State of California
The Resources Agency
Department of Water Resources

Municipal Water Quality Investigations Program

History and Studies

1983—2012

November 2013

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Foreword

The Sacramento-San Joaquin Delta (Delta) is a major source of drinking water for 25 million people of the State of California. Therefore, the quality of Delta water is an important consideration for its use as a drinking water source. However, Delta water quality may be degraded by a variety of sources and environmental factors. Close monitoring of Delta waters is necessary to ensure delivery of high quality source waters to urban water suppliers.

The Municipal Water Quality Investigations (MWQI) Program, within the Department of Water Resources, is responsible for the monitoring and research of drinking water quality in the Delta. Among all State and local agencies monitoring the Delta and its tributaries, MWQI conducts the only monitoring program to investigate the quality of source waters in the Delta with respect to its suitability for the production of drinking water.

Since 1983, the MWQI Program has been conducting comprehensive and systematic source water monitoring in the Delta region. Data and findings are presented for major water quality constituents, including organic carbon, bromide, salinity, regulated organic and inorganic constituents in drinking water, and a few unregulated constituents of current interest.

The Real Time Data Forecasting-Comprehensive Program (RTDF-CP) focuses on providing a single location that compiles and disseminates real-time drinking water quality data gathered across agencies. This data enables water managers to make operating decisions based on observed and forecasted changes in water quality. The RTDF-CP includes a network of real-time water quality monitoring stations and a modeling component intended to allow greater predictive ability of water quality in real-time and the future.

This and other MWQI Program reports are available online at the MWQI website:
http://www.wq.water.ca.gov/mwqi/pubs.cfm

For more information about the MWQI Program, please visit our homepage at
http://www.wq.water.ca.gov/mwqi/mwqi_index.cfm

The Municipal Water Quality Program (MWQP) Branch currently consists of four sections. Three of these sections, MWQI, Water Quality Special Studies, and Field Support, constitute the Municipal Water Quality Investigations Program funded by the State Water Project Contractors Authority (SWPCA).

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Mojave Water Agency
Napa County Flood Control and Water Conservation District
Palmdale Water District
San Bernardino 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

MWQI Program Participant:
Contra Costa Water District

Executive Summary

This report chronicles the evolution of the Municipal Water Quality Investigations (MWQI) Program from its inception in 1983, as the Interagency Delta Health Aspects Monitoring Program (IDHAMP), and presents a synopsis of its many publications and special studies. The purpose of this report is to provide a history of the MWQI Program, to discuss the significant accomplishments of the MWQI Program, and to summarize the studies, findings, and publications of the program. In the process of creating this report, all of the MWQI Program's nearly 30 years of work have been archived and catalogued resulting in both a physical and a web-based library.

The report is organized as follows:

- Executive Summary provides the overview of the report and program.
- Part 1 covers chapters 1 through 6, which provide information on the different aspects of the program including: the formation of the program, the discrete and real-time monitoring programs, the Real Time Data and Forecasting Comprehensive Program (RTDF-CP), emergency response, quality assurance/quality control (QA/QC), and program management.
- Part 2 covers chapters 7 through 12, which contain individual summaries of the program reports and studies.
- A full list of MWQI and related publications can be found in Appendix A

Formation of Municipal Water Quality Investigations Program

The California Department of Water Resources (DWR) was established in 1956 and the State Water Project (SWP) was authorized in 1960. Salinity and inorganic constituents were the water quality constituents of concern in the early years of the SWP. In the mid- to late-1970s trihalomethanes (THMs) were found in treated drinking water and a study conducted by the California Department of Health Services (now California Department of Public Health) found that water in the Sacramento-San Joaquin Delta (Delta) had a significant potential to produce THMs when drinking water is chlorinated. This study resulted in several other reports prepared by DWR and a panel commissioned by the DWR director, which concluded that a drinking water monitoring program focused on the public health aspects of water quality was needed.

DWR conducted a THM study from September 1981 to January 1982, and released *The State Water Project Trihalomethane Study* report in April 1982. In August 1982, the DWR director appointed a panel of recognized water quality and health scientists to evaluate the information available on THMs. In December 1982, the panel's report *Public Health Aspects of Sacramento-San Joaquin Delta Water Supplies, A Panel Report for the California Department of Water Resources*, was published. The panel concluded that the limited raw drinking water data available was not adequate to assess the public health aspects of the suitability of using the Delta for drinking water. The panel recommended the institution of a program of monitoring for constituents of human health significance.

In 1983, DWR initiated the Interagency Delta Health Aspects Monitoring Program (IDHAMP) to implement the panel's recommendations. Early information from the IDHAMP indicated drainage from Delta island peat soils was rich in organic carbon, a THM precursor. The Delta Island Drainage

Investigation (DIDI) was subsequently instituted in 1987 to develop detailed information on the nature of this carbon source and to identify potential means of mitigating its impact on Delta drinking water supplies.

The State Water Project Contractors requested a broad-based program that would provide information on known and emerging threats to drinking water quality. In 1990, DWR responded by implementing the MWQI Program which unified the IDHAMP and DIDI programs. In combination with its predecessor program IDHAMP, MWQI has conducted 30 years of water quality monitoring and research. The program's initial focus was to compile a comprehensive database on drinking water quality in the Delta and to conduct scientific studies on key aspects of Delta water quality.

The MWQI Program was expanded between 2006 and 2008 with the initiation of the Real Time Data and Forecasting Comprehensive Program (RTDF-CP). The elements of the RTDF-CP are real-time monitoring, information management and dissemination, and modeling to produce water quality forecasts. This program requires coordination between several units in DWR and requires substantially more staff than the earlier MWQI Program. The SWC participating in the MWQI Program increased funding by more than $1 million to $3.1 million to fund the greatly expanded MWQI Program.

The mission of the MWQI Program is to a) support the effective and efficient use of the SWP as a source water supply for municipal purposes through monitoring, forecasting, and reporting of SWP water quality; b) provide early warning of changing conditions in source water quality used for municipal purposes; c) provide data and knowledge based support for operational decision-making on the SWP; d) conduct scientific studies of drinking water importance; and e) provide scientific support to DWR, the State Water Project Contractors Authority-MWQI Specific Project Committee (SPC), and other governmental entities.

Drinking Water Quality Monitoring

The MWQI Program is one of the most comprehensive drinking water quality monitoring programs in the Delta. Monitoring began in 1983 under IDHAMP, and has continued since 1990 with MWQI. The number of discrete monitoring locations has changed over the years from a low of 10 to a high of 18. Special studies have sampled as many as 54 locations. Constituents sampled for include organic carbon, disinfection byproducts, and specific conductance. The MWQI Program has one of the most extensive databases of drinking water constituents for the Delta. The wide range of data gathered by the MWQI Program has been used to identify longer-term trends of water quality changes in the Delta and SWP. The data have also been used to help other agencies develop research and mitigation measures to reduce contaminants in the Delta. The water quality monitoring program consisting of discrete sampling and real-time sampling, and is described in Chapter 3, "Drinking Water Quality Monitoring."

Real Time Data and Forecasting Comprehensive Program

The Real Time Data and Forecasting Comprehensive Program (RTDF-CP) uses real-time monitoring combined with mathematical models to create short-term and long-term forecasting tools. One goal of the RTDF-CP is to provide a single location to compile and disseminate real-time drinking water quality data. Components of the RTDF-CP are monitoring, data dissemination, and modeling for water quality forecasts. Chapter 4, "Real Time Data and Forecasting Comprehensive Program," contains a detailed description of the RTDF-CP.

Real-time monitoring is the continuous measurement of water quality and flow by equipment installed in locations within the Delta, its tributaries, and the SWP. The equipment transmits the resulting data from remote locations shortly after the measurements are made. The MWQI Field Section is responsible for ensuring the instruments are operating correctly, transmitting the data provided by the instruments to the California Data Exchange Center (CDEC), and conducting maintenance in accordance with the standard operational procedures.

Data dissemination occurs in several ways. Real-time data are accessible through CDEC. Discrete sample data are available in the Water Data Library (WDL). The RTDF Report is sent to an email distribution list each day. The report contains predicted and actual values of water quality constituents, a summary table updated daily, volumetric fingerprints of source waters, and links to several forecasts. The MWQI website provides links to CDEC, WDL and the RTDF Report.

The forecasting aspect of the RTDF-CP combines mathematical modeling techniques with monitoring data to forecast water quality. The program has several goals: predict water quality, provide and enhance water quality information, and provide an early warning system for water treatment plants.

Emergency Response

The Emergency Response (ER) element is discussed in Chapter 5, “Emergency Response,” although it is a component of the RTDF-CP. The Emergency Response element was initiated in response to the Jones Tract flood in 2004 and to address the recommendations in the State Water Project Watershed Sanitary Survey, 2006 Update. It focuses on ensuring that drinking water quality constituents of concern are monitored during an emergency. The California Department of Public Health (CDPH) and the State Water Project Contractors Authority (SWPCA) wanted to determine if the existing response plan adequately addresses monitoring for drinking water constituents and protection of drinking water supplies during an emergency.

Program Management

The current organization, management, and funding of the MWQI Program is discussed in Chapter 6, “Program Management.”

For a full list of reports, see Appendix A

Chapter 1 — Introduction

The Municipal Water Quality Investigations (MWQI) Program was formed in 1990 as a partnership between the urban State Water Project Contractors and the Department of Water Resources (DWR) to monitor and evaluate drinking water concerns in the Sacramento-San Joaquin Delta (Delta).

The year 2010 will marked the 20-year anniversary for the MWQI Program. By 2012, DWR will have been conducting studies of Delta drinking water quality for 30 years. This document summarizes the accomplishments of the MWQI Program (and DWR efforts pre-dating the MWQI Program) over the last 30 years. Additionally, this report provides an introductory resource for new MWQI and water agency staff, and may provide water agency managers with justification for continued program funding. This document also provides a clear context for future work in the MWQI Program.

The organization of the report is separated into two parts; Part 1 focuses on the history and component of the MWQI Program. Part 2 focuses on the research that the MWQI Program and predecessors have conducted over the last 30 years. The appendices contain additional background information.

Part 1: History and Components of the MWQI Program

Chapter 1. Introduction

Chapter 2 Formation of the Municipal Water Quality Investigations Program- This chapter provides background on the history of the program, including the evolution of MWQI program goals and objectives.

Chapter 3 Drinking water quality monitoring- This chapter provides an overview of the discrete and real time water quality monitoring program.

Chapter 4 RTDF-CP- This chapter focuses on the goals, objectives and accomplishments of the Real Time Data Forecasting Comprehensive Program.

Chapter 5 Emergency Response- This chapter gives the background of the MWQI Program's efforts in emergency response and discusses the ongoing efforts.

Chapter 6 Program Management- This chapter gives an overview of how the MWQI Program management in terms of funding agreements, budget, organizational structure, and the subcommittees that direct the Program's activities.

Part 2: Summaries of Research conducted by the MWQI Program and its Predecessors

Chapter 7 Discrete Monitoring and Supporting Reports- This chapter summarizes the technical reports that have come out of the discrete monitoring program

Chapter 8 MWQI Program Reports- This chapter summarizes reports created by the MWQI Program on Special studies

Chapter 9 Journal Articles- This chapter summarizes the published primary literature that the MWQI Program has produced

Chapter 10 Modeling Reports and Papers- This chapter summarizes reports that have focused on the various modeling efforts

Chapter 11 Sanitary Surveys- This chapter summarizes the Sanitary Surveys that have been conducted on the State Water Project

Chapter 12 Other Program reports- This chapter summarizes the reports created by the MWQI Program not discussed in the other chapters

Chapter 13 Studies in Progress- This chapter provides summaries of studies that were in progress as of June 2012

Appendices

Appendix A The list of published reports, articles, and guidelines by Municipal Water Quality Investigations and its partners

Appendix B Acknowledgements of Current and Former MWQI Program Participants

Appendix C Acronyms, Abbreviations, and Conversion Table

Appendix D Background information on DWR Modeling

Chapter 2 — Formation of Municipal Water Quality Investigations Program

The MWQI Program was formed in 1990 as a partnership between the urban State Water Contractors and DWR to monitor and evaluate drinking water concerns in the Sacramento-San Joaquin Delta (Delta). This chapter provides the background on how and why the MWQI Program was established.

The Need for a Drinking Water Monitoring Program

DWR was established in 1956 and the State Water Project (SWP) was authorized in 1960. Salinity and inorganic constituents were the water quality constituents of concern in the early years of the SWP. The Clean Water Act of 1972 and the Safe Water Drinking Act of 1974 lead to the regulation of a broad range of constituents of concern in drinking water supplies and in treated drinking water. The U.S. Environmental Protection Agency (EPA) began the National Organic Reconnaissance Survey on drinking water systems in 1974 to look for "volatile organics" including trihalomethanes (THMs). By 1975, THMs were found in treated drinking water at greater concentrations than in raw waters. In 1976, the EPA conducted the National Organic Monitoring Survey. The conclusion was that THMs were a wide spread contaminant that could be found in drinking water as a result of disinfection with chlorine. Subsequent investigation indicated a possible link between THMs and increased incidence of cancer among exposed populations. EPA promulgated a maximum contaminant level (MCL) of 100 µg/L for total THMs in 1979 and the disinfection byproduct regulation went into effect in 1981.

During the mid-1970s, in anticipation of a new federal THM regulation, the California Department of Health Services (now California Department of Public Health) conducted a study on the Delta and found that water in the Delta had a significant potential to produce THMs when drinking water is chlorinated. DWR conducted a study from September 1981 to January 1982 to determine the sources of THM precursors in the Delta, SWP, and the Sacramento River. The *State Water Project Trihalomethane Study* was released in April 1982. This study found high concentrations of THM precursors in the Delta. THM precursor sources came from agricultural drainage, Delta peat soils, and seawater intrusion that brings bromide into the Delta. One of the key conclusions from this study was that the peripheral canal would reduce the THM precursors in SWP water compared to the existing Delta configuration. The report also recommended a routine THM monitoring program for the Delta and a survey of THM formation potential (THMFP) in waters of the entire SWP.

In August of the same year, the DWR director appointed a panel of recognized independent water quality and health scientists to evaluate the information available and make recommendations for further actions needed. In December 1982, the panel published its report, *Public Health Aspects of Sacramento-San Joaquin Delta Water Supplies, A Panel Report for the California Department of Water Resources*. The panel concluded that the source water monitoring program being conducted at that time was not adequate to assess the present or projected suitability of the Delta as a source of drinking water. The panel determined the effects of drinking water quality on public health had not received enough attention in decisions about water management for the Delta. The panel recommended the institution of a monitoring program for constituents of human health significance, namely THM precursors, sodium, asbestos, synthetic organic pollutants such as pesticides, heavy metals, and other toxicants. The panel also recommended that the monitoring program identify sources of contaminants to the Delta, determine how contaminants from each source are transported through the system, and determine how they affect concentrations at the points where water is diverted from the Delta. The panel also recommended that the information from the monitoring program be incorporated into a comprehensive analytical model that would provide information for making decisions on how to manage the Delta to protect public health.

Interagency Delta Health Aspects Monitoring Program

In July 1983, DWR, in cooperation with a number of other agencies, initiated the Interagency Delta Health Aspects Monitoring Program (IDHAMP) to implement the panel's recommendations. The program had been designed to provide long-term water quality data, which might be used to characterize tendencies in water quality during a variety of water supply conditions ranging from drought to flooding. It was also designed to be flexible enough to respond to new water quality concerns as they arise. Program participants directly funded the program. Technical guidance of the program was provided through a committee composed of representatives of the participating agencies, with participation of other relevant parties as needed, such as staff of the California Department of Public Health and the State Water Resources Control Board.

The monitoring program established by IDHAMP was DWR's first comprehensive drinking water quality monitoring program. The first years of the program focused on collecting data on pertinent health-related water quality constituents in Delta water supplies, including sodium, asbestos, selenium, THMFP, organics, and pesticides. Monthly samples were collected from 15 to 18 stations in areas representing fresh water inflow to the Delta, agricultural drainage, bay water, channels and sloughs, and water exports. As analytical methods improved and lower analytical detection limits were used to measure constituents in water quality samples, new and previously unidentified water quality concerns emerged. Among these new water quality constituents of concern was selenium in the San Joaquin River watershed, molinate and thiobencarb (rice herbicides) in the Sacramento River watershed, and insecticides such as diazinon, and waterborne pathogenic protozoa (*Giardia and Cryptosporidium*) in both watersheds.

The findings were presented in program project reports and summary reports published in 1985, 1986, 1989, and 1990. Summaries of these reports are presented in chapters 7 through 13.

Delta Island Drainage Investigation Study

The Delta Island Drainage Investigation (DIDI) was established in 1987 to assess the impacts of Delta island drainage on the quality of drinking water supplies taken from the Delta. The study was initiated after data from IDHAMP showed high THMFP in island drainage. The purpose of the DIDI study was to gather information to evaluate the quality and quantity of island drainage, discover what processes affect quality and quantity of island drainage, and determine how agricultural drainage affected Delta water quality. Another objective of the study was to identify potential means of mitigating the impacts of agricultural drainage on Delta drinking water supplies. Samples were taken from 54 agricultural drains on 20 tracts within the Delta.

MWQI Program

As more water quality data of human health significance were made available through IDHAMP and the efforts of other agencies, it was recognized that there was a need for water quality information upon which to base management decisions affecting Delta water supplies. The IDHAMP program of interagency cooperation was deemed to have been a successful mechanism for acquiring needed information. In 1985, the State Water Contractors requested a broad-based program that would provide information on known and emerging threats to drinking water quality. In 1990, DWR responded by implementing the MWQI Program which unified the IDHAMP (1983-1989) and DIDI (1987-1989) programs.

The primary concept underlying development of the program was to create a team that could function effectively together in reaching consensus for timely actions to be taken in response to water quality challenges as they arose, and to develop the capacity to respond effectively in the field. The MWQI Program was founded on the principles that water quality concerns will continue to evolve, that the program must be flexible and pro-active in order to address the new water quality challenges that will continually arise, and that the work will be performed with direct participation of, and in concert with, its participating agencies. Accordingly, the participating agencies designed a highly flexible and innovative program conducted primarily by DWR staff, with the assistance of technical staff of the participating agencies, as appropriate. Program participants directly funded the program. Technical guidance of the program is provided through a committee composed of representatives of the participating agencies, with participation of other relevant parties as needed.

The MWQI Program has been in existence for more than 20 years. In combination with its predecessor program IDHAMP, MWQI has conducted 30 years of water quality monitoring and research. The program's initial focus was to compile a comprehensive database on drinking water quality in the Delta. Since then, the program has investigated ways of managing Delta lands and waters to minimize adverse impacts on drinking water quality. The program identified sources of contaminants in the Delta and assessed their significance for drinking water quality and water treatment.

Years of monitoring effort have established a high quality, long-term database documenting the drinking water quality status of the Delta, and the phenomena that cause changes in Delta drinking water quality. Data from the program have been, and continue to be, used extensively in water quality and water supply studies and planning.

Real Time Data and Forecasting Comprehensive Program

In 2006, the MWQI Program and the State Water Contractors (SWC) realized that the tools were available to coordinate real time data acquisition and water quality forecasting to provide water agencies and municipal operators with the information to make operational decisions based on imminent changes in water quality; however, there was no mechanism to realize this capability. A meeting was held in June 2006 between the SWC agencies participating in the MWQI Program, DWR management and staff, and select outside agencies to discuss the concept of a Real Time Data and Forecasting Comprehensive Program (RTDF-CP). The RTDF-CP was developed in 2007 and 2008. The elements of the program are:

- Real-time monitoring in remote locations, which provides real time water data on constituents of concern to the drinking water community
- Information management and data dissemination, which makes the data available to the public and interested parties
- Modeling, which provides water quality forecasting

This program requires coordination between several units in DWR and requires substantially more staff than the earlier MWQI Program. The SWC participating in the MWQI Program increased program funding by over $1 million to $3.1 million to fund the greatly expanded MWQI Program.

MWQI Mission Statement

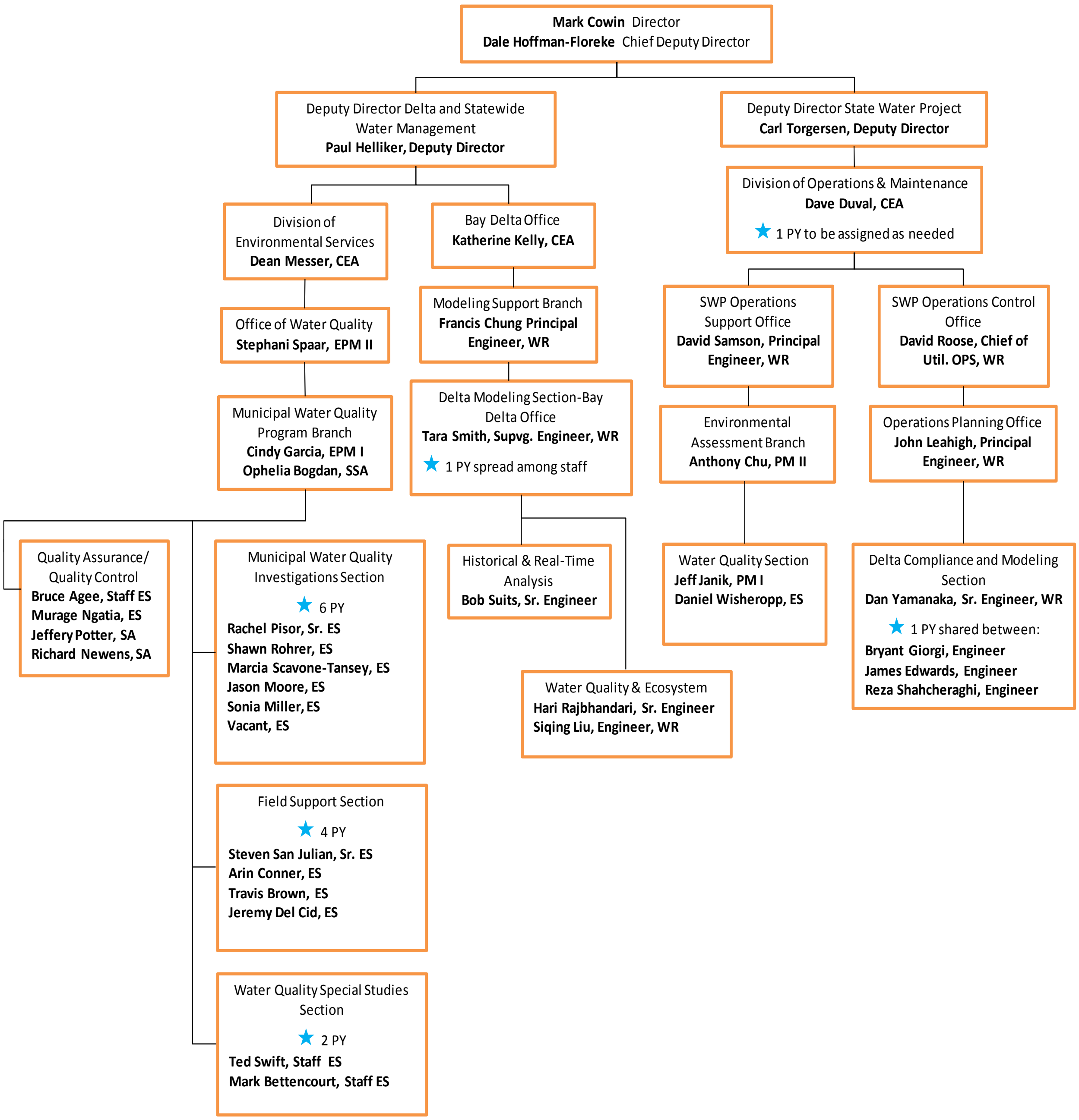
The mission of the MWQI Program is to a) support the effective and efficient use of the State Water Project (SWP) as a source water supply for municipal purposes through monitoring, forecasting, and reporting of SWP water quality; b) provide early warning of changing conditions in source water quality used for municipal purposes; c) provide data and knowledge based support for operational decision-making on the SWP; d) conduct scientific studies of drinking water importance; and e) provide scientific support to DWR, the State Water Project Contractors Authority-MWQI Specific Project Committee (SPC), and other governmental entities.

Program Structure and Organization

The MWQI Program, which is funded by State Water Project Contractors Authority (SWPCA), is spread over several DWR organizational units. The current organizational structure is shown in Figure 1. In 2002, the Division of Environmental Services was created and the Office of Water Quality was established to provide greater linkage among existing DWR water quality programs. The Municipal Water Quality Program (MWQP) Branch of the Office of Water Quality contains three sections, which are a part of the MWQI Program: the MWQI section, the Water Quality Special Studies section, and the Field Support section, The Quality Assurance/Quality Control section is also part of the MWQP Branch; however, it is not funded by SWPCA. The MWQI Program also includes one position in the Bay-Delta Modeling Section of the Bay-Delta Office and two positions in the Division of Operations and Maintenance.

Figure 1 Organizational Chart 2013

Org Chart effective 7/1/2013 of MWQI Funded Positions in The Department of Water Resources



JOB TITLE ABBREVIATIONS

CEA: Career Executive Appointment
ES: Environmental Scientist
Staff ES: 2nd level Environmental Scientist
WR: Water Resource
EPM: Environmental Program Manager
PM: Program Manager
SSA: Staff Services Analyst
SA: Scientific Aide

★ Indicates position(s) funded by the MWQI Program.

The two positions in the Division of O&M and the one position in the Bay Delta Office were among the seven new positions added to carry out the RTDF Comprehensive Program when the MWQI Program expanded in 2007/2008.

Chapter 3 — Drinking Water Quality Monitoring

The MWQI Program is one of the most comprehensive drinking water quality monitoring programs in the Delta. It has one of the most extensive databases of drinking water constituents in the Delta. The wide range of data gathered by the MWQI Program has been used to identify longer-term trends of water quality changes in the Delta and SWP. It has also been used to help other agencies develop research and mitigation measures to reduce contaminants in the Delta. Federal, state, and local agencies and the public extensively use information derived from MWQI Program. By collecting and disseminating data to diverse users, the MWQI Program increases the scientific understanding of the complex Sacramento-San Joaquin Delta.

Discrete Monitoring

Discrete monitoring involves the collection of "grab" sample data at specific stations throughout the Delta. Grab samples are used to define baseline conditions, and are essential to special studies and modeling recalibrations. The causes of changes in water quality from seasonal variations, environmental conditions, or event-based activities such as water management operations, can be estimated through discrete monitoring. The data from grab sampling represents the base of most models used in the Delta.

Discrete water quality monitoring historically focused on measures of salinity and flow. However, the list of parameters has grown over time, especially with the passage of regulations to protect human health. The number of core sampling stations has varied over the years, as monitoring locations have evolved to reflect a better understanding of how the Delta works. Figure 2 shows locations in the Delta currently monitored by MWQI Program. Monthly samples evaluate organic carbon (total and dissolved), bromide, nutrients, ultraviolet absorbance at 254 nm (UVA_{254}), minerals, turbidity, and metals. Special studies have focused on constituents of special importance, such as selenium, pesticides, and herbicides.

As a precursor to real-time sampling, autosamplers began to be used in 1993 for some studies. Autosamplers could be programmed to collect samples at minute, hourly or daily time-step in order to see variations over a specific time period. Water collected in auto samplers was later brought to the lab for analysis. Later auto-samplers were replaced by auto-analyzers, which could analyze water in near real-time.

MWQI Real Time Monitoring

Real-time monitoring is the use of analytical instruments, placed in remote settings that collect and disseminate the data through California Data Exchange Center (CDEC). It allows the current conditions at selected locations within the Delta to be known as they are occurring. This program element is comprised of a) field operations that ensure proper operation and maintenance of all automated sampling equipment, b) the timely transmission of real-time data, c) the documentation of Standard Operating Procedures, and d) the implementation and documentation of Quality Assurance/Quality Control (QA/QC) of the data.

Real-time data is necessary for the operations and management of the Delta and SWP since informed decisions can only be made with current conditions. The MWQI unit was one of the first groups that took process analyzers out of the laboratory and into the field. MWQI conducted the first real-time monitoring in the Delta and was one of the first groups to publish the real-time data over the internet.

Real-time monitoring accomplishes the following:

- Determines baseline concentrations of organic carbon, anions, nutrients, and other drinking water quality constituents
- When coupled with flow, can be used to determines the load and/or, timing, of carbon, nutrients, and anions (i.e. chloride and bromide) entering the Delta from the Sacramento and San Joaquin rivers
- Identifies and quantifies water quality changes caused by land use changes from urbanization and population growth in the Delta and its watersheds, and by actions proposed or taken by other entities that affect the Delta environment
- Provides water quality data relevant to SWP contractors and other users of Delta water supplies in a timely manner for decision making
- Provides water quality data for forecasts that assist SWP and other utilities in advanced planning efforts to optimize management of their water supplies while meeting increasingly stringent drinking water regulations

The Sievers 800 Total Organic Carbon (TOC) analyzer, purchased in 1996, tested the feasibility of using a portable TOC analyzer in a non-laboratory setting. The Sievers pilot study, conducted from 1999 to 2001 at Hood, established the process analyzer's ability to monitor raw water quality. The study proved that unattended analyzers could provide high quality, real-time data in a cost-effective manner. The real-time TOC monitoring program later evolved to include anion monitoring at four of our five real-time stations. (Table 1).

Through a CALFED grant in 2001, two Shimadzu 4100 TOC/Dissolved Organic Carbon (DOC) analyzers and later the Dionex DX 800 anion analyzers were installed at H. O. Banks (Banks) and San Joaquin River near Vernalis (Vernalis). The Shimadzu 4100 TOC/DOC analyzer and a Metrohm 850 IC anion analyzer were installed at Jones Pumping Plant. A Sievers 5310 and an YSI 6600 were purchased for installation at the newest station at Gianelli Pumping Plant. In 2012, MWQI standardized the stations. Sievers 5310, an oxidation TOC/DOC analyzer, are installed at all of the stations. Dionex ICS 2100, an anion analyzer, are installed at Vernalis, Banks, and Jones Pumping Plant. The Metrohm 850 IC anion analyzer, which was used at Jones Pumping Plant, has been moved to Gianelli Pumping Plant.

Data Dissemination

The data collected through the discrete and real-time monitoring programs are disseminated in a few ways. Dissemination occurs through the CDEC, the Water Data Library (WDL), or the MWQI website, which provides direct links to CDEC and WDL.

MWQI continuous real-time monitoring data is available on CDEC. Originally, CDEC gathered information to support the State-Federal Flood Operations Center. It now provides a centralized location to collect, store, and disseminate real-time water quality and hydrologic data that is gathered by multiple agencies monitoring water parameters within the state.

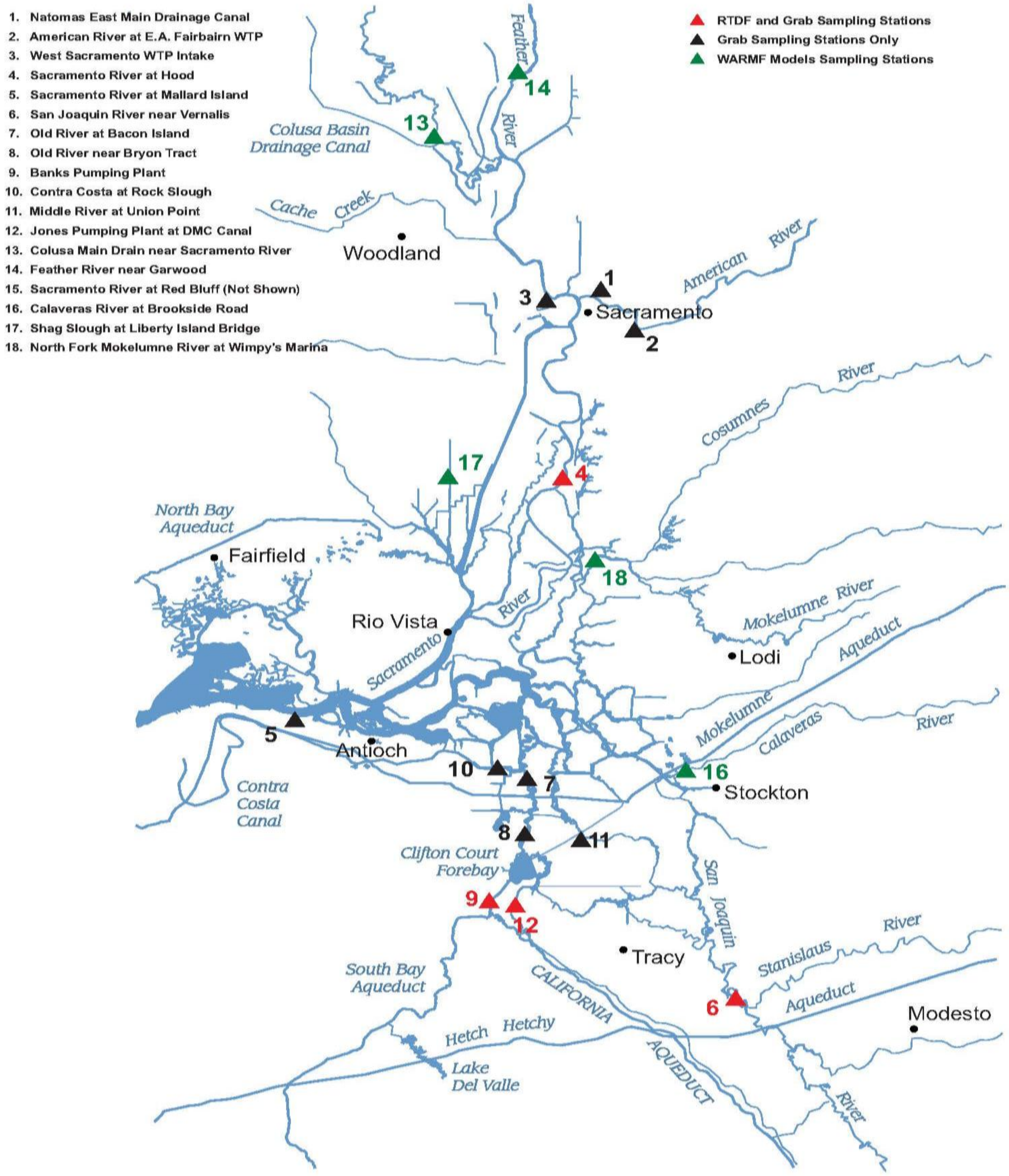
The Water Data Library is a permanent database storing certain DWR water quality data including surface water, continuous (real time), climate related, and historical information. The WDL is available to the public and accessible through the internet. The WDL database includes a Quality Assurance/Quality Control (QA/QC) filter for historical data; a "fill in the blank approach" for a range of dates, types of data, and station names; and an interactive map

Table 1.—Real-time stations Operated by the MWQI Program

Station	Parameters	Equipment	Year
Sacramento River at Hood (HOOD)	TOC TOC, DOC TOC, DOC TOC, DOC	Sievers 800 (oxidation) Shimadzu 4100 (combustion) Sievers 900 (oxidation) Sievers 5310 (oxidation)	1999-2005 2001-2011 2005-2011 2012
San Joaquin River near Vernalis (VERNALIS)	TOC, DOC bromide, chloride, nitrate, sulfate, fluoride* TOC, DOC bromide, chloride, nitrate, sulfate	Shimadzu 4110 (combustion) Dionex DX 800 (anions) Sievers 5310 (oxidation) Dionex ICS 2100 (anions)	2005-2012 2007-2012 2012 2012
H. O. Banks Pumping Plant (BANKS)	TOC, DOC bromide, chloride, nitrate, sulfate, fluoride* TOC, DOC bromide, chloride, nitrate, sulfate	Shimadzu 4100 (combustion) Dionex DX 800 (anions) Sievers 5310 (oxidation) Dionex ICS 2100 (anions)	2001-2012 2007-2012 2012 2012
Jones Pumping Plan (JONES)	TOC, DOC, bromide, chloride, nitrate, sulfate, fluoride* TOC, DOC bromide, chloride, nitrate, sulfate	Shimadzu 4100 (combustion) Metrohm 850 IC (anions) Sievers 5310 (oxidation) Dionex ICS 2100 (anions)	2009-2012 2010-2012 2012 2012
Gianelli Pumping Plant (Gianelli)	TOC, DOC EC, pH, dissolved oxygen, turbidity, temperature (deg C) bromide, chloride, nitrate, sulfate	Sievers 5310 (oxidation) YSI 6600 Metrohm 850 IC (anions)	2012 2012 2012

*Fluoride monitoring was discontinued in 2012

Figure 2 – MWQI Sampling Locations 2011



Chapter 4 — Real Time Data and Forecasting Comprehensive Program

The Real Time Data and Forecasting Comprehensive Program (RTDF-CP) uses real-time monitoring to provide specific water quality data, and then combined with mathematical models, create short-term and long-term forecasting tools. Real-time monitoring is important because current grab sample frequency does not provide a representative picture of the short-term variability that can occur in and around the Delta. This variability includes storm events, agricultural and urban discharges, or any other event that could quickly affect water quality. In addition, it is fiscally unrealistic to obtain the number of samples needed to represent what real-time sampling can accomplish.

The MWQI Program historically monitored sites within the Delta; however, activities of the RTDF-CP now encompass a larger area including the watersheds of the Delta, the SWP, and the Central Valley Project (CVP). The creation of the RTDF-CP required the collaboration of many agencies within DWR including Division of Environmental Services, Operations and Maintenance (O&M), Operations Control Office (OCO), Bay Delta Office (BDO), and outside agencies such as San Luis Delta Mendota Water Authority.

The elements of the program are:

- Real-time monitoring conducted at key locations, providing stakeholders and interested parties with timely data
- Information management and data dissemination, which makes the information from above available to the public and interested parties
- Field operations that ensure proper operation of all automated sampling equipment
- Consistent modeling with continuous updates which provides for the best forecasting possible
- QA/QC of the instruments and data

Real Time Monitoring

Real-time results are used to: a) make informed operational decisions affecting the Delta and SWP; b) support development of water quality forecasting tools for better managing of SWP water supplies; c) provide early warning of changing water quality conditions; and d) provide information for water quality and water supply planning studies.

Data Dissemination

The RTDF-CP provides a single location that compiles and disseminates specific real-time and forecasting data. This data along with a daily summary water quality report can be found on MWQI's Real Time Data and Forecasting web page. The report contains a daily summary table of specific information at the real time stations and a brief synopsis of current events in and around the Delta. Also included in the report is a link to the web page mentioned above. The summary table is updated daily showing mean daily values, seven-day averages and the percent change over the seven days.

Forecasting and Modeling

Depending on stakeholder needs, RTDF-CP modelers in the BDO and the OCO use different models to forecast flows, EC, and DOC in the various waterways in and around the Delta. The modeling results are made available on MWQI's Real Time Data and Daily Summary Water Quality Report. Water quality data used in the models can come from the real time monitoring stations, providing high frequency data, as well as discrete grab sample data. Models used to generate forecasting results include the Sacramento River Watershed Analysis Risk Management Framework (WARMF) model, San Joaquin River WARMF model, Delta Simulation Model 2 (DSM2), and the DSM2 Aqueduct Extension model. The DSM2 model has three modules included in it, Hydro, Qual, and PTM. Depending on what the needs are, one of the three modules is used. For instance, HYDRO provides flow simulations, which could be input for QUAL and PTM. QUAL simulates fate and transport of constituents of interest and PTM simulates transport of neutrally buoyant particles based on the flow field simulated by HYDRO. For more information about these models, see Appendix D.

MWQI has taken an active role in data collection and model development of several of the models used by the Department. MWQI commissioned CH2MHill in 2005 and 2008 to create the DSM2 Aqueduct Extension model, which is currently operational. MWQI has also been working with its partners to refine and update a working set of WARMF models used to create the boundary conditions that feed into the DSM2 model. In the late 1990s, work conducted for MWQI by Marvin Jung and associates was instrumental in providing the organic carbon data used in the Delta Island Consumptive Use (DICU) model. Additionally, the results from Marvin Jung and Associates and MWQI SMARTS studies from 1998 to 2000 were incorporated into DWR's DSM1 & DSM2, the DICU model, and an algorithm for the In-Delta Storage/Wetlands projects. Work on the DICU model was an important achievement for the historical DSM2 simulation of water quality.

A goal of the modeling/forecasting part of the RTDF-CP is to maximize the use of modeling results by water quality managers. By providing forecasting information, water quality conditions in the Delta and aqueduct can be estimated; water contractors can then use this information to adjust drinking water plant operations to maximize efficiency. In addition, by observing seasonal forecasts or executing planning studies, the effects of different water quality scenarios can be generated and, therefore, predicted. This provides scientists and managers information on how water quality may change at their intake facilities under different water years and operational regimes. Four objectives associated with forecasting are as follows:

Historical simulations replicate past operations, hydrological conditions, water quality, and Delta configurations. It requires the collection, processing and filling in of missing flow data, water quality data and operational data. The simulations are used to calibrate and validate the models by comparing actual results to the results simulated by the models.

Short-term forecasts use recent field and available real-time data to project Delta and Aqueduct conditions into the near future (generally two-week time steps). This data is used to create near-term changes in boundary conditions that are then used as input for short-term simulations of water quality conditions in the Delta and Aqueduct. When high resolution, accurate data is available, the precision of the forecast increases.

Seasonal forecasts are much like short-term forecasts except for their duration. Seasonal forecasts typically extend out a few months, but can extend out to one year. Like short-term forecasts, boundary conditions first are established and then future SWP operation scenarios are projected.

Planning studies require all the same inputs as seasonal forecast to set initial calibrations, however other factors can be adjusted. The studies are used to evaluate hypothetical changes by adjusting hydrological regimes, water quality standards, system operations, and Delta configurations.

In addition, effects from dredging of channels, modified reservoir releases, and sea level rise can be explored. The planning studies can also be used to simulate water quality effects from emergency events.

Chapter 5 — Emergency Response

Emergency Response Elements

The Emergency Response (ER) is presented separately, although it is a component of the Real Time Data and Forecasting Comprehensive Program (RTDF-CP). The ER element was assembled in response to the Jones Tract flood of 2004, and addresses some of the Sanitary Survey's recommendations. It focuses on monitoring for drinking water quality constituents of concern during an emergency. California Department of Public Health (CDPH) and the State Water Project contractors (SWPC) wanted to determine if the response plan in place was capable of handling future emergencies and most importantly, that drinking water quality constituent monitoring is a part of the early emergency response.

The goals of this program element are to:

- Develop and encourage policies to define the role of drinking water quality in DWR ER actions
- Incorporate drinking water quality components, (including monitoring and involving the MWQI Program), into DWR's established ER plans
- Improve dissemination of drinking water quality information between DWR and other stakeholders (i.e. SWPC, CDPH, State, and Regional Water Board's Office of Spill Prevention Response, etc.) during emergency events

During the 2004 Jones Tract flood, the MWQI Program staff quickly set-up a monitoring program. Staff from the MWQI Field Support Section developed and implemented an emergency water quality monitoring program focused primarily on organic carbon loading from Jones Tract into the south Delta and organic carbon loading at the H. O. Banks Pumping Plant.

Individual elements of the emergency response monitoring program included:

- Identifying specific concerns regarding the event and what constituents to assess
- Developing emergency response plans to identify funding and staffing needs, as well as all participating groups and their roles
- Worked with other DWR units (i.e. Division of Flood Management) to develop emergency response plans that include water quality considerations
- Performed water quality assessments and evaluations in response to emergency situations, and supply timely water quality information to emergency decision makers and public health authorities
- During emergency circumstances, worked cooperatively with emergency managers and rapidly communicate results of emergency water quality assessments
- Coordinated the MWQI Program efforts with outside agencies that have responsibilities to monitor water quality during an emergency

After the Jones Tract flood and at the recommendation of the Sanitary Survey, the MWQI Program allocated staff time to incorporate drinking water quality monitoring into the Department's emergency response actions. Unfortunately, at the time of the Jones Tract levee break the MWQI Program was not fully integrated into DWR's procedures for responding to an emergency water quality event. Nonetheless, the MWQI Section's Emergency Response element researched how the department approaches drinking water quality monitoring during an emergency by undertaking a thorough review of existing DWR emergency response policies, plans, and processes. The review looked at three important components of drinking water quality in the department's official emergency plan: a) the importance of other drinking water constituents besides salinity, b) the department's importance in monitoring drinking water quality constituents during an emergency and c) how the department disseminates data to stakeholders affected by the emergency.

Based on interviews and research of DWR's emergency policies, a draft emergency response document was produced that summarized DWR's emergency response policies, plans, and processes. Recommendations from the report included developing and encouraging policies to clarify the role of the staff from the MWQP Branch in an emergency response situation, clearly defining the role of drinking water quality in an emergency situation, and incorporating drinking water sampling components into emergency response plans and processes. Most importantly, it was determined the dissemination of drinking water quality information between DWR and all other stakeholders must be rapid and effective, with established lines of communication in place during an emergency. The draft emergency response document is currently on-hold until further development of the DWR world-class Workplace Safety System.

During the Workplace Safety System development process, other actions began. A MWQI Program safety plan for routine and emergency response monitoring was developed. Emergency contacts and staff available for fieldwork were identified. The costs associated with staff time, material resources, and laboratory analysis costs related to monitoring, were put into a framework for various emergency scenarios. In addition, an emergency response action plan was developed to guide the program. The action plan includes a list for emergency response equipment and constituents to monitor. In conjunction with the emergency response action plan, fully equipped response field kits were created to be used for water quality sampling in case of an emergency. These kits have been assembled and training was provided to each MWQI Program staff member in the spring of 2010.

Ongoing Efforts

Per the Resources Agency Secretary, DWR was beginning to develop a DWR Safety Office, which included hiring a chief safety officer that would be responsible for leading DWR's implementation of a world-class Workplace Safety System. The Workplace Safety System would provide flexible uniformity for implementation DWR-wide. It involves every staff member contributing to a safer workplace through a total quality management approach; commitment to the safety and health of its employees, partners and visitors; and values workplace safety through leadership, recognition, and education.

Until the DWR Workplace Safety System evolves to the level that includes emergency response planning, the MWQI Program staff is prepared in the event of another emergency to assist and support water quality monitoring, disseminate information to all stakeholders, and work cooperatively with all emergency managers. Program staff efforts will include attending emergency response meetings, restocking of drinking water quality ER kits, providing emergency assistance for drinking water quality monitoring as requested by emergency responders, and assisting the department's emergency response efforts as needed in the development of a DWR drinking water quality emergency response plan.

Chapter 6 — Program Management

Program Sections

Nestled within DWR's Division of Environmental Services resides the Office of Water Quality. The Municipal Water Quality Program Branch is one of three branches within the Office of Water Quality. The Municipal Water Quality Program Branch includes four sections: MWQI, Water Quality Special Studies Section, Field Support Section, and the Quality Assurance/Quality Control Section. The Municipal Water Quality Investigations Program includes all of the sections of the branch, except for the Quality Assurance/Quality Control Section. In addition, the MWQI Program includes two positions in the Water Quality Section and the Operations and Control Office, both within the Division of Operations and Maintenance, and one position in the Bay-Delta Modeling Section of the Bay-Delta Office.

Funding

As the Interagency Delta Health Aspects Monitoring Program (IDHAMP), from 1983-1990, the program was project funded by municipal, industrial, and agricultural State Water Project Contractors. In 1990, the MWQI Program, in the Division of Planning and Local Assistance, was funded through an agreement between DWR and the Urban State Water Contractors. In 2002, the MWQI Program moved organizationally to the Division of Environmental Services (DES) and the Municipal Water Quality Program Branch was created and funded by Urban State Water Contractors in conjunction with the State Water Project funding. Additional program sponsorship is provided by the Contra Costa Water District, and has been occasionally supplemented by either grants or bond money (fiscal year of 2004-2005 was the most intensive period of grant funding).

Funding for the MWQI and Field Support sections, from 1994-2007, consistently operated within an annual budget of $1.8 million. However, with the increases in basic expenditures, hiring of new staff, and expansion of the Real-Time Data and Forecasting – Comprehensive Program (RTDF-CP), these sections have been operating within an annual budget of $3.1 million since 2008. Per the funding agreement, the State Water Project Contractors Authority (SWPCA), through the Specific Projects Committee (SPC), controls $200,000. A portion of this money is used to contract for student assistants, consultants, and other needs of the program (for example, equipment purchases). Additionally, the SPC formal agreement sets up committees for specific purposes on particular projects. The process protects joint powers authority members from financial liability for specific projects.

Besides the formal funding agreement between the department and the State Water Project Contractors, the MWQI Program enters into resources agreements for work planned between DWR divisions. These agreements provide access to skills located outside of the MWQI Program to complete specialized work charged to the MWQI Program.

Committees

The direction of the MWQI Program is overseen by DES management with the input from a variety of committees, with the assistance of subcommittees. The committees help provide coordination and communication among the MWQI Program staff, water agencies, and regulatory agencies. The following committees currently assist the MWQI Program Staff and Field Support sections:

MWQI Technical Advisory Committee (MWQI TAC) is composed of technical representatives from SWC, DWR, SWPCA, Contra Costa Water District (an invited participant associated with the TAC) and other invited members of outside agencies.

Real-Time Data and Forecasting (RTDF) Steering Committee is a group of technical experts that assist with evaluating the need, and plan for other installations as may be required to fulfill the objectives of the real-time monitoring program.

Special Studies Subcommittee recommends special studies for inclusion in the workplan.

New Technologies Work Group/Subcommittee is a group with expertise in monitoring technology and techniques. The subcommittee's purpose is to advise the MWQI TAC and MWQI Program on new technologies that are efficient, cost effective, and compatible with the overall desire to expand real-time monitoring in the Delta and SWP.

MWQI-Special Projects Committee was formed to assist in the management of SWPCA funds to acquire student assistants, hire consultants, and to purchase certain goods and services deemed necessary and desirable for station operation by both the MWQI Program and the Specific Projects Committee.

Achievements

In 2007-2008, the MWQI Program received funding for new positions within Municipal Water Quality Investigations, in the department's Bay Delta Modeling, Operations Control Office, and in Operations and Maintenance, Water Quality Section.

Following the creation of the Aqueduct Model for MWQI by CH2MHill in 2008, MWQI and its partners have successfully established historical simulations for both the Delta and the Aqueduct and are now working on short-term forecasting of drinking water constituents for the Delta and the Aqueduct.

Four real-time stations monitor incoming boundary water quality conditions and water quality at two major diversion points (the Banks Pumping Plant on the SWP, and the Jones Pumping Plant on the federal Delta-Mendota Canal), with a fifth station installed in 2012 at the Gianelli Pumping/Generating Plant at the San Luis Reservoir. A number of stations provide anion as well as organic carbon data in near real-time. Data from these stations is sent to CDEC and a daily update of water quality conditions, as well as forecasting, is provided on the MWQI website.

Special studies have documented the impact of major urban/agricultural drainage into the Sacramento River and have shown that nitrosamine formation potential compounds (an emerging suite of disinfection byproducts) are present in the Sacramento and San Joaquin rivers downstream of two wastewater treatment plants.

In conclusion, the MWQI Program has evolved over the years, from an initial focus of determining sources and quantities of trihalomethane and haloacetic acid, and the organic carbon and bromide precursors responsible for their creation, to using modern water quality sensing equipment with telecommunication equipment to provide near real-time data. This data, along with data from grab samples analyzed for drinking water quality constituents of concern is used to provide information and forecasting on the most recent water quality information possible.

Chapter 7 — Discrete Monitoring and Supporting Reports

The purpose of this chapter is to provide a summary of the discrete monitoring and supporting reports of Interagency Delta Health Aspects Monitoring Program, Municipal Water Quality Investigations, and supporting reports of direct importance to the program. The reports summarized in this chapter are as follows:

Public Health Aspects of Sacramento-San Joaquin Delta Water Supplies: A Panel Report for the California Department of Water Resources

Interagency Delta Health Aspects Monitoring Program Project Report 1983-1984

Interagency Delta Health Aspects Monitoring Program Project Report 1985-1986

Interagency Delta Health Aspects Monitoring Program Monitoring Results 1986-1987

Project Report of the Interagency Delta Health Aspects Monitoring Program (Municipal Water Quality Investigations Program) Summary of Monitoring Results January 1988-December 1989

Delta as a Source of Drinking Water Monitoring Results 1983-1987

Delta Island Drainage Investigation Report of the Interagency Delta Health Aspects Monitoring Program Water Year 1987-1988

The MWQI Program additionally published annual and biennial reports detailing the results from discrete monitoring. Links to these reports are available on the MWQI website at http://www.water.ca.gov/waterquality/drinkingwater/mwqi_reports.cfm.

Public Health Aspects of Sacramento-San Joaquin Delta Water Supplies, A Panel Report for the California Department of Water Resources

Duration of Study

August 1982–December 1982

Investigators

Paul De Falco, Jr., Dr. John Doull, Dr. Alvin Greenberg, Dr. Perry McCarty (Panel Chairman), Dr. William (BJ) Miller, Dr. Donald O'Connor, and Emanuel Pearl

Background and Objectives

In August 1982, the Department of Water Resources (DWR) Director appointed a scientific panel to assess the health aspects of Sacramento-San Joaquin Delta (Delta) water for domestic use. The panel was asked to determine any health hazards that may result from use of surface water taken from the Sacramento River between Sacramento and the Delta or from the Delta itself, particularly at Clifton Court Forebay. The panel was also asked to provide information on additional treatment processes, other than standard procedures, to reduce potential health hazards and to identify the cost of these treatment processes.

Study Design

The panel met on a number of occasions and requested water quality data and information on particular concerns from water agencies treating Delta water. Other local, state, and federal agencies were contacted for additional water quality information. The locations investigated were Sacramento River near Sacramento, Rock Slough at the Contra Costa Canal, and Clifton Court Forebay. The constituents identified by the water agencies were sodium, asbestos, and a group of organic compounds collectively termed trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and tribromomethane). The panel decided to address all chemical, physical, and biological contaminants that are public health hazards. The time and resources for this study were insufficient for the panel to address aesthetic factors.

Results/Conclusions

The scientific panel concluded:

- Treatment plants being supplied water from the Delta were meeting all current drinking water requirements with few exceptions.
- Additional knowledge is required for a complete understanding of the public health impacts of drinking water. This includes:
  - Public health effects from asbestos, sodium and trihalomethanes in drinking water
  - Accuracy and precision in measuring asbestos and trihalomethanes
  - Effectiveness and reliability of drinking water treatment process for removal of constituents of concern
- Asbestos periodically occurred in relatively high concentrations in all raw waters. The source was drainage from minerals naturally present in the watershed. Conventional treatment may

significantly reduce asbestos concentrations, but it is not known in conventional treatment will be continue to be adequate. The risks posed by the uncertainty in removal could not be evaluated at that time because of lack of definitive data.

- THM could generally be maintained within the EPA drinking water requirements through appropriate operation of conventional water treatment processes. The potential for THM formation was greater in Clifton Court Forebay and Rock Slough than from the Sacramento River due to higher organic carbon sources in the Delta.
- Concentrations of sodium at Rock Slough and Clifton Court Forebay were high enough to cause concern for the health of individuals who must limit their intake of sodium to control hypertension. These concentrations are particularly high during drought and are of most concern when treated with a typical home water softener.
- The Department of Water Resources monitoring program was developed primarily to monitor water quality from an ecological perspective, and not to assess human health aspects with respect to drinking water. The program provided information for the report, but was not entirely adequate to assess the present or projected suitability of these waters as a source of drinking water supply.

The panel made the following recommendations in its report:

- Public health considerations should be given a higher priority in decision making with respect to the Delta and drinking water quality.
- The public health issue should be more fully considered in future planning by water purveyors and state authorities.
- Data collection and analysis programs and other studies to resolve public health concerns should be actively pursued. A more comprehensive analytical framework needs to be structured for analyzing alternatives to ameliorate future quality problems.
- Trihalomethanes are suspected carcinogens; and they may impose some health risk at any concentration. Therefore, water purveyors should attempt to reduce levels below the maximum levels specified by EPA interim primary drinking water regulations whenever it is feasible and not impose other health risks.
- People whose dietary intake of sodium is limited should be informed by the water purveyors of the amount of sodium in water they drink if the source is Rock Slough or Clifton Court Forebay.
- To determine the degree to which conventional treatment processes are effective in removing asbestos fibers, water purveyors should periodically monitor for asbestos fibers in both raw and treated waters.
- Domestic water purveyor should prepare to address following topics:

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

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

Interagency Delta Health Aspects Monitoring Program Project Report 1983-1984

Duration of Study

July 1983-December 1984

Investigators

Richard Woodard, William McCune, Thomas Morgester, Bert Bird, Michael Finch, Marvin Jung

Background and Objectives

In August 1982, the Department of Water Resources (DWR) appointed a scientific panel to assess the health aspects of Sacramento-San Joaquin Delta (Delta) water used for domestic purposes. The panel was to determine whether any health hazards might result from use of surface water taken from the Sacramento River or from the Delta itself. Furthermore, the panel was asked about additional treatments, other than standard procedures, that might be used to reduce health hazards and the costs associated with them. The findings of the panel were: 1) Considerations of public health, as affected by the quality of drinking water, should be given a much higher priority in decisions about the Delta, and 2) Data collection and analysis programs and other studies to resolve public health concerns should be actively pursued.

To correct the deficiencies in data, a monitoring program specific to addressing the present and projected suitability of Delta waters as a drinking water supply was recommended. The program was to identify the sources of contaminants to the Delta, investigate how the contaminants from each source are transported through the system, and how that affects the concentration at points of withdrawal. Information on factors affecting the movement and fate of the contaminants in the Delta was needed to quantify water quality impacts at possible points of withdrawal.

The results from the first report of the Interagency Delta Health Aspects Monitoring Program (IDHAMP), covering the years of 1983-1984, are presented below.

Study Design

The initial monitoring efforts were directed at obtaining water quality data on sodium, asbestos, and organic chemicals that could affect drinking water quality. The first stations sampled were:

- American River at Water Treatment Plant
- Cosumnes River at Dillard Road
- Sacramento River at Greene’s Landing
- North Bay Interim Pumping Plant Intake
- Mokelumne River at Lower Sacramento Road
- Honker Cut at Eight-Mile Road
- Rock Slough at Old River
- Clifton Court at Intake
- Delta-Mendota Intake Channel at Lindeman Road
- H. O. Banks Delta Pumping Plant Headworks
- San Joaquin River near Vernalis
- Lake Del Valle Stream Release
- Mallard Slough at Pumping Plant
- Cache Slough at Vallejo Pumping Plant
- Lindsey Slough at Hastings Cut

Results/Conclusions

- Water taken from the Sacramento-San Joaquin Delta easily met primary drinking water criteria established to protect the health of consumers.
- Sodium concentrations were generally below levels expected to cause health problems for anyone except people on severe sodium-restricted diets.
- Asbestos concentrations in waters of the Delta and its tributary streams are highly variable.
- The limited number of selenium samples showed concentrations barely above the detection limit. No data were developed to suggest that selenium constitutes a health threat.
- Trihalomethane formation potentials of southern Delta water supplies are higher than in waters tributary to the northern Delta due to bromides from seawater.
- Only a few of the 129 priority pollutants were detected in the samples and the concentrations were below established drinking water limits and not expected to pose a significant risk to consumers.
- Levels of selenium and pesticides found in the San Joaquin River were very low.

Interagency Delta Health Aspects Monitoring Program Project Report 1985-1986

Duration of Study

January 1985-June 1986

Investigators:

Marvin Jung, Richard Woodward, William McCune, Michael Sutliff, Michael Finch, Elizabeth Kingery

Background and Objectives

The summary of findings from the Interagency Delta Health Aspects Monitoring Program (IDHAMP) monitoring during the years of 1985 and 1986 was presented. During 1985, the program was expanded from the monitoring of raw water supplies to the collection of data on specific factors that can affect the water quality and quantity of exported water supplies.

Study Design

From 1985 through 1986, tidal excursions and river flows, agriculture related activities, wastewater discharges, raw water quality and treatment, and modeling water quality in the Sacramento-San Joaquin Delta (Delta) were examined. These specific factors were further divided into tasks.

Tidal excursions and river flows were examined by conducting water quality monitoring at key Delta locations for sodium, trihalomethane formation potential (THMFP), minerals, and other parameters. The study also looked at how water sources can be characterized by comparing the constituents at Delta stations. Tidal effects were examined using the direction and mixing of water along Old and Middle Rivers and channel stations.

To study the effects from agriculture related activities, irrigation water discharges were mapped. Empire Tract, Grand Island, and Tyler Island drainages were monitored for salts, pesticides, THMFP, and other constituents. The San Joaquin River near Vernalis was monitored for total and dissolved trace inorganics, pesticides, and other constituents to study the effects of San Joaquin River water quality on exported water. Pesticides were modeled using United States Environmental Protection Agency (EPA) models to determine their fate and movement. Additionally, a health effects database was started for selected chemicals and selected pesticide monitoring.

The other areas of study were wastewater discharges, raw water quality and treatment, and the use of models for water quality. The Central Valley Regional Water Quality Control Board provided effluent monitoring data in order to estimate total waste loads and to determine if special studies are needed. Raw water quality and treatment was examined by assessing THMFP. The EPA models examined were EXAMS (exposure analysis modeling system), QUAL2E (a stream quality routing model), and WASP3P (a chemical transport and fate model).

Results/Conclusions

- Selenium concentrations in the Delta were meeting the 10 µg/L drinking water standard.
- Pesticide monitoring became site and time specific for chemicals in high use or high potential of being carried by water. Pesticide concentrations were far below California Department of Public Health action levels or drinking water criteria.
- Preliminary data indicated that agricultural drain water and irrigation return water could be a significant source of trihalomethane precursor material and may have the most significant effect on the total THMFP of Delta water supplies.
- Asbestos analyses of surface waters needed to be improved to obtain reproducible results. Until then, asbestos data could not be interpreted.
- Sodium levels in Delta channels met the National Academy of Sciences recommended limit of 270 mg/L for people on moderate sodium-restricted diets.
- Using electrical conductivity and chloride to sodium ion ratios, water sources were identified. Sacramento River flow during the summer had a significant effect on water quality at H. O. Banks Pumping Plant, but the San Joaquin River had no detectable effects on water quality.
- Discharge from Sacramento Regional Wastewater Treatment Plant did not affect water quality at Hood and Greene’s Landing, likely due to dilution and treatment.
- EPA computer models would continue to be examined to study the fate and transport of constituents in surface waters and discharges in order to potentially predict the effects of pollutants on Delta water quality.

Interagency Delta Health Aspects Monitoring Program Monitoring Results 1986-1987

Duration of Study:

July 1986–December 1987

Investigators

Marvin Jung, B. J. Archer, Michael Sutliff, William McCune, Robert Atherstone, Walt Lambert, Lori Weisser, Barbara Heinsch, Hallie Whitfield, Keith Healy, David Kemena, Eric Nichol

Background and Objectives

The summary of findings from the Interagency Delta Health Aspects Monitoring Program (IDHAMP) monitoring during the years of 1986 and 1987 was presented.

Study Design

Trihalomethane Formation Potential (THMFP), total bromomethane formation potential, selenium, sodium, and pesticides were sampled for at the following stations:

American River at Water Treatment Plant
Sacramento River at Greene's Landing
Lindsey Slough at Hastings Cut
Little Connection Slough at Empire Tract
Rock Slough at Old River
Middle River at Borden Highway
San Joaquin River near Vernalis
Sacramento River at Mallard Island
Clifton Court Forebay Intake
Delta-Mendota Canal Intake
H. O. Banks Pumping Plant Headworks
North Bay Interim Pumping Plant Intake
Barker Slough at Pumping Plant
Agricultural Drain at Grand Island
Agricultural Drain at Empire Tract
Agricultural Drain at Tyler Island
Agricultural Drain at Natomas Main Drain

Results/Conclusions

Total THMFP was more than 1,000 µg/L in the three agricultural island drains. It was lowest in the north Delta and the northern tributaries with values less than 300 µg/L. The export stations had median values ranging from 400-600 µg/L.

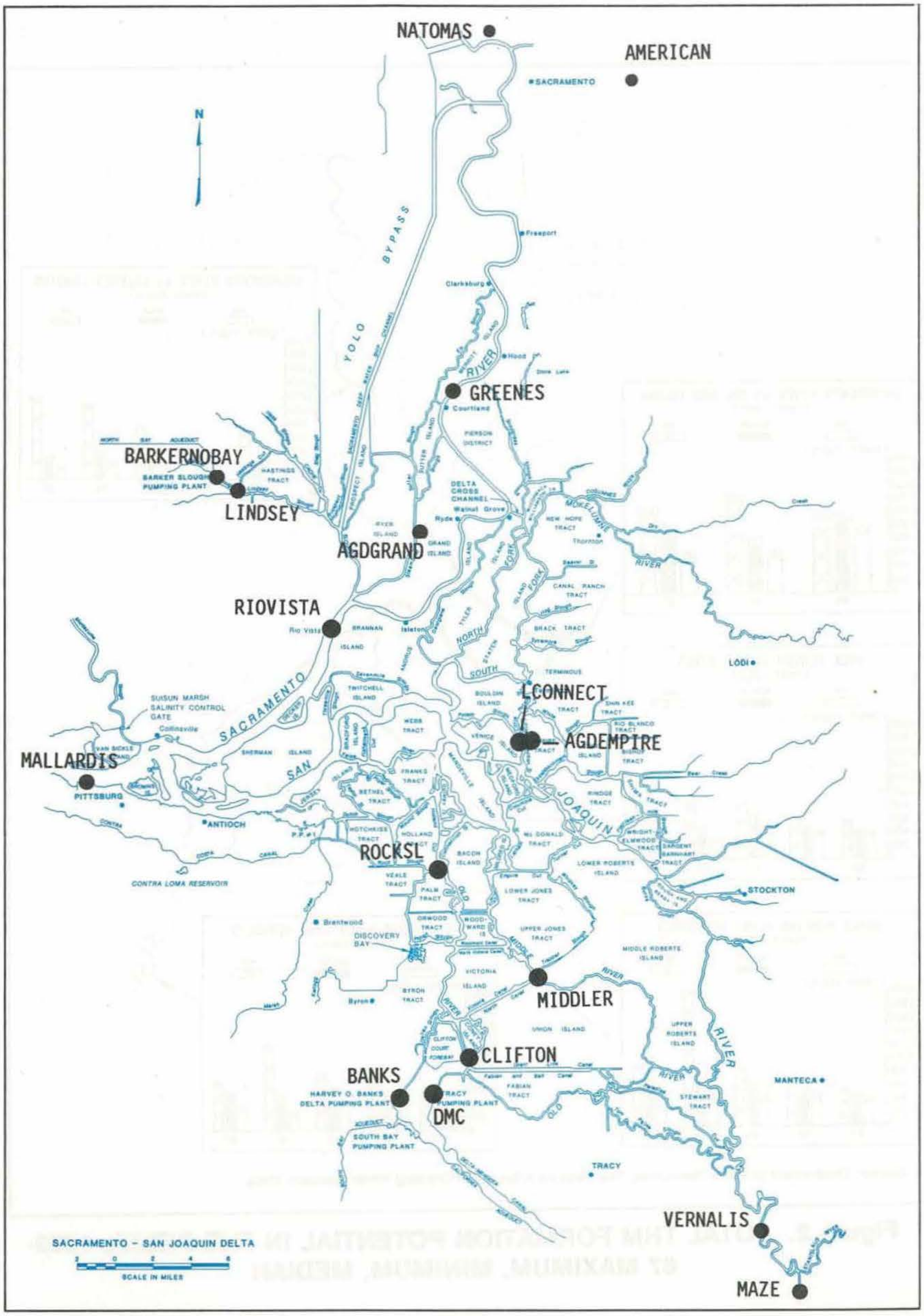
Total bromomethane formation potential was more than 90% at Mallard Island on the Sacramento River due to seawater intrusion. The southern Delta ranged between 30% and 40%, while the agricultural drains contained between 10% and 20%. The northern Delta contained less than 10% brominated trihalomethane (THM) species.

Selenium concentrations in water did not exceed the current drinking water Maximum Contaminant Level (MCL) of 10 µg/L. Only four samples had high values of 3 µg/L. Most of the samples had undetectable levels at >1 µg/L.

Median sodium values ranged from 2-73 mg/L except for samples collected from the Sacramento River at Mallard Island, which were more than 1,000 mg/L.

Pesticide concentrations were far below health concern levels; pesticides slightly more than detection levels were 2,4-D, atrazine, bentazon, bolero, dacthal, glyphosate, ordram, and simazine.

Figure 3 – Sampling Locations of Interagency Delta Health Aspects Monitoring Program 1987-1988



Project Report of the Interagency Delta Health Aspects Monitoring Program (Municipal Water Quality Investigations Program) Summary of Monitoring Results January 1988–December 1989

Duration of Study

January 1988–December 1989

Investigators

Marvin Jung & Associates, Municipal Water Quality Investigations Program

Background and Objectives

The summary of findings from the Interagency Delta Health Aspects Monitoring Program (IDHAMP) monitoring during the years of 1988 and 1989 was presented.

Study Design

Samples were taken from the following locations to test for THMFP, total bromomethane formation potential, selenium, sodium, and pesticides.

Sacramento River at Greene's Landing
Lindsey Slough at Hastings Cut
Little Connection Slough at Empire Tract
Rock Slough at Old River
Clifton Court Forebay Intake
Delta-Mendota Canal Intake at Lindemann Road
H. O. Banks Pumping Plant Headworks
Middle River at Borden Highway
San Joaquin River near Vernalis
Sacramento River at Mallard Island
San Joaquin River at Maze Rd. Bridge
North Bay Interim Pumping Plant Intake
Barker Slough at Pumping Plant
Barker Slough at North Bay Pumping Plant
Agricultural Drain at Natomas Main Drain
Sacramento River at Rio Vista Bridge
Agricultural Drain at Empire Tract
Agricultural Drain at Grand Island

Results/Conclusions

The data collected indicated the Sacramento River was the primary source of freshwater into the Sacramento-San Joaquin Delta (Delta), and that the San Joaquin River flows had been mostly diverted to Delta-Mendota Canal.

Total trihalomethane formation potential (TTHMFP) increased in the southwestern part of the Delta near the state and federal water project intakes and at the Contra Costa Water District intake due to the low and reverse flows in the western Delta. Brominated trihalomethane formation potential (TBFP) was also elevated at these stations. The major sources of brominated THM precursors were from seawater intrusion, and agricultural drain discharges into the Delta and the San Joaquin River. Saltwater intrusion caused sodium concentrations at the intakes of the export pumps to occasionally exceed the 100 mg/L recommended limit.

The Sacramento River at Mallard Island station had the greatest impact of bromides on TTHMFP and TBFP out of all the stations monitored. The average and median TBFP was more than 90% of the TTHMFP while the American River TBFP's, the least impacted station, had an average and median of about 5% of the TTHMFP. TBFP at the H. O. Banks Headworks was about 37% (average and median) of the TTHMFP and Rock Slough at Old River averaged around 44%.

On March 10, 1989, a one-time sampling of storm water runoff along Morrison Creek in Sacramento indicated urban storm runoff could potentially reach the same TTHMFP levels as seen in some agricultural drains

In July 1988, water from 30 Delta island drains was sampled for pesticide residues. Six pesticides were found above the analytical limit of detection in one or more of the drain water samples.

The measurements of the minor elements of barium, chromium, lithium, nickel, and copper in Delta water samples did not show useful tracers of water sources and mixing. Consequently, these elements were no longer monitored.

The Delta as a Source of Drinking Water Monitoring Results 1983-1987

Duration of Study

1983-1987

Investigators

Bruce Agee, Judy Heath, Marvin Jung, B. J. Archer, Michael Sutliff, William McCune, Robert Atherstone, Walt Lambert, Lori Weisser, Barbara Heinsch, Hallie Whitfield, Keith Healy, David Kemena, Eric Nichol

Background and Objectives

The purpose of the Interagency Delta Health Aspects Monitoring Program (IDHAMP), which began in 1983, was to obtain water quality information that would help in making decisions about the quality of water resources and assessing potential water treatment methods. The report provided an overview of major factors affecting Bay-Delta water quality and identifying water quality considerations for the future.

Study Design

The monitoring focused on constituents that may affect public health: THMFP, sodium, chloride, pesticides, asbestos, trace elements such as selenium, and synthetic organic pollutants. Water quality parameters, such as pH, electrical conductivity, dissolved oxygen, total organic carbon, nutrients, temperature, color, flow, and turbidity, were also measured.

Monthly sampling was conducted for total trihalomethane formation potential (TTHMFP), chloride, calcium, boron, sodium, magnesium, potassium, sulfates, nitrates, selenium, turbidity, color, electrical conductivity, pH, hardness, alkalinity, total dissolved solids, temperature, and dissolved oxygen. Pesticide sampling periods were selected to coincide with summer pesticide application, winter surface water runoff, and spring reemergent herbicide application. The sampling locations were:

American River at Water Treatment Plant
Sacramento River at Greene's Landing
Cache Slough at Vallejo Pumping Plant
Lindsey Slough at Hasting Cut
Agricultural Drain on Grand Island
Agricultural Drain Tyler Island
Little Connection Slough at Empire Tract
Agricultural Drain on Empire Tract
Rock Slough at Old River
Clifton Court Intake
Delta-Mendota Intake at Lindeman Road
H. O. Banks Delta Pumping Plant headworks
Middle River at Borden Highway
San Joaquin River near Vernalis
Lake Del Valle Stream Release
Mallard Slough at Contra Costa Water District Pumping Plant
Sacramento River at Mallard Island
North Bay Interim Pumping Plant Intake
Barker Slough at Pumping Plant
Natomas Main Drain (Agricultural)

1

Results/Conclusions

The Sacramento-San Joaquin Delta (Delta) was an acceptable source of drinking water, which, when treated, met drinking water standards.

The factors that influence Delta water quality were regulatory controls, inflow, tides, precipitation, diversions, and municipal, industrial, and agricultural activities in the Delta and in drainage areas tributary to the Delta.

TTHMFP has been one area of concern within the Delta. At the fresh water stations of Sacramento River at Greene's Landing TTHMFP was small (6%), while Mallard Island had a large TTHMFP, due in part to the bromides found in sea water. Waters taken from the Sacramento River before reaching the Delta met current THM standards, while water supplied from the Delta would require additional treatment to meet trihalomethane (THM) standards.

Sodium concentrations were less than the 20 mg/L National Academy of Science advisory level for people on severe sodium-restricted diets at American River Water Treatment Plant, Sacramento River at Greene's Landing, and North Bay Pumping Plant. Sodium concentrations were less than the 100 mg/L advisory level for people with moderate sodium-restricted diets at Rock Slough, Clifton Court, H. O. Banks Pumping Plant, and the Delta-Mendota Canal. Sacramento River at Mallard Island exceeded 100 mg/L 90% of the time.

Pesticides were found in a few samples at, or just above detection levels, indicating they have no significant impact on water quality in the Delta.

Asbestos levels were typically between 12 million and 7,500 million fibers per liter of water. Since Delta water is treated before it is distributed as drinking water, it rarely exceeded the proposed federal standard of 7.1 million asbestos fibers per liter.

During the 5-year study, selenium values never exceeded the state or federal drinking water standard of 10 µg/L at any sampling location.

Ion ratios, along with electrical conductivity, salinity, and ion concentration measurements, might be used to help identify the sources and mixing of water types. Sodium to chloride molar ion ratios, in general, decrease as fresh water (Sacramento River at Greene's Landing) mixes with seawater (Sacramento River at Mallard Island), which contains an abundance of sodium and chloride ions.

The drinking water quality of Delta water supplies could change in the future as a result of natural disasters that could cause major flooding. New construction, such as the Delta wetlands project, could also affect water quality.

Figure 4 – The Delta as a Source of Drinking Water Sampling Locations 1983-1987

Station Location Number	Station Name Station Number
1	American River at Water Treatment Plant A0714010
2	Sacramento River at Greene's Landing B9D82071327
3	Cache Slough at Vallejo Pumping Plant B9D81781448
4	Lindsey Slough at Hastings Cut B9D81581462
5	Agricultural Drain on Grand Island B9V81321357
6	Agricultural Drain on Tyler Island B9V80791347
7	Little Connection Slough at Empire Tract B9D80361300
8	Agricultural Drain on Empire Tract B9V80361299
9	Rock Slough at Old River B9D75841348
10	Clifton Court Intake KA000000
11	Delta-Mendota Intake at Lindeman Road B9C74901336
12	H.O.Banks Delta Pumping Plant at Headworks KA000331
13	Middle River at Borden Highway B9D75351293
14	San Joaquin River near Vernalis B0702000
15	Lake Del Valle Stream Release DV004000
16	Mallard Slough at Contra Costa Water District Pumping Plant B8X80221556
17	Sacramento River at Mallard Island E0B80261551
18	North Bay Interim Pumping Plant Intake KG000000
19	Barker Slough at Pumping Plant B9D81651476
20	Natomas Main Drain (Agricultural) A0V83681312

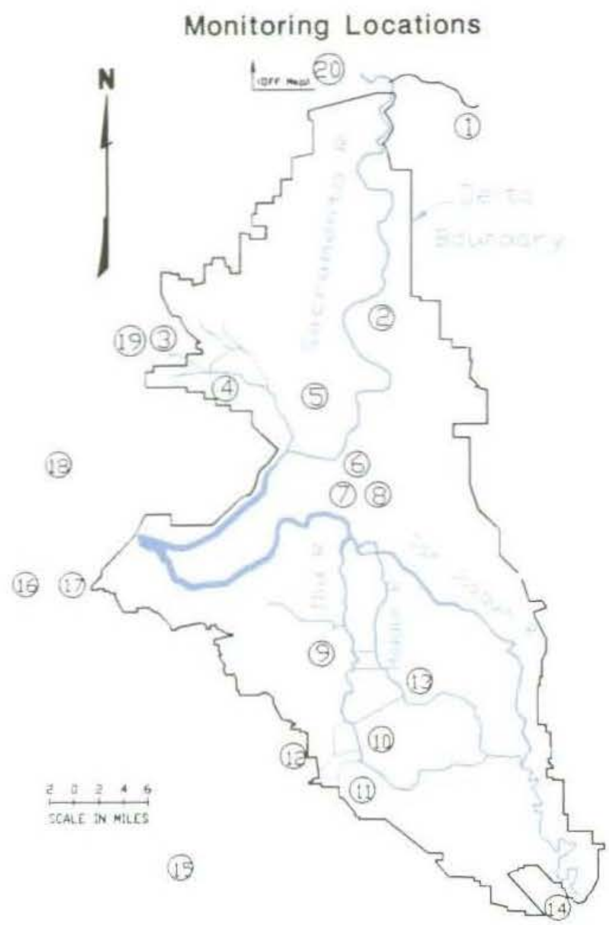


Figure 3
STATION LOCATIONS
Interagency Delta Health Aspects Monitoring Program

Delta Island Drainage Investigation Report of the Interagency Delta Health Aspects Monitoring Program Water Years 1987 and 1988

Duration of Study

1987-1988

Investigators

Marvin Jung and B. J. Archer

Background and Objectives

Water utilities are required to meet drinking water standards and trihalomethanes (THM) regulations. In order to do that, THMFP sources need examination. The Interagency Delta Health Aspects Monitoring Program (IDHAMP) study showed that agricultural drains have elevated THM precursors. The three questions this study sought to answer were:

- What is the quality and quantity of Sacramento-San Joaquin Delta (Delta) island drain water?
- What processes affect the quality and quantity of island drainages?
- What water quality impacts in the channels and at drinking water supply intakes are due to Delta island drainages?

Study Design

Quarterly sampling at 54 drains began in January 1987. By August, sampling increased to six times per year. Additional sampling was conducted during the summer peak months of June and July and the winter peak months of November to January. Water samples were tested for selenium, minerals, turbidity, dissolved organic carbon (DOC), color, TTHMFP, and pesticides. Some channel water samples were also tested for chlorophyll.

Results/Conclusions

The preliminary findings showed that bromide and the types of organic matter present affected the total THM formation potential and the distribution of the THMs formed. There were distinct differences between the characteristics of dissolved organic matter (DOM) humic and nonhumic substances in the drain and riverine Delta water samples. Besides DOC, bromide also contributes to high TTHMFP. Characteristic differences of drain and non-drain organic matter allowed for the potential study of movement by tracking the molecular weight distribution of organic material in water. Drainage DOC compounds were predominantly from Delta island soils. Data collected from the Delta Islands Drainage Investigation and Interagency Delta Health Aspects Monitoring Program showed that drain waters do have a higher potential to form THMs than Delta channel waters.

The estimates showed that drainage contributed 40% to 45% of the TTHMFP organic carbon in the Delta during the irrigation months (April through August) and 38% to 52% during the winter leaching period (November through February) during water year 1988. Pesticides were sampled as well, and if detected, they were near the detection limits.

The assessment of the impacts of island drainages, river drainage, bay water intrusion, and other potentially controllable factors on the Delta water quality will need to be completed. Further sampling of drainage was recommended as well as an expanded monitoring program.

Chapter 8 — MWQI Program Reports

The purpose of this chapter is to provide a summary of the special studies reports of the Municipal Water Quality Investigations Program. The reports summarized in this chapter are as follows:

The North Bay Aqueduct Barker Slough Watershed Water Quality Investigations

Candidate Delta Regions for Treatment to Reduce Organic Carbon Loads

Department of Water Resources Quality Assurance/Quality Control Study Characterization of Organic Carbon by Ultraviolet Absorbance Spectrophotometry

Natomas East Main Drainage Canal Water Quality Investigation – Initial Report

Steelhead Creek Water Quality Investigation – Final Report

Pilot Study on the Analytical Performance of a Total Organic Carbon Analyzer in Operation at a Field Station on the Sacramento River (Sievers)

The North Bay Aqueduct Barker Slough Watershed Water Quality Investigations

Duration of Study

July 1996–June 1997, winter sampling 1997-2001

Investigators

Phase 1: A. Mark Commandatore, Denise Webster, Marvin Jung, Phase 2: Carol L. DiGiorgio, Jaclyn Pimental

Background and Objectives

The North Bay Aqueduct (NBA) is a 27-mile underground pipeline constructed by the State Water Project to provide water to municipal and industrial customers in Solano and Napa counties. The Barker Slough Pumping Plant (BSPP), located upstream of the confluence of Barker and Lindsey sloughs provides water for the NBA. On the Campbell Ranch, Campbell Lake is a man-made lake that acts like an unmanaged reservoir in winter. Under low flows, Campbell Lake potentially serves as a shallow sink for the deposition of upstream loads of carbon and turbidity. However, under high flows, unregulated flows from the lake result in extended periods of discharge. Campbell Lake provides the extended input of high carbon and turbidity seen at the pumping plant. This has been shown by similar levels of carbon and turbidity from the Campbell Lake outflow and values seen at the forebay of the pumping plant.

The North Bay Aqueduct and its 14.5 square miles watershed had elevated levels and rapid changes in total organic carbon (TOC) (with average winter levels between 10-12 mg/L) and turbidity (averaging over 100 NTU). In order to stay in compliance with state and federal drinking water standards, the treatment operators needed to have a rapid response to changes in TOC. In extreme cases, treatment plants have been shut down to avoid the violation of finished drinking water standards. Another tactic has been to blend or switch to alternative water sources. It can cost two to four times more to treat NBA water than it would water of better quality.

The NBA investigation was conducted on Barker Slough in two phases. The first phase looked to quantify the severity of potential water quality problems, isolate the sources of those problems, and recommend management practices to improve water quality. Phase 1 occurred between July 1, 1996 and June 30, 1997. The second phase evaluated the inputs the upper watershed had on the pumping plant. Phase 2 sampling occurred during the winters of 1997 through 2001 with soil sampling occurring in 2000 with the assistance of University of California, Davis. The study resulted from the 1996 Sanitary Survey Update Report.

Study Design

The Phase 1 study sampled weekly at Barker Slough Pumping Plant (BSPP), Barker Slough at Cook Lane, Calhoun Cut at Highway 113, and Lindsey Slough at the Hastings Island Bridge. The second study expanded to include Noonan Drain at Hay Road and Barker Slough at Dally Road. Sampling in the following years changed from monthly to weekly and included rainfall events. The parameters measured were temperature, dissolved oxygen, pH, specific conductance, turbidity, bromide, organic carbon, total trihalomethane formation potential, ultraviolet absorbance at 254 nm (UVA_{254}), alkalinity, aluminum, iron, manganese, *Escherichia coli*, and selected pesticides.

Results/Conclusions

The results of the Phase 1 study showed that no single point source contributes to the Barker Slough watershed's elevated levels of organic carbon and turbidity. The likely cause was soil geochemistry. Soils in the watershed can be high in sodium. The clay particle size allows the soil to be easily suspended; the soil can remain suspended in the water column for a considerable time, creating a dispersive environment for organic carbon.

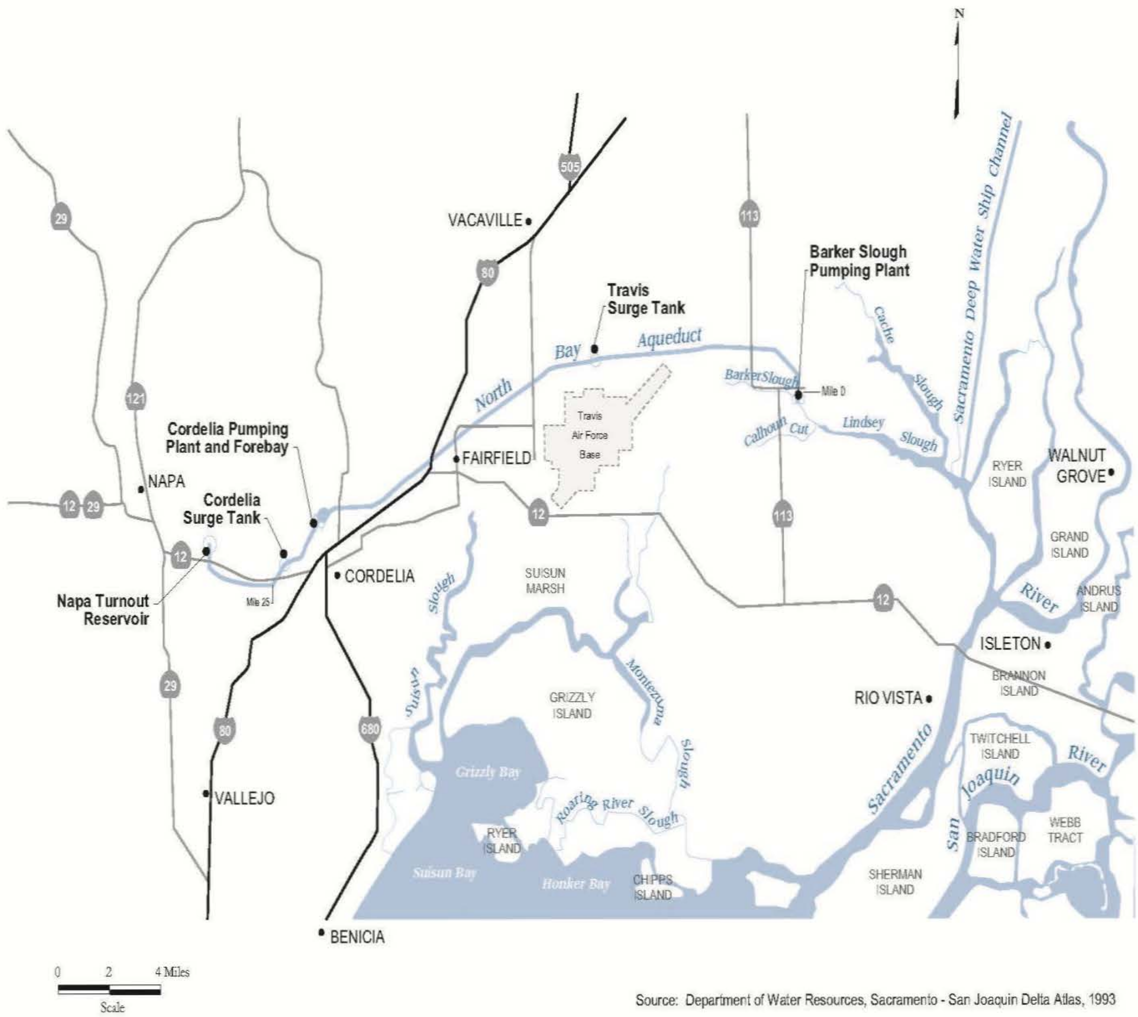
Contrary to previous assumptions, the water quality at BSPP is more heavily influenced by local runoff than by Lindsey Slough. Water quality at Calhoun Cut and Cook Lane had the poorest water quality. Those locations typically had the highest levels of dissolved organic carbon, trihalomethane formation potential, *E. coli*, and UVA_{254}. In contrast, Lindsey Slough had the lowest observed levels. Calhoun Cut had similar water quality to BSPP during the dry season.

The results of Phase 2 showed that during winter, the Barker Slough watershed experiences two different phenomena, one directly related to rainfall, and the other related indirectly. After adequate rainfall, a TOC and turbidity pulse travels through the watershed. This creates the rapid increase in TOC and turbidity seen at the pumping plant. Indirectly, extended periods of discharge from Campbell Lake and possibly Calhoun Cut compound the problem. Those two factors produce the creation of a high carbon and turbidity reservoir at the forebay. Additionally, in the absence of rain, the low pumping rates in winter cause the reservoir to clear slowly, dragging out the period of high carbon and turbidity in the NBA.

Discharge from Campbell Lake can occur over a number of days or weeks. Upstream discharge normally occurs for a few hours but returns to normal levels of input within a few days at most. The longer period of discharge explained why Campbell Lake has an extended impact on the water quality at the pumping plant. Grab sample and particle size analysis supported the hypothesis as well as a study published by Singer and Eshel in 2000. The repeating cycle of sediment loading occurs in a seasonal pattern. It also appears Cook Lane and Calhoun Cut may be affected by Campbell Lake because similar water quality can be observed at the pumping plant and these sites. During the dry season, Calhoun Cut exhibits similar water quality characteristics.

In addition to this study, the Solano County Water Agency hired a consultant to determine options for implementing best management practices (BMP). The consultant's conclusion, presented in the Solano County Water Agency North Bay Aqueduct, Barker Slough Water Quality Improvement Plan 2001, was that the BMP should focus on turbidity rather than organic carbon. Mitigation for land use, which includes grazing, agriculture, recreation, and the preservation of lands, would be beneficial for water quality.

Figure 5 – North Bay Aqueduct map



Source: Department of Water Resources, Sacramento - San Joaquin Delta Atlas, 1993

Candidate Delta Regions for Treatment to Reduce Organic Carbon Loads

Report date

January 1999

Investigators

Marvin Jung and Quy Tran

Background and Objectives

The U.S. Environmental Protection Agency (EPA) requires total organic carbon (TOC) reductions prior to disinfection when concentrations are more than 2 mg/L in order to reduce the formation of disinfection byproducts. In order to stay EPA compliant, this study investigated if it was feasible to treat agricultural drainage to lower dissolved organic carbon (DOC) levels at water supply intakes. The results of the study are used for the input data and modeled conditions for Delta Simulation Model 2 (DSM2), which is used to assess movement and distribution of organic carbon in the Sacramento-San Joaquin Delta (Delta). The modeled DSM2 results were input into the Water Treatment Cost Model for the Treatment of State Water Project waters for trihalomethane (THM) control model, which is based on the EPA national water treatment plant model, and had been modified for the high bromide levels found in the Delta.

Study Design

Data and conditions for modeling were developed by:

- Determining and standardizing monthly drainage volume estimates
- Developing monthly mean DOC and bromide concentrations and ultraviolet absorbance at 254 nanometers (UVA_{254}) values
- Computing and ranking organic mass loads from drainage discharge
- Developing criteria to select candidate regions for modeling
- Defining treatment assumptions and costs based on the Brown and Caldwell study
- Developing a list of candidate regions for modeling benefits and costs
- Composing simulated conditions to be run by DSM2, examining TOC/DOC reductions at Clifton Court Forebay

Results/Conclusions

Drainage volume estimates were made using the Delta Island Consumptive Use (DICU) model. It was discovered that four drainage areas contribute 64% of the total drainage volume during May to September.

Water quality is affected by irrigation and drainage volumes, which are connected and tend to be highest in July and August. During the July and August period, the islands can be grouped into three distinct areas with DOC concentrations, (1) less than 8 mg/L, (2) 9 to 10 mg/L, and (3) above 10 mg/L. The islands with the higher DOC levels tended to be more than 10 feet below sea level. Monthly mean concentrations of DOC, bromide concentrations, and UVA_{254} values were computed for the DSM2 and DICU models.

Monthly loading for organic carbon mass was determined by multiplying the monthly mean DOC values by monthly drainage estimates for each area. The four drainage areas mentioned above supplied 75% of the DOC during the irrigation season and 59% during the wet season.

The three factors that determined the selection of candidate regions was dry season channel flow patterns, distance of discharge to Clifton Court Forebay, and seasonal organic carbon mass loads.

Drainage samples taken in 1997 from Twitchell and Bacon islands were analyzed and jar tested. The test revealed that optimized ferric chloride coagulation removed 55% to 78% of the DOC, compared to 44% to 74% removal by alum coagulation or 38% to 97% using membranes. Cost analysis showed that 60% TOC removal would cost $1.73 per pound (in 1997 dollars). Treatment costs depend on drainage water composition and flow rates, so costs would be different for different islands. Concentrations of coagulation chemicals can be elevated in discharge water and inorganic carbon can be affected by low pH levels.

Further study was recommended to confirm the technical and economic viability of ferric chloride coagulation.

Department of Water Resources Quality Assurance /Quality Control Study Characterization of Organic Carbon by Ultraviolet Absorbance Spectrophotometry

Duration of Study

1999

Investigators

James Hockenberry, Marvin Jung

Background and Objectives

- To determine the sources and levels of organic carbon (OC) entering the Sacramento-San Joaquin Delta (Delta).
- To characterize organic carbon through spectrophotometry; specifically utilizing ultraviolet absorption (UVA) scanning techniques.
- To use data gathered from Sacramento-San Joaquin Valley watersheds, which supply the Delta, to determine where to direct Department of Water Resources' efforts to address organic carbon loading using best management practices for source surface water control.

Study Design

A Hach DR/4000 spectrophotometer was used to scan UVA at wavelengths between 200 and 500 nm. The humic fraction of OC peaks at an absorbance level of 254 nm, while fulvic acids are thought to absorb at 285 nm. Values for specific UVA are calculated using absorbance values and dissolved organic carbon levels. The natural log was calculated and charts were constructed to determine mean and normalized variability. Then a value slope was obtained and geographic and temporal comparisons were made. In addition, mineral samples were taken and data analysis was performed to verify mixing ratios.

Results/Conclusions

The regions with high natural organic matter had higher levels of absorbance. When samples had less organic carbon, they produced a more pronounced curve between 200 and 500 nm. Agricultural drains and creeks in agricultural areas had higher levels of absorbance, while rivers flowing into the valley from the Sierra had low absorbance levels.

This was a preliminary study.

Natomas East Main Drainage Canal Water Quality Investigation – Initial Report

Duration of Study

1997-2002

Investigators

Michael Zanoli, Jim Sickman, Fengmao Guo, Carol DiGiorgio, Jaclyn Pimental, Bill McCune

Background and Objectives

The Bay-Delta Authority identified the Steelhead Creek watershed, also known as the Natomas East Main Drainage Canal (NEMDC), as a study area of interest to assess sources and loads of drinking water parameters of concern. Rapid urbanization from population growth increased urban discharge, which is regulated under the Clean Water Act National Pollution Discharge Elimination System (NPDES) permit program. Monitoring under the NPDES permit program had been inadequate to address drinking water quality concerns. Under the Clean Water Act section 303(d), NEMDC is listed for diazinon, and one of its tributaries, Arcade Creek, is listed for copper and the organophosphate pesticides chlorpyrifos and diazinon.

Because both NEMDC and Arcade Creek are listed as water bodies that do not meet applicable water quality standards, NEMDC became the focus of the new Urban Sources and Loads Project. The goals were:

- Identify existing and potential sources of drinking water quality pollutants from urban sources such as urban runoff and wastewater treatment plants
- Identify data gaps
- Estimate loads of selected sources
- Assess water quality problems by their severity and their impact on drinking water quality at intake sites

The data analysis focus was on organic carbon and its relationship to other water quality parameters and watershed factors like precipitation and stream flow. Besides organic carbon, drinking water parameters of concern in urban runoff include turbidity, total dissolved solids, nutrients, and pathogens.

Study Design

The 180 square mile NEMDC watershed enters the Sacramento River near downtown Sacramento. It drains about one third of the Sacramento region, and 59% of the area was urbanized. Steelhead Creek collects drainage from Arcade Creek (highly urbanized and 303(d) listed), Robla Creek and Magpie Creek (which drain the area formerly known as McClellan Air Force Base), and the rapidly developing Dry Creek watershed.

The sampling site chosen for NEMDC was at the El Camino Avenue Bridge, located 5 km upstream from the confluence of the Sacramento and American rivers. Monthly samples taken at NEMDC were compared to the Sacramento River at Hood, the American River at Fairbairn Water Treatment Plant (WTP), the Sacramento River at the Bryte Bend WTP in West Sacramento, and H. O. Banks Pumping Plant (Banks). Samples were analyzed for total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA_{254}), total dissolved solids (TDS), general minerals, and nutrients. From July 1999 to June 2002, NEMDC stage measurements were taken. Event based sampling and rainfall measurement occurred from July 2000 to June 2002.

The Delta Simulation Model 2 (DSM2) was used to assess the individual and cumulative potential effects. Results were compared by season.

Results/Conclusions

The hydrological analysis was done using the gage and precipitation data. It showed the watershed had a "flashy" hydrograph, meaning the stream levels rise and fall rapidly along with rainfall intensity.

Electric conductance (EC) and TDS were high at NEMDC ranging from 81-561 µs/cm and 58-338 mg/L for EC and TDS, respectively. TDS levels were higher than Sacramento area runoff with an average of 211 compared to 151 for urban runoff. EC was similar to the values found at Banks Pumping Plant.

Bromide had an average of 0.054 mg/L and a high value of 0.11 mg/L. Bromide was detected in every sample, and the average values exceed the maximum contaminant level (MCL) value of 0.05 mg/L.

Nitrate levels were very high, and exceed the MCL of 10 mg/L in 22 of 64 samples analyzed.

Of purgeable organic compounds, pesticides, or other synthetic compounds, only MTBE and diazinon were detected. MTBE was detected at 1 µg/L, which is well below the MCL of 13 µg/L. Diazinon exceeded chronic toxicity criterion (0.05 µg/L), on five occasions.

The wet oxidized and combusted TOC and DOC concentrations increased and decreased during wet and dry periods. The combustion method produced higher concentrations than the wet oxidation method. The combustion method had a high of 13.1 mg/L during the wet season and a low of 5.1 mg/L during an extended dry period. The oxidation method produced a low of 3.1 mg/L during the dry season and a high of 12.7 mg/L during the wet season.

During the wet season, there was a strong correlation between turbidity and TOC, for both the combustion and oxidation methods, and between TOC and turbidity by the combustion method in the dry season. This suggests turbidity and TOC maybe controlled by a similar flushing process from similar sources, which may not be primarily urban, but rather rural sources. Stage proved to be a better predictor of TOC and DOC concentrations than precipitation.

TOC loading from NEMDC to the Sacramento River was substantial in 5 of the 12 months during the 2001-2002 stage sampling period, ranging from 4% to 21% of the load during significant storm periods. The impact of river loading was most pronounced when river flows were low and urban drainage and discharge was high.

Total and fecal coliform and *E. coli* were analyzed using both most probable number (MPN) and colony forming units (CFU) methods. MPN values were highest between November and January. Coliform data were generally high, having wet weather high ranges between 10 million to 20 million MPN/100 ml. Bacteria densities were much higher during the wet season than the dry season, ranging from median values of 10 CFU/100 ml to more than 25,000 CFU/100 ml. The highest MPN values for all bacteria were found in November, December, and January. Using the CFU method, *E. coli* values were higher than fecal coliform, ranging from several hundred to almost 10,000 CFU/100 ml. The lowest values were in February. CFU method results showed 10% of fecal coliforms exceeded the level of 10,000/100 ml, 42% of the data exceeded the regulatory level of 400/100 ml, and 70% of *E. coli* values exceeded the single sample water quality objective of 235/100 ml.

Steelhead Creek Water Quality Investigation – Final Report

Duration of Study

1997-2006

Investigators

Michael Zanoli, Elaine Archibald, Karen Enstrom, Rachel Barnett, Sabrina Bell, Carol DiGiorgio, Thomas Hawkins, Otome Lindsey, Howard Mann, Cindy Messer, Murage Ngatia, Theodore Swift, Barbara Washburn, Katie Yancey

Background and Objectives

When urbanization increases in a watershed, wastewater and urban runoff into streams and rivers increase. Steelhead Creek drains approximately 180 square miles of urbanized or impervious covered area into the Sacramento River. Urban runoff impairs water quality, with significant impairment occurring when the impervious cover is 25% or greater. The Steelhead Creek watershed had 24% impervious cover.

The objectives of this project were:

- Characterize water quality conditions in Steelhead Creek during dry weather and storm events.
- Relate water quality conditions in Steelhead Creek to activities in the upper watershed.
- Calculate the loads of key drinking water constituents from the Steelhead Creek watershed.
- Relate the Steelhead Creek loads to the urban runoff loads from the greater Sacramento metropolitan area and the loads from wastewater discharged from the Sacramento area.
- Identify data gaps.

Study Design

Constituents analyzed were total organic carbon (TOC), dissolved organic carbon (DOC), TTHMFP, ultraviolet absorbance at 254 nm (UVA_{254}), turbidity, total suspended solids (TSS), bromide, total dissolved solids (TDS), electrical conveyance (EC), nutrients, and total and fecal coliforms and *E. coli*. Samples were collected from Steelhead Creek, Arcade Creek, Sacramento River at West Sacramento Water Treatment Plant (WTP) intake, Sacramento River at Sacramento WTP intake, Sacramento Regional WTP discharge (SRWTP), and Sacramento River at Hood. In addition, the Dry Creek Conservancy collected samples from September 2004 to March 2006 from Secret Ravine Creek at Miner's Ravine, Miner's Ravine Creek at Secret Ravine, Antelope Creek at Atlantic Avenue, Cirby Creek just upstream of the Dry Creek confluence, and Dry Creek at Hayer Park.

Precipitation data from California Data Exchange Center stations was used to represent the Steelhead Creek watershed. Stage was monitored using a wire weight gage on Steelhead Creek at the El Camino Bridge, flow was monitored using a bubbler gage on Steelhead Creek just north of the bridge, and real time stage monitoring was collected by Sacramento County at the confluence of Arcade Creek and Steelhead Creek.

Results/Conclusions

Water quality showed strong seasonal patterns for all constituents except bacteria indicator organisms. Organic carbon concentrations were low during the dry period when bromide, TDS, total nitrogen, and total phosphorus were high; however, during the wet period when organic carbon concentrations were high, the other constituent were low. Orthophosphate made up most of the total phosphorus (P), indicating little particulate phosphorus in Steelhead Creek. TOC concentrations and nitrate plus nitrite levels were high when flows were less than 1,000 cfs. No significant difference was found between water year types for TOC, DOC, bromide, total Kjeldahl nitrogen, ammonia, total P, and orthophosphate.

Steelhead Creek, when compared to the upper watershed, had lower TOC concentrations than Dry Creek, but higher EC levels than most of the watershed. Steelhead Creek had lower nitrate plus nitrite and orthophosphate levels than Dry Creek. Arcade Creek had higher ammonia concentrations than both Dry Creek and Steelhead Creek. TOC, bromide, EC, total nitrogen, and total P concentrations in Steelhead Creek were significantly higher than concentrations in the Sacramento River at the West Sacramento Water Treatment Plant.

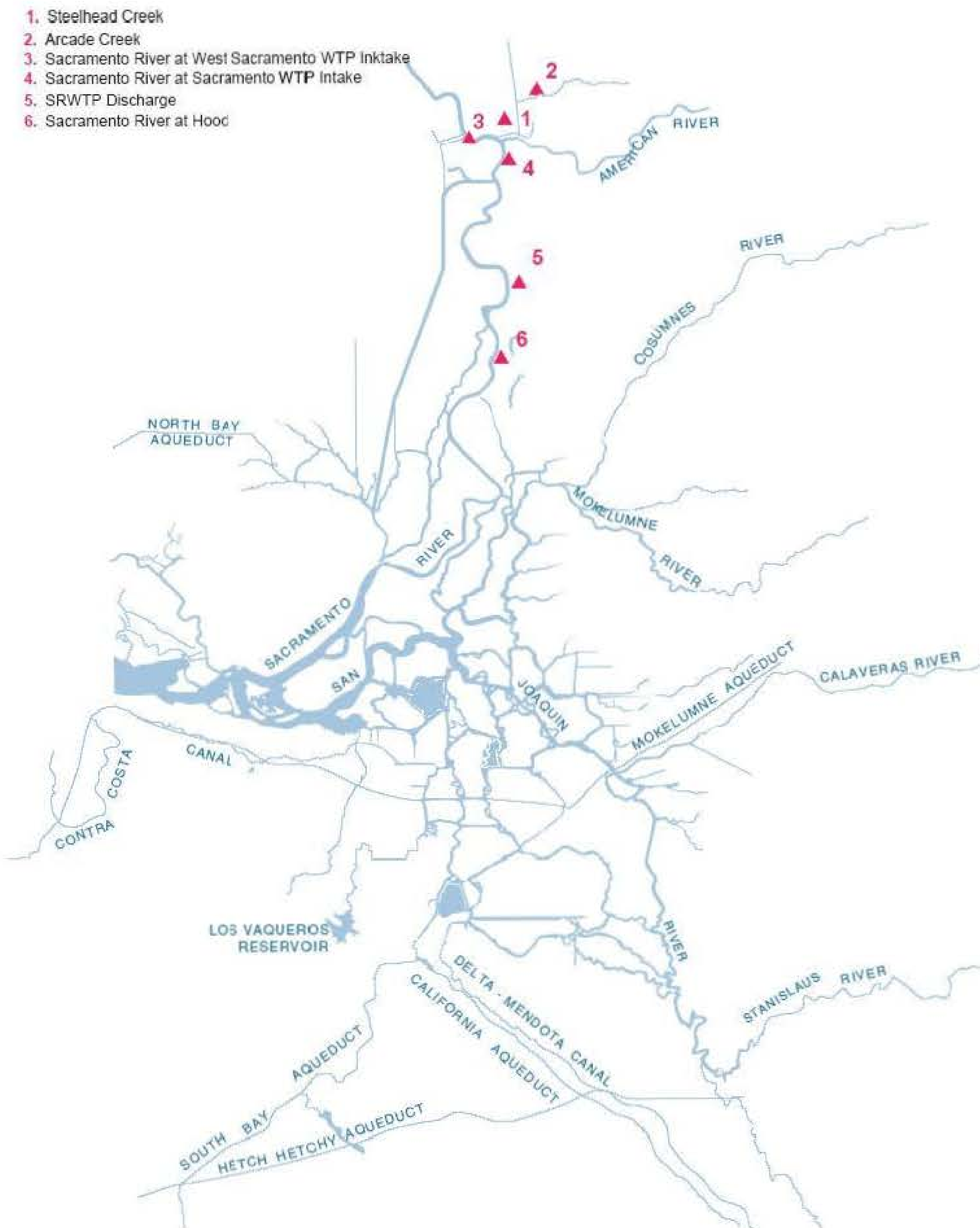
High levels of total coliforms, fecal coliforms, and *E. coli* were found year-round in Steelhead Creek, with highest levels of bacteria indicators found during and immediately after storm events. The bacteria in Steelhead Creek exceeded the drinking water guidelines and recreational use criteria every month. Total coliform levels were high at all of the sites during periods immediately following rain events and during dry periods.

Monthly loads were calculated for TOC, TDS, bromide, nitrate, nitrate plus nitrite, and orthophosphate. The TOC loads from Steelhead Creek showed the same pattern as the loads in the Sacramento River at Hood; greater loads occur from December to March and lower loads occur during the summer months. During the dry season, Steelhead Creek contributed as little as 3% of the load to the Sacramento River, however during the wet season it could increase to 93% of the river load. Alternatively, SRWTP provided an estimated daily TOC load from 40% to 60% of the total load to the Sacramento River during low flow fall months, and less than 5% of the total load during storm events.

Bromide, TDS, nitrate plus nitrite, and orthophosphate loads from Steelhead Creek were highest during the December to March period and lowest during the summer months. Based on monthly load estimates, Steelhead Creek contributes between 0.2% and 8.4% of the bromide load in the river, 0.08% to 3.5% of the TDS load, 0.6% to 19% of the nitrate plus nitrite load, and 0.6% to 14% of the orthophosphate load.

The Dry Creek Waste Water Treatment Plant influences water quality in Dry Creek and Steelhead Creek, particularly during dry periods. TDS, nitrate plus nitrite, and orthophosphate were higher downstream of the wastewater treatment plant than upstream of the plant.

Figure 6 – Steelhead Creek/NEMDC sampling locations map



Pilot Study on the Analytical Performance of a Total Organic Carbon Analyzer in Operation at a Field Station on the Sacramento River (Sievers)

Duration of Study

1999-2000

Investigators

David Gonzalez, Chris Huitt

Background and Objectives

Discrete "grab" sampling only provided a snapshot of water quality conditions at the time of sampling and the results were not obtainable until days later. Grab samples cannot follow the variations in organic carbon loading from storm events or agricultural and urban runoff. Daily sampling was economically unfeasible from a staffing and lab analysis standpoint. A real-time monitoring program was desired to monitor carbon in source waters for drinking water purposes, but unfortunately, with the equipment available in the early 1990's, it was not yet technologically feasible. In 1996, a Sievers 800 TOC analyzer, which had been developed for the NASA Space Station Freedom Project, was purchased.

In 1999, a pilot study occurred to assess the field performance of the instrument and the quality of total organic carbon (TOC) data it produced. The instrument needed to be left unattended and follow a set sampling schedule. The objectives of the study were to evaluate the reliability of the instrument, to see if the water delivery system affected the TOC sample, and to assess the instruments ability to provide data comparable to laboratory-analyzed field grab samples. Due to the novel use of this instrument, Sievers provided technical help and advice to ensure optimal field performance.

Finding a proper location for the analyzer caused a delay in the study. H. O. Banks Pumping Plant and North Bay Pumping Plant were rejected in favor of Sacramento River at Hood, where the Environmental Services Office was building a permanent monitoring facility. Considerations for the location were as follows: the ability to place the instrument in a secured location, reliable telephone service for telemetry of data, dependable electrical service for heating and air conditioning, a minimal commute from West Sacramento, accessibility during severe weather, and easy access to a source of surface water.

Study Design

A yearlong pilot study began in order to evaluate the ability of the analyzer to provide representative data over a sustained period of automated operation. During this pilot study a series of samples were collected weekly to evaluate the accuracy and reliability of the auto-analyzer and the performance of the water delivery system

During an analysis, the instrument first measures the total inorganic carbon, and then determines the total carbon content of the sample after oxidation of the organic compounds by the use of ammonium persulfate. The total organic carbon concentration is calculated by measuring the difference between the total carbon and total inorganic carbon concentrations. While the machine could process a sample every six minutes, this frequency was higher than necessary. A sensor in the instrument took a sample when a water flow was detected. A solenoid switch, controlled by a Campbell datalogger, regulated the flow of water to the instrument so that six samples were collected in a row with the first sample being taken on the hour. The first two readings were discarded so that the filters and lines were purged from the previous series of samples.

Results/Conclusions

The results of this pioneering study showed that the analyzer provided data of an acceptable precision and quality, even though the analysis of raw surface water was outside the realm of normal application for this instrument. It showed the amount of data generated economically exceeded any amount of grab samples collected and analyzed in a laboratory. It was able to provide the frequency of data required for modeling. The pilot study also showed that the concept of installing laboratory autoanalyzers in remote field applications is a practical way to provide continuous real-time TOC data to the scientific and water utility communities.

The drawback of the Sievers was its inability to handle highly turbid waters. During the study, it was determined that a prefilter was needed to block large particles from running through the system and blocking the existing factory 60-micron filter. Other sites considered for real-time monitoring have water quality issues like high turbidity and suspended solids. Even with Sievers ability to process Sacramento River water, it was determined that at other locations with severe water quality issues, another analyzer would be used.

Real-Time Monitoring of Organic Carbon in the Sacramento River and California State Water Project Using Process Analyzers

Duration of Study

2001-2003

Investigators

James O. Sickman, David Gonzalez, and Steven San Julian

Background and Objectives

Municipal Water Quality Investigations (MWQI) conducted a three-year study to test the ability of the three most feasible methods of total organic carbon (TOC) analysis using process analyzers. The goal was to use a semi-autonomous analyzer as a viable means for forecasting water quality and subsequently develop total maximum daily loads (TMDL). The three analyzers were capable of operating unattended for two weeks, could take continuous samples, and had the capability of passing data to a data-logger, which was telemetered to a database server. The MWQI Program was probably the first group to measure TOC using auto analyzers and provide that information in real time on the internet.

The 1972 Clean Water Act required setting values for TMDL in waters. Determining an appropriate baseline in waters that have large spatial and temporal variations is difficult to do with grab samples. Continuous monitoring would capture event loading and increase the accuracy of pollutant load calculations, which would help to define TMDL criteria. The industrial application of semi-autonomous analyzers expanded the water quality parameters monitored.

Study Design

The three methods considered feasible for TOC measurement are ultraviolet absorbance at 254 nanometers (UVA_{254}), high temperature combustion, and chemical oxidation. Department of Water Resources Operations and Maintenance installed a Tytronics FPA 1000 at H. O. Banks Pumping Plant (Banks) in 2000, which uses UVA_{254} absorbance. The on-line spectrophotometer was designed for process monitoring and control. The concentration of dissolved organic carbon (DOC) in the sample relates to sample absorbance at 254 nm. The Shimadzu TOC 4100 employs the established 680°C catalytic combustion and non-dispersive infrared detection method. The Shimadzu measures both TOC and DOC. Banks received one Shimadzu in September 2001 and the Sacramento River at Hood (Hood) received another machine in May 2002. The Sievers 800 TOC analyzer was installed at Hood in 1999. The analyzer employs the chemical oxidation method by using UV-persulfate with patented membrane conduct metric detection for DOC measurement.

Several types of samples were analyzed for performance evaluations of representativeness, accuracy, and precision. Precision represents repeatability and reproducibility. A target of +/- 30% as relative standard deviation was set for precision. The precision tests were done by analyzing replicate samples on the Sievers and the Shimadzu, but not on the Tytronics. Accuracy was evaluated by matrix spikes of deionized water and sampled waters to determine if the results were statistically the same as the true value. Target accuracy values were 80% to 120% for spike recoveries. Representation analysis was conducted by comparing grab samples to online measurements. Multiple samples were taken and the target value was set at 80% to 120%. A three-way comparison of samples was done to determine if the conditions were sufficiently uniform, which ensures the data is consistent. The three samples compared were grab samples taken from the site, the online samples taken before the grab sample was run, and the results of the grab samples from Bryte Laboratory. In addition, the test for completeness assessed whether the analyzers could meet the quality control (QC) criteria, thereby validating the data. The QC criteria are to capture 50% of the data a month and 75% within a year.

Results/Conclusions

Spike recoveries showed the Sievers and Shimadzu analyzers typically fell within the 80% to 120% range set for accuracy. The mean values were 102% for the Banks Shimadzu, 103% for the Hood Shimadzu, and 105% for the Sievers at Hood.

Measurements of precision at 30% revealed the Sievers had better precision (mean 1.9%) than the Banks Shimadzu (mean 3.9%) and the Hood Shimadzu (mean 8.8%).

The target levels of 80% to 120% for representativeness were primarily met; biases appeared in the three analyzers, indicating the water delivery system did not always supply representational samples. The TOC values showed no bias for the Hood Shimadzu (mean 99.9%), and the Banks Shimadzu (mean 99.0%). The DOC values for the Shimadzu's did show a low bias at Hood (mean 87%). Banks Shimadzu DOC values showed a bias from October 2001 to January 2002 (mean 72%) but overall the mean agreement was 91.6%. The agreement of the Sievers TOC samples was only 89%.

Comparisons between the laboratory and field analyzers proved somewhat problematic because laboratory results were not clearly more reliable than field results. Banks and Bryte Laboratory results typically fell into the 80% to 120% agreement range except during January and May 2002. During 2002 and 2003, the Hood Shimadzu also fell into the 80% to 120% agreement range with Bryte Laboratory.

The QC requirement of capturing data at specified levels, indicated by the completeness of online measurements, was difficult at times. The water delivery systems created more problems than the analyzers. Problems at Banks included broken intake supports, replacement of pump parts, power outages, and on occasion, the water levels were below the water system inlet. At Hood, breakdowns of two to three days occurred 2 to 11 times per year. At Hood, the Shimadzu captured 92% to 98% of the data and the Sievers captured 97% to 98% of the data except water year 2002. The Sievers experiences extended down times from problems with instrument calibration, long waits for parts, and breakdowns from the water delivery system. The Tytronics analyzer experienced extended downtime during water year 2002 as well, caused by lamp failures. The data capture for the Tytronics was 47% in 2002, 83% in 2003, and 92% in 2004.

Total organic carbon seasonal patterns showed high winter values of 5% to 8 mg/L and spring through autumn lower values around 2 mg/L at Hood. At Banks, higher values of 6% to 10 mg/L occurred in the winter with minimum levels around 2% to 3 mg/L.

Overall, when the organic carbon analyzers worked, the results were satisfactory. However, one concern arose with the Shimadzu and Sievers. The drawback of the process analyzers is that unlike their laboratory counterpart, only relatively simplistic calibrations can be done. The Shimadzu and Sievers can only perform a 2-point calibration.

Jones Tract Flood Water Quality Investigations

Duration of Study

June 2004–December 2004

Investigators

Ted Swift, Robert Duvall, Sarojini Balachandra, and MWQI Field unit

Background and Objectives

On the morning of June 3, 2004, a levee on the southwest side of Upper Jones Tract failed, forming a 300-foot breach and allowing the Middle River water to stream into the Upper Jones Tract. The volume of water pulled into the Upper and Lower Jones tracts in three days was approximately 150,000 to 200,000 acre-feet on an area of 12,000 acres, which filled to an average depth of 12 to 16 feet. It represented about 35% of the entire volume of the Sacramento-San Joaquin Delta (Delta), not including Suisun Bay, and almost 10 times the volume of water in the south Delta. The Jones Tract flood pulled primarily on the San Joaquin River, and increased seawater intrusions became a concern. After the levee was repaired in July, dewatering activity continued for approximately five months, affecting water quality at the State Water Project and Central Valley Water Project pumps to the south. The monitoring project had three purposes:

- Evaluate the water quality of pump discharge as required by the Regional Water Quality Control Board to meet water quality objectives;
- Evaluate water quality at the pumps to determine water quality effects of pump-out on drinking water source water;
- Gather and analyze data that might help assess potential water quality effects of future island water storage projects.

Study Design

MWQI Program staff conducted sampling on the day after the levee breach at Lower Jones Tract, the breach site, and in Middle River. After the breach was repaired in July, samples were collected from temporary sampling stations at Upper Jones Tract and Lower Jones Tract pumping stations. To comply with the Regional Water Quality Control Board requirements, grab samples were also collected at three Middle River sampling sites after the dewatering started. Automated water quality sondes were deployed at several locations within Jones Tract to collect continuous water quality data.

Results/Conclusions

While it was a costly catastrophe, the Jones Tract levee break of 2004 provided an excellent opportunity to study and document the water quality effects of a flood event on a Delta peat island. Results had direct bearing on several contemporary debates about the likely water quality effects of flooding or inundating a previously farmed island, and results provide guidance for the future. In general, many of the observed parameters followed more or less what would be predicted from limnology (the science of inland waters) theory (e.g., dissolved oxygen, pH, and metal solubility). The flood provided important information about characteristics specific to Delta islands (e.g., peat soil carbon loading) and drinking water effects that would have been difficult to get otherwise.

Physical conditions and weather were strong drivers of water quality conditions such as turbidity, dissolved oxygen, pH, temperature, and electrical conductance (EC). Windy days stirred up floodwater and re-suspended sediment, increasing turbidity. Dissolved oxygen concentrations were affected by physical processes, such as temperature, and by biochemical processes such as photosynthesis and microbial respiration. Comparisons between the temperature and dissolved oxygen concentrations from June through November indicated other processes besides water temperature affected dissolved oxygen (DO) variations. Often DO concentrations were higher in the surface water than the bottom due to microbial oxygen demands in the organic sediments, limited oxygen diffusion from the air, and, during daylight hours, oxygen production by algal photosynthesis. DO concentrations were frequently below the 6 mg/L requirement for the proposed In-Delta Water Storage Project's discharges.

The pH changed along with DO during the day. Photosynthesis is most likely the cause because photosynthesis increases DO and pH as algae absorbed carbon dioxide (carbonic acid) from the water. Lower carbonic acid concentrations would lead to higher pH. Microbial respiration at night tends to increase CO_2, which decreases pH.

Another important water quality parameter measured within Jones Tract was electrical conductance (EC). The EC levels did not rise above 512 µs/cm, a level often found in Delta channels. EC gradually increased during the course of pump-out operations, but only gradually. The increase was probably due to evaporation and leaching from the underlying soils.

In the beginning of June, the concentrations of total coliforms, fecal coliforms, and *E. coli* were elevated in the floodwater compared to samples collected from the nearby Middle River. However, by the end of June the total bacterial count in the floodwater dropped to very low or undetectable levels.

The concentrations of many common pesticides were less than the detection limits. Detected pesticides were metolachlor, diazinon, molinate, atrazine, diuron, simazine, and trifluralin. Diesel range organics were detected in the floodwater due to the presence of farm equipment. Benzene, toluene, ethyl benzene, xylene, gasoline range organics, oil, grease, volatile organic compounds, and semi volatile organic compounds were less than reporting limits.

Boron was always present in floodwater samples collected after the levee was repaired. The concentration varied from 0.1 to 0.2 mg/L. Levels of boron was not detected in most samples collected from the Middle River. Potassium levels were higher in the floodwater than in the Middle River. Iron and manganese concentrations above the maximum contaminant level (MCL) were recorded occasionally in Jones Tract floodwaters, likely caused by the anaerobic conditions on the bottom during the pump-out. The average concentrations of iron and manganese were at least three times the concentration at Middle River.

Concentrations of organic nitrogen and organic phosphorus nutrients increased in the Jones Tract floodwater relative to those in the surrounding river channels. Movement of floodwater to Clifton Court Forebay may have increased the algal population in the channels and forebay resulting in above normal concentrations of the taste-and-odor (T&O) compound 2-methylisoborneol (MIB) at H. O. Banks Pumping Plant. The growth and decay of algae-produced taste and odor compounds (e.g., MIB and Geosmin) which makes otherwise safe water unpalatable or unpleasant to drink. It is also an indirect source of dissolved organic carbon (DOC) and disinfection byproducts (DBPs). T&O compound concentrations were very high during parts of the pump-out operation.

DOC concentrations increased steadily throughout the dewatering period. Results showed trihalomethane concentrations in chlorinated laboratory water samples increased in parallel with DOC as dewatering activities continued at Jones Tract. Concentrations of chloroform after September were higher than 1,500 µg/L in many samples. Bromide is another disinfectant byproduct precursor, producing compounds such as bromodichloromethane. Usually, the ratio of bromide to chloride in Delta water is similar to the seawater ratio; however, the ratio at Jones Tract was higher than the ratio observed elsewhere in the Delta. The elevated ratio indicated an alternative source of bromine in the floodwater. Additional bromide may have come from brominated agrochemicals. Ultraviolet (UV) light absorption at 254 nm (UVA_{254}) data was collected through September. As has been found in other studies, DOC concentration and UVA_{254} values were highly correlated with the chloroform and bromodichloromethane concentrations.

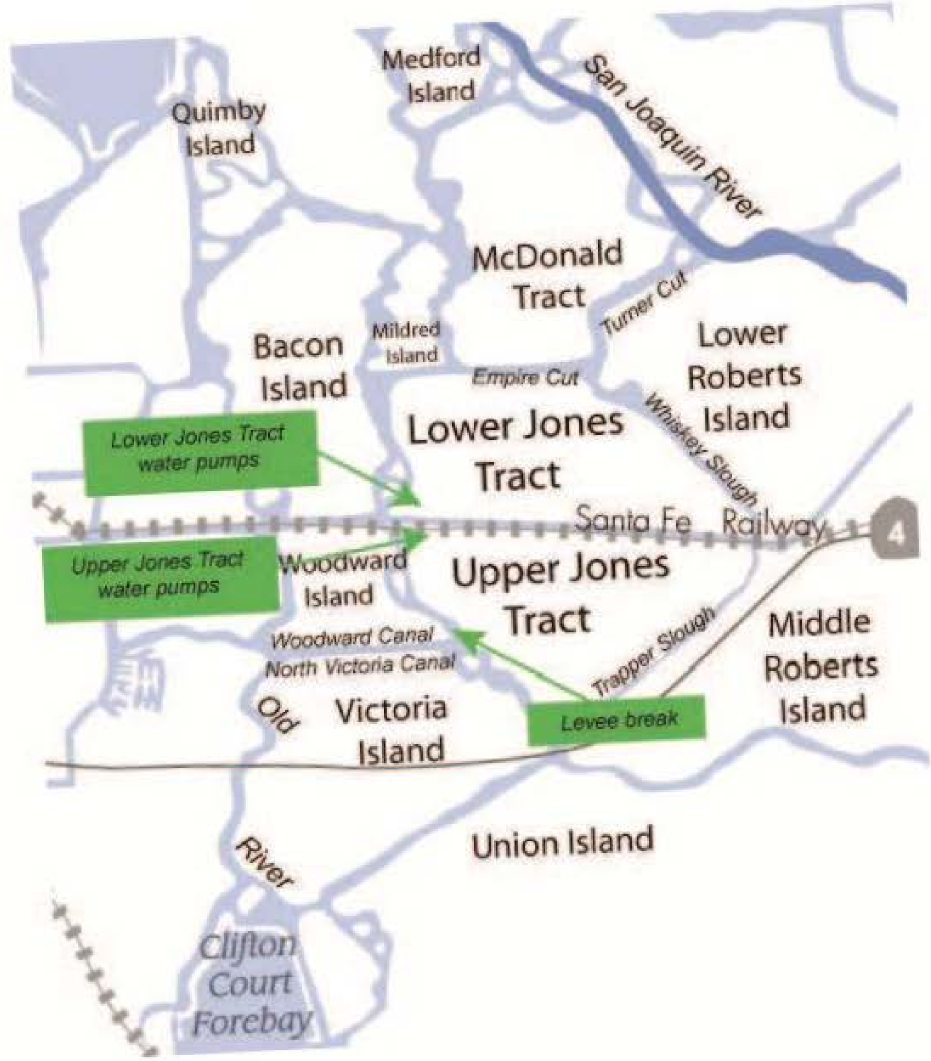
Even though most commonly measured water quality parameters did not rise to a level of concern (e.g., an MCL) during pump-out, other potential effects of interest or concern were found that could impair the use of Delta water as a drinking water source. Increased DOC concentrations, algae concentrations, disinfection byproduct potential, nutrient loading, unpleasant taste and odor compounds, and elevated dissolved manganese and iron concentrations, are all of concern. The DBP potential from DOC loading from peat soils have the most bearing for drinking water use.

The Jones Tract flood provided an opportunity to perform a natural experiment on the DOC production that might be produced by flooding of a Delta peat-soil island. Analysis included a comparison between observed organic carbon concentrations at Jones Tract and those observed or predicted in other studies performed by Department of Water Resources (DWR) and others. A dramatic water quality change was the high concentration of DOC from the peat soils. By a combination of comparing 2004 values to historical averages and Delta Simulation Model (DSM2) numerical modeling, it was possible to conclude that it was quite likely the Jones Tract flood contributed 0.5 to 1 mg/L of additional DOC to channel waters, elevating concentrations of DOC at the Delta water export facilities during pump-out operations. These increases in DOC have municipal water quality implications for any similarly flooded island.

While Jones Tract provided valuable information on water quality during the beginning stages of flooding a Delta island, the dewatering and reclamation prevented it from providing information on multi-year effects. For these effects, the report authors turned to the Special Multipurpose Applied Research Technology Station (SMARTS) study that was already underway at DWR's Bryte Lab (chapter 8). The findings of the SMARTS study showed DOC would continue to be produced by flooded island soils, but that the management of the island flooding and draining processes could affect DOC concentrations and loads. Flooding and draining the island soils resulting in exposure to air was very likely to create an initial rapid DOC release upon re-flooding. Because the fundamental controlling mechanisms of DOC production would be similar between a real flooded island and the SMARTS experimental tanks, it is presumed any island flooded for water storage would behave like Jones tract, but over time the DOC loading may decrease, though never drop to zero.

The potential DOC levels would be affected when the water was moved into and out of the storage island. It is likely that the island would be flooded in the winter with elevated TOC/DOC water (when tributaries are flowing strongly). Island soils would contribute additional DOC until the island was drained in the summer, when surrounding river channel TOC/DOC levels are lower. The resulting stored water would not help Delta management efforts to reach CALFED's water quality goal of 3.0 mg/L for TOC.

Figure 7 –Jones Tract region with pumps and levee break locations marked



Staten Island Wildlife-Friendly Farming Demonstration Study

Duration of Study

Fall 2004–Summer 2007

Investigators:

Carol DiGiorgio

Background and Objectives

Through a competitive CALFED grant process, Ducks Unlimited was awarded a grant to improve water management for waterfowl on Staten Island. Ducks Unlimited collaborated with the Nature Conservancy, and the Municipal Water Quality Investigations (MWQI) Program to conduct island improvements and examine the effects on water quality.

The purposes of this grant were to:

- Develop cost effective and efficient water management plans to improve sustainable agriculture and wildlife friendly practices, with a focus on providing quality habitat for over-wintering waterfowl, such as the greater sand hill crane and northern pintail (State listed and federal species of concern, respectively). Ducks Unlimited and the Nature Conservancy were responsible for these aspects of the grant.
- Determine carbon and nutrient loads discharged from an actively farmed Sacramento-San Joaquin Delta (Delta) peat island, and study the effect of two different soil types on the water quality in fields flooded for waterfowl use. The MWQI Program was responsible for these aspects of the grant.

Little data is available to quantify organic carbon and nutrient loading from actively farmed Delta peat islands. Most estimates of in-Delta agricultural drainage values are based on the Delta Island Consumptive Use (DICU) models rather than data; therefore, there is a high uncertainty associated with estimates of island discharge loads. Direct flow measurements and analyte concentrations from Staten Island provided a more accurate picture of carbon and nutrient loading from farming and wildlife activities. These were also used to help refine the Department's DICU model.

Study Design

Staten Island is approximately 9,200 acres, with 8,400 acres producing mostly corn, wheat, and tomatoes. Until the summer of 2006, the only pumping station on the island was on the southern end, which is also the lowest point on the island. As part of the grant funding, Ducks Unlimited installed a second pumping station on the eastern side of the island in late 2005. To calculate loading, weekly grab and/or autosampler samples were collected in the main drain leading to the pump station, slightly upstream of the inlet port. Grab samples were also collected from the Mokelumne River. Sonic transducers were used to measure flow rates through the discharge pipes. For the study assessing soil types, weekly grab samples were collected from two flooded fields each with different soil types. Samples were analyzed for organic carbon (OC), nitrate, ammonia, total Kjeldahl nitrogen (TKN), total phosphate (TP), dissolved orthophosphate, UVA_{254}, trihalomethanes (THM), and several anion and cation species.

Results/Conclusions

Depending on the season, comparisons between modeled and actual loads of organic carbon showed large discrepancies. During the winter and spring, measured organic carbon loads could be more than 100 times greater than carbon loads predicted by the DICU model. Other loading conclusions included:

- For TOC, nitrate, ammonia, and TKN, the greatest loads discharged off the island occurred in the pre-irrigation/winter discharge season.
- For orthophosphate, the greatest loads discharged off the island occurred in the summer irrigation season.
- For total phosphate, loading was similar between the summer and pre-irrigation/winter season with the greatest monthly load discharged in July 2006.
- Of the nitrogen species monitored, organic nitrogen was the primary form of nitrogen discharged off the island (55%) followed by nitrate (37%) and ammonia (8%).
- Annual TOC flux rates were similar to Twitchell Island's, but greater than flux rates for Colusa Basin Drain (CBD), Harding Slough, or urban discharge from the Natomas East Main Drainage Canal.
- Annual Staten Island nitrate flux rates were approximately half of those for Twitchell Island, but seven times and two times greater than CBD, Mud Slough, or Delta island agricultural drainage, respectively.
- Annual ammonia flux rates were identical to Twitchell Island.
- No flux rates were available for comparisons to Staten Island's TKN, total phosphate, and orthophosphate annualized flux rates.
- With respect to flow and pumping on the island, one of the most important findings was identifying that the greatest volume of water discharged off the island occurred in the summer irrigation season, not the winter rainy season.

This study also showed that water quality was dependent on a number of different factors including water management, season, and water source (i.e. groundwater vs. river water). Simplistically water quality patterns reflected whether source water originated as river or groundwater. Layered on this were the effects of residence times and biological activity. For example, during the summer irrigation season, river water influenced water quality. In the pre-irrigation/winter discharge season, groundwater and the location of the pump stations combined with pumping dynamics determined water quality. Concentrations of electrical conductivity, turbidity, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), total phosphate, and orthophosphate were lower during the summer irrigation season than in the fall and winter. Depending on the analyte, concentrations detected in the pre-irrigation/winter periods could increase tenfold compared to summer values. Statistical differences in pre-irrigation/winter TOC concentrations between the two pump stations were due to pump location, soil characteristics, and residence time of the groundwater on the island. In the winter, pumping and rainfall mobilized nitrate and ammonia. Increases in winter phosphate concentrations were potentially due to the release of phosphate bound to sediments under anoxic conditions. Although the effects of overwintering waterfowl were not examined directly, water quality dynamics could be explained by cropping patterns and the seasonal use of water dictated by agricultural needs. Waterfowl would be expected to affect water quality, but using TKN as a surrogate for waterfowl fecal input, island dynamics appeared to overwhelm any water quality signal provided from waterfowl.

The examination of water quality between two different soil types found that with the exception of ammonia and TKN, there were no significant differences in water quality between the two fields. This lack of statistical differences were probably due to the contiguous spread of water across all field soil types and, in the case of OC, the similar OC content of the soils in the two fields chosen for comparison. However, while water quality was generally similar between the two fields, with the exception of phosphate, statistical differences were always detected between the fields and the pumping plant. These differences were probably due to differences in source water between the fields and the pump stations.

Installation of a new pump station had mixed effects on water quality. In the case of total phosphate, orthophosphate, or ammonia there were no significant differences in concentrations before or after pump installation. However, statistical differences were detected for TOC, nitrate and TKN. These differences, however, could potentially be explained by factors other than the installation of the new pumping plant. In the case of TOC, precipitation patterns could potentially explain significant differences in TOC concentrations before and after pump installation. In the case of nitrate and TKN, bacterial respiration and primary productivity could potentially explain significant differences in nitrogen species before and after pump installation.

Real-Time, Continuous Monitoring of Bromide and Nutrients at Harvey O. Banks Pumping Plant and San Joaquin River near Vernalis

Duration of Study

2005-2008

Investigators

Jaclyn Pimental, David Gonzalez, Steve San Julian

Background and Objectives

Anion monitoring is an important piece of the Real-Time Data and Forecasting (RTDF) project; however increasing the number of grab samples would be both time consuming and expensive. A key component of this project was the assessment of the relative reliability of the ion chromatography systems during the period of the study. The overall objective of this project was to demonstrate that specially designed, semi-autonomous analyzers used in a field setting are a viable means of generating real-time water quality data for use in forecasting and for water utility operations.

Study Design

The automated analyzer, Dionex DX-800, was tested as a replacement for routine grab samples because it had the capability of operating independently on site for two weeks, was remotely accessible through a computer, and could store data until it was transferred to a centralized computer base. Through CALFED funding, the Dionex DX-800 was installed at H. O. Banks Pumping Plant (Banks) and on the San Joaquin River near Vernalis (Vernalis) in 2007, to monitor bromide, nitrate, phosphate, chloride, and sulfate.

Every hour a sample from the continuous stream is filtered then bypassed into a 100 μL loop and injected into an analytical column. Certain analytes are retained on the column longer than others are. After the sample comes off the column, it goes through a suppressor, which lowers the background noise. The sample then flows to the conductivity detector where the analytes are detected. The results are shown on the computer screen as a chromatograph with each analyte having its own retention time and integrated peak that determines its concentration.

Results/Conclusions

The Municipal Water Quality Investigations Program (MWQI), with the use of a Dionex analyzer, was one of the first groups to continually analyze anions (bromide, fluoride, nitrate, chlorine, and sulfate) on site, distribute that information on the internet, and published a paper on the Dionex analyzer's functionality at the two stations.

On average, the reliability of the instruments was 83% and 72% for Vernalis and Banks, respectively. The Dionex analyzer at Banks did not meet the data capture completeness level of 75% until the last six months of the study, and Vernalis only met 100% completeness for five months. The non-operational periods were attributed to part replacement, method adjustments, and problems becoming accustomed to the operational process.

The anion analyzers were accurate when measuring certified standards created by an outside-certified laboratory. A target precision level of 30%, measured as relative standard deviation, was established for both anion analyzers. With only two exceptions, this target level was met.

The results from the study showed that the Dionex analyzer was capable of producing a large amount of acceptable quality data. When working properly, it is capable of sampling hourly, 365 days a year. While the analyzers met the established targets for data quality, it took a significant amount of staff time and program resources to learn how to operate and maintain these analyzers in a remote setting. If a new anion analyzer was purchased, the recommendation was to see if there was another anion analyzer on the market.

Chapter 9 — Journal Articles

The purpose of this chapter is to provide a summary of the published primary literature by employees within Municipal Water Quality Investigations. The reports summarized in this chapter are as follows:

Cryptosporidium and Giardia Recoveries Using Environmental Protection Agency Method 1623

Filter Pore Size Selection for Characterizing Dissolved Organic Carbon and Trihalomethane Precursors from Soils

Size and XAD Fractions of Trihalomethane Precursors from Soils

Trihalomethane-Formation Potentials of Filter Isolates of Electrolyte-Extractable Soil Organic Carbon

Movement of Diuron and Hexazinone in Clay Soil and Infiltrated Pond Water

Trihalomethane Reactivity of Water- and Sodium Hydroxide-Extractable Organic Carbon Fractions from Peat Soils

Comparisons of Organic Carbon Analyzers and Related Importance to Water Quality Assessment

Effects of Urbanization on Organic Carbon Loads in the Sacramento-San Joaquin River, California

Identifying Sources of Dissolved Organic Carbon in agriculturally Dominated Rivers Using Radiocarbon Age Dating: Sacramento-San Joaquin River basin, California

Cryptosporidium and Giardia Recoveries in Natural Waters by Using Environmental Protection Agency Method 1623

Publication

Applied and Environmental Microbiology, Dec. 2002, p. 5952–5955

Duration of Study

December 1999-May 2000

Investigators

Carol DiGiorgio, David Gonzalez, Christopher Huitt

Background and Objectives

Relatively few studies had been done to examine recoveries by U.S. Environmental Protection Agency (EPA) method 1623 with environmentally realistic concentrations of organisms. A spike matrix study was done to test the method using 10 organisms/liter and at turbidity levels commonly found in the State Water Project and tributaries.

The second aspect of the study examined the filtration capacities and recovery efficiencies of the Gelman Envirochek standard and high-volume (HV) capsule filters. Analytes with nonhomogeneous distributions show sensitivity to the volume of water filtered. The selected filter would need to filter a large volume of turbid waters without becoming clogged.

Study Design

The spike matrix experiment used samples collected at the following locations: immediately above Bethany Reservoir on the California Aqueduct, Sacramento River at Hood, San Joaquin River near Vernalis, and the forebay of the Barker Slough Pumping Plant. The 1999 version of method 1623 was tested. Approximately 132 liters of ambient water were collected at a site, and then thoroughly mixed before a 10-liter sample was withdrawn for spiking. Cryptosporidium parvum spikes were prepared with the Iowa isolate, while spiking suspensions of Giardia intestinalis were prepared with the CH3 (methyl) strain. Percent recoveries were calculated by subtracting the number of organisms counted in the unspiked sample from the total number of organisms recovered from the spiked sample and then dividing this difference by the total number of oocysts spiked. For the filtration capacity experiment, samples were analyzed at Barker Slough below Campbell Lake (Campbell Lake). All filtration capacity samples were processed in the field using the 1999 version of method 1623.

Results/Conclusions

The HV filter did filter a larger volume of turbid water than the standard filter without compromising recovery efficiencies, suggesting that the HV filter may be a better choice for natural waters.

At high turbidities (88 to 99 NTU), HV filters were typically able to filter more water than the standard filters, but at some sites neither could filter 10 liters. At low turbidities (11 NTU), both filters were capable of filtering the full 10 liters. Relatively small changes in turbidity affected filtration capacity. The nature of the source water also appeared to affect filtration capacity.

Turbidity appeared to affect the spike matrix recovery experiment. Organism recoveries were lower in turbid verses non-turbid waters. Oocysts recoveries were significantly higher with the HV capsule filter in low-turbidity waters; however, in turbid waters organism recoveries were not significantly different between the two filters. Cryptosporidium recoveries ranged from 36% to 75%, and Giardia recoveries ranged from 0.5% to 53% when the HV capsule was used.

At 20 NTU or more, Giardia cysts recoveries declined steeply. Cryptosporidium recoveries remained at or above 50% at all but the highest turbidity tested. Statistically, variations in Giardia recoveries (r2=0.80) but not Cryptosporidium recoveries (r2=0.16) could be explained by turbidity. When recoveries of 50% or less occurred in both low and high turbid waters, the background matrix of the water might be as important as the absolute NTU value to recovery rates.

The greatest loading of oocysts could occur during periods of rainfall. Increased sampling frequencies would be needed to capture a clumped distribution. Periods of rainfall produce higher turbidities, which compromises the method and filter capacity. Since the erratic distribution of the target organisms occurs, any method must overcome this environmental impediment in order to develop a meaningful analysis. Designing a cost-effective and statistically valid monitoring program that evaluates the sources and load of protozoan pathogens may be difficult.

As compared to Information Collection Rule Supplemental Survey (ICRSS), recovery of 54% of oocyst was higher than the ICRSS results, but the cyst recoveries of 25% were half of the ICRSS results. While method 1623 is an improvement over the earlier Information Collection Rule (ICR) method, accurately measuring pathogen abundance in natural conditions is difficult for method 1623. The study showed matrix interference from the waters tested could compromise the method’s accuracy and precision. Increasing the sample size or the number of replicates may be of little value or use in some waters and the high cost of the method makes additional samples undesirable. Additionally the method is difficult to use for routine monitoring or total maximum daily load studies.

Filter Pore Size Selection for Characterizing Dissolved Organic Carbon and Trihalomethane Precursors from Soils

Publication

ELSEVIER Water Research 39 (2005) 1255-1264

Duration of Study

2003-2004

Investigators

Alex Chow, Fengmao Guo, Suduan Gao, Richard Breuer, Randy Dahlgren

Background and Objectives

Dissolved organic carbon (DOC) is frequently operationally defined as the fraction that passes through a 0.45 µm (micron) filter. Previous studies have looked at trihalomethane (THM) precursors that pass through a 0.45 µm pore size filter and have found inconsistent results. The filter pore size is large compared to a wide range of dissolved molecules and small particles potentially containing organic fractions, which have different reactivity in forming THM's during chlorination based on the different sized DOC fractions. This study examined the effects of filter pore size on the chemical characteristics and THM reactivity of water extracts from two representative soil types found within the Sacramento-San Joaquin Delta (Delta).

Study Design

Scribner Clay Loam soil from Twitchell Island and Rindge Muck soil from Webb Tract were selected to represent the mineral and organic soils, respectively, found in the Delta. The soil samples were collected between 0 and 0.3 meters, and were measured for moisture content, pH, potassium (K), soil organic carbon (SOC), major cations and anions, and cation exchange capacity (CEC). All the water extracts were analyzed for total organic carbon (TOC), ultraviolet absorbance at 254 nm (UVA_{254}), and THM formation potential (THMFP). The solutions used to extract organic carbon (OC) from the soil were deionized (DI) water, 0.005 M calcium (Ca^{2+}) solution, and 0.01M sodium (Na^{+}) solution. A series of filter sizes of 1.2, 0.45, 0.10, and 0.025 µm, were used to divide the organic factions into particulate, colloidal, fine colloidal, and dissolved organic carbon, respectively.

Results/Conclusions

Clay Loam soils contained 4% soil organic carbon (SOC), while the Rindge Muck contained 23% SOC. THM precursors and water extractable organic carbon are proportional to the SOC amounts. The water extractible organic carbon (WEOC) concentration in Rindge Muck was between 2.8 and 4.2 times higher than the Clay Loam was. Additionally, Rindge Muck had 3 to 4 times higher THM formation potential than the Clay Loam.

Using 0.45, 0.1, and 0.025 µm filters, the Rindge Muck retained 2.7%, 12.2%, and 14.3%, of organic carbon, respectively. The organic carbon colloidal fractions (smaller than 0.45 µm) were more homogeneous; however, DOC (smaller than 0.025 µm) represented more than 85% of WEOC. THMP reactivity was similar between colloidal organic carbon (COC) and DOC, as were SUVA (specific

UVA_{254}, or UVA_{254} divided by organic carbon concentration) and specific trihalomethane formation potential (STHMFP) in all four filtrates.

In the Clay Loam extracts, 0.45, 0.1, and 0.025 µm filters retained 5.7%, 42%, and 43% of organic carbon, respectively. Significant amounts of the WEOC were retained in the colloidal (0.1 to 0.45 µm) size range. COC accounted for 36% WEOC, but less than 20% of THM formation. In contrast, DOC accounted for 57% WEOC and 74% of THM formation.

In the Clay Loam soils, the 1.2 and 0.45 µm filtrates had particularly high SUVA but low STHMFP, while the opposite occurred in the 0.1 and 0.025 µm filtrates. High turbidities in the 1.2 and 0.45 µm sizes led to erroneously high UVA_{254} values, and thus SUVA values. The COC factions in water that pass through a 0.45 µm filter are dependent on both the carbon sources that come from the soil type and the type of cation in the water, which is affected by agricultural practices. While conventional wisdom holds that SUVA is positively correlated to STHMFP, the results showed that SUVA is not always a good surrogate for STHMFP.

The cation exchange capacity (CEC) is an indicator of the soil's ability to retain nutrients and prevent them from leaching beyond the roots. The larger the CEC, the more cations the soil can hold, and is usually an indicator of higher fertility. To test CEC, a comparison of extraction solutions was conducted using DI, Na^{+}, and Ca^{2+}, with Ca^{2+} having the strongest absorption. The specific conductance and cation type used in the extracting solution affect the amount and chemical composition of WEOC and THM precursors, and high salinity decreases DOC concentrations in soil water. The DI water and Na^{+} solution had similar results, while the Ca^{2+} solution reduced WEOC more. Clay Loam had a CEC of 37-meq/100 g soil and Rindge Muck's CEC was 149-meq/100 g soil. The amount of positively charged cations that a soil can hold is expressed as milli-equivalents per 100 grams (meg/100 g) of soil. The THM reactivity of the individual factions did not change significantly with the different extracting solutions. Both soils contained similar proportions of sand, silt, and clay in the mineral fraction.

The Clay Loam soils were more sensitive to cation effects than the Rindge Muck was, especially the Ca^{2+} extraction solution. The reduction of WEOC that passed through a 0.025 µm filter was 78% for Clay Loam soils, compared to 50% for Rindge Muck. Rindge Muck contained lower molecular weight (LMW) fulvic acids, while Clay Loam contained higher molecular weight (HMW) humic acids. The SUVA in the Ca^{2+} soils was lower than the Na^{+} soils. The WEOC from Ca^{2+} extracts that pass through 0.025 µm filter contain only the LMW fulvic acid, which is not removed by filtration or coagulation in water treatment plants. Because it remains after pre-treatment, it reacts to form THM or other disinfection byproducts. Further studies on this faction are encouraged.

While the 0.025 µm filtrate contains more homogeneous organic fractions, there was only a 5% difference in organic carbon and THM formation between the 0.1 and 0.025 µm filtrates, indicating that a 0.1 µm filter may be more efficient to collect a representative sample to determine THM precursors and therefore THM potential, especially in samples with high colloid concentrations. On the other hand, 0.45-µm filtrate potentially contains heterogeneous COC, whose chemical behavior is source dependent.

Size and XAD Fractionations of Trihalomethane Precursors from Soils

Publication

ELSEVIER Chemosphere 62 (2006) 1636-1646

Investigators

Alex T. Chow, Fengmao Guo, Suduan Gao, Richard S. Breuer

Background and Objectives

Soil organic matter is an important source of allochthonous dissolved organic matter inputs to the Sacramento-San Joaquin Delta (Delta) waterways, which is a drinking water source for 22 million people in California. The study estimated the abundance of trihalomethanes (THM) precursors in the soil and examined the chemical properties and reactivity of organic carbon fractions. Soil salinity has the potential to affect the fate of dissolved organic carbon (DOC) in soil by affecting the structure of soil organic carbon (OC) and DOC concentration in drainage water. The objective of this study was to understand salt effects on organic carbon and THM precursors leaching from representative Delta soils. The results of current and previous studies were synthesized and integrated to develop a conceptual model for describing the DOC production mechanism in the Delta.

Study Design

The mineral and peat soils chosen for this study were Scribner Clay Loam from Twitchell Island and Rindge Muck from Webb Tract, respectively. Samples were taken from the surface layer between 0 and 0.3 meters. The five different extracts used were deionized water (H_2O), 0.005 M and 0.02 M calcium (Ca) based solution, and 0.01 M and 0.04 M sodium (Na) solution. The electrical conductivity of the solutions bracketed those found in Delta during leaching and runoff conditions.

The organic carbon was separated physically into different size fractions. Water extractable organic carbon (WEOC) can pass through a 0.45 µm filter. Colloidal organic carbon (COC) passed through a 0.45 µm but not a 0.1 µm filter. Fine colloidal organic carbon (FCOC) passed through a 0.1 µm but not a 0.025 µm filter. DOC was anything that could pass through a 0.025 µm filter.

WEOC was chemically fractionated by XAD resin-fractionation into five operationally defined fractions: hydrophobic acid (HPOA), transphilic acid (TPHA), hydrophilic acid (HPIA) hydrophobic neutral (HPON), and transphilic neutral (TPHN). XAD resins are used to extract non-polar, hydrophobic compounds from aqueous solution. The eluate from XAD-8 is defined as hydrophobic acid (HPOA). The hydrophobic neutral (HPON) fractions are those compounds that adsorb onto XAD-8 but are not dissolved during back elution with sodium hydroxide (NaOH). The eluate from XAD-4 is defined as transphilic acid (TPHA). Transphilic neutral (TPHN) fractions are those compounds that adsorb onto XAD-4 resins, but are not dissolved during back elution with NaOH. The hydrophilic acid (HPIA) fraction is the carbon in the XAD-4 effluent.

All filtrates, eluates, and effluents from XAD columns were analyzed for organic carbon (OC) and THMFP.

Results/Conclusions

Less than 2% of soil organic carbon (SOC) in the samples investigated was extractable in the electrolytes studied. The Scribner Clay Loam contained 3.7% SOC, of which 1.4% was extractable. The Rindge Muck contained 23% SOC, five times more than the Scribner Clay Loam, but only 0.6% was extractable. Between the two soils, Rindge Muck contained six times more OC, had a soil cation exchange capacity (CEC) four times greater, and had five times the salinity compared to the Scribner Clay Loam.

The filter fractioned water extractable organic carbon (WEOC) was comprised of 87% DOC, 11% COC and 2% FCOC in the Rindge Muck extracts and 60% DOC, 38% COC, and 2% FCOC in the Clay Loam extracts. The Rindge Muck DOC and COC produced THMFP portions of 85% and 11%, while the DOC and COC in the Scribner Clay Loam created 78% and 20% of the THMFP, respectively. Specific trihalomethane formation potentials (STHMFP) were not significantly different among fractions in the Rindge Muck extracts or between the DOC factions of the soils, but there were significant differences between the fractions of the Clay Loam extracts.

The WEOC fractions contained 16% to 24% transphilic acid (TPHA) and hydrophilic acid (HPIA) and less than 10% of hydrophobic neutral (HPON) and TPIN together. The THMFP in TPHA, HPIA, HPON, and TPIN was about 10% each. The STHMFP of TPHA and HPIA from Rindge Muck and Clay Loam extracts were similar. The WEOC in both soil extracts were about 50%, but produced 65% of THM and were significantly higher than the other fractions, indicating that this fraction may have a higher reactivity. The STHMFP was highest in the HPOA fraction.

The deionized water extract was about 53% hydrophobic acid (HPOA). Na-based extractions resulted in an increase in HPOA to 61% to 67% of total WEOC, and were significant. The Ca-based electrolytes slightly reduced HPOA between an average of 45% and 52%. The differences between water and Ca extracts were not significant ($p > 0.05$). All other fractions appeared relatively stable with no statistical differences between extracts.

Results showed that the application of electrolyte reduced WEOC from soils, did not alter the distribution of size fractions, but slightly altered the distribution of chemical fractions. Additional results suggested that under natural leaching and runoff conditions where electrolytes with both monovalent and divalent cations are present, the DOC fraction (0.025 µm or smaller) and HPOA fraction are the most reactive THM precursors.

The study led to the proposal of a conceptual model to describe the impacts of agricultural practices on DOC production in the Delta. Winter flushing reduces the salinity levels and DOC contractions. During the summer, irrigation and high temperatures alter the soil-water content by potentially promoting microbial activity and producing significant amounts of DOC. The non-biodegradable DOC remains in the field, and when the water table drops, this part of the DOC leaches into the subsurface layer. The high temperatures cause evapoconcentration of soil water that accumulates large amounts of salt in the surface soil. Increases in salinity reduce the DOC accessible to microorganisms. In fall and winter, significant amounts of DOC and salt are accumulated. Precipitation and salt leaching practices reduce salinity, which creates more available DOC, and increases DOC levels in the soil and water. The accumulated DOC and salt concentrations decrease when the fields are flooded and drained through the drainage discharge into Delta channels. The cyclical changes of the farming cycle, summer irrigation, and winter flooding significantly alters the physical, chemical, and biological properties of peat soils and affects the availability, production, and quality of DOC in soils.

Trihalomethane Formation Potential of Filter Isolates of Electrolyte-Extractable Soil Organic Carbon

Publication

Journal of Environmental Quality 34:1992–1997 (2005)

Investigators

Alex T. Chow, Fengmao Guo, Suduan Gao, Richard S. Breuer

Background and Objectives

The properties of chlorine-reactive organic carbon (OC) from peat soils at the time of the study were currently poorly understood and few studies had been conducted with Sacramento-San Joaquin Delta (Delta) mineral soils. The difference in peat and mineral soil composition and disinfectant byproduct formation potential were not well characterized. The goals of this study were to: 1) quantify the extractable organic carbon (EOC) from two representative Delta soils using electrolytes with electrical conductivity values bracketing those of Delta soil drainage waters; 2) use filtration to nondestructively fractionate the bulk soil EOC into isolates with homogeneous properties; and 3) determine THMFP of different fractions to identify organic carbon (OC) fractions of dominant THMFP.

Study Design

The mineral and peat soils chosen for this study were Scribner Clay Loam from Twitchell Island and Rindge Muck from Webb Tract, respectively. Samples were taken from the surface layer between 0 and 0.3 meters. The five different solvents used were deionized water (H_2O), 0.005 M and 0.02 M calcium (Ca) solution, and 0.01 M and 0.04 M sodium (Na) solution. The electrical conductivity of the solutions bracketed those found in Delta. The extracts were then filtered into particulate, colloidal, fine colloidal, and soluble organic carbon for OC quantization and THMFP determination.

The extracts were classified as follows: extractible organic carbon passed through a 1.2 µm filter, particulate organic carbon (POC) passed through a 1.2 µm but not a 0.45 µm filter; colloidal organic carbon (COC) passed through a 0.45 µm but not a 0.1 µm filter; fine colloidal organic carbon (FCOC) passed through a 0.1 µm but not a 0.025 µm filter; and soluble organic carbon (SOC) was anything that could pass through a 0.025 µm filter.

Results/Conclusions

Less than 1.5% of the soil organic carbon (OC) was extractable by the electrolyte solutions of calcium and sodium.

Between the two soils, Rindge Muck contained six times more OC, had a soil cation exchange capacity (CEC) four times greater, and had five times the salinity of the Scribner Clay Loam. In both soils, the SOC and COC were the dominant fractions of water extractable organic carbon (H_2O-EOC) and the two factions produced between 91% and 93% of the THMFP. A majority of the H_2O-EOC remained after passing through a 0.025 µm filter, and it is suspected that under natural soil leaching and runoff conditions, the majority of THMFP is associated with OC smaller than 0.025 µm in diameter, for both soils.

The Rindge Muck consisted of 22.9% organic carbon (C), and H_2O-EOC was 1.47 g C/kg soil, which was 0.6% of the soil organic C. The Scribner Clay Loam had 3.7% soil organic C, which is about one-sixth that of Rindge Muck; H_2O-EOC was 0.53 g/kg soil, which was 1.4% of the soil organic C.

When divided into factions, Rindge Muck contained 10% COC, 7% POC and FCOC combined, and 86% SOC that produced 81% of THMFP. The Scribner Clay contained 36% COC, 8% combined POC and FCOC, and 57% SOC that produced 74% of the THMFP.

The effects of the electrolytes were cation dependent. Compared to deionized water, the Na-based electrolytes extracted between 5% and 11% less organic carbon from Rindge Muck and between 17% and 34% less organic carbon from Scribner Clay. There was no significant difference in THMFP between the H_2O and both of the Na-based electrolytes in both soils. While the Ca-based electrolytes affected both soils, it had a greater effect on the mineral Scribner Clay Loam soil. The two Ca-based electrolyte solutions had a reduced ability to extract organic carbon, which was more than 50% in the Rindge Muck and 87% in the Scribner Clay Loam, as compared to H_2O-EOC. In the Rindge Muck soil, the combined THMFP fractions extractible by Ca were 51% less than deionized water extraction. Three of the four Scribner Clay fractions could not be quantified for THMFP; SOC was responsible for almost 100% of the THMFP.

Results suggested that under natural leaching and runoff conditions where both monovalent (e.g., Na+) and divalent (e.g., Ca++) cation electrolytes are present; the majority of THMFP are associated with the smallest size fraction, regardless of soil type.

Movement of Diuron and Hexazinone in Clay Soil and Infiltrated Pond Water

Publication

Journal of Environmental Quality 34:2005–2017 (2005)

Duration of Study

December 1999–June 2000

Investigators

Terry Prichard, John Troiano, Joe Marade, Fengmao Guo, and Mick Canevari

Background and Objectives

The contamination of ground water by herbicides is well documented and has been studied throughout agricultural regions. Herbicides that have been detected in groundwater can continue to be used if management practices mitigate the threat of contamination, as this balances economic considerations with environmental protection. However, for mitigation to be used, it must be determined what pathway the residues are using to move into the groundwater.

Near Tracy, California, seven domestic wells tested positive for the pre-emergent herbicides atrazine, diuron, hexazinone, and simazine. That led to a study in Tracy during the 2000 growing season on an alfalfa field to determine the residual pathways of hexazinone and diuron into groundwater.

Study Design

Samples were taken before the application of the emergent herbicides, before the first irrigation and after the second irrigation. The field was irrigated using the border-check method where water is applied to the elevated end of the field and runs down the length of the check. Herbicides were applied to the field with the addition of surfactant and samples were taken after each irrigation.

Results/Conclusions

Diuron and hexazinone were not detected below 152-mm in the soil samples. However, they were found in both the ground water and pond holding water samples. Macropore flow was ruled out as a pathway due to the thickness of the clay layer and the depth to ground water (4500 mm). Instead, the investigation associated the collected pond water as the prevalent pathway for herbicide residues at this site to enter the groundwater.

The runoff water transported the herbicides into the holding pond where contaminated water seeped through the sides of the pond and raised localized ground water levels. The results suggested mitigation should focus on the runoff water. One suggestion was pumping of pond water for reuse in the same or adjacent field, instead of letting the water collect in the pond. The investigation speculated that by reducing the time and volume of water available for infiltration the amount of pesticides getting into the groundwater would be reduced.

Trihalomethane Reactivity of Water- and Sodium Hydroxide–Extractable Organic Carbon Fractions from Peat Soils

Publication

Journal of Environmental Quality 35:114–121 (2006)

Investigators

Alex T. Chow, Fengmao Guo, Suduan Gao, Richard S. Breuer

Background and Objectives

At the time of the study, very little was understood about the properties and characterization of the molecular nature of reactive organic carbon (OC). In order to get reliable characterization of reactive organic carbon, extraction, isolation, and concentration of the reactive organic carbon from the peat soil was required.

In this study, water (H_2O) and sodium hydroxide (NaOH) were used to extract bulk soil organic carbon from three soils in the Sacramento-San Joaquin Delta (Delta). The samples were compared for the trihalomethanes (THM) reactivity of organic carbon. The soil was also fractionated into humic acids, fulvic acids, and nonhumic substances to examine THM reactivity.

Study Design

Soil samples were taken from Bacon Island, Bouldin Island, and Webb Tract. Bacon Island soil was classified as Kingile-Ryde Complex and it contains the most clay of the three soils. Bouldin Island and Webb Track both had Rindge Muck soil classifications, and contained twice as much soil organic carbon compared to the Bacon Island soil. The three soils represented the major organic peat soils in the Delta. Samples were taken from the surface layer between 0 and 0.3 meters.

Deionized water (H_2O) and a 0.1M sodium hydroxide (NaOH) solution were used to extract soil organic carbon. To determine the quantity of THMFP, the soil organic carbon was separated into humic acids, fulvic acids, and non-humic substances. The H_2O and NaOH extracts were analyzed for total organic carbon (TOC), ultraviolet absorbance at a wavelength of 254 nm (UVA_{254}), and THMFP.

Results/Conclusions

The extractable soil organic carbon was 0.4% to 0.7% for H_2O and 38% to 51% for NaOH. Fulvic acid dominated the H_2O extract and made up about half of the extractable organic carbon. Depending on the soils, the humic acids and nonhumic substances contributed 23% to 35% of the extractible organic carbon. On Bacon Island, humic acids were more than 10% greater than nonhumic substances, but the Bouldin and Webb muck contained 5% greater nonhumic substances than humic acids. The percent of fulvic acids were similar to nonhumic substances in the three soils with the H_2O extract. The organic carbon in the NaOH extract was 80% was humic acids, 10% fulvic acids, and 10% nonhumic substances.

H_2O extract was on average 14% less than the NaOH extract. The difference is statistically significant. Aromatic organic substances are significantly more abundant in NaOH extracts than in H_2O extracts. The specific trihalomethane formation potential (STHMFP) of NaOH extracts were on average 29% greater than H_2O extracts and may be attributed to a higher percentage of humic acids in the NaOH extracts.

The specific ultraviolet absorbance (SUVA) of humic acids, fulvic acids, and nonhumic substances varied with extractants. SUVA of the average fulvic acids was significantly higher than the similarly averaged SUVA of humic acids and non-humic substances. Using NaOH extract, humic acids had the greatest average SUVA, followed by fulvic acids, and nonhumic substances, and the differences in the averages where highly significant. Humic acids from Bacon Island had the greatest SUVA, while Webb muck had the smallest. Fulvic acid SUVA was lowest with Bouldin Island muck. Bacon Island Kingile-Ryde Complex soil and Webb Tract Rindge Muck had similar fulvic acid SUVA. There was no difference in the nonhumic substances in the soils.

In H_2O extracts, the STHMFP followed the pattern of SUVA. STHMFP of fulvic acids was significantly higher than humic acids and nonhumic substances, which had no significant differences. NaOH extracts of fulvic acids and humic acids were similar and both were significantly different from nonhumic substances. STHMFP of humic acids was highest on Bacon Island, followed by Bouldin Island, and then Webb Track. Both the H_2O and NaOH extracts of fulvic acids and nonhumic substances were similar.

Humic acids extracted by NaOH had significantly higher SUVA and STHMFP compared to H_2O extracts, while the SUVA and STHMFP of the nonhumic H_2O-extracted fractions were greater than the NaOH extracted organic carbon. The fulvic acids had no distinguishable differences in STHMFP for either extract.

Fulvic H_2O extracts were more reactive than humic acids and nonhumic substances, and contained the most THM reactivity. With NaOH extracts, nonhumic substances were less reactive than the equally reactive fulvic and humic acids; however, humic acids contain the most THM reactivity in all three soils. The SUVA patters of organic carbon fractions from H_2O extracts were consistent with STHMFP pattern. The patterns of SUVA and STHMFP in NaOH extracts were inconsistent, and showed that SUVA did not accurately predict reactivity.

Comparisons of Organic Carbon Analyzers and Related Importance to Water Quality Assessments

Publication

San Francisco Estuary and Watershed Science. Vol. 5, Issue 2 [May 2007] Article 3

Duration of Study

Phase 1: December 2001-October 2002; Phase 2: December 2002

Investigators

Murage Ngatia and Jaclyn Pimental

Background and Objectives

From December 2001 to October 2002, samples were collected in order to compare the capability of various analyzers ability to measure organic carbon in assorted water samples. The study also examined whether differences in any of the instruments might trigger a regulatory requirement due to different concentration measurements.

Study Design

In phase one, eight sampling events took place at five different locations throughout the Sacramento-San Joaquin Delta. The locations were Sacramento River at Hood, San Joaquin River near Vernalis, H.O. Banks Pumping Plant, Check 13 on the California Aqueduct above San Luis Reservoir, and at Barker Slough. The three methods compared were high temperature combustion (HTC), ultraviolet persulfate oxidation, and wet chemical oxidation. Phase one included three high temperature combustion and three chemical oxidation analyzers used by the laboratory, field stations, and commercial contract laboratories, while phase two included three additional volunteer participants. Phase two used nine instruments to test four certified performance evaluation (PE) samples; potassium hydrogen phthalate (KHP), KHP and 30 mg sodium bicarbonate ($NaHCO_3$), caffeine, and caffeine and 30 mg $NaHCO_3$.

Results/Conclusions

Minitab 14 was used for statistical analysis. The tests used were Kruskal-Wallis (K-W) test for significant differences and K-W multiple comparison pair-wise tests using the Bonferroni method with a p-value of 0.013. In phase one, the use of box-plots showed the instruments skewed the results, with one instrument having a higher and wider scatter than the others. Pair-wise, significant differences occurred in 20% of the comparisons; however, one instrument was the cause of 80% of them. The results of the PE sample analysis indicated a few instruments were either not properly calibrated or had other problems. Furthermore, both an HTC and oxidation unit showed trouble analyzing KHP + IC (inorganic carbon), indicating that both methods can have difficulties removing IC.

Normal inter-laboratory comparisons are to blame for the differences not related to the one problematic instrument. Some of the differences are from operator errors or instrument anomalies. The U.S. Environmental Protection Agency (EPA) recognizes IC removal problems as a cause of inconsistencies due to carryover organic carbon (OC) from sparged gas in HTC analyzers, calculation errors between total carbon and IC, or an IC calibration curve that is too low. Given these problems, the EPA developed a newer analytical method to remove IC. The method was not available at the time of the study.

Previous studies comparing the methods have yielded results presenting outcomes ranging from comparable, to mixed, or HTC being more accurate. In phase one of this study, the instruments were operating under normal conditions, providing a true evaluation on the quality of Department of Water Resources (DWR) grab samples. The second phase showed the individual accuracies of the methods used by different machines. The results discredited the assumption that HTC data is superior to oxidation data. It also addressed the concerns of using different analyzers within DWR. HTC instruments are neither more efficient in handling matrix variations and analyzing particulates nor provide preferable data. Ultimately, as long as the instruments are properly operated, all standard methods are acceptable.

Effects of Urbanization on Organic Carbon Loads in the Sacramento River, California

Publication

Water Resources Research, VOL. 43, W11422, doi:10.1029/2007WR005954, 2007

Duration of Study

1999-2005

Investigators

J.O. Sickman, M.J. Zanoli, H.L. Mann

Background and Objectives

Conversion of natural landscapes to agricultural and urban areas is occurring worldwide, but little information has been collected on how urbanization is affecting organic carbon loading in rivers. Total organic carbon (TOC) loading is increased by urbanization through larger wastewater treatment plant (WWTP) releases, and during rainfall-runoff when the peak discharges happen quicker and flows are larger. A better understanding of urbanization effects on organic matter is needed to assess how ecosystems are responding to environmental change. In the Sacramento-San Joaquin Delta (Delta) region, soil oxidation produced more dissolved organic carbon (DOC), while TOC production from phytoplankton was low, potentially altering Delta productivity.

The primary objective of this study was to quantify hydrologic fluxes of organic carbon from urban areas surrounding Sacramento, and evaluate whether these inputs are a major source of organic carbon and disinfection byproducts precursors in downstream reaches of the Sacramento River. A secondary objective was to identify sources of organic carbon in urban runoff.

Study Design

The Steelhead Creek watershed, also known as the Natomas East Main Drainage Canal (NEMDC), was selected for the study site. The watershed had been urbanizing rapidly, and drains a predominantly urban landscape, which enters the Sacramento River near downtown Sacramento. NEMDC drains about one-third of the Sacramento region that at the time was 59% urbanized, 7% rice-producing farmland, and 34% undeveloped landscape.

To test the hypothesis that soil organic matter was the primary source of DOC in Sacramento non-point runoff, the study quantified TOC loading from point and non-point sources. The loads were compared to the amount of organic carbon carried downstream. Samples were taken monthly at Steelhead Creek at the El Camino Bridge (NEMDC), five km upstream from the convergence of the Sacramento and American Rivers, and at the Sacramento River at Hood (Hood), which contains the urban runoff and WWTP discharges from Sacramento. Precipitation based sampling events also occurred, producing 83 samples.

Samples were analyzed for TOC, DOC, ultraviolet absorbance at 254 nm (UVA_{254}), specific ultraviolet absorbance (SUVA), and TTHMFP. Two sampling events occurred in order to isolate DOC for radiocarbon dating at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory. To gain better understanding of urban DOC sources and reactivity with chlorine, measurements were made of the isotopic composition, chemical structure, and reactivity. Flow estimates used to calculate loading were from United States Geological Survey (USGS) gauging station information, as well as a later gauging station placed at NEMDC. Urban TOC loads were calculated by combining regional estimates of non-point source TOC loading with point source inputs from Sacramento's main wastewater treatment plant.

Results/Conclusions

The Sacramento River is the single largest input of TOC to the Delta and much of it reaches the intake pumps. During the dryer season, loading was minimal with maximum loading occurring in January.

The median measured values of TOC concentrations were 2.1, 8.9, and 23 mg/L from Sacramento River, non-point urban runoff, and wastewater treatment plant effluent, respectively. On an annual basis, at least 17% of the TOC in the Sacramento River downstream of Sacramento came from urban runoff, with 10% derived from the Sacramento Regional Wastewater Treatment Plant, and 7% from non-point runoff. NEMDC was 0.1% to 3% of discharge to river flow monthly.

During first flush storms, NEMDC TOC concentrations measured between 10 to 49 mg/L and concentrations could stay elevated up to a week. The corresponding TOC concentrations at Hood increased 25% to 100%. At shorter timescales, urban runoff contributed a larger proportion of Sacramento River TOC loads: the 10th, 50th, 90th, and 99th percentile contributions of Sacramento metropolitan area sources to daily TOC load in the Sacramento River were 10%, 20%, 38%, and 80%, respectively.

Measurements of the radiocarbon content (age) of DOC, SUVA, and specific trihalomethane formation potential (STHMFP) was made to gain a better understanding of urban DOC sources and fate. Even though radiocarbon measurements showed non-point DOC was substantially older than river samples, the DOC had similar SUVA and STHMFP. The findings indicated non-point runoff DOC is from older soil organic matter and losses of soil organic matter continue after agricultural soils are urbanized. In relationship to agricultural drainage, Sacramento non-point urban runoff has slightly lower disinfectant byproduct formation potential per mole DOC, and slightly higher SUVA.

Identifying sources of dissolved organic carbon in agriculturally dominated rivers using radiocarbon age dating: Sacramento-San Joaquin River basin, CA

Publication

Springer Biogeochemistry DOI 10.1007/s10533-009-9391-z published online 14 November 2009

Duration of Study

2003-2005

Investigators

James Sickman, Carol DiGiorgio, M. Lee Davisson, Delores Lucero, Brian Bergamaschi

Background and Objectives

The increasing concentrations of carbon detected in many rivers worldwide have been attributed to changes in terrestrial carbon balance caused by several factors including: climate change, CO_2 fertilization of terrestrial primary productivity, land use change, atmospheric deposition of nitrogen, and soil recovery from acid deposition. Few studies had been done to examine the impact on dissolved organic carbon (DOC) loads in large rivers when natural ecosystems are converted to agriculture.

This study sought to answer two questions regarding DOC sources: (1) Does the DOC carried by the two largest rivers of California's Central Valley derive from destabilization of soil organic matter? (2) What is the dominant source of the DOC load in municipal water exports from Sacramento-San Joaquin Delta (Delta)?

Study Design

To answer question 1, measurements of DOC radiocarbon content were combined with other diagnostic characteristics of DOC to qualitatively assess whether soil-derived carbon is major contributor to riverine DOC loads. To answer question 2, measurements of DOC concentration and radiocarbon content were combined with a hydrologic model of the Delta to test whether DOC contributions to the California State Water Project (SWP) can be modeled as a conservative mixture of internal sources (Delta agricultural drainage) and riverine inputs (Sacramento and San Joaquin rivers).

Surface water samples were collected approximately monthly from April 2003 to March 2004. Samples were collected from Sacramento River at Hood (Hood), San Joaquin River near Vernalis (Vernalis), SWP at the H.O. Banks Pumping Plant, and agricultural drains on Twitchell, Bouldin, and Bacon Islands. In April 2005, additional samples were collected in the Kaweah River drainage of Sequoia National Park to provide boundary conditions needed in the isotopic mixing models.

The samples were divided into whole water DOC (WW) and hydrophobic organic acids (HPOA). Whole water DOC was passed through a 0.45 µm filter and contains dissolved organic carbon and colloidal organic matter. The hydrophobic organic acids fraction is organic matter containing aromatic and aliphatic carboxylic acids, and aquatic humic substances. DAX 8 adsorbent resin was used to isolate and measure ^{14}C concentrations in hydrophobic acid fractions. All WW and HPOA isolates were analyzed for radiocarbon content at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory.

Results/Conclusions

Decades after ecosystems are converted to agriculture, old carbon losses continue. The bulk DOC age was the oldest reported for large rivers. The source of the carbon is suspected to be from either soil organic matter disturbed by human activity or from petroleum-based compounds.

New carbon will have relatively young isotope ratios, and be enriched with ^{14}C, whereas old carbon will be depleted in ^{14}C. The $\Delta^{14}C$ HPOA fractions were -204‰, 76‰, 91‰, and 2‰, for agricultural drainage, Hood, Vernalis, and at the intake of the SWP respectively. The non-HPOA factions were -254‰, -152‰, -218‰, and -175‰, for agricultural drainage, Hood, Vernalis, and at the intake of the SWP respectively. The whole water DOC (WW) $\Delta^{14}C$ was older than the HPOA factions were, as indicated by lower $\Delta^{14}C$ values. The mean WW$\Delta^{14}C$ in the rivers was approximately 1,250 to 1,900 years, and was 2,300 radiocarbon years in agricultural drains.

The average $\Delta^{14}C$ of WW DOC suggests that the majority of riverine DOC delivered to the Delta is derived from soils within the Sacramento and San Joaquin valleys. As rivers pass through regions of intensive agricultural production, older DOC is added, as indicated by the higher WW-$\Delta^{14}C$ values from the Kaweah River. This source of old hydrophilic DOC would also explain the distinct apparent age difference between the HPOA and the non-HPOA fractions. The HPOA fraction from agricultural drainage was 45% to 55% of the total DOC and 45% to 60% of the river and SWP samples.

The Sacramento River contributes about 50% of the water at the SWP, followed by the San Joaquin River, Cosumnes River, Mokelumne River, agricultural drains outside central Delta, and lastly central Delta agriculture drains.

About half of the DOC loads found at the SWP come from Sacramento River, with up to 33% from agricultural drainages, and 17% to 35% from primary productivity during the growing season. The modeled WW$\Delta^{14}C$ only matched measured $\Delta^{14}C$ in three of the twelve months, but it did capture upward and downward trends in WW$\Delta^{14}C$ values. The model predicted higher WW$\Delta^{14}C$ (younger) in December through February, during higher river discharges, and predicted lower (older) WW$\Delta^{14}C$ during the late spring and summer. The bias in the WW$\Delta^{14}C$ models derived from replacement of older riverine DOC with younger DOC from primary production (i.e., turnover of the DOC pool) during the summer.

Chapter 10 — Modeling Reports and Papers

The purpose of this chapter is to provide a summary of the various modeling work done by and for Municipal Water Quality Investigations. The reports summarized in this chapter are as follows:

Delta Alternatives Water Treatment and Cost Computer Modeling

Revisions of Representative Delta Island Return Flow Quality for Delta Simulation Model II and Delta Island Consumptive Use Model Runs

Modeled Impacts of Delta Peat Island Drainage on Organic Carbon Levels at Selected Delta Municipal Water Intakes

Proof of Concept of Forecasting of Water Quality

Delta Simulation Model II Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal, Phase 1

Delta Simulation Model II Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal, Phase 2 Analysis

Delta Alternatives Water Treatment and Costs Computer Modeling

Duration of Study

1994-1998

Investigators

Department of Planning staff, Malcolm Pirnie, Inc., Municipal Water Quality Investigations staff

Background and Objectives

Models help improve the ability to calculate the costs and savings associated with various Sacramento-San Joaquin Delta (Delta) action alternatives. The purpose of the Delta Alternatives Water Treatment and Costs Model to help provide answers as to where the best locations are that would yield good water quality with the lowest treatment requirements.

Study Design

In 1997, Malcolm Pirnie, Inc. was awarded a contract to develop a computer model to quantify source water quality, treated water quality, and treatment costs associated with Delta alternatives. The model was based on the U.S. Environmental Protection Agency's (EPA) Water Treatment Plant Model that was used to predict the effects of modifying Delta conditions on distribution system water quality.

The Malcolm Pirnie model was a modified version of the EPA model. The Department of Water Resources Delta Trihalomethane Formation Potential model and Delta Island Consumptive Use model were used as boundary conditions representing influent water quality to the Malcolm Pirnie model. The two DWR models were developed to predict water conditions after physical changes in the configuration of the Delta. The modified Malcolm Pirnie model would then be operated to evaluate the cost of varying byproduct concentration to water treatment facilities based on different Delta alternatives.

Specific tasks were to:

- Modify the EPA's Water Treatment Plant model by:
    - Incorporating Paul Hutton's neural network module, which predicted disinfection byproducts concentrations as a function of water quality parameters such as bromide, organic matter, and chlorine dose.
    - Modifying the Water Treatment Plant model so it could be used as input to the Culp-Wesner-Culp WATERCO$T model so that functions such as cost curves can be included.
- Develop costs estimates for construction, operation, and maintenance of alternative water conveyance and storage facilities.
- Run the modified model to develop cost curve relationships between downstream water treatment and Delta management alternatives. Input factors included 60 combinations of raw water total organic carbon and bromide concentrations from three water transfer and storage alternatives under two hydrologies.
- Deliverables for Malcolm Pirnie, Inc. were a report on the results of the work done, a training workshop on the model, technical support for one year, and to provide any software or documentation revisions and instructions.

Revision of Representative Delta Island Return Flow Quality for Delta Simulation Model II and Delta Island Consumptive Use Model Runs

Report Date

December 2000

Investigators

Marvin Jung and Associates

Background and Objectives

An important goal set by CALFED was development of models to simulate historical water quality conditions in the Sacramento-San Joaquin Delta (Delta). The purpose of the model run study was to explain the approach and data set used to represent the water quality parameters used in the Delta Island Consumptive Use (DICU) and Delta Simulation Model II (DSM2) computer models. In order for models to be successful, two things must be established; 1) Confidence in the baselines levels for salts and organic carbon used in the models, 2) Error bounds for future simulation results. By running the model, the goal was to identify data gaps and weak modeling assumptions, and then make refinements and adjustments to the models.

Study Design

To develop the monthly values for dissolved organic carbon (DOC), data collected from drainage water collected by Municipal Water Quality Investigations (MWQI) from 1982-1997 was tabulated, and then grouped and combined by island and tract. Statistical analysis and plots were done on the data to divide them into three sub-groups based on trend and highest DOC concentrations. Unsampled areas were given similar classifications based on patterns and characteristics of bordering areas.

Similar to DOC, electrical conductivity (EC) data was tabulated, plotted, and based on general trends of the highest EC values, subdivided into four EC ranges and mapped for regional differences. Based on primary water source, monthly averages of EC, total dissolved solids (TDS), bromide, and chloride were computed for the three subregions described in Bulletin 123, published in 1976.

DOC, ultraviolet absorbance (UVA_{254}), THMFP, bromide, and chloride correlations were determined. In addition, monthly average values computed for TDS, calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), and sulfate (SO_4), divided by sub-region, and plotted to find seasonal trends. Descriptive statistics, dot plots, and box and whisker plots of monthly DOC concentrations were made for each island. The seven-year hydrological period chosen was 1991-1997. The historical daily changing flows and water levels were put into the model.

Results/Conclusions

DOC concentrations were associated with location, season, soil type, and land surface elevations. Four islands located on the periphery of the Delta lowland were ranked as having low-DOC (15 mg/L or less). There were nine mid-range islands occurring in the Delta lowlands with DOC values of 16 mg/L to 30 mg/L. The remaining 19 islands in the lowland were classified as high-range DOC subarea, with values greater than 30 mg/L. Observed DOC values were lower in the summer, thought to be caused by pumping drain water off of the islands.

To determine if there were any strong relationships among DOC, THMFP carbon (TFPC), and UVA_{254} nm, regression analysis from 1991-1997 was used. Correlations were strong between DOC and UVA (r=0.95), and good between TFPC and DOC (r=0.86), and TFPC and UVA (r=0.87). Overall, there was no significant difference among the three DOC range subareas.

Bromide concentrations were influenced by seawater intrusion and primary source water. The Pearson correlation matrix was used to show that bromide concentrations correlated extremely well for EC, TDS, CI, and Na (r=0.96-0.98) in the western Delta; however, the western Delta was also impacted by daily tides and had the highest EC concentrations (more than 2001 µm). The northern segment of the Delta had the lowest EC drain values (less than 1001 µm), were barely impacted by tides. The highest correlation with chloride was bromide (r=0.85), and the EC correlation to TDS was r=0.98. The southeastern portion of the Delta was less influenced by tides, had mostly midrange EC values (between 1000 and 2000 µm), the best correlation was between EC and TDS (r=0.98), and chloride correlated well with bromide (r=0.93).

The mineral constituents of TDS, calcium, magnesium, sodium, chloride, and sulfate were computed to find the monthly average concentrations and then plotted to show seasonal trends by subregions. To avoid skewing data, data was omitted from highly saline islands and tracts, and when no other values were available for the same region. Mineral salt concentrations were generally highest in the winter when pumping off drain water leached deposited salts from summer irrigation. Like EC and bromide patterns, the northern Delta regions had lower salt concentrations, while the west Delta had higher values.

Modeled Impacts of Delta Peat Island Drainage on Organic Carbon Levels at Selected Delta Municipal Water Intakes

Report Date

October 2003

Investigators

Carol DiGiorgio

Background and Objectives

By using the Delta Simulation Model 2 (DSM2), the study was able to provide a first look at the effects of Sacramento-San Joaquin Delta (Delta) island drainage to the dissolved organic carbon (DOC) concentrations at the municipal water intake facilities.

Study Design

Limited access to Delta island agricultural drains make it difficult to quantify the drainage volume of water leaving the island with the purpose of understanding Delta island carbon contributions. The Delta Island Consumptive Use (DICU) model for lowland agricultural diversions and returns in the Delta was developed, and estimates of modeled volumes and monthly trends have shown general agreement with actual drainage volume measurements. The DICU is part of the larger DSM2 model, which is central to predicting water quality parameters throughout the Delta and intake facilities.

By running the DSM2 model with and without estimated DOC loads from the DICU model, theoretical best and worst-case scenarios were examined. The scenario outcomes were determined by examining any pattern changes and relative percentage changes in the simulated runs. If no appreciable change was observed at the Delta intakes, then further perusing modeling on Delta island carbon contributions would be impractical.

The locations chosen for the model were H. O. Banks Pumping Plant (Banks), the Tracy Pumping Plant, Old River at Highway 4, and Old River at Rock Slough. The conditional setup for operation of various gates, barriers, and pumping regimes within the model were run under D-1641 conditions for the 16 year planning sequence of 1976 to 1991. Marvin Jung and Associates, Inc. developed the drainage values used in the model and all monthly data was averaged to allow comparisons. The island drainage was divided into three types: a low DOC value (below 15 mg/L), a mid-range DOC value (between 16 mg/L to 30 mg/L), and a high DOC value (above 30 mg/L). These classifications were based on location, season, soil type, and land surface elevation taken from 1982 to 1987. Water years were classified either as wet or dry to determine if there was any effect of removing island drainage under different hydrological conditions.

Results/Conclusions

The modeled runs did show that the reduction of DOC from Delta island drainages had an impact on DOC levels recorded at the four study locations. No matter the year type or the season, removal of DOC from Delta island drainages reduced DOC concentrations at the intakes by 1% to 65% over the 16-year model run. The effect was more pronounced during dry years, with average yearly concentrations being reduced by 19% to 49%. In wet years, the average DOC concentrations was reduced by 5% to 42%. Monthly average decreases ranged from 17% to 42%.

Seasonal and monthly patterns also occurred, which coincided with agricultural activities. The patterns showed DOC removal in July through September provided greater improvement than October to December. In three of the four sites, the average yearly reduction was 32% to 35% and the average yearly reduction was 25% at the Tracy Pumping Plant. In addition, the greater reduction of DOC at the intakes during the summer occurs during peak demand.

From October through the winter, another peak in DOC occurs. During the latter part of fall, farmers will flood and drain their fields to remove salt buildup, and discharge water with higher DOC levels. The other phenomenon that occurs in winter is storms create flush events that carry increased DOC loads and flow towards the intakes. In contrast to the summer background levels, winter DOC levels can create large and rapidly changing DOC concentrations at the intakes. It is predominantly in dry years that island drainage treatment provides wider changes in DOC concentrations.

For this model run, the only variation that changed was the estimated amounts of DOC from Delta island drainage. By looking at these background levels, summer DOC levels are more stable compared to concentrations during the winter or from runoff. One implication is that despite contributions from other sources within the Delta, agricultural drainage could potentially have a significant impact during the summer and early fall growing season. Reducing DOC concentrations in agricultural drainage during these times potentially has the greatest ability to improve drinking water quality at the intakes.

Proof of Concept of Forecasting of Water Quality

Report Date

June 2003, December 2003, and January 2004. The project was conducted in three stages, resulting in three report dates.

Investigators

Bob Suits, Jim Wilde, Tony Liudzius, and Paul Hutton

Background and Objectives

One goal of the Real-Time Data and Forecasting project is to advance the use of real-time water monitoring with computer models in order to provide water quality forecasts. The multistep process allows forecasts to be made for the Sacramento-San Joaquin Delta (Delta), the California Aqueduct, and O'Neill Forebay, eventually extending the model to include the South Bay Aqueduct. Another purpose is to determine the feasibility and potential usefulness of such forecasts because they will vary depending on how early or late it is in the precipitation season. By looking at the forecasts, the strengths and weaknesses in the forecasting assumptions and tools can be identified. The forecasts can be supplied to contractors, allowing them to stay up to date on supply conditions and delivery capacity.

Study Design

The proof of forecast used four scenarios, measured three water quality constituents at five reporting locations using three different models for the period of January 1998 through December 1998. The four scenarios used the historical hydrology and operations, and DWR's 50% Exceedance Forecasts for January 1, March 1, and May 1. Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Bromide were the water quality constituents. Depending on the model, various inputs including flow, EC, imports, and exports were assumed for the simulations. The first proof of concept used the DSM2 model to forecast H. O. Banks Pumping Plant (Banks) and Tracy pumping plant values. The second proof of concept used the Banks and Tracy values as inputs for the O'Neill/San Luis blending model and the California Aqueduct model to forecast the values at O'Neill outlet and Checks 41 and 66. The startup settings of any constituents reflected the actual Delta conditions up to the start of the simulation.

Results/Conclusions

The relationship between flow and salinity can greatly affect the outcome of a model when determining exports and water quality at the intakes, as was shown in the simulations. During times of high river flows, EC in the southwestern and western Delta is flushed out and pushed away from the intakes at the State Water Project (SWP) and Delta-Mendota Canal (DMC). Another effect of very wet years is that Delta exports and actual deliveries of aqueduct water is reduced. Low flows caused by reduced delivers lengthen the time water remains in the aqueduct.

EC, TDS, and bromide levels were predominantly higher in the forecast as compared to the historical simulation at all locations. The differences seen between the forecast and the historical simulations are from the large inflows from the Sacramento River and the San Joaquin River from February through July. These inflows influenced water quality in the aqueduct, so that the results in the downstream locations in the aqueduct follow the same water quality trend from the DSM2 simulations. Delta exports and actual deliveries were lower than exports and deliveries projected by any of the forecasts, which caused water quality trends to travel slower down the aqueduct.

With all the simulations, the May forecasts had improvements, especially over the January forecasts. By May, the newer inflow and export data had changed the EC-flow relationship, allowing EC levels in the western Delta to start lower than the previous forecasts. In addition, Delta Cross Channel operation, timing, and installation of the barriers, and exports improved the forecast. From summer to the winter, while all of the forecasted EC at SWP intake included Martinez, the historical simulation showed the higher flows from San Joaquin River completely replaced Martinez, and therefore western delta inflows. The significantly improved forecasts were due to combination of factors, rather than more accurately forecasted inflows and exports.

The modeled simulations conducted successfully demonstrated water quality forecasting proof of concepts for the Delta, O'Neill Forebay, and the California Aqueduct. Water quality and allocation forecasts made early in the year will have errors due to the high uncertainly levels, but still may be useful to water users. However, fall forecasts for water quality and allocations made in May are subject to less uncertainty, and any updates will provide additional resolution.

It was determined the short term forecasting in the Delta worked well, but that level of effort needed to be extended through the aqueduct. Data from the San Joaquin River upstream from Vernalis is a limitation that is more critical for short-term dissolved organic carbon (DOC) forecasts, especially during wetter years when the San Joaquin River water is more dominant at the pumps. The forecasts are dependent on many factors including the hydrology and operations forecasts, river flows, and Delta consumptive use, making forecasts before May prone to error. A useful qualitative assessment of the forecasts is to use volumetric and constituent "fingerprints."

The final recommendations from the proof of concept reports were:

- Focus on short-term salinity forecasts for the aqueduct model.
- Include fingerprinting information in short-term forecasts.
- Develop data retrieval system for forecasted aqueduct operations.
- Add TDS, bromide, and DOC concentrations to DSM2 forecasts.
- Improve flow and water quality forecasts in DMC, South Bay and California aqueducts, and O'Neill Forebay.
- Consider hydrology and operations in San Joaquin River upstream of Vernalis in water quality forecasts.
- Produce seasonal forecasts in May and update through September, and provide forecasts to utilities through the real-time data and forecasting email distribution.

Delta Simulation Model II extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal, Phase 1

Report Date

June 2005

Investigators:

CH2MHILL

Background and Objectives

An extension of the Delta Simulation Model 2 (DSM2) model to include the California Aqueduct, the South Bay Aqueduct, and the Delta-Mendota Canal (DMC) was needed. An extended model was developed and calibrated for salinity transport and hydraulics (flow and stage) through the system. The connected model would be used for real-time data and forecasting, creating water quality planning, and forecasting simulation capabilities, similar to those available in the Sacramento-San Joaquin Delta (Delta).

Study Design

The project approach included the following steps:

- Review system operations
- Collect and review hydrologic, operational, and water quality data
- Collect and review physical system data
- Develop DSM2 application
- Calibrate and verify model
- Document model

The system operations review covered the four field divisions and the multiple pumping plants, facilities and check structures. An operational overview of the State Water Project (SWP) system, influencing parameters, diversion, and check structures was done. Data was collected on the DMC to gain an understanding of the physical system and operations.

Hydrological, operational, and water quality data were collected and reviewed. Internet resources provided hydrological data. Operation data, such as deliveries and diversions, was collected through published reports. Water quality data was acquired through California Data Exchange Center website.

Physical system parameters were integrated into the model using data from the Department of Water Resources State Water Project Data Handbook (1997 and 2003) and the United States Bureau of Reclamation document "Milepost at Structure Site – Delta-Mendota Canal (1985 and 1992).

The development of the DSM2 model had many steps. The physical system geometry was converted into DSM2 format by using excel to generate ASCII files. Inflows, diversions, water balance, and required closure terms were added into the model. Using the water quality model (QUAL), EC data was added to the model. The California Aqueduct consists of 67 channels and 68 nodes, DMC has 21 channels and 22 nodes, the South Bay Aqueduct was given 8 channels and 9 nodes, and the West Branch received 2 channels and 3 nodes. While most nodes were placed at check structures, distinctions were not always that clear.

The calibration of the model occurred for the 3-year period of January 1, 2001 through December 31, 2003. The model used 2000 as a ramp down year to set the model in equilibrium starting on January 1, 2001.

Results/Conclusions

The model performed well for a wide range of expected flows and salinity conditions. The calibration provided acceptable reproductions.

Several limitations to the model exist. Water balance is required for calibration, possibly creating errors with closure terms. The diversion timing data has to be inputted at a constant level, which can create spikes in the calibration mode. Treating the San Luis Reservoir as a fully mixed body of water is considered a limitation in the model. Lastly, the gate operations are simplistic, and adjustments of gate operations cannot be made. The problems primarily produce difficulties in the calibration mode, but are not expected to have an effect when the model is used for forecasting and planning.

The recommendations were:

- Gate operations – The unreleased database version of the DSM2 model will allow for gate operations adjustments, allowing it to mimic the actual system more closely.
- Link to existing DSM2 – The completion of the DSM2 extension will allow the Delta model and the aqueduct models to be merged into one model covering SWP operations.
- Conduct Tracer Test – Collecting accurate flow velocity data over a variety of flows will improve the model and provide information on possible spill scenarios.
- San Luis Reservoir – Conduct further studies on San Luis Reservoir to examine how operation changes can improve water quality.
- Planning mode – Use CALSIM boundary conditions to run model in planning mode, which avoids the problems associated with using closure terms and measured data.
- Forecasting mode – Collect and centralize the necessary information required to run the model in forecasting mode.

Delta Simulation Model II Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal Phase 2 Analysis

Report Date

June 2008

Investigators

CH2MHILL

Background and Objectives

By using the suggestions from phase 1, improvements to the Delta Simulation Model 2 (DSM2) model were investigated. The model would be enhanced by adding a planning mode and a forecasting mode application.

Study Design

Phase 2 consisted of four tasks:

- Tracer tests for determination of travel time
- Analysis of San Luis Reservoir and O'Neill Forebay (O'Neill)
- Development of planning simulation mode
- Development of forecast mode implementation plan

Results/Conclusions

A tracer test was run under a full range of possible flow conditions between 1,901 cfs and 10,491 cfs. Two sets of five model runs were done, based on flows through either Dos Amigos Pumping Plant or H. O. Banks Pumping Plant (Banks). Travel times were shown to be related more to the net flows through the reach, and not flow into the reach, since diversions can have a considerable influence on travel times. Travel times from Banks to O'Neill took between 2 and 21 days depending on pumping rates. The travel times from Banks to Check 67 and from O'Neill Forebay to Check 67 ranged from 12.42 to 31.33 days.

An investigation into San Luis Reservoir and O'Neill Forebay was done to improve electrical conductivity (EC) results for the model. Sampling showed EC in San Luis Reservoir is well mixed vertically, so a more complex 2-reservoir model was unnecessary. The boundary conditions were refined, resulting in a decrease of 9% in root mean square (RMS) errors. Average EC levels would not be decreased by shifting pumping operations around the spring/neap tidal cycle. Additionally, while filling the reservoir when salinity levels are lower at Banks and Jones Pumping Plant would have a minor improvement on salinity levels, switching inflows from October and November to February and March raises concerns over water supply availability.

The model was run in the planning mode using CALSIM2 model results for boundary conditions. Monthly decisions for water supply distribution and allocations based on storage were made using the CALSIM2 model. Running both models together in the planning mode allowed for studying the effects of pumping curtailments and re-plumbing the system. One thing the model did show was that San Luis Reservoir has a damping capacity on annual EC fluctuations.

In order to run the model in forecasting mode, the following pieces of data are required:

- Current conditions required to initialize the model
- Boundary flows and water quality at Banks and Jones Pumping Plants
- Deliveries and diversions from the aqueduct and Delta-Mendota Canal (DMC)
- San Luis Reservoir and Gianelli Pumping-Generating Plant operations
- O'Neill Pumping-Generating Plant operations
- Groundwater pump-ins and stormwater inflows

The five-step implementation plan included data retrieval, data processing and quality review, model simulations, processing and review of model results, and distribution of model results.

While there are still limitations with the short- and long-term forecasts, initiation of the model is feasible with all the real-time data available. Lastly, maintaining an up-to-date historical simulation of the aqueduct and DMC was suggested.

Chapter 11 — Sanitary Surveys

Since 1990, the water agencies treating water from the State Water Project (SWP) have been required to conduct a watershed sanitary survey every five years. The intent of a sanitary survey is to identify actual or potential sources of contamination and other related factors, which are capable of producing adverse impacts on water quality used for domestic purposes. The survey is a requirement based on the California Surface Water Treatment Rule, and is administered by the California Department of Public Health (CDPH), which was formerly the California Department of Health Services. The State Water Project Contractors Authority (SWPCA) has assumed responsibility for conducting the Watershed Sanitary Survey of the State Water Project (SWP). They have partnered with MWQI to satisfy the requirements.

The reports summarized in this chapter are from the 1996, 2001, and 2006 surveys. The 1990 and 2011 survey were not included in this report. For information on the 1990 and 2011 surveys, please refer to the MWQP Publication Website at http://www.water.ca.gov/waterquality/drinkingwater/mwqi_reports.cfm

California State Water Project Sanitary Survey Update Report 1996

California State Water Project Watershed Sanitary Survey Update Report 2001

California State Water Project Watershed Sanitary Survey 2006 Update

California State Water Project Sanitary Survey Update Report 1996

Duration of Study

1990-1996

Investigators

Raymond Tom, Richard Sapudar, Collette Zemitis, Marc Commandatore

Background and Objectives

The U.S. Environmental Protection Agency (EPA) and California Department of Public Health (CDPH), under the Surface Water Treatment Rule, require drinking water purveyors to conduct sanitary surveys every five years. The intent of a sanitary survey is to identify actual or potential sources of contamination and other related factors, which are capable of producing adverse impacts on water quality used for domestic purposes.

A detailed investigation of Del Valle, San Luis, Pyramid, Castaic, Silverwood, and Perris, along with the Barker Slough/North Bay Aqueduct (NBA) watershed and the open channel section of the Coastal Aqueduct occurred in the 1996 update. In addition, an emphasis was placed on the occurrence of coliforms and the pathogens *Giardia lamblia* and *Cryptosporidium* parvum in the water supply.

Study Design

The Municipal Water Quality Investigations Program (MWQI) obtained most of the data from the State Water Project Water Quality Monitoring Program, and from a questionnaire sent to the municipal contractors of the State Water Project (SWP). The questionnaire asked the following questions: can new and proposed regulations be met, what difficulties have been encountered treating water, what successful tactics were used to handle problems, how the system was adapted for each situation. In addition, the contractors were asked to identify any known or potential threats to SWP water quality. Responses for known or potential threats were agricultural runoff to source waters, algae and other aquatic plant blooms, taste and odor (T&O) problems, sediment and turbidity in the Aqueduct, asbestos, transportation accidents, and petroleum product pipeline spills.

The contaminant sources were identified through field surveys, data base searches, existing literature, and interviews. Environmental databases were searched to identify certain environmental concerns that arose from activities in the watersheds and adjacent areas. Checklists of potential contamination sources were prepared, and forwarded to CDPH.

Several important characteristics described for each watershed related to land use, population center data, agriculture, grazing, hydrology, surface geology and hydrology, soils, and vegetation. The watershed boundaries for each study area were defined.

Results/Conclusions

Sixteen of the 18 (89 percent) questionnaires were returned. Turbidity was a major concern for many of the 16 agencies responding, as were water quality parameters such as temperature variations, pH, and alkalinity. T&O were other concerns expressed by many agencies, and appeared to be closely related to algae blooms and subsequent decay in the California Aqueduct and reservoirs. Other responses related to

T&O problems were methylisoborneol/geosmin, pondweed blooms, and high nutrient loading. Fresh water shrimp were also a concern. Total organic carbon (TOC) and bromide created many treatment challenges for some agencies. Metal constituents in the water have created treatment problems for a few water agencies. Of the 12 respondents (66 percent) to this question, four of the agencies were operating under the Phase 1 disinfection byproducts (DBP) rule. The number of agencies performing pathogen monitoring was 11 out of 18 (61 percent).

In general, the highest total coliform counts were found in the NBA. Coliforms were analyzed using the most probable number (MPN) method. The median total coliform value in the NBA was 110 MPN/100 ml. Other areas of elevated coliform concentrations were the South Bay Aqueduct (SBA) terminus with a median total coliform value 240 MPN/100 ml, and Palmdale water treatment plant (WTP) which receives water from the East Branch of the California Aqueduct with a median total coliform 30 MPN/100 ml.

The highest median fecal coliform value of the data evaluated was in the Cordelia Forebay (median = 63 MPN/100 ml) in the North Bay area. In the South Bay area, the median fecal coliform value for 100 percent South Bay Aqueduct water was higher than water blended with San Luis water. In Southern California, the Palmdale WTP intake had higher fecal coliform values than that of the Antelope Valley East Kern Water Agency WTP.

Due to variations in the reporting limits and analytical laboratory performance, it was difficult to compare the results of *Giardia lamblia*, and *Cryptosporidium* analyses between sites. However, available data showed high positive concentrations of *Giardia lamblia* and *Cryptosporidium* in the Sacramento-San Joaquin Delta (Delta), as measured by Metropolitan Water District of Sothern California (MWDSC).

Giardia lamblia was detected in samples in the South Bay area, Delta-Mendota Canal (DMC) at O'Neill Forebay, Greene's Landing on the Sacramento River, five Southern California WTPs, and in Lake Perris. *Cryptosporidium* was detected at Greene's Landing, H. O. Banks Pumping Plant (Banks), DMC, Check 29 of the California Aqueduct, Santa Clara Valley Water District WTP, and at MWDSC treatment plants.

The greatest enrichment of SWP water with trihalomethane (THM) formation material occurred in the Delta and in the NBA at Barker Slough watershed. The enrichment was about 100300 µg/L TTHMFP. TTHMFP decreased as the water moved from north to south in the Aqueduct, with values at Southern California export sites about 50 µg/L lower.

The NBA at Barker Slough had the highest median TOC concentration of all SWP sites. The next highest median TOC concentrations were at DMC and Check 11 (O'Neill Forebay) with TOC concentrations of 4.3 mg/L and 4.4 mg/L respectively. TOC concentrations decreased as water moved along the Aqueduct, ranging 3.0 to 3.8 mg/L at the terminal reservoirs of the east and west branches of the Aqueduct.

Median bromide values in the Delta ranged from 0.02 mg/L at the American River and the Sacramento River to 0.37 mg/L at the San Joaquin River near Vernalis. The NBA at Barker Slough had a low median concentration of bromide of 0.05 mg/L. The median concentration of bromide at Banks and the Delta-Mendota canal was 0.3 mg/L. The stations along the California Aqueduct showed median bromide values of 0.22 mg/L at Banks Pumping Plant, to concentrations between 0.35 and 0.50 mg/L at the reservoirs (Silverwood, Perris, Pyramid, and Castaic).

Total dissolved solids (TDS) concentrations were greater south of the Delta than in the Delta. The NBA had a TDS concentration of 176 mg/L, and California Aqueduct stations had TDS concentrations that ranged from 315 to 390 mg/L due to TDS contributions from the San Joaquin River. There did not appear to be significant increases in TDS concentrations along the California Aqueduct as a result of discharges into the Aqueduct.

The Delta region showed low electrical conductivity (EC) values for the American and Sacramento rivers (median EC values of 65 and 176 micromhos/cm respectively). San Joaquin River water introduced high concentration of salts into the Delta as seen by the median EC value of 855 micromhos/cm at Vernalis.

Turbidity median values ranged from 16 to 20 NTU in the NBA. Turbidity was generally higher during the winter months of January through March. The highest turbidity value (180 NTU) was observed in March 1995 during a period of unusually heavy precipitation.

Median chloride concentrations in SWP ranged from 26 mg/L in the NBA at Barker Slough to 120 mg/L at Lake Perris and San Luis Reservoir. The South Bay Aqueduct median chloride concentration was 76 mg/L. Other stations along the Aqueduct had median chloride values of 80 to 100 mg/L. All the chloride concentrations measured along the Aqueduct were well below the secondary maximum contaminant level (MCL) of 250 mg/L.

All of the nitrate median values were less than the state MCL of 45 mg/L. Median nitrate values ranged from 0.10 mg/L at Lake Perris to 3.9 mg/L at the DMC O'Neill Forebay.

Nitrate was likely introduced to the source waters of the California Aqueduct primarily from agricultural drainage in the San Joaquin and Sacramento rivers and in the Delta, and from wastewater treatment plant (WWTP) discharges. Nitrate concentrations in the SWP were generally less than 5 mg/L, which was much less than the state MCL of 45 mg/L.

Median arsenic, barium, chromium, selenium, and silver concentrations were less than the federal and state MCL. All cadmium concentrations measured along the Aqueduct were less than the reporting limit of 0.005 mg/L except for one sample at Pyramid Lake, which was measured at the reporting limit.

All lead concentrations at SWP stations were less than the federal action-level for treatment for lead, which is 0.015 mg/L.

All mercury concentrations measured along the Aqueduct were less than the reporting limit of 0.001 mg/L, except for one concentration measured on February 19, 1992. This apparently anomalous value was from one of 57 samples and had a concentration of 0.006 mg/L.

When pesticides were found in SWP, they were usually at very low concentrations and widely distributed. In general, these chemicals had been present in the Sacramento and San Joaquin rivers when they were found in SWP.

Specific conclusions were:

- The *Giardia lamblia* and *Cryptosporidium* data from available raw water sources varied in quantity and quality from treatment plant to treatment plant. The data was not adequate to observe trends in *Giardia lamblia* and *Cryptosporidium* concentrations over time, and it was difficult to compare results of *Giardia lamblia* and *Cryptosporidium* data between raw water sources of treatment plants due to difficulties with the current analytical techniques. The limited information on *Giardia lamblia* and *Cryptosporidium* suggested raw water concentrations of these pathogenic organisms from SWP water were very low. The potential sources of pathogenic organisms in the watersheds were livestock grazing, recreational use and facilities, WWTP failures, and wildlife areas.

- Total and fecal coliform data from raw water sources available at the time of the survey were difficult to evaluate for comparisons due to differences in analytical techniques used by the water agencies. In general, raw water coliform values reported by the water agencies were highest for those agencies receiving water from the NBA and the South Bay Aqueduct (SBA).
- Water was enriched substantially with THMFP and organic carbon (OC) as it passed through the Sacramento-San Joaquin Delta.
- Elevated dissolved solids and turbidity measurements were found in the California Aqueduct, south of the Delta. The elevated dissolved solids and turbidity appeared to be primarily a result of salts and sediment in the Delta estuary and the San Joaquin River, and of floodwater inflows to the California Aqueduct from Cantua and Salt creeks.
- Elevated bromide concentrations were found in the export sites of the Delta, the San Joaquin River near Vernalis, and at some of the reservoirs in the east and west branches of the California Aqueduct. These concentrations, which ranged from 0.30 to 0.50 mg/L, complicate achievement of the bromate and trihalomethane levels required by the Disinfectants/Disinfection Byproducts Rule.
- Of the nine watersheds surveyed, five watersheds were identified as having facilities that generate, transport, treat, store, or dispose of hazardous waste existing within the watershed. In addition, 25 emergency responses to hazardous materials releases both within the watersheds and in adjacent watersheds were identified.
- Storm water runoff from the city of Sacramento contributed total and dissolved organic carbon to the rivers that flow into the Delta. This runoff might have been a significant source of OC to the Delta.
- The NBA had more water quality problems when compared to other components of SWP. Aluminum, iron, and manganese were above the secondary MCLs at the NBA. Organic carbon concentrations were highest in the NBA watershed. Potential sources included agricultural and urban runoff and upstream releases of stagnant waters. Coliform concentrations at drinking water supply intakes of the NBA suggested significant microbial contamination may exist in the watershed from cattle and sheep grazing.
- Significant microbial contamination of the Lake Del Valle watershed might have occurred from cattle grazing and recreational facilities and activities. Limited information provided on *Giardia lamblia* and *Cryptosporidium* in raw water sources suggested concentrations of these pathogenic organisms from Lake Del Valle and the SBA were not significant.
- Of the nine watersheds surveyed, four watersheds were identified as having eight solid waste landfills existing either within the watershed or in adjacent watersheds. Potential contamination in the watershed from the solid waste landfill sites and operations included runoff from the landfill sites, accidental releases of solid waste during transportation through the watershed, and failure of

the leachate collection systems. Contaminants released from the landfill sites and operations could include nutrients, OC, coliforms, and pathogenic organisms.

- Leaking underground storage tanks typically resulted in subsurface contamination to soil and groundwater, which might affect surface water. All of the watersheds contained underground storage tanks for diesel fuel or gasoline storage. In five of the watersheds, leaking underground storage tanks were identified. The five tanks were associated with operation of equipment or recreation activities at the lakes and were within 1,000 feet of a surface water body.
- An emergency action plan developed by Department of Water Resources provides comprehensive, easy to follow and up-to-date information to persons responding to emergencies, and serves as a reference for pre-emergency training. The emergency action plan for each of the five field divisions of SWP followed the same format, designed to provide logical pre-emergency training to provide quicker reference in emergencies, and to reduce obsolescence by making updating easier.
- Several oil pipelines existed within close proximity of SWP facilities. During a March 1995 storm, a Chevron oil pipeline ruptured, releasing oil to Arroyo Pasajero and ultimately to the Aqueduct. Other incidences of oil pipeline breaks near SWP facilities included the April 1993 failure of ARCO's Line 63 which released 147,000 gallons, and the failure of ARCO's Line 1 during the January 17, 1994 Northridge earthquake.

California State Water Project Watershed Sanitary Survey Update Report 2001

Duration of Study

1996-2001

Investigators

Michael Zanoli, Carol DiGiorgio, Fengmao Guo, Marvin Jung, William McCune, Steven Murphy, Murage Ngatia, James Sickman

Background and Objectives

The sanitary survey is required every five years under the California Surface Water Treatment Rule and the federal Surface Water Treatment Rule. The purpose is to describe control and management practices, describe potential contamination sources (PCS) or activities, determine appropriate treatment levels, and identify actions or recommendations for improvement or control of contamination sources.

More details on contaminant sources and a detailed analysis of indicator organisms and pathogens are included in the 2001 sanitary survey update. The survey assists State Water Project (SWP) contractors in complying with California Department of Public Health (CDPH) Drinking Water Source Assessment Program requirements, by providing information on the assessment and vulnerabilities of their source water.

Study Design

Unlike the previous survey, no new field surveys or monitoring studies were done. Instead, existing data and information was relied upon, which required extensive coordination and cooperation. Of the 29 questionnaires sent out, 12 were completed.

The 2001 undertaking for each watershed included:

- Review and evaluation of SWP contractor questionnaires
- Communication with various agencies and review of reports and data on water quality issues
- Describe and map watershed areas
- Evaluate known or suspected contaminants and areas by developing inventories of PCS and activities in each area and determining the susceptibility of each area from those sources and activities
- Create reports and summaries of the results

The potential threats and sources of contamination were:

- Recreation
- Wastewater treatment/facilities (includes treatment plant effluent discharges, storage, transport, treatment, disposal to land, and septic systems)
- Urban runoff and traffic accidents/spills
- Animal populations (includes grazing, dairies, and wild animals)
- Algal blooms
- Agricultural activities (includes agricultural cropland use, pesticide/herbicide use, and agricultural drainage)

- Mining and Logging
- Solid or hazardous waste disposal facilities
- Unauthorized activity (includes illegal dumping, and leaking underground tanks)
- Groundwater discharges and seawater intrusion
- Geologic hazards (landslides, earthquakes, floods), and fires

Evaluation criteria of PCS was: drinking water regulations actually or nearly being exceeded, constituents of concern increasing water treatment costs or affecting operations, proximity of PCS, beach closures from high bacteria counts, waste or spills, availability of water quality data, and the lack of data on the PCS in the watershed.

Results/Conclusions

This sanitary report covered several distinct areas, which are covered individually.

Regulatory overview

Primary maximum contamination levels (MCLs) are enforceable drinking water standards designed to protect human health. They address 78 chemical and 6 radioactive contaminants. Secondary MCLs are California enforceable, are set for taste, odor, and appearance, and consist of 17 chemicals. Action levels, set by the CDPH, are based on health advisory levels, are non-enforceable, and consists of 15 contaminants of current interest and 29 contaminants of historical interest.

New rules and laws went into effect since the last sanitary survey. Arsenic in drinking water had a MCL of 10 µg/L and a maximum contamination level goal (MCLG) of zero for drinking water. Stage 1 of the Disinfectants and Disinfection Byproducts Rule (D/DBP) set maximum residual disinfection level goals and maximum residual disinfectant levels for chlorine, chloramines, and chlorine dioxide. MCLs were established for total trihalomethanes (TTHM), haloacetic acids, chlorite, and bromate. The Interim Enhanced Surface Water Treatment Rule (IESWTR) was designed to improve microbial control by establishing MCLG, microbial removal requirements, requirements for operations and design of water facilities, and required sanitary surveys for all surface water and groundwater under direct influence systems.

The Total Coliform Rule sets a MCLG of zero for total coliform and a MCL based on presence or absence of coliforms. The rule required routine sampling at regular intervals. The Surface Water Treatment Rule (SWTR) required treatment to ensure at least 99.9% (3-log) removal and/or inactivation of *Giardia lamblia* cysts and at least 99.99% (4-log) removal and/or inactivation of viruses. Turbidity level requirements were 0.5 NTU with a daily average goal of 0.2 NTU. The disinfection requirements of the SWTR was a disinfectant concentration level of at least 0.2 mg/L of total chlorine, combined chlorine, or chlorine dioxide.

Several proposed rules were being considered at the time of this study. They included having an enforceable sulfate MCL, and the finalizing of a radon MCLG and MCL. The unregulated contaminant-monitoring rule established criteria for a monitoring program for unregulated contaminants with the hope of providing an early warning of its presence before serious health effects occur. The Radionuclides (nonradon) Rule sets drinking water standards for combined radium-226/-228, (adjusted) gross alpha, beta particle, photon radioactivity, and uranium. The Revised CDPH unregulated chemicals requiring monitoring reduced the required monitoring from 52 to 9 chemicals of greater concern. Lastly, CDPH reviewed the MCL for 13 contaminants and of the 8 reviewed so far, 6 are recommended for revising downward the MCL.

The drinking water parameters of concern presented to CALFED in 2000 list total organic carbon, dissolved organic carbon, bromide, pathogens, contaminants that cause MCL violations, total dissolved solids (TDS), salinity, nutrients, algal blooms, and turbidity.

Locations

North Bay

The Barker Slough/North Bay Aqueduct (NBA) investigation led to a special study conducted by municipal water quality investigations (MWQI). In agreement with a recent study done by an independent consultant, no single source was responsible for the extensive water quality problems. Besides grazing, urban runoff, and recreation, other potential sources included natural processes within the watershed, such as the geological makeup of the watershed or hydrology interactions. It was recommended that studies be done on the effects of Argyll Park, urban runoff flow measurements, livestock contamination, and development of a range management plan, and future monitoring of agricultural actives. The conclusion of these suggestions was presented in the North Bay Aqueduct study, which was discussed in the discrete monitoring and supporting reports chapter.

Delta

The Sacramento-San Joaquin Delta (Delta) is used for a number of reasons, but data at the time of the study did not exist that described its users or the reasons for its use. Known uses were boating, fishing, swimming, agriculture, and both intake and outflow from water treatment plants (WTP). While definitive information was not available, there were conclusions as to the contaminations and their sources.

Boating was a very popular use of the Delta waterways, but pathogens, MTBE, and trace metals were probable contaminants. Other recreational activities may introduce pathogens from a lack of restrooms, however there was nearly no sampling done from beaches or by local agencies. Urban runoff to the Delta was increasing, but drinking water concerns were not part of the monitoring, and extreme episodic peaks were unknown. Many of the Delta islands were used for livestock, confined animal feeding operations, and agriculture. While animals can introduce pathogens into the waterways, agricultural drainage was the primary source of organic carbon (OC), bromide, TDS, electrical conductance (EC), nitrogen, and phosphorus.

OC and EC levels rose in the summer through the fall, and water quality at H. O. Banks Pumping Plant (Banks) was highly influenced by the San Joaquin River during high flows and the Sacramento River during normal flows. The hydrodynamics of the San Joaquin River create higher levels of TDS, OC, EC, nitrogen, and phosphate levels that were three times higher than the Sacramento River. The two most significant threats to the Delta at the time of the study were levee failure from earthquakes and saltwater intrusion, which is a dominant source of EC, TDS, and bromide.

South Bay

The water quality parameters carbon and bromide created concerns for all South Bay Aqueduct (SBA) contractors. Cattle grazing was a significant potential source of pathogens and nutrients. Algal blooms clogged filters and created taste and odor (T&O) problems that were occasionally treated with copper sulfate.

The South Bay Aqueduct's main problems were nutrients, pathogens, turbidity, and T&O issues. The two dominate sources of the problems were cattle grazing and algal blooms. The minor problems were TDS/salts, OC, pesticides, and trace elements. The sources were wastewater treatment/facilities, and urban runoff. Potential geological hazards from several minor and major faults within the area were considered a minor problem.

Lake Del Valle's potential contaminants came from recreational use, wastewater treatment facilities, animal grazing, algal blooms, and land use changes. The threats were OC, nutrients, pathogens, turbidity, MTBE, and erosion. Minor issues were TDS/salts, pesticides, silt deposits, and trace elements. The sources of the minor issues were urban runoff, agricultural activities, and multiple mines. There were potential geological hazards from one of several major active faults.

San Luis Reservoir

San Luis Reservoir had contamination threats from recreation, animal populations, algal blooms, earthquakes, and fires. The water quality concerns were turbidity, nutrients, pathogens, and T&O issues. Minor concerns were from wastewater treatment/facilities, agricultural activities, landslides, erosion, and traffic accidents and spills. The minor threats to drinking water quality were TDS/salts, OC, pesticides, and trace elements.

Southern California

The reservoirs in Southern California had similar problems to other areas of the SWP; grazing, pathogens, algae, T&O, and recreational activities, such as boating, created elevated MTBE and hydrocarbons levels. It was recommended that an integrated watershed management program be implemented. Castaic and Silverwood lakes were supply points for most SWP southern California use and have increased water quality concerns.

Pyramid Lake problems included nutrients, pathogens, turbidity, MTBE, and petroleum hydrocarbons. The sources were recreational activities, crude oil pipelines, animal populations, and geological hazards from three major and several smaller faults in the watershed. OC, pesticides, and trace elements from wastewater treatment/facilities, agricultural activities, mines, and traffic accidents or spills were minor threats to drinking water quality.

Castaic Lake's major threats included recreational activities, wastewater treatment facilities, animal populations, algal blooms, traffic accidents and spills, fires, and earthquakes. Constituents included pathogens, MTBE, erosion caused turbidity, T&O problems, hydraulic pump oil, crude oil, and the fire related constituents of ash, sediment, turbidity, and increased TDS. OC was regarded as a minor threat.

Recreation was the prime potential contaminant at Silverwood Lake. In addition, four wastewater treatment facilities, animal populations which were mostly wild animals, algal blooms, urban runoff, and land use changes were the sources of MTBE, pathogens, turbidity, OC, nutrients, 2- methyl-isoborneol (MIB), geosmin, T&O problems, and soil erosion. Pesticides from agricultural activities and earthquakes were minor threats.

The highest numbers of recreational visitors and unique problems occurred at Lake Perris. Nutrients, pathogens, turbidity, T&O issues, MTBE, and petroleum hydrocarbons were the water quality constituents of concern. Contaminant sources and activities included wastewater treatment/facilities, hypolimnetic anoxia, and leaking underground storage tanks. Minor water quality issues were OC and animal populations.

California Aqueduct

Water quality conditions in the California Aqueduct were largely determined by Delta conditions, floodwater inflows from the Diablo range, and PCS in San Luis Reservoir. Kern River Intertie, and Cross Valley Canal water improved mineral quality, but caused significant sediment loads.

Clifton Court to O'Neill Forebay had T&O problems caused by three main sources, algal blooms, turbidity from wind erosion, and traffic accidents and spills of hydrocarbons. Saline groundwater and several faults were citied as geological hazards. Minor constituents of concern were TDS/salts, OC, bromide, pesticides, nutrients, and trace elements. Potential sources for the minor concerns were recreation, urban runoff, animal populations, and agricultural activities.

The O'Neill Forebay holds water from the California Aqueduct and the Delta-Mendota Canal. The canal is a potential source of TDS/salts, OC, bromide, nutrients, pathogens, turbidity, and T&O problems. Recreational activities or domestics and wild animals may introduce pathogens and nutrients. Pesticides, trace elements, and fires were minor threats to O'Neill Forebay.

The section of the aqueduct from the O'Neill Forebay to Check 21 near Kettleman City had several threats to water quality from a few activities. The threats were TDS/salts, OC, bromide, nutrients, pathogens, trace elements, turbidity, asbestos, mercury, and hydrocarbons. The sources of the threats included floodwater inflows, wild animals, livestock related activities, mines, groundwater discharges, marine deposits, saline springs, selenium, and serpentine outcroppings.

From Kettleman City to the Kern River Intertie, the only two major problems were pathogen contamination from recreational activities and hydrocarbons or hazardous material from accidents or spills. Water service turnouts potentially caused pesticide, nutrient, and trace element issues.

The aqueduct from the Kern River Intertie to the East and West Branch Bifurcation had a small number of water quality parameters of concern. The Kern River Intertie stirred up turbidity, groundwater discharges provided TDS/salts and arsenic, and accidents or spills introduced hydrocarbons . OC, bromide, pesticides, nutrients, and pathogens were minor concerns associated with the Kern River Intertie, Cross Valley Canal, groundwater discharges, and recreation. Gas, oil, and geothermal wells are around the aqueduct.

In the Coastal Branch of the Aqueduct, the concerns are pesticides, nutrients, pathogens, and T&O problems. The problem sources are animal grazing, agricultural activities, algal blooms, pump-outs, and earthquakes.

The main problem in the East Branch of the California Aqueduct was T&O issues from algal blooms. Other parameters include TDS/salts, OC, pesticides, nutrients, pathogens, trace elements, turbidity, and hydrocarbons. The sources were recreation, traffic accidents and spills, urban runoff, and algal blooms. Minor threats to the West Branch were from animals, recreation, and urban runoff. The water quality parameters of minor concern were pesticides, nutrients, pathogens, and turbidity.

Emergency Response

During an emergency, the Department of Water Resources (DWR) has six major responsibilities:

- Planning and managing statewide water resources
- Developing, operating, and maintaining the SWP
- Protecting the Sacramento-San Joaquin Delta
- Providing dam safety, flood management, and emergency assistance
- Educating the public
- Providing local assistance

In order for DWR to fulfill the responsibilities, the DWR Recovery Action Plan and the Emergency Response Plan were drafted. Emergency Action Plans (EAPs) provide an organized and comprehensive plan of action for the field level. The plans identify chain of command, required procedures, and the roles and responsibilities of staff.

The EAP is divided into five parts: Basic information, emergency response, appendices, enclosures, and oversized references. Basic information includes background information and guidance for EAP implementation. Emergency response contains specific emergency response procedures. The appendices contain informational items such as descriptions of aqueduct check structures, reporting forms, and turnout summaries. Names and phone numbers are found in the fourth section, “enclosures.” The oversized references contain foldout maps and facility lists.

The Emergency Response Plan is the main document forming the overarching structure for the EAPs. Specifically, the Emergence Response Plan:

- Establishes and maintains guidelines for division and district/field offices for responding to emergencies including the preparation and execution of EAPs
- Outlines how DWR will respond to and manage flood and dam emergencies, incidents on the SWP, acts of terrorism and war, and provide the necessary support to other state agencies, especially the Office of Emergency Services, during catastrophic events
- Identifies the organization and functions that DWR staff may be assigned to during an emergency using the Standardized Emergency Management Systems concept
- Outlines the responsibilities of key DWR staff
- Integrates essential emergency organizations

Pathogens

Problems existed with pathogen monitoring. The California Department of Public Health (CDPH) required the presence or absence of *E. coli* be reported. Minimal levels of treatment were required to remove *Giardia* and viruses, and meet the EPA’s health risk recommendations. Total coliforms were used as a guideline, but there were several methods used to find coliform densities, which skewed the results higher or lower than actual levels. No correlation was found between total coliforms and *Giardia* densities, so total coliform densities were not an accurate test for *Giardia*. Watersheds without fecal contamination should not have *Cryptosporidium*, but high levels of coliforms should trigger monitoring for *Cryptosporidium*. High levels of coliforms indicated the presence of pathogens, but they were not necessarily there. One reason that correlations may not have been found was the flaws in the detection methods for pathogens.

The Information Collection Rule (ICR) immunofluorescent assay method was designed for pathogen monitoring. Most of the monitoring results for pathogens in this sanitary survey used the ICR method, so strong conclusions cannot be made. The ICR method was notorious for its high rates of false positives and negatives, its lack of sensitivity, and poor recovery, accuracy, and precision; however, it may have been useful in determining the presence or absence of *Giardia*. Method 1623 was introduced in 1999, and was less susceptible to false positives and has higher recovery rates. However, it also had significant problems, such as whether matrix effects caused recovery variability. Additionally, monitoring for organisms that were not homogeneously distributed creates inherent problems for any study or monitoring program. Given the unreliability of recoveries and high costs, pathogen testing may not have been feasible.

The Southern California water treatment plants (WTP) profiled consistently had the lowest total coliforms, fecal coliforms, and *E. coli* bacteria densities. Fecal coliforms and *E. coli* numbers were low, but some of the highest total coliform densities were found at the SBA treatment plants. The high total coliform numbers may be a result of the Colilert™ method, making it difficult for direct comparisons between watersheds. Bacterial contamination may have been occurring between the Cordelia Forebay and Napa's Jameson Canyon WTP. The NBA watershed and pumping plants had the highest total coliform, fecal coliform, and *E. coli* numbers. The most likely source of fecal contamination for Barker Slough and the NBA was cattle, which commonly used the slough. DWR's routine sampling showed the lowest coliform levels at Banks.

Median *Giardia* concentrations derived from ICR were below the detection limit. Using Method 1623 resulted in different conclusions than those from the ICR data. Since no correlation between total coliforms and *Giardia* densities was found, and if the Colilert™ method over estimates total coliform densities, it may have been inappropriate to use total coliform densities to suggest *Giardia* log removal levels. According to the questionable ICR data on *Cryptosporidium*, all WTPs profiled would need first bin log removals, which would have been met with the Interim Enhanced Surface Water Treatment Rule (IESWTR) and stage 2 of the D/DBP requirements.

California State Water Project Watershed Sanitary Survey 2006 Update

Duration of Study

2001-2006

Investigators

Archibald Consulting

Background and Objectives

The California Department of Public Health (CDPH) requested this sanitary survey address the Jones Tract levee failure and emergency procedures, the coordinated pathogen monitoring for Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), and review significant changes to watersheds and their effects on water quality. The Technical Review Committee wanted the survey to include the evaluation of sources of water quality problems in the State Water Project (SWP) and recommended actions to fix them. There were several issues addressed in the report.

Results/Conclusions

Regulations

The Stage 1 Disinfectants and Disinfection Byproducts Rule (D/DBP) and the Interim Enhanced Surface Water Treatment Rule (IESWTR) were promulgated in 1998. The goal of the Stage 1 D/DBP rule was to balance microbial risk with the risk from disinfection byproducts (DBP). Maximum Contaminant Levels (MCL) were set as 0.08 mg/L for total trihalomethane (TTHM), 0.06 mg/L for the sum of 5 haloacetic acids, 1.0 mg/L for chlorite, and 0.01 mg/L for bromate. It required specific amounts of total organic carbon (TOC) be removed prior to disinfection. The IESWTR set the Maximum Contaminant Level Goal for *Cryptosporidium* at zero, and the treatment technique requirement of 2-log (99%) removal of *Cryptosporidium*. The requirements were for all large water treatment facilities.

The Stage 2 D/DBP and LT2ESWTR were promulgated in 2006. It kept the same MCLs for TTHM, haloacetic acids, chlorite and bromate, but required compliance at all points in the distribution system. The LT2ESWTR required systems that used surface water sources to conduct source water monitoring to see if additional treatment was needed for *Cryptosporidium*.

In addition, several source water protection regulations were enacted, total maximum daily loads (TMDLs) set, and agricultural drainage regulated. The Central Valley Regional Water Control Board was responsible for protecting water quality, issuing discharge permits, and setting TMDLs for the valley’s water. Agricultural discharge needed to be monitored as a part of the agricultural waiver of waste discharge requirements for discharges from irrigated lands. The waiver requires that TOC, total dissolved solids (TDS), nutrients, and bacteria be monitored during irrigation and storm events. TMDLs for different constituents were set for the Sacramento River Basin and the San Joaquin Basin. CALFED also developed a drinking water policy for the Central Valley, a water quality program plan, and a drinking water policy to go with the basin plan.

Water quality in watersheds and SWP

The Technical Review Committee identified organic carbon (OC), salinity, bromide, nutrients, turbidity, trace elements, organics, and pathogens as the key water quality constituents of concern.

Organic Carbon

The San Joaquin River had higher total organic carbon (TOC) than Sacramento River, but lower than North Bay Aqueduct (NBA). During high flows, the San Joaquin River was the primary source of dissolved organic carbon at the pumping plants. TOC concentrations tended to be similar between the South Bay Aqueduct (SBA) and the rest of the California Aqueduct. Seasonal patterns were seen in the Sacramento-San Joaquin Delta (Delta) and watershed with peaks during the wet season. These patterns affected TOC levels at the pumping plants and the rest of the SWP. Real-time monitoring had shown grab samples did not catch the high peaks that occur and that more real-time monitoring was needed.

Salinity

Electrical conductivity (EC) was low in the Sacramento River, increased in San Joaquin River, and was higher and more variable at NBA, but lower than H. O. Banks Pumping Plant (Banks). The San Joaquin River, seawater intrusion, and Delta agricultural drainage are the primary source of EC at the pumping plants. There was an increase in EC from Banks to the San Luis Reservoir. The EC levels then decreased and remained similar in the rest of the SWP. A distinct seasonal pattern was seen, which varied by location. Low EC levels were seen in the Sacramento River in early summer, and increased until late fall or early winter. The San Joaquin River had low levels in the spring which rose until increased flow occurred during late fall or winter. TDS loads in the SWP varied greatly and related to pumping rates.

Bromide

The Sacramento River had low levels of bromide and the San Joaquin River had high levels. The NBA had higher and more variable levels than Hood, and the levels were much lower than Banks, where seawater was the primary source of bromide. The secondary sources of bromide to pumping plants were the San Joaquin River and Delta agricultural drainage. Bromide increased significantly from Banks to the San Luis Reservoir, where the level noticeably decreased. The remainder of the aqueduct had steady bromide concentrations. Bromide, like OC and salinity, had distinct seasonal patterns that vary by location. The Sacramento River stayed low all year, while concentrations in the San Joaquin River were low in the spring and climb until flow increased in winter or spring. Banks followed the San Joaquin River pattern, but levels decreased earlier in the winter. The SBA and California Aqueduct followed the Banks pattern with highest levels occurring in the fall.

Nutrients, Algal Blooms, and Taste and Odor Incidents

Loading of nitrogen and phosphorus occurred during wet winters in all locations. The Sacramento River had the lowest concentrations, the NBA had higher concentrations, and the San Joaquin River had considerably higher and more variable concentrations than the Sacramento River. Nutrient concentrations were high at Banks and did not change much in the SBA. South of O’Neill, nitrogen concentrations increased, but phosphorus remained similar. Nutrient levels were low at Castaic Lake.

Monitoring for 2- methyl-isoborneol (MIB) and geosmin began in 2001 at some locations in the SWP. Peak levels of more than 10 ng/L occurred at Banks where those peak levels travelled quickly to the SBA. MIB that was transported down the aqueduct decreased in concentration with increasing distance, but

MIB and geosmin were produced at high levels within the aqueduct. The Southern California reservoirs generated high levels of MIB and geosmin that created problems every summer.

Turbidity

Turbidity in the Sacramento River and San Joaquin River were related to flows, with higher turbidities occurring with winter storms. The higher and more variable turbidity at Barker Slough created treatment challenges for NBA contractors, especially during peak flows in winter. While median turbidities at Banks were lower than the Sacramento and San Joaquin Rivers, tremendous variability created peak levels of 100 NTU during spring and summer months. The SBA had turbidity levels, similar to Banks, and experienced the same challenges as NBA. Turbidity decreased between Banks and Check 13 as well as between Castaic and Silverwood lakes. South of the San Luis Reservoir, turbidity was highly variable from floodwater inflows, diversions, and project operations.

Trace elements and pesticides

Samples collected throughout the year in the SWP displayed few detects for chlorinated organic chemicals, organ-phosphorus pesticides, herbicides, carbamate, pesticides, and a variety of other synthetic organics. All concentrations were below MCLs. Arsenic was potentially problematic because of its presence in groundwater inflows from southern San Joaquin Valley.

Pathogens and indicator organisms

NBA contractors, Central Coast Water Agency, Metropolitan Water District of Southern California (MWDSC), and Castaic Lake Water Agency had all initiated LT2ESWTR monitoring.

SBA, Santa Clara Valley Water District, Antelope Valley East Kern Water Agency, and Palmdale Water District have completed LT2ESWTR monitoring. Crestline Lake Arrowhead Water Agency was to begin monitoring in April 2008.

The SBA was approved for 2-log Cryptosporidium, 3-log Giardia and 4-log virus removal treatment classification.

The log level removal for the other remaining water districts was not decided at the time of the report.

Key concerns Delta/State Water Project

Delta

The three major actions that raised concerns in the Sacramento-San Joaquin Delta (Delta) as a source of drinking water were urbanization, land conversions, and recreational activities. As wastewater discharges increased from urbanization, concerns over the cost of increased levels of treatment required, increased discharges near drinking water diversion locations, and *Giardia* and *Cryptosporidium* regularly found in treated wastewater raised questions on water quality impacts. The urbanized areas contained numerous contaminants including pet waste, chemicals, and anthropogenic waste, and during rains, the urban runoff increased the load of contaminants in the Delta and its watersheds. Land use changes such as ecosystem restoration and crop replacement by farmers had the potential to increase carbon loading and increase carbon levels at intakes. Little information was quantified about recreational activities within the Delta, but known contaminants were trace metals and petroleum hydrocarbons from motorized recreation and pathogens from body contact and improper disposal of sewage.

North Bay Aqueduct

Poor source water and rapid fluctuations in water quality generated consistent challenges for the treatment plants during the wet season. Actions taken after the two NBA study reports included the creation of a hydrodynamic model of the Barker Slough watershed, evaluating the feasibility of exchanging water with Solano Project water, and studying treatment processes to remove OC.

South Bay Aqueduct

Actions taken in the SBA since the 2001 sanitary survey included the SBA Improvement and Enlargement Program, an assessment of watershed contamination sources, and the development of a watershed program. The improvement and enlargement program reduced wastes and turbidity from flowing into the aqueduct, removed sediment, and created Dyer Reservoir. Assessment of the watershed confirmed the Bethany Headlands had the highest concentrations of most of the constituents monitored. Every sample collected contained *Giardia* and *Cryptosporidium*. The watershed protection program plan provided recommendations for managing contamination sources.

Cattle grazing, algal blooms, and potential actions by the East Bay Regional Park District were ongoing concerns. Cattle grazing was a predominate activity in the Bethany Reservoir watershed, and because the cows were known carriers of pathogens, they were the likely cause of the high pathogen levels. Warm water, abundant sunshine, and high nutrient concentrations contributed to algal blooms, which caused T&O problems, filter clogging, increased operational cost, and difficulties in meeting customer demands.

San Luis Reservoir

San Luis Reservoir was plagued by the San Luis low-point problem, which influenced the water quality and reliability of deliveries to Central Valley Project (CVP) and SWP contractors. State and federal water projects were limited in the water they could use from San Luis Reservoir because lowered water levels created algal, T&O, and other treatment problems for Santa Clara Valley Water District, San Felipe Division Contractors, and anyone else using water from the Pacheco Pumping Plant intake. A feasibility study of alternatives was conducted to determine which alternatives would best suit the numerous parties with interests in San Luis Reservoir water.

Non-project inflows

Stemming from the 1976-1977 drought, the SWP had accepted non-project water inflows to the aqueduct, but those inflows raised water quality concerns. From 2001 to 2004, most of the 360,000 acre-feet of water contained higher concentrations of nitrate, arsenic, sulfate, and chromium VI, but lower concentrations of bromide and TOC. Even though an updated policy has been in place, more monitoring was desired because the modeled mass load calculations were much lower than the actual concentrations.

Castaic Lake

The previous sanitary survey identified cattle grazing as potential sources of pathogen contamination. However, a study done showed gull roosting caused more *E. coli* contamination than cows. Fences were installed to manage the cows and management practices of discouraging gull roosting have been employed by MWDSC.

Lake Perris

Lake Perris's key water quality concerns were pathogens, T&O, algal toxins, and anoxia in the hypolimnion and these problems limited MWDSC's ability to withdraw water. A study collecting coliforms was done to determine the effects of body-contact recreation. Thermal stratification on the lake produced algal created T&O in the epilimnion and anaerobic conditions in the hypolimnetic layer that made the lake, at times, unacceptable for drinking water. In 2005, a study determined the potential liquefaction of the foundation of the dam during an earthquake. In response, the lake was lowered 25 feet from previous normal elevation, but this had increased the T&O problems from benthic algae as well as caused concerns about operation flexibility.

Incidents and Emergency Response

Jones Tract Levee Failure

A portion of the west levee of Upper Jones Tract, located in the southern Delta, failed on June 3, 2004 resulting in the flooding of Upper and Lower Jones tracts.

Wastewater Spills in the Delta Watershed

During the study period, Stockton, Lathrop, Isleton, and the Sacramento County Sanitation District reported spills of raw or partially treated wastewater into the Delta watersheds. Record rainfall in December 2005 caused spills of raw wastewater, partially treated wastewater, and river overflow into wastewater ponds in the Sacramento-San Joaquin River watershed and Delta. In response, the Statewide General Waste Discharge Requirements for Sanitary Sewer Systems, Water Quality Order No. 2006-03 was adopted in May 2006. The order provided a statewide regulatory approach to overflows, and required the development and implementation of a sewer systems management plan and the establishment of standard procedures for immediate response to spills.

Wastewater Spills in Silverwood Lake

Heavy rains and a high water lake level in January 2005 damaged two sections of an effluent outfall line carrying chlorine-disinfected secondary treated wastewater. An estimated 9.2 million gallons from the first break and 2.1 million gallons from the second break were released in the Silverwood watershed. Samples from the pipeline break, untreated Devil’s Canyon Afterbay water, and mills WTP influent were positive for *Cryptosporidium* and *Giardia* at significant levels compared to historical data, implying water quality at Silverwood Lake was affected.

A sewer main carrying raw wastewater broke in March 2005, and released 250 gallons of raw wastewater into Cleghorn Creek, ¼ mile upstream of Silverwood Lake. During repairs in April, a force-main that carried chlorinated secondary effluent was punctured, and released approximately 300 gallons into Cleghorn Creek. High levels of fecal coliforms were detected downstream; further testing was positive of *Giardia*, but not *Cryptosporidium*.

Fifty to 100 gallons of wastewater spilled from a bathroom to a beach on Silverwood Lake in July 2005. Sampling showed Cryptosporidium was detected only at the spill site.

Runoff/Turbidity

The Old Fire in October 2003 burned 40% of the watershed of Silverwood Lake, and the first heavy rains in December carried large amounts of debris into the lake. Metals were elevated and high turbidities caused T&O problems that prompted changes in water blends and chemical dosages in order to stay in compliance. Heavy rains in the winter of 2004-2005 caused increased runoff that led to high turbidity levels at Devil Canyon and Crestline Lake Arrowhead Water Agency WTP intake on Silverwood Lake.

High turbidity levels in Castaic Lake were caused by heavy rainfall in January 2005, and the high runoff into Elderberry Forebay and Castaic Lake.

Oil Spill in Pyramid Lake

On March 23, 2005, heavy rains triggered a landslide that broke a pipeline carrying light crude oil. An estimated 126,000 gallons spilled into Posey Canyon, 1.3 miles above Pyramid Lake. Samples collected from March 24 to April 7, showed detects in the cove of the lake, but volatile organic compounds were found at levels less than reporting limits near the lake center, Pyramid outlet tower, and Piru Creek release point. No immediate water quality threat occurred as contracted water came from Castaic Lake and there was no exchange of water until after the oil had diminished.

Concerns with system operations and maintenance

There were several concerns with the operation and maintenance of the SWP. Clifton Court Forebay experienced sediment loading and the shallow waters provided an encouraging climate for algal to grow, both problems creating T&O issues. Sedimentation was also a problem for the forebay and storage tanks along the coastal branch. In order to combat T&O problems, a Solar Bee solar powered water circulator was employed to keep sediment suspended and reduce T&O issues. In Hesperia, two miles of the aqueduct were open to direct urban runoff. As population increased, more urban runoff caused water quality problems from those users downstream. MWDSC reliance on SWP water caused changes in water quality from changes in pattern demands. High volume deliveries occurred earlier in the year and deliveries continued nearly year-round. The water quality changes from the increased need of SWP water resulted in increased operational costs in order to remain in compliance of water quality regulations.

Chapter 12 — Other Program Reports

The purpose of this chapter is to provide a summary of the results from small studies, work conducted by Municipal Water Quality Investigations with other agencies, and studies done in collaboration with consultants. The reports summarized in this chapter are as follows:

Study of Dredge Material Reuse Site to Improve the South Delta at Clifton Court Forebay

Delta Island Drainage Volume Estimates 1954-1955 versus 1995-1996

SMARTS

In Delta Storage Program

Department of Water Resources and United States Geological Survey Delta Islands Water Use Study

Rice Field Drainage Study

New Parameters Study

Studies of Dredge Material Reuse Sites to improve the South Delta at Clifton Court Forebay

Duration of Study

1992-1998

Investigators

Victoria Island: Cassandra Enos, Mike Ford, Judy Heath, Mike Minnazaheri, Steve Roberts, Rick Woodard, and Carrie Stephens; Twitchell Island: Cassandra Enos, Carrie Stephens; Bryon Tract: Richard Sapudar, Denise Webster, (David Gonzalez, Ian Waters, Walter Lambert, Diana Stoliker); Grant Line Canal: Richard Sapudar, Jim Hockenberry, Denise Webster (David Gonzalez, Walter Lambert)

Background and Objectives

The purpose of the Interim South Delta Program (ISDP) was to improve water levels and circulation in south Delta channels for local agricultural diversions, and to improve south Delta hydraulic conditions by increasing diversion into Clifton Court Forebay and by maximizing the frequency of pumping at H. O. Banks Delta Pumping Plant. In 2000, the ISDP turned into the South Delta Improvements Program.

Both programs were designed to have a positive effect on water quality while allowing for improvements to Clifton Court Forebay. The South Delta Improvements Program Preferred Alternative proposed Clifton Court Forebay remain its present size, but with a few modifications. An intake structure, two flow control structures, and a fish control structure were proposed for the areas in and around the forebay. In addition, dredging would occur in the channels along Old River between Clifton Court Forebay and North Victoria Canal.

There was concern the disposal of dredge material on the island and levees, or into settling ponds, would potentially release contaminants into surface and/or groundwater resulting in oxidation and acidification reactions. When sediments are conveyed to land, previously anoxic sediments slowly become oxygenated, or oxidized. This process can release metals, trace elements, and other contaminants associated with the oxidizable fraction. Acidification of the sediment had the potential to oxidize, releasing even more trace elements, leach contaminants from the soil to the groundwater, and cause effluent discharges to exceed water quality standards. Another concern was the potential effect suspended contaminated sediments would have on aquatic and benthic organisms, and on downstream drinking water treatment plants. Therefore, a series of special studies was conducted to look at environmental impact due to dredging.

Study Design

The ISDP did three studies on dredge material disposal activities. The studies were conducted from 1992 through 1996. The findings of these studies were presented in the Victoria Island Baseline Study of Dredge Material Reuse Sites, published in November 1995, Twitchell Island Baseline Study of Dredge Material Reuse Sites, published in January 1996, and Byron Tract Baseline Study of Dredge Material Reuse Sites published in March 1998.

The South Delta Improvements Program later conducted a fourth study, the Environmental Study of Dredged Materials Grant Line Canal. The results were published in January 2000. The purpose was to 1) improve the reliability of existing State Water Project facilities and operations within the south Delta, 2) ensure water of adequate quantity and quality was available for diversion to use within the South Delta Water Agency's service area, and 3) to contribute to restoring the ecological health of aquatic resources in the lower San Joaquin River and south Delta.

During the four studies, samples were collected from channel waters, agricultural drain waters, dredged sediment, levee soil, soil from proposed sediment disposal areas, and levee reuse sites. Collected samples were sent to a laboratory and analyzed for chemicals of environmental and drinking water treatment concern.

Results/Conclusions

At all study sites, comparisons of the soil sample results, with criteria from the Central Valley Regional Water Quality Control Board (CVRWQCB), San Francisco Regional Water Quality Control Board (SFRWQCB), and California Hazardous Waste Regulations indicated the soils were of acceptable quality for the intended use. Review of the results also indicated potential leaching of the effluent was not likely to affect ground water. However, a potential for the dredge material effluent to exceed water quality criteria for copper and pH did exist. Therefore, it was recommended that effluent samples be closely monitored for copper and pH prior to discharge into channel water.

Results for Victoria Island Baseline Study of Dredge Material Reuse Sites for the interim South Delta Program

The Victoria Island sampling occurred in 1992. Samples for this study included channel water and soil from the proposed setting pond disposal and levee maintenance sites.

Most of the organic constituents analyzed in the settling pond and levee soil samples had not-detectable results. Tributylin was not detected in any of the samples. However, all of the settling pond soil sites exceeded San Francisco Regional Water Quality Control Board (SFRWQCB) criterion of 0.003 mg/kg dry weight for total DDT. While detected, significant quantities were not present in the setting pond's discharge.

Trace metals were found in detectable concentrations in most of the settling pond and levee soil samples. Soluble lead, zinc, copper, and nickel were found in the settling pond and levee soil samples, but sample concentrations did not exceed SFRWQCB criteria, Central Valley Regional Water Quality Control Board (CVRWQCB) Maximum Concentrations or Total Threshold Limit Concentration (TTLC) values. Soluble zinc and nickel did not surpass their respective Water Quality Objectives (WQOs) at any sites. Three settling pond sites and one levee site had lead concentrations that exceeded the lead WQO of 0.00099 mg/L. Copper also went beyond the WQO of 0.0054 mg/L at several locations. CVRWQCB Maximum Concentrations and Soluble Threshold Limit Concentration (STLCs) were not exceeded at any of the sites.

Comparisons of the soluble analyses and the above criteria showed the decant waters from settling ponds on Victoria Island could be discharged into the channel water. Monitoring was advised due to the potential for pH and copper to surpass water quality criteria before being discharged; however, results indicated the soils were acceptable for the intended use.

Results for Twitchell Island Baseline Study of Dredge Material Reuse Sites for the interim South Delta Program

Samples for the Twitchell Island Dredge study were collected on four occasions from October 1992 to June 1995. Samples were taken from channel water, agricultural drainage water, and soil from the proposed sediment disposal and levee reuse sites.

Several synthetic organic compounds were evaluated and only two results were detectable. Tributylin was detectable in only one soil sample on the island.

Trace metals were found in detectable amounts in most of the island and soil samples. SFRWQCB criteria or TTLC values were not exceeded in any of the samples, but a few samples surpassed their total maximum values (TMVs). In both the island and soil samples, most of the detectable concentrations for nickel and selenium were over their respective TMVs. While total selenium concentrations exceeded the CVRWQCB Total Maximum Value, none of the soluble concentrations were above the CVRWQCB Soluble Maximum Value.

Comparable to the total metal results, the detected concentrations of soluble trace metals were below STLC values. Soluble results were beneath Soluble Maximum Values (SMV) without discharge to the river. Discharge to the river did have a few metal concentrations that exceeded SMV. Soluble copper was found in every island and levee soil sample at levels exceeding the SMV for discharge to the river.

The findings indicated the soil quality was acceptable for the intended use. Ground water was not likely to be affected by potential leaching through either the island or the levee soils. Because of the potential of the dredge material to violate water quality criteria for copper and pH, it was advised that effluent samples be monitored prior to their addition to channel waters.

Results for Byron Tract Baseline Study of Dredge Material Reuse Sites Interim South Delta Program

Soil, water, and aquatic sediment studies were conducted in 1992, 1994, 1995, and 1996. Baseline data was collected on both the dredge material reuse sites and on Old River sediments to be dredged. Levee reuse sites adjacent to Highway 4 and proposed sediment disposal areas had samples taken of channel water, agricultural drainage, and soil.

In the analysis of several synthetic organic compounds, only two results were detected. Both of the DDT detects in the soil were significantly below all applicable criteria.

Soluble lead concentrations were above SMV with discharge to the river. Concentration levels higher than TMV were only found in one lead sample. All of the detectible copper concentrations exceeded SMV with discharge to the river but fell below SMV without discharge. One roadside sample had soluble nickel concentrations that exceeded SMV. Nearly all of the samples had total nickel concentrations above TMV.

Even though most of the soil and island samples had detectable concentrations of trace metals, no samples exceeded their SFRWQCB criteria or TTLC values. Total metals and soluble metals did not exceed STLC values. Many of the samples exceeded the SMV with river discharge criteria, but not the SMV without river discharge. Samples taken from Old River sediments for soluble metals fell below the Maximum Contaminant Levels for drinking water.

Bryon Tract dredge sites had acid-generation potential (N/A) below the CVRWQCB's minimum level of three, and Old River sediment's N/A ratios were much greater than three. Potential leaching from the slightly acidified Byron Tract soils was not likely to occur due to the neutralizing Old River sediment. Discharge monitoring to meet water quality standards or Waste Discharge Requirements was unlikely; however, groundwater monitoring was recommended.

Based on criteria from CVRWQCB, SFRWQCB, and California Hazardous Waste Regulations, the samples were non-hazardous and acceptable for the intended use. In addition, the results indicated the potential leaching of the soils by the effluent was not likely to affect groundwater.

Results for Environmnetal Study of Dtedge Materials Grant Line CanalSouth Delta Improvements Program

A fourth study was done on dredged materials for the South Delta Improvements Program. In January 2000, the report Environmental Study of Dredge Materials Grant Line Canal was published. The study was a continuation of sampling studies associated with Old River in 1992, 1994, 1995 and 1996, which looked at the potential of releasing contaminants during the dredging process. Samples analyzed were from channel water, sediment, and a sediment water extract, also known as elutriate. Because the Central Valley Regional Water Quality Control Board (CVRWQCB) did not have criteria for dredged material at that time, the California Department of Toxic Substances Control Title 22 Total Threshold Limit Concentrations (TTLC) and Soluble Threshold Limit Concentrations (STLC) were used instead.

Oil and grease were detected at low concentrations in a couple of samples, but gasoline and diesel fuel were not. One organophosphate insecticide was detected in the elutriate, but the remaining synthetic organic compounds, such as agricultural chemicals, were below detection limits for both sediment and water results.

The sediment analysis showed all samples contained arsenic, zinc, lead, nickel, chromium, and copper. None of the sediment samples detected cadmium, mercury, and selenium. The soil samples did not exceed their TTLC, STLC, or MCLs. Similarly, while trace metals were detected in background levels of Grant Line Canal and elutriate samples, all levels were far below their MLCs and the Proposed California Toxics Rule limits.

A Simultaneously Extracted Metals (SEM): Acid Volatile Sulfide (AVS) ratio comparison was done on the sediment. The ratios of the sediment samples ranged from not detectable AVS (5 samples) to nearly 2 (2 samples).The mixing of the sediment into settling ponds should remove the potential of bioaccumulation or toxicity to aquatic life from metals. From the acid-generation potential results, it was determined the sediment was unlikely to become acidic or leach metals into the soil or groundwater.

To determine whether disinfection byproducts would increase, a THMFP-SDS test was conducted. Even though dissolved organic carbon and total organic carbon were elevated in the elutriate, the results pointed toward no significant increase, and even a possible decrease in THMFP. The results of UVA_{254} testing of the sediment elutriate as compared to background channel water, supported those findings.

The only concern that might have required further testing or monitoring was a toxicity identification evaluation if the dewatered sediments showed traces of toxicity. Although unlikely, if toxicity was found, it was recommended the test be conducted to determine the source. After extensive analysis with contaminants below regulatory levels, the study did show dredge materials were suitable for most uses including levee stabilization, upland or agricultural applications.

Delta Island Drainage Volume Estimates 1954-1955 verses 1995-1996

Report Date

January 1998

Investigators

Marvin Jung, Quy Tran

Background and Objectives

Drainage volume data affects Department of Water Resources (DWR) computer model results for projecting past and future water use and water quality. Mass load computations of drain water constituents, such as salts and organic carbon (OC), depend on drainage volume estimates. Reasonable drainage volume estimates are needed in modeling and water quality assessment studies. In order to develop baseline conditions for comparison to future alterations that affect agriculture and water treatment in the Sacramento-San Joaquin Delta (Delta), this study was done to test the feasibility of estimating present drainage volumes from power use and pump test records and comparing the results to historical land uses.

Study Design

Drainage volumes estimates collected by DWR from 1954 to 1955 were compared to United States Geological Survey (USGS) estimates taken in 1995 and 1996. Comparisons were done on rainfall, land use, drainage by sub-regions and seasons, land use changes, and the completeness of the data sets used. The two reports used were *Quantity and Quality of Waters Applied to and Drained From the Delta Lowlands*, DWR Report number 4, 1956 and USGS open-file report 97-350, *Drainage-return, Surface water, and Land-use Data for the Sacramento-San Joaquin Delta with Emphasis on Twitchell Island, California*.

Results/Conclusions

The drainage volume estimates were more than 10% lower in the 1995-1996 USGS study. In the 1954-1955 DWR study, 82% of the pump efficiencies and power use records were available. The average of the 82% was used for the remaining unknown 18%. The USGS study was nearly the opposite. Pumping efficiency data was available for about 20% of the pumps. That was used to create a mean pump value for the remaining 80%. The available power information from PG&E was aggregated for areas no smaller than 36 square miles in size, preventing the identification of drainage volume from specific islands and tracts.

The significant difference in the estimated amount of Delta lowland drainage in the USGS 1995-96 study and in the DWR 1954-55 study was the result of a less complete database in the former study. Both studies showed accurate drainage volume discharge information could be achieved if both power use records and pump test efficiency data were available for a pump station. Future attempts to obtain accurate drainage discharge data will require cooperation and permission directly from landowners and reclamation districts to periodically run pump efficiency tests and to obtain power use records or to install flow meters at each pump.

For the MWQI Five-Year Summary Report from 1987 to 1991, a simple model was made to estimate the contribution of dissolved organic carbon (DOC) from Delta drainage. Delta channel DOC predictions based on 1954-1955 drainage estimates were in close agreement with observed DOC values, indicating the volume of drainage discharge may not have changed significantly since the 1950s.

Special Multipurpose Applied Research Technology Station (SMARTS)

Duration of Study

1998-2000

Investigators

Marvin Jung and Associates Inc. and Lori Weisser

Background and Objectives

The Special Multipurpose Applied Research Technology Station (SMARTS) was implemented as a new approach to collect information on changes in water quality. The initial part of the first study was to test if a flexible multipurpose testing facility was feasible. Experiments were conducted on factors that would affect water quality if a peat soil environment was either flooded for water storage or managed as a wetland, as proposed by CALFED.

The study was comprised of two main efforts. The first phase, initially focused on the construction of the tanks and then examined the interactions of soil depth, water depth and water exchange rates after the tanks were usable. The second phase examined the seasonal water quality changes and used those results to develop best practices to minimize organic carbon in waters when peat soils are converted to wetlands or island water storage.

Study Design

The SMARTS facility was constructed in 1998, and was designed to conduct experiments to examine the interactions of three different factors, allowing for the examination of eight effects. The facility consisted of nine tanks, four 810-gallon and five 1500-gallon capacity. The tanks were set up to compare peat soil depth, water depth, and the exchange rate of water. The ninth tank was a control to see if the materials would have any effects on the test results. The depth of the peat soil was either 1.5 feet or 4 feet. The depth of the water was 2 feet or 7 feet. The water was either not exchanged or had an exchange rate of approximately 1 or 1.5 times per week.

The first experiment began in July of 1998 and lasted 12 weeks. The soil was mixed, loaded into the tanks, trampled down, and leveled out before West Sacramento tap water was added to flood the soils. Sampling occurred weekly, with the first samples taken one week after the tanks were filled with water. Without a budget in place, tarps were not purchased to cover the tanks and evaporation and algal growth proved slightly problematic, subsequently leading to the refilling of tanks and the necessary testing for chlorophyll-a. Submersible pumps were used to circulate the water within the tanks. After the experiment, the soils were removed for disposal.

The second experiment lasted a year, observing seasonal changes in water quality with the initial three factors of water depth, soil depth, and water exchange rate. Sampling occurred every two weeks from January to August, when minor changes in water quality implemented quarterly sample events. In this experiment, larger submersible pumps were used to circulate water and covers were used to prevent evaporation, algal growth, and to prevent rainfall gain. Months after the end of the experiment and the stopping of the submersible pumps, two additional samples were taken in June and September 2000.

New soil was brought in from Twitchell Island for the second experiment; however, the tanks were filled in two different events. The smaller tanks were filled with soil collected in November 1998. A storm event occurred before the second set of tanks was filled in December and the resulting soil was clumpy, muddy, and wet. The rain event allowed for the differences in flooding dry peat soil against recently leached peat soil to be examined.

The study sampled for total organic carbon (TOC), dissolved organic carbon (DOC), TTHMFP, electrical conductivity (EC), mineral salts, nutrients, and algae; good water quality was thought of as low amounts and/or concentrations of the parameters.

Results/Conclusions

The first experiment showed the three factors of soil depth, water depth, and water exchange rate, had significant additive influences. The best water quality occurred with the combination of high water depth and continuous water exchange, which produced TOC at 2.3 mg/L and DOC at 1.9 mg/L. The tank with no water exchange, shallow water, and high peat soil depth produced TOC at 166 mg/L, DOC at 108 mg/L, EC at 532 µS/cm and a TTHMFP of 11,300 µg/L. In addition, the algal mat created chlorophyll-a levels of 200 µg/L. Based on all of the water quality parameters and indexes used, water in this tank could be classified as either eutrophic or hypereutrophic. In the 12-week experiment, soil parameters did not stabilize leading to the creation of a second experiment lasting a year.

Three recommendations came out of the first study. The design, construction, and operation of a flooded peat environment must consider the three factors of soil depth, water depth, and water exchange rate. Long-term studies are needed to better understand the processes involved. Studies that are more intensive are required to quantitatively predict water quality changes from different types of wetlands and various management schemes.

The second study observed seasonal patterns in TOC/DOC concentrations. The warming seasonal temperatures encouraged microbial breakdown of organic matter within the soil, providing a supply of organic matter and nutrients. The result was the tank that had the deep soil and shallow non-exchanged water had the highest increases in TOC, DOC, THMFP, color, EC, total phosphorus, bromide, and alkalinity.

The second experiment also examined the effects of rain on the peat soil. The rain removed much of the iron, phosphate, sulfate, and nitrogen from the second batch of soil. The DOC concentration was four and a half times less than the flooded dry peat soils. The effects of the rain showed flooded soils drained prior to re-flooding have a smaller impact to water quality. Comparisons of the soils loaded into the tanks before the rain and after the rain showed much of the soluble organic matter and nutrients were washed away reducing DOC and THMFPs.

Even with the differences between the flooded and leached soils in experiment two, the additional two samples after the end of the experiment strongly suggested the seasonal cycle would repeat itself. Organic carbon may still be available from the peat soil because weakly bound fractions that are more humic dissipate into DOC faster, while the strongly bound organic fractions will degrade to become a source of DOC.

Soil depth is an important factor because peat soil is a large reservoir for organic carbon containing high levels of TTHMFP, EC, and nutrients. Both studies showed increased soil depth would increase levels of water quality constituents of concern. The studies also showed increased water depth and increased water exchange rates would decrease concentrations of water quality constituents, creating a balance to the negative effects of soil depth.

Three factors affect drinking water quality and should be incorporated into the design and operation of either a wetlands or water storage. The first experiment showed surface water exchange was an important factor for water quality; therefore, attention to the timing and duration of exchange rates is necessary to ensure the water quality remains similar to incoming water. Water depth was also a factor. Biologically productive wetlands exist in shallow water, but create water quality problems. On the other hand, the deeper depths that improve drinking water quality may conflict with maximizing wetland ecological benefits. The last factor concerned soil depth and therefore peat content. Peat soils will continue to release organic carbon seasonally, so locations with a higher mineral soil content would be preferred.

Other best management practices for a flooded island water storage included removing crop residues prior to flooding, or plowing the soil during the warm months to encourage release of carbon from the soil. Experiment 2 showed flooding and draining of the island before long-term storage can be beneficial; however, care must be taken to minimize alternating oxidation-reduction conditions caused by repeated wet and dry cycles in the soil.

In Delta Storage Program Draft Summary Report for the Integrated Storage Investigations

Report Date

February 2002

Investigators

Department of Water Resources (DWR), CALFED, United States Bureau of Reclamation (USBR) for the CALFED Bay-Delta Program

Background and Objectives

In-Delta storage was identified as one of five potential storage projects. The proposed project was to use Webb Tract and Bacon Island as storage reservoirs and transform Bouldin Island and Holland Tract into habitat islands. The proposal needed to meet CALFED water supply reliability and ecosystem restoration objectives. The purpose of In-Delta storage is to help meet:

- The ecosystem needs of the Sacramento-San Joaquin Delta (Delta)
- Environmental Water Account and Central Valley Project Improvement Act goals
- Provide water for use within the Delta
- Increase reliability, operational flexibility, and water availability for the south of the Delta water use by the State Water Project and the Central Valley Project.

Study Design

URS Corporation performed risk analyses to evaluate the risk of failure due to operation, seismic, and flooding events. CH2M HILL conducted an evaluation of the proposed Delta Wetlands fish screens, siphons, and pumping stations. Environmental Research Associates conducted bio-productivity studies to predict the organic carbon (OC) component related to algae and aquatic plant activity. USBR conducted water temperature and dissolved oxygen studies to predict differences in reservoir and channel waters. Municipal Water Quality Investigations (MWQI) conducted the field water quality studies. The first study examined soil and water samples from Webb Tract and Bouldin Island. The second study was the Special Multipurpose Research Technology Station (SMARTS), which looked at the effects of flooding a peat-soil island. The information from the experiments was combined with conceptual models and algorithms to predict changes in OC in soils.

The following study areas were examined:

- Operational studies using CALSIM 2 daily Delta operations model
- Water quality evaluations using field, laboratory, and modeling studies
- Engineering investigations to evaluate the adequacy of the project
- Environmental evaluations that included surveys, field studies, habitat management plans, fish screen evaluations, environmental impact assessments, and monitoring and mitigation plans and costs
- Economic analysis of annual cost, benefits, impacts to Delta economy, and qualitative descriptions

Results/Conclusions

General requirements of the project were not to exceed any applicable water quality objectives in a water quality control plan and to not cause a water treatment plant to exceed contamination levels for disinfection byproducts (DBP). Specific goals were set for total organic carbon (TOC), chloride, DBP, dissolved oxygen, and temperature.

Modeled results showed the Delta Wetlands Project operations do not comply with Water Quality Management Plan (WQMP), dissolved organic carbon (DOC), and DBP criteria. DOC and DBP impacts could be greater than model projections and WQMP compliance would affect water supply. Key findings from the various study areas are listed below.

Engineering investigations

- The embankment and inlet/outlet structures do not meet DWR design standards
- There is risk of operational, seismic, and flooding events with the potential of causing degraded water quality, supply interruption, and salt-water intrusion
- Seepage control systems needed improvement
- Climate change may require the embankments to be raised

Operational studies

- In-Delta storage could catch early winter flows
- Reductions in yields are expected from compliance requirements, but will require further evaluation

Water quality evaluations

- Predicted DOC concentrations range from 10 to 20 mg/L
- Within 150 days, 50% to 80% of the carbon loading would occur, and after 10 months of storage, carbon loading would be more than 90%
- Based on diversions and discharges, phytoplankton would contribute 1 to 6.5 mg/L carbon (C) for 3 to 5 years and aquatic vegetation was likely to contribute 1 to 10 mg/l C
- Water quality modeling shows the project may not comply with criteria, possibly reducing supply and availability
- Temperatures in the reservoirs have the potential to be 1 to 9°F higher than in the channels

Environmental evaluations

- Listed fish species will likely be impacted by insufficient fish screens on intake pumps
- Islands will require remediation before storage or habitat mitigation is done
- Recreational benefits need to be included
- Proposed fish screens not feasible from environmental and design problems

Economic analysis

- The initial cost was $591 million, with a potential to go higher with variations in design
- Further allocation studies are needed to complete a cost and benefit analysis
- There was minimal impact from the loss of agricultural land on economy
- Using Victoria Island as an alternative increases capital cost from agricultural land loss and re-engineering costs associated with raising Highway 4 and creating a new connecting structure for Clifton Court

Department of Water Resources and U.S. Geological Survey Delta Island Water Use Study

Duration of Study

December 1993–April 1996

Investigators

United States Geological Survey (USGS) and Municipal Water Quality Investigations (MWQI)

Background and Objectives

The Delta Island Water Use Study was designed to obtain quantitative and qualitative information on Sacramento-San Joaquin Delta (Delta) island water use and drainage water quality. USGS was to collect information on power use data and relate it to water use to determine if it was feasible to use electrical power records to measure pumped water discharges from Delta islands. The other USGS component was to determine if it was possible to estimate historical power consumption and pumped volume using historical PG&E database records.

The water quality objectives of Twitchell Island drainage focused on by MWQI was to obtain baseline water quality information on siphoned water onto and drainage off of the island, calculate mass loads of chemical constituents, and compare the mass loading from Delta islands to mass loading by the Delta rivers.

Study Design

Twitchell Island, located in Sacramento County, has 21 siphons and 2 drainage pumps on 3,516 acres. Three of the 21 siphons were metered for flow at the end of 1994, with nine more added in June 1995. Flow data was collected on a weekly basis from the agricultural drain and from selected siphons on the island.

Water quality samples were collected three times a week with an auto-sampler from the agricultural drain on Twitchell Island. The samples were analyzed for temperature, specific conductance (EC), dissolved organic carbon (DOC), and ultraviolet absorbance at 254 nanometer (UVA_{254}).

Grab samples were taken on a weekly basis from agricultural drains and siphons in operation. The samples were analyzed for temperature, specific conductance, pH, dissolved oxygen, turbidity, DOC, ultraviolet absorbance, bromide, and other minerals.

Results/Conclusions

The main agricultural drain had DOC concentrations from less than 10 mg/L in the fall to 60 mg/L, with concentration peaks and mass loading occurring from January to March. Drainage was highest during the winter months, similar to the flow trend in the Sacramento River. Smaller peaks in DOC concentrations and loading occurred during August and September.

Water diverted onto the island had DOC concentrations from 1 to 2 mg/L to almost 40 mg/L. The highest DOC concentrations occurred April, and the lowest concentrations occurred in August and September, opposite of the concentrations found in the Sacramento River.

Organic carbon concentrations in Delta island drainage increase when water is diverted for irrigation or leaching. The amount of increase is dependent on the source of the siphoned water and concentrations often increase 10 to 20 mg/L DOC. The available flow-meter data combined with water quality data was used to calculate mass loads for the Twitchell Island main agricultural drain, and for the Sacramento River at Greene's Landing. Peak loading occurred in January through March on Twitchell Island, while the Sacramento River peak loading occurred from February to April. Because siphon use is greatest in the summer months, the greatest mass loading of DOC onto the islands occurred in the summer months.

One major unmet objective was to use PG&E electrical power data to extrapolate drainage from Twitchell Island to other islands in the Delta. The objective could not be met due to (1) the inability to obtain adequate PG&E database records for estimating historical power consumption or pumped volume in the Delta, and (2) finding it was not feasible to use electrical power records to measure pumped water discharges from Delta islands.

USGS was unable to consistently relate, with accuracy, pumped island drainage volume to electrical power use, and pump test records. Different database formats and billing cycles, outdated pump test data, and inaccurate coding of past electrical power use records from PG&E complicated USGS efforts in identifying metered pump stations and computing monthly pumped drain water volumes.

Rice Field Drainage Study

Duration of Study

1994-1996

Investigators

Municipal Water Quality Investigations/Northern District

Background and Objectives

Total organic carbon (TOC) levels in the Sacramento River were suspected to increase because of changes in rice straw decomposition practices associated with the Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991 (AB1378) of California State Health and Safety Code Section 41865. The act reduced the allowable burnable acreage requiring farmers to dispose of their rice straw by other methods including flooding. The rice drainage study examined whether rice field drainage would increase total and dissolved organic carbon (DOC) concentrations in the Sacramento River and potentially affect municipal water facility treatment practices downstream.

Study Design

More than 500,000 acres of rice were farmed in the Sacramento Valley during 1994. Fifty-nine percent of the rice fields were burned and twenty-one percent was purposely flooded for decomposition. The Colusa Basin and Sutter Bypass drains, American River, and Sacramento River at three stations were monitored in February and March 1995. For 12 days, during rice field drainage, TOC and DOC were monitored at the sampling locations. The study extended to a second year in 1996 and three additional sites were added, with sampling done by Department of Water Resources Northern District. The samples were analyzed for TOC, DOC, ultraviolet absorbance at 254 nm (UVA_{254}), THMFP, alkalinity, and sulfate.

Results/Conclusions

The data indicated organic carbon loads from rice field drains affected Sacramento River's water quality. Mass load estimates were made on sample days without flooding (February 23 and 27, 1995 and March 2 and 6, 1995). The organic carbon load from the Colusa Basin and Sutter Bypass drains comprised 7% to 26% of the lower Sacramento River's load. Other sources, including the Feather River and some unaccounted rice drains, were estimated to comprise 17% to 63% of the downstream load. The American River, which has no rice drain water, contributes 7% to 16% of the lower Sacramento River's load. Based on these loading estimates, the agricultural drain loads increased TOC levels at the lower stations by 3% to 22%. Sacramento River TOC levels were similar between Colusa and Greene's Landing on three of the four sample days when flooding from heavy precipitation did not occur.

New Parameters Study

Duration of Study

1995-1997

Investigators

Municipal Water Quality Investigations

Background and Objectives

Proposed constituents to be regulated under drinking water regulations had been put in place by the U.S. Environmental Protection Agency's (EPA's) Chemical Contaminant Phase II and Phase V Rules, and new potential constituents had been listed for Phase VI-B. In addition, proposals for, or changes to, arsenic, sulfate, lead and copper rules were imminent. Little historical data was available for concentrations of those constituents in the Sacramento-San Joaquin Delta (Delta). The New Parameters Study gathered information on the constituents to determine which parameters might need to be added to routine Municipal Water Quality Investigations (MWQI) monitoring, based on the frequency and level of detection.

The results could be used to: (1) obtain monitoring waivers for constituents, (2) provide data that can be used to satisfy a system's initial sampling requirements, and (3) provide data that may be used to evaluate future best available technology requirements.

The new Phase II and Phase V rules under USEPA's drinking water regulations established limits for several organic and inorganic chemicals. Notices published in 1991 finalized the Phase II Rule for synthetic organic compounds and inorganic compounds. The rule regulates 38 organic and inorganic chemicals and requires monitoring for an additional 30 unregulated contaminants. Five of the original 38 chemicals were re-proposed in Phase II-B and became effective in 1993. The Phase V Rule regulated 13 synthetic organic chemicals, 5 inorganic chemicals, and 3 volatile organic chemicals. Sulfate was removed from the original list and a sulfate rule was to be proposed by 1998. Part of the Phase V Rule was for compliance monitoring to begin in larger public water systems in 1993 and for systems with less than 150 connections to begin monitoring in 1996.

Phase VI-B amended the Safe Drinking Water Act's requirement of regulating 25 new standards every three years to a new process based on occurrence, relative risk, and cost benefit analyses. Under the new requirement, the EPA selects at least five new candidate contaminants for potential regulation every five years. The focus would be to find contaminants that pose the greatest health risk.

Changes from the new rules included amendments to the arsenic, lead, and copper rules, plus a newly proposed sulfate rule. The proposed 1995 revision to the arsenic rule was pushed back to allow the EPA to perform further research on the health effects at low levels of exposure. The new regulation was due in 2000 with the final resolution issued within a year. An amended copper rule sought to reduce the reporting burden. The final regulation called for treatment techniques that included lead service line replacement and source water treatment. The federal lead and copper rule reset the maximum containment level goal (MCLG) to 0 mg/L for lead and 1.3 mg/L for copper. It also banned lead-containing products in public water systems. Sulfate was deferred from the 1990 list of contaminants due to cost concerns for treating waters. In 1994, the new proposed rule set the MCLG and maximum contaminant level (MCL) at 500 mg/L and applied to all water systems. In 1996, a study on the health risks of sulfate in drinking was to begin, with the mandate that sulfate be included as one of five contaminants considered for regulation in the new five-year regulatory cycle process.

Study Design

The list of constituents monitored were based on the current standard compliance monitoring requirements, i.e., those regulated by Phase II, Phase II-B, Phase V, and the proposed list in Phase VI-B. The study was conducted at major sites of diversion from the Delta. The five original sites sampled included: (1) Barker Slough Pumping Plant (North Bay), (2) Contra Costa Pumping Plant, (3) Delta-Mendota Canal, (4) Old River at Bacon Island, and (5) H. O. Banks Pumping Plant. Old River near Byron was added as an additional site in June 1996. Sampling occurred quarterly from June 1995 through December 1996.

California Department of Public Health (CDPH) had the ability to grant waivers for specific water quality constituents if there were poor analytical results or if the assessed vulnerability was low. All parameters were sampled for, because laboratories charge by the method used, and not the number of parameters analyzed.

Quality Assurance/Quality Control (QA/QC) analysis was done on samples collected in the field and laboratory, as well as data quality assessment for both collected and laboratory data. Field duplicates, matrix spikes, laboratory control samples, and method blanks were the QA/QC samples taken and analyzed.

Results/Conclusions

In most cases, organic analytes were either not detectable or detected at concentrations below their respective MCLs. The organic analytes detected during the study were: the herbicides 2,4-D, Simazine, Diquat and the chlorinated herbicide Dalapon; the pesticides 2,4,5-T and Glyphosate; and the insecticides formetenate hydrochloride (also known as Carzol) and aminomethyl-phosphoric acid. The only analyte that exceeded both federal and state MCLs was Bis (2-ethylhexyl) phthalate (also known as DEHP), which is sometimes used in pesticides and found in plastics. Arsenic was present at all sites below the MCL and zinc was regularly detected at all sites, while selenium was only detected at the Delta-Mendota Canal. Overall, the Barker Slough and Contra Costa Pumping Plant sampling sites had the greatest occurrence of pesticides; pesticide 2,4-D had the highest number of detects. The Delta-Mendota Canal was the one sampling location that did not have any pesticide detects.

Chapter 13 — Studies in Progress

The purpose of this chapter is to provide a summary of the studies that were in progress as of June 2013. The reports summarized in this chapter are as follows:

This section includes studies that were underway during the writing of this report.

Delta Simulation Model 2 Boundary Update

Source, Fate, and Transport of Nitrosamines and their precursors in the Sacramento-San Joaquin Delta and State Water Project

Investigation of Organic Carbon and Bromide Long-Term Trends and Seasonal Patterns in the Delta using Municipal Water Quality Investigations Historical Data

O'Neill Forebay Water Circulation Study

Lathrop Urban Sources and Loads Investigation

Nitrosamines, their precursors, and Cryptosporidium/Giardia Occurrence from Waste Water Treatment Plant Facilities in the Delta

Spectrofluorometer Investigation

Delta Simulation Model 2 Boundary Update

Duration of Study

January 2008 to March 2010

Investigators

Joe Christen

Background and Objectives

The Delta Simulation Model 2 (DSM2) has used assumed boundary conditions for the East Side streams and Yolo Bypass based on the American River and the Sacramento River, respectively. The assumed values are not representative data, and therefore do not capture seasonal or flow-related variations in water quality. Due to the lack of data, a study of organic carbon (OC) data was undertaken to fill in the data gaps within the DSM2 model.

Study Design

A 15-month, biweekly discrete sampling study was conducted at six locations. Shag Slough at the Liberty Island Bridge represented Yolo Bypass inflow. The Mokelumne River at Wimpy's Marina was selected to represent both the Cosumnes and Mokelumne rivers. The Calaveras River at Brook Road in Stockton represents the third East Side stream. Three interior Sacramento-San Joaquin Delta (Delta) stations at Old River at Tracy Boulevard, Old River at the temporary barrier near Fink Road, and Grant Line Canal at Tracy Boulevard were included in the calibration update study.

During water year 2010, additional sampling events occurred during significant storm events to capture elevated dissolved organic carbon (DOC) concentrations often seen during storm flows. When flows from the Sacramento River top the Fremont Weir, sampling also occurred at Cache Slough downstream of the Yolo Bypass. Samples were analyzed for DOC concentrations and ultra-violet absorbance at 254 nm (UVA_{254}).

Results/Conclusions

The results of this study demonstrate current DSM2 assumptions for DOC concentrations at the Delta boundaries of the Mokelumne River, Calaveras River, and the Yolo Bypass underestimate actual DOC concentrations during high flow conditions. The difference between the surrogate data and the actual values are likely because they have different watersheds. The Yolo Bypass watershed is predominantly agriculture and the wetlands of Liberty Island. The Calaveras River is not influenced by New Hogan Reservoir, but rather the agricultural lands below the reservoir. The Mokelumne River also has agriculture and wetlands in its lower reaches. In comparison, the surrogate data is from the American River, and the watershed is predominately forested land with minimal influence from lowland agriculture or wetlands.

Yolo Bypass

Throughout the study period, DOC concentrations at Shag Slough were consistently greater than at Hood. The difference in mean concentrations between the two stations was relatively large (3.3 mg/L). The DOC values ranged from 3.3 mg/L to 9.7 mg/L, and had a median value of 4.9 mg/L. The consistent difference in concentrations between the Hood and Shag Slough stations and the strong relative difference

(83%) in the means of the data are evidence that DOC data from Hood is not an adequate surrogate for DOC in the Yolo Bypass.

Mokelumne River

The Mokelumne River DOC concentrations showed increases during storm flows that appeared to vary in the strength of the response. The difference between the mean of the low DOC concentrations (1.98 mg/L) was 0.32 mg/L and 0.24 mg/L greater than the assumed low flow boundary conditions for the dry season and wet season respectively. The mean of the high DOC concentrations (6.07 mg/L) was 2.12 mg/L greater than the assumed early winter high flow boundary condition of 3.95 mg/L, a relative difference of 43%. The minimum and maximum DOC values were 1.3 mg/L and 9.4 mg/L, respectively. The differences between the low flow DOC assumptions in the Mokelumne River and the mean of the values measured under low flow conditions are less than the reporting limit (0.5 mg/L) for laboratory analysis for DOC concentration.

Calaveras River

Similar to the Yolo Bypass, storm flows during the study period originated downstream of New Hogan Reservoir, in a predominately agricultural area. Values for DOC in the Calaveras River during and following storm flows occasionally were greater than 10 mg/L, with a maximum value of 18.7 mg/L. The minimum and median values were 3.3 mg/L and 5 mg/L, respectively.

While the initial sampling for the study has been completed, it has been determined that additional sampling will continue to provide the modelers with additional information for these locations.

Sources, Fate, and Transport of Nitrosamines and their Precursors in the Sacramento-San Joaquin Delta and the State Water Project

Duration of Study

2008-2010

Investigators

Carol DiGiorgio, Stuart W. Krasner, Yingbo C. Guo, Melissa S. Dale, Michael J. Sclimenti, MWQI Field Section

Background and Objectives

Nitrosamines (NDMA) are highly carcinogenic compounds with cancer-causing potentials much higher than trihalomethanes (THMs). Drinking water facilities that have switched from chlorine to chloramines to reduce THM formation in their distribution system may find themselves in the untenable position of reducing THMs only to generate toxic nitrosamines, if certain organic nitrogen precursors are present.

The California Department of Public Health has set notification levels of 10 ng/L each for NDMA, N-nitrosodiethylamine (NDEA), and N-nitroso-di-n-propylamine (NDPA), with a Public Health Goal for NDMA of 3 ng/L. The Environmental Protection Agency's (EPA's) Unregulated Contaminant Monitoring Rule 2 (UCMR2) has also listed six nitrosamines as contaminants to be monitored during the 2008-2010 period to support the agency's determination of whether to regulate these contaminants in the interest of protecting public health. These nitrosamines are NDEA, NDMA, NDPA, N-nitroso-di-n-butylamine (NDBA), N-nitroso-methylethylamine (NMEA), and N-nitroso-pyrrolidine (NPYR), Early indications suggest nitrosamines will become the next set of contaminants regulated in treated drinking water by the EPA.

A special study was initiated in July 2008 to investigate nitrosamines and their precursors. The study was undertaken with the help of the Metropolitan Water District of Southern California (MWDSC). The two goals of the study were to identify and quantify potential sources of nitrosamines and their precursors, and to examine the fate and transport of nitrosamines and their precursors.

Study Design

The first part of a two-part study collected quarterly samples from West Sacramento Drinking Water Intake, Sacramento River at Hood, San Joaquin River at Mossdale, San Joaquin River at Holt, San Joaquin River near Vernalis, H. O. Banks Pumping Plant, and Twitchell Island agricultural drain. Sampling began in July 2008 and ended in July 2010.

Along with standard field measurements, samples were analyzed by Bryte Laboratory for total organic carbon (TOC), dissolved organic carbon (DOC), diuron, total Kjeldahl nitrogen (TKN), ammonia, nitrates + nitrites, total phosphate ultraviolet absorbance at 254 nm (UVA_{254}), THMFP, and haloacetic acid formation potential (HAAFP).

A subset of each sample was split and sent to MWDSC's chemistry laboratory, where samples were analyzed for eight nitrosamines and nitrosamine formation potential

Results/Conclusions

The results show:

- To date, no nitrosamines have been detected at any of the sampling sites of this study. Photodegradation may be one explanation for these results.
- There were distinct differences in concentrations of nitrosamine formation potential (NDMAFP) depending on whether samples were collected upstream or downstream of a wastewater treatment plant (WWTP) and at agricultural sites.
- Trends were similar between the three tracers (caffeine, carbazampine, and primidone) when comparing urban discharge to location. If the precursors for nitrosamines or their formation potentials were wastewater derived, then relative to upstream sites, high levels of the tracers should be seen at sites downstream of WWTPs. If these disinfection byproducts (DBP) or the precursors are not urban derived, then we should expect to see low concentrations of urban discharge tracers.

The conclusions presented so far are:

- To date, no instantaneous nitrosamines have been detected in sampling locations of the Sacramento-San Joaquin Delta.
- Sampling sites downstream of WWTPs and from peat island agricultural discharge had the highest concentrations of NDMAFP.
- Primidone appears to be a good tracer for WWTP discharge.
- Diuron, a commonly used herbicide in the area, does not appear to be a major source of NDMA precursors.
- DOC and the DBPs currently regulated by the EPA are not necessarily good predictors of NDMAFP.

Investigation of Organic Carbon and Bromide Long Term Trends and Seasonal Patterns in the Delta using Municipal Water Quality Investigations Historical Data

Duration of Study

2009-2010

Investigators

Joe Christen

Background and Objectives

The analysis of seasonal behavior and interannual trends in organic carbon (OC) concentrations were the focus of this study. Information gained from the study is expected to help 1) improve understanding of the seasonality and presence or absence of long-term trends in organic carbon and bromide loading into the Sacramento-San Joaquin Delta (Delta), 2) provide general rules that can be applied to seasonal and annual water quality forecasting, and 3) improve cultural practices for source water protection. The findings may also be useful for forecasting organic carbon transport and fate in the Delta water quality changes in response to Delta management practices, and the proposed conversion of Delta lands into wetland habitats.

Study Design

Trends of seasonal and inter-annual patterns were assessed for organic carbon concentration data from three water quality monitoring stations, Sacramento River at Hood (Hood), the San Joaquin River near Vernalis (Vernalis), and the H. O. Banks Pumping Plant (Banks). The two periods tested were the 10 water years from 1999-2008, and the entire available periods of record (≥19 years). Existing grab samples and high-frequency real-time monitoring program data for dissolved organic carbon (DOC), total organic carbon (TOC), flow, runoff, precipitation, and pumping rates were collected from existing databases, and examined for accuracy and completeness. DOC concentration, DOC loads, and flow data were tested from trends using the seasonal Kendall test on Minitab 14 software. A seasonal Kendall slope estimator was used for an estimate of the magnitude of changes for trending.

TOC data had limited availability prior to 1999. Data from 1989 was available for DOC, with the exceptions of November 1994 to June 1996 at Vernalis and August 1997 to January 2000 at Banks. TOC and DOC grab sample data sets were collected from the California Water Data Library. Daily average flow data were obtained from the Dayflow database. Real-time TOC and DOC data, daily precipitation, water year classifications, and water year total basin runoff were obtained through the California Data Exchange Center.

Results/Conclusions

The initial main points from the organic carbon analysis are:

- There was a decrease in DOC concentrations at Hood, Vernalis, and Banks in the water years of 1987 and 1989 to 2008 period.
- In the recent 10 years (1999–2008), there was an increase in DOC at Hood and Vernalis. There was no change at Banks.

- The trends were sequential at Hood and Vernalis, with a decreasing period followed by an increasing period.
- The decreasing period was stronger or longer than the increasing period, which resulted the finding of an overall decreasing trend.
- The sequential trends reflected interannual changes in precipitation and flow. Interannually, DOC was opposite to flow.
- Reservoir operations introduced a lag in the interannual flow-DOC relationship (Reservoirs may also be responsible for the inverse relationship and diluting effect, but more work could be done to investigate this).
- DOC trends at Banks were driven by operations and exports.
- Increased cross Delta flows due to increased exports resulted in an increased presence of low DOC Sacramento River water.
- All DOC trend magnitudes were an order smaller than seasonal variation (< 0.80 mg/L).
- The trends discovered were on a roughly decadal scale. The trends were cyclical at Hood and Vernalis. DOC trends underlying the decadal signal will be of even smaller magnitude and not of practical significance.

Bromide Results are not available yet.

O'Neill Forebay Water Circulation Study

Duration of Study

2009–2012

Investigator

Jason Moore

Background and Objectives

O'Neill Forebay's water flow behavior has important implications for water quality modeling and forecasting. Therefore, the objectives of this study are to: 1) better understand water flow patterns in O'Neill Forebay under a range of conditions, 2) support more accurate numerical modeling of the O'Neill Forebay region of the Delta Simulation Model II (DSM2) Aqueduct Extension model, and 3) improve forecasting of water quality characteristics in subsequent parts of the State Water Project (SWP).

This study will examine at the extent of mixing between O'Neill Forebay water and water discharged into the forebay from the Delta-Mendota Canal (DMC). At times water discharged from the DMC may hug the forebay shoreline, flowing directly downstream to Check 13 and short circuit mixing in the forebay.

Study Design

The first phase of the project involves the examination of historical electrical conductance (EC) readings at several locations to look for patterns and correlations. Data from H. O. Banks Pumping Plant, Jones Pumping Plant, the O'Neill EC station on the DMC and Check 13 will be analyzed for difference in EC readings. EC will also be evaluated when pump-ins and withdrawals are occurring in and from the forebay. EC fingerprint of ions at Check 13 would show the effects of source water if a large discrepancy is found between Central Valley Project (CVP) and SWP waters. Short-circuiting can be confirmed if EC at the SWP's Check 13 is influenced by CVP in O'Neill Forebay.

Should inadequate mixing occur, the potential next phase would be to conduct transects in the forebay by boat using a GPS linked YSI sonde with an EC probe. Sampling frequency would ideally be monthly; however, sampling would be dependent on boat allowance in the forebay. Should a third phase be needed, it would involve placing a real-time EC sensor in the forebay of Gianelli Pumping Plant. A further study would be done on the data collected similar to the initial historical study.

Results/Conclusions

No results are available currently.

Lathrop Urban Sources and Loads Investigation

Duration of Study

2009-2012

Investigators

Rachel Pisor

Background and Objectives

The goal of the Lathrop Urban Sources and Loads Investigation is to study the effects of urbanization on the drinking water quality of the San Joaquin River. The ongoing study will quantify background concentrations and loads discharged by Lathrop during first flush and rain events. One benefit of this study is to provide a baseline of water quality conditions and land use patterns.

The objectives of this project are:

- Determine the effects of Lathrop's storm water discharges on the water quality of the San Joaquin River during first flush and major storm events.
- Determine loads of key drinking water constituents of concern.
- Conduct a land use analysis utilizing Geographical Information Systems (GIS) to determine the overall impervious cover in the city.
- Develop a baseline of current water quality conditions for future use by water managers.

Study Design

Water quality samples will be collected at eight storm water pumping stations that discharge directly to the San Joaquin River and along the river upstream and downstream of the pumping stations. Sampling occurs during first flush events, storm events, and between storms. Samples are analyzed for pathogens, TTHMFP, and haloacetic acid formation potential (HAAFP), organic carbon (OC), electrical conductivity (EC), minerals, metals, nutrients, pesticides, bacteria, turbidity, total dissolved and suspended solids (TDS), and ultraviolet absorbance at 254 nm (UVA_{254}).

Statistical comparisons will be made for concentrations and loads based on stations, storms, seasons, and water years. Load calculations will be done for organic carbon, bromide, and nutrients. Additionally, analyses include examining differences between upstream and downstream points on the rivers, between grab samples from the river stations and the eight pumping stations, and between the individual storms.

The areas were divided by regions (Figure 7). The Industrial Station is in an industrial area. M1, M2, M3, M5, and M6 serve the Mossdale region. The Historic Station covers the historical region. The Stone Bridge Station collects water from the Stone Bridge development in northeastern Lathrop. The San Joaquin River stations (Brant Bridge, San Joaquin River at Mossdale, and San Joaquin River at Lathrop) will be analyzed as a separate region.

Results/Conclusions

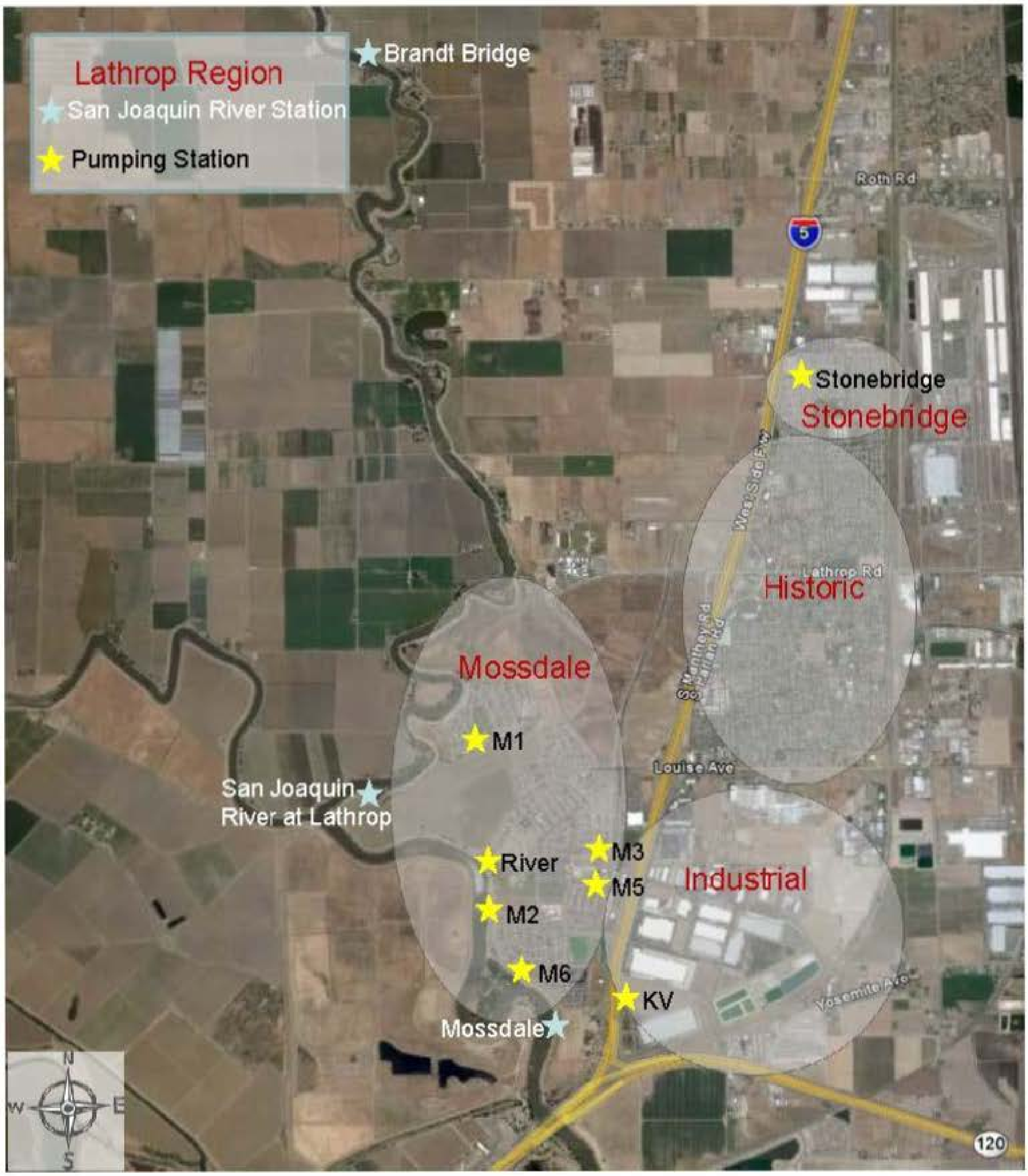
The results shown in this report reflect the preliminary results from the first season's data.

Most sample concentrations (OC, UVA_{254}, ammonia, dissolved orthophosphate, total phosphorus and pathogens) were significantly lower on the San Joaquin River than the city pumping stations. The exceptions to this were THMFP, HAAFP, EC, TDS, bromide, and dissolved and total nitrogen. There were slight decreasing seasonal trends for TOC, UVA_{254}, and pathogens, although additional data is needed to confirm these trends. For all constituents, the samples taken on the San Joaquin River had a smaller range than those taken from the city pump stations.

Organic carbon concentrations were the most variable in the Mossdale region (the region with most stations). An average of 85% of the total organic carbon was in the dissolved form. There was a high correlation between UVA_{254} and dissolved organic carbon, and between UVA_{254} and THMFP although these correlations were not as strong for the San Joaquin River stations. The ammonia concentrations from the city pump stations were considerably higher than those from the San Joaquin River stations. Generally, nitrate concentrations from the city pumping stations were lower than those collected from the San Joaquin River with the exception of those collected from M1.

High counts of total coliforms, fecal coliforms, and *E. coli* were present during storm events, especially during the first event of the season, indicating that it was a first flush event. Samples taken from the city pump stations were much higher than those collected from the San Joaquin River were. The highest fecal coliform sample was taken at the Historic Station and was much higher than any other samples for the season. The highest *E. coli* sample was collected during the first flush event. The highest sample count was collected at the Historic Station. For all three pathogens, there was a slight decreasing seasonal trend.

Figure 8 – Lathrop Study Map



Nitrosamines and their Precursors Occurrence from Waste Water Treatment Plant Facilities in the Delta

Duration of Study

2010-2012

Investigators

Joe Christen and Metropolitan Water District Southern California

Background and Objectives

This study began in 2010. It was the second part of a two-part study focusing on the two largest wastewater treatment plants (WWTP), the Sacramento Regional Wastewater Treatment Plant and the City of Stockton Regional Wastewater Control Facility. The second part of the study involves boat sampling as opposed to only shore sampling, in order to better quantify nitrosamines, their precursors, and WWTP tracers in discharge effluent. The Sacramento plant discharges disinfected secondary treated effluent into the Sacramento River, while the Stockton facility discharges tertiary treated wastewater into the San Joaquin River. These sites were chosen as the Sacramento facility is upstream of a potential peripheral canal location at Hood and the Stockton facility could affect the water quality at H. O. Banks Pumping Plant.

Study Design

The locations sampled by land are the Sacramento River at Hood, Sacramento River upstream of the diffuser pipe, SRCSD diffuser pipe, San Joaquin River upstream of Stockton, Stockton MUD WWTP, San Joaquin River downstream of Stockton, and San Joaquin River at Holt. Sampling events will happen at least quarterly. Boat sampling will occur up river, at, and down river from the two WWTP discharge points. Composite trawl samples will be collected at two depths for nitrosamines. Stockton has agreed to provide effluent and access to their facility.

Along with standard field measurements, samples will be analyzed by Bryte Laboratory for dissolved organic carbon, diuron, ammonia, nitrates + nitrites, and UVA_{254}. A subset of each sample is split and sent to Metropolitan Water District of Southern California’s chemistry laboratory, where samples are analyzed for eight nitrosamines and nitrosamine formation potential testing.

Results/Conclusions

No results are available yet.

Cryptosporidium/Giardia Occurrence from Waste Water Treatment Plant Facilities in the Delta

Duration of Study

2010-2012

Investigators

MWQI staff

Background and Objectives

This study began in 2010, focusing on the two largest wastewater treatment plants (WWTP), the Sacramento Regional Wastewater Treatment Plant and the City of Stockton Regional Wastewater Control Facility. The study involves boat sampling in addition to shore sampling, in order to better quantify and WWTP tracers in discharge effluent. The Sacramento plant discharges disinfected secondary treated effluent into the Sacramento River, while the Stockton facility discharges tertiary treated wastewater into the San Joaquin River. These sites were chosen as the Sacramento facility is upstream of a potential peripheral canal location at Hood and the Stockton facility could affect the water quality at H. O. Banks Pumping Plant.

Study Design

The locations sampled by land are the Sacramento River at Hood, Sacramento River upstream of the diffuser pipe, SRCSD diffuser pipe, San Joaquin River upstream of Stockton, Stockton MUD WWTP, San Joaquin River downstream of Stockton. Sampling events will happen bimonthly. The protozoan pathogens *Cryptosporidium* and *Giardia* will be studied from WWTP discharges.

Boat sampling will occur up river, at, and down river from the two WWTP discharge points. Sample collection for *Cryptosporidium* and *Giardia* will occur directly downstream of the diffuser pipe along the bottom of the Sacramento River. Stockton has agreed to provide effluent and access to their facility.

Sample analyses for *Cryptosporidium* and *Giardia* will be conducted by an outside laboratory.

Results/Conclusions

No results are available yet.

Spectrofluorometer Investigation

Duration of Study

2010-2013

Investigator:

Ted Swift

Background and Objectives

The Spectrofluorometer Investigation will determine the usefulness of using spectrofluorometry to quantify constituents of concern and to identify distinct characteristics of source waters as a method of “fingerprinting” to validate Delta water models.

A fluorometer is an instrument that excites the sample at one light wavelength and measures the resultant fluorescence at a longer wavelength. Many dissolved and suspended substances in the water fluoresce at characteristic combinations of excitation and emission wavelengths. A spectrofluorometer extends that principle by exciting the sample across a rapidly scanned range of ultraviolet-to-visible light wavelengths, while simultaneously measuring light emission across another band of wavelengths. The results are an excitation-emission matrix (EEM). The wavelength at which excitation and emission occur is specific to the chemical molecule involved. This project will make use of a high-performance FluoroMax 4 spectrofluorometer made by Horiba/Jobin-Yvon, purchased several years ago by the Department of Water Resources (DWR) Quality Control group and housed at the DWR Bryte Laboratory.

Study Design

Samples will be taken monthly at West Sacramento Drinking Water Intake, Sacramento River at Hood, Sacramento Water Intake on the American River, San Joaquin River near Vernalis, H. O. Banks Pumping Plant, the Colusa Basin Drain, Barker Slough Pumping Plant, Jones Pumping Plant, the Mokelumne River, and the Old River at Bacon Island. These will provide a wide range of water types, with a variety of seasonal water quality patterns. Bryte Laboratory will be analyzing split samples for total organic carbon (TOC), dissolved organic carbon (DOC), pH, Ultraviolet Absorbance at 254nm (UVA_{254}), and nutrients, including organic nitrogen. Weck Laboratories will be analyzing subsamples for THMFP and haloacetic acid formation potential (HAAFP). The Spectrofluorometer Investigation will also utilize samples from the Nitrosamine study to seek out features that correlate with nitrosamine formation potential.

The resulting data will be analyzed to identify distinguishing features in the excitation-emission matrix (EEM) that are correlated with characteristics such as DOC and TOC concentration, THMFP, HAAFP, Nitrosamine formation potential, and algal biomass. Analytical tools will include multiple regression, parallel factor analysis, and principle component analysis.

Results/Conclusions

Samples will be collected and measured. No analysis results are available, but extensive literature strongly suggests this approach may accurately quantify multiple constituents of concern from a single EEM measurement. Visual inspection of EEMs from different sites shows clear differences in EEM features.

Appendix A — List of Publications

Discrete Monitoring Program Reports (date published)

1. Interagency Delta Health Aspects Monitoring Program Project Report (May 1985)

2. Interagency Delta Health Aspects Monitoring Program Project Report (December 1986)

3. The Delta as a Source of Drinking Water Summary of Monitoring Results - 1983 To 1987 Interagency Delta Health Aspects Monitoring Program (January 1989)

4. The Delta as a Source of Drinking Water Monitoring Result - 1983 To 1987 Interagency Delta Health Aspects Monitoring Program (August 1989)

5. 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 1990)

6. Project Report of The Interagency Delta Health Aspects Monitoring Program (Municipal Water Quality Investigations Program) Summary of Monitoring Results January 1988-December 1989 (October 1990)

7. Annual Report of The Municipal Water Quality Investigations Program Summary of Monitoring Results January 1990-December 1990 (February 1993)

8. Five-Year Report of The Municipal Water Quality Investigations Program Summary and Findings During Five Dry Years January 1987-December 1991 (November 1994)

9. Executive Summary of Five-Year Report of The Municipal Water Quality Investigations Program Summary and Findings During Five Dry Years January 1987-December 1991 (November 1994)

10. 1992-1993 Biennial Memorandum Report of The Municipal Water Quality Investigations Program (April 1995)

11. Data Report of The Municipal Water Quality Investigations Program Summary of Monitoring Results Water Year 1994 (July 1995)

12. Municipal Water Quality Investigations Program Annual Report Water Year 1995 (August 1996)

13. Municipal Water Quality Investigations Program Annual Report October 1995-December 1996 (December 1997)

14. Municipal Water Quality Investigations Program Annual Report 1997-1998 (October 2000)

15. The Municipal Water Quality Investigations Program Summary and Findings from Data Collected August 1998 through September 2001 (July 2003)

16. The Municipal Water Quality Investigations Program Summary and Findings from Data Collected October 2001 through September 2003 (June 2005)

17. The Municipal Water Quality Investigations Program Summary and Findings of Data Collected from the Sacramento-San Joaquin Delta Region, October 2003 through September 2005 (December 2006)

18. The Municipal Water Quality Investigations Program Summary and Findings of Data Collected from the Sacramento-San Joaquin Delta Region, October 2005 through September 2007 (June 2008)

19. The Municipal Water Quality Investigations Program Summary and Findings of Data Collected from the Sacramento-San Joaquin Delta Region, October 2007—September 2009 (June 2010)

Program Reports

1. The North Bay Aqueduct Barker Slough Watershed Water Quality Phase 1 Report (July 1998)

2. Pilot Study on the Analytical Performance of a Total Organic Carbon Analyzer in Operation at a Field Station on the Sacramento River Memorandum Report (May 2001)

3. Water Quality Investigations of the Barker Slough Watershed, 1997-2001 North Bay Aqueduct Summary (May 2002)

4. Natomas East Main Drainage Canal Water Quality Investigation Initial Technical Report Urban Sources and Loads Project (October 2003)

5. Real-time monitoring of organic carbon in the Sacramento River and California State Water Project Using Process Analyzers (April 2005)

6. Staten Island Wildlife-Friendly Farming Demonstration Water Quality Monitoring Final Report (June 2007)

7. Steelhead Creek Water Quality Investigation Final Technical Report (February 2008)

8. Real-Time, Continuous Monitoring of Bromide and Nutrients at Harvey O. Banks Pumping Plant and San Joaquin River near Vernalis Final Report (July 2008)

9. Jones Tract Flood Water Quality Investigations (July 2009)

Journal Articles

1. Cryptosporidium and Giardia Recoveries in Natural Waters by Using Environmental Protection Agency Method 1623 (December 2002) Applied and Environmental Microbiology

2. Size and XAD fractions of trihalomethane precursors from soils (August 2005) Elsevier Chemosphere

3. Movement of Diuron and Hexazinone in Clay Soil and Infiltrated Pond Water (October 2005) Journal of Environmental Quality

4. Trihalomethane Formation Potential of Filter Isolates of Electrolyte-Extractable Soil Organic Carbon (October 2005) Journal of Environmental Quality

5. Filter pore size selection for characterizing dissolved organic carbon and trihalomethane precursors from soils (2005) Elsevier Water Research

6. Trihalomethane Reactivity of Water- and Sodium Hydroxide–Extractable Organic Carbon Fractions from Peat Soils (January-February 2006) Journal of Environmental Quality

7. Comparison of Organic Carbon Analyzers and Related Importance to Water Quality Assessments (May 2007) San Francisco Estuary and Watershed Science

8. Effects of Urbanization on Organic Carbon Loads in the Sacramento River, California (November 2007) Water Resources Research

9. Identifying sources of dissolved organic carbon in agriculturally dominated rivers using radiocarbon age dating: Sacramento-San Joaquin River Basin, California (November 2009) Springer Biogeochemistry

Modeling Reports

1. Proof of Concept DWR Modeling Results of Forecasting California Aqueduct Water Quality (DWR 2003)

2. Modeled Impacts of DWR Peat Island Drainage on Organic Carbon Levels at Selected DWR Municipal Water Intakes Memorandum Report (October 2003)

3. Proof of Concept California Aqueduct Water Quality Modeling Results for Water Quality Forecast Memorandum Report (December 2003)

4. Proof of Concept Seasonal Water Quality Forecast (January 2004)

5. DWR Extension for the California Aqueduct, South Bay Aqueduct, and DWR-Mendota Canal (DWR 2005)

6. DWR Extension for the California Aqueduct, South Bay Aqueduct, and DWR-Mendota Canal Phase 2 Analysis (DWR 2008)

DWR Reports, Manuals, and Publications

1. Quality Assurance Project Plan For Real-Time Monitoring Of Organic Carbon In The Delta (August 2001)

2. Draft Guidelines for Preparing Quality Assurance Project Plans (October 1993)

3. *Sampling Manual for Environmental Measurement Projects* (Quality Assurance Technical Document 2): This document provides technical information on procedures for DWR water-related sampling and data collection activities. (April 1994)

4. *Compilation of Soil and Sediment Standards, Criteria and Guidelines* (Quality Assurance Technical Document 7): This document provides soil and sediment values, which can be used to establish data quality objectives for the study and as reference values for comparison of resulting data from soil, and sediment analyses. (February 1995)

5. Municipal Water Quality Investigations Program Field Manual (August 1995)

6. *Compilation of Federal and State Drinking Water Standards and Criteria (*Quality Assurance Technical Document 3): This document provides a listing of federal and State drinking water standards, criteria, and regulations. (June 1997)

7. *Quality Assurance Guidelines for Analytical Laboratories* (Quality Assurance Technical Document 1): This document provides guidance on selecting and evaluating the performance of laboratories performing chemical analyses for DWR. (September 1997)

8. *Quality Assurance Management Plan for Environmental Monitoring Programs* (Quality Assurance Technical Document 5): This document describes how DWR plans and implements the necessary QA/QC practices to help management ensure that the results of technical environmental monitoring work are of the type and quality needed for their intended use. (June 1998)

9. *Compendium of Water Quality Investigations in the Sacramento-San Joaquin Delta* (Quality Assurance Technical Document 4): This document identifies the agencies that have conducted water quality studies in the Sacramento-San Joaquin Delta. (August 1998)

10. *Guidelines for Preparing Quality Assurance Project Plans* (Quality Assurance Technical Document 6): This document provides the guidelines that program managers can use to prepare their project-specific quality assurance project plans. (August 1998)

11. Bryte chemical Laboratory Quality Assurance Manual (Quality Assurance Technical Document 8): This document addresses the quality assurance and quality control measures used by Bryte Chemical Laboratory in determining the organic, inorganic, and biological entities found in California waters. May 2006

12. Water Quality Field Manual for the State Water Project (May 2006)

13. Quality Assurance Project Plan for Real-Time, Continuous Monitoring of Bromide and Nutrients at H.O. Banks Pumping Plant and San Joaquin River near Vernalis (April 2008)

Sanitary Surveys

1. California State Water Project Sanitary Survey Update Report 1996 (May 1996)

2. California State Water Project Watershed Sanitary Survey Update Report 2001 (December 2001)

3. California State Water Project Watershed Sanitary Survey 2006 Update (June 2007)

4. California State Water Project Watershed Sanitary Survey 2011 Update (June 2012)

Other MWQI Publications

1. State Water Project Trihalomethane Study (April 1982)

2. Public Health Aspect of Sacramento-San Joaquin Delta Water Supplies: A Panel Report for the California Department of Water Resources (December 1982)

3. Delta Water Quality: A Report to the Legislature on Trihalomethanes and the Quality of Drinking Water Available from the Sacramento-San Joaquin Delta (October 1991)

4. Victoria Island Baseline Study of Dredge Material Reuse Sites for the Interim South Delta Program (November 1995)

5. Twitchell Island Baseline Study of Dredge Material Reuse Sites for the Interim South Delta Program (January 1996)

6. Bench-Scale Assessment of Treatability of Delta Waters by Coagulation and Membranes University of Colorado-Boulder (August 1997)

7. Delta Island Drainage Volume Estimates 1954-1955 versus 1995-1996 (January 1998)

8. Bryon Track Baseline Study of Dredge Material Reuse Sites Memorandum Report, Interim South Delta Program (March 1998)

9. 1997 Compendium of Water Quality Investigations in the Sacramento River Watershed, Sacramento-San Joaquin Delta, and San Francisco Bay Area (August 1998)

10. Candidate Delta Regions for Treatment to Reduce Organic Carbon Loads – Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program (January 1999)

11. A Trial Experiment On Studying Short-Term Water Quality Changes In Flooded Peat Soil Environments – SMARTS (July 1999)

12. Environmental Study of Dredge Materials Grant Line Canal, South Delta Improvements Program (January 2000)

13. Integrated Storage Investigations Off-Aqueduct Storage Pre-Feasibility Study DRAFT (July 2000)

14. Integrated Storage Investigations In-Delta Storage Pre-Feasibility Study DRAFT (August 2000)

15. 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 (September 2000)

16. Final Report of Experiment #2: Seasonal Water Quality Changes in Flooded Peat Soil Environments Due to Peat Soil, Water Depth, and Water Exchange Rate – SMARTS (December 2000)

17. Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs (December 2000)

18. Department of Water Resources QA/QC Study Characterization of Organic Carbon by Ultraviolet Absorbance Spectrophotometry (2000)

19. Integrated Storage Investigations In-Delta Storage Program Draft Summary Report CALFED Bay-Delta Program (February 2002)

20. Quantity and Quality of Waters Applied To and Drained From the Delta Lowlands Report No. 4 Investigation of the Sacramento-San Joaquin Delta (July 1956)

Appendix B — Contributors and Participants

Current Program Contributors and Participants

State Agencies	
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Federal Agencies	
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Antelope Valley-East Kern Water Agency	Kern County Water Agency
Castaic Lake Water Agency	Metropolitan Water District of Southern California
Central Coast Water Authority	Mojave Water Agency
City of Benicia	Palmdale Water District
City of Fairfield	San Bernardino Valley Municipal Water District
City of Napa	San Gorgonio Pass Water Agency
City of Santa Maria	Santa Clara Valley Water District
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Coachella Valley Water District	Reclamation District 2068
County of Butte	Reclamation District 2075
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Appendix C — Acronyms, Abbreviations, and Conversion Table

Banks	H. O. Banks Pumping Plant
BDO	Bay-Delta Office
BSPP	Barker Slough Pumping Plant
CDEC	California Data Exchange Center
CDPH	California Department of Public Health
CFU	Colony Forming Units
COC	colloidal organic carbon
CSDP	Cross-Section Development Program
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
D/DBP(s)	disinfectant/disinfection byproduct(s)
DBP	disinfection byproduct
Delta	Sacramento-San Joaquín Delta
DES	Division of Environmental Services
DICU	Delta Island Consumptive Use
DIDI	Delta Island Drainage Investigation
DMC	Delta-Mendota Canal
DO	Dissolved Oxygen
DOC	dissolved organic carbon
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
EAP	Emergency Action Plan
EC	electrical conductivity
EPA	Environmental Protection Agency
ER	Emergency Response
FCOC	fine colloidal organic carbon
FLIMS	Field and Laboratory Information Management System
HAA(s)	Haloacetic acids
HAAFP	haloacetic acids formation potential
HTC	high temperature combustion
ICR	Information Collection Rule
ICRSS	Information Collection Rule Supplemental Survey
IDHAMP	Interagency Delta Health Aspects Monitoring Program
ISDP	Interim South Delta Program
IESWTR	Interim Enhanced Surface Water Treatment Rule
L	Litters
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule

MCL	maximum contaminant level
MCLG	maximum contaminant level goal
mg	milligram
mg/L	milligrams per liter
MIB	2- methyl-isoborneol
ml	milliliters
mpn	most probable number
MWDSC	Metropolitan Water District of Southern California
MWQ	Municipal Water Quality
MWQI	DWR Municipal Water Quality Investigations
MWQI TAC	Municipal Water Quality Investigations Technical Advisory Committee
MWQP	Municipal Water Quality Program
NBA	North Bay Aqueduct
NDEA	N-nitrosodiethylamine
NDMA	Nitrosamines
NDPA	N-Nitrosodi-n-propylamine
NEMDC	Natomas East Main Drainage Canal
nm	Nanometers
NMEA	N-nitroso-methylethylamine
NPDES	National Pollution Discharge Elimination System
NPYR	N-nitroso-pyrrolidine
NTU	Nephelometric Turbidity Units
OC	Organic Carbon
OCO	Operations Control Office
O&M	Operations and Maintenance
PCS	Potential Contamination Sources
pH	negative log of the hydrogen ion activity
PTM	Particle Tracking Model
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAMP	Quality Assurance Management Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
RTDF	Real Time Data and Forecasting
RTDF-CP	Real Time Data and Forecasting-Comprehensive Program
SBA	South Bay Aqueduct
SFRWQCB	San Francisco Regional Water Quality Control Board
SMARTS	Special Multipurpose Applied Research Technology Station
SMV	Soluble Maximum Values
SOC	Soil Organic Carbon
SPC	Specific Project Committee
STLC	Soluble Threshold Limit Concentration

SJR	San Joaquin River
$SUVA_{254}$	specific UVA_{254}
SWC	State Water Contractors
SWP	State Water Project
SWPC	State Water Project Contractors
SWRCB	State Water Resources Control Board
SWPCA	State Water Project Contractors Authority
SWTR	Surface Water Treatment Rule
T&O	Taste and Odor
TBFP	Brominated trihalomethane formation potential
TDS	total dissolved solids
TFPC	Trihalomethane Formation Potential Carbon
THM	trihalomethane
THMFP	trihalomethane formation potential
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TMV	total maximum values
TOC	total organic carbon
TTHM	total trihalomethane
TTHMFP	total trihalomethane formation potential
TTLC	Total Threshold Limit Concentration
UCD	University of California, Davis
USBR	U.S. Bureau of Reclamation
USGS	U. S. Geological Survey
UVA_{254}	ultraviolet absorbance measured at a wavelength of 254 nanometers
WARMF	Watershed Risk Management Framework
WDL	Water Data Library
WREM 60	Water Resources Engineering Memorandum 60
WQO	Water Quality Objectives
WTP	water treatment plant
WWTP	wastewater treatment plant
WY	water year
µg/L	micrograms per liter
µm	micrometers
µS/cm	micro Siemens per centimeter

Metric Conversion Table

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 (ML)	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
Power	kilowatts (kW)	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
Concentration	milligrams per liter (mg/L)	parts per million (ppm)	1.0	1.0
Electrical conductivity	microsiemens per centimeter (µS/cm)	micromhos per centimeter (µmhos/cm)	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8X°C)+32	0.56(°F-32)

Appendix D — Background on DWR Models Used by the MWQI Program and Partners

The Department of Water Resources (DWR) uses models that are descriptions of reality using mathematical calculations that provide insight into the hydrological processes within a system. The models rely on historical measurements, input data from other models, or projected conditions. Model verification compares model predictions to field measurements, showing if water quality conditions can be accurately simulated by the model's output. Well-tuned models are useful in predicting and assessing the water quality effects of future changes in the Sacramento-San Joaquin Delta (Delta).

Models Used

DWR and the U. S. Bureau of Reclamation (USBR) have been actively involved in Delta modeling for more than 30 years. Of the multiple models used by DWR, the MWQI Program and partners primarily use the Watershed Analysis Risk Management Framework (WARMF) model and the Delta Simulation Model II (DSM2), which incorporates the Delta Island Consumptive Use (DICU) model.

WARMF

Systech Water Resources, Inc. developed WARMF. By incorporating a sequence approach and supplying adequate information, WARMF allows users to make informed decisions on watershed planning and analysis. It consists of five modules: engineering, data, knowledge, consensus, and total maximum daily load (TMDL). The engineering module is a watershed model that has inputs for land uses and surfaces, hydrology, precipitation, runoff, point and nonpoint loads, and water quality. By clicking on a station on the GIS map, the data module provides time series and calibration data on water quality, reservoir releases, meteorology, and air quality. The knowledge module contains documents and data for regulations, case studies, past modeling activities, or any other data needed for model input or the watershed. The TMDL module is a bottom-up approach that uses a series of control points to provide step-by-step calculations for TMDL. The consensus module allows the stakeholders to learn about the issues in easy to understand terms, and use consensus to make the decisions. Some of the benefits provided by the WARMF model include: availability of multiple data sources; TMDL calculations, illustrated water quality status; and the integration of models, databases, and graphical software into a map-based tool.

DSM2

Delta Simulation Model 2 (DSM2) is central to MWQI Real-Time Data and Forecasting Comprehensive Program (RTDF-CP). Almost all of the models mentioned below either are part of DSM2 or provided support to data that is used in the DSM2 model. The DSM2 model has been extended to include the California and South Bay aqueducts. Six new monitoring locations (2 Eastside streams, the Yolo Bypass, and 3 interior Delta stations) are being added into the calibrations to refine the model.

The DSM2 model is a one-dimensional model that simulates tidal hydraulics, water quality, and particle tracking. It can calculate stages, flows, velocities, transport of individual particles, and mass transport processes for conservative and non-conservative constituents like salts, dissolved organic carbon (DOC), and trihalomethane formation potential. For the model to work, extensive input data is required for DSM2. The input data categories are physical parameters of the system that include channel cross sections and geometry information, description of flow control structures like gates and barriers, initial estimates for stage and flow, and the time-varying input of inflows and exports used as boundary conditions. With the data inputs in place, the model can run historical conditions, forecast future conditions, or be used in planning studies. The planning studies allow the evaluation of potential changes in Delta conditions associated with changes in flow patterns from boundary conditions or gate operations, and ascertain impacts associated with projects in the Delta.

DSM2 is composed of three “sub” models. The sub models are HYDRO, QUAL, and the Particle Tracking Model (PTM). The HYDRO module of DSM2 provides the inputs of flow, velocities, depth, and water surface elevations into a one-dimensional model. It was originally developed from FOURPT, a four-point finite difference, one dimensional, unsteady, open channel hydrodynamic model originally developed by the USGS in Reston, Virginia. The model was amended by altering the inputs and outputs, adding open water elements, and water project facilities. The model was also made to incorporate channel geometry. Channel geometry is a major factor that influences tidal hydraulics, as it relates velocity to surface slope and the channel hydraulic radius. The use of boat-mounted depth sounder connected to a GPS unit collects accurate bathymetry data, allowing accurate channel geometry inputs in the model. Other inputs come from historical data, boundary condition data, or simulation data, and can be set to run in constant, regular time, or irregular time series. The HYDRO output of hydrodynamic data then becomes the input for QUAL and PTM.

QUAL is also a one-dimensional model that simulates water quality by providing the fate and transport of conservative and non-conservative constituents such as electrical conductivity (EC), dissolved oxygen (DO), and DOC. It was modified from the Branched Lagrangian Transport Model originally developed by Harvey Jobson of the USGS in Reston, Virginia in 1980. Additional features include open water areas, gates, and diagnostic modeling used in tracking. HYDRO provides the flow field where QUAL can then use a constituent like EC to simulate how it will disperse and travel to specified locations. It is set up to provide information every 15 minutes.

The PTM is the particle-tracking model, used to track the fate of individual particles. It does this by using velocity, flow, and depth from the HYDRO module of the DSM2 model. Unlike the other two components of DSM2, the PTM is a three-dimensional model. There are four movements associated with each particle that simulate advection and dispersion: transverse velocity, vertical velocity, transverse mixing, and vertical mixing. Particles can be given a unique identity, have changing characteristics such as buoyancy or velocities, and be inserted into any node. In addition, fall velocities that add either an additional downward (+) or upward (-) component, or put a vertical restriction on a particles range within a channel, will limit the roaming capability of that particle. After the simulation, histories of the particles can be shown as animations of movement, seen as the numbers of particles that pass by a node, or the number of particles that remain in an area of the channel.

The Delta Island Consumptive Use (DICU) model uses diversions, returns, land use, farming practices, and climatic conditions as its data inputs, and is also used as an input for DSM2. The model requires detailed data to accurately represent the hydrodynamics, water quality, and particle fate and transport. The simple explanation of the model is that net DICU equals diversions onto islands minus the drainage return from those islands plus any seepage that might occur. Positive net values indicate fewer diversions, whereas negative net values show more diversions than returns. The DICU model is important since most of the Delta islands are used for agriculture. The agricultural irrigation water is discharged back into the Delta channels, which has an impact on Delta water quality and consumption.