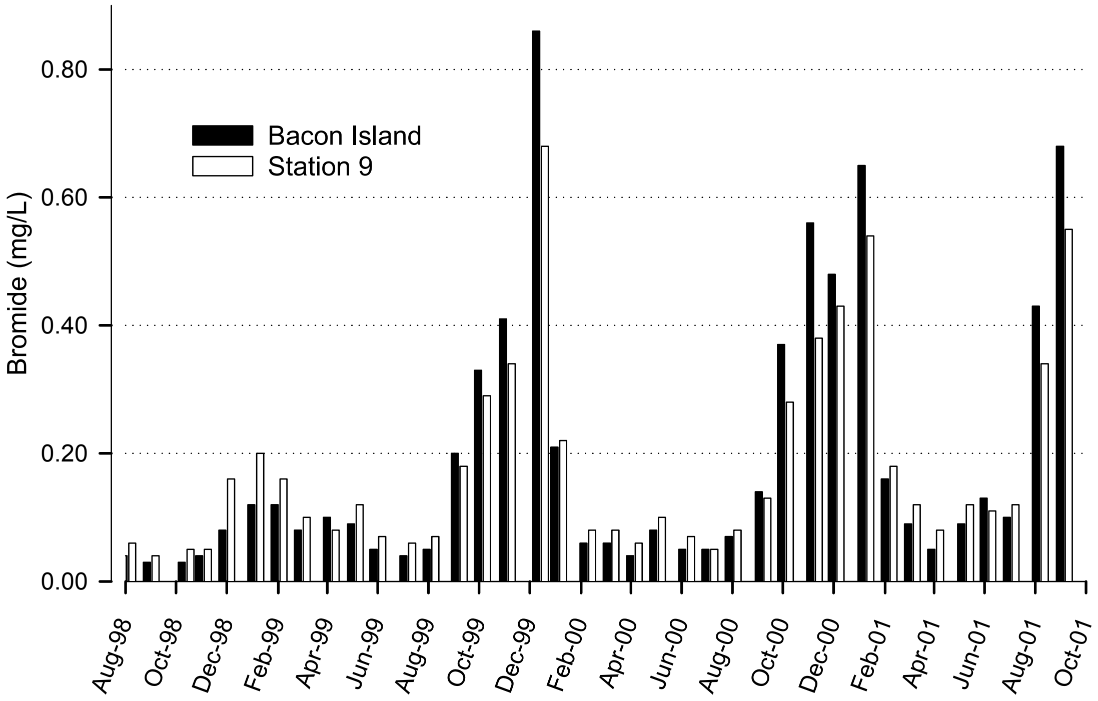


Figure 5-4 Bromide at three diversion stations

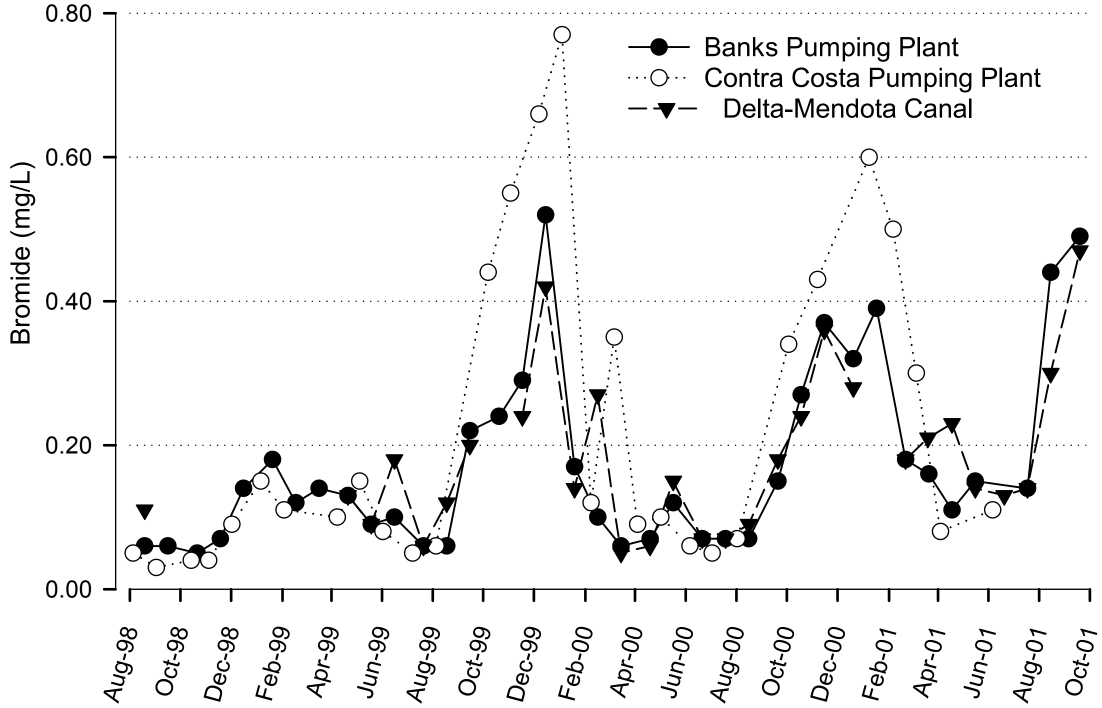


Figure 5-5 Bromide concentrations at the Mallard Island station

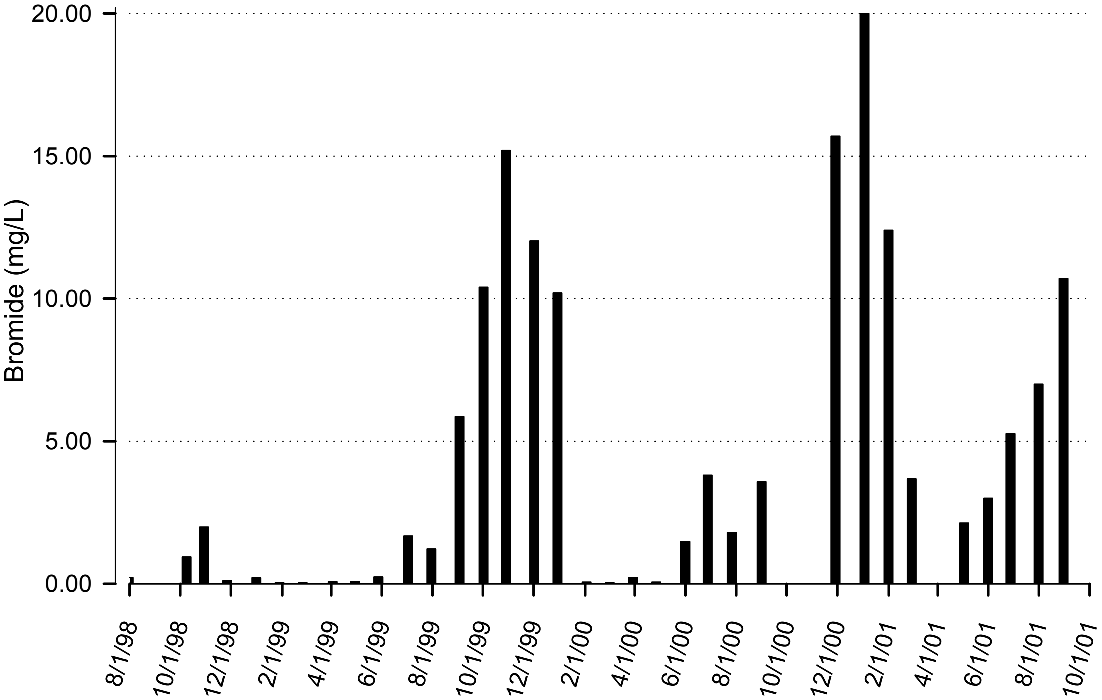


Figure 5-6 Bromide at two Delta agricultural pumping stations

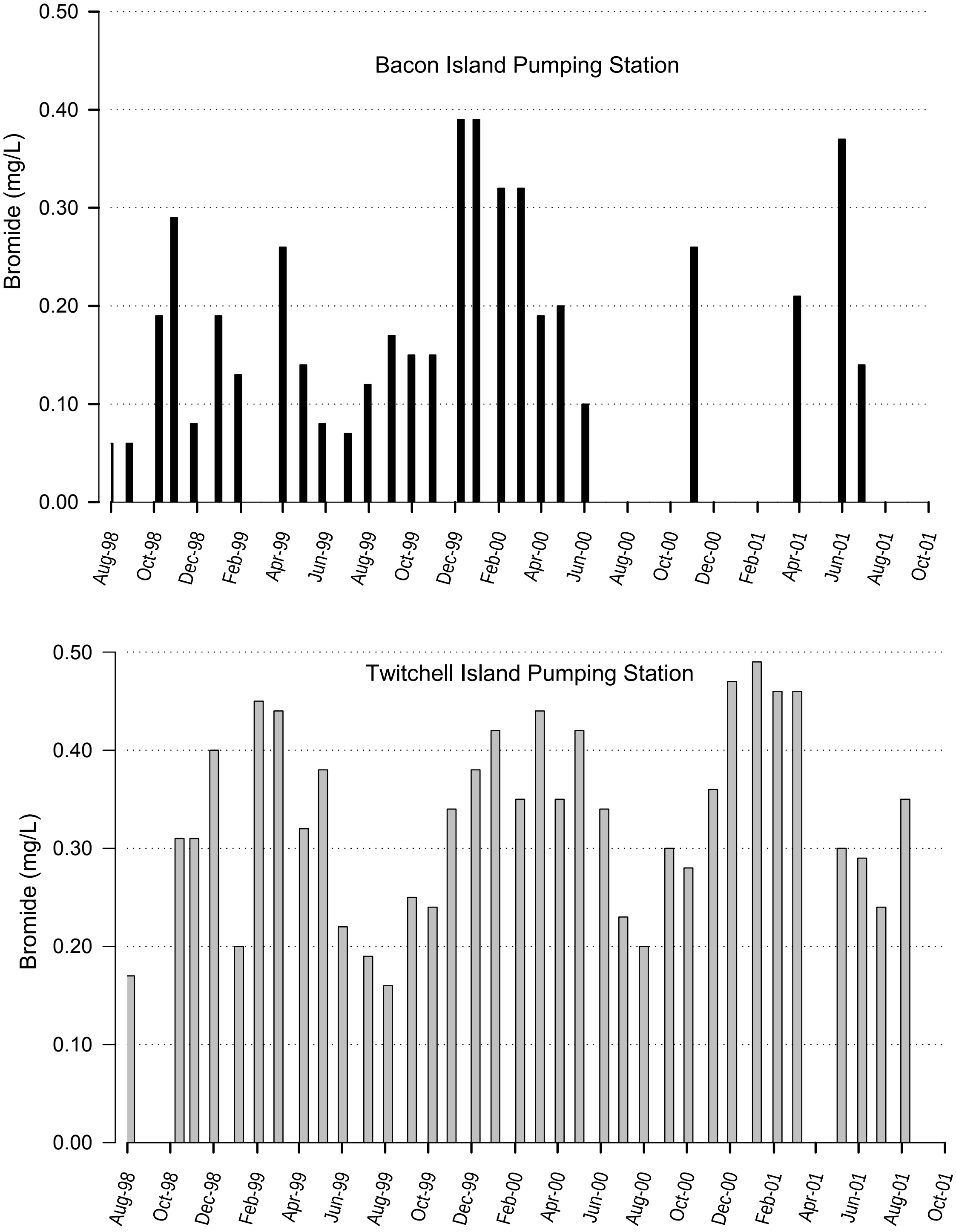


Figure 5-7 Bromide at the Natomas East Main Drainage Canal

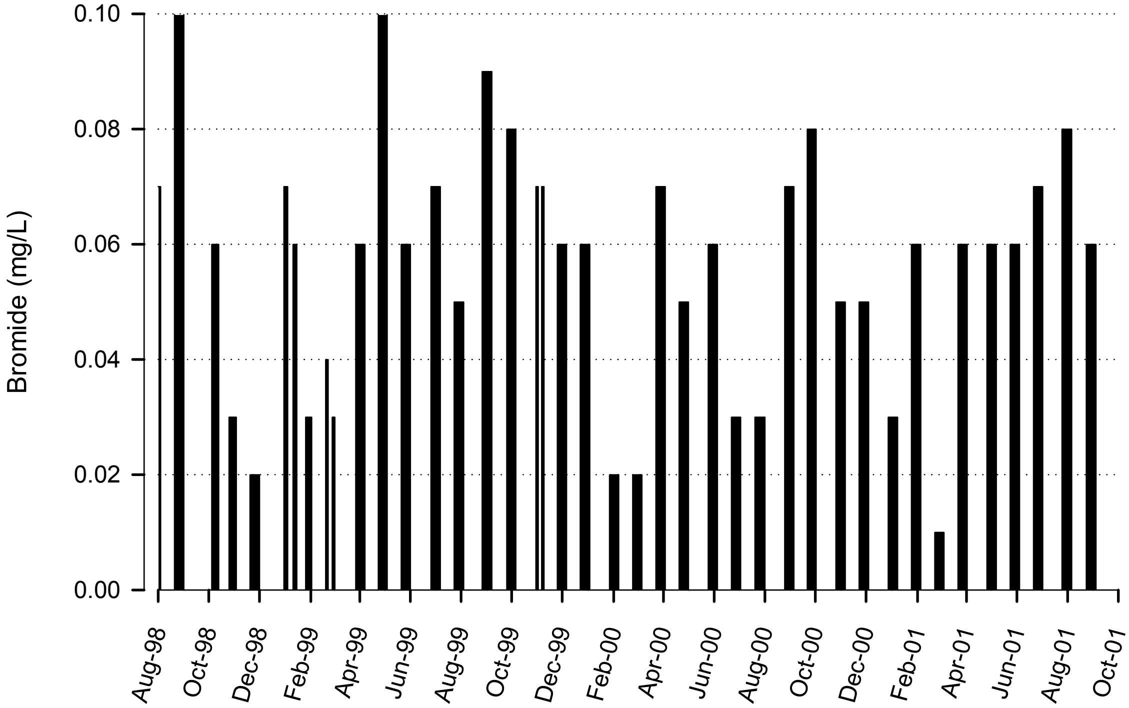
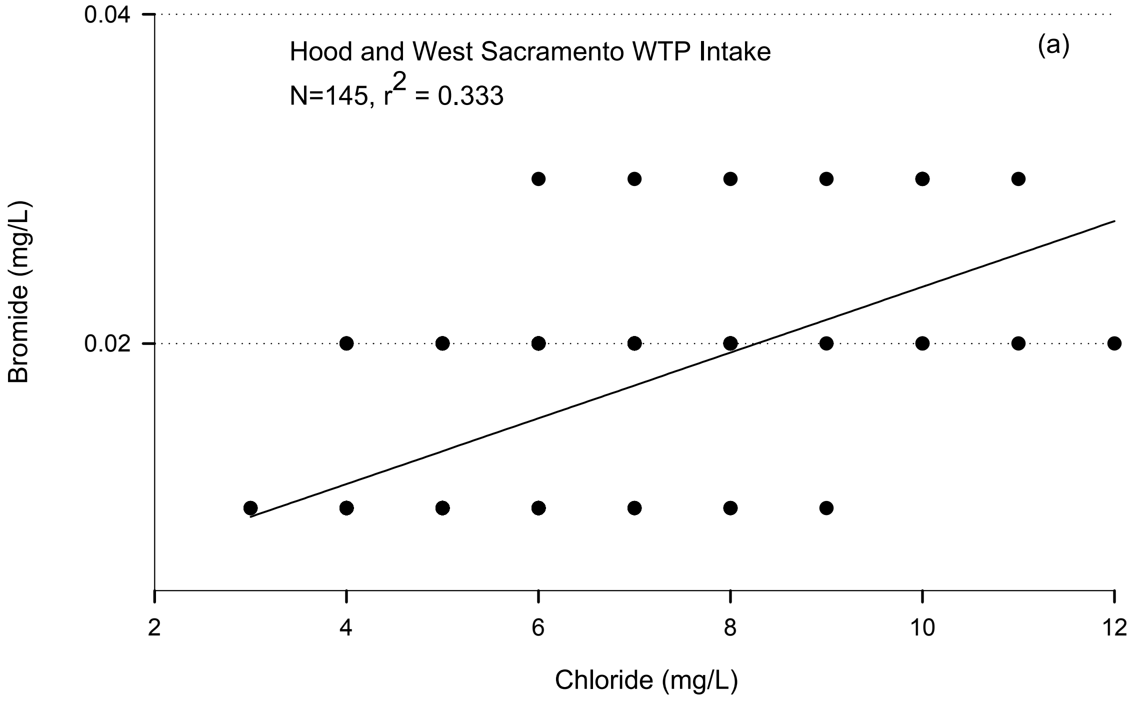


Figure 5-8 Bromide and chloride relationship at three stations



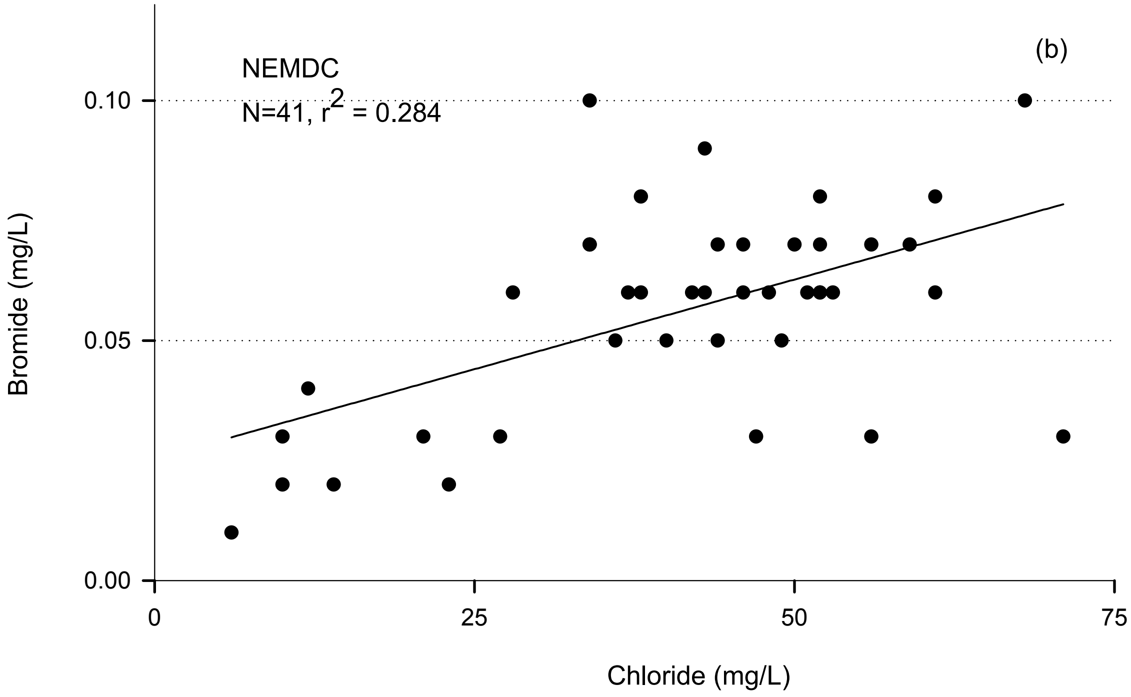
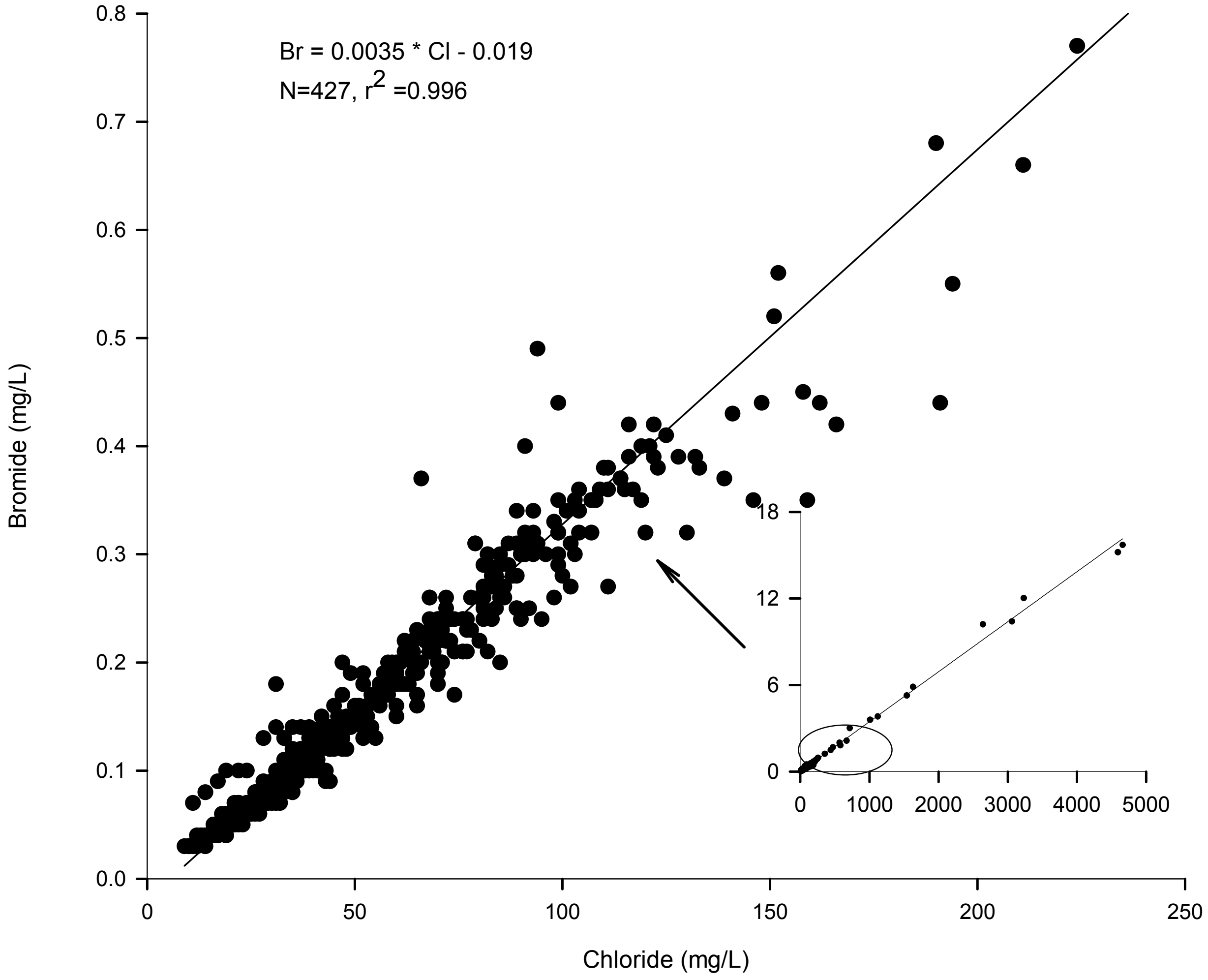


Figure 5-9 The relationship between bromide and chloride at 10 stations



Chapter 6
Electrical Conductivity and Salinity

General Relationships between EC and TDS in Delta Waters

In natural waters, the relationship between electrical conductivity (EC) and total dissolved solids (TDS) is linear. Waters at the 14 stations of Municipal Water Quality Investigations Program (MWQI) represent a wide spectrum of salinity varying from low salinity fresh waters to seawaters. A total of 694 samples were collected. The general EC range was from 40 to 17,600 µS/cm (Figure 6-1). Approximately 97% of the EC data were less than 1,500 µS/cm (Figure 6-1). The 3% of the samples with EC greater than 1,500 µS/cm were all collected from the Mallard Island station. Although EC and TDS varied widely among various stations, the relationship between EC and TDS is strongly linear (Figure 6-1), which can be described by this equation:

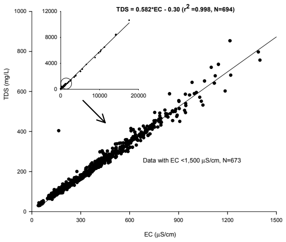


Figure 6-1 Relationship between EC and TDS at 14 MWQI stations

TDS = 0.58*EC–0.30, [r2 = 0.998]

This analysis further suggests that TDS (in milligrams per liter) at all 14 stations can be estimated numerically as 58% of the value of EC in µS/cm.

Ranges, Seasonality, and Differences among Stations

Table 6-1 summarizes the range, average, and median TDS/EC ratios for each station during the reporting period. The stations belong to either of 2 general categories separated by a TDS/EC ratio of 0.58. TDS/EC ratios in waters from the San Joaquin River (SJR), Delta channels, diversion stations, and the Sacramento River at Mallard Island station were equal or less than the empirical value of 0.58 (Table 6-1). TDS/EC ratios in the rest of the stations are greater than 0.58 (Table 6-1). Waters with low mineral content, such as water from the American River and Upper Sacramento River, are known to have higher TDS/EC ratios. Waters for the 2 agricultural drainage sites also had higher TDS/EC ratios. This may have been due to the presence of nonconducting organic residues, which will not evaporate significantly at the temperatures for the determination of TDS.

Table 6-1 Summary of TDS/EC ratios in 14 MWQI stations

Table 6-2 Summary of EC at 14 MWQI stations

Table 6-3 Summary of statistics for TDS

American River at the Fairbairn WTP Intake

At the E.A. Fairbairn Water Treatment Plant (WTP) intake on the American River, EC ranged from 40 to 71 µS/cm with an average of 55 µS/cm and a median of 54 µS/cm. TDS varied from 30 to 54 mg/L. Both the average and median TDS were 39 mg/L (Table 6-2 and Table 6-3). Both EC and TDS at this station are the lowest among all stations. The TDS/EC ratio at this station was higher than the ratio for all other stations.

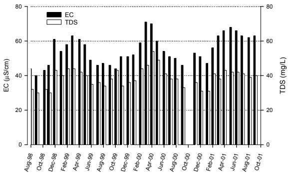


Figure 6-2 Monthly EC and TDS at the American River WTP Intake

EC and TDS were both higher during the wet months than during the dry months for the reporting period (Figure 6-2); however, these differences were not statistically significant (p=0.078 and 0.336 for EC and TDS, respectively). Neither EC nor TDS varied significantly by water year (p=0.058 and 0.834 for EC and TDS, respectively), despite the 2001 water year being classified as a dry year as opposed to the wetter 1999 and 2000 water years, which were both classified as above normal years.

Sacramento River Stations

The ranges for EC were 112 to 241 µS/cm at the West Sacramento WTP Intake and 96 to 228 µS/cm at Hood (Table 6-2). TDS at these stations ranged from 71 to 148 mg/L and 61 to 137 mg/L, respectively (Table 6-3). The median EC was 155 µS/cm for both stations. The average EC of monthly samples were 161 and 158 µS/cm for West Sacramento WTP Intake and Hood, respectively, which were not statistically different (p=0.462). The median TDS was 97 mg/L for West Sacramento WTP Intake and 95 mg/L for Hood (Table 6-3). The average TDS from monthly samples were 100 and 97 mg/L for West Sacramento WTP Intake and Hood, respectively, which were not statistically different (p=0.791) according to the Wilcoxon Rank-sum test.

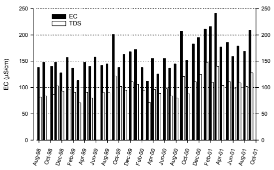


Figure 6-3 Monthly EC and TDS at West Sacramento WTP Intake

Seasonality of both EC and TDS appears to have been related to the amount of runoff in the contributing watershed. At the West Sacramento WTP Intake, average EC and TDS were the highest during the dry 2001 water year (Figure 6-3). Both EC and TDS were elevated during the wet months (Figure 6-3), but no statistically significant differences were found between the wet and dry months (p=0.121 and 0.200 for EC and TDS, respectively). The variations in EC and TDS were even smaller during the relatively wetter 1999 and 2000 water years. Regardless of the water years, EC and TDS increased in September. This increase is attributable to the rice drainage returns to the Sacramento River. Rice drainage effects on salinity in the Sacramento River are discussed in the section "Agricultural Drainage to the Sacramento River."

Seasonal patterns of EC and TDS at Hood were similar to those at the West Sacramento WTP Intake despite low mineral water entering the Sacramento River between the West Sacramento WTP and Hood. Although water from the American River is low in mineral content, inflows are generally small compared to the inflows from the upper Sacramento River. Two wastewater treatment plants also discharge to the Sacramento River between the West Sacramento WTP Intake and Hood (see Figure 4-1). Wastewater discharges may counter the effect of dilution from the American River water inflows. Weekly EC and TDS data collected at Hood are presented with Loess smoothing in Figure 6-4. EC and TDS appear to have increased over the reporting period with both parameters the highest during the 2001 water year and with little difference between the 1999 and 2000 water years (Figure 6-4).

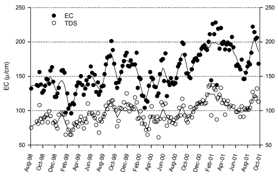


Figure 6-4 Weekly EC and TDS at the Hood station

A Kruskal-Wallis Test suggests that average EC and TDS were significantly different among the 3 water years (p<0.0001 for both EC and TDS). A multiple comparison analysis was performed using Duncan's Multiple Range Test on rank transformed data. Average EC was significantly higher in the 2001 water year than in the 1999 and 2000 water years. Average EC was statistically higher in the 2000 water year than in the 1999 water year. Similarly, average TDS was significantly higher in the 2001 water year than in the 1999 and 2000 water years. However, no significant difference was found in average TDS between the 1999 and 2000 water years at the 5% significance level.

The years before the 1999 water year were classified as wet years (refer to Chapter 3). These conditions led to greater inflows of lower EC water into Shasta and Oroville reservoirs; furthermore, these reservoirs were nearly full in the late spring of 1998, which led to more carry-over of low EC water released to the Sacramento River during the 1999 and 2000 water years.

San Joaquin River Stations

At the SJR near Vernalis and the SJR at Highway 4 stations, the majority data ranges, average and median EC and TDS were similar (Table 6-2 and Table 6-3). The results of Wilcoxon Rank-sum test suggest that there was no significant difference in average monthly EC (p=0.573) and TDS (p=0.593) between the 2 stations. Despite the difference in sampling frequency, temporal patterns of both EC and TDS at both stations were similar (Figure 6-5 and Figure 6-6). This is due to their similarities in hydrology (refer to Chapter 4).

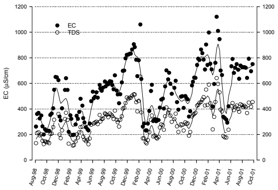


Figure 6-5 Weekly EC and TDS at San Joaquin River near Vernalis

Both EC and TDS were generally higher during the wet months than during dry months of each water year (Figure 6-5 and Figure 6-6). EC and TDS were higher during the 2001 water year than during the previous 2 water years due to lower watershed runoff in the 2001 water year. At Vernalis, water year average EC and TDS were highly significantly different (p<0.0001 for both EC and TDS). A Duncan's multiple comparison analysis on rank transformed EC and TDS data suggests that average EC and TDS were significantly higher in the 2001 water year than in the 1999 and 2000 water years. Average EC and TDS were statistically higher in the 2000 water year than in the 1999 water year. Lower EC and TDS during the 1999 water year may be the result of high watershed runoff during the previous 2 water years.

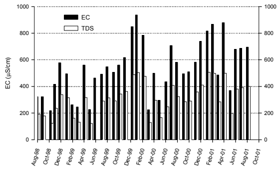


Figure 6-6 Monthly EC and TDS at San Joaquin River at Highway 4

At both stations, EC and TDS were generally higher during June, July, and August than during the other dry months of each water year (Figure 6-5 and Figure 6-6). This increase generally coincided with the increased agricultural activity in the lower San Joaquin watershed, reflecting the increases in irrigation return waters to the lower SJR watershed.

Channel Stations

The average and median of both EC and TDS were higher at Station 9 than at Bacon Island (Table 6-2 and Table 6-3); but these differences were not statistically significant at the 5% level (p values were 0.234 and 0.208 for EC and TDS, respectively). Although sampling dates were different, EC and TDS were much lower at the 2 Old River stations than at the 2 SJR stations (Table 6-2 and Table 6-3). EC and TDS were nearly twice as high in the channel stations as in the upper Sacramento River stations, reflecting that water quality in the channels are affected by inputs from multiple sources. As at the stations along both the SJR and Sacramento River, EC and TDS at the channel stations were generally higher during the wet months than during the dry months (Figure 6-7 and Figure 6-8).

Although the majority of the water in Old River is a mixture from the 2 major river systems flowing into the Delta, the relative contribution from either river varies with hydrologic conditions in the rivers and pumping regimes at the diversion stations along the Old River. In addition, a small fraction of the water is agricultural drainage from various Delta islands. When Delta outflows are low, the tides can bring in water from the bay. The biological processes in nutrient-rich channel waters also affect water quality. Consequently, seasonal patterns of EC and TDS at the Old River stations not only had some resemblance to those of both the SJR and Sacramento River but also some of their own characteristics.

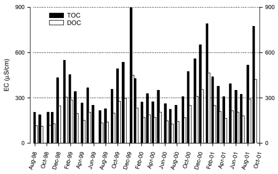


Figure 6-7 Monthly EC and TDS at Old River at Station 9

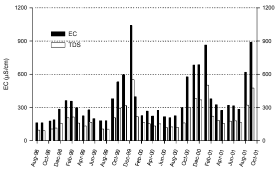


Figure 6-8 Monthly EC and TDS at the Bacon Island Station on Old River

Diversion Stations

Of the 3 diversion stations, the Banks Pumping Plant and the Delta-Mendota Canal (DMC) station were sampled on the same day each month, but the Contra Costa Pumping Plant was sampled on a different day. Therefore, data collected from Banks and DMC stations were not compared with data from the Contra Costa Pumping Plant. Samples at the Contra Costa Pumping Plant were collected at the pumping outlet. Samples were collected only when pumping was scheduled on a sampling date. Because of this, some data are not available for the Contra Costa Pumping Plant, especially during the 2001 water year.

The range and data dispersion were the greatest at the Contra Costa Pumping Plant, followed by the DMC (Table 6-2 and Table 6-3). Although average EC and TDS were the highest at the Contra Costa Pumping Plant, the highest median EC and TDS were found at the DMC. This inconsistency could be attributed to the differences in data collection dates and sampling frequency.

Seasonal patterns of EC and TDS were similar to those at the Old River stations (Figure 6-9). EC and TDS were generally higher during the wet months than during the dry months. During the wet months, both EC and TDS were considerably higher at the Contra Costa Pumping Plant than at the other 2 diversion stations. Both the average and median EC and TDS were higher at DMC than at Banks (Table 6-2 and Table 6-3). However, the differences in EC and TDS at both stations were not statistically different (p values were 0.375 and 0.448 for EC and TDS, respectively).

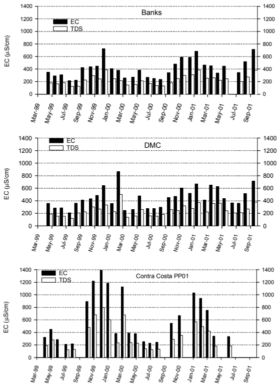


Figure 6-9 Monthly EC and TDS at three Delta diversion stations

Chloride and Sulfate

Chloride and sulfate affect the taste and odor of finished drinking water. The maximum contaminant level (MCL) for chloride and for sulfate is the same: 250 mg/L. Drinking water providers report increased taste and odor complaints from customers when chlorides are greater than 100 mg/L (Holm 2003 pers comm). Although concentrations of chloride and sulfate in source waters of the Delta do not represent those of finished drinking waters, chloride and sulfate data are summarized here for a brief overview of both parameters.

Table 6-4 Chloride and sulfate at 14 MWQI monitoring stations (mg/L)

Chloride and sulfate levels were generally low in most Delta stations except at the Mallard Island station (Table 6-4). Chloride at the Mallard Island station was high and frequently exceeded the MCL of 250 mg/L due to seawater influence. Contra Costa Water District has an intake at Mallard Slough adjacent to Mallard Island but only uses the intake when chlorides are less than 65 mg/L (Holm and Denton 2003 pers comm). Sulfate occasionally was also above the MCL at Mallard Island. Chloride and sulfate at Mallard ranged from 10 to 4,660 mg/L and from 11 to 637 mg/L, respectively. In contrast, chloride and sulfate at the 3 diversion stations never exceeded the MCL of 250 mg/L.

The Contra Costa Pumping Plant #1 is also affected by seawater influence. During the reporting period, both chloride and sulfate were low at this station: average chloride and sulfate were 65 and 54 mg/L, respectively; median chloride and sulfate were 36 and 38 mg/L, respectively (Table 6-4).

Agricultural drainage waters, which often contain higher levels of chloride and sulfate, affect the stations on the SJR and Old River, but they don't appear to have raised the concentrations of chloride and sulfate above their MCLs. Even in the 2 agricultural drainage stations, chloride never exceeded the MCL of 250 mg/L (Table 6-4). Although sulfate at the Bacon Island Pumping Plant reached 343 mg/L, average and median chloride and sulfate were low. Agricultural return water is a relatively small fraction of the water in the SJR system and in the Old River; therefore, chloride and sulfate in these river stations remained low despite the discharges from agricultural drainage sites.

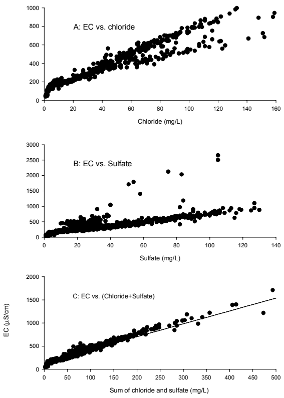


Figure 6-10 EC, Chloride, and sulfate relationships

Average and median concentrations of chloride were similar in the urban drainage Natomas East Main Drainage Canal (NEMDC) and in Old River stations, including the diversion stations. However, the ranges were narrower in the NEMDC than in the Old River (Table 6-4), suggesting that chloride was less variable in NEMDC than in Old River. Sulfate concentrations were higher at NEMDC than at the American River at E.A. Fairbairn WTP, the Sacramento River at Hood, and the West Sacramento WTP Intake, but lower than at all other stations.

Chloride and EC were highly correlated at the various stations; however, a single linear regression equation could not describe the relationship between chloride and EC at all 14 stations (Figure 6-10(a)). Instead, the stations fell into 3 major clusters. The first cluster represents waters with chloride concentrations less than 15 mg/L and EC of less than 250 mg/L; these are mostly waters collected from the American River, the West Sacramento WTP Intake, and the Sacramento River at Hood. The remainder of the stations belonged to the remaining 2 clusters, which are both linear. Therefore, at least 3 separate linear equations would be needed to describe the relationships between EC and chloride.

As with chloride, a single linear regression equation could not describe the relationship between sulfate concentration and EC for all stations. Although the majority of the data fell on a linear line, scattering occurred, especially where sulfate was from 10 to 40 mg/L, and EC was less than 600 µS/cm

(Figure 6-10(b)). The samples with high EC are mostly from the Mallard Island station.

Despite the lack of a single linear relationship between EC and chloride and sulfate individually for all 14 stations, a statistically significant linear equation,

$$EC=147.9+2.78*(\text{chloride}+\text{sulfate})$$

($p<0.0001$ for the overall regression and the regression coefficient), could be used to describe the relationship between EC and the sum of both chloride and sulfate with an r^2 of 0.995 (Figure 6-10(c)).

Relationships Between EC and Major Cations

The combined concentrations of chloride and sulfate can be used to predict EC of all 14 stations (see section "Chloride and Sulfate"). Anions such as chloride and sulfate do not exist alone in the water; they always pair in balance with cations. Among the various cations, sodium, calcium, and magnesium are the most abundant and contribute the most to EC. The other cations exist in much smaller quantities. Therefore, for cations only the relationships between EC and sodium, calcium, and magnesium are presented.

Like chloride and sulfate, concentrations of sodium, calcium, and magnesium at the 14 stations may be roughly divided into 3 groups. The group with the lowest concentrations is not affected by seawater influence. Stations of this group include the American River at E.A. Fairbairn WTP, the West Sacramento WTP Intake, and the Sacramento River at Hood. Within this group, sodium ranged from 2 to 17 mg/L, and the combined calcium and magnesium from 5.0 to 28.9 mg/L (Table 6-5). Seawater influences resulted in the detection of the highest concentrations of sodium, calcium, and magnesium at the Mallard Island station (Table 6-5). The remainder of the stations belongs to the third group, which except for the NEMDC station either directly or indirectly are affected by seawater. Concentrations of sodium, calcium, and magnesium in these stations were similar (Table 6-5).

Table 6-5 Summary of sodium, calcium, and magnesium at 14 MWQI monitoring stations

Like the anions (chloride and sulfate), EC was highly correlated with sodium, calcium, and magnesium individually at each station, but no single linear regression equation described relationships for all stations (data not shown). However, a strong linear relationship exists between EC and the sum of the cations (Figure 6-11). This figure shows the majority of the data with all 730 data points plotted in the inset. EC may be predicted by the equation,

$$EC = 39.5 + 5.0*(\text{sodium}+\text{calcium}+\text{magnesium}),\ [r^2 = 0.997],$$

with $p<0.0001$ for both the overall equation and regression constant.

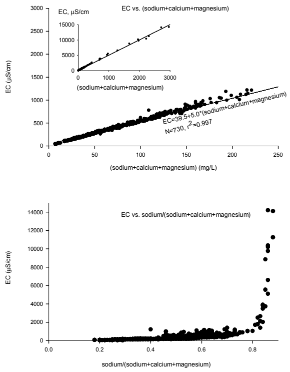


Figure 6-11 Relationships between EC and major cations at 14 MWQI stations

The data during the reporting period suggest that the relative percentage of sodium, as expressed by the ratio, sodium /(sodium+calcium+magnesium), was important (Figure 6-11). When sodium composed 80% of the cationic makeup—that is, when the sodium/(sodium+calcium+magnesium) ratio reached 0.8—EC increased more rapidly, suggesting that sodium will be the dominant cation contributing to EC when a cation ratio is above 0.8.

The lowest sodium/(sodium+calcium+magnesium) among the 14 MWQI stations was found in the American River at E.A. Fairbairn WTP, followed by 2 Sacramento River stations at West Sacramento WTP Intake and at Hood (Table 6-5). Mallard Island is the only station that had a ratio that exceeded 0.8 (Table 6-5). The average and median ratios for NEMDC were 0.5, suggesting that sodium and the combined amounts of calcium and magnesium were roughly equal. The ratios for the remainder of the stations were around 0.6.

Factors that Affect EC and Salinity in Delta Waters

Seawater Influence

The Delta is strongly influenced by tidal events. Figure 6-12 presents a general picture of seawater influence in the western part of the Delta as indicated by the presence of high chloride concentrations from 1921 through 1943. Chloride levels as high as 1,000 mg/L were observed on the Sacramento River upstream of Rio Vista during 7 years of the 23-year period. This was before Shasta, Folsom, and Oroville dams were built. Reservoirs help reduce seawater influence by releasing low-salinity water that dilutes salt content and reduces seawater influence to Delta waters during the dry months of each year.

Figure 6-12 Seawater influence in the Delta, 1921-1943 (map)

The Mallard Island station is affected heavily by daily tides. Monitoring data for EC and TDS suggest that EC and TDS were widely variable (Figure 6-13, Table 6-2, and Table 6-3). The general range of EC was from 171 to 17,600 µS/cm, while average and median EC were 4,199 and 2,120 µS/cm, respectively. These high EC and TDS concentrations have not been observed at the other stations, including the 2 agricultural drainage stations (Table 6-2 and Table 6-3).

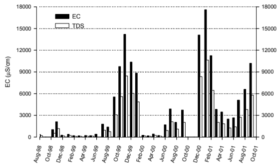


Figure 6-13 Monthly EC and TDS at Mallard Island station

Like bromide, both EC and TDS were higher during the wet months than during the dry months (Figure 6-13). This is perhaps attributable to lower Delta outflows, especially during dry runoff years. Delta outflows are generally higher during the dry months than during the wet months when dams, lakes, and reservoirs are storing water and releasing less. Delta outflows measured at Chipps Island near Mallard Island are summarized in Chapter 3 (Figure 3-3). When Delta outflows were strong such as during the 1998 and 1999 water years and from February to May of 2000 when the contributing Delta watersheds rainfall was delayed, EC and TDS were lower due to both dilution and suppression of seawater influence.

During the 3 water years, EC and TDS at Mallard were affected by runoff in the upper watersheds. EC and TDS levels were the lowest during the 1999 water year and highest in the 2001 water year (Figure 6-13). The 1999 water year was an above-normal year, and the 2 previous water years, 1997 and 1998, were wet years. Strong outflows (Figure 3-3) from 1997 and 1998 lowered both EC and TDS. In contrast, the 2001 water year was classified a dry year, and runoff in the contributing watersheds was the lowest among the

3 water years (Figure 3-3). Therefore, EC and TDS were highest during both the wet and the dry months of the 2001 water year.

In-Delta Agricultural Drainage

In-Delta agricultural drainage contributes salts and increases EC and TDS in Delta waters. Average and median EC and TDS were significantly higher in agricultural drainage waters than in the surrounding waters (Table 6-2 and Table 6-3). EC and TDS showed little variation among the water years (Figure 6-14). Within each water year, they were higher during the wet months than during the dry months. Increased EC and TDS during the wet months were due perhaps to annual salt leaching activities. Each winter, farmers flood the land to leach salts from the soil. The amount of salt drained to the ditches generally does not vary significantly from year to year; therefore, EC and TDS varied little during the 3 water years.

The monitoring data for Bacon Island agricultural drainage were incomplete due to the amount of missing data for 2000 and 2001 water years. Although the average and median EC and TDS were lower at the Bacon Island agricultural drain than at the Twitchell Island drain station, the difference may not have existed if all the data had been available. A statistical comparison of EC and TDS between the 2 agricultural drainage sites could not be made.

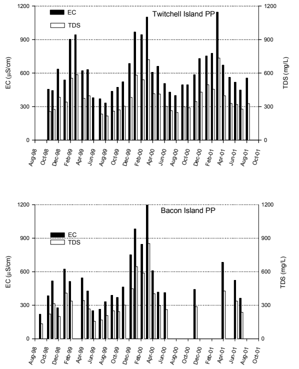
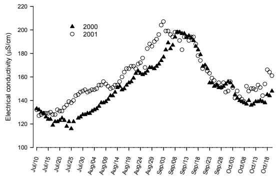


Figure 6-14 Monthly EC and TDS at the agricultural pumping plants at Bacon and Twitchell islands

Agricultural Drainage to the Sacramento River

Drainage from rice fields in the Sacramento Valley contributes considerable TDS to the Sacramento River during the drainage season of each water year. Figure 6-15 presents average daily EC data from the U.S. Bureau of Reclamation (USBR) station at Greenes Landing on the Sacramento River for the period July through October in water years 2000 and 2001. Greenes Landing is approximately 2 miles downstream from the Hood station (Figure 4-1). Rice drainage usually begins in August and continues until the end of September each year. In response to rice drainage, EC began to increase in mid-August and peaked in mid-September, then dropped close to normal levels after rice drainage was completed at the end of September. EC averages for September were 40% and 27% higher than July averages in 2000 and 2001, respectively.



Note: Data from CDEC, accessed August 13, 2002. The EC recorder is maintained by the U.S. Bureau of Reclamation. EC was mean daily average.

Figure 6-15 Effects of rice drainage on EC at Greenes Landing

The increase in EC in September was attributable presumably to rice drainage returns to the Sacramento River rather than to a reduction in the percent of water from the American River. Water at the Greenes Landing station is a mixture of water from both the upper Sacramento and American rivers. During each September of the reporting period, there was little variation in the amount of water released to the American River from Lake Natoma, and there were only minor changes of flow in the Sacramento River at Freeport (data not shown).

The Sacramento River also receives irrigation discharges from rice fields and row crops, which also increase salinity during June and July (see Chapter 4 section "The Hood Station").

Agricultural Drainage to the San Joaquin River

Figure 6-16 Stations on the San Joaquin River from DMC to Vernalis (map)

As discussed, EC and TDS are higher in water collected at the SJR near Vernalis station (Figure 6-5) than at the Sacramento River at Hood. The high EC and TDS in the SJR may be attributable to intensive agricultural activities in the upper SJR watershed and the lack of large freshwater releases from dams, reservoirs, and tributaries to dilute summer runoff. Figure 6-16 is a watershed map showing the SJR and some non-MWQI stations where EC data were collected by the San Joaquin District of the California Department of Water Resources (DWR). A summary of mean daily EC for 2 stations on the SJR and 3 stations on 3 major tributaries are presented in Table 6-6. Although data periods varied, the data clearly demonstrate the differences among the stations.

Table 6-6 EC at stations on the San Joaquin River and its major tributaries

Although agricultural return waters were not monitored for EC and TDS along the SJR from the Vernalis station to the upstream station near Stevinson during the reporting period, data suggest that additional loads of salts to the upper SJR existed (Table 6-6). Water inflows from the 3 major tributaries—Merced River near Stevinson, Tuolumne River at Modesto, and Stanislaus River at Ripon—were all low in EC (Table 6-6). Average EC for the waters of the 3 tributaries ranged from 102 to 180 µS/cm; the range for median EC was similar (Table 6-6). If there were no additional loads of salts, the EC of the SJR would have been low.

The contributions of high EC from both the Salt Slough and Mud Slough inflows are clearly demonstrated by comparing mean daily EC at 3 stations—the SJR near Stevinson, the SJR near Patterson, and the Merced River near Stevinson. The SJR near Stevinson and the SJR near Patterson are about 38 stream miles apart; the mouth of the Merced River is between the 2 stations, approximately 24 miles upstream from the SJR near Patterson (Figure 6-16). At the SJR near Stevinson station, average daily EC was 1,142 µS/cm, and median was 1,200 µS/cm (Table 6-6). High EC at this station was due perhaps to both low flows and high salt concentration in inflows. During the reporting period, average flow at this station was 150 cubic feet per second (cfs) with a median of 57 cfs. In contrast, average flow at downstream SJR near Patterson was 1,262 cfs with a median of 913 cfs. These values were 8 to 16 times greater than those at the SJR near Stevinson station.

The SJR near Patterson station receives inflows from the Merced River, which is low in EC as indicated by low EC at the Merced River near Stevinson station (Table 6-6). Despite higher flows and dilutional inflows, average EC at SJR near Patterson was 1,128 µS/cm with a median of 1,168 µS/cm, which is similar to those at the upstream SJR near Stevinson station (Table 6-6). This is due to the fact that the Patterson station also receives inflows from both Salt Slough and Mud Slough.

Although monitoring data for both Salt Slough and Mud Slough were not available, EC in drainage waters of Salt and Mud sloughs would have to be high to counter the dilutional effects of low-EC inflows from the Merced River. Both Salt Slough and Mud Slough collect agricultural drainage returns from the watershed. The irrigation return waters are concentrated water from the DMC, which contains moderately high salts even before condensation in agricultural lands. The soils in some of the areas were developed from geologic marine deposits, which also contribute salts to the drainage waters.

In addition to irrigated agriculture, many dairy farms are in the upper SJR watershed in Stanislaus and Merced counties. Although estimates for TDS loads are not available, discharges from these operations increase EC and TDS in both groundwater and surface water. The effects of dairies on water quality are discussed extensively in Chapter 4 of *Sanitary Survey Update 2001* (DWR 2001).

Urban Drainage in and near the Delta

Many wastewater treatment plants and urban drainage areas are scattered throughout the Delta and the watersheds that contribute runoff to the Delta. The amount of salts contributed by these wastewater treatment operations and other urban drainage to Delta source waters are discussed in *Sanitary Survey Update 2001*, especially in Chapter 4 (DWR 2001).

During the reporting period, MWQI monitored one urban drainage canal in the Sacramento River watershed—NEMDC at El Camino in north Sacramento. Although NEMDC is outside the legal Delta, its mouth is less than 2 miles from the I Street Bridge, which is the upstream end of the legal Delta. The average and median EC and TDS were considerably higher in NEMDC than in the American River at the E.A. Fairbairn WTP and in the Sacramento River at the West Sacramento WTP Intake, both of which are close to NEMDC (Table 6-2 and Table 6-3). Instead, EC and TDS at NEMDC were quite similar to those of the channel stations, which are heavily influenced by agricultural drainage, inputs from the SJR, and (to a lesser extent) seawater influence.

Average and median EC and TDS at NEMDC were similar to those of the channel stations (Table 6-2 and Table 6-3). A strong and persistent seasonal pattern was not observed. Episodic events could drastically alter this general pattern such as the increases in EC and TDS in September of 1998 and 1999 and in April 2000 and 2001 (Figure 6-17). However, EC and TDS may be significantly lower during or immediately after a sustained heavy rainfall and runoff such as those during January and March of 2001. Both EC and TDS increased slightly during the dry months, especially during the 2000 water year, but average EC and TDS during the dry months were not significantly different from those during the wet months of the reporting period (p was 0.215 and 0.200 for EC and TDS, respectively).

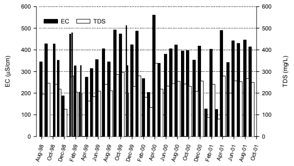


Figure 6-17 EC and TDS at NEMDC station

Table 6-1 Summary of TDS/EC ratios at 14 MWQI stations

Station	Sample number	Range	Average	Median
American and Sacramento River stations				
American River at E.A. Fairbairn WTP	37	0.60–0.97	0.71	0.71
West Sacramento WTP Intake	37	0.51–0.74	0.62	0.62
Sacramento River at Hood	157	0.49–0.80	0.62	0.61
Sacramento River at Mallard Island	34	0.51–0.64	0.56	0.57
San Joaquin River stations				
San Joaquin River near Vernalis	156	0.50–0.65	0.58	0.58
San Joaquin River at Highway 4	36	0.54–0.64	0.58	0.58
Channel stations				
Old River at Station 9	37	0.50–0.64	0.57	0.56
Old River at Bacon Island	37	0.52–0.71	0.57	0.57
Delta diversion stations				
Banks Pumping Plant	29	0.51–0.67	0.56	0.55
Delta-Mendota Canal	30	0.52–0.70	0.56	0.56
Contra Costa Pumping Plant	29	0.51–0.73	0.57	0.56
Agricultural drainage stations				
Bacon Island Pumping Plant	25	0.58–0.72	0.65	0.65
Twitchell Island Pumping Plant	34	0.56–0.68	0.61	0.60
Urban drainage station				
Natomas East Main Drainage Canal	41	0.54–0.69	0.60	0.60

Table 6-2 Summary of electrical conductivity at 14 MWQI stations (µS/cm)

Station	Sample number	Range	Majority data range	Data Dispersion (IQR)	Average	Median
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	37	40–71	44–68	47–62	52	54
West Sacramento WTP Intake	38	112–241	124–212	140–179	161	155
Sacramento River at Hood	160	96–228	115–207	137–178	158	155
Sacramento River at Mallard Island	35	171–17,600	187–14,130	367–6,070	4,199	2,120
San Joaquin River Stations						
San Joaquin River near Vernalis	160	195–1,120	231–865	351–700	543	549
San Joaquin River at Highway 4	37	218–937	226–870	415–686	539	510
Delta channel stations						
Old River at Station 9	38	187–908	204–776	263–470	391	350
Old River at Bacon Island	38	162–1,040	175–868	223–393	372	290
Diversion stations						
Banks Pumping Plant	29	215–725	228–703	291–466	408	384
Delta-Mendota Canal	30	208–862	254–693	312–517	443	422
Contra Costa Pumping Plant	30	161–1,390	190–1,205	247–732	522	367
Agricultural drainage stations						
Bacon Island Pumping Plant	25	220–1,216	254–955	370–609	513	442
Twitchell Island Pumping Plant	35	332–1,145	377–1,008	464–708	621	561
Urban drainage station						
Natomas East Main Drainage Canal	41	125–561	188–492	328–430	374	397

Table 6-3 Summary of statistics for total dissolved solids (mg/L)

Station	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	37	30–54	31–47	35–42	39	39
West Sacramento WTP Intake	37	71–148	78–130	89–110	100	97
Sacramento River at Hood	157	61–137	72–126	85–108	97	95
Sacramento River at Mallard Island	34	101–10,603	115–8,382	194–3,629	2,458	1,215
San Joaquin River stations						
San Joaquin River near Vernalis	156	113–652	137–505	203–409	315	318
San Joaquin River at Highway 4	36	122–507	129–501	227–394	313	315
Delta channel stations						
Old River at Station 9	37	112–465	118–428	151–277	223	204
Old River at Bacon Island	37	90–551	102–480	133–221	210	162
Diversion stations						
Banks Pumping Plant	29	123–388	128–385	170–262	228	220
Delta Mendota Canal	30	120–501	145–376	184–297	248	234
Contra Costa Pumping Plant	29	92–797	107–680	138–421	298	228
Agricultural drainage stations						
Bacon Island Pumping Plant	25	134–853	159–634	237–403	334	298
Twitchell Island Pumping Plant	34	216–735	243–633	281–426	383	344
Urban drainage station						
Natomas East Main Drainage Canal	41	80–338	126–296	200–256	224	233

Table 6-4 Chloride and sulfate at 14 MWQI monitoring stations (mg/L)

Station	Chloride				Sulfate			
	Sample number	Range	Average	Median	Sample number	Range	Average	Median
American and Sacramento River stations								
American River at E.A. Fairbairn WTP	37	1–2	2	2	31/37[a]	1–6	2	2
West Sacramento WTP Intake	38	2–12	5	4	38	3–15	7	6
Sacramento River at Hood	158	2–11	6	5	159	2–15	7	7
Sacramento River at Mallard Island	30	10–4,660	964	458	31	11–637	138	58
San Joaquin River stations								
San Joaquin River near Vernalis	153	16–139	64	65	153	23–164	67	68
San Joaquin River at Highway 4	35	19–128	64	60	35	22–130	65	65
Delta channel stations								
Old River at Station 9	34	13–190	48	39	38	12–71	29	26
Old River at Bacon Island	34	10–246	45	30	38	8–42	23	22
Diversion stations								
Banks Pumping Plant	35	18–151	48	43	38	14–60	33	31
Delta-Mendota Canal	28	19–122	55	51	31	14–125	40	33
Contra Costa Pumping Plant	27	9–224	65	36	30	11–195	54	38
Agricultural drainage stations								
Bacon Island Pumping Plant	25	18–132	62	49	24	10–343	71	44
Twitchell Island Pumping Plant	31	45–191	100	90	33	11–127	39	28
Urban drainage station								
Natomas East Main Drainage Canal	41	6–71	41	44	41	6–34	21	21

a. Positive detects/total sample number

Table 6-5 Summary of sodium, calcium, and magnesium at 14 MWQI monitoring stations[a]

Station	Sample number	Sodium			Calcium+ magnesium			Sodium/(sodium + calcium + magnesium)		
		Range	Average	Median	Range	Average	Median	Range	Average	Median
American and Sacramento River stations										
American River at E.A. Fairbairn WTP	37	2–3	2	2	5.0–10.0	7.2	7.0	0.18–0.29	0.24	0.23
West Sacramento WTP Intake	38	5–16	10	9	13.8–28.9	19.5	19.0	0.26–0.39	0.33	0.33
Sacramento River at Hood	159	5–17	10	10	11.9–26.1	18.0	18.0	0.25–0.42	0.35	0.35
Sacramento River at Mallard Island	35	11–3,060	697	314	17.0–501.1	121.4	64.0	0.38–0.88	0.73	0.83
San Joaquin River stations										
San Joaquin River near Vernalis	159	18–135	59	60	16.0–80.0	37.9	39.0	0.51–0.64	0.59	0.58
San Joaquin River at Highway 4	37	20–104	59	56	18.0–63.0	40.1	41.0	0.51–0.66	0.58	0.58
Delta channel stations										
Old River at Station 9	38	16–112	42	35	17.0–42.0	27.6	27.5	0.45–0.75	0.57	0.55
Old River at Bacon Island	38	13–147	41	27	15.3–41.0	25.1	24.0	0.42–0.78	0.56	0.53
Diversion stations										
Banks Pumping Plant	37	18–91	41	36	20.0–40.0	27.6	26.0	0.46–0.72	0.57	0.56
Delta-Mendota Canal	31	18–102	47	42	20.0–60.0	31.5	30.0	0.47–0.70	0.58	0.57
Contra Costa Pumping Plant	30	12–188	59	37	16.4–82.0	34.8	30.0	0.41–0.73	0.58	0.56
Agricultural drainage stations										
Bacon Island Pumping Plant	25	20–88	48	46	21.0–133.0	45.0	39.0	0.40–0.61	0.53	0.53
Twitchell Island Pumping Plant	35	38–132	72	64	23.0–86.0	40.7	36.0	0.53–0.71	0.64	0.64
Urban drainage station										
Natomas East Main Drainage Canal	41	8–50	35	38	12.0–53.0	32.6	30.0	0.36–0.65	0.51	0.50

a. Data unit is mg/L except for the unitless sodium/(sodium + calcium + magnesium) ratio.

Table 6-6 Electrical conductivity at stations on the San Joaquin River and its major tributaries (μS/cm)

Station	Sampling days	Summary period	Range	Majority data range	Data dispersion (IQR)	Average	Median
San Joaquin River near Stevinson	426	07/27/2000–09/30/2001	141–1,874	432–1,624	935–1,432	1,142	1,200
Merced River near Stevinson	433	07/24/2000–09/30/2001	45–373	59–301	134–237	180	175
San Joaquin River at Patterson	326	11/01/2000–09/30/2001	408–1,619	608–1,481	1,029–1,265	1,128	1,168
Tuolumne River at Modesto	272	01/01/2001–09/30/2002	49–325	63–267	123–211	166	165
Stanislaus River at Ripon	785	08/01/1999–09/30/2001	52–170	68–145	85–99	102	100

Figure 6-1 Relationship between EC and TDS at 14 MWQI stations

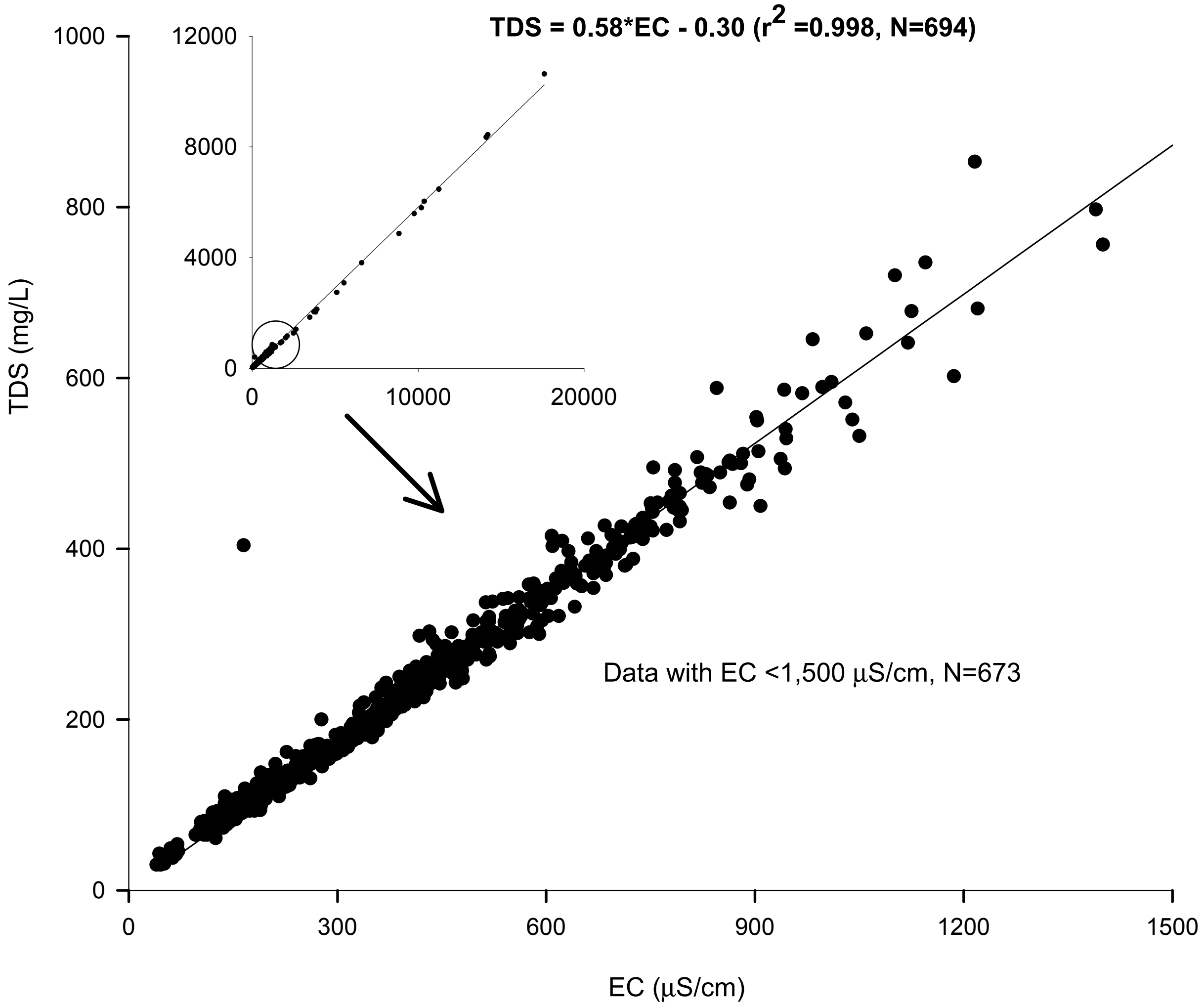


Figure 6-2 Monthly EC and TDS at the American River WTP Intake

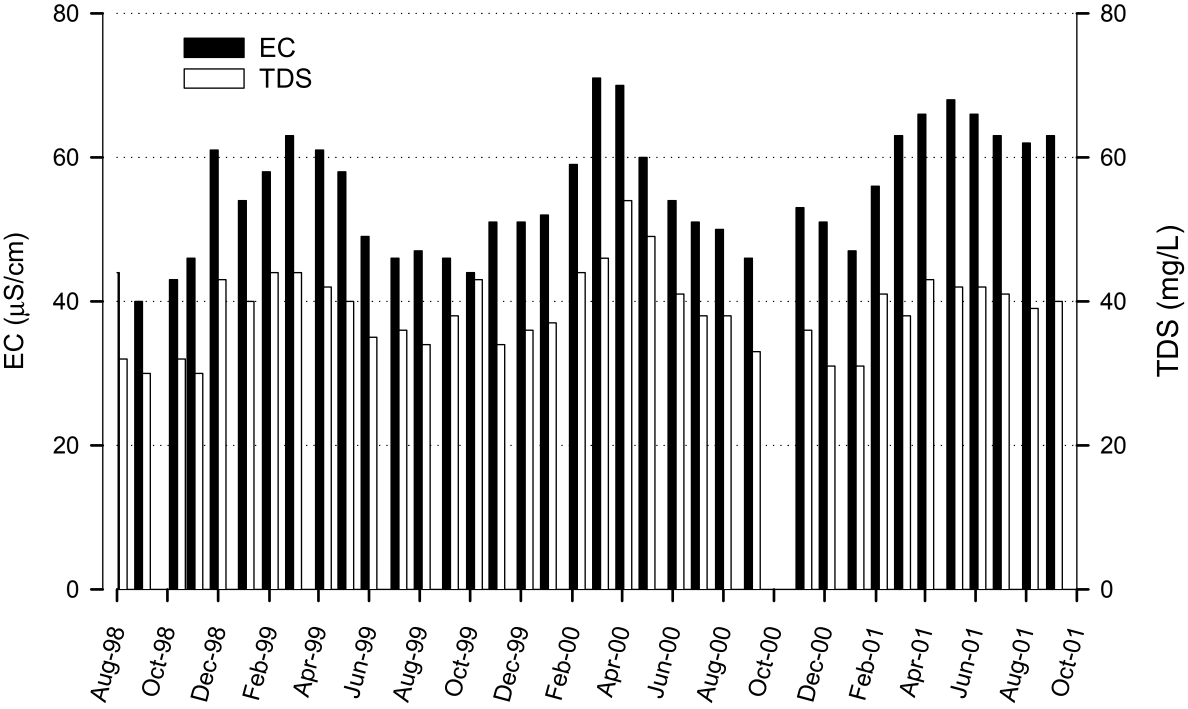


Figure 6-3 Monthly EC and TDS at the West Sacramento WTP Intake

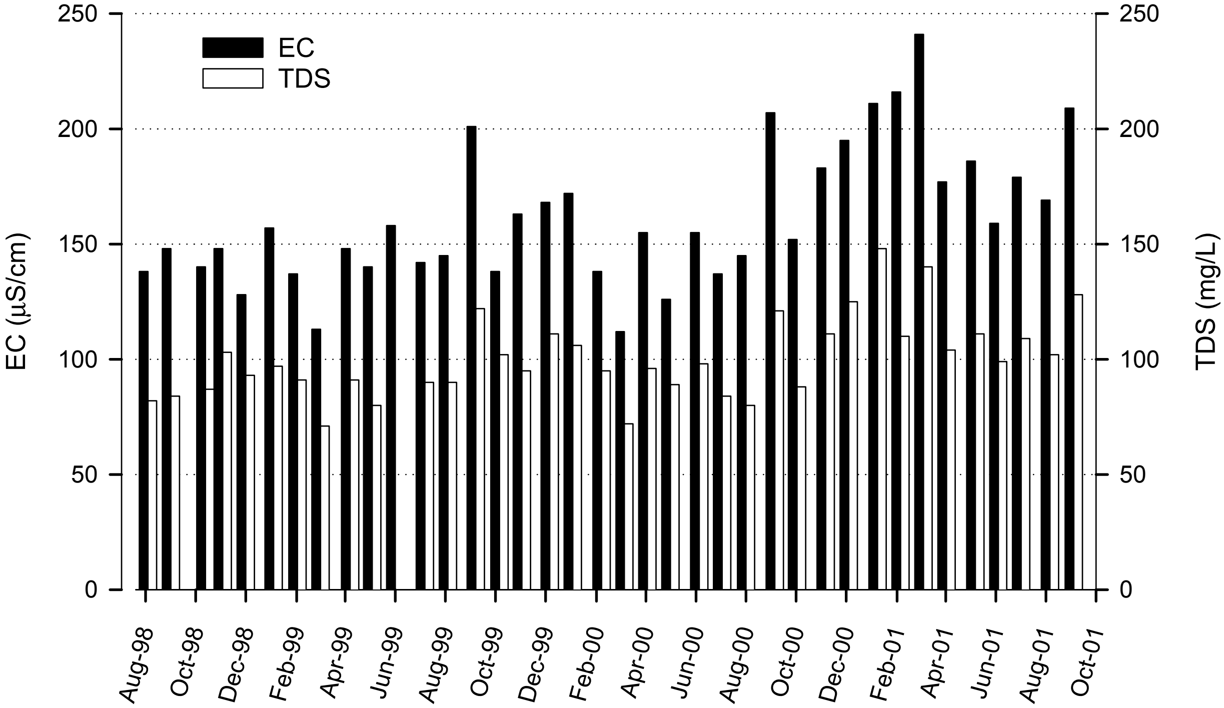


Figure 6-4 Weekly EC and TDS at the Hood station (Loess smoothing parameter = 0.05)

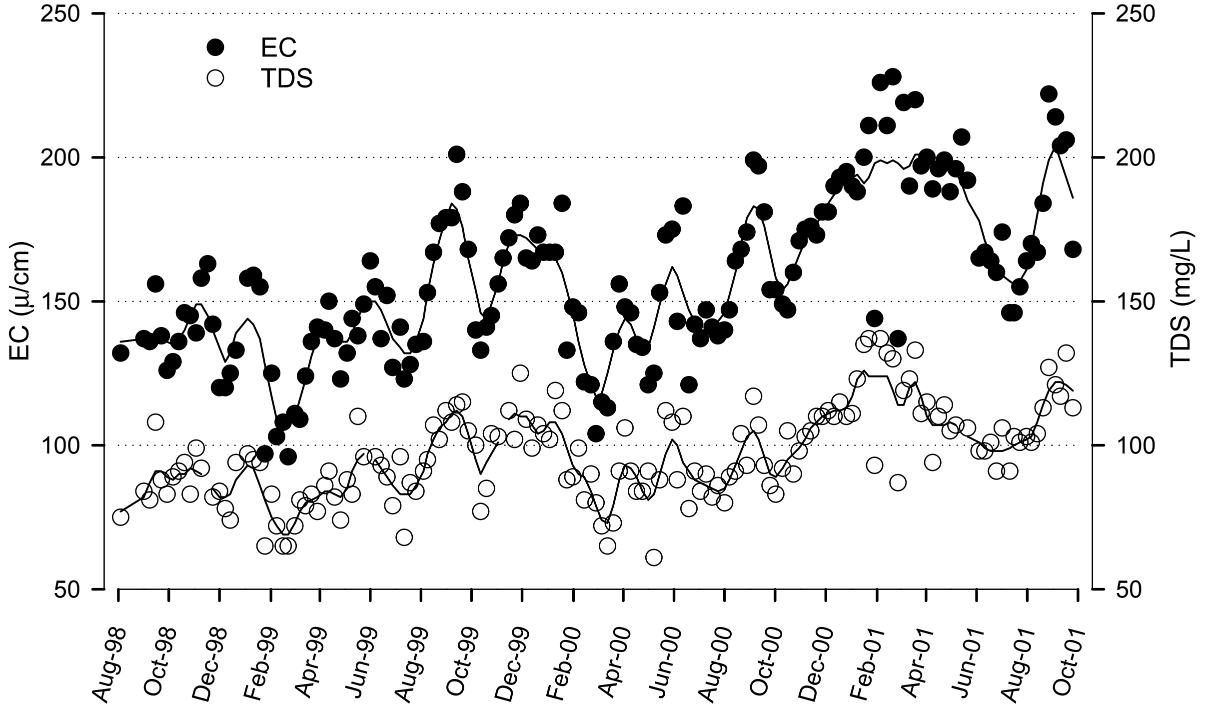


Figure 6-5 Weekly EC and TDS at San Joaquin River near Vernalis (Loess smoothing parameter = 0.05)

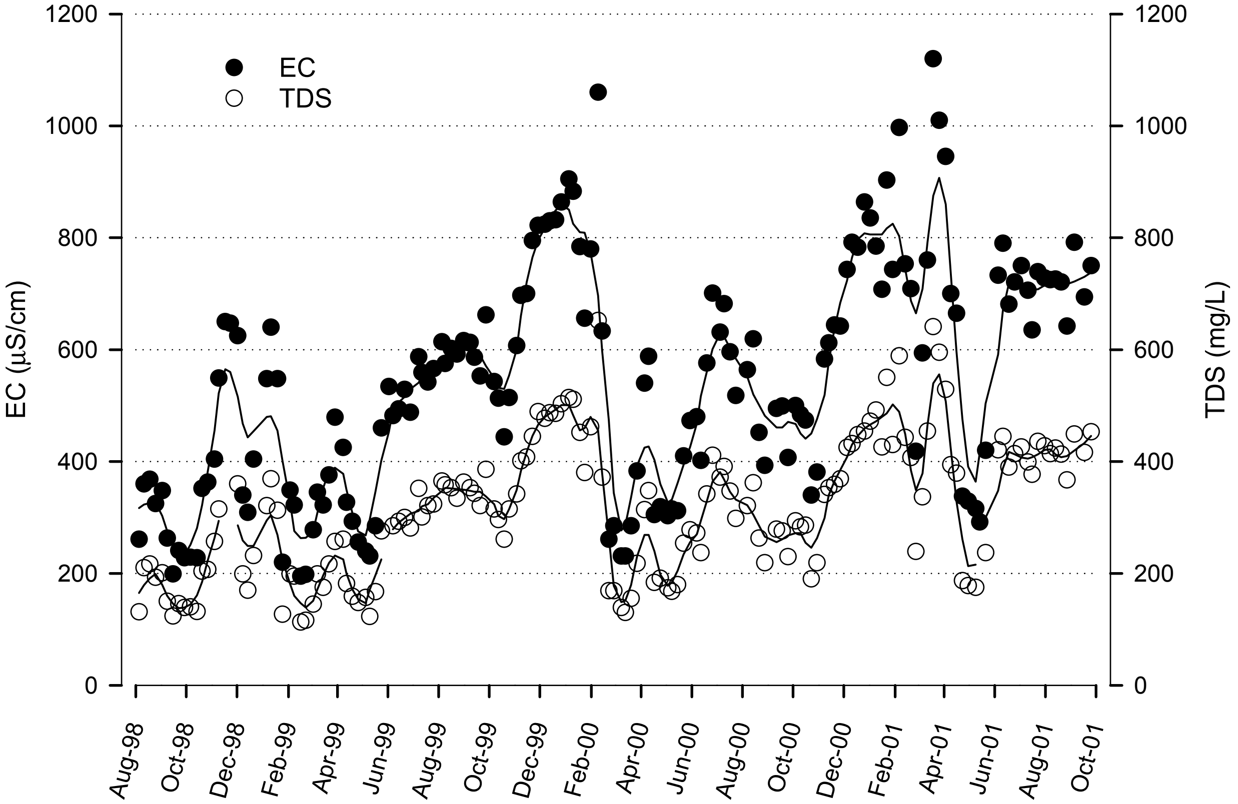


Figure 6-6 Monthly EC and TDS at the San Joaquin River at Highway 4

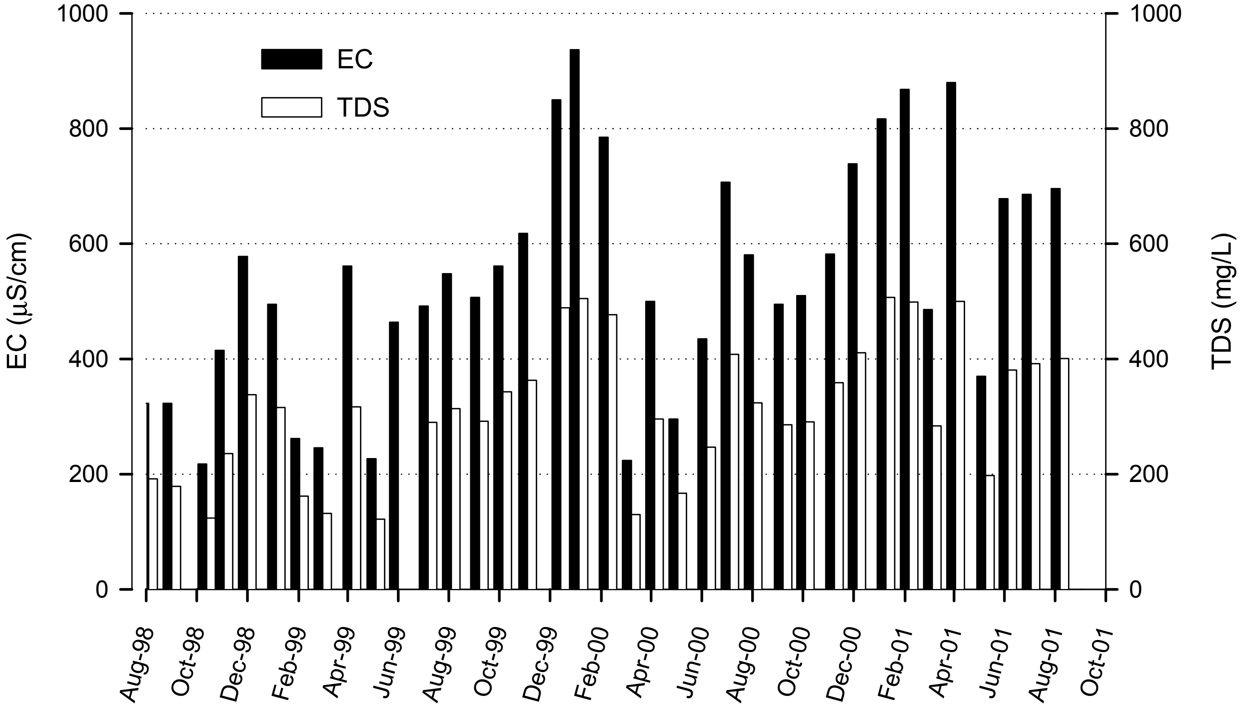


Figure 6-7 Monthly EC and TDS at Old River at Station 9

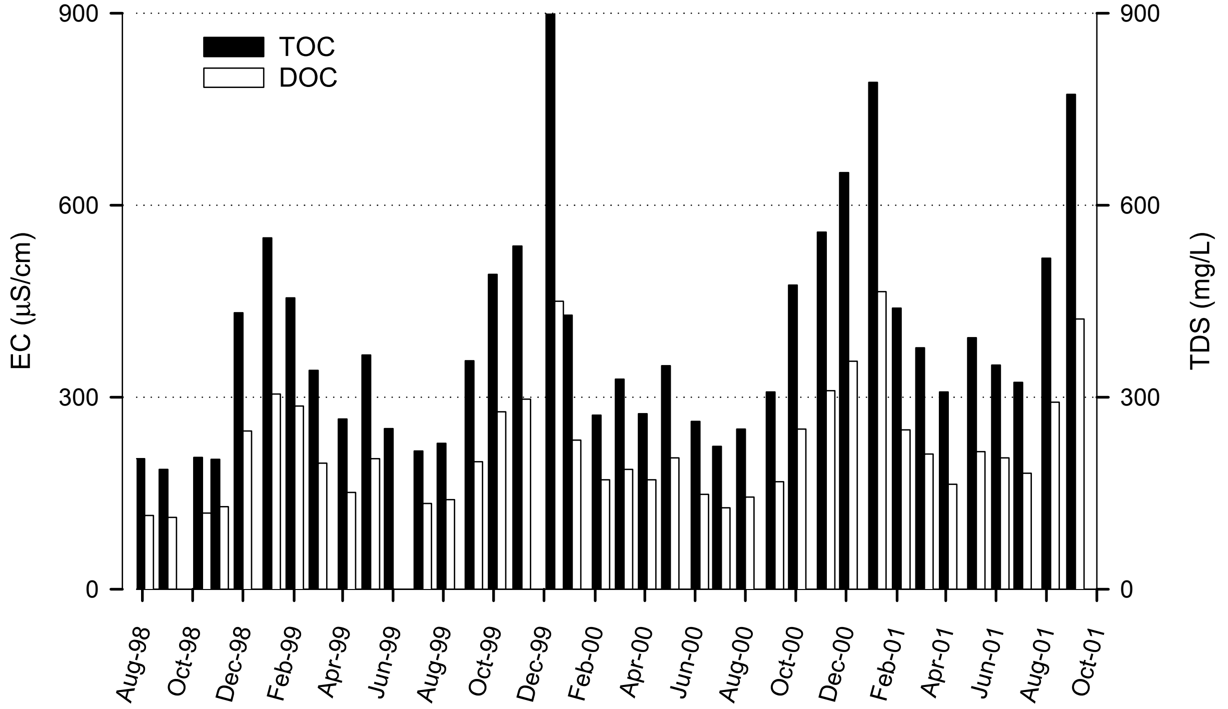


Figure 6-8 Monthly EC and TDS at the Bacon Island Station on Old River

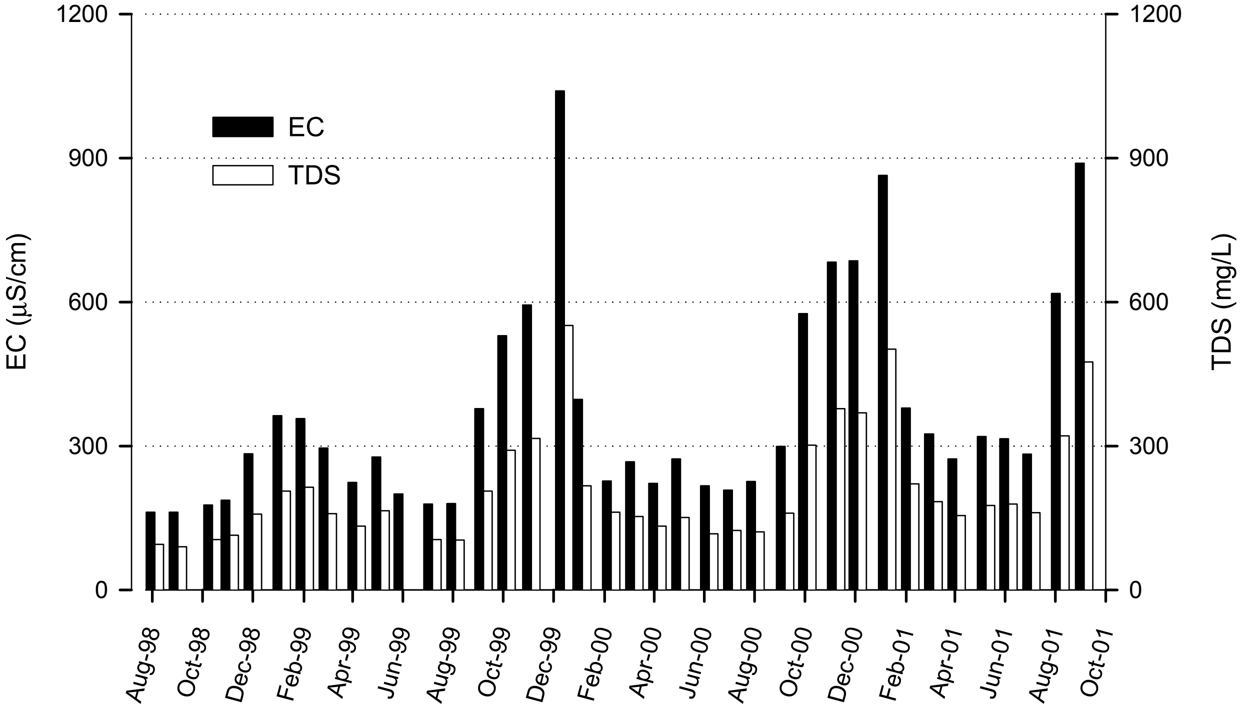
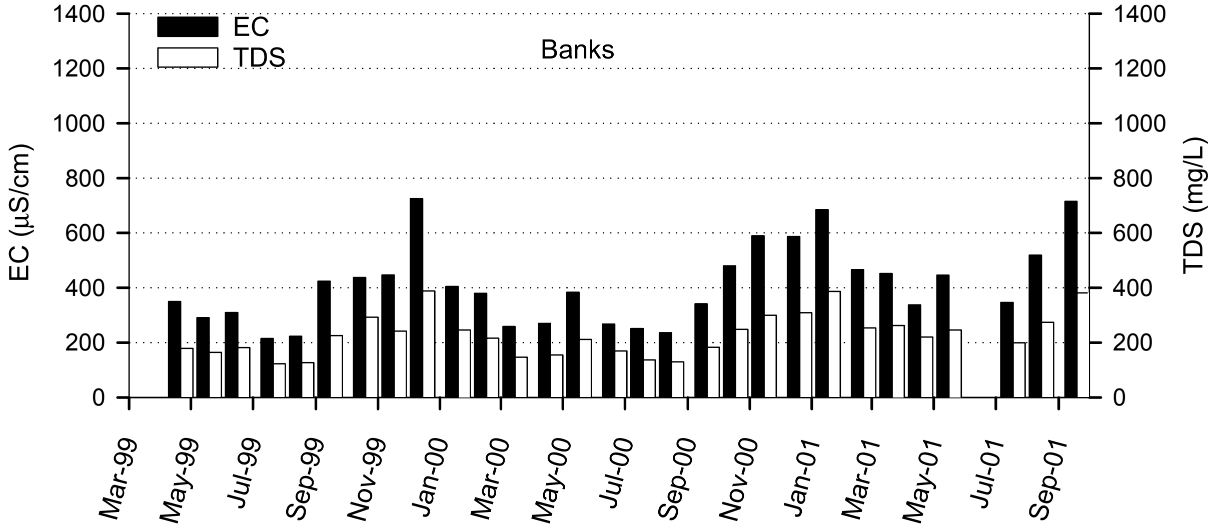
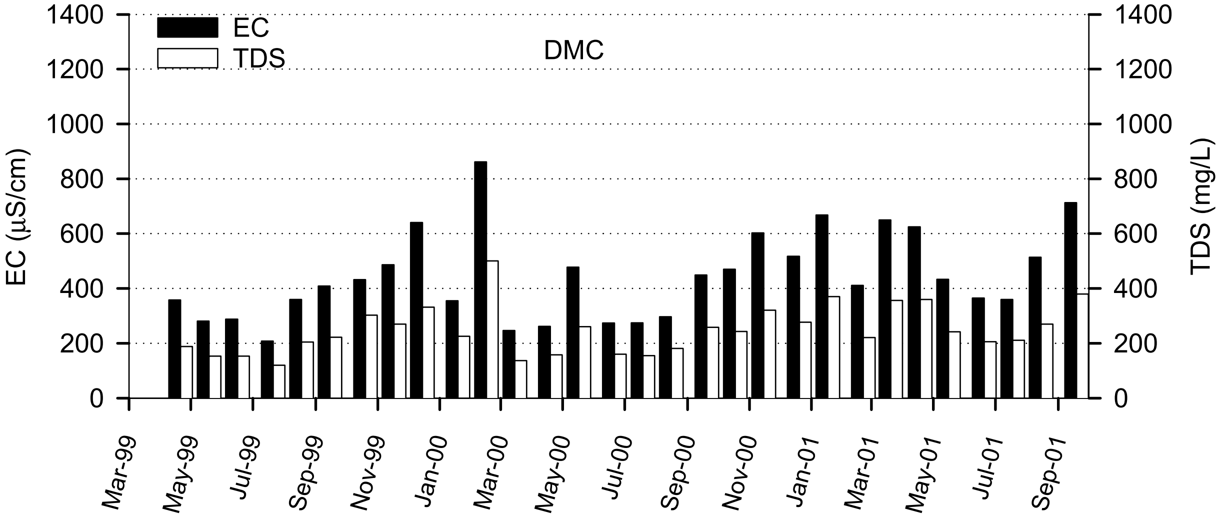


Figure 6-9 Monthly EC and TDS at three Delta diversion stations





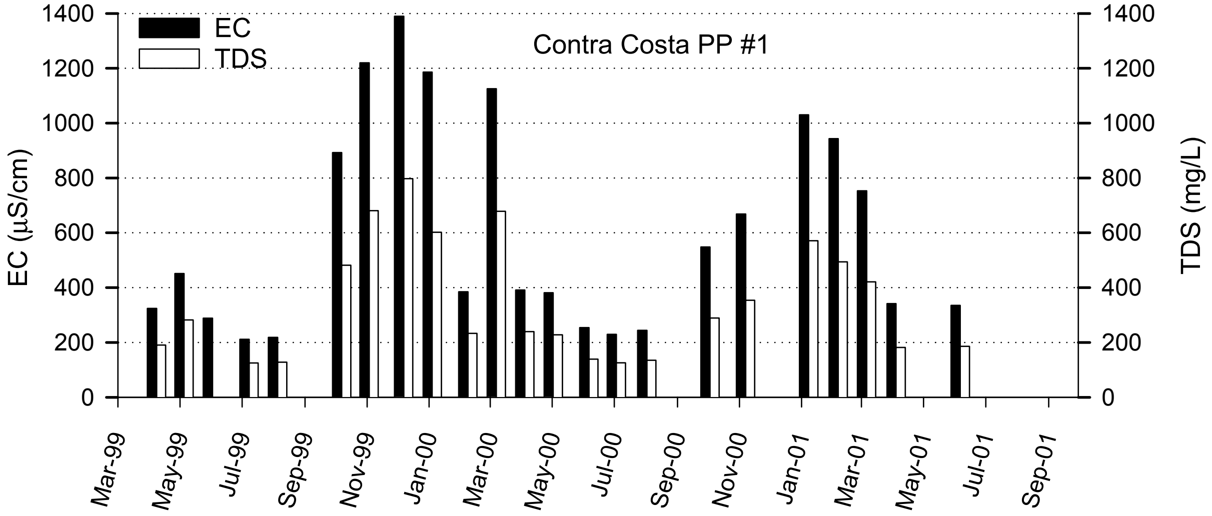


Figure 6-10 EC, chloride, and sulfate relationships

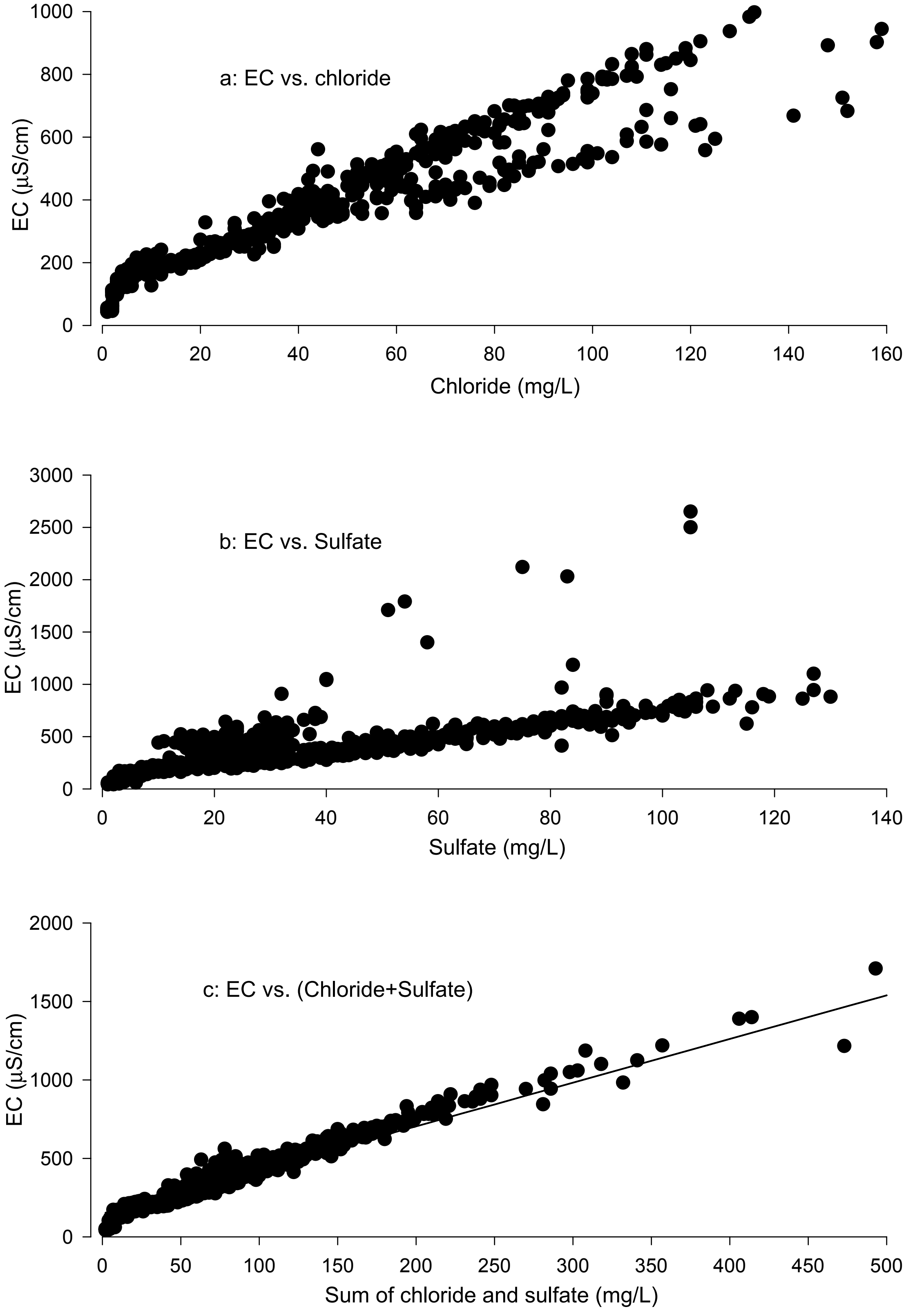
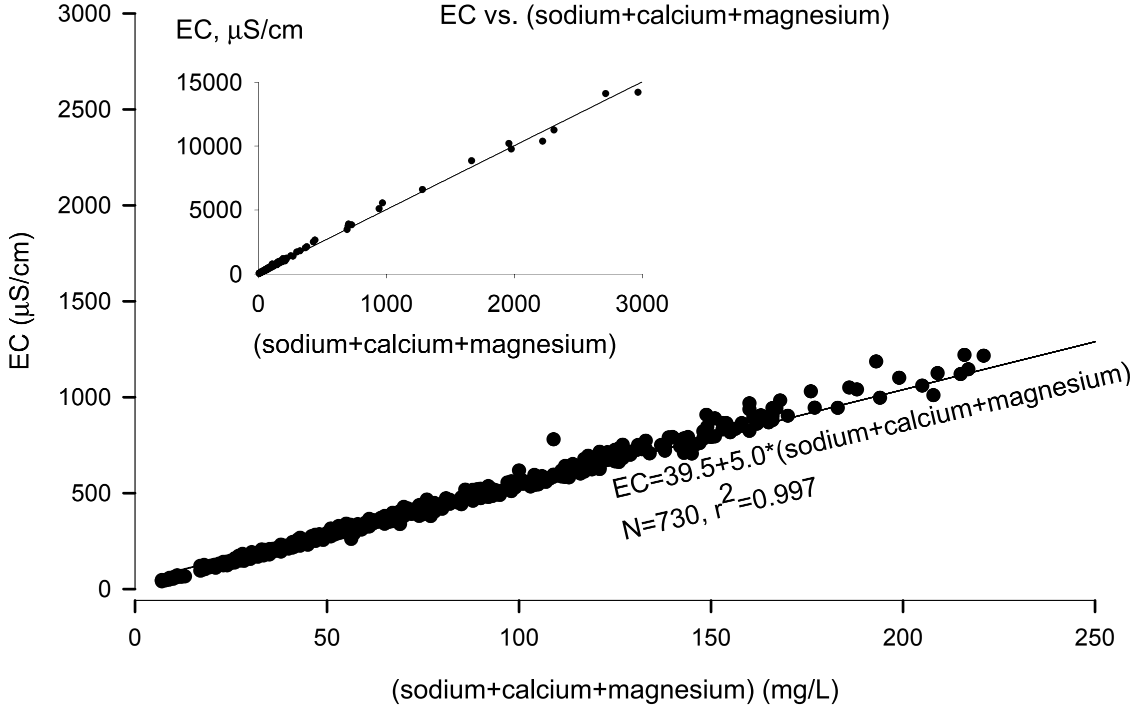


Figure 6-11 Relationships between EC and major cations at 14 MWQI stations



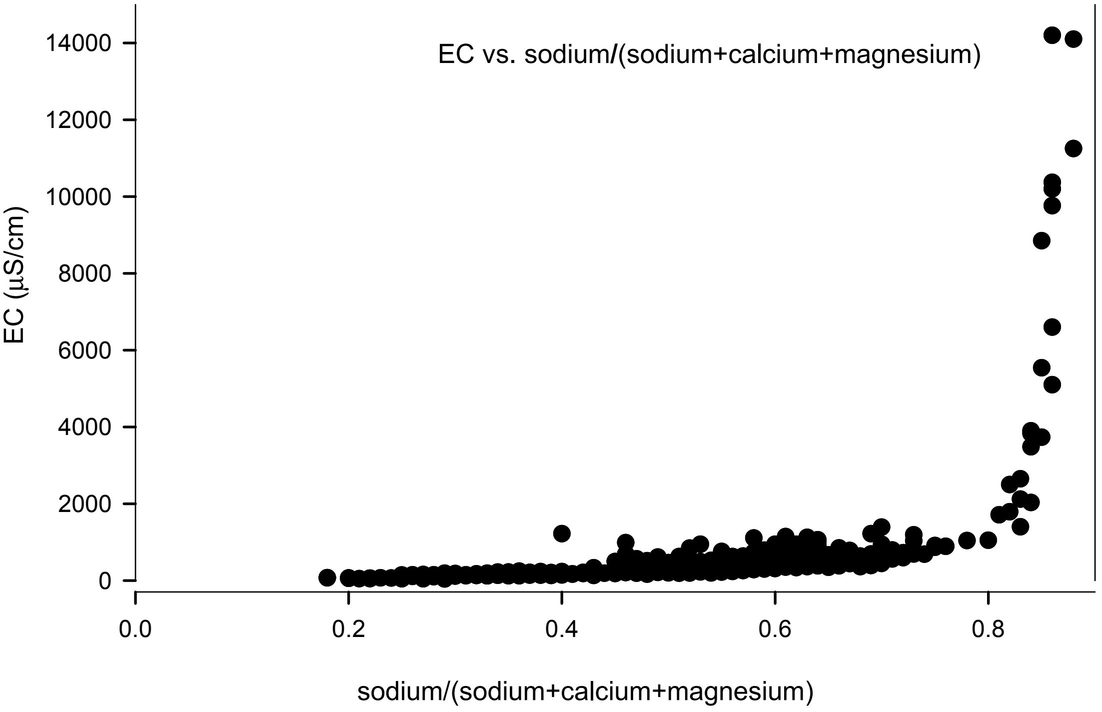
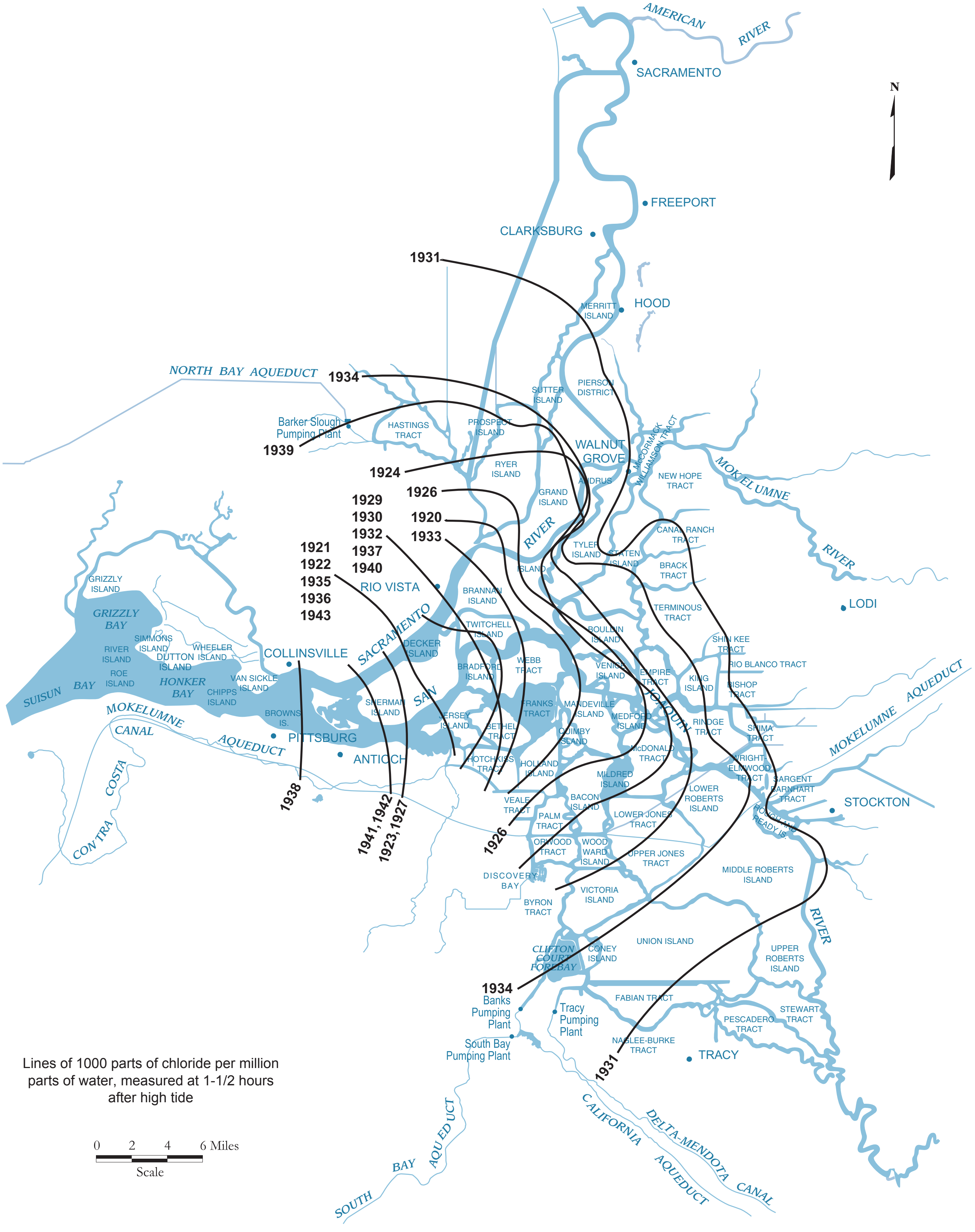


Figure 6-12 Seawater influence in the Delta, 1921-1943



Lines of 1000 parts of chloride per million parts of water, measured at 1-1/2 hours after high tide

Source: Department of Water Resources, Sacramento - San Joaquin Delta Atlas, 1993. Reprinted from Sanitary Survey Update 2001

Figure 6-13 Monthly EC and TDS at the Mallard Island station

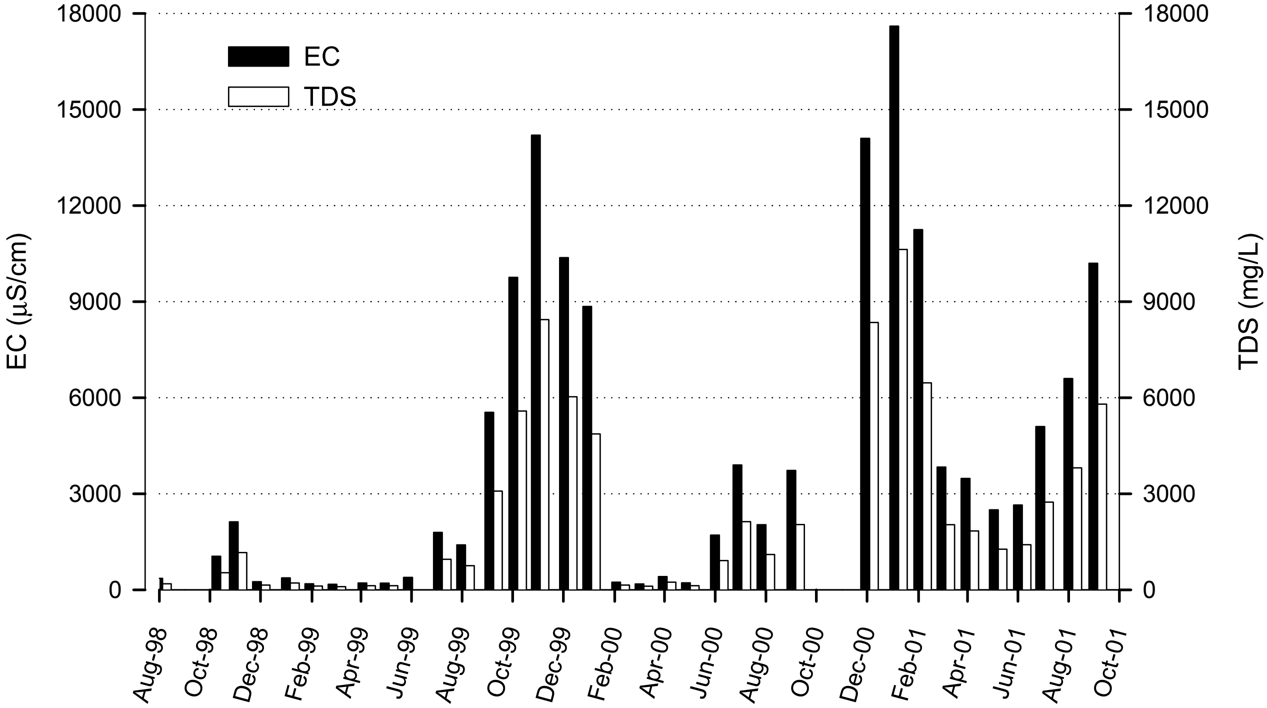
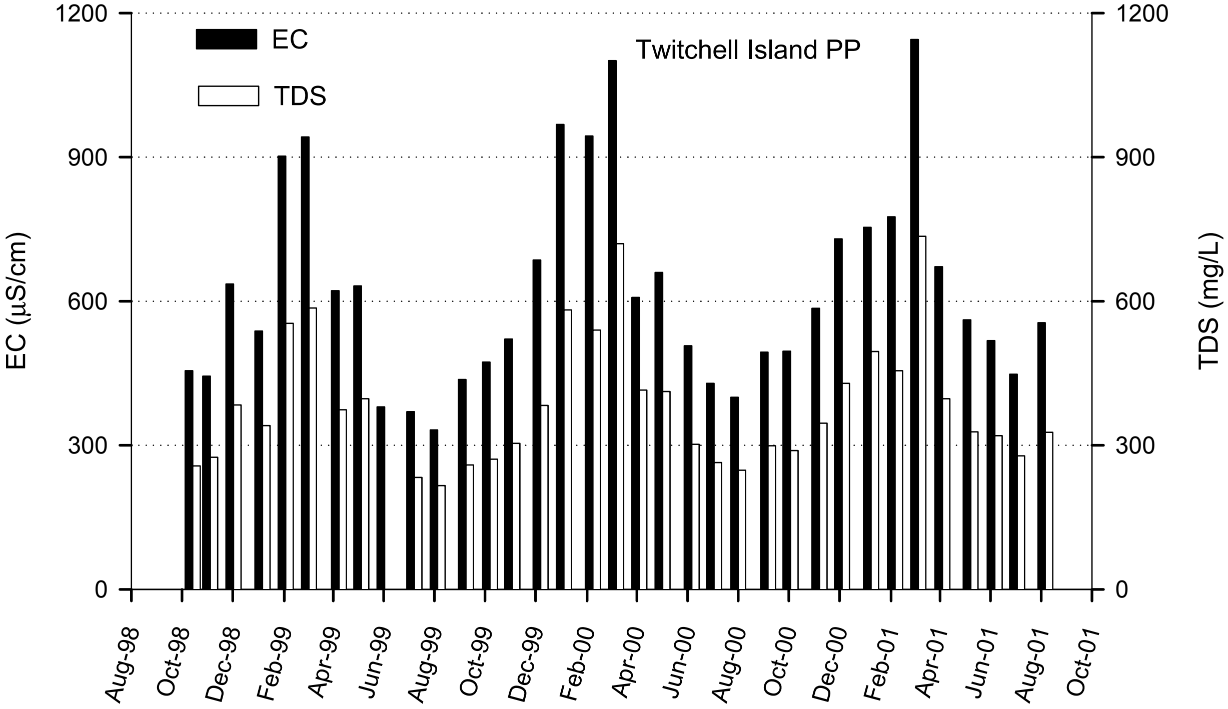


Figure 6-14 Monthly EC and TDS at the agricultural pumping plants at Bacon and Twitchell islands



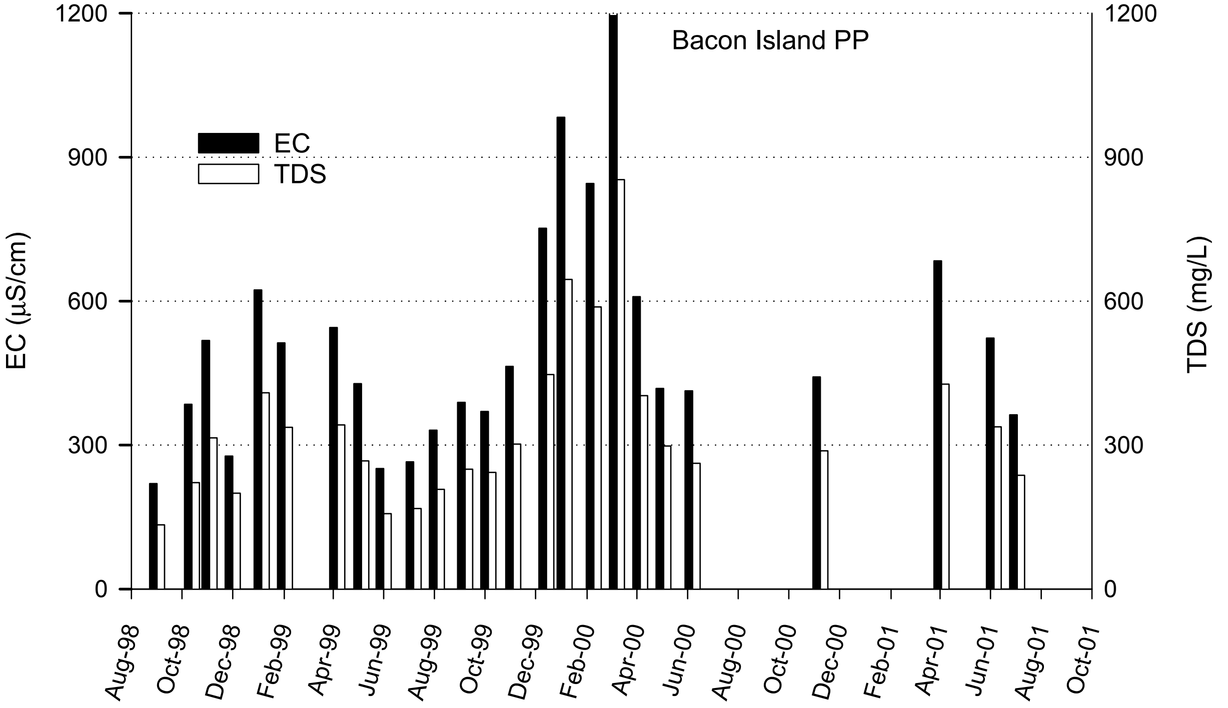
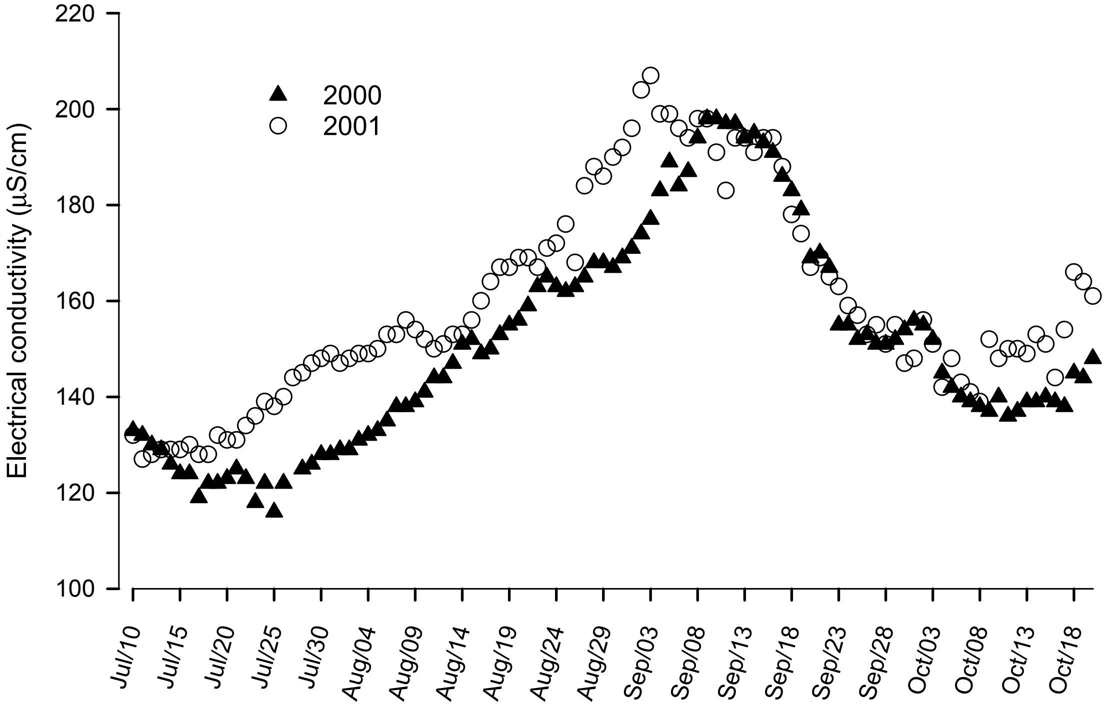
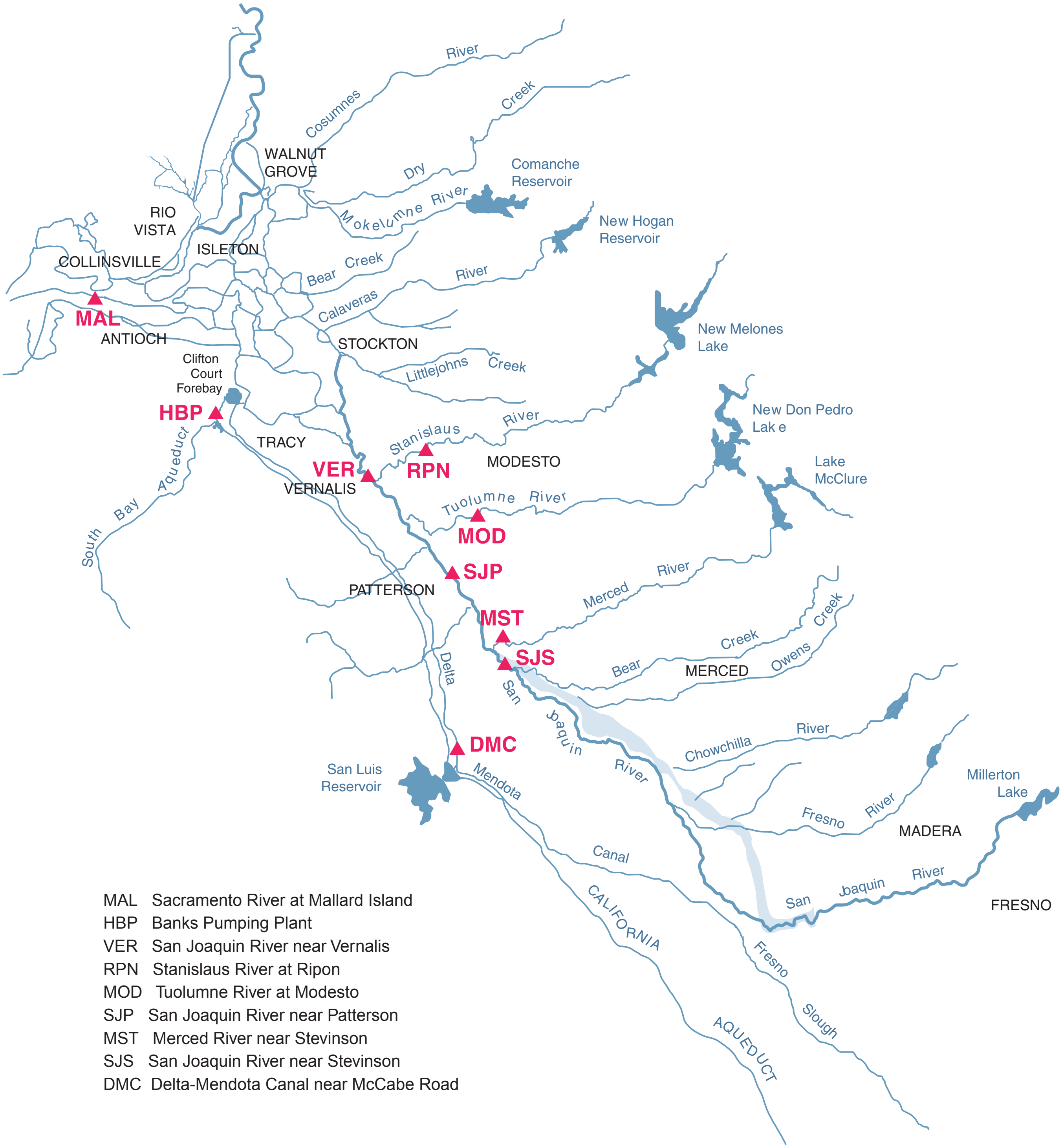


Figure 6-15 Effects of rice drainage on EC at Greenes Landing



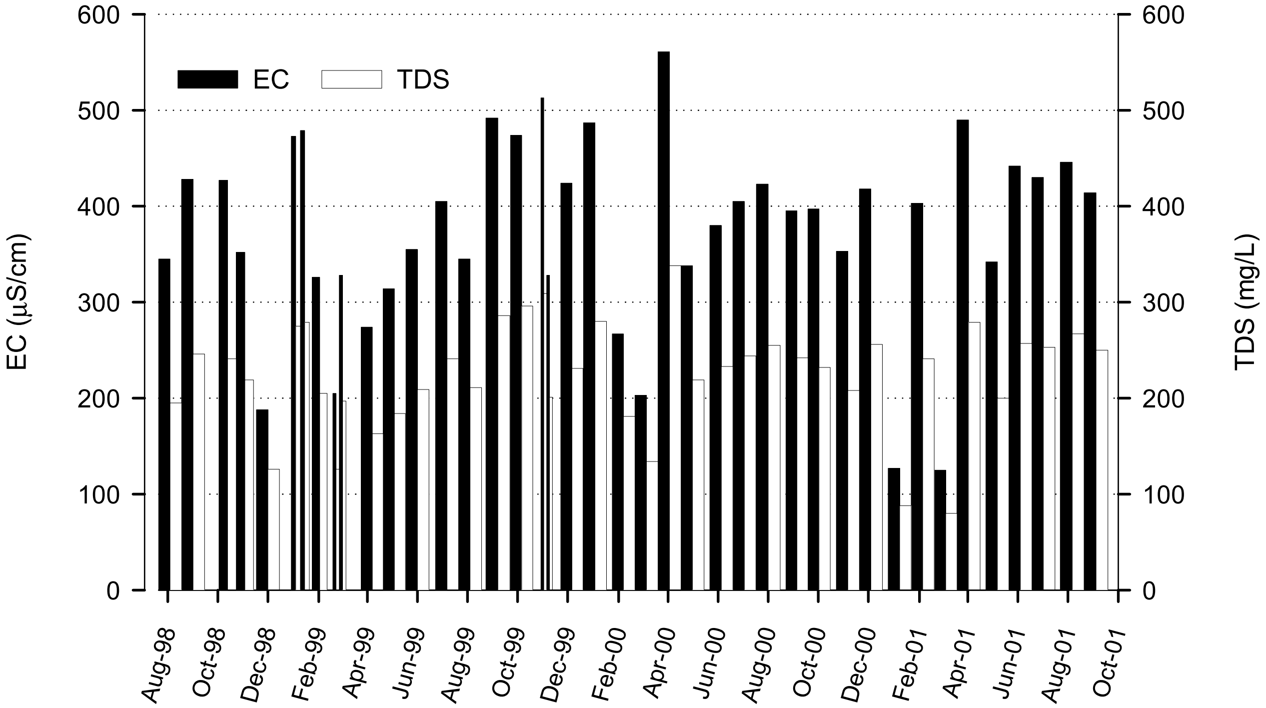
Note: Data from CDEC, accessed August 13, 2002. The EC recorder is maintained by the U.S. Bureau of Reclamation. EC was daily average.

Figure 6-16 Stations in the San Joaquin River watershed from Delta-Mendota Canal to Vernalis



MAL	Sacramento River at Mallard Island
HBP	Banks Pumping Plant
VER	San Joaquin River near Vernalis
RPN	Stanislaus River at Ripon
MOD	Tuolumne River at Modesto
SJP	San Joaquin River near Patterson
MST	Merced River near Stevinson
SJS	San Joaquin River near Stevinson
DMC	Delta-Mendota Canal near McCabe Road

Figure 6-17 EC and TDS at the Natomas East Main Drainage Canal station



Chapter 7
pH, Alkalinity, Hardness, and Turbidity

This chapter summarizes data for pH, alkalinity, hardness, and turbidity collected during the reporting period. A brief overview of the general ranges of these water quality parameters is provided.

pH

Table 7-1 Summary of pH at 14 MWQI monitoring stations

The overall pH range for all stations was from 6.3 to 8.9 (Table 7-1). Source waters in the Delta were generally slightly alkaline with median pH ranging from 7.1 to 7.9 (Table 7-1). The pH is generally lower in waters of the American and upper Sacramento rivers than in waters from the San Joaquin River (SJR) and from stations inside the Sacramento-San Joaquin Delta (the Mallard Island, Delta channels, and diversion stations) (Table 7-1). The higher pH at stations of the SJR and inner Delta may be attributable to seawater influences and algal photosynthesis in the nutrient rich waters. Seawater influence slightly increases pH of the water directly, and phytoplankton activity indirectly increases water pH by consumption of dissolved carbon dioxide in the water. The slightly acidic waters were mostly agricultural drainage return waters or waters heavily influenced by agricultural drainage. The lower pH in agricultural drainage waters was probably attributable to the presence of acidic leachates from organic soils.

Alkalinity

Alkalinity is unregulated. Waters of high alkalinity have an unpleasant taste. According to the federal Disinfectants and Disinfection Byproducts (D/DBP) Rule (EPA 1998), alkalinity is one of the criteria used for removal of total organic carbon (TOC) by enhanced coagulation and enhanced softening. Adequate alkalinity is needed to aid coagulation and flocculation (Breuer 2002 pers comm).

Table 7-2 Summary of alkalinity at 14 MWQI monitoring stations

The overall alkalinity at all 14 stations ranged from 16 to 169 mg/L as $CaCO_3$ (Table 7-2). Waters from both the American and upper Sacramento rivers had the lowest alkalinity, whereas waters from the SJR and agricultural drainage stations had the highest alkalinity (Table 7-2).

Although alkalinity varied at each station, the variations were relatively small for most stations as indicated by the narrow interquartile range (IQR) and by the small differences between the median and average for each station (Table 7-2). When the medians are used for comparing alkalinity among the stations, the American River waters had the lowest median alkalinity of 23 mg/L as $CaCO_3$. The medians for the Delta channel stations, the Sacramento River stations including the Mallard Island station, and the Banks Pumping Plant were from 60 to 67 mg/L as $CaCO_3$. The other stations had a median alkalinity from 73 to 90 mg/L as $CaCO_3$ (Table 7-2). For the 3 diversion stations, median alkalinity ranged from 66 to 73 mg/L as $CaCO_3$ (Table 7-2).

TOC in the Delta rivers, channels, and diversion stations varied widely, but generally fell between 2.0 and 8.0 mg/L (refer to Chapter 4). With the ranges of alkalinity and TOC, the D/DBP Rule would require removal of approximately 25% to 35% of TOC before disinfectants may be added (EPA 1998).

Hardness

Table 7-3 Summary of hardness at 14 MWQI monitoring stations

When all 14 stations are considered, the overall range of water hardness was from 14 to 1,858 mg/L as $CaCO_3$ (Table 7-3). The lowest hardness was found in the American River water, and the greatest hardness was found at Mallard Island, which is heavily influenced by seawater. If the Mallard Island station is excluded, hardness for the river and Delta channel stations ranged from 14 to 245 mg/L as $CaCO_3$; the average and median hardness were from 21 to 123 mg/L as $CaCO_3$ and from 21 to 129 mg/L as $CaCO_3$, respectively. For the 3 diversion stations, hardness ranged from 50 to 270 mg/L as $CaCO_3$, with the average hardness ranging from 86 to 111 mg/L as $CaCO_3$ and the median from 83 to 94 mg/L as $CaCO_3$ (Table 7-3).

Hardness at the 2 SJR stations and the 2 agricultural drainage stations were similar and were approximately twice as high as hardness at the 2 upper Sacramento River stations (Table 7-3). The 2 Delta channel stations, the Banks Pumping Plant, the DMC, and the NEMDC had similar water hardness. However, hardness at the Contra Costa Pumping Plant was somewhat higher than at the Delta channel stations. This may be due to the Contra Costa Pumping Plant's proximity to Mallard Island and the impact from seawater. Electrical conductivity (EC) and total dissolved solids (TDS) were higher at the Contra Costa Pumping Plant than at the Delta channel stations (refer to Chapter 6).

Turbidity

Table 7-4 Summary of turbidity data for 14 MWQI monitoring stations

The turbidity range for all stations was from 1 to 109 NTU (Table 7-4). Of all stations, only the American River at E.A. Fairbairn WTP had an average and median turbidity of less than the maximum contaminant level of 5 NTU; the median and average turbidity at other stations were mostly 10 NTU or more (Table 7-4).

Stations with the highest turbidity include the Mallard Island station, the 2 agricultural drainage stations, and the NEMDC. Average turbidity for these stations ranged from 27 to 40 NTU (Table 7-4). Among the river and channel stations, turbidity values at the SJR stations were higher than those at the Sacramento and Old River stations (Table 7-4). Average and median turbidity at the 3 diversion stations were from 10 to 16 NTU and from 9 to 15 NTU, respectively (Table 7-4).

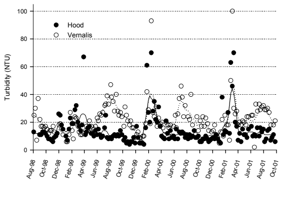


Figure 7-1 Weekly turbidity at Hood and Vernalis stations

Higher turbidity values in these waters are usually associated with heavy runoff during rain events in the watershed. Therefore, turbidity is often higher during wet months than during the dry months as demonstrated by weekly turbidity data from the Sacramento River at Hood and the SJR near Vernalis (Figure 7-1). Water quality at these 2 stations is representative of the waters entering the Delta from the 2 major rivers that supply water to Delta channels. Turbidity at both stations was highly variable during each water year. For the Hood station, turbidity was much higher during the wet months than during the dry months (Figure 7-1). This increase in turbidity resulted from watershed runoff with high turbidity. During the dry months when there was a lack of rainfall, turbidity variations at the Hood station were small (Figure 7-1). At Vernalis, in addition to expected increased turbidity during the wet months, turbidity was highest during the dry months (Figure 7-1). This was mainly attributable to turbid irrigation return waters.

Although both major contributing rivers had their distinct seasonality, such seasonality seems to disappear at the diversion stations (Figure 7-2). Turbidity was lower during part of the wet months and increased from June to October (Figure 7-2). The decreases in turbidity during the wet months may be due to particulate settling when flows are reduced because most dams, reservoirs, and lakes release less water. Also during the wet months low water temperatures reduce phytoplankton activity in Delta channels. Thus high turbidity observed in waters of both the SJR and Sacramento River during the wet months may not be observed in Delta channels and diversion stations. During summer, rapid growth of phytoplankton often causes high turbidity in channel water. In response to high phytoplankton activity during the summer, turbidity was higher during the dry months of each water year (Figure 7-2). In addition, the diversity of water inflows to the diversion stations causes seasonal patterns of turbidity to differ from those of either the Sacramento River or the SJR. Water at the diversion stations include waters from the 2 major rivers, the Sacramento River and the SJR, as well as water from agricultural drainage returns and seawater.

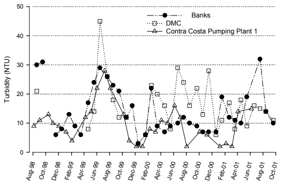


Figure 7-2 Monthly turbidity at three diversion stations

Table 7-1 Summary of pH at 14 MWQI monitoring stations

Station	Sample number	Range	Majority data range	Data dispersion (IQR)	Median
		---------------------------- pH units	--------------------------		
American and Sacramento River stations					
American River at E.A. Fairbairn WTP	37	6.4–7.8	6.6–7.7	7.5–7.6	7.5
West Sacramento WTP Intake	37	6.4–7.8	6.6–7.7	7.5–7.6	7.5
Sacramento River at Hood	160	6.8–7.9	7.1–7.8	7.5–7.7	7.6
Sacramento River at Mallard Island	35	6.9–8.0	7.1–7.9	7.5–7.8	7.7
San Joaquin River stations					
San Joaquin River near Vernalis	160	6.9–8.7	7.2–8.5	7.5–7.9	7.8
San Joaquin River at Highway 4	37	7.1–8.7	7.3–8.4	7.5–8.0	7.7
Delta channel stations					
Old River at Station 9	38	7.1–8.3	7.3–7.9	7.4–7.8	7.7
Old River at Bacon Island	38	7.1–8.9	7.3–8.3	7.4–7.9	7.8
Diversion stations					
Banks Pumping Plant	38	6.6–8.0	6.9–7.8	7.1–7.4	7.2
Delta-Mendota Canal	31	6.9–8.1	6.9–8.0	7.3–7.8	7.6
Contra Costa Pumping Plant	30	7.0–8.7	7.3–8.5	7.7–8.2	7.9
Agricultural drainage stations					
Bacon Island Pumping Plant	25	6.3–8.4	6.5–7.6	6.9–7.3	7.1
Twitchell Island Pumping Plant	35	6.6–7.4	6.7–7.3	7.0–7.2	7.1
Urban drainage station					
Natomas East Main Drainage Canal	41	7.0–8.2	7.1–7.9	7.4–7.7	7.6

Table 7-2 Summary of alkalinity at 14 MWQI monitoring stations

Station	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
		mg/L as $CaCO_3$				
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	37	16–28	18–28	20–25	23	23
West Sacramento WTP Intake	38	47–92	53–87	60–73	67	64
Sacramento River at Hood	159	39–87	47–80	54–69	62	60
Sacramento River at Mallard Island	35	51–86	52–86	58–77	67	66
San Joaquin River stations						
San Joaquin River near Vernalis	159	37–142	45–119	60–117	85	90
San Joaquin River at Highway 4	37	45–122	47–120	69–106	86	88
Delta channel stations						
Old River at Station 9	38	44–85	52–80	58–73	66	67
Old River at Bacon Island	38	43–102	52–78	56–70	64	65
Division stations						
Banks Pumping Plant	38	47–84	50–82	61–72	66	66
Delta-Mendota Canal	31	46–112	54–94	63–81	73	73
Contra Costa Pumping Plant	30	46–153	51–139	62–90	80	73
Agricultural drainage stations						
Bacon Island Pumping Plant	25	32–116	44–116	60–104	79	75
Twitchell Island Pumping Plant	35	64–100	74–98	80–90	85	84
Urban drainage station						
Natomas East Main Drainage Canal	41	34–169	50–138	64–113	88	75

Table 7-3 Summary of hardness at 14 MWQI monitoring stations

Station	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
		mg/L as CaCO3				
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	37	14–30	14–27	18–23	21	21
West Sacramento WTP Intake	38	42–90	47–78	52–67	60	59
Sacramento River at Hood	160	35–81	42–71	49–61	55	55
Sacramento River at Mallard Island	34	52–1,858	54–1,319	73–519	423	221
San Joaquin River Stations						
San Joaquin River near Vernalis	159	48–245	60–184	85–155	123	129
San Joaquin River at Highway 4	36	55–193	57–181	99–150	122	127
Delta channel stations						
Old River at Station 9	38	51–131	58–124	71–102	86	87
Old River at Bacon Island	38	46–138	52–122	62–93	79	74
Diversion stations						
Banks Pumping Plant	37	61–127	63–114	68–100	86	83
Delta-Mendota Canal	31	60–184	63–153	79–109	98	91
Contra Costa Pumping Plant	30	50–270	54–238	66–147	111	94
Agricultural drainage stations						
Bacon Island Pumping Plant	25	64–403	66–262	89–172	136	118
Twitchell Island Pumping Plant	35	72–261	79–258	89–133	126	113
Urban drainage station						
Natomas East Main Drainage Canal	41	36–165	57–145	80–120	97	86

Table 7-4 Summary of turbidity at 14 MWQI monitoring stations

Station	Sample number	Range	Majority data range	Data dispersion (IQR)	Average	Median
		NTU				
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	37	1–11	1–8	1–2	3	2
West Sacramento WTP Intake	38	6–65	7–28	10–17	15	13
Sacramento River at Hood	160	4–70	5–32	8–15	14	11
Sacramento River at Mallard Island	35	14–66	18–59	21–45	32	27
San Joaquin River stations						
San Joaquin River near Vernalis	160	2–100	8–39	14–26	22	19
San Joaquin River at Highway 4	34	7–37	9–31	14–26	20	21
Delta channel stations						
Old River at Station 9	37	5–20	5–18	8–15	12	12
Old River at Bacon Island	38	4–27	4–24	7–14	12	10
Diversion stations						
Banks Pumping Plant	38	3–68	6–31	9–20	16	12
Delta-Mendota Canal	30	3–45	6–29	11–21	16	15
Contra Costa Pumping Plant	30	2–28	2–22	5–13	10	9
Agricultural drainage stations						
Bacon Island Pumping Plant	24	2–86	11–76	22–54	40	34
Twitchell Island Pumping Plant	35	1–60	12–47	17–34	27	25
Urban drainage station						
Natomas East Main Drainage Canal	41	7–109	10–89	16–32	29	21

Note: All statistics are calculated from positively detected samples only; positive detects are samples with turbidity greater than the reporting limit of 1 NTU.

Figure 7-1 Weekly turbidity at Hood and Vernalis stations

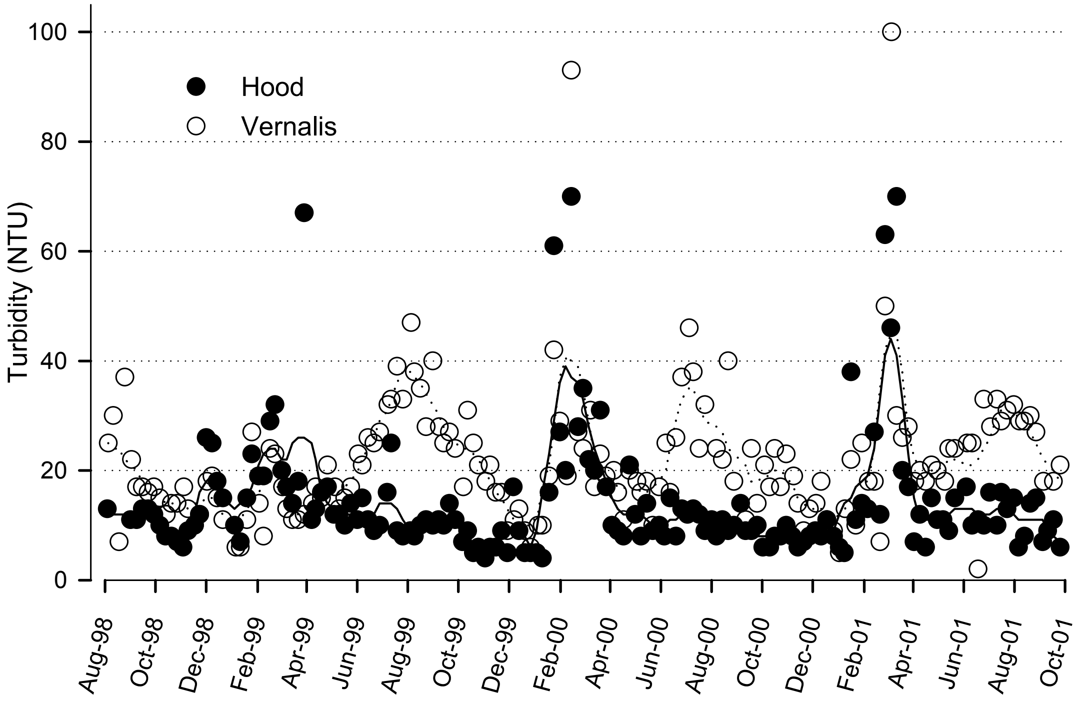
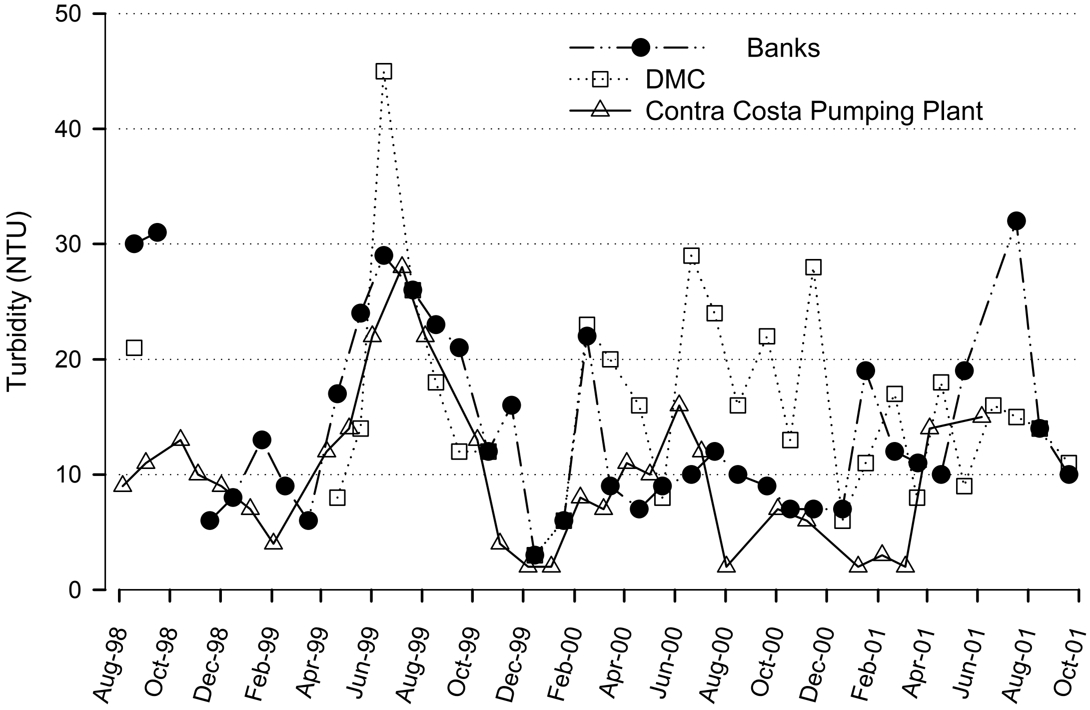


Figure 7-2 Monthly turbidity at three diversion stations



Chapter 8
Other Water Quality Constituents

This chapter discusses water quality parameters that are either regulated by national and State law or are of current monitoring interests. Federal or California drinking water standards have been established for most of these parameters in the form of primary or secondary maximum contaminant levels (MCLs). The federal government established these primary and secondary MCLs. Primary MCLs are enforceable, and the secondary standards are non-enforceable. The California Department of Health Services (DHS) has primacy for implementing the federal Clean Water Act in California, which requires state agencies and all public drinking water systems to adopt their own MCLs that are at least as stringent as the federal standards. Through California's Safe Drinking Water Act, primary and secondary MCLs have been promulgated with the difference that California secondary MCLs are enforceable. Constituents discussed here include metallic ions, some inorganic constituents, and organics that affect taste, odor, and appearance of drinking water.

Constituents Affecting Taste, Odor, and Appearance

Among the constituents that affect taste, odor, and appearance of drinking water, turbidity, methyl tertiary-butyl ether (MTBE), aluminum, copper, iron, manganese, silver, and zinc were monitored by the Municipal Water Quality Investigations (MWQI) Program of the California Department of Water Resources (DWR). Turbidity is presented in Chapter 7. The remaining constituents are presented here.

Methyl Tertiary-Butyl Ether

MTBE is an organic additive to gasoline products. This organic compound is often detected above its detection limit and sometimes at high levels in groundwater wells near gas stations with leaky underground storage tanks. Although its adverse health effects at the levels found in surface waters and groundwater remain unknown, MTBE can impart an objectionable odor and taste to drinking water.

DHS set an enforceable primary drinking water MCL for MTBE at 0.013 mg/L. A secondary MCL of 0.005 mg/L is also enforceable in California. Of the 650 weekly or monthly samples collected, MTBE was detected at or above its reporting limit of 0.001 mg/L in 159 samples or 24.5% (Table 8-1). No analyses exceeded either the primary or secondary MCL of DHS. Average and median MTBE varied from 0.001 to 0.002 mg/L, which are below DHS primary and secondary MCLs.

Table 8-1 Summary of MTBE at 14 MWQI monitoring stations

Concentrations of MTBE were never detected at the American River station, the Mallard Island station, or the 2 agricultural drainage stations at Bacon and Twitchell islands (Table 8-1). MTBE was seldom detected at the Vernalis station or at the Natomas East Main Drainage Canal (NEMDC).

However, it was frequently detected in the Sacramento River and in channel waters (Old River). For example, 53% of the weekly samples collected at the Hood station had MTBE at or above its reporting limit. Urban runoff and recreational boating activities may be attributable to the presence of MTBE in the Sacramento River and in Sacramento-San Joaquin Delta channels. Despite these positive detections, concentrations in both rivers never exceeded 0.005 mg/L. At the 3 diversion stations, MTBE was detected at or above the reporting limit in approximately 29% of the samples; however, concentrations were low. Such low MTBE concentrations in Delta source waters were already below its primary and secondary MCLs. Due to its high volatility, MTBE evaporates easily with disturbances and temperature changes during water treatment processes; therefore, these low MTBE concentrations did not appear to cause concern on finished drinking water.

Metallic Constituents

In addition to MTBE, several other constituents—aluminum, copper, iron, manganese, silver, and zinc—affect the taste, odor, or appearance of finished drinking water. Historical data indicate that these constituents were not a threat to Delta waters (DWR 1994, DWR 2001, Woodard 2000). Regular monitoring of these constituents may not be necessary at all stations. Thus, MWQI monitored them at only 3 stations—Banks Pumping Plant, Delta-Mendota Canal, and NEMDC. Data collected during the reporting period suggest that concentrations of the 6 constituents were seldom above their MCLs except for aluminum, iron, and manganese at the NEMDC station (Table 8-2). Of the 38 samples collected at NEMDC, only 2 samples had aluminum above its MCL of 0.2 mg/L. Manganese exceeded its MCL in 6 of the 38 samples. Inflow from NEMDC is relatively small. When water from NEMDC is mixed with water from the American River, both aluminum and manganese will be significantly lower than their MCLs. Therefore, both aluminum and manganese were low at the diversion stations. Among these 6 constituents, silver and zinc were never detected above their detection limits.

Table 8-2 Summary of data for metallic constituents

Article 19 of the *Standard Provisions for Water Supply Contract* (DWR 1962) set specific objectives for copper, iron, manganese, and zinc. Concentrations of all 4 constituents never exceeded the specified maximum concentrations.

Constituents Affecting Human Health

Constituents that may adversely affect human health from exposure above their MCLs include aluminum, antimony, arsenic, asbestos, barium, beryllium, cadmium, chromium (total), copper, cyanide, fluoride, lead, mercury, nickel, nitrate, nitrite, selenium, and thallium. Aluminum and copper are presented in Table 8-2. Nine constituents—antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, and selenium—were monitored at the 2 diversion stations. Arsenic was also monitored at an urban drainage. These constituents were not routinely monitored at all MWQI stations because historical data indicate that they did not appear to threaten quality of Delta source waters (DWR 1994, DWR 2001, Woodard 2000).

Three of the 9 monitored contaminants—antimony, cadmium, and lead—were never detected at or above their respective reporting limits (Table 8-3). Barium and mercury were each detected once, but concentration was much lower than their respective MCLs. Selenium was occasionally detected at or above its reporting limit, but average and median concentrations of selenium were much lower than its MCL of 0.05 mg/L. Nickel was detected in most samples, but the highest concentration was 0.002 mg/L, which was 2% of the MCL; the average and median nickel concentrations were only 1% of the MCL. Although concentrations were low, arsenic was found in all samples collected at the diversion stations. Arsenic was higher at NEMDC than at the diversion stations, but concentrations were always lower than the MCL for arsenic. In addition, water inflows from NEMDC were small. Therefore, NEMDC should not be a major contributor of arsenic. The sources of arsenic throughout the Delta remain unclear. The health effects of arsenic are complex and not entirely understood, but it is clear that arsenic concentrations in source waters should be kept as low as possible. Arsenic monitoring throughout the Delta region should continue in Delta source waters.

Table 8-3 Summary of regulated constituents in drinking water having federal and State primary MCLs

Article 19 of the *Standard Provisions for Water Supply Contract* specifies objectives for arsenic, chromium, lead, and selenium (DWR 1962). During the reporting period, concentrations of all 4 constituents never exceeded the maximum concentrations.

Boron

Boron is not regulated, but California requires monitoring of boron in drinking water. The DHS action level (AL) for boron is 1 mg/L. ALs are based on health advisory levels of contaminants that have no primary MCLs. ALs are not enforceable, but exceeding them prompts statutory requirements and recommendations by DHS for consumer notice. At higher levels, source removal may be recommended.

Boron is high in the Delta and may represent a concern in water of small isolated areas near or at geological faults. For instance, average boron at an agricultural drain in south Delta was 12.4 mg/L in 34 samples collected from March 1988 to April 1993 (McCune 2002 pers comm).

During the reporting period, boron was never detected at or above its reporting limit in the American River at the E.A. Fairbairn Water Treatment Plant (WTP) Intake, at the Sacramento River at Hood, or at the Sacramento River at the West Sacramento WTP (Table 8-4). Although boron was frequently detected at or above its reporting limit in waters from the San Joaquin River (SJR) stations, channel waters, agricultural drainage stations, and at NEMDC, concentrations were all below the DHS AL of 1 mg/L. At the diversion stations, average boron concentration was from 0.2 to 0.3 mg/L, which was also below boron's AL. Boron concentrations at the diversion stations did not exceed its Article 19 specified monthly average of 0.6 mg/L.

Table 8-4 Summary of boron at MWQI stations

Nutrients

Among various nutrients, nitrate and nitrite are mandatory health-related constituents with established drinking water standards requiring monitoring. The primary MCLs for nitrate and nitrite are 45 mg NO_3/L and 1 mg NO_2/L, respectively. During the reporting period, nitrate was monitored at all stations. Although nitrate as a contaminant never exceeded its MCL (Table 8-5), nitrate concentrations were high in the SJR and the Old River and were also high in the agricultural and urban drainage sites. Consequently, nitrate was moderately high at all of the diversion stations (Table 8-5). These high nitrate levels indicated high total nitrogen reserves in Delta waters. High levels of nitrogen and phosphorus collectively promote the growth of algae and, subsequently, affect water quality by increasing concentrations of organic carbon, turbidity, and by forming taste and odor-producing compounds.

Table 8-5 Summary of nitrate at MWQI stations

Despite some slight variations, nitrate at the diversion stations was generally higher in the wet months of each year and lower in the dry months (Figure 8-1(a)). Lowered nitrate concentration during the dry months may be partly attributable to increased agal activities in the rivers and channels of the Delta. Nitrate concentration in the SJR as measured at the Vernalis station is much higher than in the Sacramento River as measured at the Hood station (Figure 8-1(b)). Although a wet month nitrogen buildup and an early dry month decline were also observed in both rivers, seasonal changes of nitrogen in the rivers were different from those at the diversion stations. Nitrogen levels in both rivers began to rise in June of each year and reached the highest levels between July and October (Figure 8-1(b)), which coincide with the agricultural drainage inflows to both rivers.

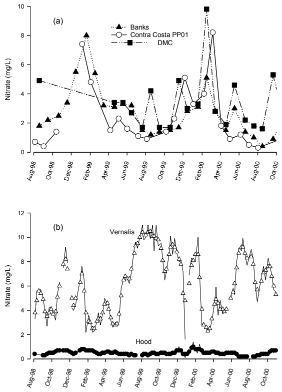


Figure 8-1 Nitrate at three diversion stations and two river stations

At the Banks Pumping Plant, ammonia, Kjeldahl nitrogen, and phosphorus were also monitored in addition to nitrate (Figure 8-2). Kjeldahl nitrogen, which includes organic forms of nitrogen, ranged from 0.3 to 0.8 mg/L with average and median concentrations of 0.5 and 0.4 mg N/L, respectively. The sum of nitrate and nitrite was from 0.13 to 1.20 mg N/L (Table 8-6). Ammonia was frequently detected at low levels at the Banks Pumping Plant. Total phosphorus, which represents total phosphorus in unfiltered samples, at the Banks station ranged from 0.07 to 0.16 mg P/L with average and median levels of 0.11 and 0.10 mg P/L, respectively. About 60% to 70% of the total phosphorus was dissolved orthophosphate (Table 8-6).

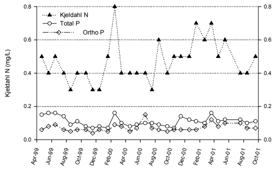


Figure 8-2 Nutrients at the Banks Pumping Plant station

Seasonal changes of Kjeldahl nitrogen at Banks mostly followed similar cyclic patterns found for nitrate, but the magnitude of seasonal changes was smaller (data not shown). Differences in magnitude occurred because Kjeldahl nitrogen represents organic forms of nitrogen, which must be converted to inorganic forms before it becomes bioavailable. Seasonal patterns were less obvious for both total phosphorus and orthophosphate. Both forms of phosphorus remained relatively stable with some slight increases from February to April and some decline during July and August of each year, presumably due to algal consumption of orthophosphates and nitrogen.

Table 8-6 Summary of nutrient data at the Banks Pumping Plant

Although nutrient levels were generally high in most Delta waters, concentrations of nitrate and the sum of nitrate and nitrite never exceeded their respective primary MCLs set by DHS. These primary MCLs are 45 mg/L for nitrate and 10 mg N/L for the sum of nitrate and nitrite.

Table 8-1 Summary of MTBE at 14 MWQI monitoring stations

Station	Positive detects/ samples	Range	Average	Median
		-----------------------------	-----mg/L-----	---------------------
American and Sacramento River stations				
American River at E.A. Fairbairn WTP	0/37	<0.001	-	-
West Sacramento WTP Intake	6/37	0.001–0.002	0.001	0.001
Sacramento River at Hood	84/159	0.001–0.005	0.002	0.002
Sacramento River at Mallard Island	0/35	<0.001	-	-
San Joaquin River stations				
San Joaquin River near Vernalis	2/160	0.001–0.002	0.001	0.001
San Joaquin River at Highway 4	8/36	0.001–0.004	0.002	0.002
Delta channel stations				
Old River at Station 9	25/37	0.001–0.004	0.002	0.002
Old River at Bacon Island	13/38	0.001–0.002	0.001	0.001
Delta diversion stations				
Banks Pumping Plant	8/29	0.001–0.002	0.001	0.001
Delta-Mendota Canal	5/7	0.001–0.003	0.002	0.001
Contra Costa Pumping Plant	6/30	0.001–0.003	0.002	0.002
Agricultural drainage stations				
Bacon Island Pumping Plant	0/4	<0.001	-	-
Twitchell Island Pumping Plant	0/3	<0.001	-	-
Urban drainage station				
Natomas East Main Drainage Canal	2/38	0.001–0.001	0.001	0.001

Table 8-2 Summary of data for metallic constituents

		Stations		
	MCL	Banks	DMC	NEMDC
Constituent	mg/L			
Aluminum	0.2			
Detects/sample number		2/38	15/31	30/38
Range		0.02–0.08	0.01–0.06	0.01–0.37
Average		0.03	0.04	0.06
Median		0.03	0.04	0.02
Copper	1.0			
Detects/sample number		38/38	31/31	37/38
Range		0.001–0.007	0.002–0.005	0.002–0.005
Average		0.002	0.002	0.003
Median		0.002	0.002	0.003
Iron	0.3			
Detects/sample number		29/38	20/31	35/38
Range		0.005–0.066	0.005–0.117	0.013–0.323
Average		0.020	0.037	0.080
Median		0.014	0.037	0.047
Manganese	0.05			
Detects/sample number		32/38	7/31	37/38
Range		0.005–0.032	0.005–0.020	0.008–0.085
Average		0.014	0.011	0.040
Median		0.013	0.011	0.037
Silver	0.1			
Detects/sample number		0/38	0/31	-
Range		<0.001	<0.001	-
Zinc	5.0			
Detects/sample number		0/38	0/31	-
Range		<0.005	<0.005	-

Table 8-3 Summary of regulated constituents in drinking water having federal and State primary MCLs

Constituent	MCL	Stations Banks	 DMC	 NEMDC
	---mg/L---			
Antimony	0.006			
Detects/sample number		0/20	0/17	-
Range		<0.005	<0.005	-
Arsenic	0.01			
Detects/sample number		38/38	31/31	37/38
Range		0.001–0.003	0.001–0.003	0.001–0.006
Average		0.002	0.002	0.003
Median		0.002	0.002	0.003
Barium	2.0 or 1.0 (DHS)			
Detects/sample number		0/29	1/30	-
Range		-	<0.05–0.05	-
Average		-	0.05	-
Median		-	0.05	-
Cadmium	0.005			
Detects/sample number		0/38	0/31	-
Range		-	-	-
Chromium (total)	0.1 or 0.05 (DHS)			
Detects/sample number		19/38	19/31	-
Range		0.004–0.008	0.003–0.009	-
Average		0.006	0.005	-
Median		0.006	0.005	-
Lead	0.015[a]			
Detects/sample number		0/38	0/31	-
Range		-	-	-
Mercury (inorganic)	0.002			
Detects/sample number		1/38	0/30	-
Range		<0.0002–0.0002	-	-
Average		0.0002	-	-
Median		0.0002	-	-
Nickel	0.1 (DHS)			
Detects/sample number		19/20	21/21	-
Range		0.001–0.002	0.001–0.002	-
Average		0.001	0.001	-
Median		0.001	0.001	-
Selenium	0.05			
Detects/sample number		12/39	4/15	-
Range		0.001–0.002	0.001–0.003	-
Average		0.001	0.002	-
Median		0.001	0.002	-

[a] Action level that triggers treatment actions if exceeded in more than 10% of tap water samples.

Table 8-4 Summary of boron at MWQI stations

Station	Positive detects/ sample number	Range	Average	Median
		---------------------mg/L---------------		
American and Sacramento River stations				
American River at E.A. Fairbairn WTP	0/37	-	-	-
West Sacramento WTP Intake	0/38	-	-	-
Sacramento River at Hood	0/160	-	-	-
Sacramento River at Mallard Island	25/35	0.1-1.2	0.4	0.3
San Joaquin River stations				
San Joaquin River near Vernalis	159/160	0.1-0.8	0.3	0.3
San Joaquin River at Highway 4	37/37	0.1-0.6	0.3	0.3
Delta channel stations				
Old River at Station 9	28/38	0.1-0.4	0.2	0.1
Old River at Bacon Island	15/30	0.1-0.2	0.1	0.1
Diversion stations				
Banks Pumping Plant	28/37	0.1-0.3	0.2	0.2
Delta-Mendota Canal	30/31	0.1-0.6	0.2	0.2
Contra Costa Pumping Plant	23/30	0.1-0.6	0.3	0.2
Agricultural drainage stations				
Bacon Island Pumping Plant	25/25	0.1-0.3	0.2	0.2
Twitchell Island Pumping Plant	35/35	0.1-0.2	0.1	0.1
Urban drainage station				
Natomas East Main Drainage Canal	35/41	0.1-0.2	0.2	0.2

Note: Boron is currently an unregulated constituent that requires monitoring.

Table 8-5 Summary of nitrate at 14 MWQI stations

Station	Positive detects/ sample number	Range	Average	Median
		--------------------mg NO_3 /L----------------		
American and Sacramento River stations				
American River at E.A. Fairbairn WTP	9/25	0.1–0.8	0.3	0.2
West Sacramento WTP Intake	25/26	0.1–0.8	0.4	0.4
Sacramento River at Hood	112/113	0.1–12.4	0.8	0.5
Sacramento River at Mallard Island	23/23	0.9–8.2	1.7	1.4
San Joaquin River stations				
San Joaquin River near Vernalis	112/112	1.6–28.0	6.4	6.4
San Joaquin River at Highway 4	25/25	2.8–9.3	6.0	6.1
Delta channel stations				
Old River at Station 9	26/26	0.5–9.5	2.5	1.8
Old River at Bacon Island	25/25	0.1–6.4	1.8	1.4
Diversion stations				
Banks Pumping Plant	28/28	0.4–8.0	2.7	2.7
Delta–Mendota Canal	20/20	1.6–9.8	3.4	2.9
Contra Costa Pumping Plant	22/22	0.3–8.2	2.4	1.5
Agricultural drainage stations				
Bacon Island Pumping Plant	14/19	0.4–13	3.8	2.8
Twitchell Island Pumping Plant	23/23	0.1–12	2.8	1.1
Urban drainage station				
Natomas East Main Drainage Canal	36/36	1.8–21.0	10.0	9.4

Note: Nitrate was determined by Standard Method 4500 except at NEMDC where EPA Method 300 was used.

Table 8-6 Summary of nutrient data at the Banks Pumping Plant

	Ammonia (mg N/L)	Nitrate + nitrite (mg N/L)	Kjeldahl nitrogen (mg N/L)	Orthophosphorus	Total P
				--------------(mg P/L)---------------	
Detects/sample number	29/29	29/29	29/29	29/29	29/29
Range	0.02–0.15	0.13–1.20	0.3–0.8	0.04–0.15	0.07–0.16
Average	0.06	0.57	0.5	0.07	0.11
Median	0.05	0.51	0.4	0.06	0.10

Figure 8-1 Nitrate at three diversion stations and two river stations

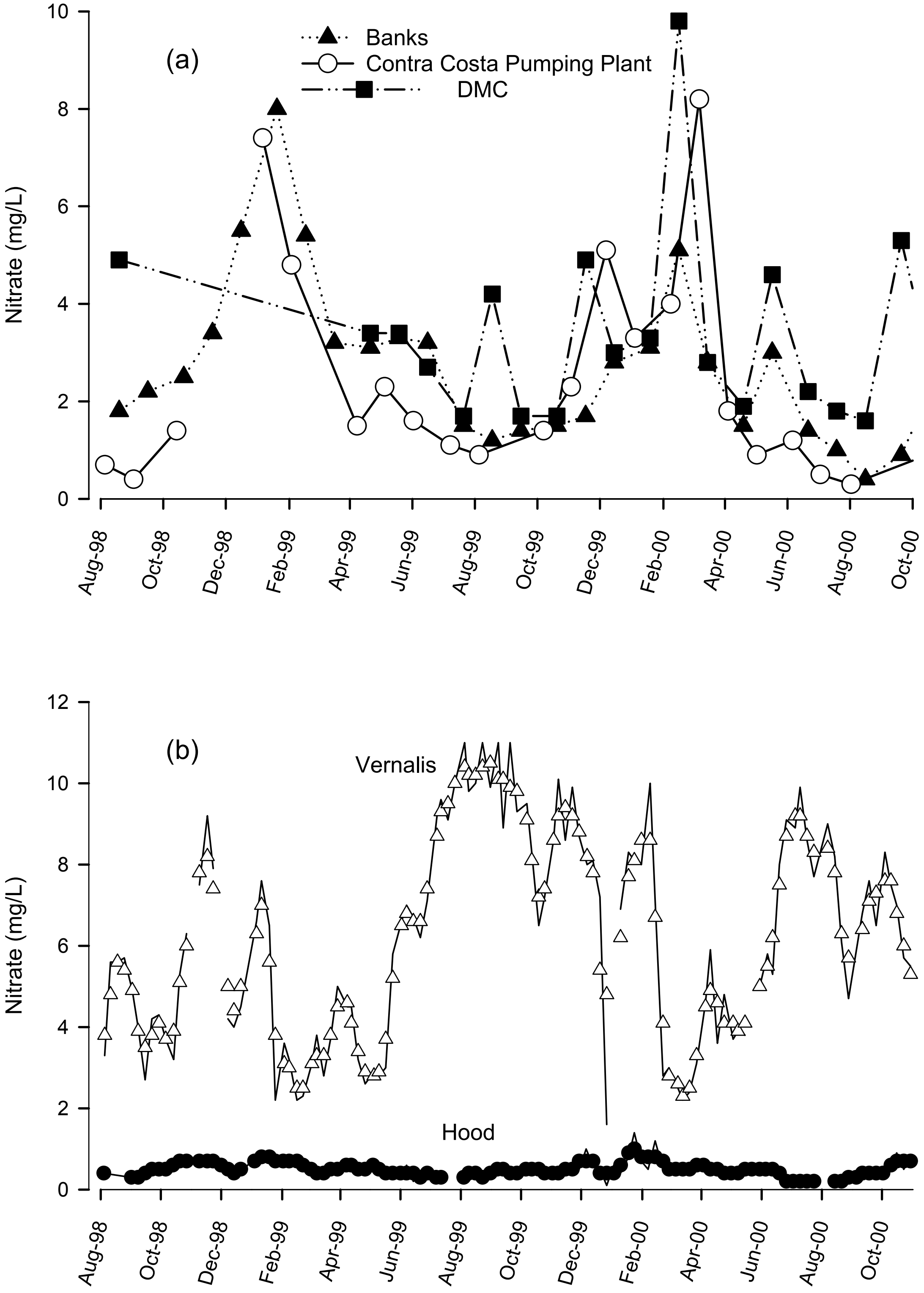
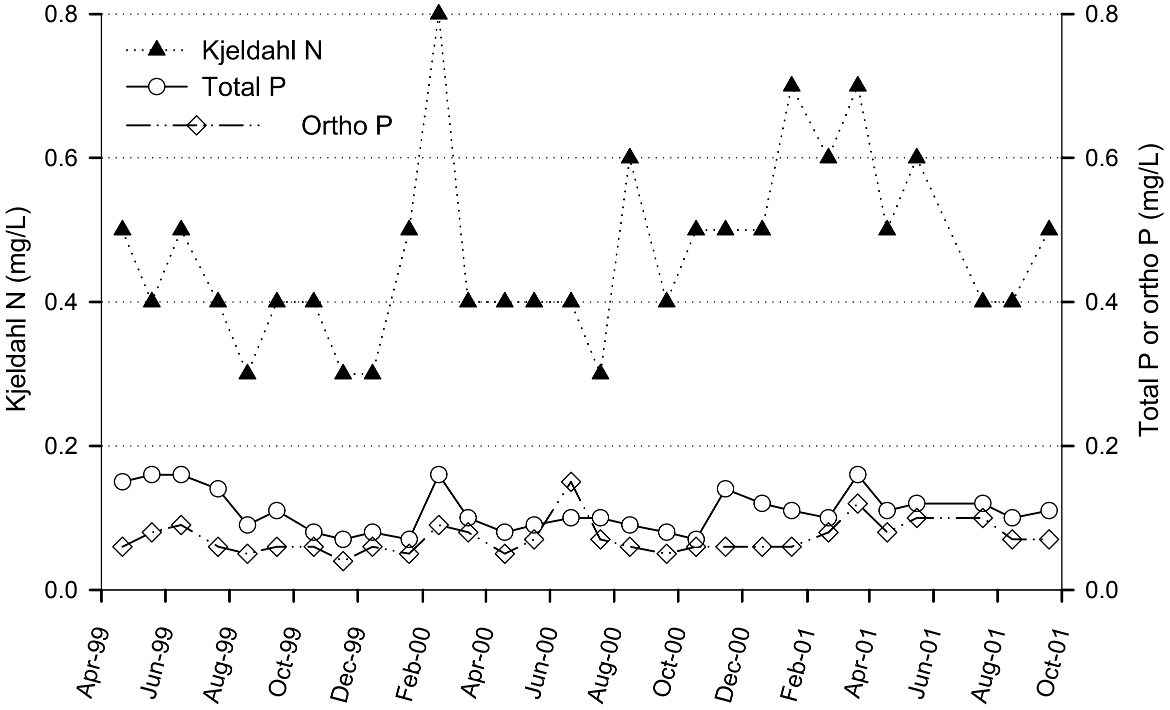


Figure 8-2 Nutrients at the Banks Pumping Plant Station



Chapter 9
Data Quality Review

Jaclyn Pimental and Murage Ngatia

Overview

This data quality review covers the reporting period from August 1, 1998, through September 30, 2001. The Municipal Water Quality Investigations (MWQI) Program monitored and collected data from 14 stations during this reporting period.

The data review was performed using the available quality control (QC) data stored in the California Department of Water Resources' (DWR) Field and Laboratory Information Management System (FLIMS) database. The database was used to retrieve the data and flag the analyses that were outside established control limits.

The data quality review indicated that overall the 1998–2001 MWQI project data were of acceptable quality. A few analyses were outside the control limits, but they were not considered to have a significant impact on the overall data quality of the project. The results of the review are presented below.

Field Procedures Quality Control

Field Duplicates

Field duplicates are replicate samples taken at a randomly selected station during each field run to evaluate precision of field and laboratory procedures. The results of field duplicate analyses are evaluated by calculating relative percent differences (RPDs) and comparing the RPDs with established control limits. The equation for expressing precision is:

$$RPD = (D_1 - D_2)/[(D_1 + D_2)/2] \times 100,$$

where D1 is the first sample value and D2 is the second sample value. During the study period, 2,698 field duplicate analyses were performed and 55 (2%) of the RPDs exceeded the acceptable control limits (Table 9-1). The results indicate that field and laboratory procedures were of acceptable precision for the project.

Table 9-1 Field duplicates

Field Blanks

Field blanks are purified water samples taken to the field and filtered or left unfiltered. Filtered blanks help check for contamination from field sample processing procedures. Unfiltered blanks check for contamination from containers and preservatives. In the study period, 107 field blank analyses were performed, and none of them exceeded the control limit.

Internal Quality Controls

Internal QCs are procedures used in the laboratory to ensure that the analytical methods are in control. Environmental samples are grouped in "batches," with approximately 20 samples per batch. Generally, one of each QC measure such as method blank, matrix spike, etc. is performed with each batch to confirm that the analytical method is in control. In some cases the laboratory performs more than one of each of the QC measures to ensure the quality of the batch. The total number of internal QC analyses performed per analyte is shown in Table 9-2. The following is a review of the internal QC for the project.

Table 9-2 Total internal QC batches grouped by analyte

Sample Holding Times

Holding time is the period during which a sample can be stored after collection and preservation without significantly affecting the accuracy of its analysis. During the 1998-2001 study period, approximately 14,183 environmental analyses were conducted and 26 analyses (0.18 %) exceeded the holding time. The analyses that exceeded the holding times are listed in Table 9-3. The analytes that exceeded holding times were alkalinity, nitrate, total organic carbon (TOC), total dissolved solids (TD), orthophosphate and turbidity. Turbidity, orthophosphate, and nitrate have a holding time limit of 48 hours, whereas alkalinity has a holding time limit of 14 days, TOC has a limit of 28 days, and TDS has a limit of 7 days. The table shows the number of hours or days that the samples were held by the laboratory compared to their holding time limits. The analytes in the table exceeded holding time limits from a couple of hours to several days. Although the frequency of these exceedances was low, the results of the specific analyses should be interpreted with caution.

Table 9-3 Holding time exceedances

Method Blanks

The purpose of method blanks is to detect and quantify contamination introduced through sample preparation or analytical procedures in the laboratory (some "background noise" is allowed). A total of 3,821 method blanks were performed from August 1998 through September 2001, and 19 (0.5%) exceeded the control limits.

Table 9-4 Method blank exceedances

Table 9-4 shows the number of method blanks outside the control limits. The analytes were alkalinity and TDS. Table 9-5 shows the frequency of method blank contamination for these analytes. The frequency of method blanks out of the control limits was 6.7% for alkalinity and 2.1% for TDS. The samples affected by method blank contamination are shown in Table 9-6.

Table 9-5 Number of batches with method blank exceedances

Table 9-6 Environmental samples associated with method blank exceedances

Laboratory Control Samples

Laboratory control sample (LCS) recoveries are used to assess the accuracy of the analytical method especially when matrix interference occurs in the analyses of the environmental samples. LCSs are prepared by adding a known concentration of analyte of interest into a clean medium. The LCS is then analyzed, and the results are compared to the laboratory's control limits. During the period of August 1998 through September 2001, 5,654 LCS analyses were performed (Table 9-2) and none of the results exceeded the control limits. Therefore, the laboratory analyses for the project were of acceptable accuracy.

Matrix Spike Recovery

Matrix spike recoveries indicate the accuracy of recovering a known concentration of substance in a matrix of interest. The results of matrix spike recoveries indicate the accuracy of analysis given the interference peculiar to a given matrix. Matrix spikes are prepared by adding a known concentration of method analytes to an environmental sample with known background concentration. The percent recovery must fall within acceptable limits. During the study period, 7,554 matrix spike recoveries were performed, and only 81 (1.1%) exceeded the control limits. The batches with matrix spike recoveries outside the control limits are shown in Table 9-7. The analytes that had matrix spike exceedances were alkalinity, ammonia, boron, bromide, bromoform, chloride, calcium, magnesium, nitrate, sulfate, silver, sodium and trichloacetic acid (TCAA). Alkalinity had a frequency of exceedance of 2.2% (Table 9-8). Some of the recoveries were high, but the RPDs and LCS for those batches were within limits; therefore, the batch is considered in control. Recoveries that were lower than the control limits can be attributed to matrix interference, but the LCS for those batches were in control.

Table 9-7 Matrix spike recovery exceedances

Table 9-8 Frequency of QC batches with matrix spike recovery exceedances

The analytes with the highest frequency of exceedances were TCAA, silver and sodium (Table 9-8). TCAA and sodium were out of recovery limits for both matrix spikes and spike duplicate, which suggests matrix interference. The LCS and RPDs were within limits for all of these analytes; therefore, the batch was considered in control.

The low frequency of recoveries outside the control limits for the remaining analytes was considered insignificant to the overall data quality of the project. Therefore, the laboratory analyses were of acceptable accuracy, and matrix interference did not have significant effects on the analyses. The environmental samples in these batches are shown in Table 9-9.

Table 9-9 Samples with matrix spike recovery exceedances

Matrix Spike Duplicates

Matrix spike duplicate results indicate the precision of the analytical method in a given matrix. The difference between the duplicate samples is reported as an RPD. This difference is compared against the laboratory's control limits as a conservative approach to determining precision. During the study period, 3,537 matrix spike duplicates were performed. Only 3 matrix spike duplicate batches exceeded the control limits (0.08%), shown in Table 9-10. The analytes were bromide and sodium, and the frequency of exceedance is shown in Table 9-11. The frequency of samples outside the control limits for both analytes was very low. The environmental samples are shown in Table 9-12. This indicates that matrix interference had no significant effects in the precision of the laboratory analysis of the environmental samples.

Table 9-10 Matrix spike duplicate exceedances

Table 9-11 Number of matrix spike duplicate recovery exceedances

Table 9-12 Samples with matrix spike duplicate exceedances

Sample Duplicates

Sample duplicates are environmental samples that are divided into 2 aliquots in the laboratory and analyzed independently to determine the repeatability of the analytical method. The RPD for the duplicate results must fall within the established control limits. During the study period, there were 2,284

RPD sample duplicate analyses performed, and the RPDs for 10 sample duplicates (0.43%) exceeded the control limits. The sample duplicate batches outside of the control limits are shown in Table 9-13.

Table 9-13 Sample duplicate exceedances

A total of 498 sample duplicate analyses were performed for DOC, and only 5 (1%) were outside the control limits. Out of 92 TOC sample duplicate analyses performed with the combustion method, only one (1%) was outside the control limits. There were 383 TOC sample duplicate analyses performed with the oxidation method, and only 2 (0.5%) were out of the control limits. Turbidity and TDS had very low frequencies of duplicates outside of the control limits and, therefore, did not have a significant impact on the overall data quality of the project (Table 9-14). These results indicate the laboratory had acceptable precision in its analysis of the project samples. The environmental samples are shown in Table 9-15.

Table 9-14 Number of sample duplicate exceedances

Table 9-15 Samples with sample duplicate exceedances

Table 9-1 Field duplicates

Analyte	Collection date	Sample number	Sample duplicate	Result 1	Result 2	RPD %	RPD limit %
Bromodichloromethane	8/11/1998	CB0898A2549	CB0898A2550	29	65	77	20
Dibromoacetic Acid (DBAA)	8/4/1998	CB0898A2658	CB0898A2659	1	4	120	30
Dibromochloromethane	8/11/1998	CB0898A2549	CB0898A2550	23	29	23	20
Dissolved boron	5/15/2000	CD0500B1367	CD0500B1368	0.2	0.1	67	25
Dissolved boron	2/22/1999	CB0299A0916	CB0299A0918	0.0341	0.00	200	25
Dissolved boron	3/3/1999	CB0399A1205	CB0399A1207	0.075	0.00	200	25
Dissolved boron	3/15/1999	CB0399A1238	CB0399A1239	0	0.178	200	25
Dissolved boron	12/14/1999	CB1299A3304	CB1299A3307	0.1304	0.1	26	25
Dissolved bromide	8/4/1998	CB0898A2524	CB0898A2527	0.016	0.01	46	20
Dissolved bromide	1/11/1999	CB0199A0022	CB0199A0024	0.02	0.01	67	20
Dissolved bromide	4/26/1999	CB0499A1617	CB0499A1618	0.09	0.13	36	20
Dissolved bromide	11/8/1999	CB1199A2915	CB1199A2916	0.39	0.26	40	20
Dissolved bromide	12/6/1999	CB1299A3295	CB1299A3296	0.02	0.01	67	20
Dissolved bromide	12/7/1999	CB1299A3311	CB1299A3313	0.6	12.02	181	20
Dissolved chloride	2/22/2000	CB0200B1029	CB0200B1031	3	4	29	20
Dissolved chloride	2/2/1999	CB0299A0869	CB0299A0870	3	4	29	20
Dissolved chloride	2/22/1999	CB0299A0916	CB0299A0918	3	2	40	20
Dissolved chloride	5/4/1999	CB0599A1847	CB0599A1850	1	2	67	20
Dissolved magnesium	1/31/2000	CB0100B0348	CB0100B0350	5.24	7	29	25
Dissolved magnesium	7/7/1999	CB0799A2237	CB0799A2240	2	1	67	25
Dissolved magnesium	8/4/1999	CB0899A2434	CB0899A2437	1.51	2	28	25
Dissolved nitrate	8/4/1998	CB0898A2524	CB0898A2527	0.4	0.3	29	20
Dissolved nitrate	4/7/1999	CB0499A1512	CB0499A1515	0.1	0.2	67	20
Dissolved nitrate	5/17/1999	CB0599A1901	CB0599A1903	0.4	0.3	29	20
Dissolved nitrate	11/2/1999	CB1199A2889	CB1199A2890	0.5	0.4	22	20
Dissolved nitrate	12/14/1999	CB1299A3304	CB1299A3307	2.4	1.8	29	20
Dissolved sulfate	2/28/2000	CB0200B1076	CB0200B1078	3	2	40	20
Dissolved sulfate	3/13/2000	CD0300B0797	CD0300B0799	4	3	29	20
Dissolved sulfate	4/5/2000	CD0400B1289	CD0400B1292	22	15	38	20
Dissolved sulfate	9/22/1998	CA0998A0303	CA0998A0305	4	5	22	20
Dissolved sulfate	8/4/1998	CB0898A2524	CB0898A2527	4	6	40	20
Dissolved sulfate	8/4/1998	CB0898A2658	CB0898A2659	21	12	55	20
Dissolved sulfate	1/25/1999	CB0199A0053	CB0199A0055	4	5	22	20
Dissolved sulfate	2/2/1999	CB0299A0869	CB0299A0870	4	3	29	20
Dissolved sulfate	4/7/1999	CB0499A1512	CB0499A1515	2	1	67	20
Dissolved sulfate	12/20/1999	CB1299A3334	CB1299A3336	7	5	33	20
Hardness	1/31/2000	CB0100B0348	CB0100B0350	48	59	21	20
Hardness	7/7/1999	CB0799A2237	CB0799A2240	18	14	25	20

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Table 9-1 continued

Analyte	Collection date	Sample number	Sample duplicate	Result 1	Result 2	RPD %	RPD limit %
TDS	1/10/2000	CB0100B0319	CB0100B0321	86	119	32	15
TDS	1/5/1999	CB0199A0010	CB0199A0014	271	316	15	15
TDS	3/8/1999	CB0399A1217	CB0399A1219	66	81	20	15
TDS	12/13/1999	CB1299A3326	CB1299A3327	594	487	20	15
TOC	10/6/1999	CB1099A2812	CB1099A2815	1.6	1.1	37	30
Turbidity	1/3/2000	CB0100B0280	CB0100B0283	1.5	1.9	24	15
Turbidity	1/5/2000	CB0100B0299	CB0100B0300	11.3	9.6	16	15
Turbidity	6/19/2000	CD0600B1438	CD0600B1439	31.2	26.3	17	15
Turbidity	11/4/1998	CB1198A3852	CB1198A3856	19.5	16.7	15	15
Turbidity	9/8/1998	CA0998A0297	CA0998A0299	9	10.6	16	15
Turbidity	1/6/1999	CB0199A0017	CB0199A0019	16.8	20.2	18	15
Turbidity	8/23/1999	CB0899A2480	CB0899A2481	38.2	28	31	15
Turbidity	10/5/1999	CB1099A2826	CB1099A2830	33	28	16	15
Turbidity	10/7/1999	CB1099A2821	CB1099A2823	29.3	21.6	30	15
Turbidity	10/25/1999	CB1099A2809	CB1099A2810	19	22.3	16	15
Turbidity	12/13/1999	CB1299A3326	CB1299A3327	9.9	12.5	23	15
UV absorbance @254 nm	3/2/1999	CB0399A1210	CB0399A1211	0.126	0.16	24	10

TDS = Total dissolved solids
TOC = Total organic carbon

Table 9-2 Total internal QC batches grouped by analyte

Analyte	Method	LCS recovery	RPD–LCS duplicate	Matrix Spike	RPD–Matrix Spike Duplicate	Method Blank	RPD sample duplicate	Surrogate recovery
Minor elements								
Aluminum	EPA 200.8 (D)	86	43	172	86	43		
Arsenic	EPA 200.8 (D)	86	43	172	86	43		
Barium	EPA 200.8 (D)	76	38	160	80	38		
Boron	EPA 200.7 (D)	354	175	550	271	221		
Cadmium	EPA 200.8 (D)	76	38	156	78	38		
Chromium	EPA 200.8 (D)	78	39	158	79	39		
Copper	EPA 200.8 (D)	86	43	176	88	43		
Iron	EPA 200.8 (D)	86	43	178	89	43		
Lead	EPA 200.8 (D)	78	39	162	81	39		
Manganese	EPA 200.8 (D)	86	43	178	89	43		
Nickel	EPA 200.8 (D)	60	30	98	49	30		
Selenium	EPA 200.8 (D)	62	31	76	38	31		
Silver	EPA 200.8 (D)	76	38	156	78	38		
Zinc	EPA 200.8 (D)	78	39	158	79	39		
Bromide								
Bromide	EPA 300.0 28d Hold	253	174	631	280	165	11	
THMFP								
Bromodichloromethane	DWR THMFP (Buffered)			32	12	13		22
Bromoform	DWR THMFP (Buffered)			32	12	13		22
Chloroform	DWR THMFP (Buffered)			32	12	13		22
Dibromochloromethane	DWR THMFP (Buffered)			32	12	13		22
Bromochloroacetic acid (BCAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19
Dibromoacetic acid (DBAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19
Dichloroacetic acid (DCAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19
Monobromoacetic acid (MBAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19
Monochloroacetic acid (MCAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19
Trichloroacetic acid (TCAA)	DWR HAAFP (Reactivity)	12	6	16	6	6		19

Table continued on next page

Table 9–2 continued

Analyte	Method	LCS recovery	RPD-LCS duplicate	Matrix Spike	RPD-Matrix Spike Duplicate	Method Blank	RPD sample duplicate	Surrogate recovery
Organic carbon								
DOC	EPA 415.1 (D) Ox	408	197			203	498	
TOC	EPA 415.1 (T) Ox	358	177			178	383	
TOC	EPA 415.1 (T) Cmbst	90	45			45	92	
UV absorbance @254nm	Std Method 5910 B	226	112			135	223	
EC and salts								
Conductance (EC)	Std Method 2510 B					105	298	
Calcium	EPA 200.7 (D)	354	175	618	278	222	1	
Magnesium	EPA 200.7 (D)	354	175	618	278	222	1	
Chloride	EPA 325.2	210	105	394	178	109	3	
Sodium	EPA 200.7 (D)	354	175	562	276	222		
Sulfate	EPA 375.2	206	103	380	173	108	1	
Nutrients								
Nitrate	EPA 300.0 28d Hold	60	29	62	26	30		
Nitrate	Std Method 4500-NO_3 F	334	167	356	155	328		
Ammonia	EPA 350.1	64	32	88	44			
Kjeldahl nitrogen	EPA 351.2	50	25	42	21	29		
Orthophosphate	Std Method 4500-P, F	58	29	74	37	29		
Phosphorus	EPA 365.4	50	25	44	22	29		

DOC = dissolved organic carbon
TOC = total organic carbon

Table continued on next page

Table 9-2 continued

Analyte	Method	LCS recovery	RPD-LCS duplicate	Matrix Spike	RPD-Matrix Spike Duplicate	Method Blank	RPD sample duplicate	Surrogate recovery
Miscellaneous								
pH	pH - Std Method 2320 B						6	
pH	Std Method 5910 B						15	
Hardness	Std Method 2340 B							
Alkalinity	Std Method 2320 B	335	164	603	270	224	38	
Methyl tert-butyl ether (MTBE)	EPA 502.2	2		308	144	131		149
Turbidity								
Turbidity	EPA 180.1	448	220			274	311	
Turbidity	Std Method 2130 B							
TSS	EPA 160.2					30	104	
TDS	Std Method 2540 C					187	299	
Total		5,654	2,847	7,554	3,537	3,821	2,284	513

TSS = Total suspended solids
TDS = Total dissolved solids

Table 9-3 Holding time exceedances

Analyte	Collection date	Sample number	Holding time	Limit
Alkalinity	9/27/1999	CB0999A2608	15 days	14
Alkalinity	8/7/2000	CD0800B1604	32 days	14
Alkalinity	9/27/1999	CB0999A2606	15 days	14
Alkalinity	9/27/1999	CB0999A2607	15 days	14
Alkalinity	8/7/2000	CD0800B1603	32 days	14
Nitrate	11/7/2000	CB1100B1571	143 hours	48
Nitrate	11/7/2000	CB1100B1572	142 hours	48
Nitrate	11/7/2000	CB1100B1569	145 hours	48
Organic Carbon (Total) by Combustion	12/5/2000	CB1200B0054	44 days	28
Organic Carbon (Total) by Combustion	12/11/2000	CB1200B0066	31 days	28
Organic Carbon (Total) by Combustion	12/5/2000	CB1200B0055	44 days	28
Organic Carbon (Total) by Combustion	12/11/2000	CB1200B0065	31 days	28
TDS	8/21/2000	CD0800B1620	8 days	7
TDS	8/21/2000	CD0800B1619	8 days	7
Turbidity	1/8/2001	CB0101B1666	69 hours	48
Turbidity	1/8/2001	CB0101B1665	70 hours	48
Turbidity	1/9/2001	CB0101B1671	189 hours	48
Turbidity	6/21/1999	CB0699A2086	53 hours	48
Turbidity	6/21/1999	CB0699A2088	53 hours	48
Turbidity	11/20/2000	CB1100B1605	168 hours	48
Turbidity	1/8/2001	CB0101B1667	68 hours	48
Turbidity	1/8/2001	CB0101B1664	72 hours	48
Turbidity	1/9/2001	CB0101B1669	191 hours	48
Turbidity	6/21/1999	CB0699A2087	54 hours	48
Turbidity	11/20/2000	CB1100B1604	170 hours	48
Orthophosphate	11/7/2000	CB1100B1572	142 hours	48

TDS = Total dissolved solids

Table 9-4 Method blank exceedances

Analyte	Method	Batch number	Result	Reporting Limit	Units
Alkalinity	Std Method 2320 B	BL00B6128	1.8	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6181	1.6	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6206	1.6	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6247	1.9	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6291	1.3	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6310	1.5	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6344	1.5	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6376	1.5	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6433	1.5	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6449	1.2	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6487	1.4	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6557	1.3	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B6640	1.6	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B5899	1.1	1	mg/L as C
Alkalinity	Std Method 2320 B	BL00B5904	1.1	1	mg/L as C
TDS	Std Method 2540 C	BL00B5900	9	1	mg/L
TDS	Std Method 2540 C	BL00B5905	2	1	mg/L
TDS	Std Method 2540 C	BL00B6022	4	1	mg/L
TDS	Std Method 2540 C	BL00B6292	6	1	mg/L

TDS = Total dissolved solids

Table 9-5 Number of batches with method blank exceedances

Analyte	Total batches	Batches with method blanks out of limits	Frequency of samples out of limits (%)
Alkalinity	224	15	6.7
TDS	187	4	2.1

TDS = Total dissolved solids

Table 9-6 Environmental samples associated with method blank exceedances

Analyte	Method	Batch number	Sample number	Collection date
Alkalinity	Std Method 2320 B	BL00B6128	SLA0500B0101	5/17/2000
Alkalinity	Std Method 2320 B	BL00B6128	DA0500B0255	5/17/2000
Alkalinity	Std Method 2320 B	BL00B6128	DA0500B0249	5/17/2000
Alkalinity	Std Method 2320 B	BL00B6128	CD0500B1383	5/22/2000
Alkalinity	Std Method 2320 B	BL00B6128	CD0500B1384	5/22/2000
Alkalinity	Std Method 2320 B	BL00B6128	CD0500B1385	5/22/2000
Alkalinity	Std Method 2320 B	BL00B6128	CD0500B1383	5/22/2000
Alkalinity	Std Method 2320 B	BL00B6181	CD0500B1391	5/30/2000
Alkalinity	Std Method 2320 B	BL00B6181	CD0500B1392	5/30/2000
Alkalinity	Std Method 2320 B	BL00B6181	CD0500B1393	5/30/2000
Alkalinity	Std Method 2320 B	BL00B6181	CD0500B1392	5/30/2000
Alkalinity	Std Method 2320 B	BL00B6181	CD0500B1392	5/30/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1404	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1405	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1406	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1407	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1408	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1413	6/6/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1414	6/6/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1415	6/6/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1416	6/6/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1417	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1418	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1419	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1420	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1421	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1422	6/7/2000
Alkalinity	Std Method 2320 B	BL00B6206	CD0600B1404	6/5/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1430	6/12/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1431	6/12/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1432	6/12/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1438	6/19/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1439	6/19/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1440	6/19/2000
Alkalinity	Std Method 2320 B	BL00B6247	CD0600B1438	6/19/2000
Alkalinity	Std Method 2320 B	BL00B6291	SLA0600B0117	6/21/2000
Alkalinity	Std Method 2320 B	BL00B6291	DZ0600B5852	6/21/2000
Alkalinity	Std Method 2320 B	BL00B6291	DZ0600B5853	6/21/2000
Alkalinity	Std Method 2320 B	BL00B6310	CD0600B1446	6/26/2000
Alkalinity	Std Method 2320 B	BL00B6310	CD0600B1447	6/26/2000
Alkalinity	Std Method 2320 B	BL00B6310	CD0600B1448	6/26/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1462	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1463	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1464	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1465	7/3/2000

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Table 9-6 continued

Analyte	Method	Batch number	Sample number	Collection date
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1466	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1471	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1472	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1473	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1474	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1475	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1518	7/5/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1519	7/5/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1521	7/5/2000
Alkalinity	Std Method 2320 B	BL00B6344	CD0700B1522	7/5/2000
Alkalinity	Std Method 2320 B	BL00B6376	CD0700B1472	7/3/2000
Alkalinity	Std Method 2320 B	BL00B6376	CD0700B1481	7/10/2000
Alkalinity	Std Method 2320 B	BL00B6376	CD0700B1482	7/10/2000
Alkalinity	Std Method 2320 B	BL00B6376	CD0700B1483	7/10/2000
Alkalinity	Std Method 2320 B	BL00B6376	CD0700B1482	7/10/2000
Alkalinity	Std Method 2320 B	BL00B6433	CD0700B1525	7/17/2000
Alkalinity	Std Method 2320 B	BL00B6433	CD0700B1526	7/17/2000
Alkalinity	Std Method 2320 B	BL00B6433	CD0700B1527	7/17/2000
Alkalinity	Std Method 2320 B	BL00B6433	SLA0700B0202	7/19/2000
Alkalinity	Std Method 2320 B	BL00B6433	DZ0700B6600	7/19/2000
Alkalinity	Std Method 2320 B	BL00B6449	DZ0700B6604	7/19/2000
Alkalinity	Std Method 2320 B	BL00B6449	CD0700B1507	7/24/2000
Alkalinity	Std Method 2320 B	BL00B6449	CD0700B1508	7/24/2000
Alkalinity	Std Method 2320 B	BL00B6449	CD0700B1509	7/24/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1550	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1551	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1552	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1553	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1554	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1584	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1586	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1583	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1639	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1642	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1643	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1585	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1582	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1586	8/1/2000
Alkalinity	Std Method 2320 B	BL00B6487	CD0800B1643	8/2/2000
Alkalinity	Std Method 2320 B	BL00B6557	CD0800B1602	8/7/2000
Alkalinity	Std Method 2320 B	BL00B6557	CD0800B1603	8/7/2000
Alkalinity	Std Method 2320 B	BL00B6557	CD0800B1604	8/7/2000
Alkalinity	Std Method 2320 B	BL00B6557	CD0800B1603	8/7/2000
Alkalinity	Std Method 2320 B	BL00B6640	CD0800B1610	8/14/2000
Alkalinity	Std Method 2320 B	BL00B6640	CD0800B1611	8/14/2000
Alkalinity	Std Method 2320 B	BL00B6640	CD0800B1612	8/14/2000

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Table 9-6 continued

Analyte	Method	Batch number	Sample number	Collection date
Alkalinity	Std Method 2320 B	BL00B6640	CD0800B1611	8/14/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1275	4/3/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1276	4/3/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1278	4/3/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1279	4/3/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1284	4/4/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1285	4/4/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1286	4/4/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1287	4/4/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1288	4/4/2000
Alkalinity	Std Method 2320 B	BL00B5899	CD0400B1275	4/3/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1289	4/5/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1290	4/5/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1291	4/5/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1292	4/5/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1293	4/5/2000
Alkalinity	Std Method 2320 B	BL00B5904	CD0400B1289	4/5/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1275	4/3/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1276	4/3/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1278	4/3/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1279	4/3/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1284	4/4/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1285	4/4/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1286	4/4/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1287	4/4/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1288	4/4/2000
TDS	Std Method 2540 C	BL00B5900	CD0400B1275	4/3/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1289	4/5/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1290	4/5/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1291	4/5/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1292	4/5/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1293	4/5/2000
TDS	Std Method 2540 C	BL00B5905	CD0400B1289	4/5/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1333	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1334	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1336	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1337	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1346	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1342	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1343	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1344	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1345	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1333	5/1/2000
TDS	Std Method 2540 C	BL00B6292	SLA0600B0117	6/21/2000
TDS	Std Method 2540 C	BL00B6292	DZ0600B5852	6/21/2000
TDS	Std Method 2540 C	BL00B6292	DZ0600B5853	6/21/2000

TDS = Total dissolved solids

Table 9-7 Matrix spike recovery exceedances

Analyte	Method	Batch number	Recovery (%)	Control limits (%)
Alkalinity	Std Method 2320 B	BL00B5848	78	80–120
Alkalinity	Std Method 2320 B	BL00B5848	65	80–120
Alkalinity	Std Method 2320 B	BL00B5961	121	80–120
Alkalinity	Std Method 2320 B	BL00B5961	126	80–120
Alkalinity	Std Method 2320 B	BL98A2656	123	80–120
Alkalinity	Std Method 2320 B	BL98A2656	124	80–120
Alkalinity	Std Method 2320 B	BL98A2793	62	80–120
Alkalinity	Std Method 2320 B	BL98A2793	62	80–120
Alkalinity	Std Method 2320 B	BL99A3722	73	80–120
Alkalinity	Std Method 2320 B	BL99A3735	121	80–120
Alkalinity	Std Method 2320 B	BL99A4736	124	80–120
Alkalinity	Std Method 2320 B	BL99A4736	122	80–120
Alkalinity	Std Method 2320 B	BL99A5002	81	80–120
Ammonia	EPA 350.1	BL98A2161	134	85–118
Ammonia	EPA 350.1	BL98A2161	126	85–118
Boron	EPA 200.7 (D)	BL00B6568	46	80–120
Boron	EPA 200.7 (D)	BL00B6568	44	80–120
Bromide	EPA 300.0 28d Hold	BL00B5279	70	80–120
Bromide	EPA 300.0 28d Hold	BL00B5279	70	80–120
Bromide	EPA 300.0 28d Hold	BL99A3133	74	80–120
Bromide	EPA 300.0 28d Hold	BL99A3133	75	80–120
Bromide	EPA 300.0 28d Hold	BL99A3697	79	80–120
Bromide	EPA 300.0 28d Hold	BL99A3697	64	80–120
Bromide	EPA 300.0 28d Hold	BL99A3839	71	80–120
Bromide	EPA 300.0 28d Hold	BL99A3839	73	80–120
Bromoform	DWR THMFP (Buffered)	BL98A2214	122	80–120
Calcium	EPA 200.7 (D)	BL00B7067	79	80–120
Calcium	EPA 200.7 (D)	BL01B7789	127	80–120
Calcium	EPA 200.7 (D)	BL01B7789	124	80–120
Calcium	EPA 200.7 (D)	BL01B7839	77	80–120
Calcium	EPA 200.7 (D)	BL01B7839	75	80–120
Calcium	EPA 200.7 (D)	BL01B9038	78	80–120
Calcium	EPA 200.7 (D)	BL01B9038	78	80–120
Calcium	EPA 200.7 (D)	BL99A3424	123	80–120
Calcium	EPA 200.7 (D)	BL99A3424	129	80–120
Calcium	EPA 200.7 (D)	BL99A5040	63	80–120
Calcium	EPA 200.7 (D)	BL99A5040	62	80–120
Chloride	EPA 325.2	BL00B6544	116	85–115
Chloride	EPA 325.2	BL00B6544	118	85–115
Chloride	EPA 325.2	BL98A2474	84	85–115
Chloride	EPA 325.2	BL99A3887	82	85–115
Chloride	EPA 325.2	BL99A3887	82	85–115
Chloride	EPA 325.2	BL99A4625	79	85–115
Chloride	EPA 325.2	BL99A4625	80	85–115

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Table 9-7 continued

Analyte	Method	Batch number	Recovery (%)	Control limits (%)
Magnesium	EPA 200.7 (D)	BL01B7789	122	80–120
Magnesium	EPA 200.7 (D)	BL01B7789	123	80–120
Nitrate	Std Method 4500-NO_3 F	BL00B6136	74	80–120
Nitrate	Std Method 4500-NO_3 F	BL00B6136	73	80–120
Silver	EPA 200.8 (D)	BL00B6305	74	80–120
Silver	EPA 200.8 (D)	BL00B6305	79	80–120
Silver	EPA 200.8 (D)	BL00B6305	77	80–120
Silver	EPA 200.8 (D)	BL00B6305	79	80–120
Silver	EPA 200.8 (D)	BL00B6305	71	80–120
Silver	EPA 200.8 (D)	BL00B6305	72	80–120
Silver	EPA 200.8 (D)	BL99A4242	79	80–120
Sodium	EPA 200.7 (D)	BL00B5818	120	80–120
Sodium	EPA 200.7 (D)	BL00B6260	156	80–120
Sodium	EPA 200.7 (D)	BL00B6260	160	80–120
Sodium	EPA 200.7 (D)	BL00B6395	125	80–120
Sodium	EPA 200.7 (D)	BL00B6395	142	80–120
Sodium	EPA 200.7 (D)	BL01B7789	120	80–120
Sodium	EPA 200.7 (D)	BL01B8997	120	80–120
Sodium	EPA 200.7 (D)	BL99A3052	74	80–120
Sodium	EPA 200.7 (D)	BL99A3052	10	80–120
Sodium	EPA 200.7 (D)	BL99A3424	68	80–120
Sodium	EPA 200.7 (D)	BL99A3424	63	80–120
Sodium	EPA 200.7 (D)	BL99A3424	37	80–120
Sodium	EPA 200.7 (D)	BL99A3424	67	80–120
Sodium	EPA 200.7 (D)	BL99A4257	177	80–120
Sodium	EPA 200.7 (D)	BL99A4257	194	80–120
Sodium	EPA 200.7 (D)	BL99A5040	67	80–120
Sodium	EPA 200.7 (D)	BL99A5040	59	80–120
Sulfate	EPA 375.2	BL99A3855	74	85–115
Sulfate	EPA 375.2	BL99A3855	75	85–115
Sulfate	EPA 375.2	BL99A3929	117	85–115
Sulfate	EPA 375.2	BL99A3929	116	85–115
Sulfate	EPA 375.2	BL99A4488	117	85–115
TCAA	DWR HAAFP (Reactivity)	BL98A2318	67	70–130
TCAA	DWR HAAFP (Reactivity)	BL98A2318	69	70–130

TCAA = Trichloroacetic acid

Table 9-8 Frequency of QC batches with matrix spike recovery exceedances

Analyte	Total matrix spikes	Matrix spike recoveries out of limits	Frequency of samples out of limits (%)
Alkalinity	603	13	2.2
Ammonia	88	2	2.2
Boron	550	2	0.4
Bromide	631	8	1.2
Bromoform	56	1	1.7
Chloride	780	7	0.9
Calcium	618	11	1.7
Magnesium	618	2	0.3
Nitrate	638	2	0.3
Silver	156	7	4.4
Sodium	562	17	3.0
Sulfate	764	5	0.7
TCAA	16	2	12.5

TCAA = Trichloroacetic acid

Table 9-9 Samples with matrix spike recovery exceedances

Analyte	Method	Batch number	Sample number	Collection date
Alkalinity	Std Method 2320 B	BL00B5848	CD0300B0844	3/20/2000
Alkalinity	Std Method 2320 B	BL00B5848	CD0300B0845	3/20/2000
Alkalinity	Std Method 2320 B	BL00B5848	CD0300B0846	3/20/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1317	4/17/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1318	4/17/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1319	4/17/2000
Alkalinity	Std Method 2320 B	BL00B5961	DA0400B0218	4/19/2000
Alkalinity	Std Method 2320 B	BL00B5961	DA0400B0224	4/19/2000
Alkalinity	Std Method 2320 B	BL00B5961	SLA0400B0086	4/19/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1325	4/24/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1326	4/24/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1327	4/24/2000
Alkalinity	Std Method 2320 B	BL00B5961	CD0400B1318	4/17/2000
Alkalinity	Std Method 2320 B	BL98A2656	CB1098A3702	10/20/1998
Alkalinity	Std Method 2320 B	BL98A2656	CB1098A3703	10/20/1998
Alkalinity	Std Method 2320 B	BL98A2656	CB1098A3704	10/20/1998
Alkalinity	Std Method 2320 B	BL99A3722	CB0599A1847	5/4/1999
Alkalinity	Std Method 2320 B	BL99A3722	CB0599A1848	5/4/1999
Alkalinity	Std Method 2320 B	BL99A3722	CB0599A1850	5/4/1999
Alkalinity	Std Method 2320 B	BL99A3722	CB0599A1851	5/4/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1856	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1857	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1858	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1859	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1860	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1861	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1862	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1863	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1864	5/5/1999
Alkalinity	Std Method 2320 B	BL99A3735	CB0599A1865	5/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB0999A2606	9/27/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB0999A2607	9/27/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB0999A2608	9/27/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2826	10/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2827	10/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2828	10/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2829	10/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2830	10/5/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2812	10/6/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2813	10/6/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2815	10/6/1999
Alkalinity	Std Method 2320 B	BL99A4736	CB1099A2816	10/6/1999
Alkalinity	Std Method 2320 B	BL99A5002	SLZ1199A9000	11/17/1999
Alkalinity	Std Method 2320 B	BL99A5002	CB1199A2931	11/22/1999

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Table 9-9 continued

Analyte	Method	Batch number	Sample number	Collection date
Alkalinity	Std Method 2320 B	BL99A5002	CB1199A2932	11/22/1999
Alkalinity	Std Method 2320 B	BL99A5002	CB1199A2933	11/22/1999
Alkalinity	Std Method 2320 B	BL98A2793	CB1198A3873	11/17/1998
Alkalinity	Std Method 2320 B	BL98A2793	CB1198A3874	11/17/1998
Alkalinity	Std Method 2320 B	BL98A2793	CB1198A3875	11/17/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2524	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2525	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2526	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2527	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2658	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2659	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2660	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2661	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2662	8/4/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2533	8/5/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2534	8/5/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2535	8/5/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2536	8/5/1998
Ammonia	EPA 350.1	BL98A2161	CB0898A2537	8/5/1998
Boron	EPA 200.7 (D)	BL00B6568	CD0800B1602	8/7/2000
Boron	EPA 200.7 (D)	BL00B6568	CD0800B1603	8/7/2000
Boron	EPA 200.7 (D)	BL00B6568	CD0800B1604	8/7/2000
Bromide	EPA 300.0 28d Hold	BL00B5279	CB0100B0319	1/10/2000
Bromide	EPA 300.0 28d Hold	BL00B5279	CB0100B0320	1/10/2000
Bromide	EPA 300.0 28d Hold	BL00B5279	CB0100B0321	1/10/2000
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0022	1/11/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0023	1/11/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0024	1/11/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0038	1/19/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0039	1/19/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0040	1/19/1999
Bromide	EPA 300.0 28d Hold	BL99A3133	CB0199A0022	1/11/1999
Bromide	EPA 300.0 28d Hold	BL99A3697	CB0499A1617	4/26/1999
Bromide	EPA 300.0 28d Hold	BL99A3697	CB0499A1618	4/26/1999
Bromide	EPA 300.0 28d Hold	BL99A3697	CB0499A1619	4/26/1999
Bromide	EPA 300.0 28d Hold	BL99A3839	SLA0599A0205	5/19/1999
Bromide	EPA 300.0 28d Hold	BL99A3839	DA0599A0154	5/19/1999
Bromide	EPA 300.0 28d Hold	BL99A3839	DA0599A0146	5/19/1999

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Table 9-9 continued

Analyte	Method	Batch number	Sample number	Collection date
Bromoform	DWR THMFP (Buffered)	BL98A2214	CB0898A2524	8/4/1998
Bromoform	DWR THMFP (Buffered)	BL98A2214	CB0898A2525	8/4/1998
Bromoform	DWR THMFP (Buffered)	BL98A2214	CB0898A2526	8/4/1998
Bromoform	DWR THMFP (Buffered)	BL98A2214	CB0898A2527	8/4/1998
Calcium	EPA 200.7 (D)	BL01B9038	CB0801B0685	8/27/2001
Calcium	EPA 200.7 (D)	BL01B9038	CB0801B0684	8/27/2001
Calcium	EPA 200.7 (D)	BL01B9038	CB0801B0686	8/27/2001
Calcium	EPA 200.7 (D)	BL00B7067	DZ1000B1499	10/18/2000
Calcium	EPA 200.7 (D)	BL00B7067	DZ1000B1501	10/18/2000
Calcium	EPA 200.7 (D)	BL99A3424	CB0399A1238	3/15/1999
Calcium	EPA 200.7 (D)	BL99A3424	CB0399A1239	3/15/1999
Calcium	EPA 200.7 (D)	BL99A5040	CB1199A2931	11/22/1999
Calcium	EPA 200.7 (D)	BL99A5040	CB1199A2932	11/22/1999
Calcium	EPA 200.7 (D)	BL99A5040	CB1199A2933	11/22/1999
Calcium	EPA 200.7 (D)	BL01B7789	CB0201B1776	2/26/2001
Calcium	EPA 200.7 (D)	BL01B7789	CB0201B1777	2/26/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0173	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0171	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0174	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0169	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0170	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0172	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0175	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0177	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0178	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0169	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0169	3/6/2001
Calcium	EPA 200.7 (D)	BL01B7839	CB0301B0171	3/6/2001
Chloride	EPA 325.2	BL00B6544	CD0800B1550	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1551	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1552	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1553	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1554	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1584	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1586	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1583	8/1/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1639	8/2/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1642	8/2/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1643	8/2/2000

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Table 9-9 continued

Analyte	Method	Batch number	Sample number	Collection date
Chloride	EPA 325.2	BL00B6544	CD0800B1585	8/2/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1582	8/2/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1602	8/7/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1603	8/7/2000
Chloride	EPA 325.2	BL00B6544	CD0800B1604	8/7/2000
Chloride	EPA 325.2	BL98A2474	CA0998A0306	9/29/1998
Chloride	EPA 325.2	BL98A2474	CA0998A0307	9/29/1998
Chloride	EPA 325.2	BL98A2474	CA0998A0308	9/29/1998
Chloride	EPA 325.2	BL99A3887	SLA0599A0205	5/19/1999
Chloride	EPA 325.2	BL99A3887	DA0599A0154	5/19/1999
Chloride	EPA 325.2	BL99A3887	DA0599A0146	5/19/1999
Chloride	EPA 325.2	BL99A4625	CB0999A2596	9/20/1999
Chloride	EPA 325.2	BL99A4625	CB0999A2597	9/20/1999
Chloride	EPA 325.2	BL99A4625	CB0999A2598	9/20/1999
Magnesium	EPA 200.7 (D)	BL01B7789	CB0201B1776	2/26/2001
Magnesium	EPA 200.7 (D)	BL01B7789	CB0201B1777	2/26/2001
Nitrate	Std Method 4500-NO_3 F	BL00B6136	SLA0500B0101	5/17/2000
Nitrate	Std Method 4500-NO_3 F	BL00B6136	DA0500B0255	5/17/2000
Nitrate	Std Method 4500-NO_3 F	BL00B6136	DA0500B0249	5/17/2000
Silver	EPA 200.8 (D)	BL00B6305	DZ0600B5852	6/21/2000
Silver	EPA 200.8 (D)	BL99A4242	SLA0799A0394	7/21/1999
Silver	EPA 200.8 (D)	BL99A4242	DA0799A0208	7/21/1999
Silver	EPA 200.8 (D)	BL00B6305	SLA0600B0117	6/21/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1462	7/3/2000
Sodium	EPA 200.7 (D)	BL99A3052	CB0199A0020	1/6/1999
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1474	7/3/2000
Sodium	EPA 200.7 (D)	BL01B8997	CB0801B0669	8/20/2001
Sodium	EPA 200.7 (D)	BL01B7789	CB0201B1776	2/26/2001
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1481	7/10/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1518	7/5/2000
Sodium	EPA 200.7 (D)	BL00B6568	CD0800B1603	8/7/2000
Sodium	EPA 200.7 (D)	BL00B6568	CD0800B1602	8/7/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1475	7/3/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1519	7/5/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1522	7/5/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1471	7/3/2000
Sodium	EPA 200.7 (D)	BL00B6260	CD0600B1432	6/12/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1521	7/5/2000
Sodium	EPA 200.7 (D)	BL00B6568	CD0800B1604	8/7/2000
Sodium	EPA 200.7 (D)	BL00B6260	CD0600B1431	6/12/2000

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Table 9-9 continued

Analyte	Method	Batch number	Sample number	Collection date
Sodium	EPA 200.7 (D)	BL01B8997	CB0801B0671	8/20/2001
Sodium	EPA 200.7 (D)	BL99A5040	CB1199A2933	11/22/1999
Sodium	EPA 200.7 (D)	BL00B5818	CD0300B0798	3/13/2000
Sodium	EPA 200.7 (D)	BL00B5818	CD0300B0797	3/13/2000
Sodium	EPA 200.7 (D)	BL00B5818	CD0300B0799	3/13/2000
Sodium	EPA 200.7 (D)	BL99A5040	CB1199A2932	11/22/1999
Sodium	EPA 200.7 (D)	BL00B6260	CD0600B1430	6/12/2000
Sodium	EPA 200.7 (D)	BL99A3052	CB0199A0013	1/5/1999
Sodium	EPA 200.7 (D)	BL99A5040	CB1199A2931	11/22/1999
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1463	7/3/2000
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1483	7/10/2000
Sodium	EPA 200.7 (D)	BL99A3424	CB0399A1239	3/15/1999
Sodium	EPA 200.7 (D)	BL00B6395	CD0700B1482	7/10/2000
Sulfate	EPA 375.2	BL00B7236	DZ1100B2357	11/15/2000
Sulfate	EPA 375.2	BL00B7236	DZ1100B2357	11/15/2000
Sulfate	EPA 375.2	BL00B7236	DZ1100B2358	11/15/2000
Sulfate	EPA 375.2	BL00B7236	SLA1100B0374	11/15/2000
Sulfate	EPA 375.2	BL00B7236	DZ1100B2357	11/15/2000
Sulfate	EPA 375.2	BL00B7236	SLA1100B0374	11/15/2000
Sulfate	EPA 375.2	BL99A3855	CB0599A1856	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1857	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1858	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1859	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1860	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1861	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1862	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1863	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1864	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1865	5/5/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1883	5/10/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1884	5/10/1999
Sulfate	EPA 375.2	BL99A3855	CB0599A1885	5/10/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2043	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2044	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2045	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2046	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2047	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2025	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2026	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2028	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2029	6/1/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2050	6/2/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2051	6/2/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2052	6/2/1999

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Table 9-9 continued

Analyte	Method	Batch number	Sample number	Collection date
Sulfate	EPA 375.2	BL99A3929	CB0699A2053	6/2/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2054	6/2/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2065	6/7/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2066	6/7/1999
Sulfate	EPA 375.2	BL99A3929	CB0699A2067	6/7/1999
Sulfate	EPA 375.2	BL99A4488	CB0899A2488	8/31/1999
Sulfate	EPA 375.2	BL99A4488	CB0899A2489	8/31/1999
Sulfate	EPA 375.2	BL99A4488	CB0899A2490	8/31/1999
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2524	8/4/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2525	8/4/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2526	8/4/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2527	8/4/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2658	8/4/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2533	8/5/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2534	8/5/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2535	8/5/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2536	8/5/1998
TCAA	DWR HAAFP (Reactivity)	BL98A2318	CB0898A2537	8/5/1998

TCAA = Trichloroacetic acid

Table 9-10 Matrix spike duplicate exceedances

Analyte	Method	Batch number	Result	Control limits
Bromide	EPA 300.0 28d Hold	BL99A3697	21.0	0–20
Sodium	EPA 200.7 (D)	BL01B7832	23.6	0–20
Sodium	EPA 200.7 (D)	BL99A3424	58.6	0–20

Table 9-11 Number of matrix spike duplicate recovery exceedances

Analyte	Total matrix spike duplicates	Matrix spike duplicate recoveries out of limits	Frequency of samples out of limits (%)
Bromide	280	1	0.4
Sodium	276	2	0.7

Table 9-12 Samples with matrix spike duplicate exceedances

Analyte	Method	Batch number	Sample number	Collection date
Bromide	EPA 300.0	BL99A3697	CB0499A1617	4/26/1999
Bromide	EPA 300.0	BL99A3697	CB0499A1618	4/26/1999
Bromide	EPA 300.0	BL99A3697	CB0499A1619	4/26/1999
Sodium	EPA 200.7 (D)	BL01B7832	CB0301B0162	3/5/2001
Sodium	EPA 200.7 (D)	BL99A3424	CB0399A1239	3/15/1999
Sodium	EPA 200.7 (D)	BL01B7832	CB0301B0163	3/5/2001
Sodium	EPA 200.7 (D)	BL01B7832	CB0301B0160	3/5/2001
Sodium	EPA 200.7 (D)	BL01B7832	CB0301B0161	3/5/2001
Sodium	EPA 200.7 (D)	BL01B7832	CB0301B0164	3/5/2001
Sodium	EPA 200.7 (D)	BL99A3424	CB0399A1238	3/15/1999

Table 9-13 Sample duplicate exceedances

Analyte	Method	Batch number	Result %	Limit %
TOC	EPA 415.1 (T) Ox	BL00B6701	161	0-30
TOC	EPA 415.1 (T) Ox	BL00B6193	36	0-30
TOC	EPA 415.1 (T) Cmbst	BL01B7534	35	0-30
DOC	EPA 415.1 (D) Ox	BL99A4748	32	0-30
DOC	EPA 415.1 (D) Ox	BL99A3922	50	0-30
DOC	EPA 415.1 (D) Ox	BL98A2776	41	0-30
DOC	EPA 415.1 (D) Ox	BL01B7462	180	0-30
DOC	EPA 415.1 (D) Ox	BL00B6787	75	0-30
TDS	Std Method 2540 C	BL00B6022	15	0-15
Turbidity	EPA 180.1	BL00B6513	16	0-15

TOC = Total organic carbon
DOC = Dissolved organic carbon
TDS = Total dissolved solids

Table 9-14 Number of sample duplicate exceedances

Analyte	Method	Total sample duplicates	Sample duplicates out of limits	Frequency of samples out of limits (%)
DOC	EPA 415.1 (D) Ox	498	5	1
Solids	Std Method 2540 C	299	1	0.33
TOC	EPA 415.1 (T) Ox	383	2	0.5
TOC	EPA 415.1 (T) Cmbst	92	1	1
Turbidity	EPA 180.1	311	1	0.32

DOC = Dissolved organic carbon
TOC = Total organic carbon

Table 9-15 Samples with sample duplicate exceedances

Analyte	Method	Batch number	Sample number	Collection date
TOC	EPA 415.1 (T) Ox	BL00B6701	CD0800B1618	8/21/2000
TOC	EPA 415.1 (T) Ox	BL00B6701	CD0800B1619	8/21/2000
TOC	EPA 415.1 (T) Ox	BL00B6701	CD0800B1620	8/21/2000
TOC	EPA 415.1 (T) Ox	BL00B6701	CD0800B1620	8/21/2000
TOC	EPA 415.1 (T) Ox	BL00B6193	CD0500B1391	5/30/2000
TOC	EPA 415.1 (T) Ox	BL00B6193	CD0500B1392	5/30/2000
TOC	EPA 415.1 (T) Ox	BL00B6193	CD0500B1393	5/30/2000
TOC	EPA 415.1 (T) Ox	BL00B6193	CD0500B1393	5/30/2000
TOC	EPA 415.1 (T) Cmbst	BL01B7534	CB1200B0075	12/26/2000
TOC	EPA 415.1 (T) Cmbst	BL01B7534	CB1200B0102	12/18/2000
TOC	EPA 415.1 (T) Cmbst	BL01B7534	DZ0101B4838	1/10/2001
TOC	EPA 415.1 (T) Cmbst	BL01B7534	DZ0101B4839	1/10/2001
TOC	EPA 415.1 (T) Cmbst	BL01B7534	DZ0101B4840	1/10/2001
TOC	EPA 415.1 (T) Cmbst	BL01B7534	CB1200B0073	12/26/2000
TOC	EPA 415.1 (T) Cmbst	BL01B7534	CB1200B0074	12/26/2000
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2822	10/7/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2823	10/7/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2824	10/7/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2825	10/7/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2804	10/12/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2805	10/12/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2803	10/12/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2804	10/12/1999
DOC	EPA 415.1 (D) Ox	BL99A4748	CB1099A2825	10/7/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2050	6/2/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2051	6/2/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2052	6/2/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2053	6/2/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2054	6/2/1999
DOC	EPA 415.1 (D) Ox	BL99A3922	CB0699A2051	6/2/1999
DOC	EPA 415.1 (D) Ox	BL98A2776	CB1198A3873	11/17/1998
DOC	EPA 415.1 (D) Ox	BL98A2776	CB1198A3874	11/17/1998
DOC	EPA 415.1 (D) Ox	BL98A2776	CB1198A3875	11/17/1998
DOC	EPA 415.1 (D) Ox	BL98A2776	CB1198A3874	11/17/1998
DOC	EPA 415.1 (D) Ox	BL01B7462	CB1200B0073	12/26/2000
DOC	EPA 415.1 (D) Ox	BL01B7462	CB1200B0074	12/26/2000
DOC	EPA 415.1 (D) Ox	BL01B7462	CB1200B0075	12/26/2000
DOC	EPA 415.1 (D) Ox	BL01B7462	CB1200B0074	12/26/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1652	9/5/2000

Table continued on next page

Table 9-15 continued

Analyte	Method	Batch number	Sample number	Collection date
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1653	9/5/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1654	9/5/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1655	9/5/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1656	9/5/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1661	9/6/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1662	9/6/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1663	9/6/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1665	9/6/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1653	9/5/2000
DOC	EPA 415.1 (D) Ox	BL00B6787	CD0900B1665	9/6/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1333	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1334	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1336	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1337	5/1/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1346	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1342	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1343	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1344	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1345	5/2/2000
TDS	Std Method 2540 C	BL00B6022	CD0500B1333	5/1/2000
Turbidity	EPA 180.1	BL00B6513	CD0800B1639	8/2/2000
Turbidity	EPA 180.1	BL00B6513	CD0800B1642	8/2/2000
Turbidity	EPA 180.1	BL00B6513	CD0800B1643	8/2/2000
Turbidity	EPA 180.1	BL00B6513	CD0800B1585	8/2/2000
Turbidity	EPA 180.1	BL00B6513	CD0800B1582	8/2/2000
			CD0800B1585	8/2/2000

TOC = Total organic carbon
DOC = Dissolved organic carbon
TDS = Total dissolved solids

References

Literature cited

[DWR] California Department of Water Resources. 1962. Article 19. Water Quality. Standard Provisions for Water Supply Contract. First approved 3 Aug 1962 and subsequently executed with each of the State Water Project contractors

[DWR] California Department of Water Resources, Division of Local Assistance, Water Resources Assessment Program. 1990. Delta Island Drainage Investigation Report of the Interagency Delta Health Aspects Monitoring Program: A Summary of Observations During Consecutive Dry Year Conditions, Water Years 1987 and 1988. June.

[DWR] California Department of Water Resources, Division of Local Assistance, Water Quality Assessment Branch. 1994. Five-year Report of the Municipal Water Quality Investigations Program, Summary and Findings During Five Dry Years, January 1987-December 1991. Nov.

[DWR] California Department of Water Resources, Division of Local Assistance, Water Quality Assessment Branch. 1995. 1992-1993 Biennial Memorandum Report of the Municipal Water Quality Investigations Program. Apr.

[DWR] California Department of Water Resources, Division of Local Assistance, Water Quality Assessment Branch. 1995. Data Report of the Municipal Water Quality Investigations Program, Summary of Monitoring Results, Water Year 1994. July.

[DWR] California Department of Water Resources, Division of Local Assistance, Water Quality Assessment Branch. 1996. Municipal Water Quality Investigations Program Annual Report, Water Year 1995. Aug.

[DWR] California Department of Water Resources, Division of Planning and Local Assistance, Water Quality Assessment Branch. 1997. Municipal Water Quality Investigations Program Annual Report, October 1995-December 1996. Dec.

[DWR] California Department of Water Resources, Division of Planning and Local Assistance, Water Quality Assessment Branch. 2000. Municipal Water Quality Investigations Program Annual Report, 1997-1998. Oct.

[DWR] California Department of Water Resources, Division of Planning and Local Assistance, Water Quality Assessment Branch, Municipal Water Quality Investigations Program. 2001. California State Water Project Watershed Sanitary Survey Update Report 2001. Sacramento: Under the direction of State Water Contractors. 2 v. (various pagings) p. Dec.

[SWRCB] California State Water Resource Control Board. 2000. Water Right Decision 1641 (revised). http://www.waterrights.ca.gov/baydelta/d1641.htm. Accessed on 12 Mar 2002.

Eaton AD, Clesceri LS, Greenberg AE, Franson MAH, American Public Health Association, American Water Works Association, Water Environment Federation. 1995. Standard methods for the examination of water and wastewater. 19th edition. Washington, DC: American Public Health Association. p 5-60.

Fong S. 2002. Bryte Chemical Laboratory quality assurance manual. Quality Assurance Technical Document 8. Sacramento: Bryte Chemical Laboratory, Water Quality Assessment Branch, Environmental Services Division, California Department of Water Resources. Apr.

Helsel DR, Hirsch RM. 1992. Statistical Methods in Water Resources. Amsterdam, the Netherlands; New York: Elsevier Science B.V. xvi, 522 p.

SAS Institute Inc. 1999. Chapter 38 "The Loess Procedure". SAS/STAT User's Guide. Version 8 ed. Gary, NC: SAS Institute. p 1853-1900.

[EPA] US Environmental Protection Agency, Office of Water. 1998 (Dec). Stage 1 Disinfectants and Disinfection Byproducts Rule. http://www.epa.gov/cgi-bin/epaprintonly.cgi. Accessed on 20 Sep 2002.

[EPA] US Environmental Protection Agency, Office of Water. 2000. Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs. 1st edition. Washington, DC: US Environmental Protection Agency. Report nr EPA-822-B00-001.

Woodard R. 2000. Sources and Magnitudes of Water Quality Constituents of Concern in Drinking Water Supplies Taken from the Sacramento-San Joaquin Delta. Prepared for the CALFED Bay-Delta Program. 22 Sep.

Personal communications

Agee B, MWQI. 2000. Changes in the measurement of total organic carbon at Bryte Laboratory. Office memorandum to Bryte Laboratory customers measuring TOC. 15 Dec.

Agee B, MWQI. 2001. Estimated DOC/TOC ratios for modeling purposes. Office memorandum to Paul Hutton. 17 May.

Agee B, MWQI. 2002. Comparability codes for Bryte Laboratory data. e-mail to Bryte Chemical Laboratory customers. 1 Mar.

Breuer RS, MWQI. 2002. Office discussion with Fengmao Guo. 14 Nov.

Holm L, Contra Costa Water District. 2003. Review comments. Sent to RS Breuer via Richard Woodard. 10 Feb.

Holm L and Denton R, Contra Costa Water District. 2003. Review comments. Sent to RS Breuer via Richard Woodard. 10 Feb.

Matthews D, Santa Clara Valley Water District. 2001. e-mail to Mike Zanoli, MWQI. 23 July.

McCune B, MWQI. 2002. Office discussion on boron in San Joaquin Valley and rice drainage to NEMDC from Reclamation District 1000 Pump # 6. 18 Dec.

Woodard R, State Water Contractors. 2003. Review comments. Sent to RS Breuer. 10 Feb.

Glossary

A

af
acre-foot/acre-feet

AL(s)
action level(s)

APHA
American Public Health Association

AWWA
American Water Works Association

B

BLM
US Bureau of Land Management

C

CCWD
Contra Costa Water District

CDEC
California Data Exchange Center

cfs
cubic feet per second

CIMIS
California Irrigation Management Information System

CVP
Central Valley Project

CVRWQCB
Central Valley Regional Water Quality Control Board

D

D/DBP(s)
disinfectant/disinfection byproduct(s)

DES
Division of Environmental Services

DHS
California Department of Health Services

DMC
Delta-Mendota Canal

DOC
dissolved organic carbon

DWR
California Department of Water Resources

E

EC
electrical conductivity

EPA
US Environmental Protection Agency

ESWTR
Enhanced Surface Water Treatment Rule

F

FLIMS
Field and Laboratory Information Management System

H

HAAs
Haloacetic acids

I

IEP
Interagency Ecological Program

IQR
interquartile range

L

L
Liters

LCS
Laboratory control sample

M

maf
million acre-feet

MCL
maximum contaminant level

MDL
method detection limit

mg/L
milligrams per liter

MTBE
methyl tertiary-butyl ether

MWDSC
Metropolitan Water District of Southern California

MWQI
DWR Municipal Water Quality Investigations

N

NEMDC
Natomas East Main Drainage Canal

nm
nanometers

NTU(s)
nephelometric turbidity unit(s)

O

O&M
DWR Division of Operations and Maintenance

OWQ
Office of Water Quality

P

pH
negative log of the hydrogen ion activity

POC
particulate organic carbon

Q

QA/QC
quality assurance/quality control

R

RPD
relative percent difference

S

SJR
San Joaquin River

SRWTP
Sacramento Regional Wastewater Treatment Plant

$SUVA_{254}$
Specific UVA_{254}

SWC
State Water Contractors

SWP
State Water Project

SWRCB
State Water Resources Control Board

SWTR
Surface Water Treatment Rule

T

TCAA
trichloroacetic acid

TDS
total dissolved solids

THM
trihalomethane

TKN
total Kjeldahl nitrogen

TOC
total organic carbon

TSS
total suspended solids

TTHMFP
total trihalomethane formation potential

U

USBR
US Bureau of Reclamation

US EPA
see EPA

UVA_{254}
ultraviolet absorbance measured at a wavelength of 254 nanometers

W

WTP
water treatment plant

WWTP
waste water treatment plant

µ

µg/L
micrograms per liter

µm
micrometers

µS/cm
microsiemens per centimeter

Metric Conversion Factors

Quantity	*To Convert from Metric Unit*	*To Customary Unit*	*Multiply Metric Unit By*	*To Convert to Metric Unit Multiply Customary Unit By*
Length	millimeters (mm)	inches (in)	0.03937	25.4
	centimeters (cm) for snow depth	inches (in)	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Area	square millimeters (mm^2)	square inches (in^2)	0.00155	645.16
	square meters (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometers (km^2)	square miles (mi^2)	0.3861	2.590
Volume	liters (L)	gallons (gal)	0.26417	3.7854
	megaliters	million gallons (10*)	0.26417	3.7854
	cubic meters (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic meters (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekameters (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic meters per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	liters per minute (L/mn)	gallons per minute (gal/mn)	0.26417	3.7854
	liters per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megaliters per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekameters per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lbs)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb.)	1.1023	0.90718
Velocity	meters per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (k/W)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.32456	2.989
Specific capacity	liters per minute per meter drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per liter (mg/L)	parts per million (ppm)	1.0	1.0
Electrical conductivity	microsiemens per centimeter (µS/cm)	micromhos per centimeter	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8X°C)+32	0.56(°F-32)

Appendix A
Method for Converting TOC by Combustion to TOC by Oxidation

Background

California Department of Water Resources' Bryte Chemical Laboratory analyzed all Municipal Water Quality Investigations (MWQI) Program samples for organic carbon during the 3-year reporting period. For the past 15 years, both total and dissolved organic carbon (TOC and DOC) in water samples have been determined by a wet oxidation method (oxidation) (Agee 2000 pers comm). Beginning November 2000 Bryte changed its TOC method from wet oxidation to a combustion method. The method change was prompted by the concern of some Bryte laboratory customers that the oxidation method may under-report TOC during peak TOC events (that is, during storm runoff events). During the reporting period, TOC for MWQI samples was determined by the oxidation method from August 1998 through October 2000 and by the combustion method from November 2000 through September 2001. DOC was determined by the oxidation method during the entire 3-year reporting period.

The combustion method generally measures a greater portion of the TOC in a sample than does the oxidation method. Combustion converts most combustible organic carbon to gaseous carbon dioxide; TOC concentrations are derived from the amount of carbon dioxide produced during combustion. In contrast, the oxidation method, which uses chemical oxidation, is generally less powerful than the combustion method especially for samples with elevated particulate organic carbon. Initial exploratory studies suggest that TOC values by combustion were generally 10% to 15% higher than TOC values by oxidation (Agee 2000 pers comm). Greater differences were found in more recent MWQI TOC analyses. Although the combustion method generally measures more TOC than does the oxidation method, both methods measure only a fraction of the organic carbon. The relative advantage of one method over the other is under debate. Because statistical analysis could not be made with TOC data from 2 different methods, TOC values by combustion were transformed to their approximate TOC values by oxidation through a conversion process outlined below. The data used for this analysis are available online or on a CD-ROM (see Appendix B).

Appendix B Report and Data in Electronic Format

Approach

Bryte analyzed a small number of water samples collected from 11 MWQI stations by both oxidation and combustion methods prior to fully implementing the combustion method in November 2001. This small data set alone was insufficient for deriving a reliable statistical relationship because most data were collected from September to October of 2000, which were dry months. The data set was not representative of data for the entire 3-year period. A reliable predictive relationship requires a larger data set with samples collected during both dry and wet months. Therefore, a total of 281 MWQI samples analyzed for TOC by both oxidation and combustion methods from September 2000 through August 2002 were retrieved for this analysis, in addition to the smaller data set collected September to October of 2000. Of the 281 samples, a total of 21 samples were excluded from this analysis. Seventeen of the 21 samples were excluded because of possible erroneous data for TOC combustion. These samples generally contained low DOC. TOC by oxidation was slightly higher than DOC, but TOC by combustion was 3 to 6 times higher than DOC with a median of 6.6 mg/L. The other 4 samples were eliminated because TOC values by oxidation were lower than DOC.

The 260 samples included in this analysis represent 11 MWQI stations (Figure A-1). No sample was analyzed for TOC using both TOC methods for the 2 MWQI agricultural drainage stations. This didn't affect the analysis because no TOC combustion data from these 2 sites needed conversion. Samples were collected weekly at both San Joaquin River near Vernalis and Sacramento River at Hood. Thus, proportionately more data came from these 2 sites (Figure A-1). Of the 260 samples included in this analysis, 99 samples (38%) were collected during the dry months (May to October), and 161 were collected during the wet months (Figure A-1).

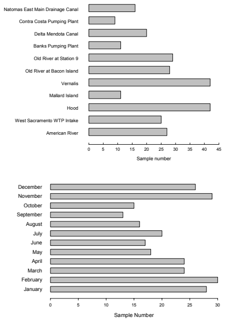


Figure A-1 Sample distribution by station and by month

The relationship between TOC by oxidation and by combustion appears to have been linear (Figure A-2); however, the data split into 2 distinct clusters, suggesting that a single regression equation was inadequate to describe the relationship for all the data. The cluster with relatively less scattering and running slightly above and roughly parallel to the 1:1 line (Cluster A) represented samples having TOC by combustion just slightly higher than TOC by oxidation. The other cluster with much greater data dispersion (Cluster B) represented samples with TOC by combustion much higher than TOC by oxidation. A considerable portion of the samples in Cluster A was collected during the dry months, but the majority of samples in Cluster B was taken during the wet months. As mentioned in Chapter 4, organic carbon levels could fall back to baseline levels between rain events during the wet months. Thus, sample collection time alone cannot cleanly separate the 2 clusters.

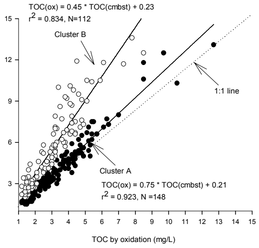


Figure A-2 TOC (combustion) vs. TOC (oxidation): Data clusters and regression equations for conversion

Further examination of the 2 clusters suggests that the ratio between TOC by combustion and DOC (TOC(cmbst)/DOC) was characteristic of each data cluster. By roughly separating the 2 clusters through visual examination, TOC(cmbst)/DOC ratio in Cluster A ranged from 0.93 to 1.53 with only 4 samples outside this range; TOC(cmbst)/DOC ratio in Cluster B varied between 1.52 and 2.98. Based on these observations, a TOC(cmbst)/DOC ratio of 1.5 was arbitrarily chosen to separate the 2 clusters for regression analysis. Although it was an arbitrary choice, this ratio was an adequate one. For samples with TOC(cmbst)/DOC ratios of 1.5 or less, TOC by combustions is at most 50% higher than DOC. Since TOC by oxidation is generally higher than DOC but lower than TOC by combustion, the ratio of TOC by oxidation over DOC will be less than 1.5. These samples were generally samples with little or no particulate organic carbon (POC). The differences between TOC by combustion and TOC by oxidation were generally small. However, samples with a TOC(cmbst)/DOC ratio of 1.5 or more were generally samples containing high POC. For these samples, TOC by combustion was invariably much higher than TOC by oxidation. For example, the TOC by combustion values for Cluster B samples could be from 1.5 to nearly 3 times as high as TOC by oxidation.

When the 260 data values were separated by a TOC(cmbst)/DOC ratio of 1.5, Cluster A contained 148 samples; and Cluster B, 112 samples. Of all the samples in Cluster A, 10 samples had a TOC(cmbst)/DOC of 1.0 or less suggesting that TOC by combustion is either the same or less than DOC. TOC by combustion was occasionally less than DOC due to normal analytical error. These data are valid because they are within the acceptable error range as specified in the *Quality Assurance Manual* (Fong 2002).

The relationship between TOC by combustion and TOC by oxidation were both linear and statistically significant (Figure A-2). For samples in Cluster A, the linear relationship can be described by the following equation:

$$\text{TOC(ox)} = 0.75 * \text{TOC(cmbst)} + 0.21 \ (r^2 = 0.923)$$

The regression for samples in Cluster B is

$$\text{TOC(ox)} = 0.45 * \text{TOC(cmbst)} + 0.23 \ (r^2 = 0.834).$$

Data Conversion

The conversion followed a 2-step process. First, the TOC(cmbst)/DOC ratio of all samples that needed to be converted was computed. Extremely high or low values due to laboratory error were excluded. Then an adequate equation was applied to each sample. For samples having TOC(cmbst)/DOC ratios of 1.5 or less, the equation derived from Cluster A

$$\text{TOC(ox)} = 0.75 * \text{TOC(cmbst)} + 0.21$$

was used to convert TOC by combustion into TOC by oxidation. Some TOC by combustion data within the group was taken as TOC by oxidation without conversion. These samples typically had a TOC(cmbst)/DOC of less than 1.15 and low TOC values. Conversion may result in the TOC being lower than the DOC. For samples having TOC(cmbst)/DOC ratios of 1.5 or more (up to about 3), the equation developed from Cluster B

$$\text{TOC(ox)} = 0.45 * \text{TOC(cmbst)} + 0.23$$

was applied. However, for samples with TOC combustion values of less than 2.5, conversion with this equation may result in TOC being lower than DOC. When this occurred, the other equation was applied despite the TOC(cmbst)/DOC indicating otherwise. This is appropriate because considerable data overlap occurred when TOC was lower than about 2 mg/L (Figure A-2).

Of the 725 TOC by oxidation analyses included in this report, 132 or 18% were estimated from TOC by combustion. The distribution of estimated TOC are summarized in Table A-1. The data sets are available online or on a CD-ROM (see Appendix B).

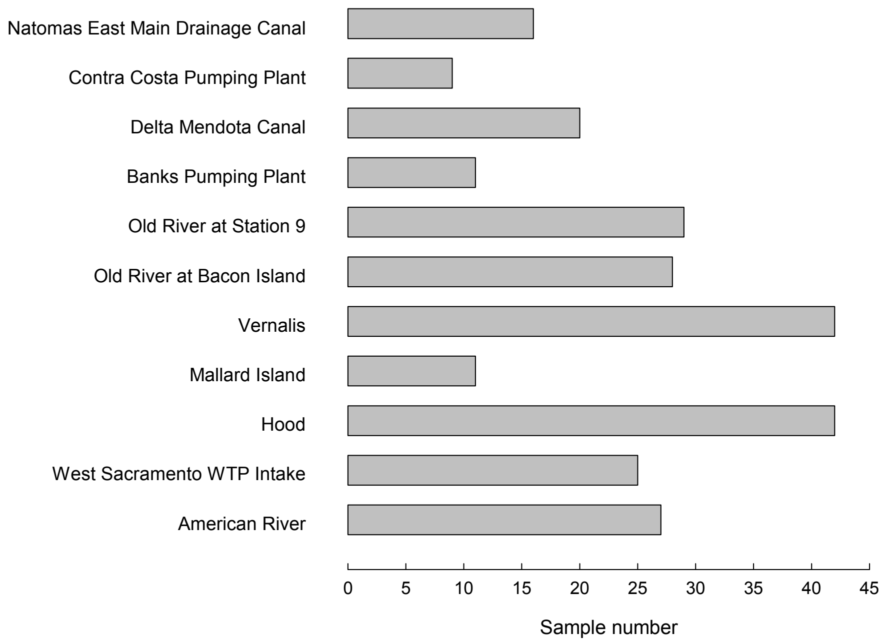
Table A-1 Summary of converted TOC by combustion at 14 stations

Although the above method works reasonably well for this particular data set, the equation cannot be applied for water samples collected at agricultural drainage sites. The data set does not include samples from drainage returns, and it is favorably biased toward samples collected during the wet months. However, no TOC from agricultural drainage returns needed to be converted during the 3-year reporting period.

Table A-1 Summary of converted TOC by combustion at 14 stations

Station	Total number of TOC by combustion	Number of converted TOC by combustion	Percent converted
American and Sacramento River stations			
American River at E.A. Fairbairn WTP	36	9	25
West Sacramento WTP Intake	36	6	17
Sacramento River at Hood	162	38	23
Sacramento River at Mallard Island	34	8	24
San Joaquin River stations			
San Joaquin River near Vernalis	156	40	26
San Joaquin River at Highway 4	34	7	21
Delta channel stations			
Old River at Station 9	38	5	13
Old River at Bacon Island	36	3	8
Diversion stations			
Banks Pumping Plant	37	3	8
Delta-Mendota Canal	27	1	4
Contra Costa Pumping Plant	29	5	17
Agricultural drainage stations			
Bacon Island Pumping Plant	25	0	0
Twitchell Island Pumping Plant	35	0	0
Urban drainage station			
Natomas East Main Drainage Canal	40	5	13
Total	725	130	

Figure A-1 Sample distribution by station and by month



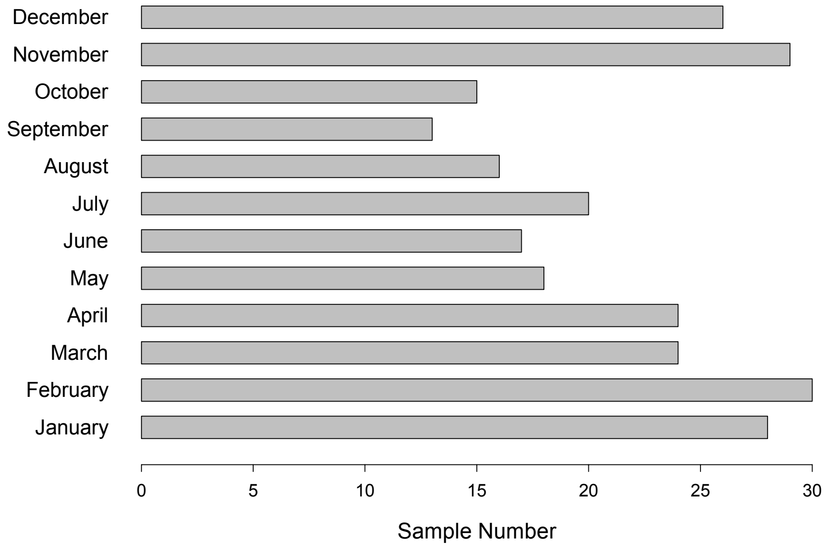
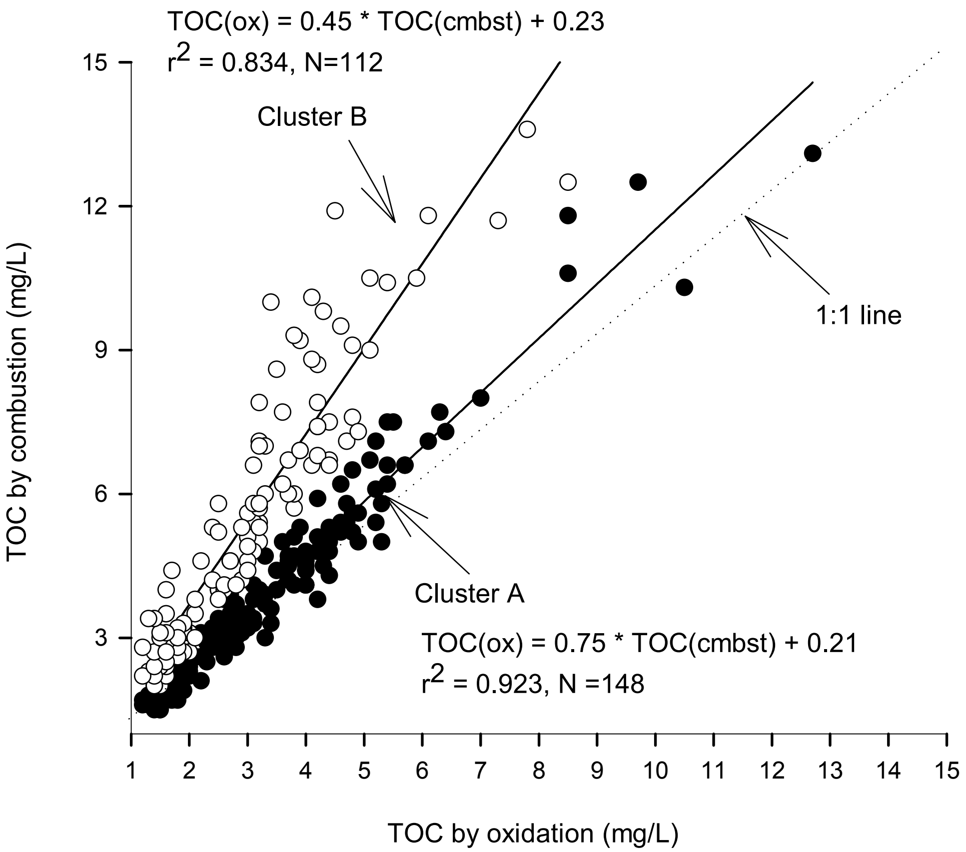


Figure A-2 TOC (combustion) vs. TOC (oxidation): Data clusters and regression equations for conversion



Appendix B
Report and Data in Electronic Format

This report and its data set are available electronically, either online or on CD-ROM.

You can find this report online at the Municipal Water Quality Investigations Program Web site: http://www.wq.water.ca.gov/mwq/index.htm. MWQI is a program within the Division of Environmental Services, a division of the California Department of Water Resources. All raw data are presented in MS Excel format. The report is provided as a portable document format (PDF). Acrobat Reader is required to view the report and is available free online.

For information about CD availability, contact Municipal Water Quality Investigations Program through its Web site or mail requests to the MWQI Program, P.O. Box 942836, Sacramento, CA 94236-0001.

California Department of Water Resources home page has links to DWR Web sites.
wwwdwr.water.ca.gov/

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