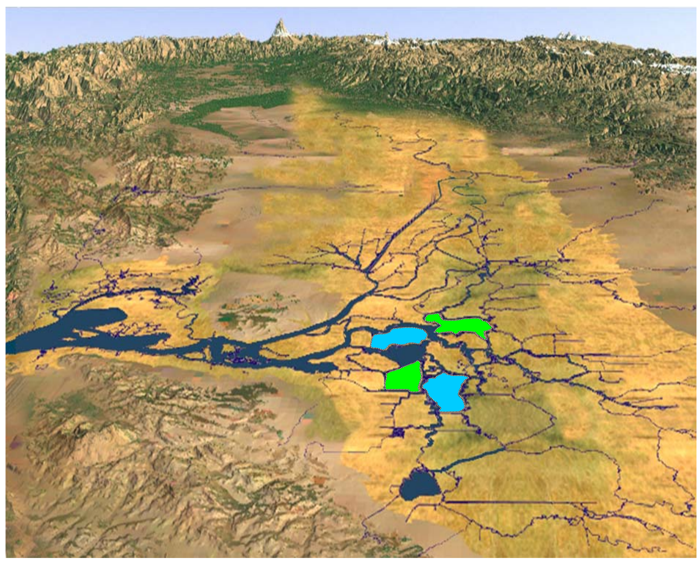
INTEGRATED STORAGE INVESTIGATIONS

IN-DELTA STORAGE PROGRAM
STATE FEASIBILITY STUDY
DRAFT REPORT ON WATER QUALITY



CALIFORNIA BAY-DELTA AUTHORITY

DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA

Division of Planning and Local Assistance
Department of Water Resources

December 2003

ORGANIZATION

FOREWORD

We acknowledge the technical assistance provided by Reclamation in carrying out the role of federal lead agency for the CALFED Integrated Storage Investigations. Reclamation will continue to provide technical assistance through the review of the State Feasibility Study reports and DWR will work with Reclamation to incorporate comments and recommendations in the final reports.

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Chapter 1: GENERAL

1.1 Introduction

The CALFED Record of Decision (ROD) identifies five surface water storage projects: Enlarged Shasta, Los Vaqueros, Sites Reservoir, 250 to 700 TAF of additional storage in the upper San Joaquin River watershed and In-Delta Storage. The purposes of new storage in the Delta are to increase operational flexibility for the Central Valley Project (CVP) and the State Water Project (SWP) and to provide ecosystem benefits in the Delta. The ROD includes an option to explore the lease or purchase of the Delta Wetlands (DW) Project, a private, In-Delta storage proposal by DW Properties. The ROD also provides the option to initiate a new project, in the event that the DW Project proves cost prohibitive or infeasible.

In 2001, the California Department of Water Resources, Bay-Delta Agencies (formerly CALFED agencies) and the U.S Bureau of Reclamation began a joint planning study to evaluate the DW Project and other In-Delta storage options. The joint planning study, completed in May 2002, concluded that the project concepts proposed by DW were generally well planned. However, project modifications and evaluations were needed to make the project acceptable for public ownership. The DW project has since been revised and studied as the In-Delta Storage Project. Additional information on In-Delta Storage are available at http://www.isi.water.ca.gov/ssi/indelta/index.shtml

The In-Delta Storage Project consists of developing Webb Tract and Bacon Island as reservoir islands. To mitigate the environmental impacts caused by the proposed project, Holland Tract and Bouldin Island will be developed as habitat islands. The locations of the project and habitat islands in the San Joaquin-Sacramento Island Delta are shown in Figure 1.1. Water will be diverted to the In-Delta Storage reservoirs during the winter months when flows are high and released back to Delta channels during the summer months when demand is high and flows are low.

The project islands soil is predominantly from carbon-rich peat and during the storage period it is expected that leaching of organic carbon (OC) from this soil together with biological productivity could increase OC loads in the reservoirs. Because of the proximity of the project to urban intakes, total organic carbon (TOC) and other water quality standards like Chloride, Bromate, Trihalomethane and Water Temperature could be impacted by reservoir releases. Thus, estimates for OC concentrations and other water quality measures of the stored water and the impacts of the released water at the urban intakes and Delta channels are keys to assessing the viability of the project. This report summarizes the findings of a series of numerical and experimental studies intended to assess the impacts of In-Delta Storage projects in the Delta water quality.

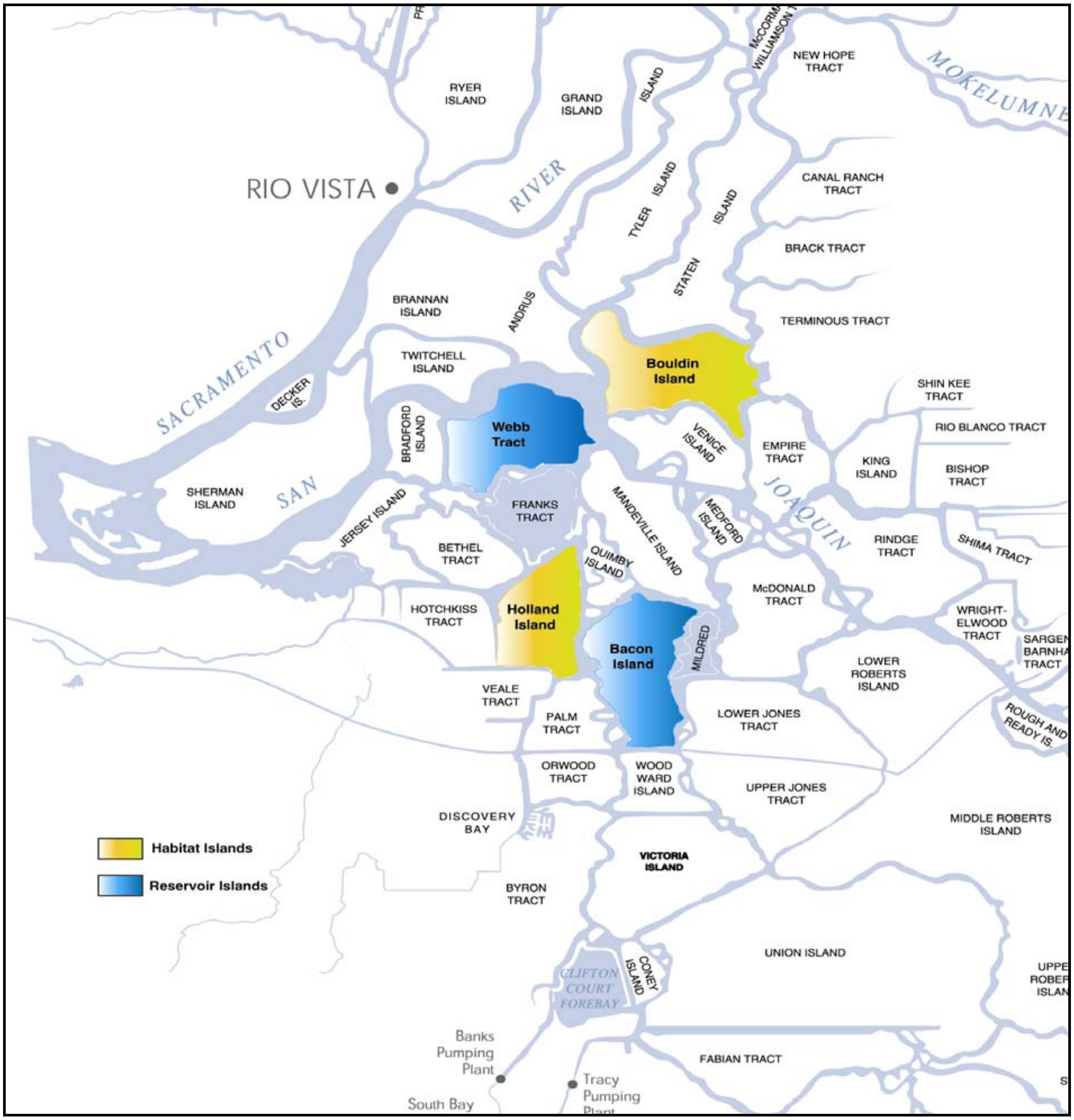

Figure 1.1: Proposed Habitat and Reservoir Islands for In-Delta Storage Project

1.2 Water Quality Requirements

The water quality requirements for the DW Project are set forth in SWRCB Decision 1643 (D1643) as agreed by DW Properties and the California Urban Water Agencies (CUWA). The ISI operations must be carried out such that the guidelines outlined in Water Quality Management Plan (D1641) and D1643 are not violated.

1.2.1 General Requirements

Discharges of water from the project shall not cause: (1) an exceedance of any applicable water quality objective in a water quality control plan adopted by the SWRCB or by the RWQCB; (2) any recipient water treatment plant to exceed the maximum contaminant levels for disinfection byproducts as set forth by EPA in Title 40, Section 141.12 & 141.30. The regulated classes of disinfection byproducts are trihalomethanes, haloacetic acids, chloride, and bromate (SWRCB, condition 14.a.). For the purpose of determining that the Project has caused an exceedance of one or more of the operational screen criteria, an uncertainty of ±5% of the screening criteria will be assumed.

1.2.2 Long-Term Requirement

The Project is required to mitigate 150% of the net increase in TOC and salt (i.e. TDS, bromide and chloride) loading greater than 5% in the urban diversions due to Project operations.

1.2.3 Total Organic Carbon

The project operation shall not cause or contribute to total organic carbon (TOC) concentrations that will violate either criterion:

- Increase in TOC concentration at a SWP, CVP, CCWD pumping plant, or at a receiving water treatment plant that will cause the limit of 4.0 mg/L to be exceeded;
- Incremental increase in TOC concentration at a SWP, CVP, or CCWD pumping plant of greater than 1.0 mg/L (14-day average) (SWRCB, condition 14.b).

In this study DOC was used as a surrogate for TOC.

1.2.4 Chloride

Chloride concentration shall not:

- Increase more than 10 mg/L chloride concentration at any of CCWD's intakes
- Cause any increase in salinity of more than 10 mg/L chloride (14-day running average salinity) at any urban intake in the Delta
- Cause or contribute to any salinity increase at one or more urban intake in the Delta if the intake is exceeding 90% of an adopted salinity standard (Rock Slough chlorine standard defined in SWRCB Decision 1641) (SWRCB, condition 14.c.)

1.2.5 Disinfection Byproducts

The Project operations will be curtailed, rescheduled, or constrained to prevent impacts on drinking water quality at any water treatment plant receiving water from the Delta based on the following WQMP screening criteria:

- Modeled or predicted Total Trihalomethanes (TTHM) concentrations in drinking water in excess of 64 µg/L as calculated in the raw water of an urban intake in the Delta or at the outlet of a water treatment plant.
- Modeled or predicted Bromate concentrations in drinking water in excess of 8 µg/L as calculated in the raw water of an urban intake in the Delta or at the outlet of a water treatment plant.

1.2.6 Dissolved Oxygen (DO)

No discharge of stored water would be allowed if the DO of stored water:

- Is less than 6.0 mg/L, or
- Causes the level of DO in the adjacent Delta channel to be depressed to less than 5.0 mg/L, or
- Depresses the DO in the San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L September through November. (SWRCB, condition 19.a.)

1.2.7 Temperature

No discharge of stored water would be allowed if:

- The temperature differential between the discharged water and receiving water is greater than 20º F,
- If the discharged water causes an increase in the temperature of channel water by more than:
  - 4º F when the temperature of channel water ranges from 55º F to 66º F
  - 2º F when the temperature of channel water ranges from 66º F to 77º F
  - 1º F when the temperature of channel water is 77º F or higher (SWRCB, 20.b)

1.3 Scope of Work

1.3.1 Modeling Studies

The Delta Simulation Model (DSM2) was used to assess the impacts of the In-Delta Storage reservoirs on Delta water quality in channels and at urban intakes. The following work was done as part of the modeling studies.

- Revise the organic carbon growth algorithm in DSM2 to address carbon loading from peat soils and biological productivity.
- Revise estimates for likely organic carbon concentrations in storage water in comparison to the base No Action condition.
- Create dispersion rules for CALSIM II recirculation studies and check final reservoir DOC at the urban intakes for the final CALSIM II run.
- Compare water quality constituents under base No Action conditions with In-Delta Storage Project operations under D1643 and WQMP.
- Provide input to Reservoir Stratification studies.

1.3.2 Water Quality Field Investigations

The following work was done as part of the field investigations to estimate the organic carbon loading from peat soils and biological productivity on the reservoir islands.

- Review literature on organic carbon loading in the Delta for information that may be applicable to In-Delta Storage project.
- Evaluate likely DOC concentrations and loads expected in the stored water using mesocosms or physical models of the proposed reservoir islands.
- Integrate results from filed studies with mathematical models of the proposed reservoir islands.

1.3.3 Temperature and Stratification Modeling

The DYRSEM model study was conducted by the Flow Science Inc., and the study period covered three representative years (dry, normal and wet) for different project operation scenarios. The DYRSEM model study focused on the following issues.

- Develop meteorological data sets for the reservoir islands.
- Determine if the reservoir islands will stratify using the one-dimensional DYRESM model.
- Quantify likely water temperatures for the reservoir islands and discuss potential changes in channel temperature resulting from reservoir discharge.

A report by Flow Science Inc. outlining the detailed methodology, assumptions and results of the DYRSEM model studies of the In-Delta storage islands is given in Appendix C.

1.4 Organization of Report

This report has four sections and one appendix. This section is organized to present general information including the overview of the project and scope of the work. Methodology and findings of the DSM2 model studies of water quality parameters are given in Chapter 2. Chapter 3 provides the details of the Water Quality Field Investigations. DO and temperature modeling study results are given in Chapter 4. Conclusions of the study and recommendations are given at the end of each chapter. Consultant's report on stratification of the reservoir islands are given in the appendix.

Chapter 2: WATER QUALITY MODELING STUDIES

2.1 Overview

Three DSM2 daily time step 16-year planning studies were run in HYDRO and QUAL based on the proposed operations for the IDS project islands: Webb Tract and Bacon Island. The Delta inflows, exports and island operations used in these studies were provided from the CALSIM II Daily Operations Model (DOM). A basic description of the DSM2 / CALSIM II scenarios is listed in Table 2.1.1.

Table 2.1.1: Summary of DSM2 Studies.

Study	*Basic Study Objective*	*CALSIM II Operational Constraints*
Study 1	No Action Base	D1641
Study 4[1]	Water Supply / EWA / ERP	D1641 / D1643 / EWA & ERP
Study 4b	DOC Resolution Through Circulation	Study 4 with DOC Constraints

1. Study 4 was used to develop fingerprinting results, but no water quality results from study 4 will be presented.

All three studies were based on separate CALSIM II runs. However, CALSIM II's study 4b includes information from DSM2's study 1 and study 4. The interaction between CALSIM II and DSM2 is illustrated in Figure 2.1.1. Study 1 provided the base line DOC concentrations at the urban intakes. Study 4 used fingerprinting information to provide the project island volume - flow relationships that were integrated into CALSIM II in order to constrain project releases to meet the DOC standards consistent with the State Water Resources Control Board (SWRCB) water rights decision D1643. Due to time constraints, study 4 was not used to analyze DOC or EC based on the study 4 CALSIM II operations.

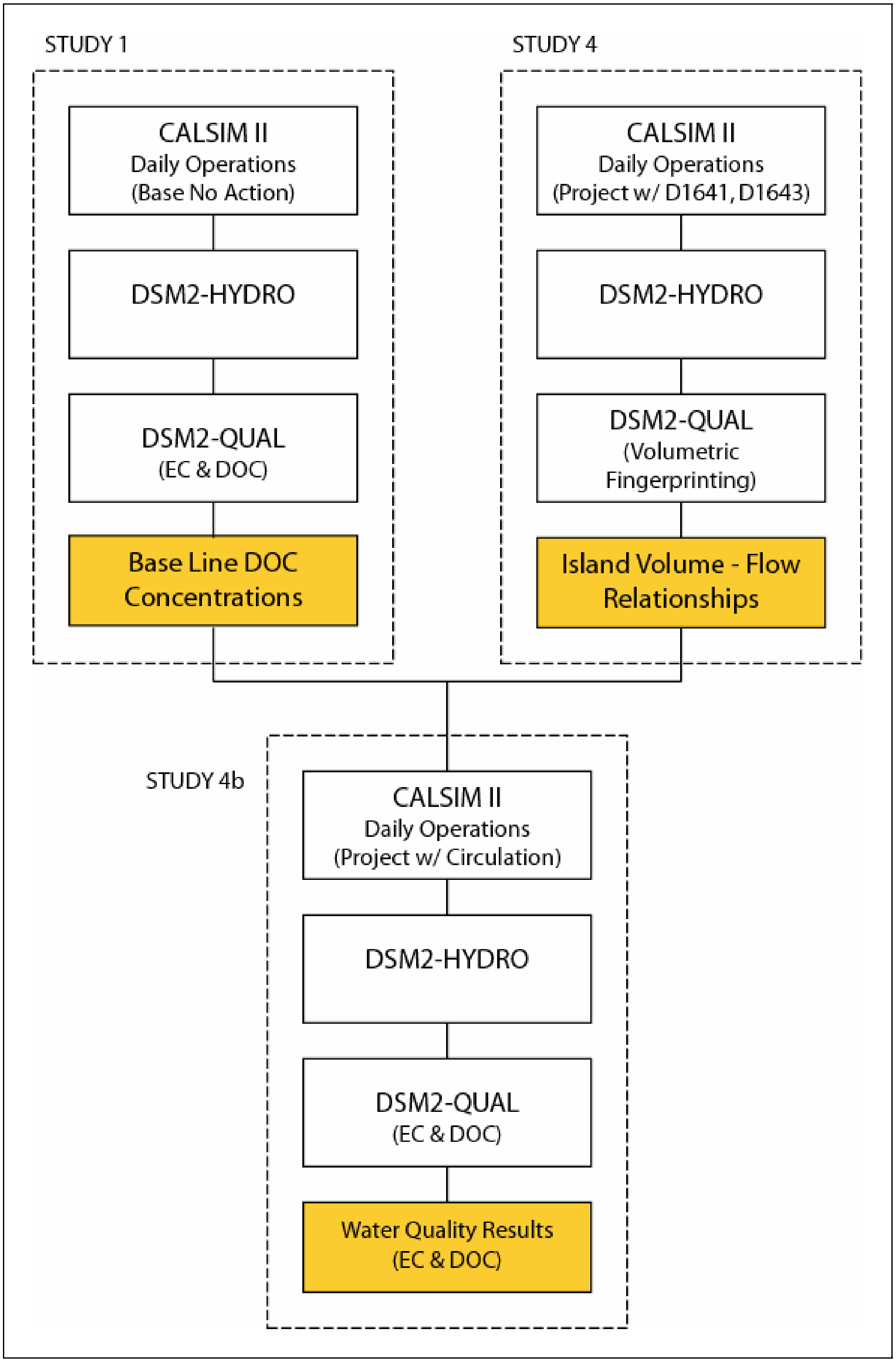

Figure 2.1.1: Study Methodology.

2.2 Delta Hydrodynamics

The major tributary flows, exports, diversions, and operations of the gates and barriers in the Delta affect the hydrodynamics in the Delta. Understanding these hydrodynamics is essential when examining the water quality for any Delta location. The Delta hydrodynamics for all three studies are summarized below. (NOTE: for information related to the operation of the project islands in study 4 and study 4b, see *Section 2.4*.)

2.2.1 Sacramento River and San Joaquin River Inflows

Time series illustrating both the daily average and change in daily average flows (alternative – study 1) for the Sacramento and San Joaquin rivers are shown below. All of the CALSIM II simulations were based on the same hydrology and 2020 level of development demands. The difference between the base and alternative flows and exports was based on how CALSIM II chose to operate the entire system.

For both rivers, the change in daily average flow was calculated as the difference of the base case flow from the alternative. Positive values correspond to periods when the alternative flow was higher than the base case flow. Negative values correspond to periods when the base case flow was higher.

2.2.1.1 Sacramento River

The monthly average difference in Sacramento River Flows for both alternatives (study 4 and study 4b) is shown in Figure 2.2.1. The largest changes in Sacramento flow in April (an increase in Sacramento River flows in the alternatives) and July (a decrease in Sacramento River flows in the alternatives). Since July is a typical project island release month (see *Section 2.4.2.1* for more information about project releases and diversions), this change in Sacramento inflows to the Delta is likely the result of the availability of IDS water to meet SWP and CVP demands.

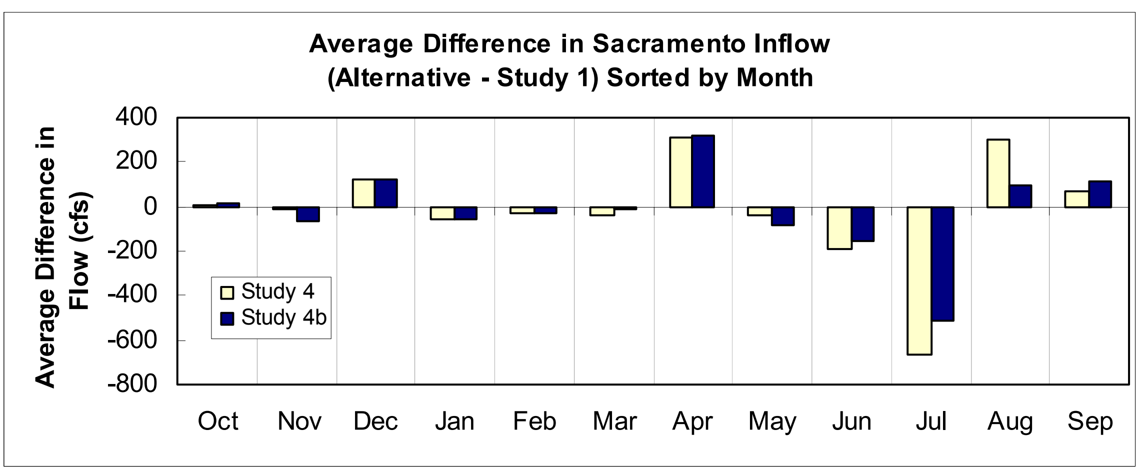

Figure 2.2.1: Difference in Sacramento River Flows (Alternative – Study 1) Stored By Month.

The daily average flows on the Sacramento River (Figure 2.2.2) are highly varied over the course of the 16-year study. The changes in these daily flows due to the operation of the IDS project is illustrated in Figure 2.2.3.

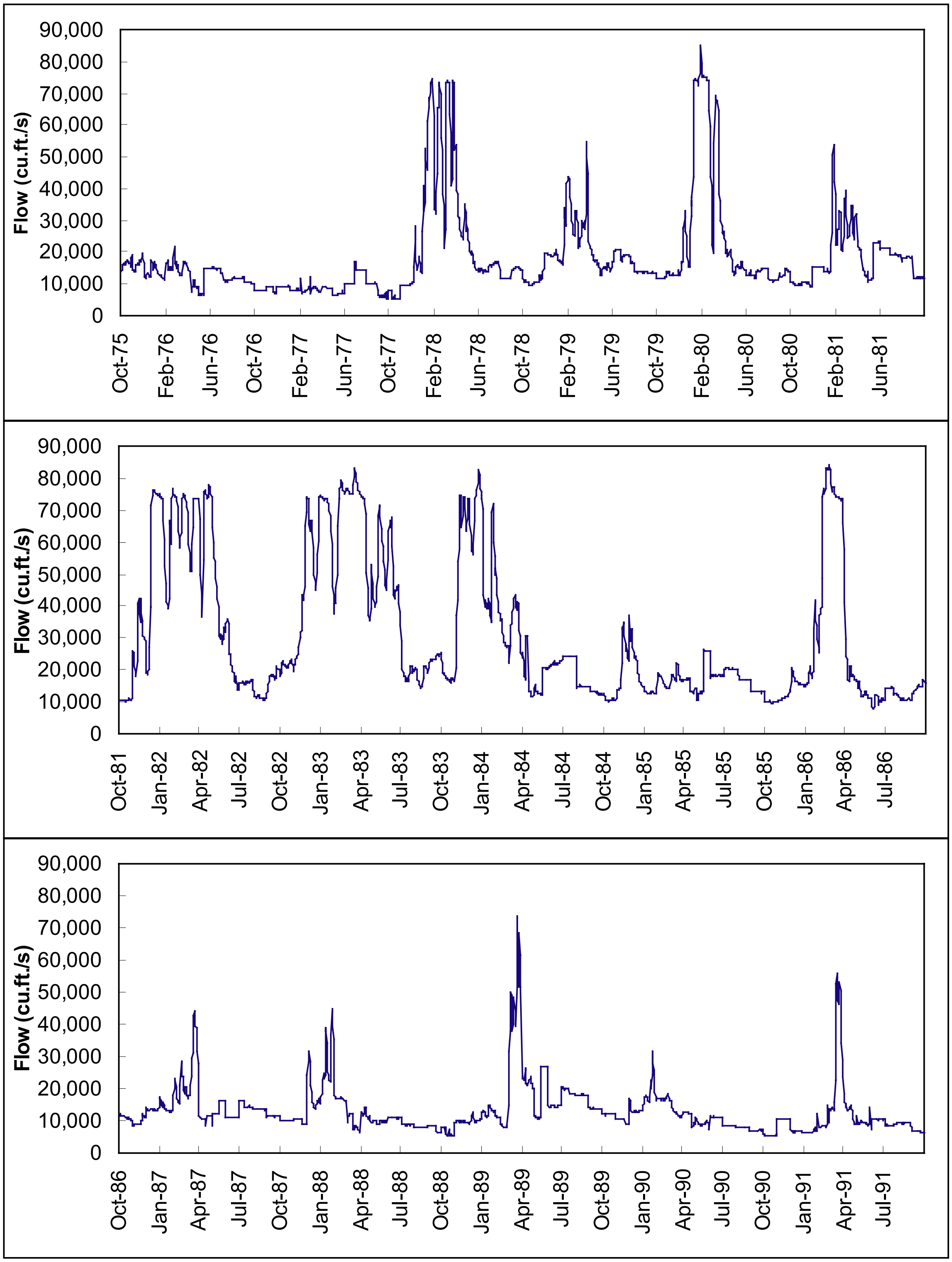

Figure 2.2.2: Daily Average Flow on the Sacramento River for Study 1 (Base).

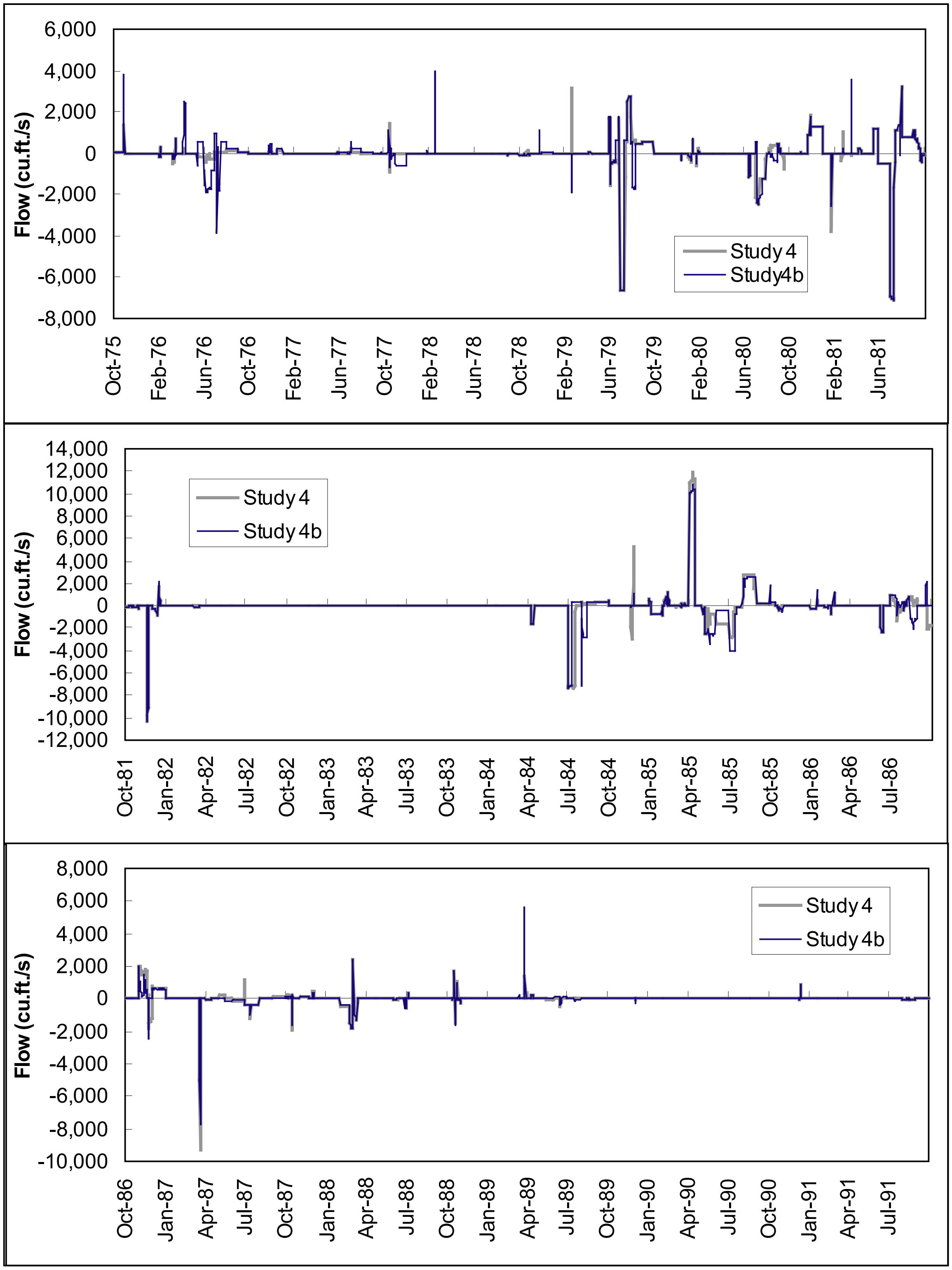

Figure 2.2.3: Change in Daily Average Flow on the Sacramento River due to Study 4 and Study 4b.

2.2.1.2 San Joaquin River

The daily San Joaquin River flows were used to determine the operation of the South Delta barriers (see *Section 2.2.4*). The daily average flows provided by CALSIM II's DOM were calculated by distributing the CALSIM II monthly average flows to a daily pattern based on historical observations.

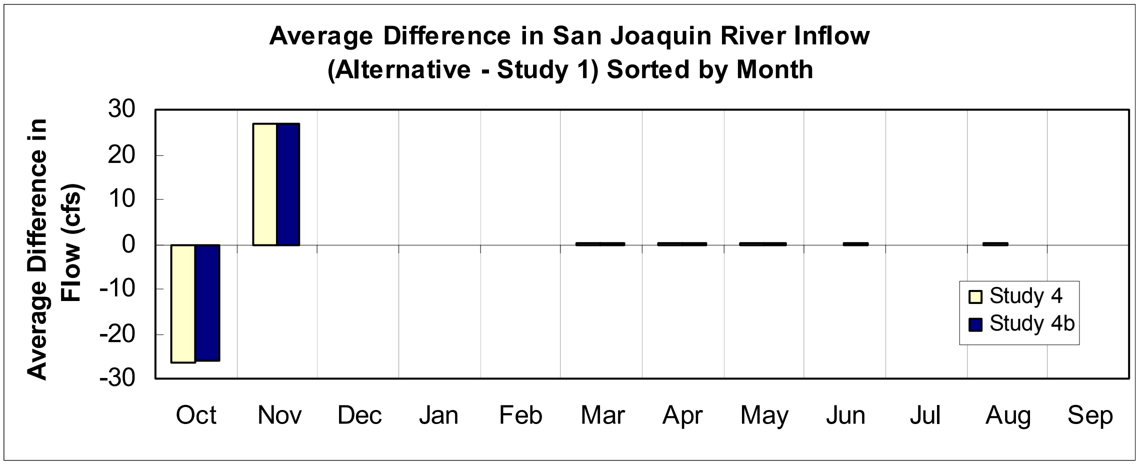

Figure 2.2.4: Difference in San Joaquin River Flows (Alternative – Study 1) Stored By Month.

The daily average flows on the San Joaquin (Figure 2.2.5) are seasonally varied over the course of the 16-year study. As shown in Figure 2.2.6, the changes in the San Joaquin flows by either alternative (study 4 or study 4b) from the base case flows are relatively insignificant. The only major change, a 400 cfs change, occurred in the Fall of 1982, and was consistent between both studies.

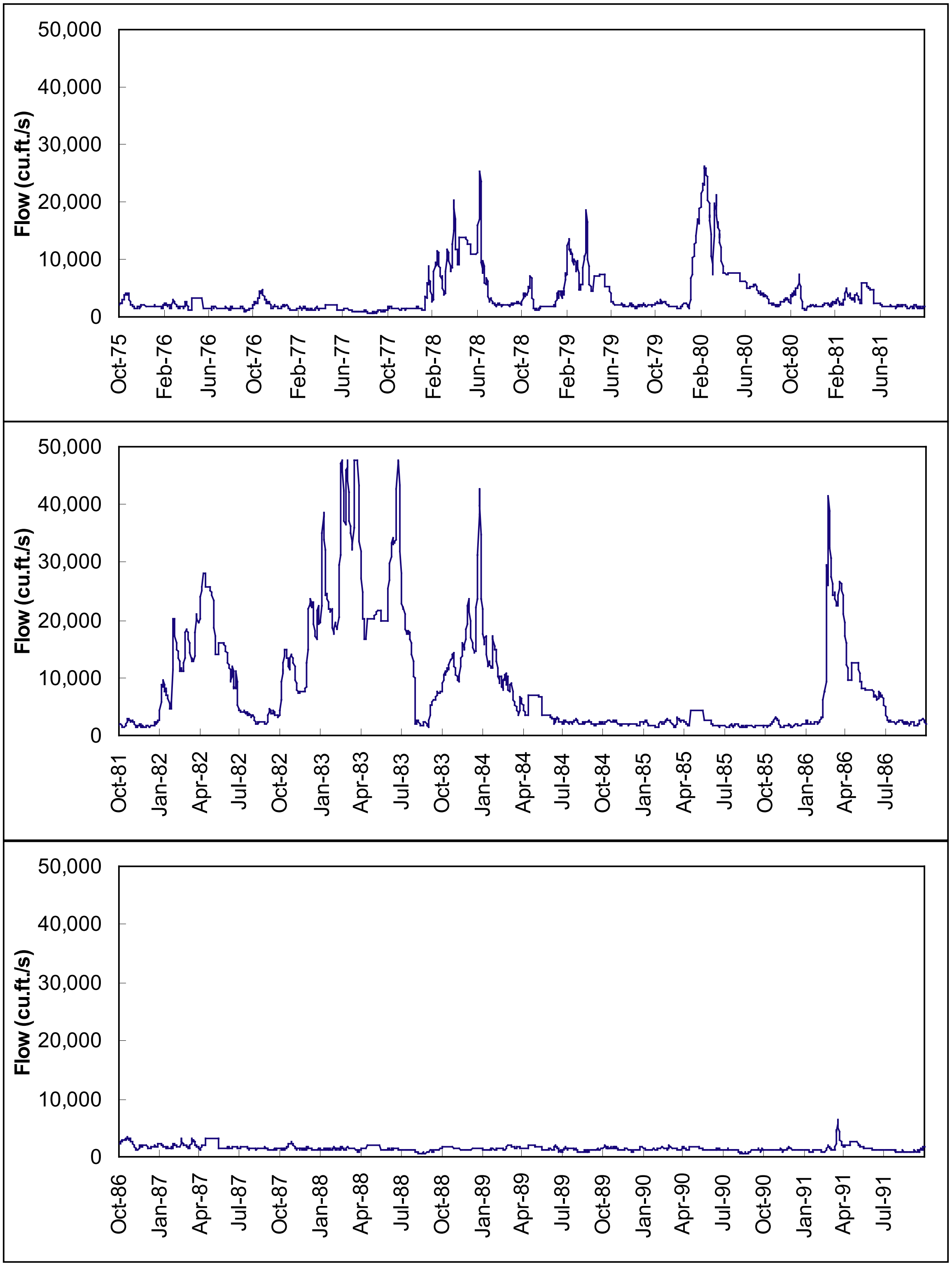

Figure 2.2.5: Daily Average Flow on the San Joaquin River for Study 1 (Base).

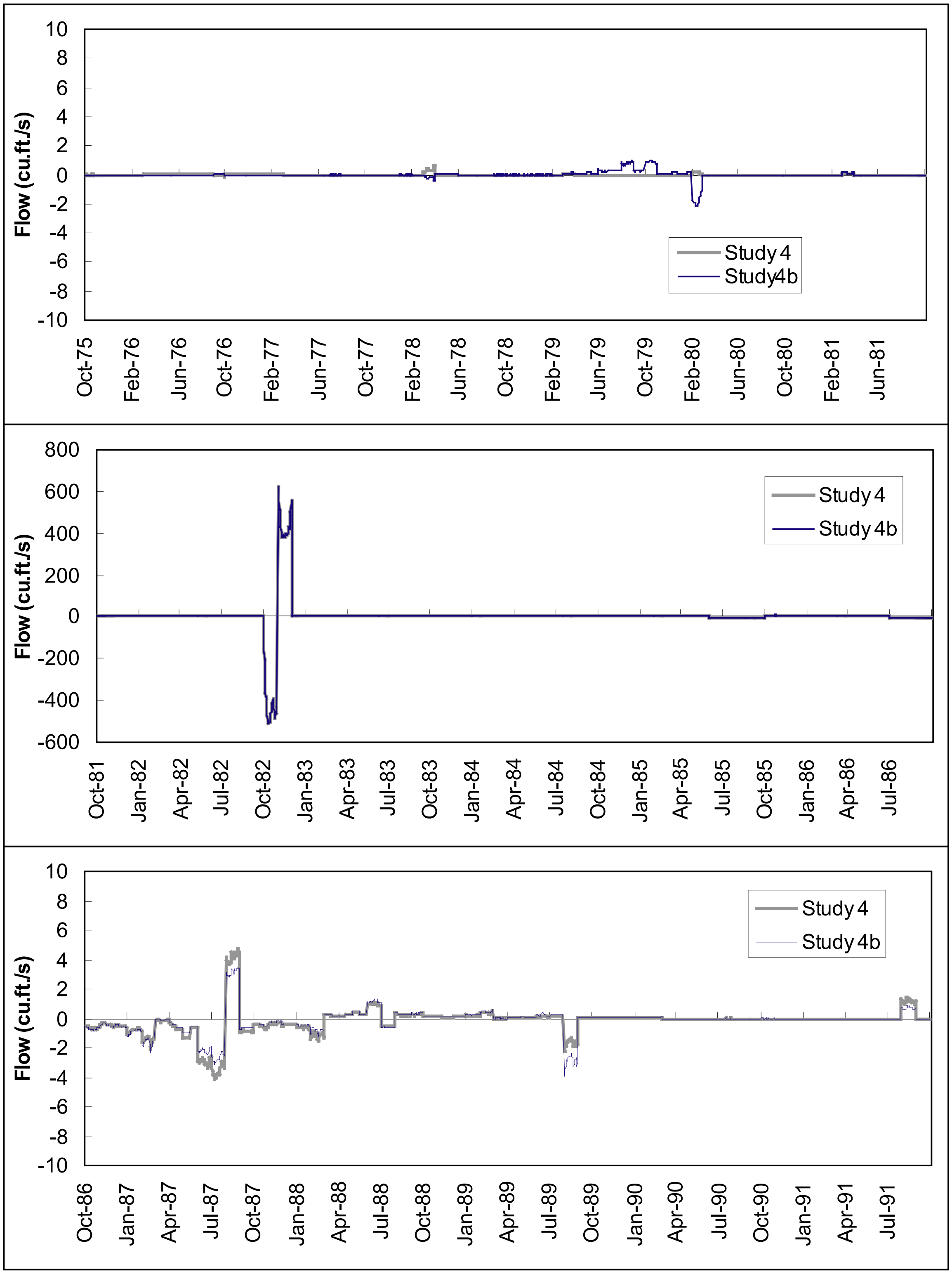

Figure 2.2.6: Change in Daily Average Flow on the San Joaquin River due to Study 4 and Study 4b.

2.2.2 Combined Exports

In addition to diversions and releases from the IDS islands (see *Section 2.4.2*), changes in the amount and timing of both the SWP and CVP exports have a significant impact on the flow patterns in the Delta. A net increase in SWP and CVP exports was expected, since the primary objective of the project was to increase SWP and CVP project storage. As shown below in Figure 2.2.7, the most significant increases in the exports occurred in July and August.

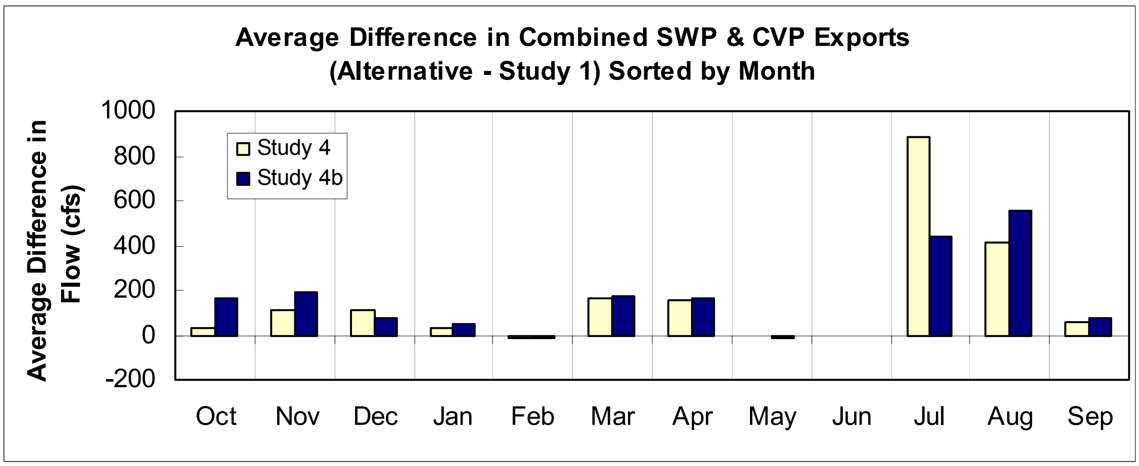

Figure 2.2.7: Difference in Combined SWP and CVP Exports (Alternative – Study 1) Stored By Month.

The daily averaged combined SWP and CVP exports for study 1 during the entire 16-year simulation are shown in Figure 2.2.8. The time series of the change in the combined SWP and CVP exports due to the operation of the project in both alternatives is shown in Figure 2.2.9.

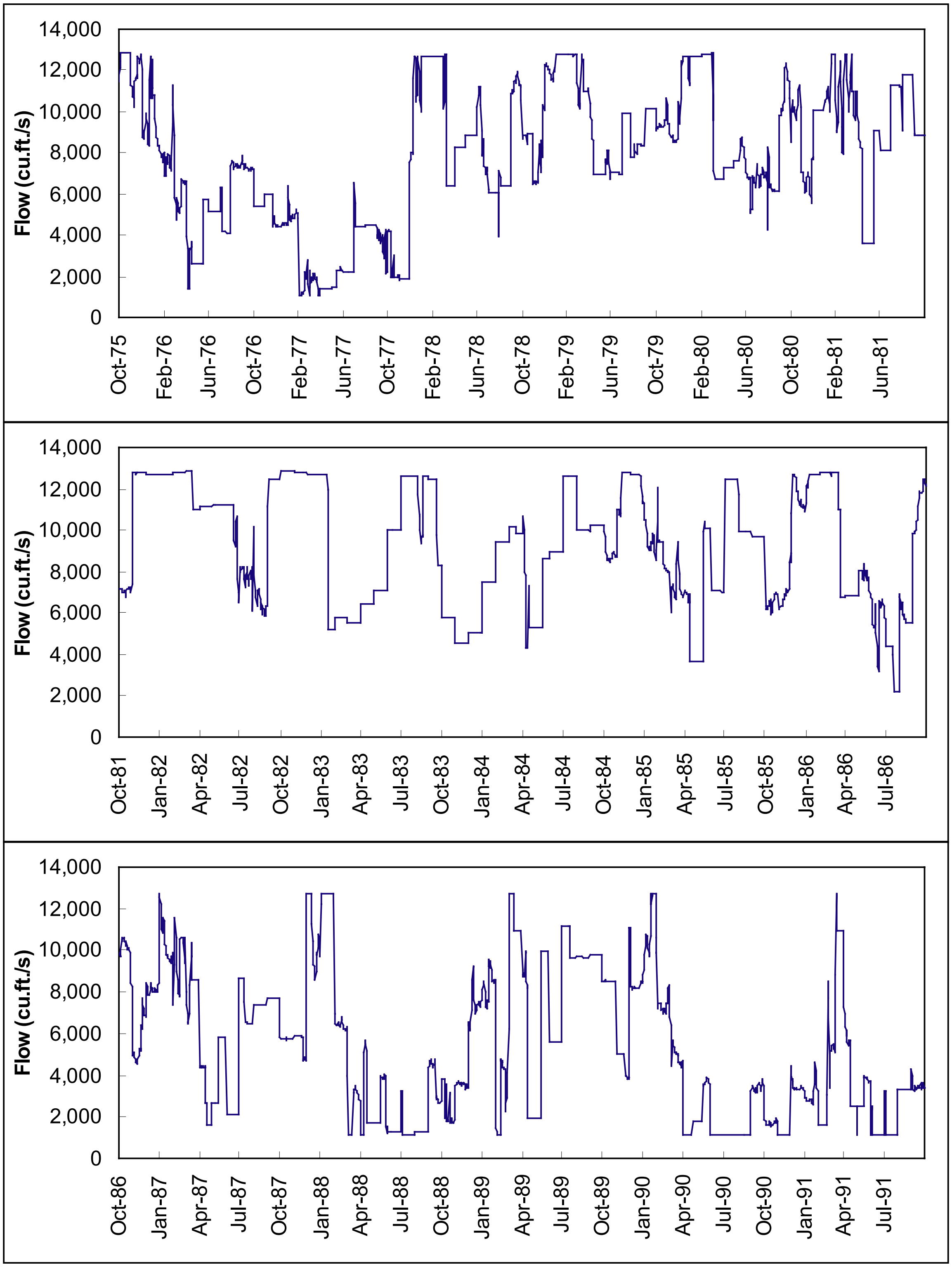

Figure 2.2.8: Daily Average Combined SWP and CVP Exports for Study 1 (Base).

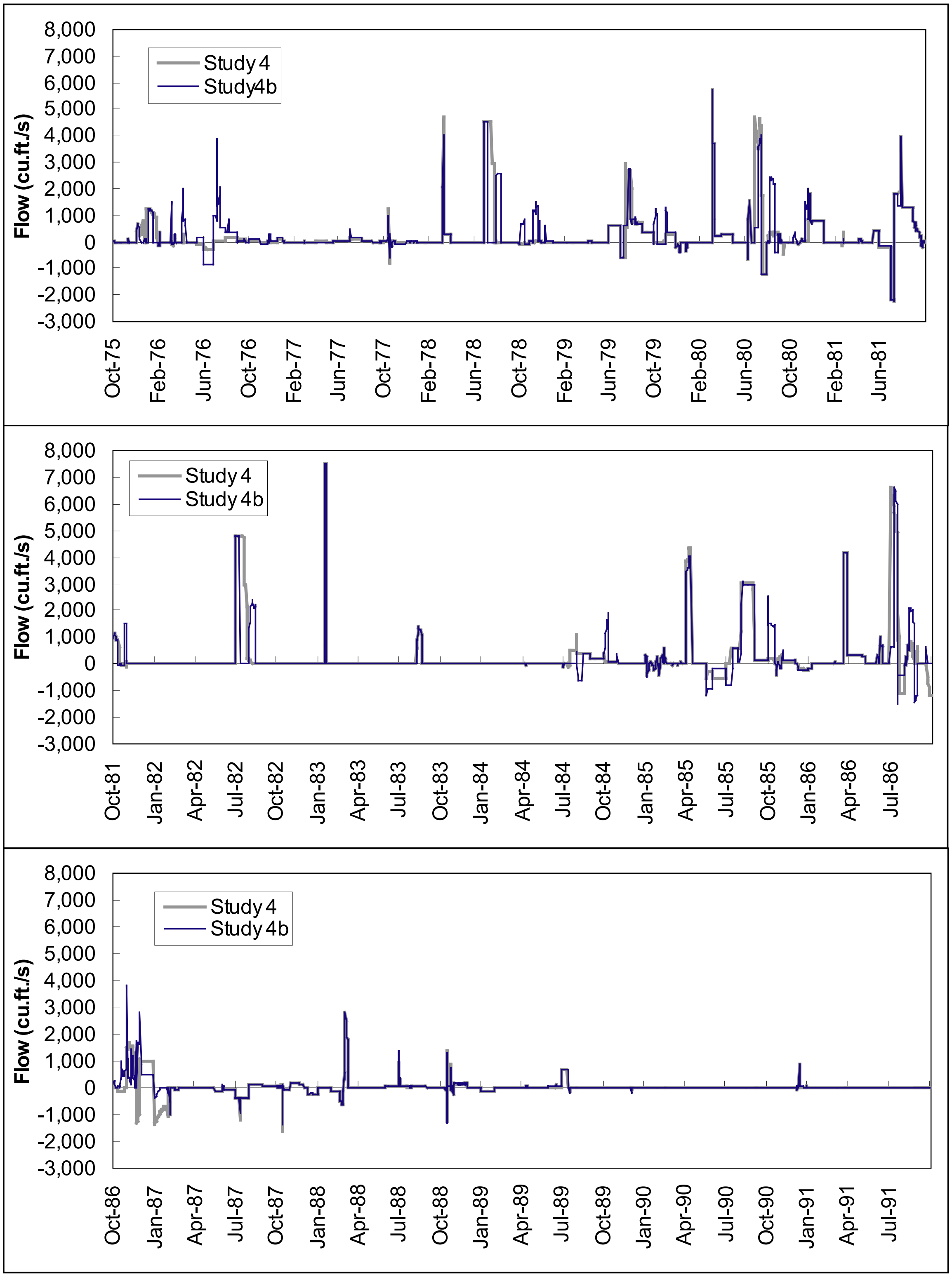

Figure 2.2.9: Change in Daily Average Combined SWP and CVP Exports due to Study 4 and Study 4b.

2.2.3 Contra Costa Water District Diversions / Exports

CALSIM II calculates CCWD's combined Rock Slough and Los Vaqueros Reservoir diversions and exports at a single point. Though DSM2's grid would make it possible to simulate the two urban intakes independently, it would be necessary to develop a series of rules to emulate the CCWD operation. DSM2 assumed that all of the CALSIM II CCWD diversions were from Rock Slough.

The significance of this assumption has not been tested, but the location of the CCWD diversions and exports may also be sensitive to the type of water quality constituent being simulated. For example, by assuming all CCWD diversions take place at Rock Slough, water quality results at Rock Slough are more likely to include a higher percentage of ocean water, while water in the Old River is more likely to include a lower percentage of ocean water. Since ocean water is a significant source of chlorides, this assumption could result in higher Rock Slough chloride concentrations and lower Los Vaqueros Reservoir intake (and possibly SWP and CVP) chloride concentrations.

2.2.4 Gates and Barriers

The operation of the Delta Cross Channel was taken directly from CALSIM II. As described by Easton (2003), the DCC can be opened only on specific days per month, as specified in input to CALSIM II. However, the DCC will be closed on any day when:

- Sacramento River Delta inflow exceeds 25,000 cfs,
- Mokelumne River Delta inflow exceeds 8,700 cfs, or
- The Rio Vista minimum instream flow requirement constrains Delta operations and the flow in Georgiana Slough if the DCC is closed will be sufficient to meet the necessary Delta exports.

Though the monthly average of percentage of time the DCC was opened is nearly the same for all the scenarios (e.g., Table 2.2.1), the daily operation of the DCC was much more varied between different scenarios.

Table 2.2.1: Monthly Average of Percentage of Time DCC Open.

Scenario	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Study 1	86%	54%	38%	25%	0%	0%	0%	0%	81%	99%	100%	94%
Study 4	86%	56%	38%	25%	0%	0%	0%	0%	81%	99%	100%	94%
Study 4b	86%	55%	38%	25%	0%	0%	0%	0%	81%	99%	100%	94%

The four South Delta barriers, Middle River, Old River, Grant Line Canal (west), and Head of Old River at the San Joaquin River, were modeled as permanent barriers. The purpose of the first three barriers is to improve the water levels in the South Delta. The Head of Old River at the San Joaquin River barrier is designed to prevent fish from swimming down the Old River and ending up at the SWP and CVP pumps.

All four barriers were treated as gated weirs. Flow could pass in either direction of the barriers when the gates in the barriers were not operating. When the gates were operating, the barriers restricted flow downstream through the barrier.

The locations of all four barriers are shown below (Figure 2.2.10). The operations for all four barriers are listed in Tables 2.2.2, 2.2.3, and 2.2.4. The same operations were used in the base and alternative simulations. Although the Old River and Middle River barriers used the same schedule of operations, the physical configuration of the two barriers was different. This schedule of operations was based on a CALSIM II D1641 monthly study.

San Joaquin River flows were used to determine when the gates in the barriers should not be operated. When the flow in San Joaquin River exceeded 8,600 cfs (such as it did in 1982 and 1983), the Head of Old River at San Joaquin River fish barrier was not operated. Similarly, when the flow in the San Joaquin River exceeded 20,000 cfs, the remaining three barriers were not operated.[1]

[1] Although this study was based on daily average CALSIM II flows, the schedules of barrier operations were based on SJR flows from an older D1641 monthly CALSIM II study. Though the daily average CALSIM II flows were based on monthly CALSIM II results, in June 1978, some of the daily average flows exceeded the SJR flow removal criteria listed above.

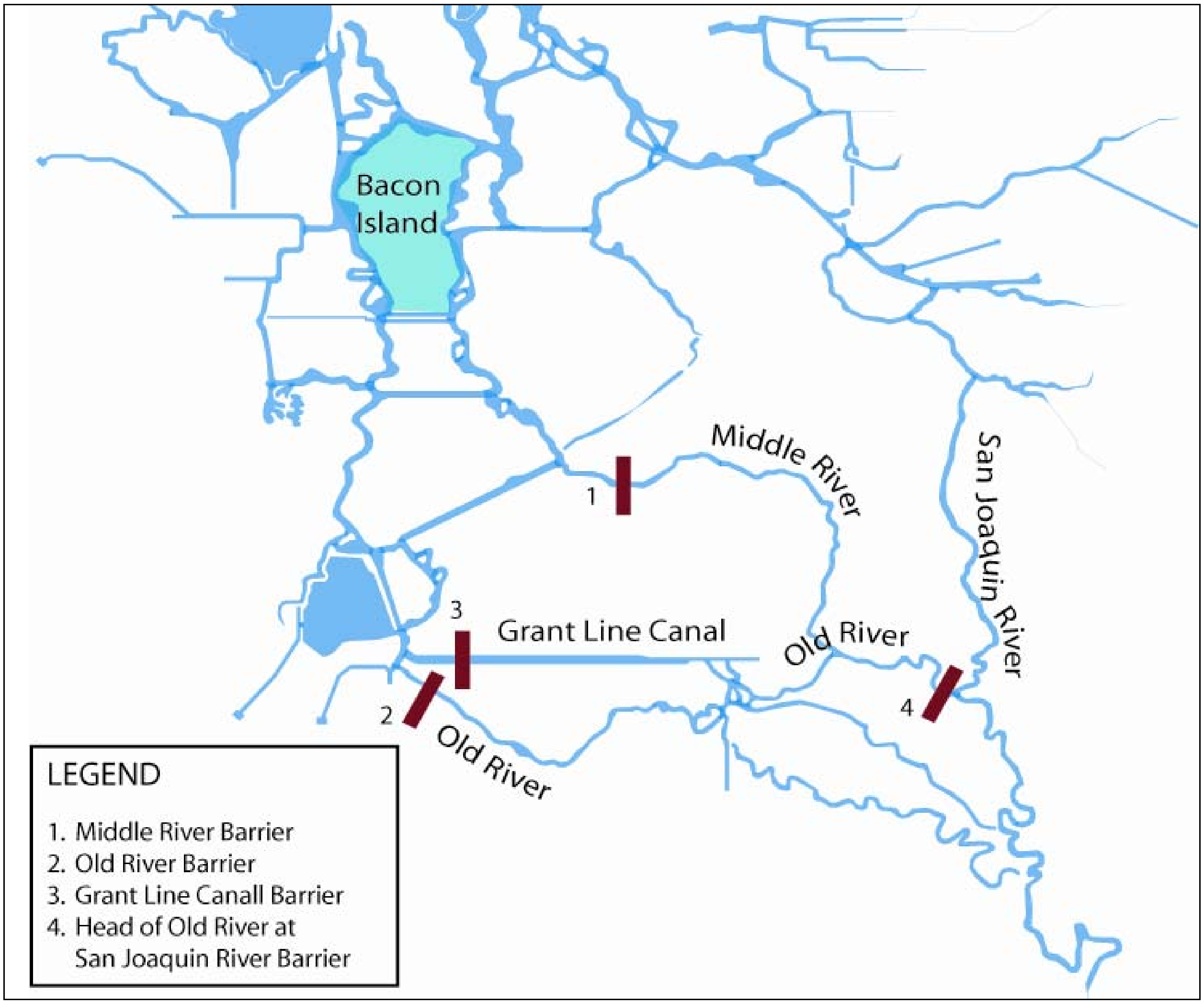

Figure 2.2.10: South Delta Permanent Barrier Locations.

Table 2.2.2: Old River and Middle River Barrier Operation.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												

Legend

Gates are not operating, i.e. open

Gates are operating, i.e. closed (restricts downstream flow)

Table 2.2.3: Grant Line Canal Barrier Operation.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												

Legend

Gates are not operating, i.e. open

Gates are operating, i.e. tidal operations (restricts downstream flow)

Table 2.2.4: Head Old River at San Joaquin River Barrier Operation.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												

Legend

Barrier not installed

Barrier installed (restricts flow downstream when stage < 11 ft)

2.2.5 Delta Island Consumptive Use

Though originally used to calculate Delta wide consumptive use for the original Delta Simulation Model (DWRDSM) as described by Mahadevan (1995), the DICU model has been modified to calculate the historical consumptive use in the Delta for DSM2. In order to remain consistent with the level of development used in the CALSIM simulations, a 2020-Level of Development was used to adjust the historical Delta Island consumptive use using the department's ADICU model. The adjusted consumptive use was then applied to 257 locations (model nodes) in the Delta to represent agricultural diversions and returns to and from Delta islands and the seepage from Delta channels to the islands.

The scope of this study is not to account for the impact of the operation of the project islands on the entire Delta, but rather to focus on quantifying the water quality impacts at the four major urban intakes. Thus, the same consumptive use patterns were used in both the base (study 1) and alternative (study 4 and 4b) simulations. Even though the land use associated with the two project islands would be different for the alternatives based on the real operation of the project, it was decided to not rerun the DICU and ADICU models to account for the changes in land use. Previous DSM2 studies (Mierzwa, 2001) have shown that the change in base case simulated DOC at the State Water Project (SWP) and Rock Slough (RS) intakes due to removing the return flows (and hence the water quality associated with those follows) from Bacon Island and Webb Tract is small.

2.3 Delta Water Quality

Water quality inputs, EC and DOC, were applied in DSM2-QUAL to the flows generated in DSM2-HYDRO at the river and ocean Delta boundaries and at interior Delta locations. With the exception of EC at Martinez, the water quality concentrations for both EC and DOC at all of the flow inputs into the Delta were based on standard monthly varying DSM2 planning studies concentrations (i.e. the concentrations themselves did not change between studies). However, the relative amount of each constituent brought into the Delta is variable between studies. The amount at each boundary input is the product of the concentration assumed for that boundary and the volume of water that enters at the boundary.

EC and DOC were simulated as a conservative constituent while in the Delta channels. DSM2 has been calibrated and validated for EC and validated for DOC (insert reference to EC and DOC calibration and validations). However, DOC was treated as a non-conservative constituent inside the project islands (see *Section 2.4.4*). The mixing of Delta water with island water is discussed in *Sections 2.4.3 and 2.4.4*.

2.3.1 EC

Martinez EC was generated using Net Delta Outflow from the CALSIM II daily results and an updated G-model (Ateljevich, 2001). By incorporating tidal information into the process of estimating EC at Martinez, data was generated for a 15-minute time step. Since Sacramento inflow is an important component to Net Delta Outflow, the 15-minute Martinez EC was different in all of the simulations.

Monthly CALSIM II Vernalis EC was smoothed to a 1-hour time step using a mass conservative tension spline.[2] The hourly EC at Vernalis was virtually identically for all of the simulations.

Lack of adequate EC – flow relationships made it necessary to assume fixed concentrations to assign to the flows at the other major inflow boundaries to the Delta (see Table 2.3.1). These values are the standard values used to represent the quality associated with these inflow boundaries. The concentrations were used in study 1 and study 4b (EC was not simulated in study 4).

Table 2.3.1: EC at Delta Inflow Boundaries.

Boundary Inflow	**EC (umhos/cm)**
Sacramento River	160
Yolo Bypass	175
Eastside Streams (Mokelumne and Cosumnes Rivers)	150
City of Stockton Waste Water Treatment Plant Releases	0

[2] This mass conservative tension spline is a specific type of spline that preserves the monthly average value when creating hourly values.

The monthly varying EC concentrations assigned to the agricultural return flows are based on field observations that have been prepared for use in DSM2 by the Delta Island Consumptive Use (DICU) model (DWR, 1995). This report divided EC return concentrations into three sub regions: north, west, and southwest, based on Bulletin 123 and Municipal Water Quality Investigations (MWQI) data. The same monthly varying time series was used each year for each sub region (i.e. every October for the north sub region assigned the same concentration to agricultural return flows in the north sub region). However, as discussed in Section 2.2.5, the agricultural return flows changed from year to year, thus an individual island's EC contribution to the Delta would change at the product of its return flow and repeating monthly concentration. The same concentrations were used in study 1 and study 4b.

2.3.2 DOC

DOC from the ocean boundary at Martinez and Stockton Waste Water Treatment Plant releases were considered negligible (i.e. 0 mg/L). The standard monthly varying DSM2 16-year planning study DOC concentrations applied at the remaining DSM2 flow input boundaries were generated based on historical DOC – flow relationships (Suits, 2002). The DOC concentrations associated with agricultural return flows are based on DICU model results (Jung, 2000). The Delta was divided into three sub regions based on observed DOC return quality concentrations: low-, mid-, and high-range DOC. These sub regions are different than those associated with EC.

2.4 Project Islands

The principle difference between study 1 (no action base) and the two alternatives (study 4 and study 4b) was the addition and operation of the IDS project island reservoirs: Bacon Island and Webb Tract. The location of the two project islands is shown in Figure 2.4.1. In the two DSM2 alternative simulations, the project islands were modeled as isolated reservoirs. The representation of the project islands in DSM2 is described below in *Section 2.4.1*.

In addition to isolating the reservoirs from the Delta channels, several additional processes unique to operating the IDS project island as short-term reservoirs were addressed. The processes related to hydrodynamics include: diversion and release schedules (at two integrated facilities per island), evaporation losses, and seepage returns (see Figure 2.4.2). The island processes related to hydrodynamics are described in *Section 2.4.2*.

Water quality in each project island is related to the concentration of the inflows and the concentration already in the island. EC in the project islands is treated as a conservative constituent. A complete description of mixing conservative constituents is discussed in *Section 2.4.3*. As shown in Figure 2.4.2, several important organic carbon sources, representing the interaction of the island water with the organic carbon rich peat soils and the bioproductivity of carbon from aquatic plants and algae, provide additional organic carbon mass to the project islands. A detailed description of the method used to account for this non-conservative treatment of DOC is discussed in *Section 2.4.4*.

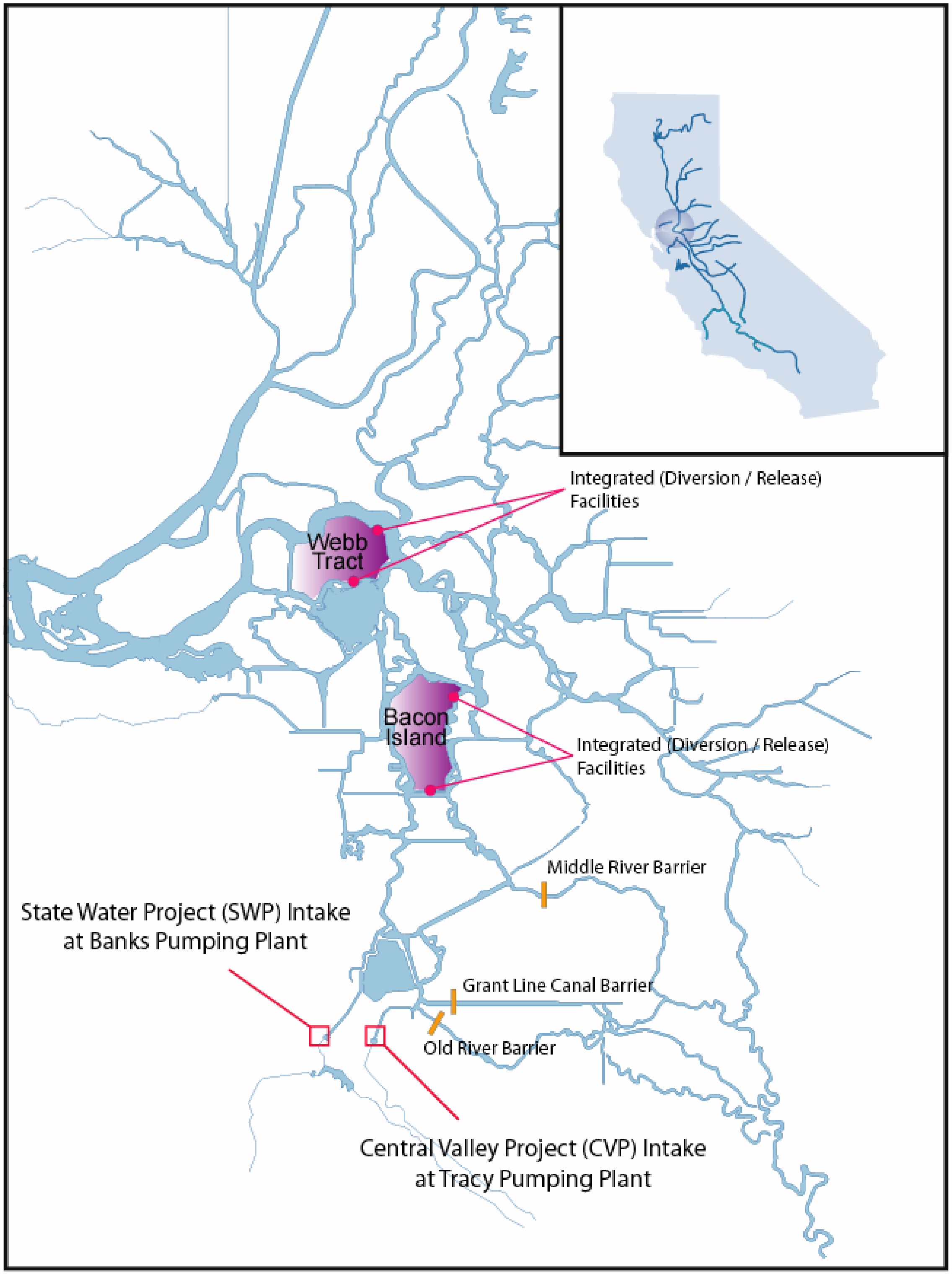

Figure 2.4.1: Location of Project Islands.

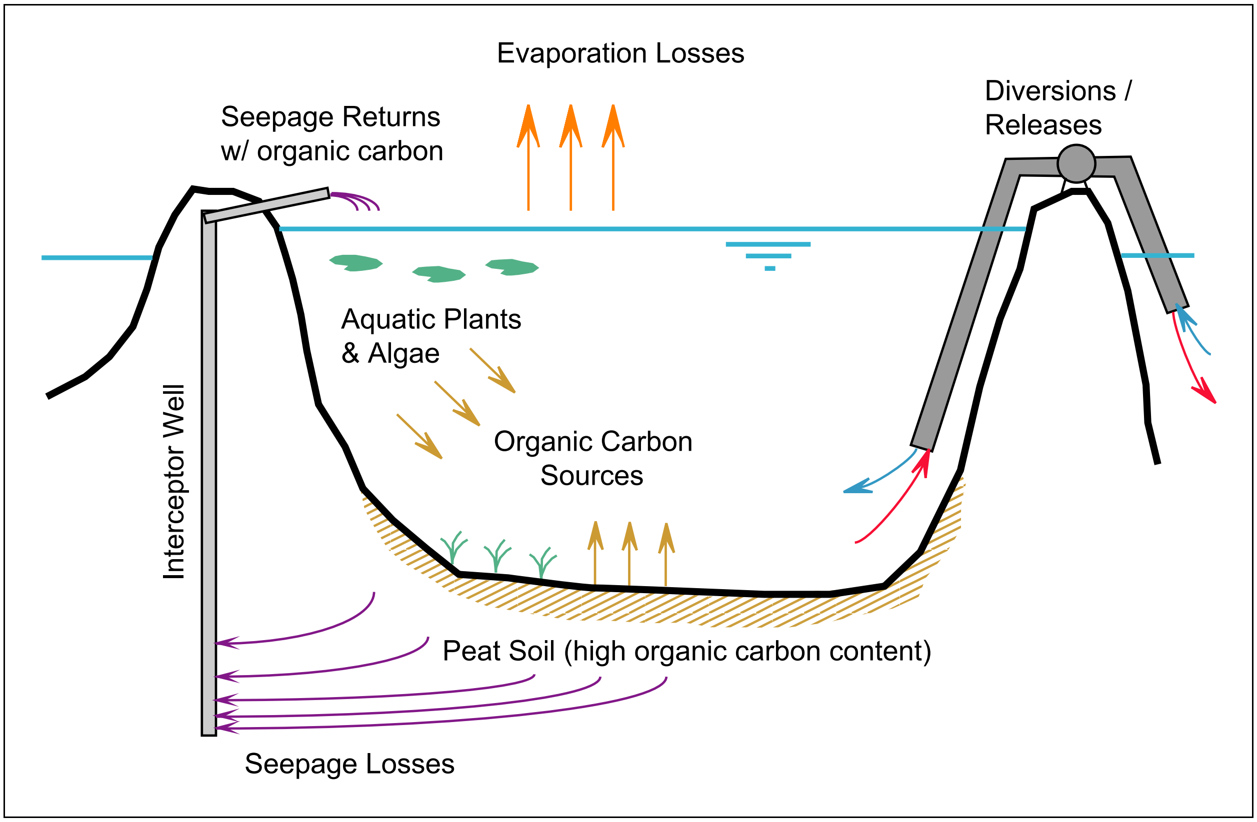

Figure 2.4.2: Project Island Processes Simulated in DSM2.

2.4.1 DSM2 Physical Representation of the Project Islands

DSM2 treats reservoirs as tanks with constant surface areas and variable depths, thus elevation (stage) in the reservoirs is a linear function associated with net flows into (or out of) the reservoirs. The DSM2 surface area for each reservoir was fixed such that when at a depth of 20 ft that each island's storage capacity would approximate its design storage capacity. The configuration of the project islands as modeled by DSM2 is shown in Table 2.4.1.

Table 2.4.1: DSM2 Project Island Configuration.

Island	Design Storage Capacity (TAF)	DSM2 Surface Area (acres)	Northern Integrated Facility DSM2 Node	Southern Integrated Facility DSM2 Node
Bacon Island	120	5,450	128	213
Webb Tract	118	5,370	40	103

In order to prevent DSM2 from drying up (DSM2 does not support wetting and drying, thus some amount of water must always be kept on every channel or reservoir in the model), a dead pool of 0.1 ft was added. The initial depth of the active storage pool at the start of each DSM2 simulation was determined by relating the CALSIM storage to the following DSM2 storage-depth relationship:

$$Stage_{DSM2} = \frac{Storage_{CALSIM} \times 1000}{A_{DSM2}} + BottomElev_{DSM2} + Stage_{DeadPool} \qquad \text{Eqn. 4.1}$$

where,

A_{DSM2}	= DSM2 Surface Area (acres),
$BottomElev_{DSM2}$	= DSM2 Reservoir Bottom Elev (ft),
$Stage_{DSM2}$	= Initial Stage in DSM2 (ft),
StageDeadPool	= Depth of the DSM2 Dead Pool (ft), and
$Storage_{CALSIM}$	= Storage in CALSIM at start of DSM2 simulation (taf).

Two integrated (diversion and release) facilities were used on each island to fill and empty the island reservoirs. The location of the each integrated facility in DSM2 corresponds with the approximate field location (see Figure 2.4.3 and Table 2.4.1). A description of the modeled operation of the facilities for both islands is explained in *Section 2.4.2.1*.

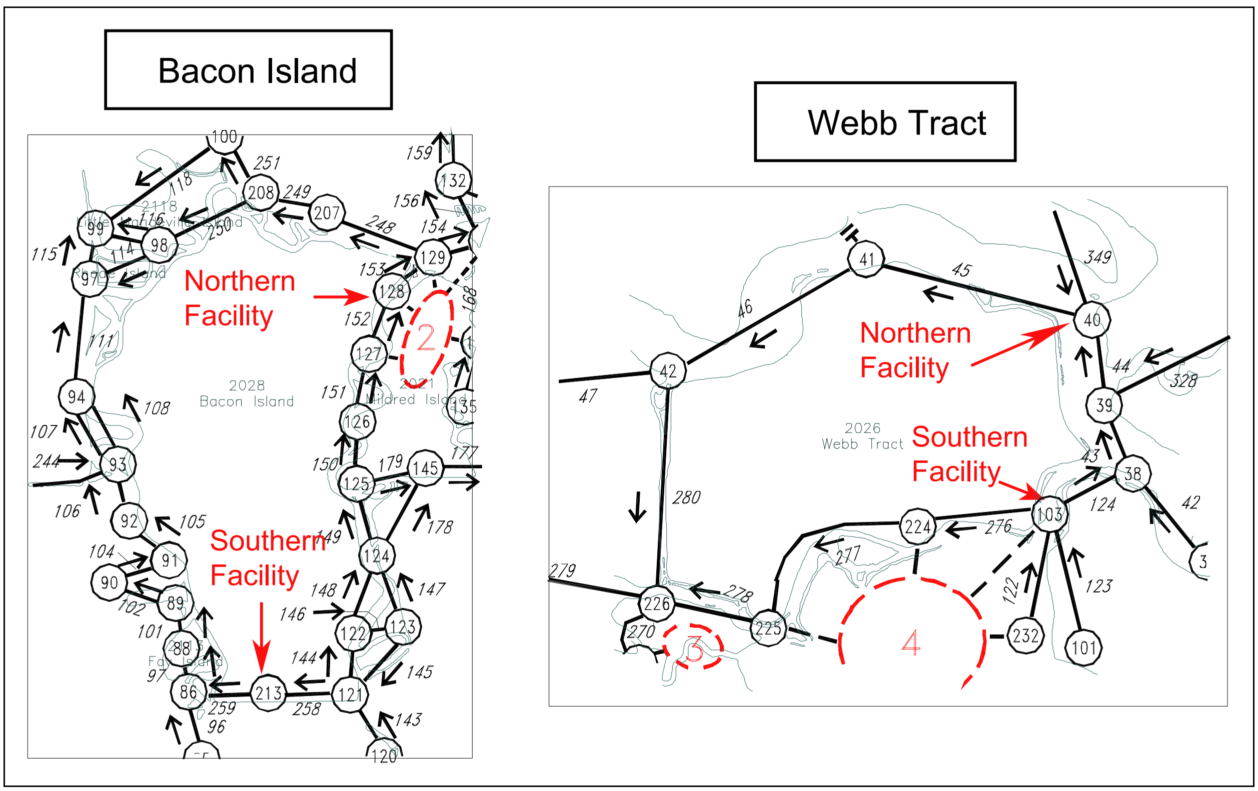

Figure 2.4.3: DSM2 Grid Surrounding Bacon Island and Webb Tract.

2.4.2 Project Island Hydrodynamics

For study 4 and study 4b, CALSIM II determined the daily diversions to and releases from the project islands, in addition to optimizing the exports at both the Banks (SWP) and Tracy (CVP) Pumping Plants. Depending upon water quality and project constraints, project diversions and releases were used to improve water quality of the island reservoirs themselves or to meet increases SWP and CVP project demands. Diversions to and releases from the project islands to the surrounding channels were controlled in DSM2-HYDRO by "object-to-object" transfers when simulating EC and DOC (study 4b). The other two hydrodynamic processes unique to the project islands: evaporation and seepage were included in the simulation of the reservoirs in study 4b.

For the fingerprinting simulation (study 4), the project islands were not directly modeled. The diversions and releases were treated as additional sinks and sources, not unlike the way DSM2 simulates the urban exports and river inflows to the Delta. Since the project islands were not directly modeled, there was no need to include estimates of evaporation or seepage when simulating the hydrodynamics for the fingerprinting runs. The flow rates assigned to the diversions and exports were the same as those used in study 4b, thus the quantity of water in the Delta Channels remain unchanged.

There was no direct physical connection between the project islands and neighboring channels. Instead, water was pumped via two integrated facilities for each island (see *Section 2.4.2.1*). Diversions onto an island were assumed to be uniformly mixed with the water already present on the island. The concentration of EC or DOC released from an island was assumed to be the same concentration of the island, thus releases had no immediate impact on the island's EC or DOC concentration. However, releases from the islands had immediate and at times significant impacts on the EC and DOC concentrations of neighboring channels. In the case of a diversion scheduled soon after or concurrent to a release (which is typical in a circulation operation), the newly mixed water from the release may move to the diversion point and be returned to the island.

2.4.2.1 Integrated Facilities: Diversions and Releases

Each island used two different integrated facilities to divert and release water (see Figures 2.4.1, 2.4.2, and 2.4.3). The northern Bacon Island facility is located on the Middle River near Mildred Island. The southern Bacon Island facility is located in the middle of Santa Fe Cut, nearly equidistant between the Middle and Old Rivers. The northern Webb Tract facility is located on the San Joaquin River near the head of the North Fork of the Mokelumne River. The southern Webb Tract facility is located near the junction of the Old and False Rivers. The southern Webb Tract facility is also near the northeastern corner of Frank's Tract.

Diversions to and releases from the island reservoirs were taken directly from the CALSIM II, thus the storage simulated in DSM2 is identical to the storage used in CALSIM II. Although CALSIM II combined the north and south facilities for each island, the following basic operation rules were used by DSM2 to divide the CALSIM II derived flows between the two facilities:

Diversions	**Releases**

If Div_{CALSIM} > 2250 cfs Then
$Div_{SouthDSM2}$ = 2250 cfs
$Div_{NorthDSM2} = Div_{SouthDSM2} - Div_{CALSIM}$
Else
$Div_{SouthDSM2} = Div_{CALSIM}$
	If Rel_{CALSIM} > 2250 cfs Then
	$Rel_{NorthDSM2}$ = 2250 cfs
	$Rel_{SouthDSM2} = Rel_{NorthDSM2} - Rel_{CALSIM}$
	Else
	$Rel_{NorthDSM2} = Rel_{CALSIM}$

where,

Div_{CALSIM} = CALSIM Total Island Diversion (cfs),
$Div_{SouthDSM2}$ = DSM2 Diversion at Island's Southern Facility (cfs),
$Div_{NorthDSM2}$ = DSM2 Diversion at Island's Northern Facility (cfs),
Rel_{CALSIM} = CALSIM Total Island Release (cfs),
$Rel_{SouthDSM2}$ = DSM2 Release at Island's Southern Facility (cfs), and
$Rel_{NorthDSM2}$ = DSM2 Release at Island's Northern Facility (cfs).

The above project island integrated facility operation rules can be generalized to say that the majority of the project diversions will be taken from each island's southern facility, while the majority of the project releases will occur at each island's northern facility. Diversions and releases to and from the project islands for each island as a whole and the north and south integrated facilities on each island are summarized in Tables 2.4.2 and 2.4.3 for both study 4 and study 4b. The percent of time that water was diverted to or released from the project islands was calculated as the number of days that there was any positive diversion or release over the course of the 16-year DSM2 simulation. The average diversions and releases were calculated only when there was a positive diversion or release respectively (i.e. this value is not for the entire 16-year simulation, but represents the average diversion or release). The average diversions include small "topping-off" diversions made throughout the year to account for evaporation losses, thus the average of diversions greater than 100 cfs is also presented in Table 2.4.2.

Table 2.4.2: Summary of DSM2 Project Island Diversions.

Island	**Study**	**Facility**	**% Time of Diversions**		**Ave. Diversion (cfs)**		**Max. Div. (cfs)**
			Div. > 0 cfs	**Div. > 100 cfs**	**Div. > 0 cfs**	**Div. > 100 cfs**	
Bacon Island	Study 4	Total	66.2%	4.7%	165	2,247	4,500
		North	1.8%	1.7%	1,511	1,525	2,250
		South	66.2%	4.7%	125	1,677	2,250
	Study 4b	Total	80.7%	53.6%	324	475	4,500
		North	1.7%	1.7%	1,316	1,328	2,250
		South	80.7%	53.6%	297	433	2,250
Webb Tract	Study 4	Total	77.7%	3.3%	107	2,365	4,500
		North	1.3%	1.3%	1,704	1,725	2,250
		South	77.7%	3.3%	77	1,676	2,250
	Study 4b	Total	89.4%	55.9%	259	408	4,500
		North	1.8	1.6%	1,348	1,457	2,250
		South	89.4%	55.9%	232	365	2,250

Table 2.4.3: Summary of DSM2 Project Island Releases.

Island	Study	Facility	% Time of Releases	Ave. Release (Releases > 0 cfs) (cfs)	Max. Release (cfs)
Bacon Island	Study 4	Total	7.2%	1,467	3,000
		North	7.2%	1,288	2,250
		South	2.3%	571	750
	Study 4b	Total	55.6%	460	3,000
		North	55.6%	444	2,250
		South	1.9%	540	750
Webb Tract	Study 4	Total	3.5%	2,117	3,000
		North	3.5%	1,716	2,250
		South	2.1%	676	750
	Study 4b	Total	55.6%	406	3,000
		North	55.6%	386	2,250
		South	1.7%	603	750

The maximum diversion or release at any of the facilities was limited to 2,250 cfs. The maximum diversion for the islands was 4,500 cfs, while the maximum release was limited to 3,000 cfs. The difference in the percent of time that water is diverted in each island's southern facility versus the amount of time that water is diverted in the northern facility is due to the diversion of small amounts of water in order to account for evaporation losses. The average diversions, including these "topping-off" operations and without these operations (i.e. diversions greater than 100 cfs), are shown in Table 2.4.2. The average diversions excluding the topping-off operations are more representative of the flows that will have a significant impact on the water quality in the island reservoirs.

2.4.2.2 Operation Strategies: Circulation

One of the primary differences between study 4 and study 4b is the use of a circulation operation in study 4b in order to improve the water quality in the project islands.[3] Circulation operations take advantage of the fact that both islands have two integrated facilities, by diverting water through on facility while simultaneously releasing water through the other facility. The net difference in flow rates will determine if water is being stored or released from the project islands. For this particular circulation simulation, CALSIM limited the circulation to 500 cfs. Like the standard release operations, releases made under a circulation operation still are subject to all Delta water quality standards. Figure 2.4.4 shows examples of the relative flow rates for the north and south facilities for diversion only, release only, and circulation operations.

[3] The other primary difference is the addition of DOC constraints to study 4b. These constraints were developed using fingerprinting information from study 4 even though it did not include a circulation operation.

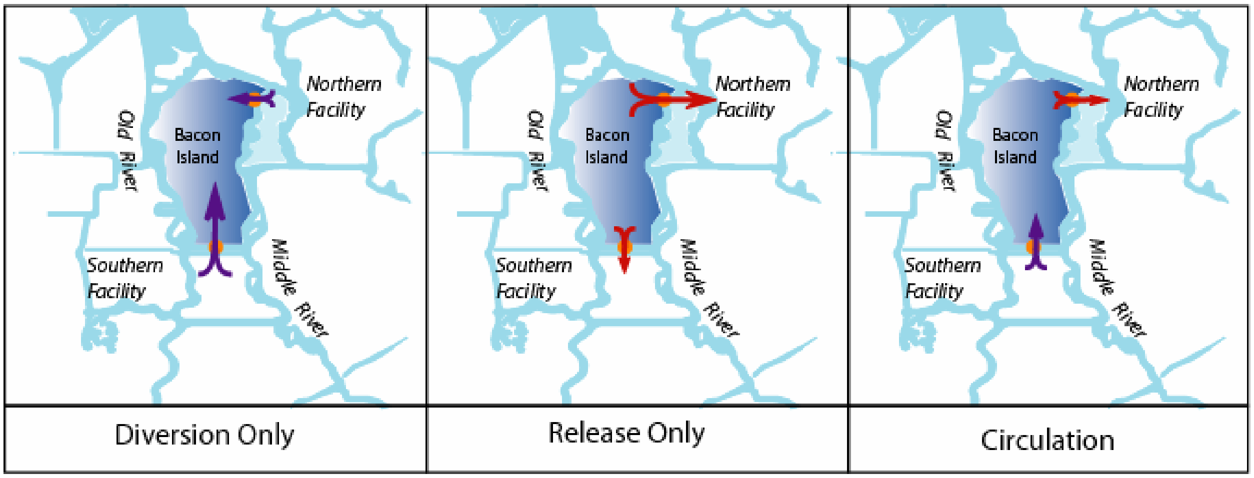

Figure 2.4.4: Examples of Typical Diversion Only, Release Only, and Circulation Operations.

2.4.2.3 Evaporation Losses

In addition to diversions and releases associated with operating the project islands, evaporation losses and surplus agricultural diversions were provided by CALSIM II. Under the current IDS proposal, both islands will retain their agricultural diversion water rights, and this water was used to make up for the evaporation losses. Since the reservoirs were simulated as sinks and sources of additional water for the fingerprinting work (study 4), evaporation losses were only included in study 4b (see Table 2.4.4). These evaporation losses were applied directly to each project island.

Table 2.4.4: Summary of CALSIM II Evaporation Losses for Study 4b.

Island	Min CALSIM II Evaporation (cfs)	Ave CALSIM II Evaporation (cfs)	Max CALSIM II Evaporation (cfs)
Bacon Island	0.8	10.5	42.8
Webb Tract	1.1	10.0	42.2

Though the evaporation losses vary from day to day, they do follow typical seasonal cycles. The minimum evaporation losses occurred in December, while the maximum evaporation losses occurred in June. This evaporation losses and the shifting of the historical diversion of additional water to make up for these losses resulted in minor fluctuations in island storage.

2.4.2.4 Seepage

Because the elevation of most Delta islands is lower than the low tide water surface in the channels that surround the islands, seepage usually occurs from the channels onto the islands. This typical seepage pattern (see Figure 2.4.5) is accounted for by the DICU Model and simulated in DSM2 for all Delta islands, including the project islands. However, when water is stored on the IDS project islands, the gradient of ground water flow between the neighboring channels and islands will at times be reversed (see Figure

2.4.5). Water from the island reservoirs would move to the channels, carrying with it organic carbon from the island peat soils.[4]

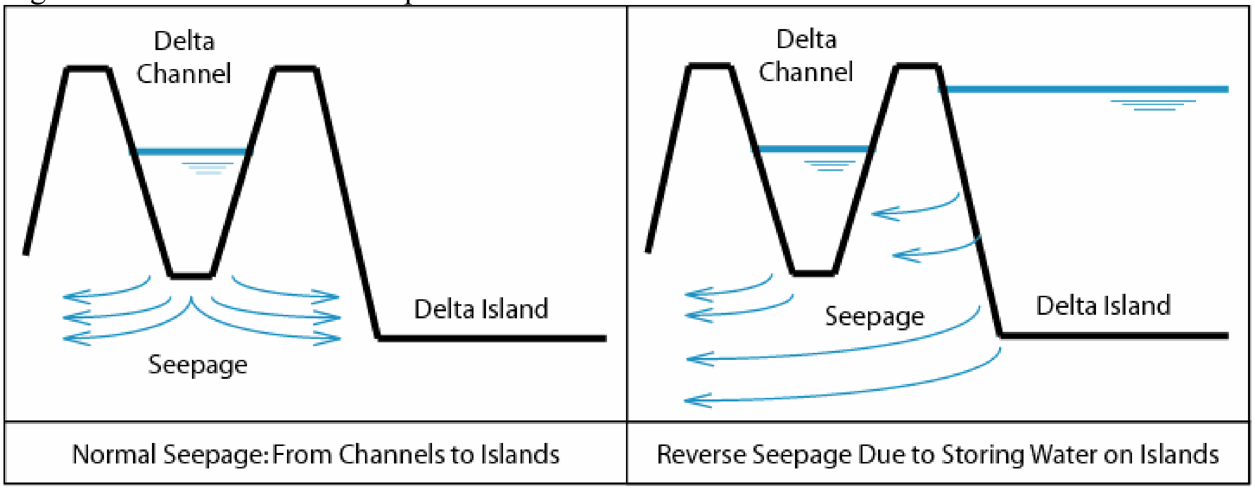

Figure 2.4.5: Comparison of Normal Seepage and Reverse Seepage Due to IDS.

To prevent this reverse seepage, the IDS project will use interceptor wells to collect water moving from the islands to the channels. After collecting the water, the wells will return the seepage flows back to the island.

Although there is no net change in storage due to seepage when using wells to return water lost due to seepage, the collected water will have a high concentration of organic carbon. In order to account for the addition of this organic carbon to the island reservoirs, seepage losses and returns were provided by DWR's Integrated Storage Investigations group for both Bacon Island and Webb Tract. The seepage flow rates used in DSM2 are summarized in Table 2.4.5. Since DSM2 treats reservoirs as buckets (i.e. the surface area is fixed and the volume is a function of stage), the seepage losses were not divided between the different wells, but instead were taken directly from the island reservoir. The return flows from the interceptor wells were added back to the reservoirs. There is no interaction of the seepage water with the neighboring channels.

Table 2.4.5: Summary of Project Island Seepage for Study 4b.

Island	Seepage Flow Rate (cfs)	% of Time w/ Seepage in 16-yrs (%)	Ave. CALSIM II Stage w/ Seepage (ft)	Max. CALSIM II Stage w/ Seepage (ft)
Bacon Island	9.8	24.9%	3.2	4.0
Webb Tract	8.3	22.1%	3.5	4.0

In the field, seepage losses will occur only at times when the stage in the island reservoirs is higher than the stage of the surrounding channels; however, it was necessary to assume a fixed water level for each island to trigger when seepage would occur. Seepage flows resulted only when the stage results from CALSIM II were greater than or equal to -1.0

[4] Since the Delta Island Consumptive use for the project islands was not changed for the alternative simulations, the normal channel to island seepage (in this case a loss to the system) was not changed. Seepage from the islands to channels is being intercepted, thus some fraction of the water that would have traveled from the Delta channels to the project islands.

ft. In situations where the project islands were partially full, this reverse seepage would not occur.[5] The percentage of time during the 16-year DSM2 planning study that there was any seepage on the islands is shown in Table 2.4.5. That average and maximum CALSIM II stage results for both islands are shown in Table 2.4.5. CALSIM II's bottom elevation for Bacon Island and Webb Tract was -16 and -18 ft, respectively.

2.4.2.5 Stage / Storage

Storage is an important variable that determines the concentration of new organic carbon mass added to the reservoirs and when seepage will occur. In study 4, diversions to the islands were treated as sinks, and releases from the islands were considered sources. As with the treatment of evaporation and seepage, project island stage and storage were only simulated in study 4b.

It was already pointed out in *DSM2 Physical Representation of the Project Islands* that although DSM2 models stage in the project islands as a linear function related to a fixed reservoir surface area and the change in storage, that the storage represented in DSM2 is the exact same as the storage represented in CALSIM II. As part of the preprocessing for DSM2, CALSIM II stage results were used to calculate when seepage from the project islands would occur.

The 16-year minimum, average, and maximum daily average storage (TAF) in each project island is shown in Table 2.4.6. The storage associated with the 10th, 25th, 50th, 75th, and 90th percentiles for each location is also shown. These percentiles were computed by ranking the 5,844 daily average storage volumes for each island in ascending order, and then associating a storage with a specified percentile. The 10th percentile represents the 584th lowest concentration, the 50th percentile represents the median concentration, and the 90th percentile represents the 5260th lowest concentration (or the 584th highest concentration).

Table 2.4.6: Summary of Project Island Storage (TAF) for Study 4b.

Island	Min	Ave	Max	Percentiles				
				10th	25th	50th	75th	90th
Bacon Island	1	45	115	1	1	32	88	115
Webb Tract	1	34	101	1	1	1	72	101

The 50th percentile storages correspond with the median (middle) value. Both Bacon Island and Webb Tract were effectively empty over 25% of the time (i.e. there was no significant storage on either island in the 25th percentile). The average storage for both islands is greater than the median (50th) storage. This suggests that when the reservoir is

[5] The alternative to using a fixed CALSIM II stage trigger would have been to run iterative DSM2-HYDRO simulations. Since the volume of storage is not affected by seepage, no seepage flows would have been included I the first HYDRO simulation. The stage results from the first HYDRO simulation would be used to develop seepage estimates based on the elevation differential between an island and its surrounding channels for a second HYDRO simulation. Using this technique, the seepage flowrates could vary with time based not only on the island stage, but upon the actual gradient of water flow. Time constraints prevented this technique from being used.

full, it tends to remain full. This conclusion is supported by the time series of daily average storage for both reservoirs (Figure 2.4.6).

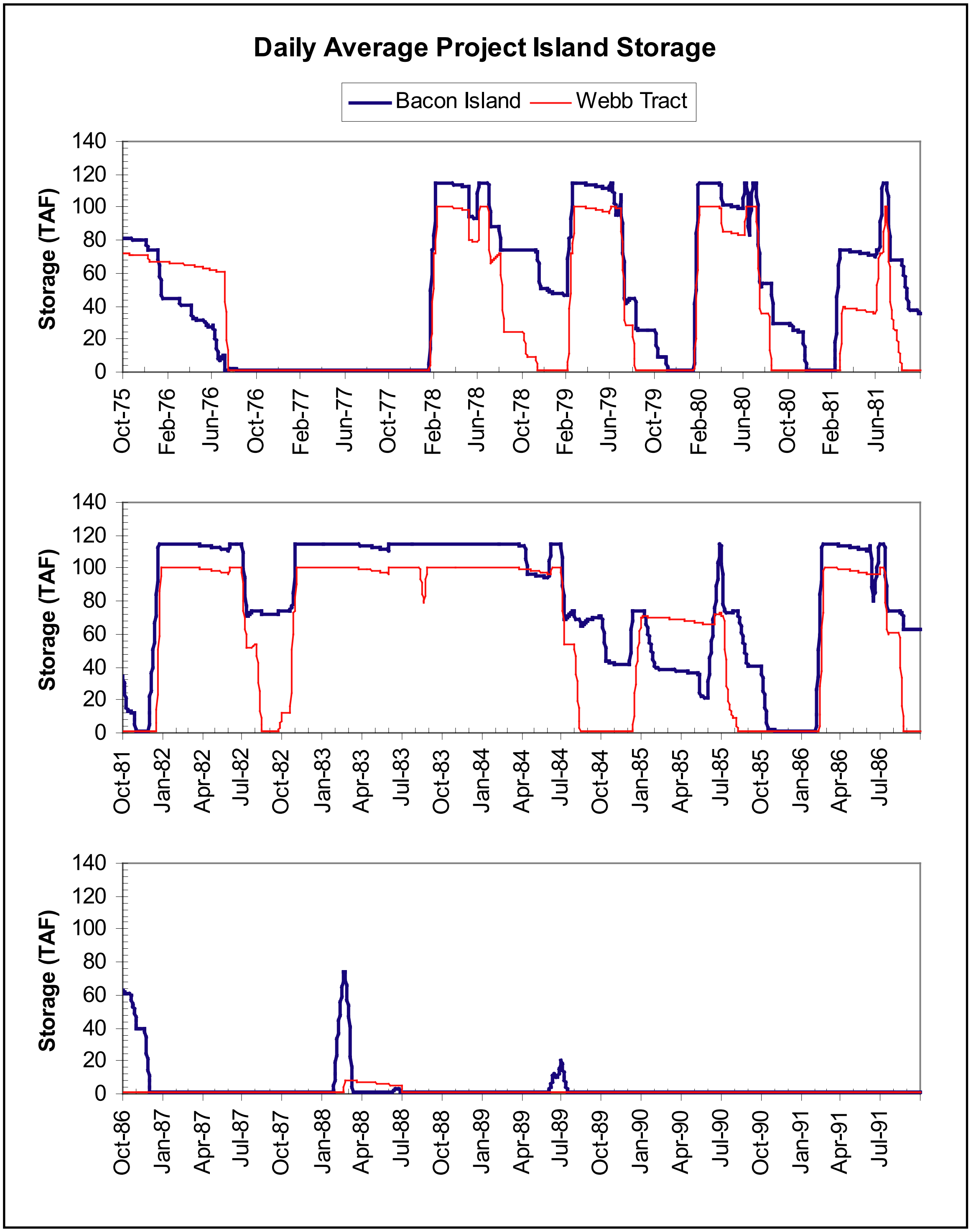

Figure 2.4.6: Daily Average Project Island Storage for Study 4b.

2.4.3 Project Island EC

EC is simulated as a conservative constituent in DSM2. Changes to the EC concentration on the project islands due to a filling operation are a function of both the volume of water already on the island, V_2, and the volume of water diverted to the island, V_4, and the concentrations associated with these volumes, C_2 and C_3, respectively (see Figure 2.4.7). A simple mixing equation is used to blend the concentrations of incoming water with the concentrations of existing water. Since DSM2 is a 1-dimensional model, water inside the reservoirs is assumed to be uniformly mixed.

When there is no diversion into the island, the EC concentration on the island will not change. Although the small evaporation "topping-off" diversions (see *Section 2.4.2.1*) will change the project island EC, the volume of water diverted onto the island is small enough that these changes are minor.

Releasing water from the islands will have no impact on the EC concentration, C_5, inside the reservoirs. However, the concentration in the adjacent channels, C_7, will change. While the volume of water released, V_6, may have a significant impact on the EC concentration in the neighboring channels, the net water added to the Delta itself is small. The impact on local stage should be minor (i.e. storage in the channel should be about the same). The change in local channel EC will be a function based on the amount of water released and the amount of channel water that is not displaced by the project island releases and the respective concentrations associated with both volumes of water (see Figure 2.4.7).

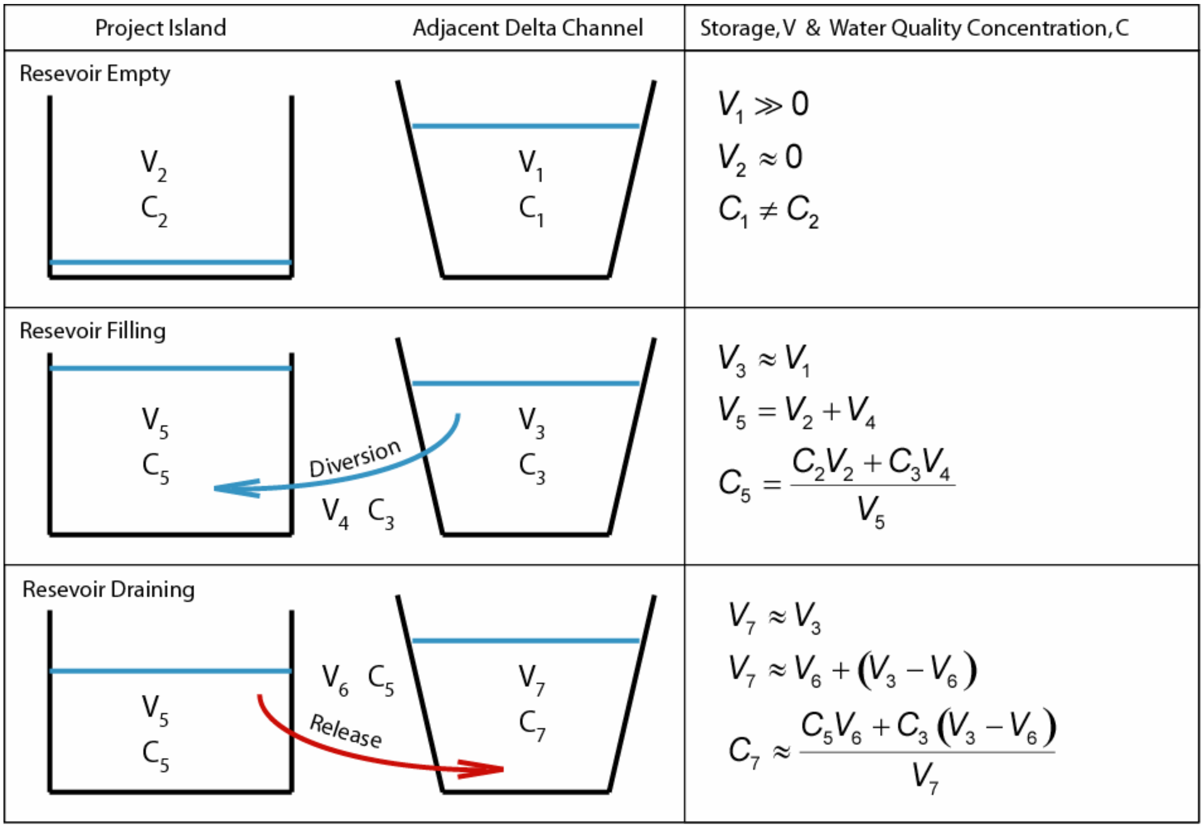

Figure 2.4.7: Mixing Project Island EC with Adjacent Delta Channels.

The EC associated with seepage was determined by running study 4b in an iterative process. In the first QUAL simulation, the EC associated with seepage return flows was set to 0 umhos/cm. The instead of setting EC to 0 umhos/cm, the EC for each island from the first iteration was assigned as the concentration of the seepage return flows. Since the EC concentration assigned to the seepage flows returned to the islands was the same concentration as the water removed by seepage, seepage had no impact on island EC. This iterative process was necessary in order to use the exact same hydrodynamic results that were used when modeling DOC.

The 16-year daily average minimum, average, and maximum EC associated with both project islands is shown in Table 2.4.7. Though the minimum values are similar to the 10% (10^{th} percentile) EC concentrations, indicating that the minimum is a good indicator of what low EC concentrations on the islands would be like, the maximum values are considerably higher than the 90% EC concentration. In other words, there is a greater variation in the higher EC concentrations.

Table 2.4.7: Summary of Project Island EC (umhos/cm) for Study 4b.

Island	Min	Ave	Max	Percentiles				
				10%	25%	50%	75%	90%
Bacon Island	221	402	813	259	316	383	468	560
Webb Tract	186	433	1,101	204	229	349	608	781

The 16-year time series of project island EC is shown in Figure 2.4.8. It is important to note that EC changes only when water (of any amount) is diverted unto the islands.

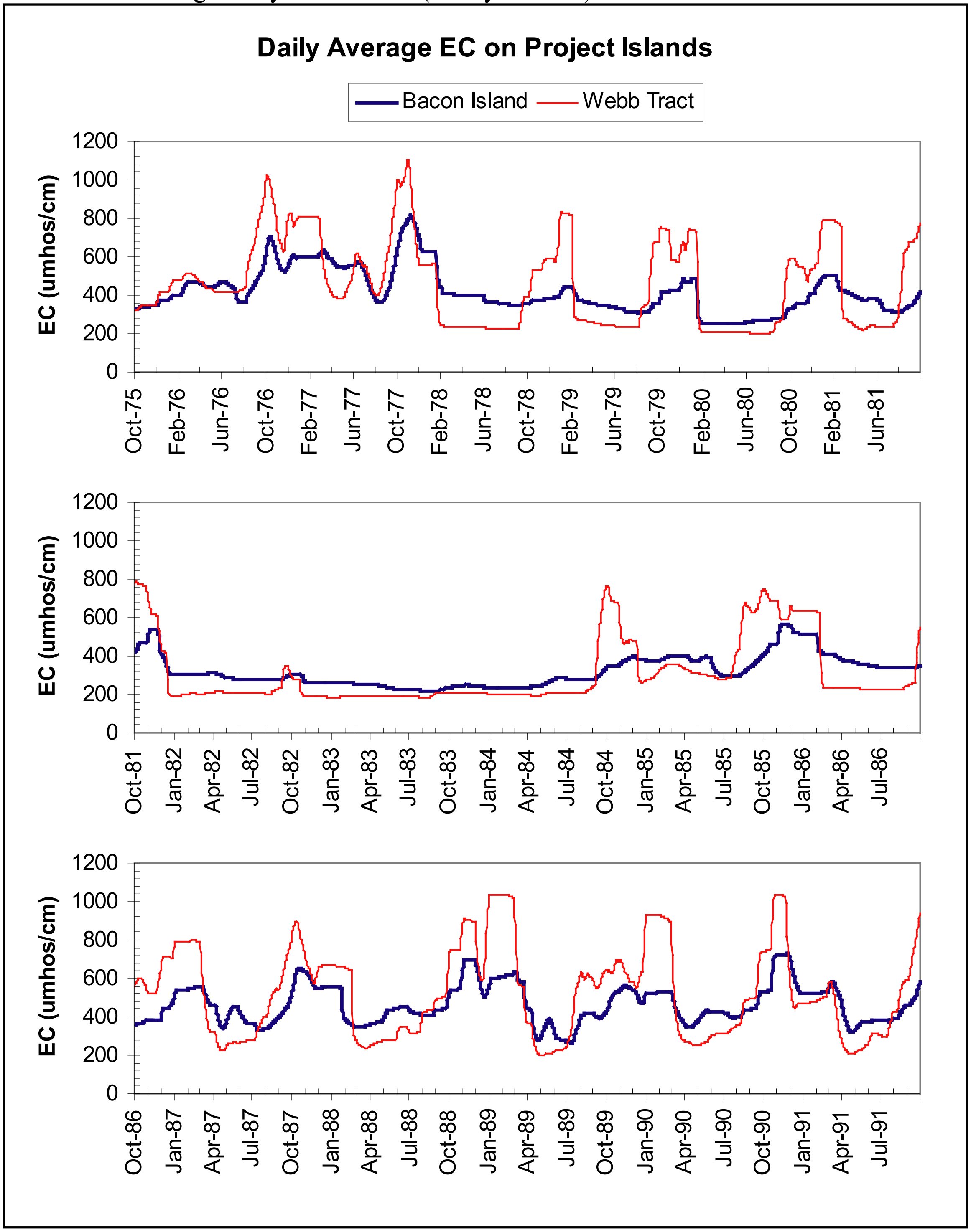

Figure 2.4.8: Daily Average EC (umhos/cm) on Project Islands for Study 4b.

2.4.4 Project Island DOC

Located in the Central Delta, the peat soils from both Bacon Island and Webb Tract are a significant source of the high DOC concentrations of the agricultural returns common to all of the DSM2 water quality simulations. Agricultural return DOC concentrations from both islands can exceed 30 mg/L (Jung, 2000). The principal source of this organic carbon is the peat soils that line the bottoms of both islands.

Storing water on these islands will not only increase the amount of water that comes into contact with the organic carbon rich soils, but as the stored water mixes with the soils, additional organic carbon may enter the stored water through leaching and microbial decay of the saturated peat soils (see Figure 2.4.2). Jung (2001) reported on impact on organic carbon related to flooded Delta islands and conducted new experiments using peat soils from both Bacon Island and Webb Tract. Jung's work suggested that understanding and modeling the processes involved in flooding a peat rich island were important.

The concentration inside either island is both a function of the mixing associated with diversions to the islands (similar to how EC is mixed), the production of organic carbon mass from algae and wetlands plants, and the addition of organic carbon mass due to leaching and microbial decay of the peat soils. The increase in DOC concentration associated with storing water on the peat soil islands is accounted for in QUAL by a DOC growth algorithm (Mierzwa *et al.*, 2003). These relationships are based on field studies conducted by DuVall (2003) that took into account both the increases in organic carbon mass due to decay and leaching as well as the increases due to production of new organic carbon from algae and wetland plants. The organic carbon growth rates, shown in Table 2.4.8, vary over the course of the year.

Table 2.4.8: Project Island Organic Carbon Growth Rates (gC/m2/day)

Island	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Bacon Island	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59
Webb Tract	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59

In study 4b, seepage flows passed through the organic carbon rich peat soils and were returned to the project islands using interceptor wells. The DOC concentrations of these seepage returns represent the amount of organic carbon that would be entrained in the seepage flows and moved back onto the islands. No direct field tests have been conducted to separate out which organic carbon sources contribute to seepage return quality. Instead of using the same iterative approach that was used when modeling EC seepage return quality, it was assumed that the DOC concentration associated with the seepage return flows was 20 mg/L. It is important to note that seepage only occurs when the stage in an island is greater than -1 ft. At times the DOC concentration of water on a project island is greater than 20 mg/L, and at other times the DOC concentration is less than 20 mg/L. The significance of this assumption can be ascertained by examining the organic carbon concentration on the project islands and the amount of water passing through the interceptor well system.

A summary of the DOC on both project islands for study 4b is shown in Table 2.4.9. The 16-year time series of project island DOC is shown in Figure 2.4.9.

Table 2.4.9: Summary of Project Island DOC (mg/L) for Study 4b

Island	Min	Ave	Max	Percentiles				
				10th	25th	50th	75th	90th
Bacon Island	3	27	337	5	9	13	32	57
Webb Tract	2	28	273	4	7	11	37	70

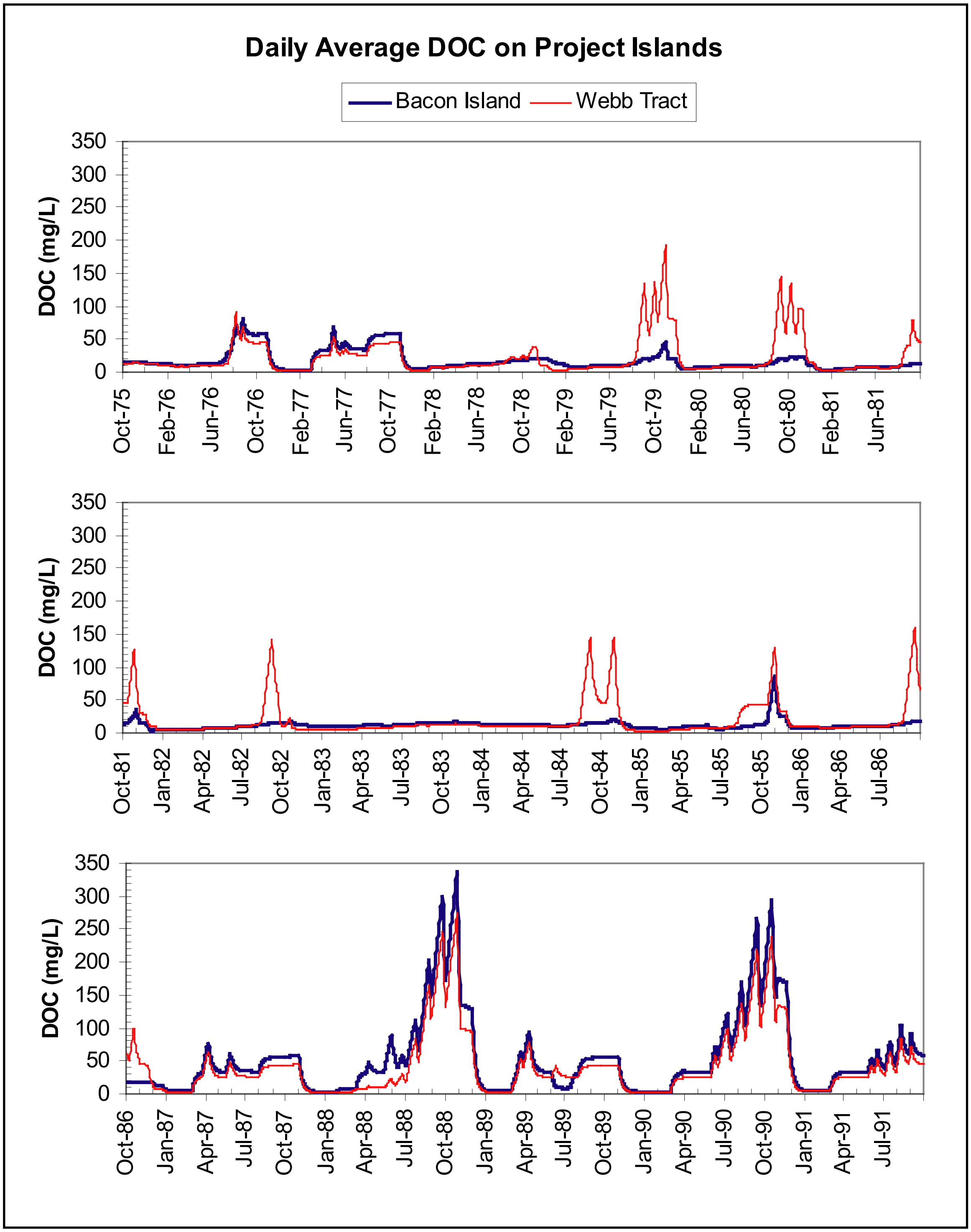

Figure 2.4.9: Daily Average DOC (mg/L) on Project Islands for Study 4b.

2.5 Results

Using the DSM2-QUAL fingerprinting, EC, and DOC results, the change in water quality at four Delta urban intakes: CCWD intake at Rock Slough, CCWD Los Vaqueros Reservoir intake on the Old River, SWP Banks Pumping Plant, and CVP Tracy Pumping Plant, was evaluated. The fingerprinting results were used to develop DOC constraints in CALSIM II. They also provide insight into the internal flow patterns in the Delta. Chloride concentrations at the urban intakes were calculated based on observed EC-chloride regressions. DOC at the intakes was reported as simulated, but then DOC and EC were used to calculate total trihalomethane (TTHM) and bromate formation.

2.5.1 Fingerprinting

Prior CALSIM / DSM2 IDS studies made use of DSM2's ability to track particles through DSM2-PTM to develop flow based DOC constraints in CALSIM II (Mierzwa, 2003). Based on conclusions made during the testing of the previous island-particle fate relationships, a new methodology for estimating the amount of organic carbon reaching the urban intakes in CALSIM was developed.

As described by Anderson (2002), fingerprinting can be used in DSM2 to estimate the original sources of water at a given location. A fingerprinting simulation was set up using study 4 where the diversions to the project islands were treated as a sink of water much like an export, and the releases from the project islands were treated as new sources of water much like a river inflow to the Delta.

Each of the inflows into the Delta, including the Martinez stage boundary and releases from each project island, was assigned a unique conservative tracer constituent and then simulated in QUAL independently of the other boundaries. The amount of water from the Sacramento River, San Joaquin River, Bacon Island and Webb Tract combined, and all other sources at the four urban intakes is shown in Figures 2.5.1 –2.5.4. As expected, the relative contribution of the San Joaquin River water is both a function of time of year and proximity to Vernalis. The fingerprinting plots also illustrate the length of time that water released from the projects remains in the vicinity of the urban intakes. For example, though the Feb. 1988 Bacon Island release ended on Feb. 20th, 1988, a measurable fraction of the water moving through the CVP Tracy Pumping Plant (Figure 2.5.4) came from the project islands.

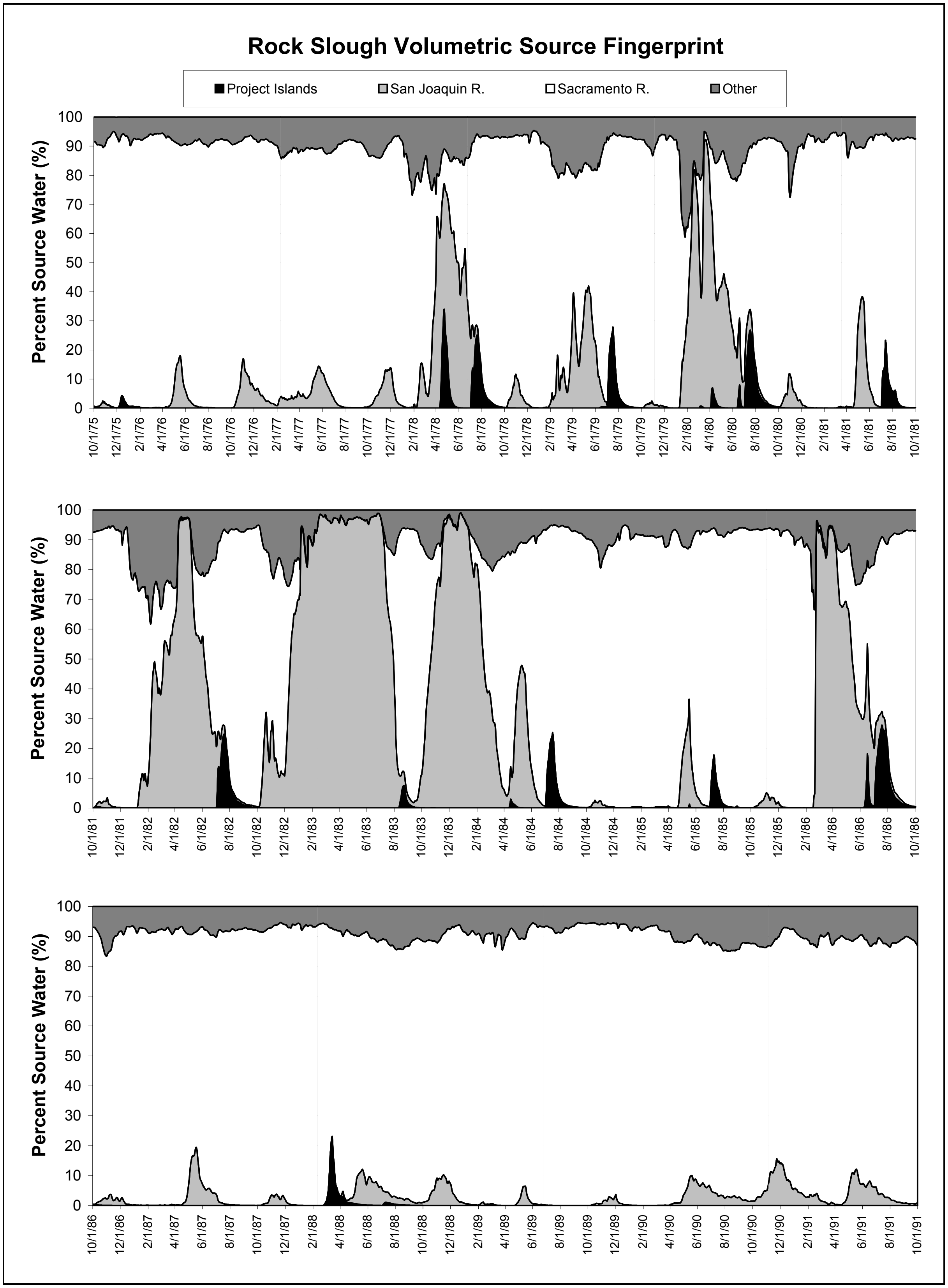

Figure 2.5.1: Old River at Rock Slough Volumetric Source Fingerprint.

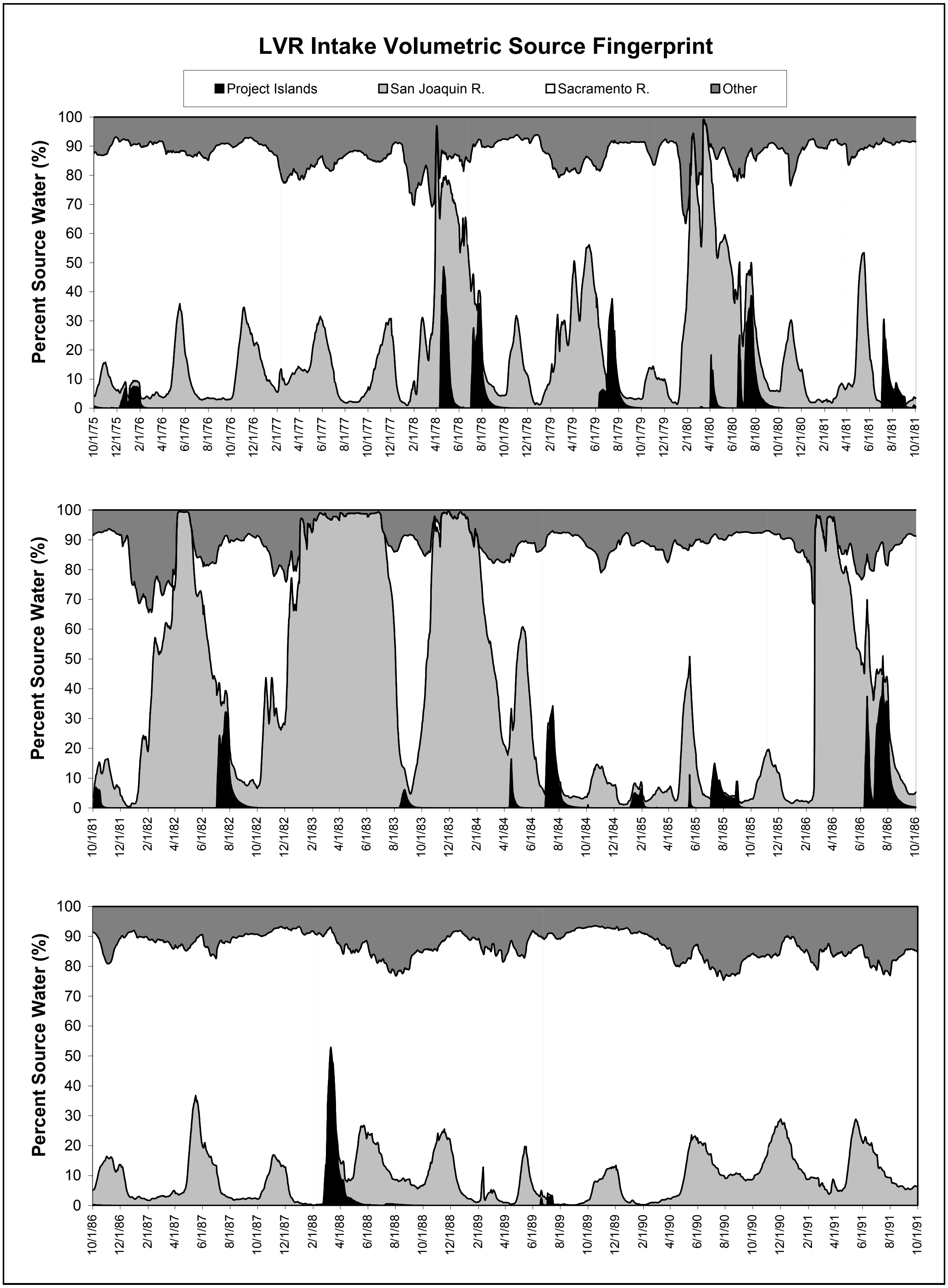

Figure 2.5.2: Old River at LVR Intake Volumetric Source Fingerprint.

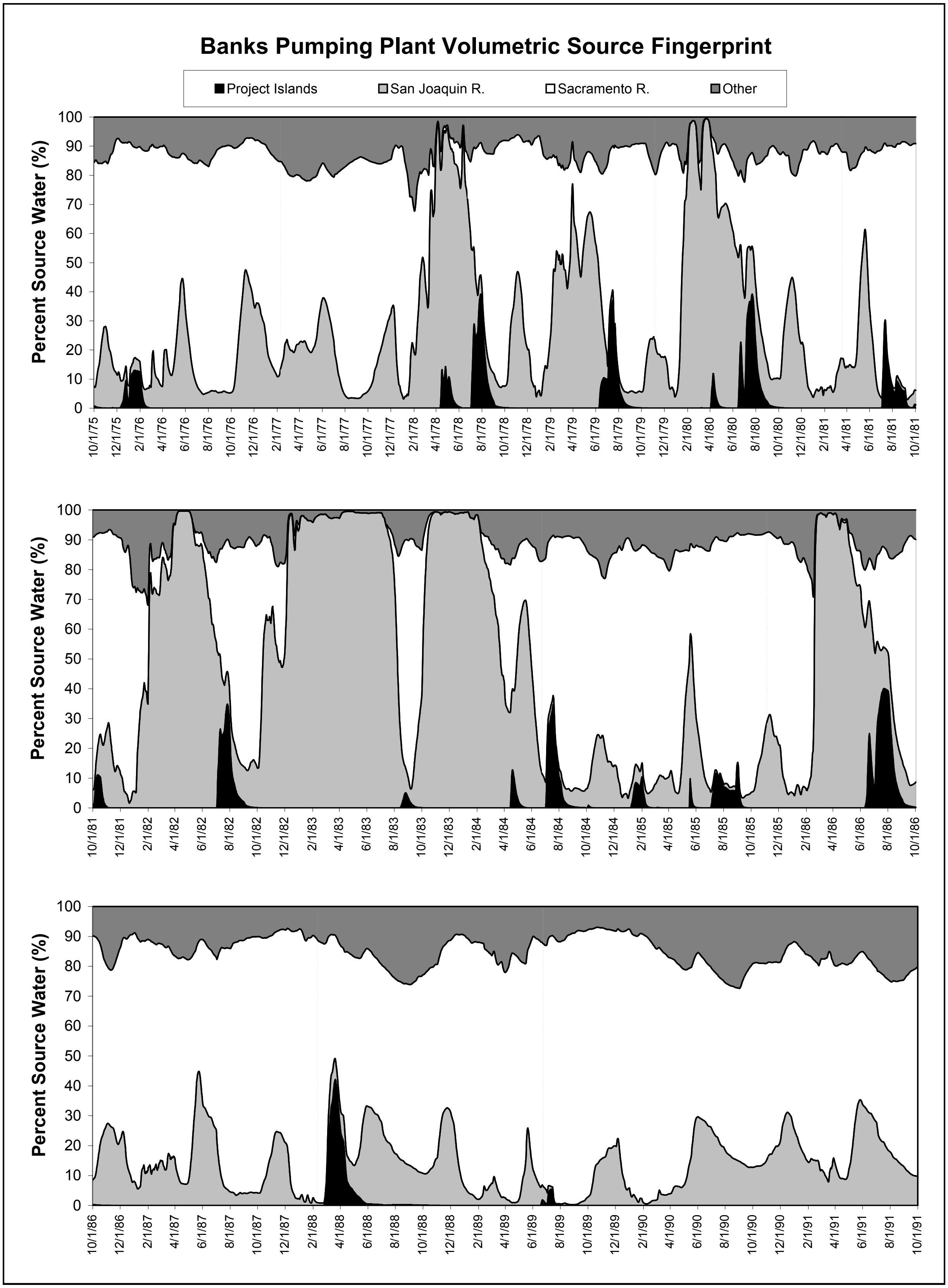

Figure 2.5.3: Banks Pumping Plant Volumetric Source Fingerprint.

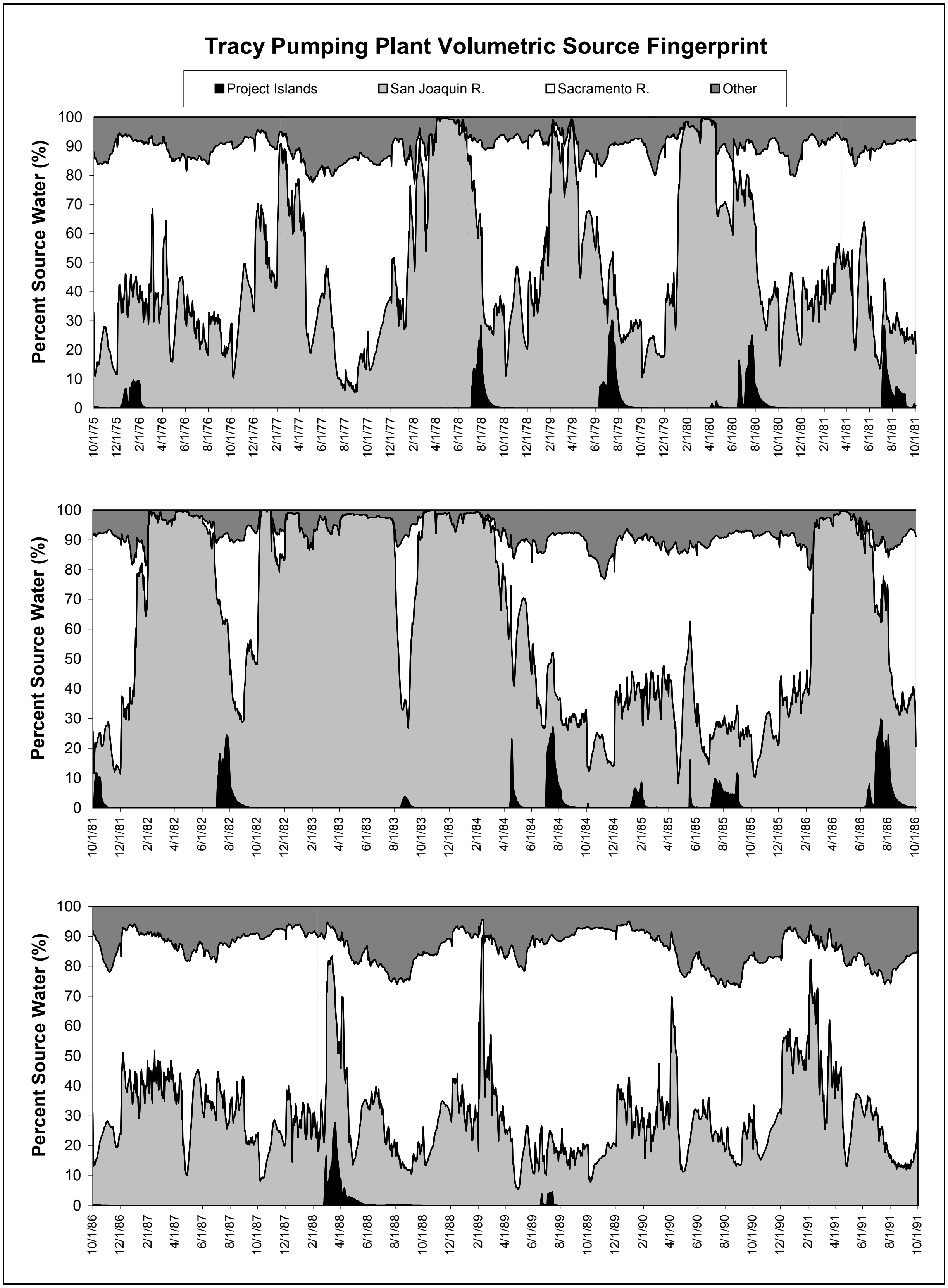

Figure 2.5.4: Tracy Pumping Plant Volumetric Source Fingerprint.

The percentage of total water at each urban intake coming from each island is shown in Figures 2.5.5 – 2.5.8. These percentages were then related to various flow parameters such as: E/I ratio, island releases, Sacramento River inflow, San Joaquin River inflow, total inflows, combined SWP and CVP exports, and combined CCWD diversions. Relationships, based on multiple linear regressions, were developed for each export location for use in CALSIM (see Table 2.5.1). However, since CALSIM does not separate the CCWD diversions, export location project island volume – flow relationships were not developed for CCWD's Los Vaqueros Reservoir intake (though the fingerprinting results are still shown as they may be useful in addressing other water quality concerns).

The length of time that project release water remains in the Delta is important when developing DOC constraints in CALSIM. Water released at the beginning of a release period would be contributing new organic carbon loads to the urban intakes, whereas water released towards the end of a release period or at the beginning of a release period shortly after a previous release period needs to take into account the organic carbon already present in the Delta. With this in mind, running averages of the releases were used when developing the project island equations.

The relative orders of magnitude of the variables shown in Table 2.5.1 are listed in Table 2.5.2. Although the hydrodynamics in study 4 did not include a circulation operation similar to the operation CALSIM II optimized in study 4b, modeling and work time constraints prohibited using DSM2 to generate an updated set of equations based on the proposed circulation operation. A formal scale analysis to reduce or simplify the equations 5.1 – 5.9 was not conducted, but each equation was quickly checked using numbers taken from the range listed in Table 2.5.2 and found to yield reasonable results. Next, the equations were added to CALSIM II as shown above.

Table 2.5.1: Percent Volume of Water Project Island at Urban Intakes.

Urban Intake	Island	Relationship	R^2	Eqn. #
RS	Bacon	**Apr. – Nov., Q_{SJR} > 8,500 cfs** $V = -1.93\times10^{-3} Q_{Sac} - 1.3\times10^{-3} Q_{SJR} + 1.2\times10^{-3} Q_{inflow} + 1.27\times10^{3} Q_{SWP+CVP} - 4.4\times10^{2} E/I - 6.43\times10^{3} Q_{CCWD} + 1.02\times10^{-2} Q_{Bacon,\,20-day\ ave} - 9.79\times10^{6}$	0.84	5.1
		Apr. – Nov., Q_{SJR} ≤ 8,500 cfs $V = 0.05$	N/A	5.2
		Dec. – Mar., E/I ≤ 0.37 $V = 1.89\times10^{-2} Q_{Sac} + 2.49\times10^{-2} Q_{SJR} - 2.0\times10^{-3} Q_{inflow} - 5.58\times10^{-2} Q_{SWP+CVP} + 7.80\times10^{2} E/I - 1.0860\times10^{2} Q_{CCWD} + 1.43\times10^{-2} Q_{Bacon,\,20-day\ ave} + 1.05\times10^{4}$	0.92	5.3
		Dec. – Mar., E/I > 0.37 $V = -1.16\times10^{-5} Q_{Sac} + 1.83\times10^{-5} Q_{SJR} + 4.71\times10^{-7} Q_{inflow} - 6.03\times10^{-6} Q_{SWP+CV} - 1.4\times10^{-1} E/I + 5.60\times10^{-4} Q_{CCWD} + 3.36\times10^{-4} Q_{Bacon,\,20-day\ ave} + 1.6\times10^{-1}$	0.88	5.4
	Webb	$V = 8.8\times10^{-3} Q_{Webb,\,20-day\ ave} + 8.5\times10^{-2}$	0.90	5.5
SWP	Bacon	$V = 2.56\times10^{-4} Q_{SWP+CVP} - 3.6\times10^{-4} Q_{SWP} + 1.9\times10^{-1} E/I + 5.2\times10^{-3} Q_{Webb,\,20-day\ ave} - 3.69\times10^{-1}$	0.80	5.6
	Webb	$V = -6.54\times10^{-1} E/I + 1.13\times10^{-2} Q_{Bacon,\,18-day\ ave} + 4.77\times10^{-1}$	0.70	5.7
CVP	Bacon	$V = 6.1\times10^{-3} Q_{Bacon,\,8-day\ ave} + 1.67\times10^{-1}$	0.69	5.8
	Webb	$V = -5.2x10^{-05} Q_{SWP+CVP} + 2.01\times10^{-4} Q_{CVP} + 3.07\times10^{-1} E/I + 3.6\times10^{-3} Q_{Webb,\,20-day\ ave} - 2.59\times10^{-1}$	0.79	5.9

Table 2.5.2: Sensitivity of Flow Parameters in Table 5.1.

Variable	*Flow Parameter*	*Range of Values*
E/I	Delta export / inflow ratio	0 – 1
Q_{CCWD}	Contra Costa WD diversions	0 – 600 cfs
$Q_{Bacon,\ 8-day}$	8-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Bacon,\ 20-day}$	20-day average of Bacon Island releases	0 – 2,500 cfs
$Q_{Webb,\ 20-day}$	20-day average of Webb Tract releases	0 – 2,500 cfs
Q_{CVP}	CVP exports	0 – 5,000 cfs
$Q_{SWP+CVP}$	Combined SWP & CVP exports	1,500 – 13,000 cfs
Q_{SJR}	San Joaquin River flow	1,000 – 50,000 cfs
Q_{Sac}	Sacramento River flow	5,000 – 80,000 cfs
Q_{inflow}	Total Delta inflows	6,000 – 200,000 cfs

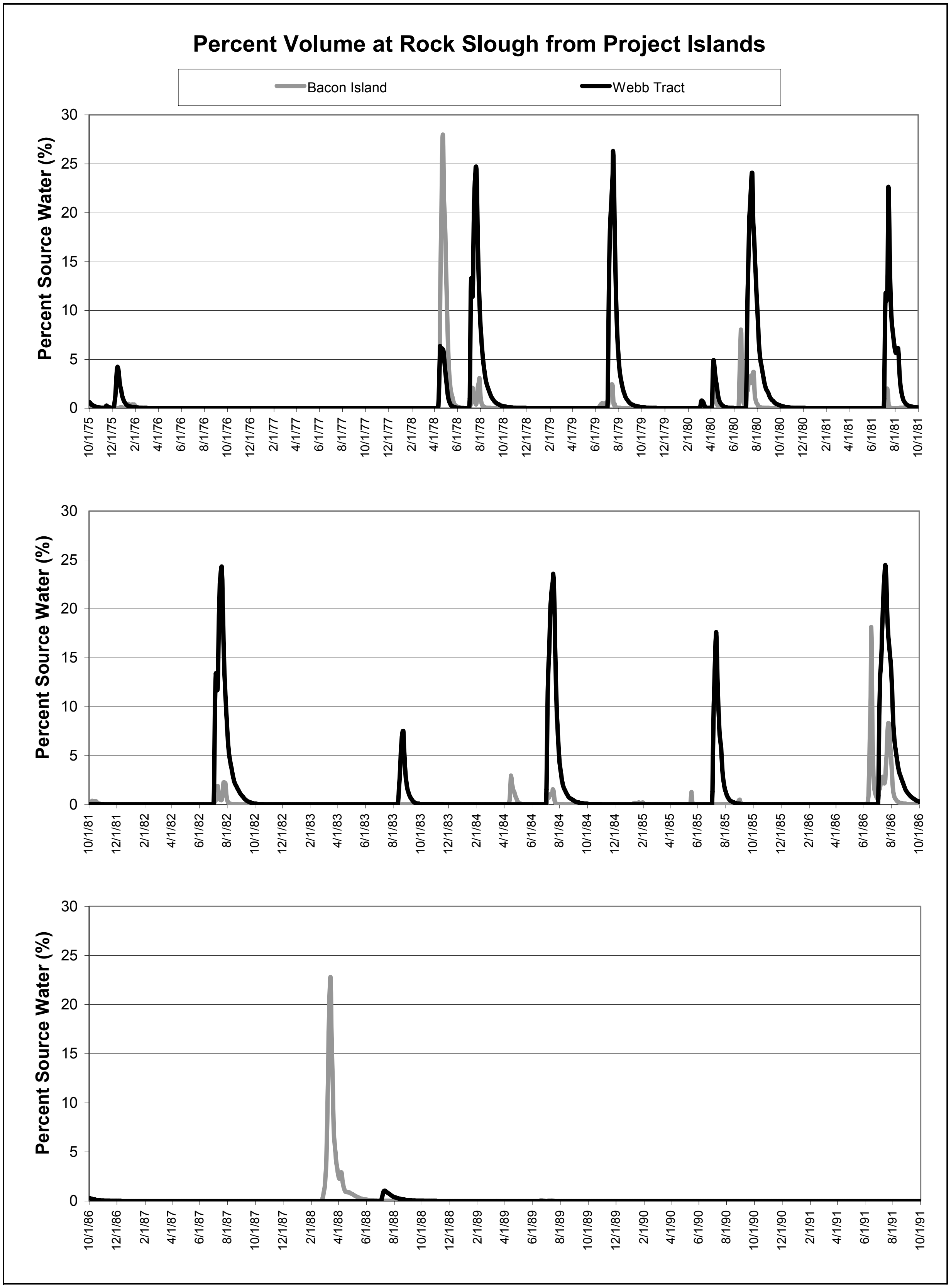

Figure 2.5.5: Percent Volume at Old River at Rock Slough from Project Islands.

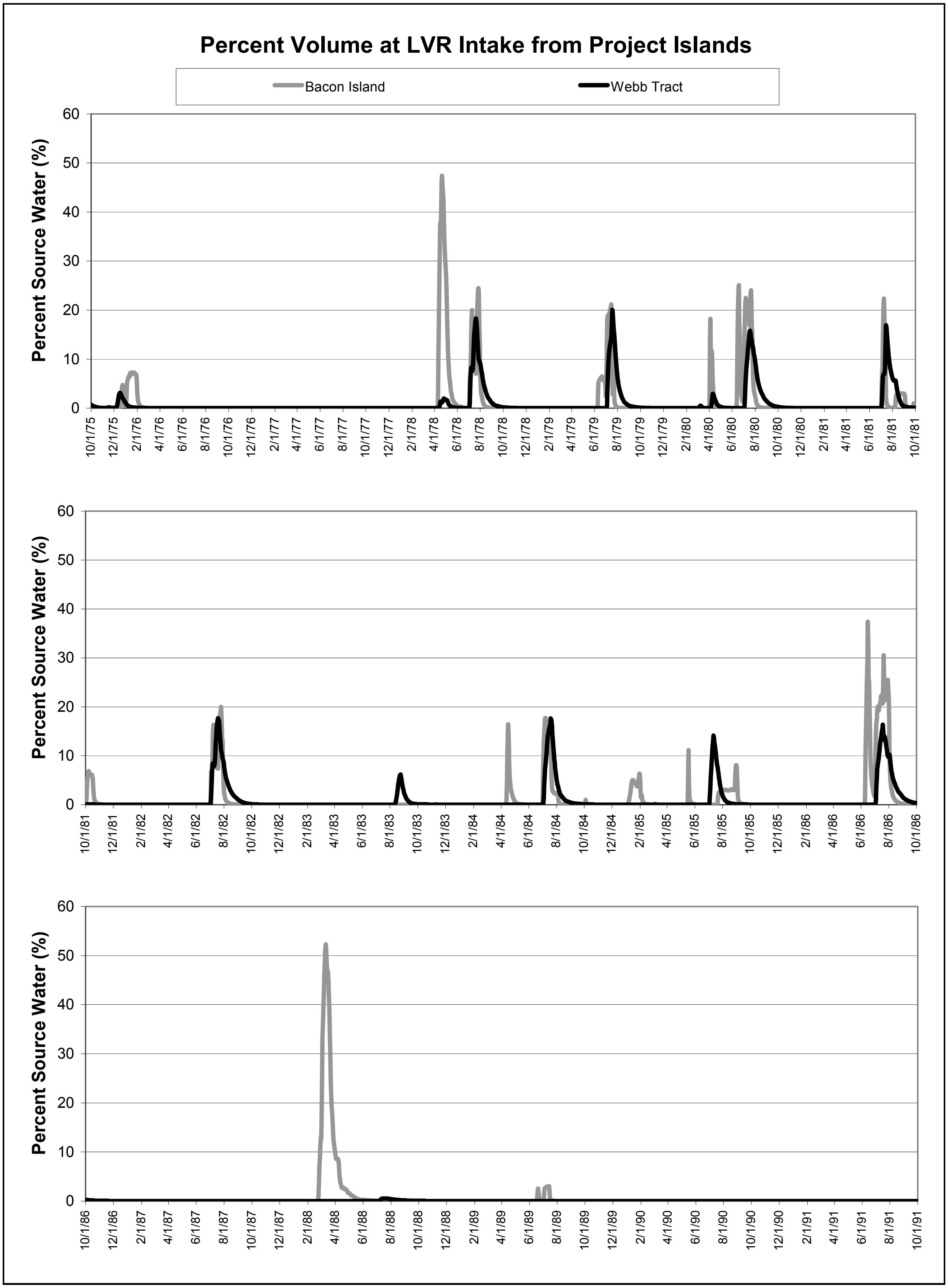

Figure 2.5.6: Percent Volume at Old River at LVR Intake from Project Islands.

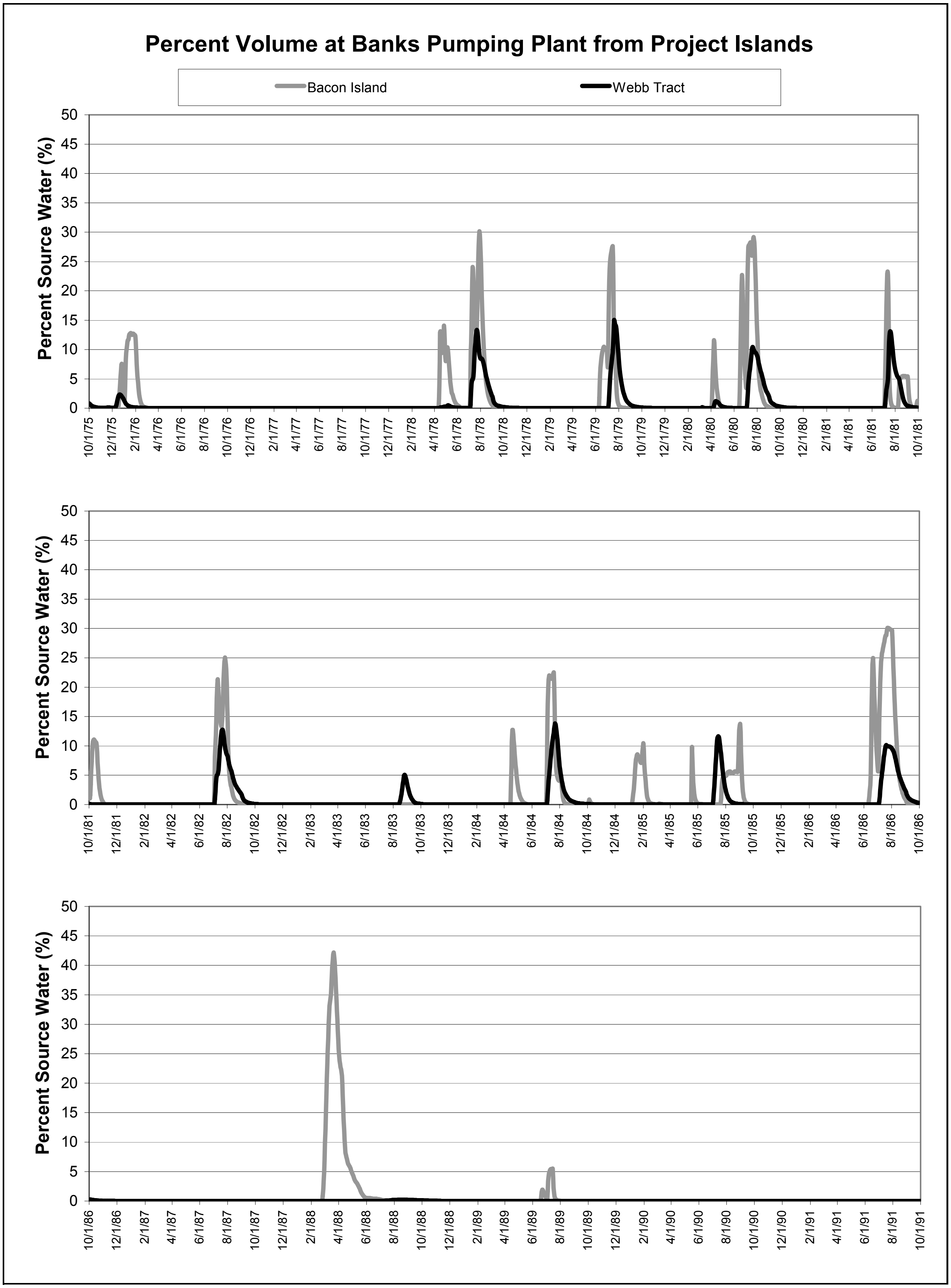

Figure 2.5.7: Percent Volume at Banks Pumping Plant from Project Islands.

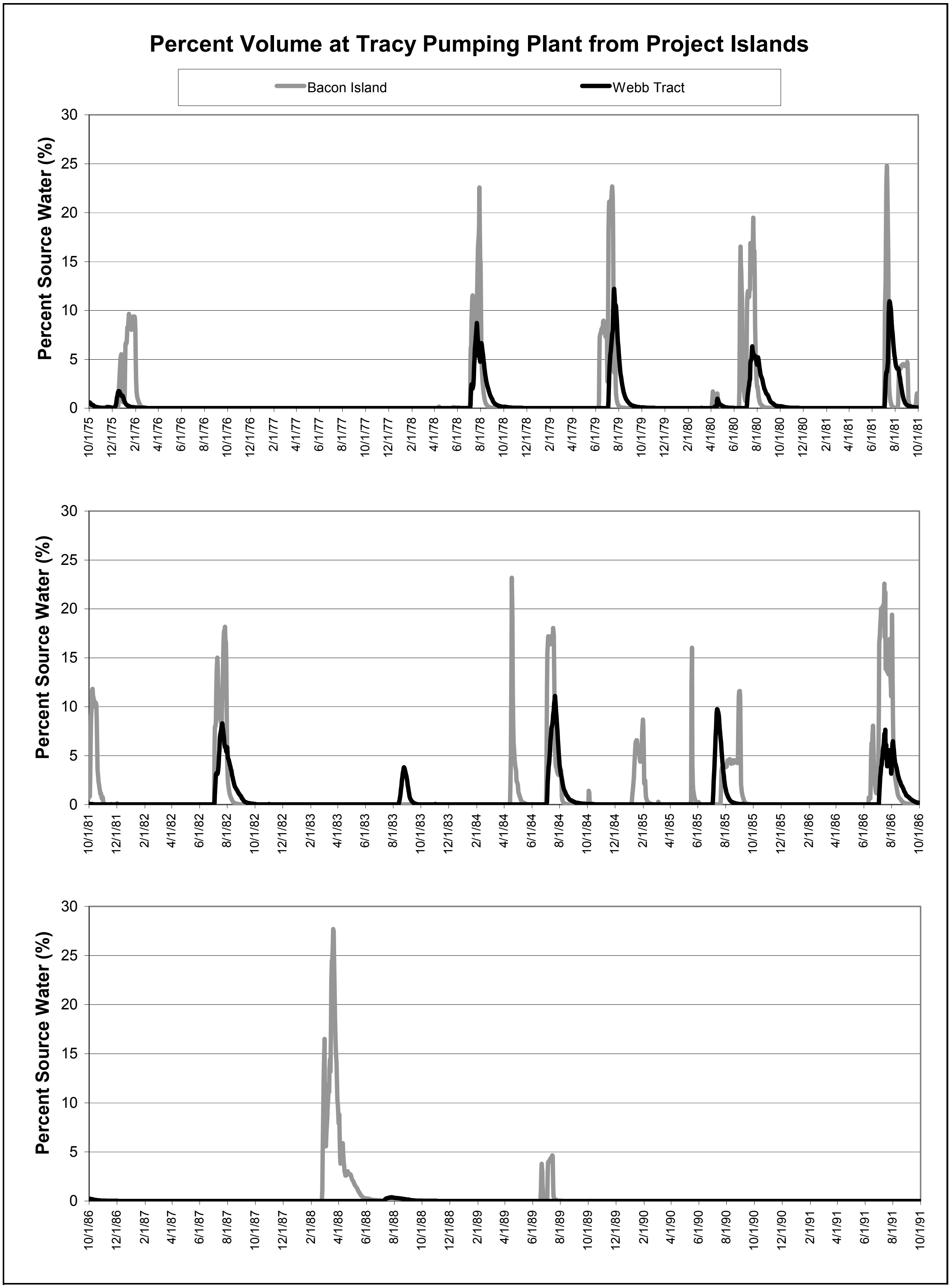

Figure 2.5.8: Percent Volume at Tracy Pumping Plant from Project Islands.

2.5.2 Chloride at Urban Intakes

The EC results from DSM2-QUAL were converted to chloride concentrations at the four major South Delta urban intake locations using the following relationships (Suits, 2001):

$$Chloride_{CCWD\,PP\,\#1} = \frac{EC_{RS} - 89.6}{3.73} \qquad \text{Eqn. 5.10}$$

$$Chloride = \frac{EC - 160.6}{3.66} \qquad \text{Eqn. 5.11}$$

Equation 5.10 was used to convert modeled EC to chloride concentration for Contra Costa Water District's Rock Slough diversion location (Contra Costa Pumping Plant #1). This equation is not only converting EC to chloride, but also transporting it through Rock Slough since it is based on a regression of EC data from the entrance to Rock Slough on the Old River and chloride data at the other end of Rock Slough at the entrance to the CCWD pumping plants. Though the Chloride results are still labeled as Old River at Rock Slough (RS), Equation 5.10 was used to better illustrate the chloride impact at the actual CCWD Rock Slough intake.

Equation 5.11 was used to convert modeled EC to chloride for the remaining three Delta urban water supply intakes: CCWD's Los Vaqueros Reservoir (LVR) intake on the Old River, the SWP's Banks Pumping Plant intake, and the CVP's Tracy Pumping Plant.

Both relationships developed were based on field observations. However, during a few periods QUAL's simulated EC concentrations were so low that using these field conversions resulted in negative chloride concentrations. Since this is not physically possible, these negative values were set to minimum non-negative chloride concentration for each location.

The 16-year minimum, average, and maximum daily averaged chloride at the four urban intakes is shown below in Table 2.5.3. The chloride concentration associated with the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles for each location is also shown. These percentile concentrations were computed by ranking the 5,844 daily average concentrations for each location in ascending order, and then associating a concentration with a specified percentile. The 10^{th} percentile represents the 584^{th} lowest concentration, the 50^{th} percentile represents the median concentration, and the 90^{th} percentile represents the 5260^{th} lowest concentration (or the 584^{th} highest concentration).

Table 2.5.3: Summary of Daily Averaged Chloride (mg/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10th	25th	50th	75th	90th
RS	Study 1	8	102	318	31	42	81	153	200
	Study 4b	8	103	309	32	43	82	157	201
LVR	Study 1	3	81	257	20	32	68	123	160
	Study 4b	3	82	248	21	33	68	125	160
SWP	Study 1	3	74	215	19	34	67	109	139
	Study 4b	3	74	208	19	34	67	111	148
CVP	Study 1	3	85	223	16	50	84	121	148
	Study 4b	3	86	222	16	50	84	121	148

Although both study 1 and study 4b violated the current (D1641) 250 mg/L chloride Delta water quality standard at Rock Slough and Los Vaqueros Reservoir intake, the 90th percentile results show that for 90% of the 16-year simulation that chloride was less than 201 and 160 mg/L at each location respectively. In other words, the maximum (and minimum) values represent extreme events. Furthermore, though the maximum chloride concentrations decreased in study 4b at all four locations, the percentile results for study 1 and study 4b at each of the four locations were similar. The exception to this trend would be the 75th percentile for Rock Slough, where chloride increased from 153 to 157 mg/L.

The Water Quality Management Plan (WQMP, 2000) limited the operation of the IDS project such that the 14-day running average of chloride would not exceed 90% of the current D-1641 250 mg/L chloride standard. A summary of the 14-day average chloride results is presented in Table 2.5.4. Taking a 14-day average of the daily chloride results did not make any significant changes in the chloride concentration summary statistics.

Table 2.5.4: Summary of 14-Day Average Chloride (mg/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10th	25th	50th	75th	90th
RS	Study 1	9	102	302	32	42	81	153	198
	Study 4b	9	103	291	33	43	82	157	197
LVR	Study 1	3	81	246	21	33	68	123	158
	Study 4b	3	82	237	21	34	68	125	157
SWP	Study 1	3	74	214	20	34	67	110	138
	Study 4b	3	74	207	20	35	67	112	138
CVP	Study 1	3	85	217	17	49	84	121	147
	Study 4b	3	86	217	16	50	84	122	147

As noted in Section 2.2.3, all of CCWD's diversions were assumed to be at Rock Slough. The sensitivity of this assumption on EC and chloride is unknown. However, the daily averaged and 14-day average chloride results shown in Tables 2.5.3 and 2.5.4 show that the chloride at Rock Slough was significantly higher than the chloride at the other three urban intakes.

Time series plots of the 14-day running average chloride concentrations for all four urban intakes are presented in Figures 2.5.9 – 2.5.12. Both the study 1 (base case) and study 4b results are shown for the entire 16-year DSM2 simulation.

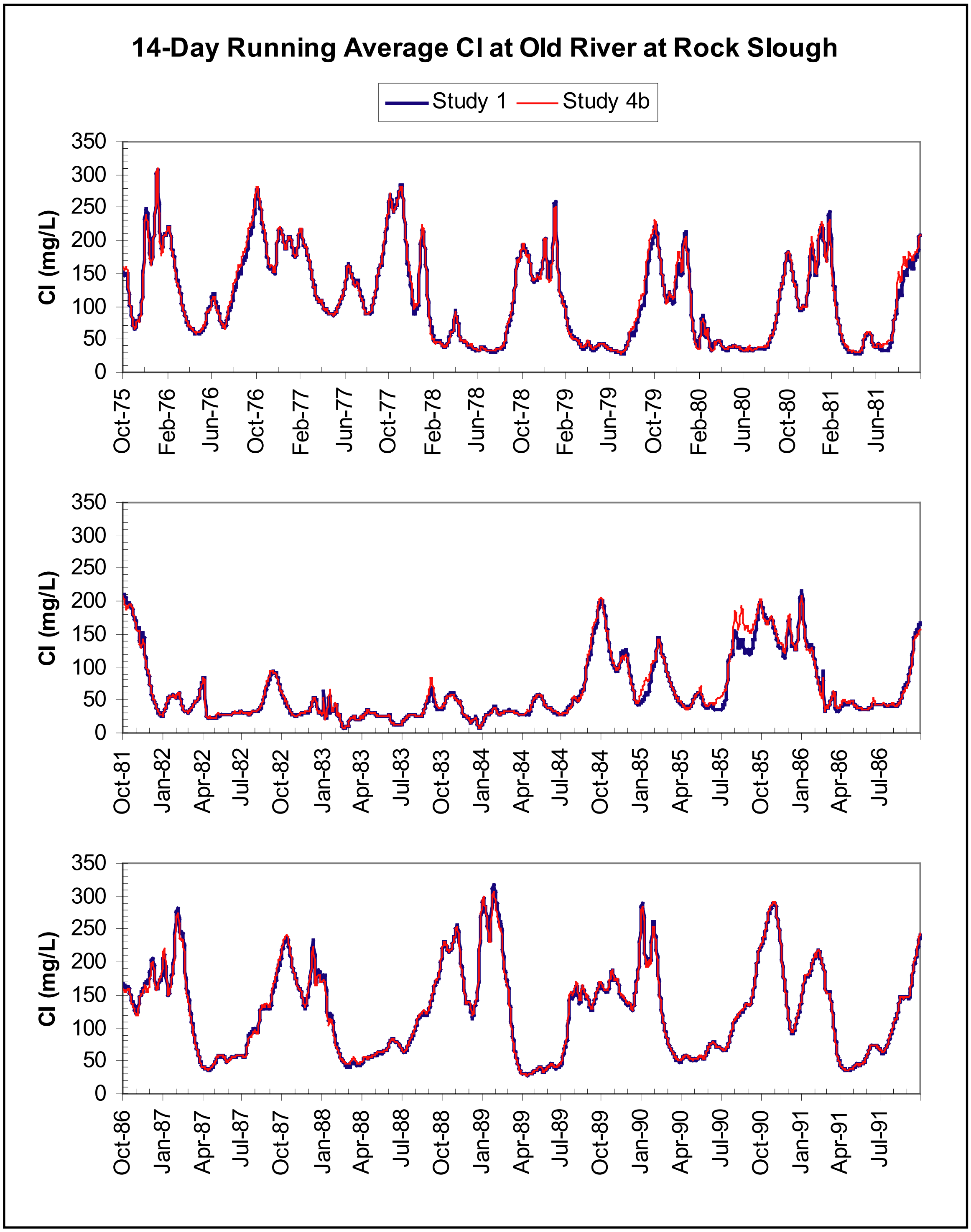

Figure 2.5.9: 14-Day Running Average Cl (mg/L) at Old River at Rock Slough (RS).

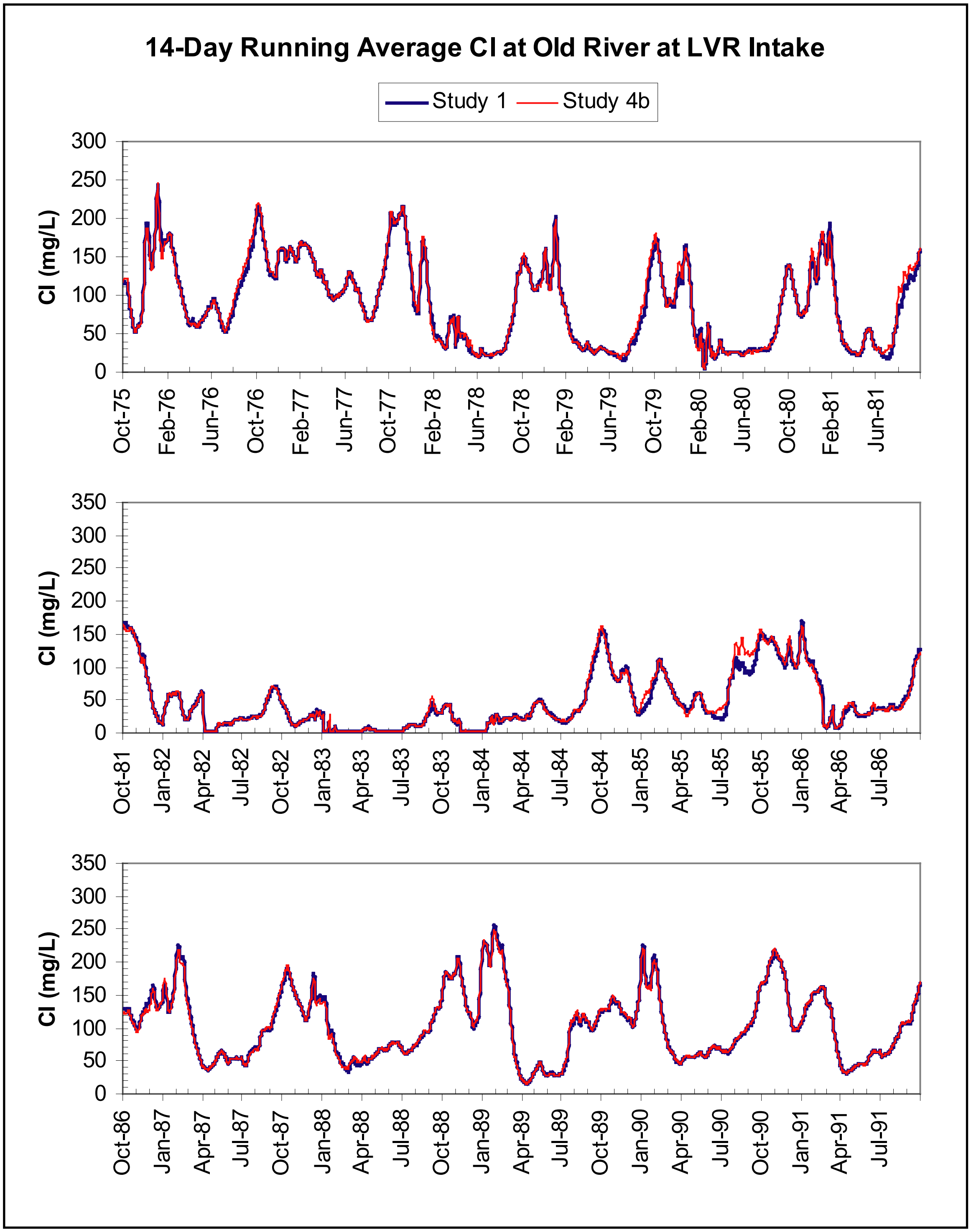

Figure 2.5.10: 14-Day Running Average Cl (mg/L) at Old River at LVR Intake (LVR).

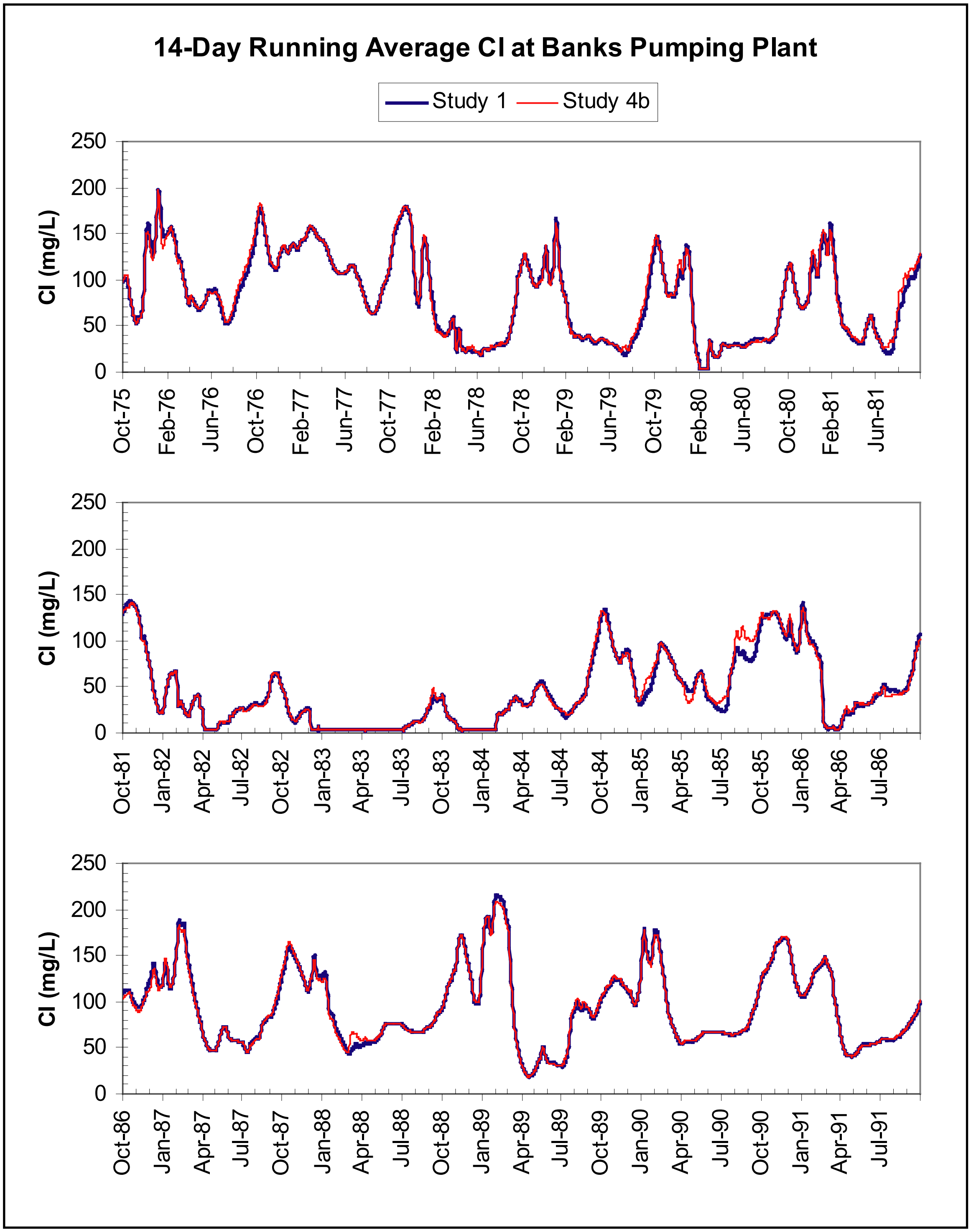

Figure 2.5.11: 14-Day Running Average Cl (mg/L) at Banks Pumping Plant (SWP).

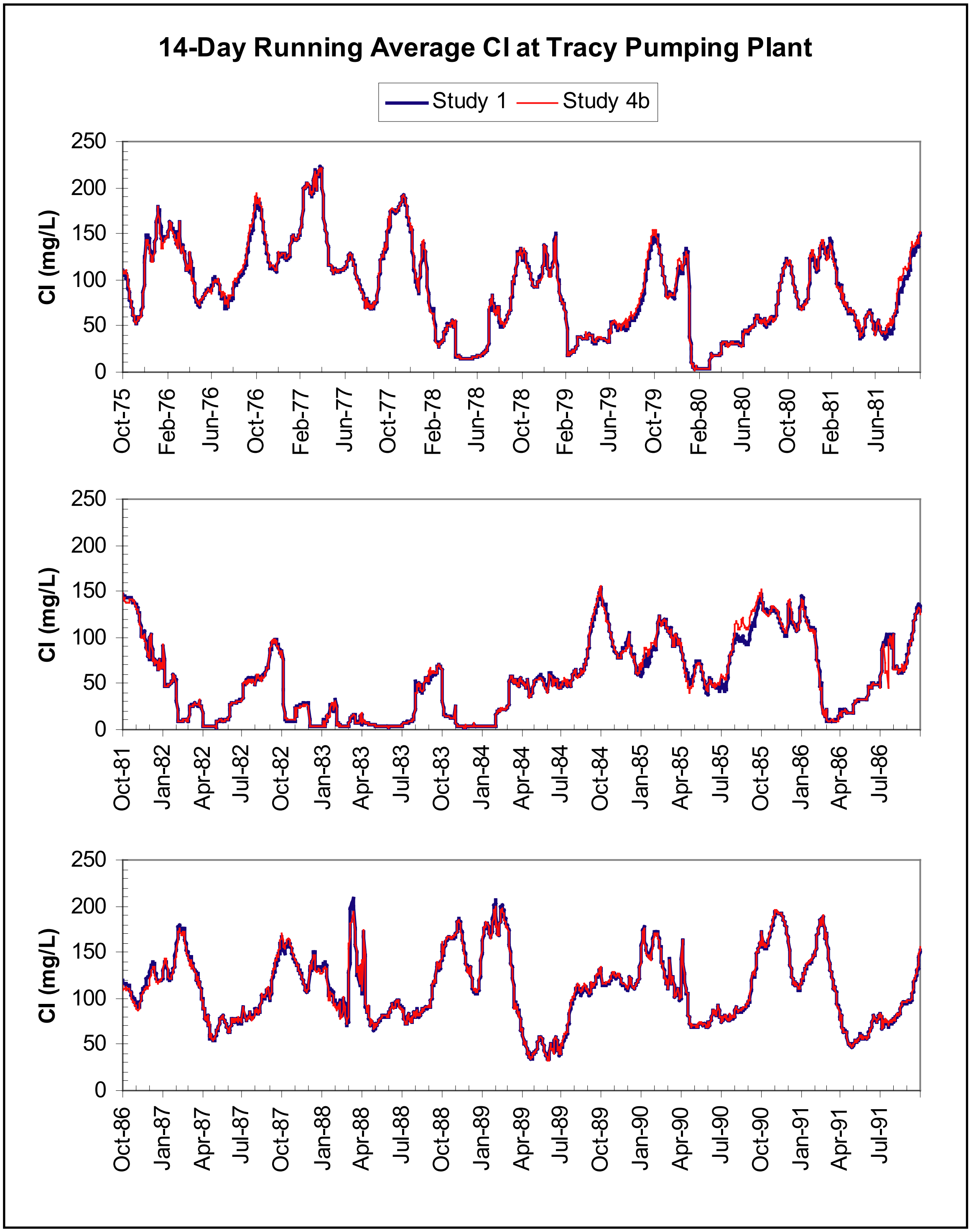

Figure 2.5.12: 14-Day Running Average Cl (mg/L) at Tracy Pumping Plant (CVP).

The WQMP stipulated that the maximum increase in 14-day average chloride concentration due to operation of the project is 10 mg/L when the 14-day average base case (study 1) chloride concentration is less than 225 mg/L, otherwise no increase is allowed (Hutton, 2001). The change in the 14-day average chloride was calculated (see Table 2.5.5) at each of the four urban intake locations as the difference between study 4b and study 1. Though the 16-year maximum increase in chloride violated the 10 mg/L standard at each of the four locations, the 90% chloride concentrations was less than 10 mg/L at all of the intakes. The average change in chloride concentrations is slightly higher than the median (50% results), thus implying the presence of a few extreme values or outliers.

Table 2.5.5: Summary of Change in 14-Day Ave. Chloride (mg/L) at Urban Intakes.

Urban Intake	Min	Ave	Max	Percentiles				
				10th	25th	50th	75th	90th
RS	-12.5	1.2	40.7	-3.6	-0.7	0.4	2.1	5.8
LVR	-12.2	0.9	32.1	-3.3	-0.9	0.2	1.7	5.1
SWP	-15.4	0.6	23.5	-3.1	-0.8	0.1	1.4	4.2
CVP	-21.8	0.4	17.5	-2.4	-0.7	0.1	1.1	3.2

The number of days and percentage of time in the 16-year simulation (5844 days) that the WQMP change in chloride constraint was exceeded are listed in Table 2.5.6. These counts do not take into account the degree or magnitude of the exceedence of the WQMP standard.

Table 2.5.6: Number of Days and Frequency the WQMP Chloride Constraint is Exceeded.

Urban Intake	# Days > Standard	% Days > Standard
RS	464	8%
LVR	259	4%
SWP	181	3%
CVP	86	1%

Time series plots of the change (study 4b – study 1) in 14-day running average chloride at all four urban intakes are shown below in Figures 2.5.13 – 2.5.16. The WQMP D1643 change in chloride standard is also shown. When the study 1 chloride concentration was greater than 225 mg/L, the WQMP chloride standard dropped to 0 mg/L. Otherwise, the increase in chloride was limited to 10 mg/L.

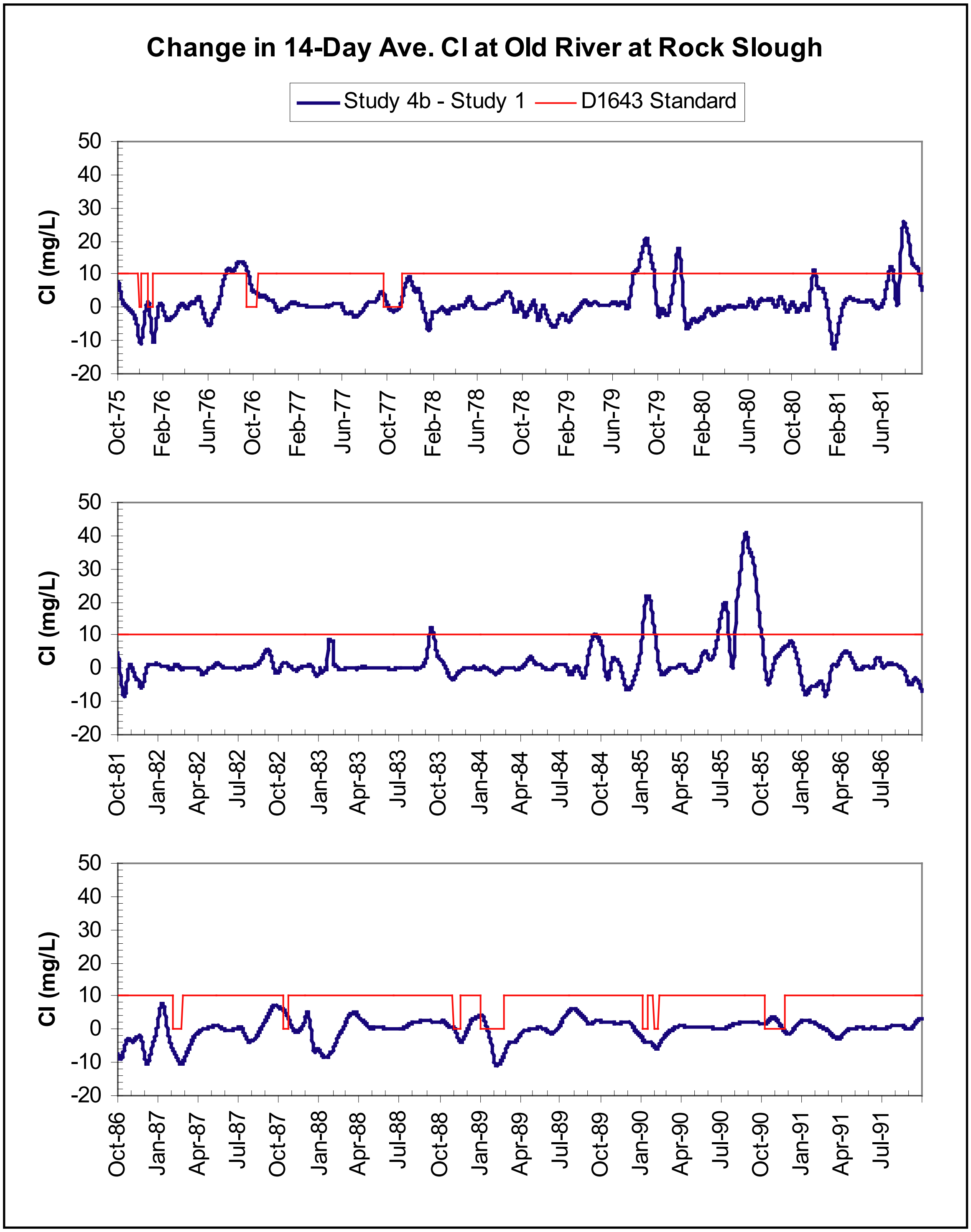

Figure 2.5.13: Change in 14-Day Average Cl (mg/L) at Old River at Rock Slough (RS).

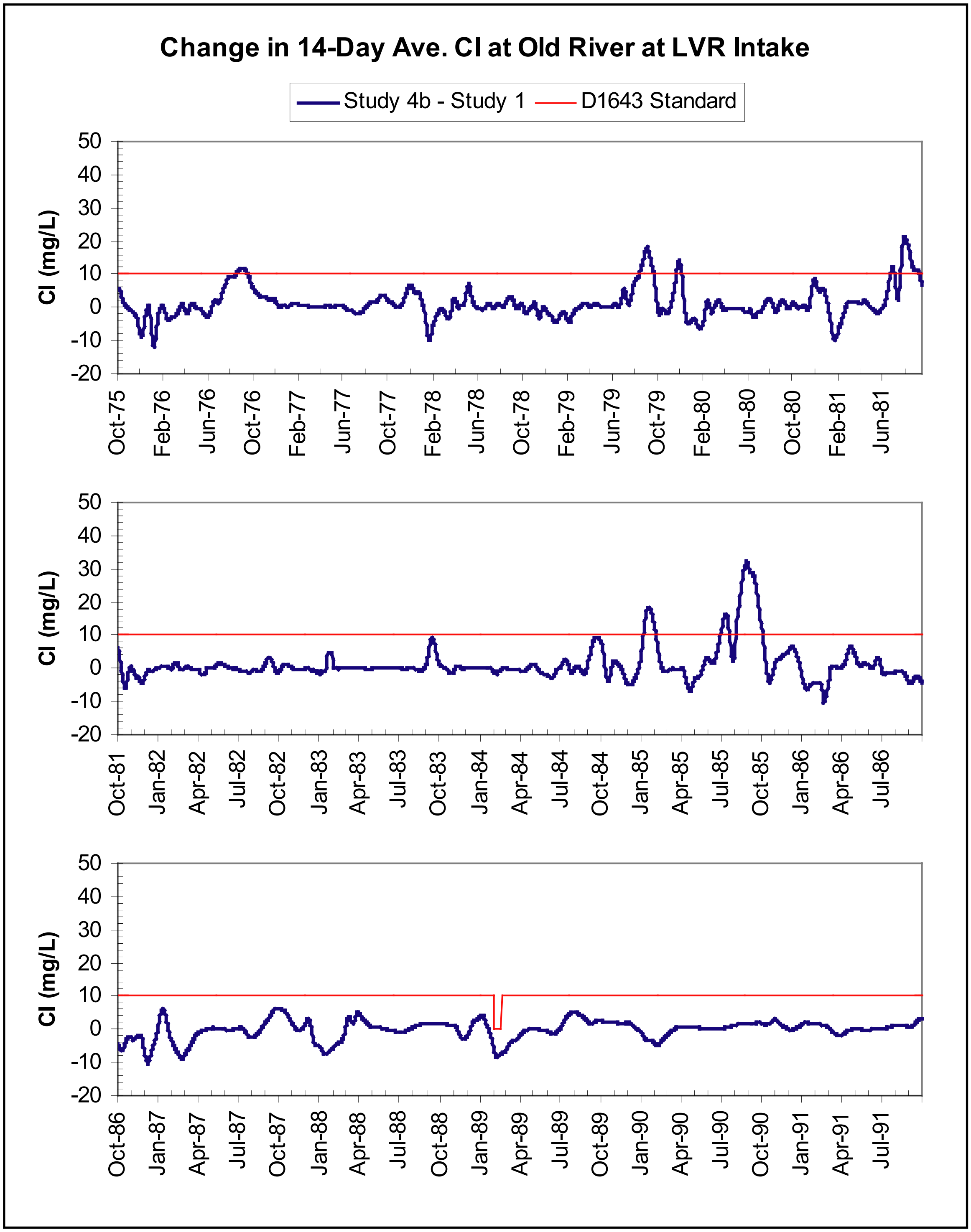

Figure 2.5.14: Change in 14-Day Average Cl (mg/L) at Old River at LVR Intake (LVR).

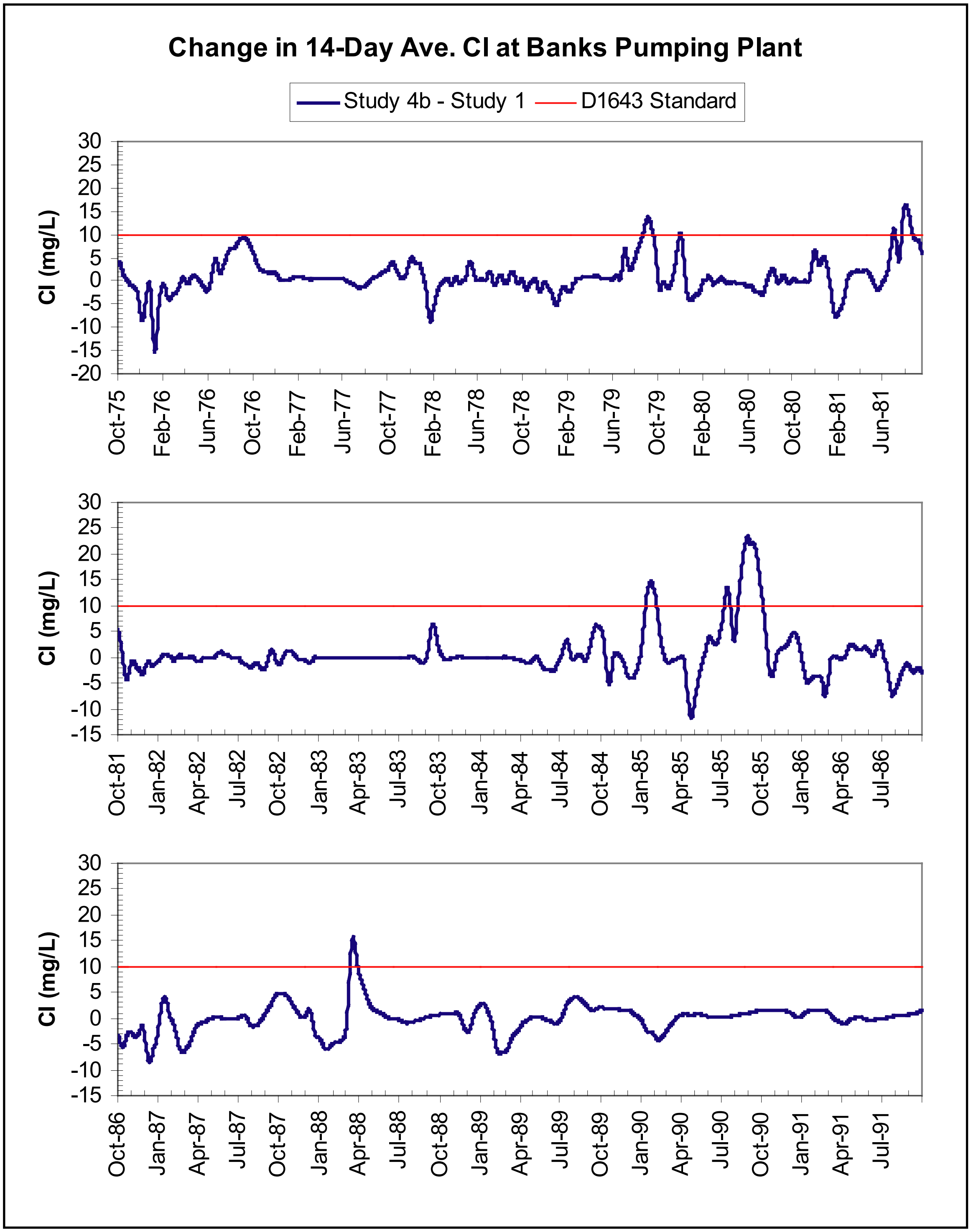

Figure 2.5.15: Change in 14-Day Average Cl (mg/L) at Banks Pumping Plant (SWP).

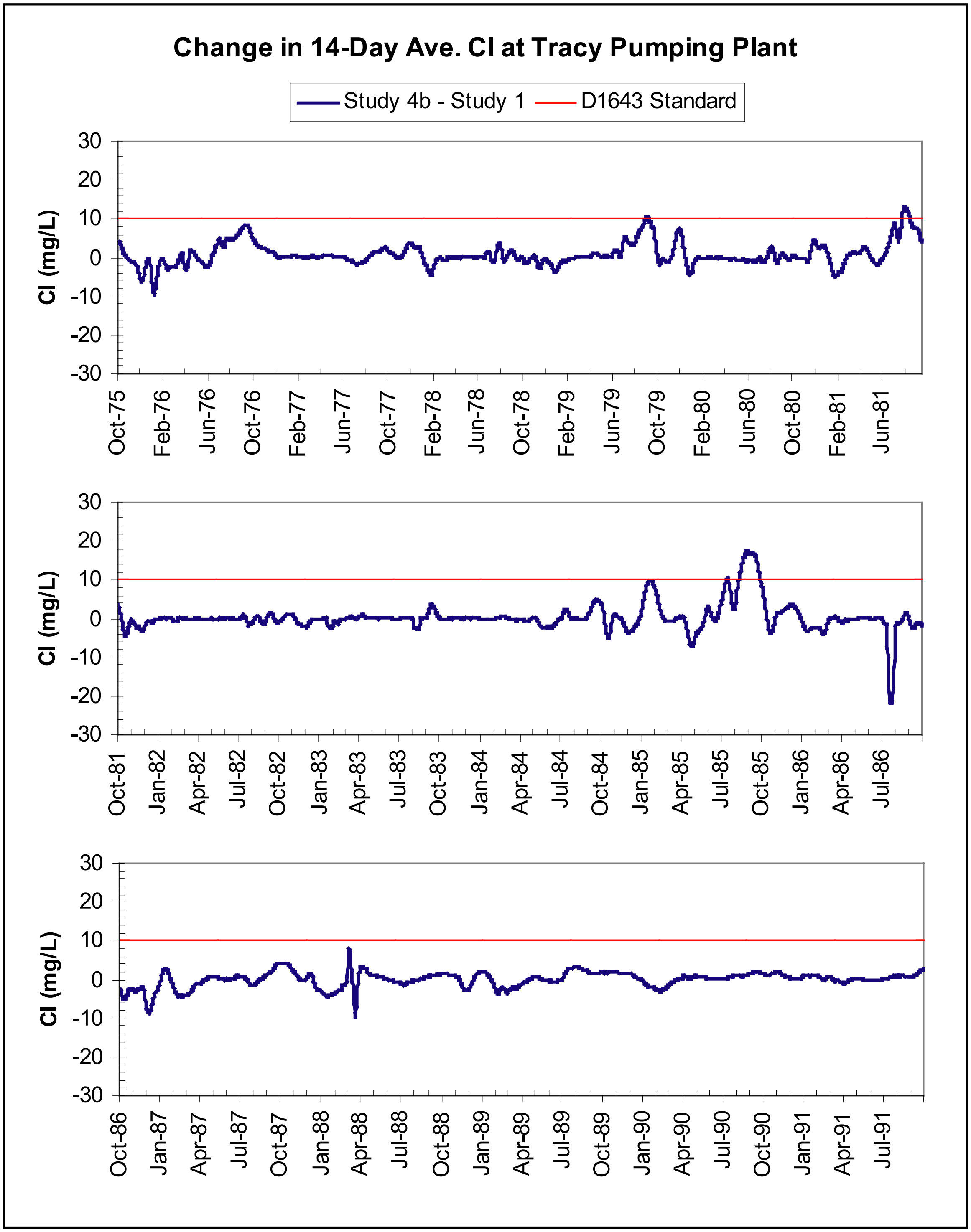

Figure 2.5.16: Change in 14-Day Average Cl (mg/L) at Tracy Pumping Plant (CVP).

2.5.3 DOC at Urban Intakes

DSM2 directly simulated DOC both in the channels as a conservative constituent and project islands as a non-conservative constituent. The increase in carbon mass (non-conservative treatment of organic carbon) was limited to just the project islands (see

Section 2.4.4). Otherwise the mixing and dispersion of DOC in the Delta was similar to how QUAL simulates EC (see *Section 2.4.3*).

The 16-year minimum, average, and maximum daily averaged DOC concentration at the four urban intakes is shown below in Table 2.5.7. The DOC concentration associated with the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles for each location is also shown. The method and interpretation of percentile water quality results is described in *Section 2.5.2*.

Table 2.5.7: Summary of Daily Averaged DOC (mg/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
RS	Study 1	2.1	3.3	11.3	2.2	2.4	2.9	3.7	5.0
	Study 4b	2.2	3.7	11.3	2.6	2.9	3.4	4.1	5.2
LVR	Study 1	2.2	3.6	11.3	2.5	2.7	3.3	4.1	5.3
	Study 4b	2.4	4.2	11.3	3.0	3.3	3.9	4.8	5.7
SWP	Study 1	2.3	3.7	11.3	2.6	2.9	3.4	4.2	5.3
	Study 4b	2.6	4.4	11.3	3.2	3.6	4.1	4.9	5.8
CVP	Study 1	2.4	3.7	11.1	2.8	3.0	3.4	4.0	5.1
	Study 4b	2.6	4.3	11.1	3.2	3.5	3.9	4.7	5.7

The 14-day average DOC constraints called for by the Delta Wetlands WQMP were calculated every day as the average of the 14 previous days (WQMP, 2000). This was done not only to remain consistent with CALSIM, but also under the assumption that forecasting and operations would make use of the previous 14 days worth of field and modeling data. A summary of the 14-day averaged DOC concentrations is shown in Table 2.5.8.

Table 2.5.8: Summary of 14-Day Average DOC (mg/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
RS	Study 1	2.1	3.3	10.8	2.2	2.4	2.9	3.7	5.0
	Study 4b	2.3	3.7	10.9	2.7	2.9	3.4	4.1	5.2
LVR	Study 1	2.2	3.6	10.6	2.5	2.7	3.3	4.2	5.3
	Study 4b	2.5	4.2	10.6	3.0	3.4	3.9	4.8	5.6
SWP	Study 1	2.3	3.7	10.8	2.6	2.9	3.4	4.2	5.3
	Study 4b	2.7	4.4	10.8	3.3	3.6	4.1	4.9	5.8
CVP	Study 1	2.4	3.7	11.0	2.8	3.0	3.4	4.0	5.1
	Study 4b	2.7	4.3	11.0	3.3	3.5	3.9	4.7	5.6

Time series plots of the 14-day running average DOC at all four urban intakes are shown below in Figures 2.5.17 –2. 5.20. Study 4b's 14-day running average DOC is consistently higher than study 1 at all four locations and throughout the entire 16-year simulation. However, the magnitude of this difference is fairly small and is discussed below in greater detail.

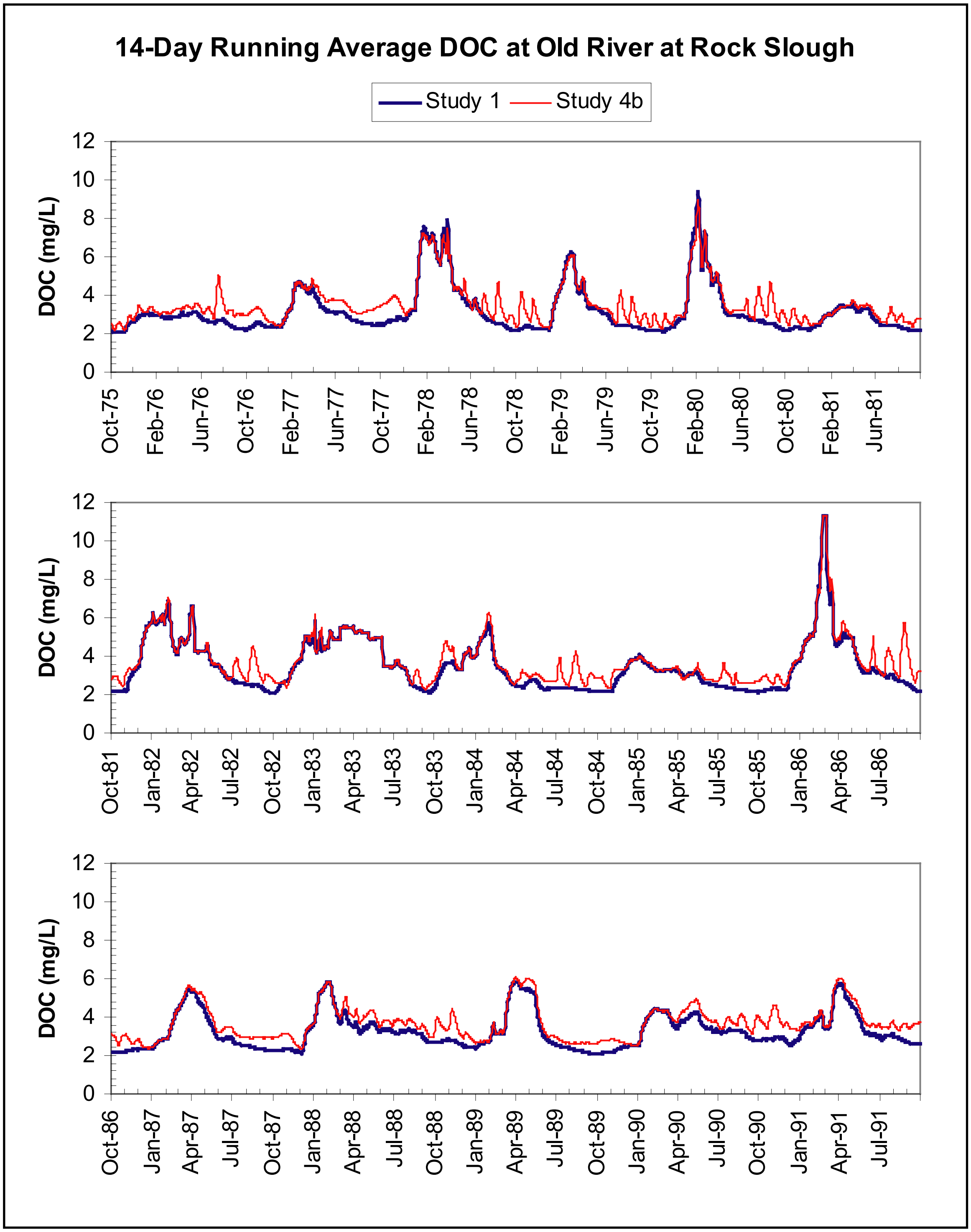

Figure 2.5.17: 14-Day Running Average DOC (mg/L) at Old River at Rock Slough (RS).

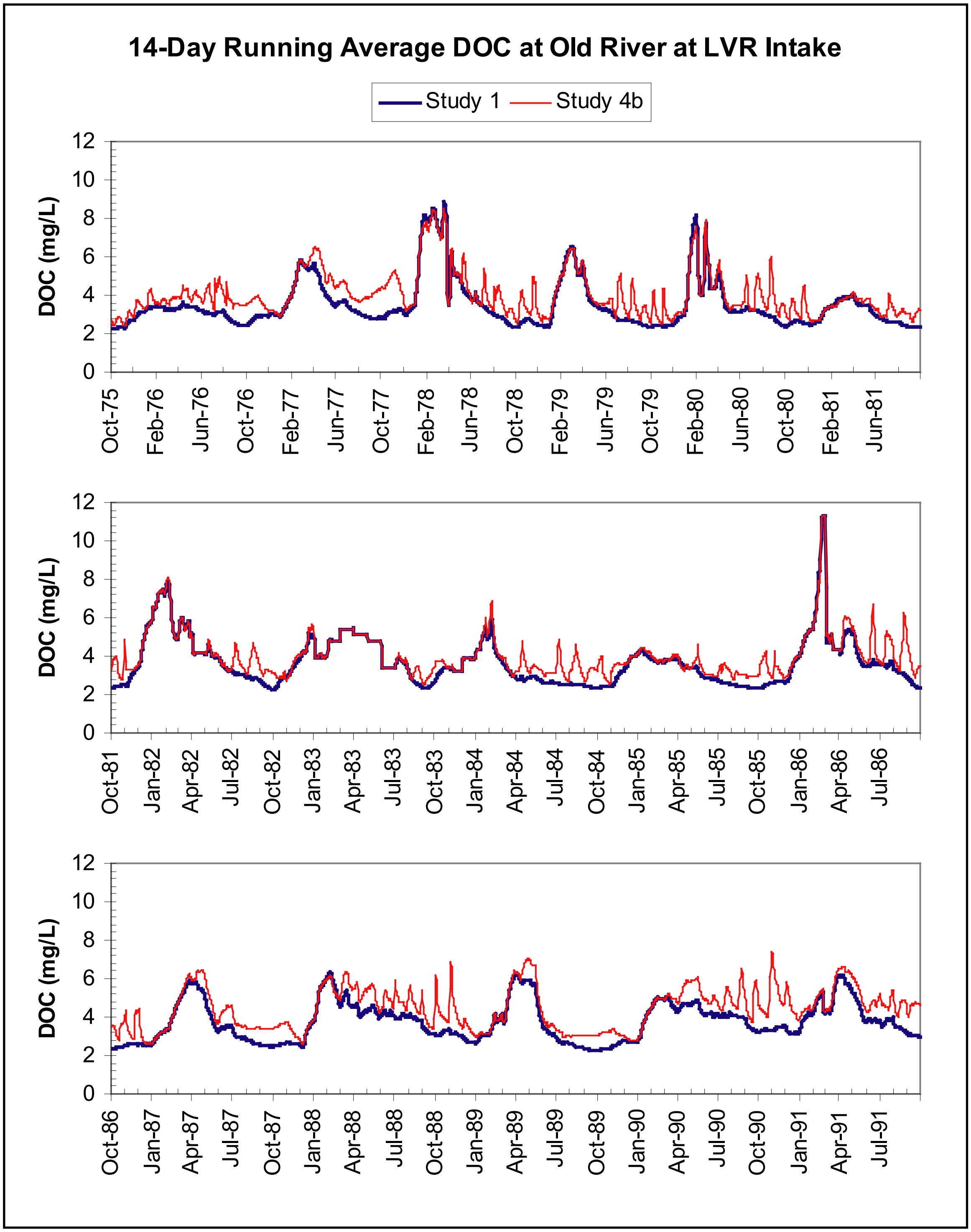

Figure 2.5.18: 14-Day Running Average DOC (mg/L) at Old River at LVR Intake (LVR).

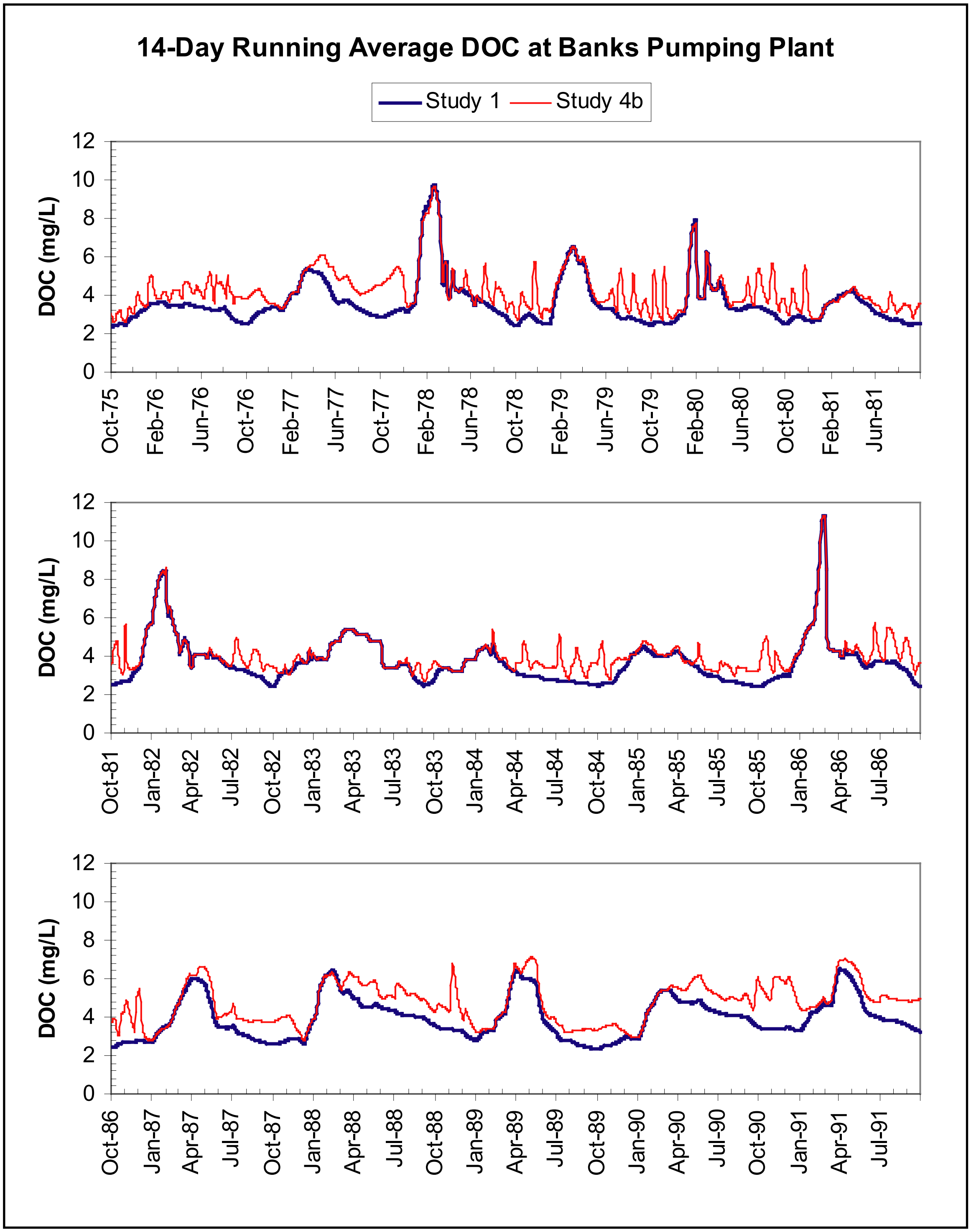

Figure 2.5.19: 14-Day Running Average DOC (mg/L) at Banks Pumping Plant (SWP).

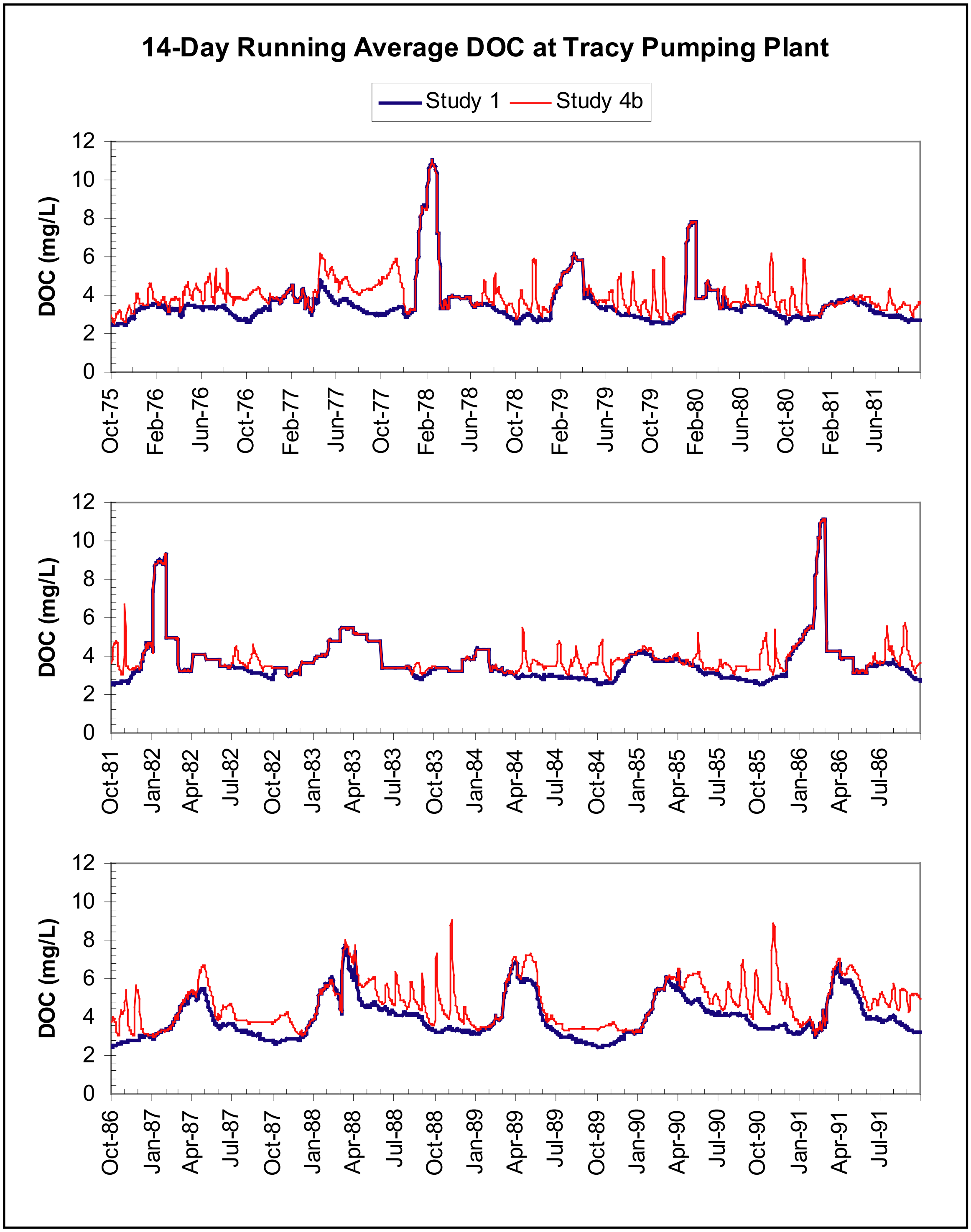

Figure 2.5.20: 14-Day Average DOC (mg/L) at Tracy Pumping Plant (CVP).

Violations of the Water Quality Management Plan (WQMP) DOC standard are not based on the 14-day averages, but instead on the difference between the new IDS operation and the modeled base case (WQMP, 2000). According to the WQMP, when the modeled base case DOC is less than 3 mg/L or greater than 4 mg/L, the maximum increase in DOC at any urban intake is 1 mg/L. When the base case DOC is between 3 mg/L and 4 mg/L, the 14-day average DOC at any urban intake can not exceed 4 mg/L (in other words, the maximum allowed increase is the difference between 4 mg/L and the base case). The incremental WQMP constraint is illustrated below in Figure 2.5.20(a).

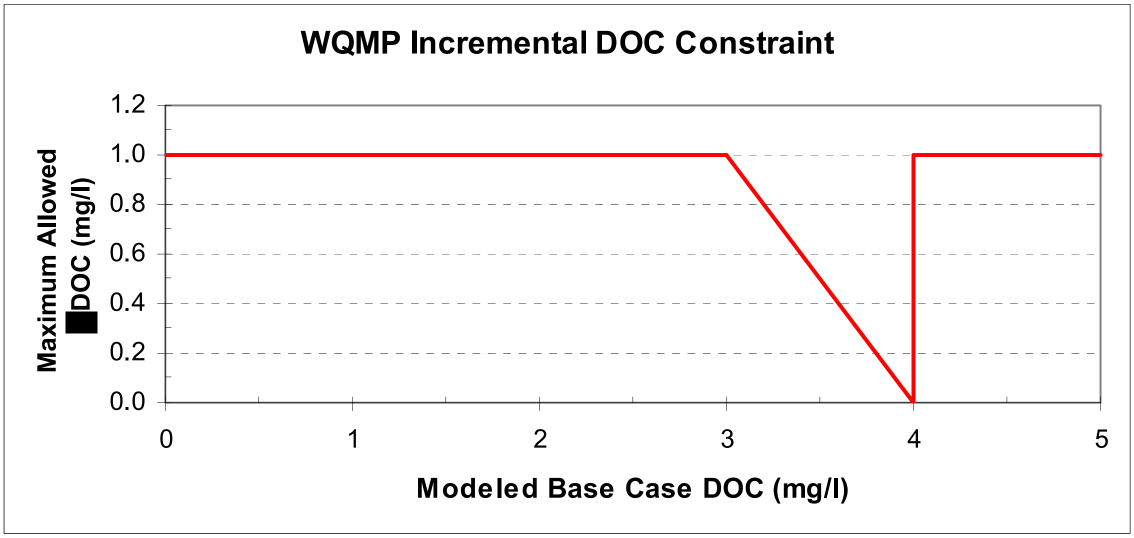

Figure 2.5.20(a): WQMP Incremental DOC Constraint.

The 16-year minimum, average, and maximum change (study 4b - study 1) in the 14-day average DOC at the urban intakes is shown in Table 2.5.9. The 10^{th} percentile results so no impact due to the operation of the project. With the exception of Rock Slough, the 90^{th} percentile results are greater than 1 mg/L. It is important to note that the WQMP DOC constraint listed above varies between 0 and 1 mg/L, thus the percentile results can only be used to estimate the magnitude of the change in DOC due to the operation of the project, but not the frequency that the WQMP DOC constraint is exceeded.

Table 2.5.9: Summary of Change in 14-Day Ave. DOC (mg/L) at Urban Intakes.

Urban Intake	Min	Ave	Max	Percentiles				
				10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
RS	-0.6	0.4	2.6	0.0	0.1	0.3	0.6	0.8
LVR	-0.6	0.5	3.3	0.0	0.1	0.4	0.8	1.2
SWP	-0.4	0.6	2.7	0.0	0.1	0.5	1.0	1.3
CVP	-0.2	0.5	4.4	0.0	0.0	0.4	0.8	1.3

The number and frequency of days out of the 5,844 day simulation when the variable WQMP DOC constraint was exceeded were calculated using the modeled base case (study 1) to find the WQMP standard and the change in 14-day average DOC (Table 2.5.10).

Table 2.5.10: Number and Frequency of Days the WQMP DOC Constraint is Exceeded.

Urban Intake	# Days > Standard	% Days > Standard
RS	517	9%
LVR	1,369	23%
SWP	1,925	33%
CVP	1,513	26%

Time series plots of the change (study 4b – base) in 14-day running average DOC at all four urban intakes are shown below in Figures 2.5.21 – 2.5.24. The WQMP D1643 change in DOC standard is also shown.

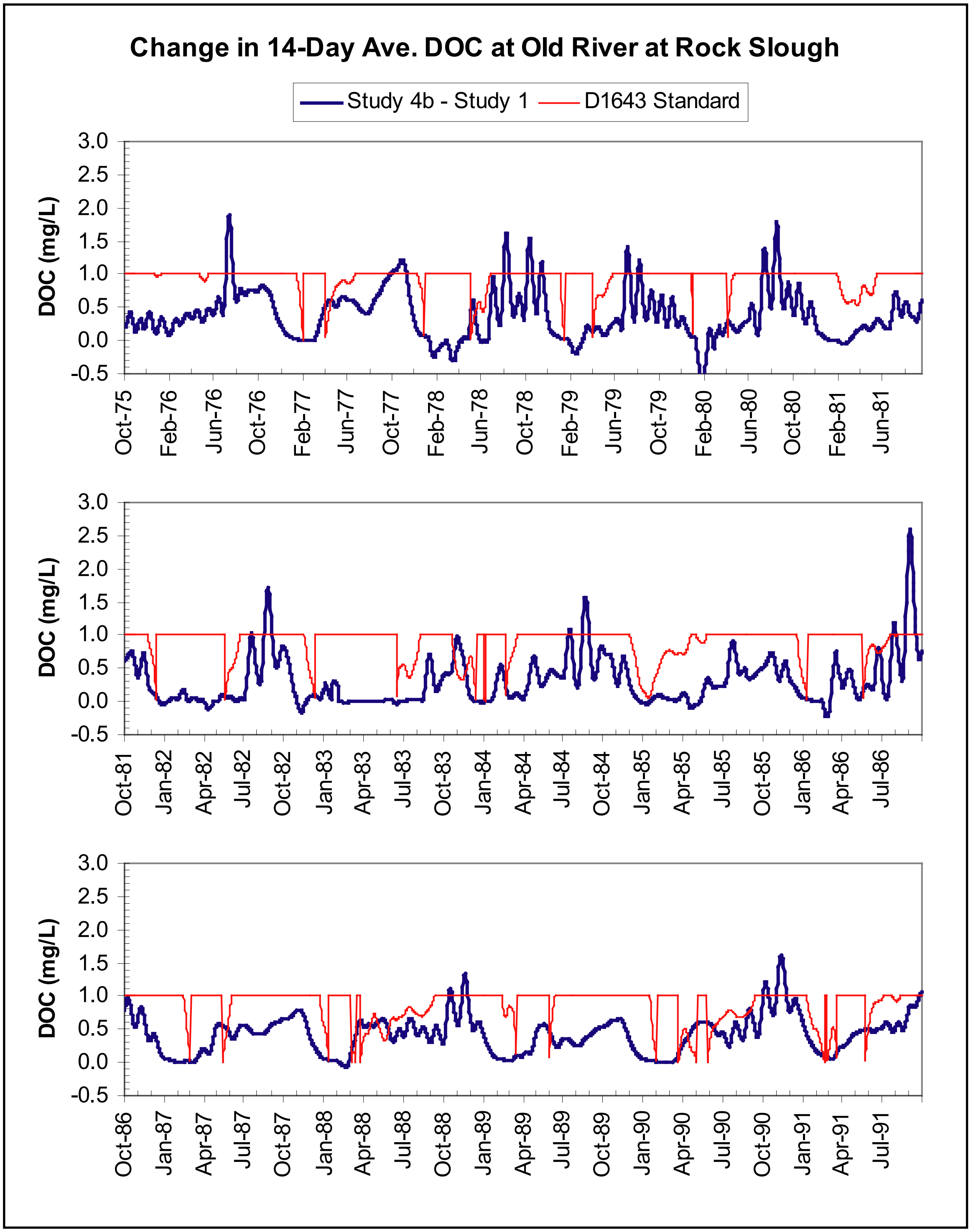

Figure 2.5.21: Change in 14-Day Average DOC (mg/L) at Old River at Rock Slough (RS).

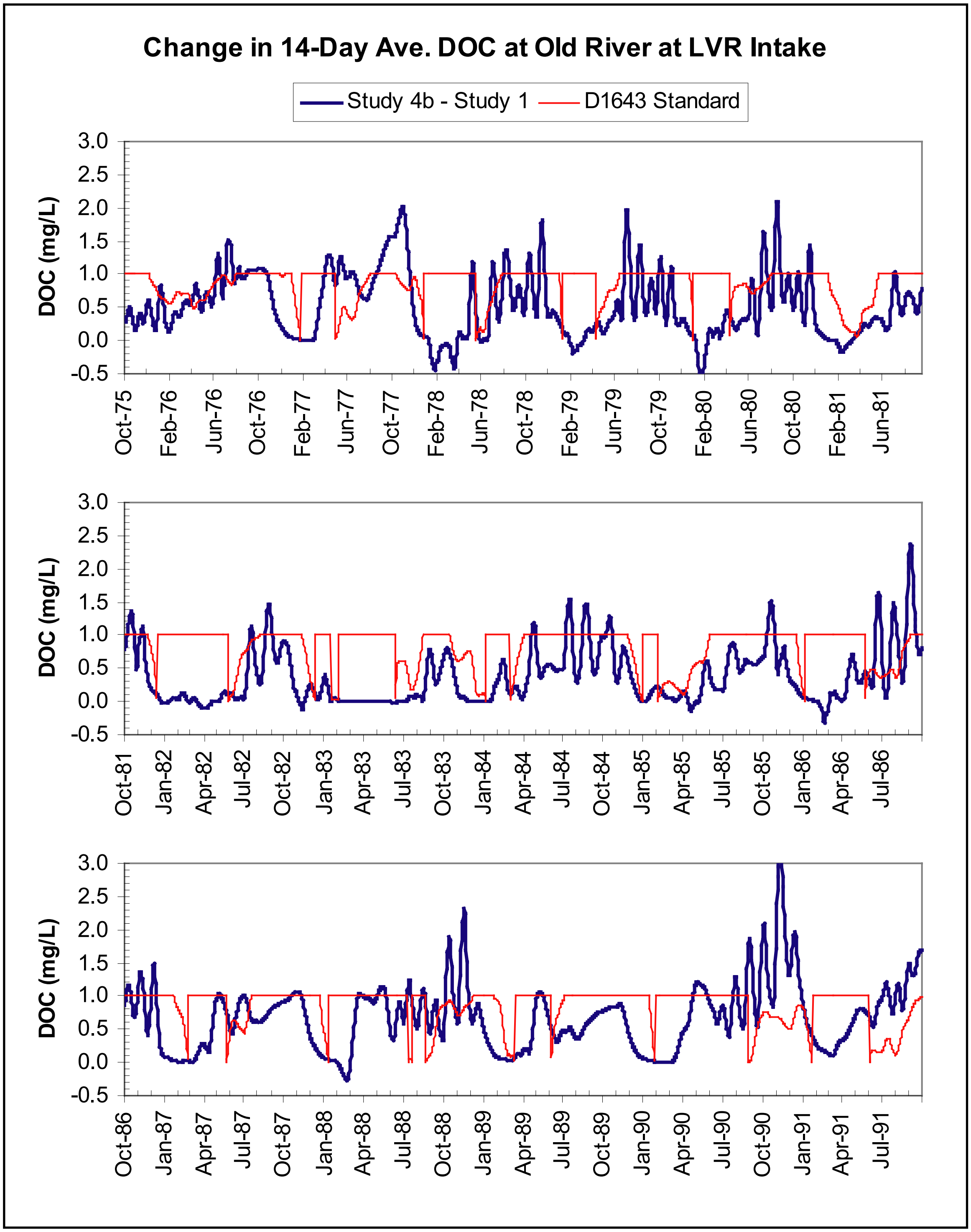

Figure 2.5.22: Change in 14-Day Average DOC (mg/L) at Old River at LVR Intake (LVR).

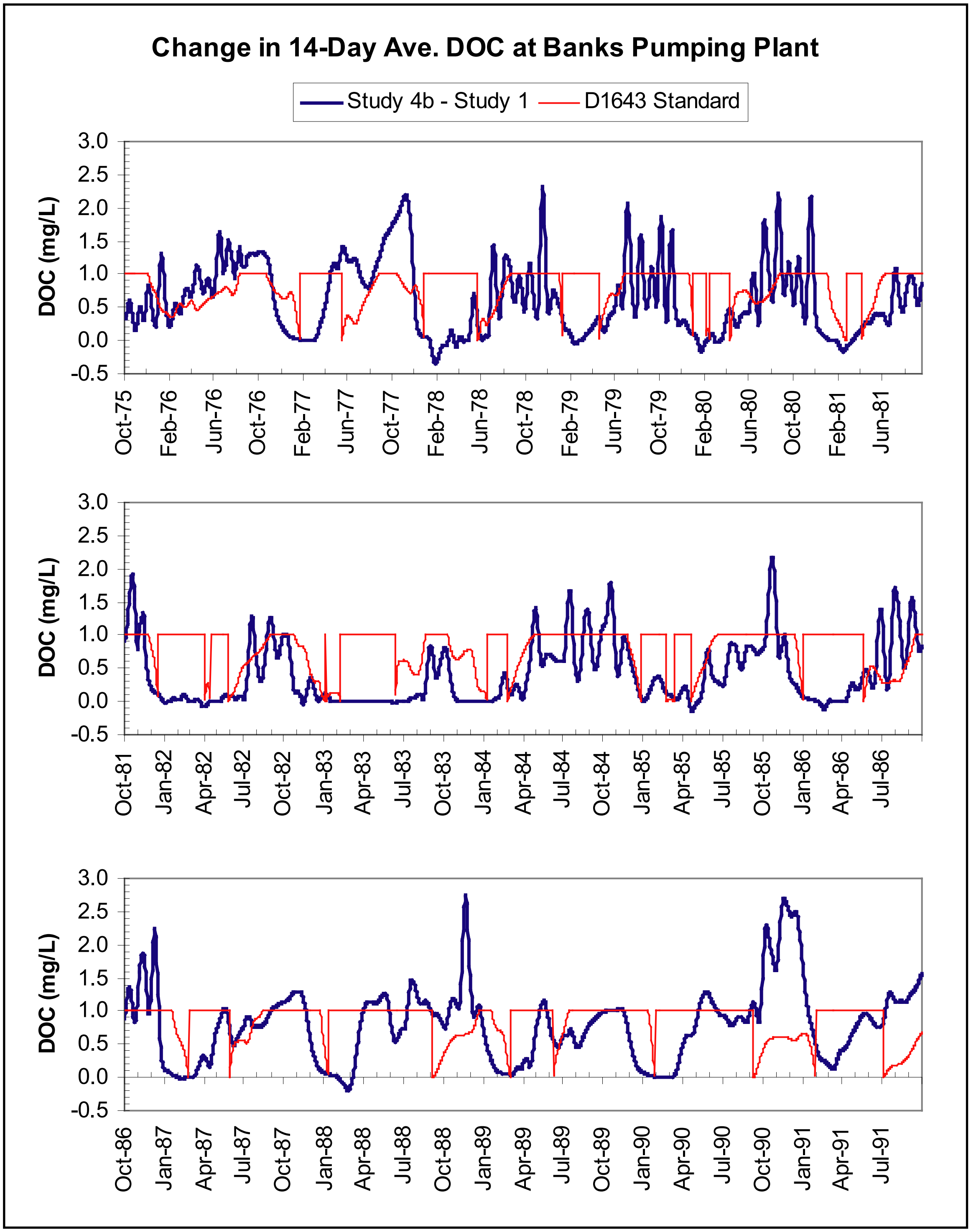

Figure 2.5.23: Change in 14-Day Average DOC (mg/L) at Banks Pumping Plant (SWP).

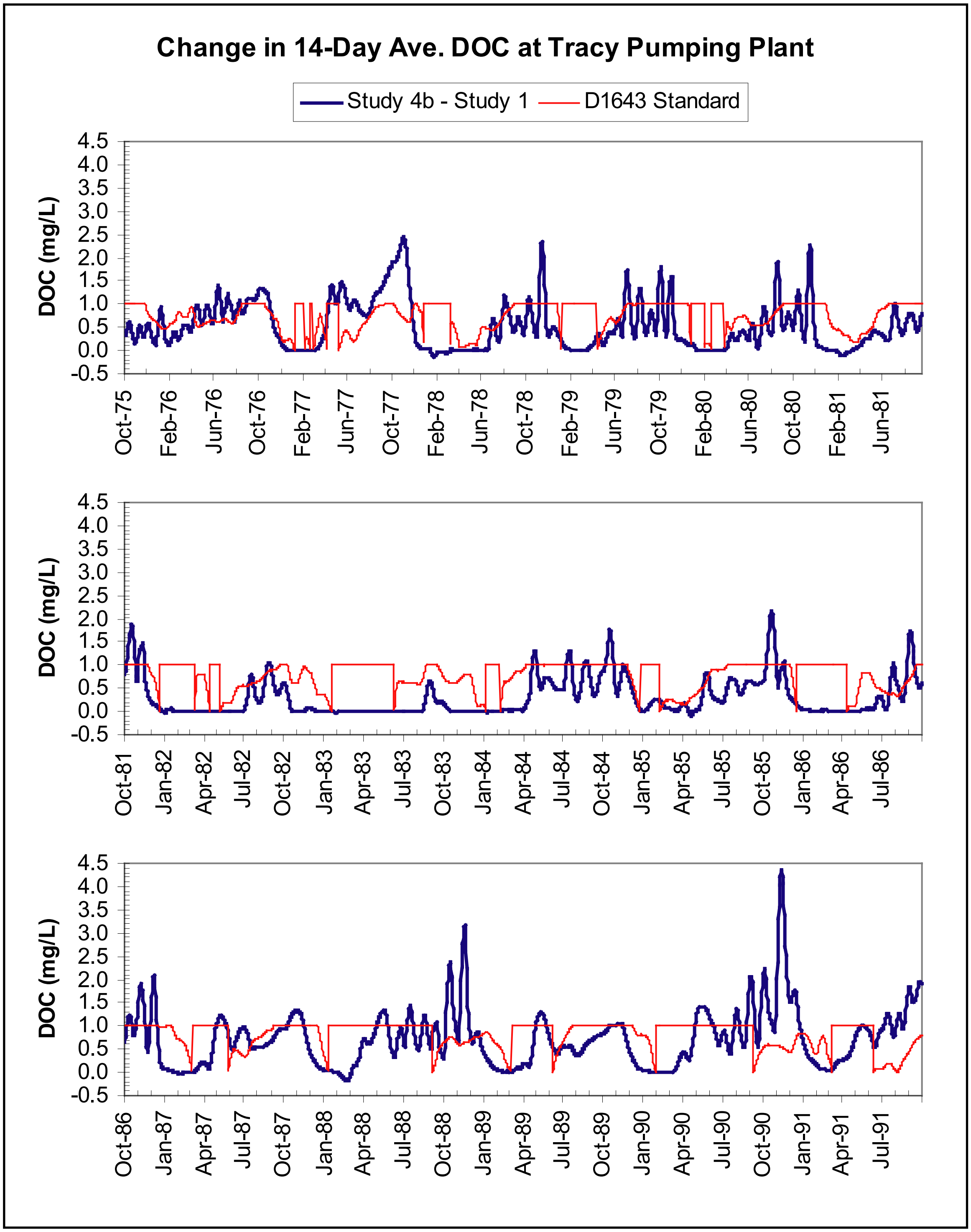

Figure 2.5.24: Change in 14-Day Average DOC (mg/L) at Tracy Pumping Plant (CVP).

2.5.4 TTHM at Urban Intakes

Like the chloride and DOC constraints, the impact of total trihalomethane (TTHM) formation is measured by increases in the project alternative when compared to the modeled base case concentration. TTHM is not directly modeled in DSM2. The WQMP established an incremental standard (described below) and agreed upon the basic modeling approach to be used to calculate TTHM. TTHM is calculated as a function of EC, DOC, and water temperature using the following formulas (Hutton, 2001):

$$TTHM = C_1 \times DOC^{0.228} \times UVA^{0.534} \times (Br+1)^{2.01} \times T^{0.48} \quad \text{Eqn. 5.12}$$

where

TTHM = total trihalomethane concentration (ug/L),
C_1 = 14.5 when DOC < 4 mg/L,
C_1 = 12.5 when DOC ≥ 4 mg/L,
DOC = raw water dissolved organic carbon (mg/L) from DSM2,
UVA = raw water ultraviolet absorbance at 254 nm (1/cm) from DOC,
Br = raw water bromide concentration (mg/L) from EC, and
T = raw water temperature (C).

Although UVA boundary conditions have been developed for DSM2, due to time constraints UVA was not simulated in DSM2-QUAL. Instead, relationships between UVA and DOC were developed for each of the four urban intakes based on MWQI grab sample data (Wilde, 2003). Based on the grab sample data the following regressions were used to convert modeled DOC into UVA:

$$UVA_{RS} = 0.0374 DOC_{RS} - 0.0152 \quad \text{Eqn. 5.13}$$

$$UVA_{LVR} = 0.0401 DOC_{LVR} - 0.021 \quad \text{Eqn. 5.14}$$

$$UVA_{SWP} = 0.0366 DOC_{SWP} - 0.0121 \quad \text{Eqn. 5.15}$$

$$UVA_{CVP} = 0.037 DOC_{CVP} - 0.0209 \quad \text{Eqn. 5.16}$$

The bromide concentration at Rock Slough was developed from regressions of (1) Contra Costa Canal Pumping Plant #1 chloride data to Contra Costa Canal Pumping Plant #1 data, and (2) Contra Costa Canal Pumping Plant #1 chloride data to Rock Slough EC (Suits, 2001). The bromide relationship used in Equation 5.12 for Rock Slough is:

$$Br_{RS} = \frac{EC_{RS} - 118.7}{1040.3} \quad \text{Eqn. 5.17}$$

The bromide relationship used for the remaining urban intake locations was developed based on Delta wide relationships (Suits, 2001):

$$Br = \frac{EC - 189.2}{1020.77} \quad \text{Eqn. 5.18}$$

During a few periods DSM2-QUAL's EC concentrations were so low that using these field conversions would have resulted in negative bromide concentrations. A mimimum bromide concentration of 0.05 ug/L was assumed during these periods.

The monthly average water temperatures used in Equation 5.12 are shown below in Figure 2.5.25. These temperature data originally came CCWD water treatment plant averages (Hutton, 2001).

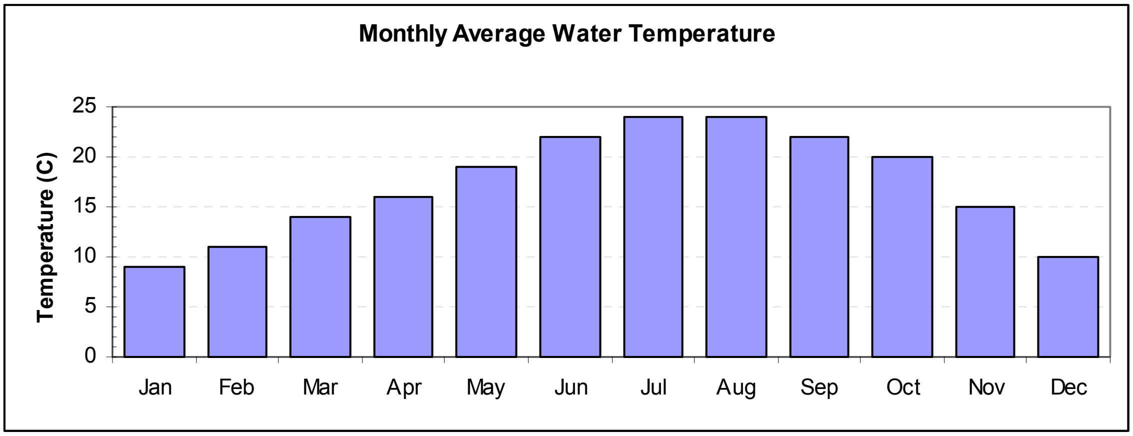

Figure 2.5.25: Monthly Average Water Temperature Used to Calculate TTHM.

The 16-year minimum, average, and maximum daily averaged TTHM concentration at the four urban intakes for study 1 (base case) and study 4b is shown below in Table 2.5.11. The TTHM concentration associated with the 10th, 25th, 50th, 75th, and 90th percentile at each location is also shown. These percentiles were calculated in the same manner as the chloride percentiles (see *Section 2.5.2*). Although the 50th percentile (median) TTHM concentrations for all locations are similar to the 16-year average concentrations, the 90th percentile concentrations are much lower than the 16-year maximums.

Table 2.5.11: Summary of Daily Averaged TTHM (ug/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10th	25th	50th	75th	90th
RS	Study 1	18	37	88	25	29	35	43	52
	Study 4b	18	42	115	27	31	38	49	60
LVR	Study 1	17	36	77	25	29	35	42	50
	Study 4b	17	41	131	27	32	38	48	57
SWP	Study 1	19	35	63	25	29	35	40	47
	Study 4b	19	40	82	27	32	38	47	53
CVP	Study 1	17	37	102	26	30	37	43	49
	Study 4b	17	41	113	26	32	40	49	57

The 14-day average TTHM constraints called for by the Delta Wetlands WQMP were calculated every day as the average of the 14 previous days (WQMP, 2000). This was done not only to remain consistent with CALSIM, but also under the assumption that forecasting and operations would make use of the previous 14 days worth of field and modeling data. A summary of the 14-day average TTHM constraints is shown in Table 2.5.12.

Table 2.5.12: Summary of 14-Day Average TTHM (ug/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10th	25th	50th	75th	90th
RS	Study 1	19	37	85	26	29	35	43	51
	Study 4b	20	41	104	27	32	38	49	59
LVR	Study 1	20	36	73	25	29	35	42	50
	Study 4b	20	41	108	28	32	39	48	57
SWP	Study 1	20	35	61	26	29	35	40	47
	Study 4b	20	40	75	27	32	38	47	52
CVP	Study 1	18	37	89	26	30	37	43	49
	Study 4b	18	41	103	26	32	40	49	56

Time series plots of the 14-day running average TTHM at all four urban intakes are shown below in Figures 2.5.26 – 2.5.29.

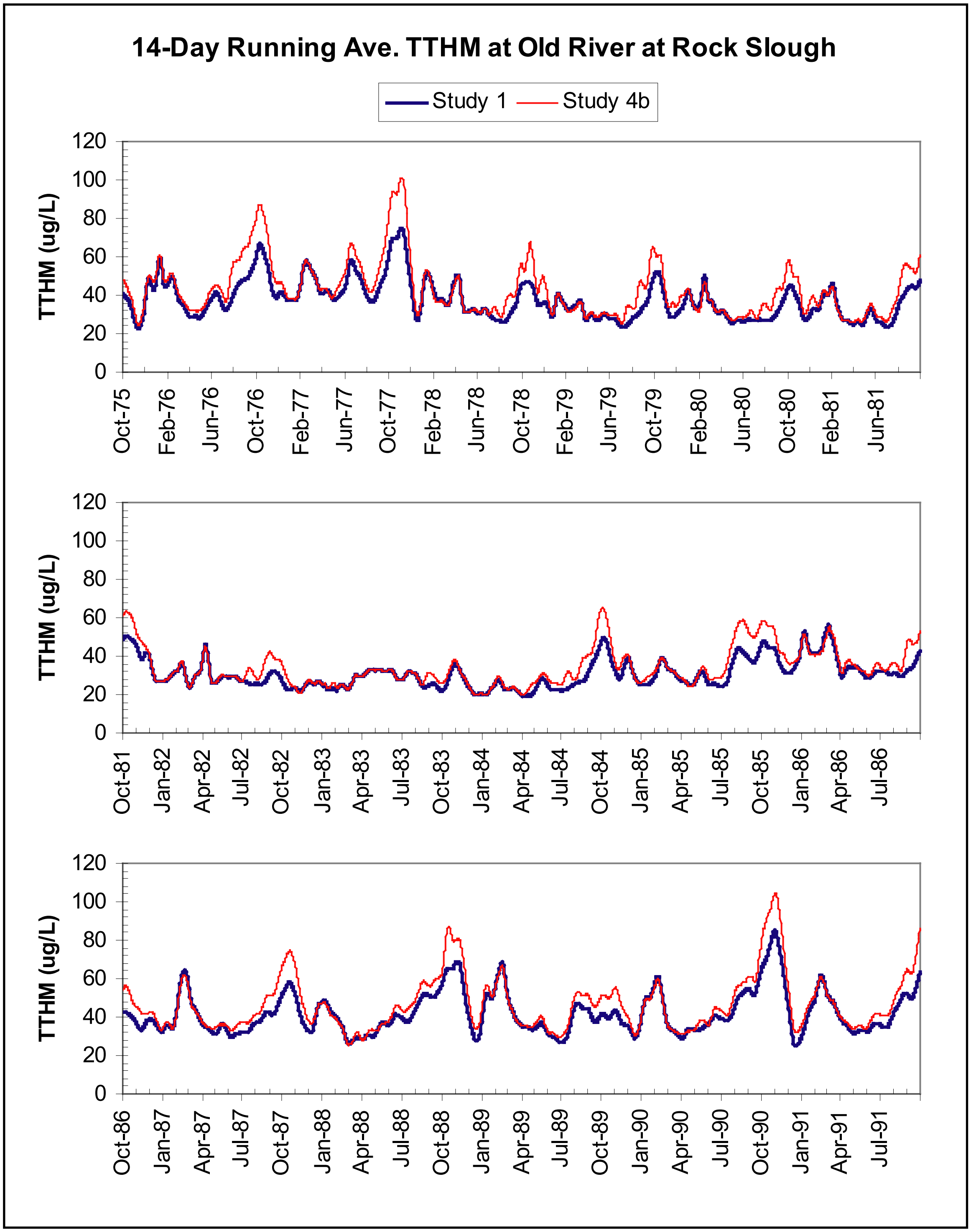

Figure 2.5.26: 14-Day Average TTHM (ug/L) at Old River at Rock Slough (RS).

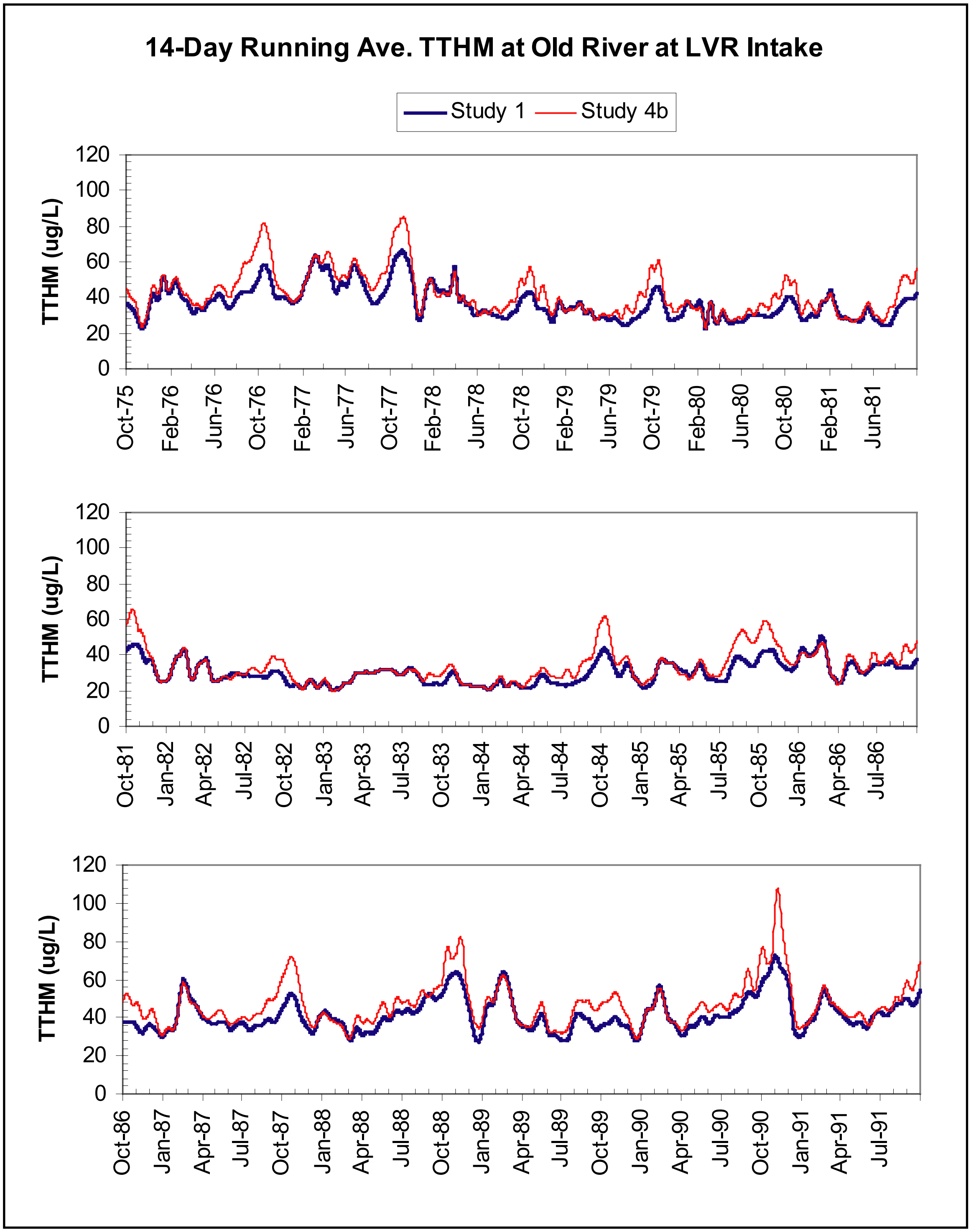

Figure 2.5.27: 14-Day Average TTHM (ug/L) at Old River at LVR Intake (LVR).

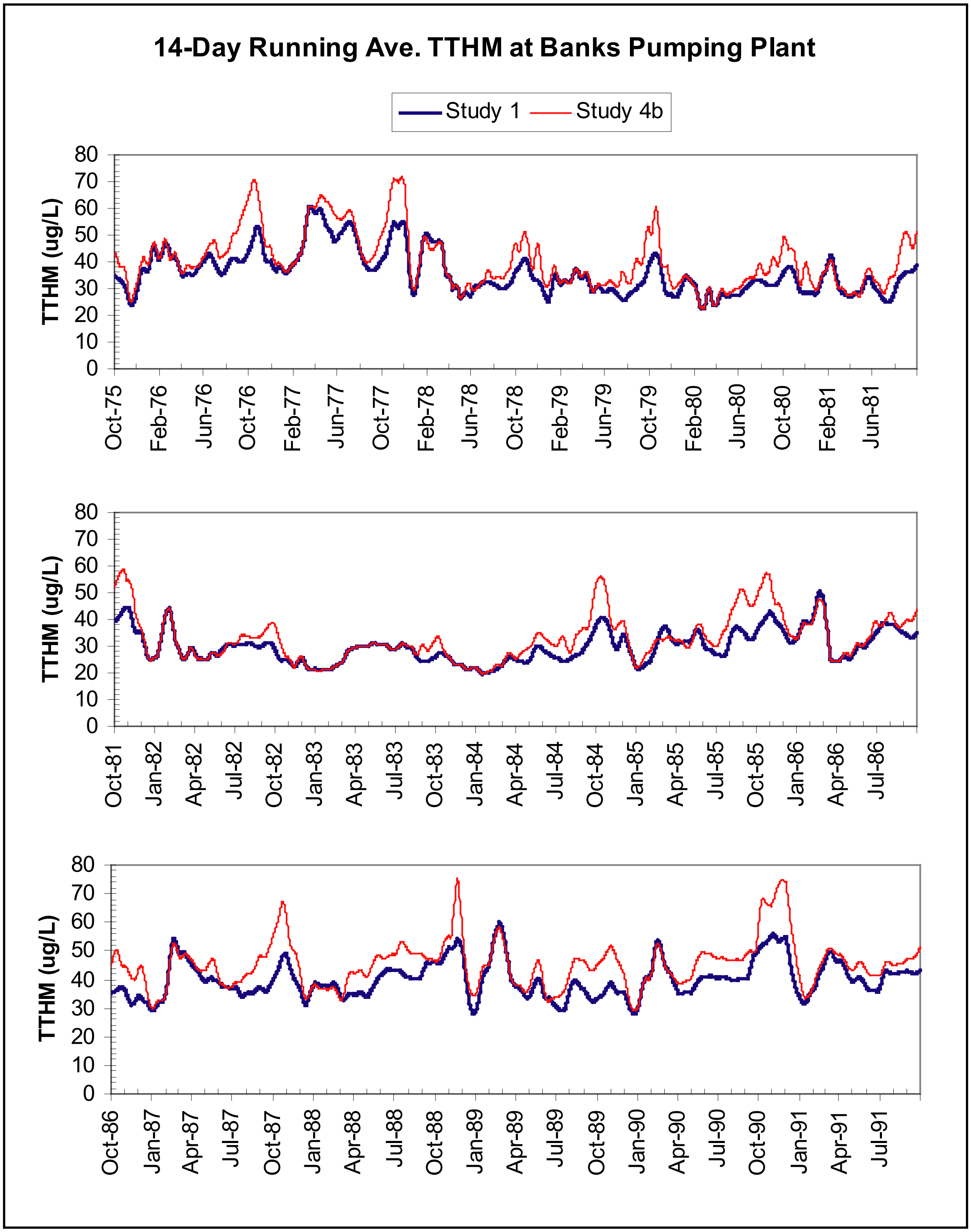

Figure 2.5.28: 14-Day Average TTHM (ug/L) at Banks Pumping Plant (SWP).

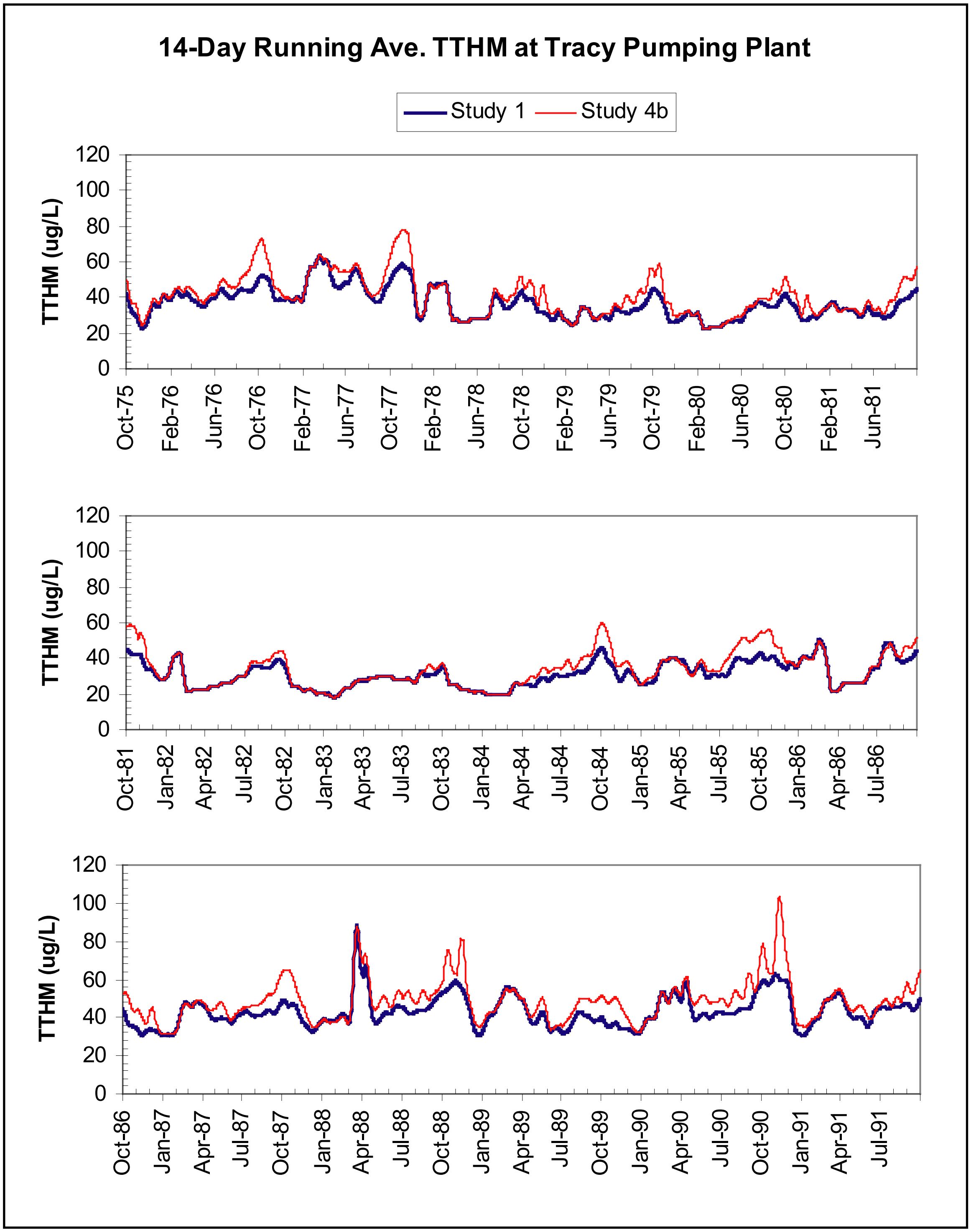

Figure 2.5.29: 14-Day Average TTHM (ug/L) at Tracy Pumping Plant (CVP).

Violations of the Water Quality Management Plan (WQMP) TTHM standard are not based on the 14-day averages, but instead on the difference between the new IDS operation and the modeled base case (WQMP, 2000). According to the WQMP, when the modeled base case TTHM is less than or equal to 64 ug/L, the modeled project (alternative) TTHM can not exceed 64 ug/L. When the base case TTHM already exceeds

64 ug/L, the 14-day average increase in TTHM concentration at any urban intake can not exceed 3.2 ug/L. The incremental WQMP constraint is illustrated below in Figure 2.5.30.

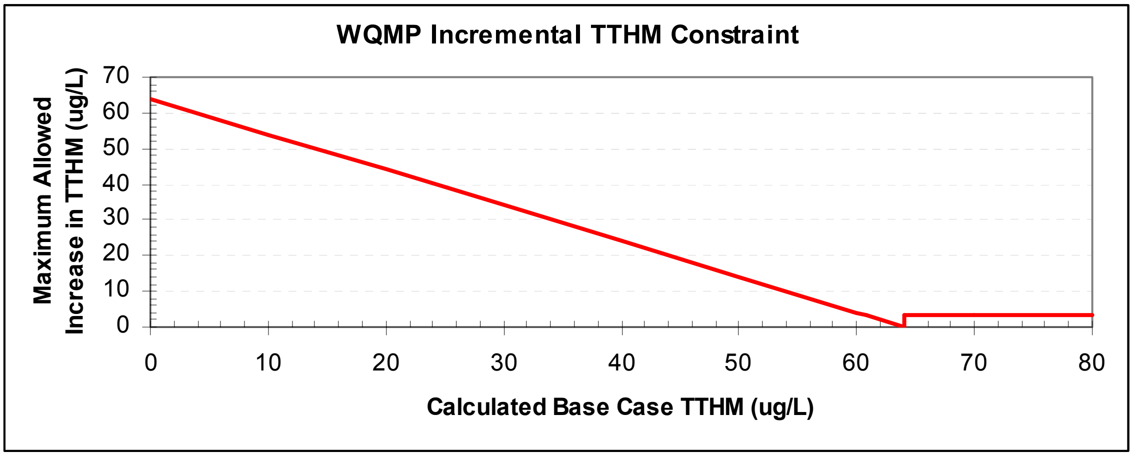

Figure 2.5.30: WQMP Incremental TTHM Constraint.

The 16-year minimum, average, and maximum change (study 4b - study 1) in the 14-day average TTHM at the urban intakes is shown in Table 2.5.13. The 10th percentile results so a slight improvement (decrease) in TTHM concentrations, while the 25th percentile results show an equivalent increase in TTHM concentrations.

Table 2.5.13: Summary of Change in 14-Day TTHM (ug/L) at Urban Intakes.

Urban Intake	Min	Ave	Max	Percentiles				
				10th	25th	50th	75th	90th
RS	-3.5	4.5	26.7	-0.4	0.3	2.9	7.1	12.1
LVR	-4.5	4.6	37.7	-0.5	0.5	3.2	7.1	12.0
SWP	-4.8	4.3	22.1	-0.2	0.4	3.0	6.9	11.0
CVP	-3.1	4.1	42.5	-0.1	0.1	2.6	6.5	10.9

The number and frequency of days out of the 5,844 day simulation when the variable WQMP TTHM constraint was exceeded were calculated using the modeled base case (study 1) to find the WQMP standard and the change in 14-day average TTHM (Table 2.5.14).

Table 2.5.14: Number and Frequency of Days the WQMP TTHM Constraint is Exceeded.

Urban Intake	# Days > Standard	% Days > Standard
RS	355	6%
LVR	290	5%
SWP	175	3%
CVP	229	4%

Time series plots of the change (study 4b – study1) in 14-day running average TTHM at all four urban intakes are shown below in Figures 2.5.31 – 2.5.34. The WQMP D1643 change in TTHM standard is also shown.

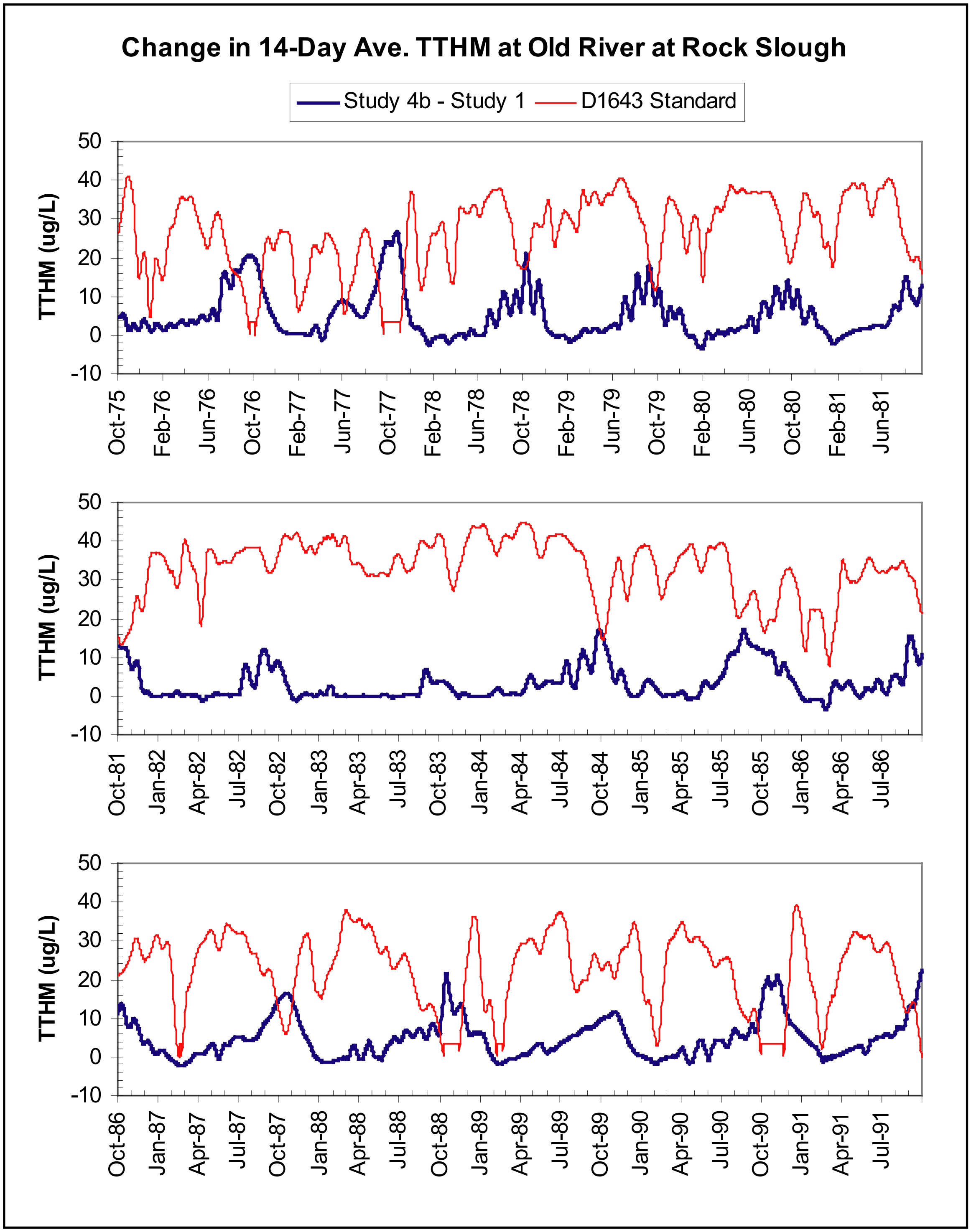

Figure 2.5.31: Change in 14-Day Average TTHM (ug/L) at Old River at Rock Slough (RS).

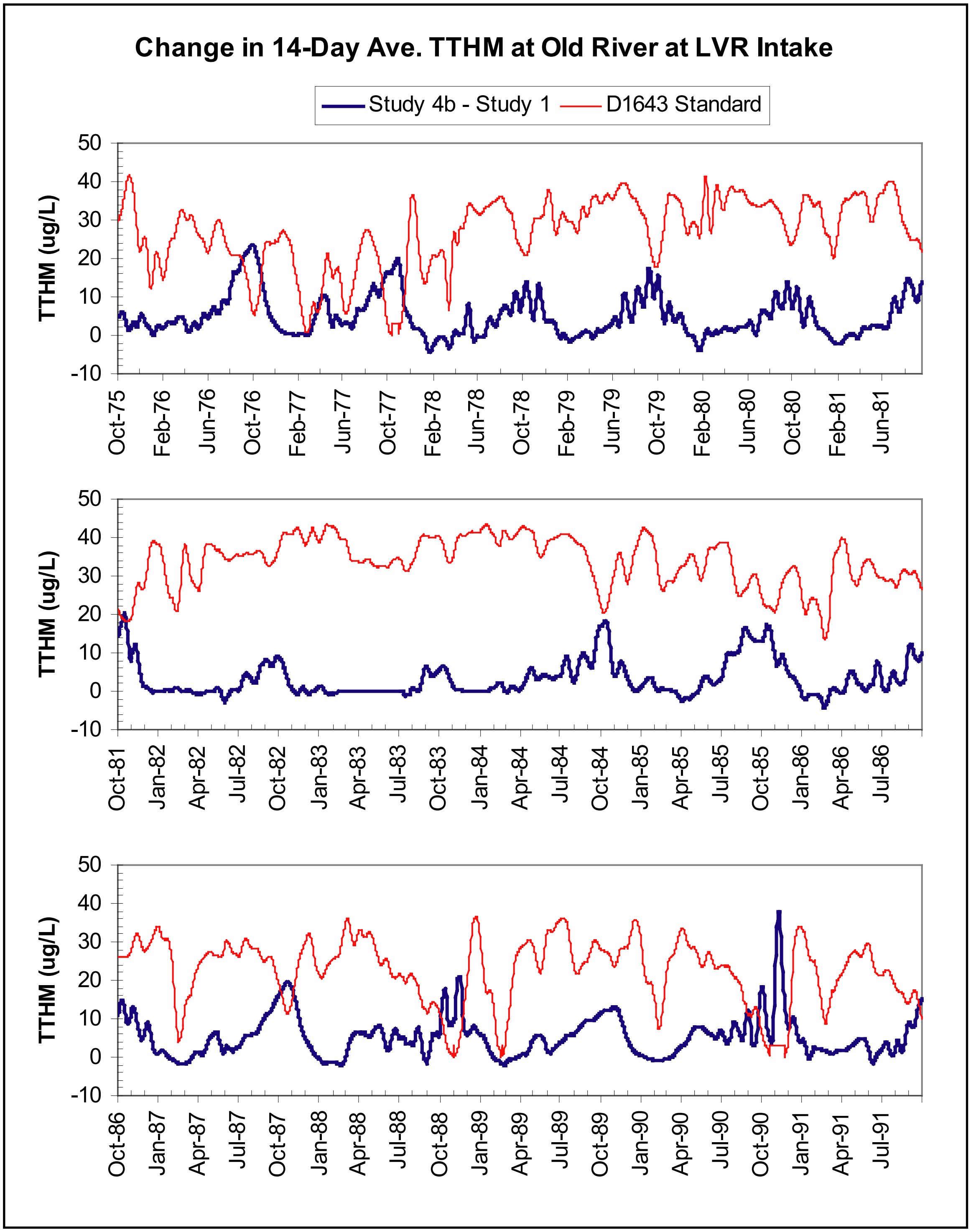

Figure 2.5.32: Change in 14-Day Average TTHM (ug/L) at Old River at LVR Intake (LVR).

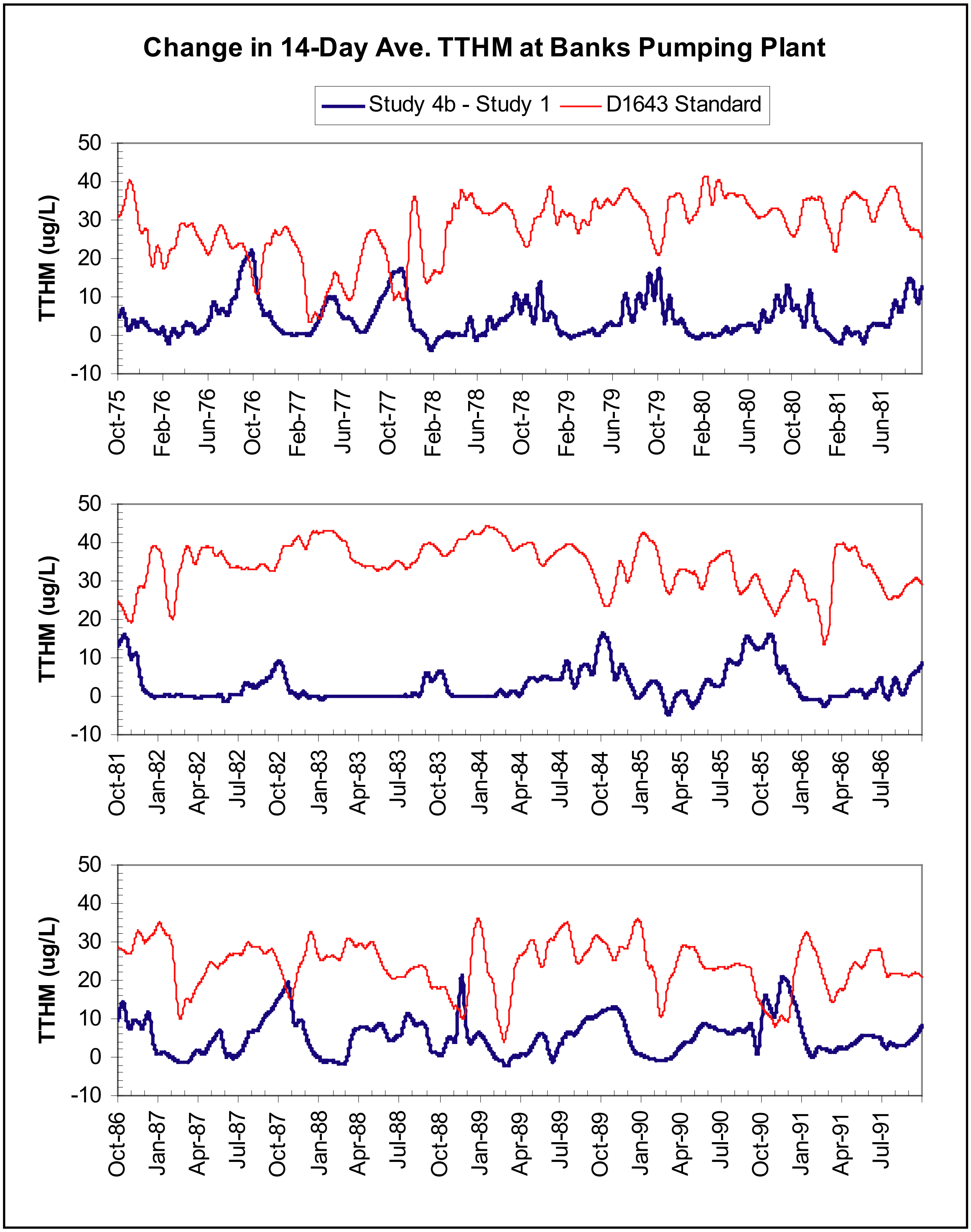

Figure 2.5.33: Change in 14-Day Average TTHM (ug/L) at Banks Pumping Plant (SWP).

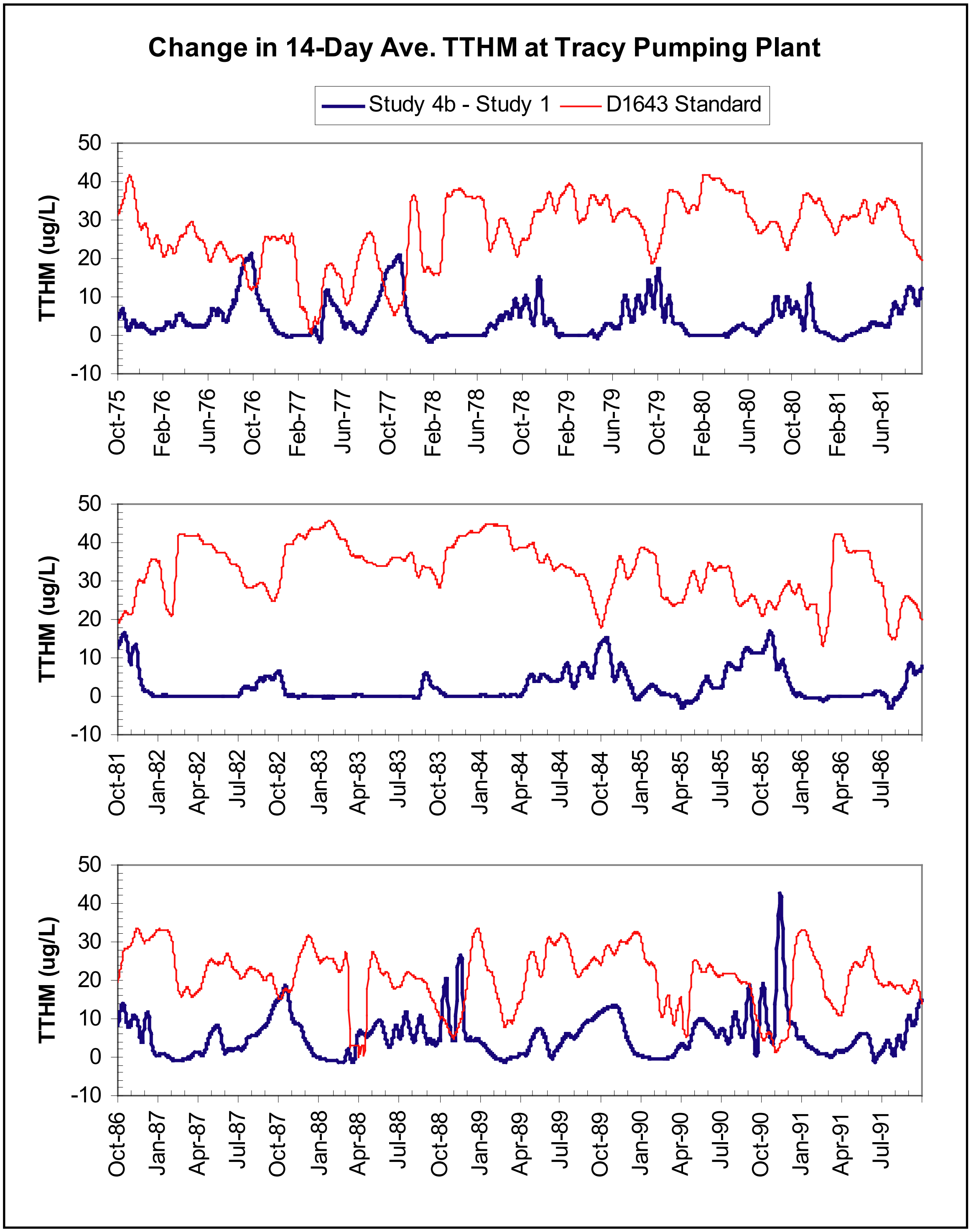

Figure 2.5.34: Change in 14-Day Average TTHM (ug/L) at Tracy Pumping Plant (CVP).

2.5.5 Bromate at Urban Intakes

Like the other water quality constraints, the impact of bromate (TTHM) formation is measured by increases in the project alternative when compared to the modeled base case concentration. Like TTHM, bromate is not directly modeled in DSM2. The WQMP established an incremental standard (described below) and agreed upon the basic modeling approach to be used to calculate bromate. Bromate is calculated as a function of EC, and DOC using the following formulas (Hutton, 2001):

$$BRM = C_2 \times DOC^{0.31} \times Br^{0.73} \qquad \text{Eqn. 5.19}$$

where

BRM = bromate concentration (ug/L),
C_2 = 9.6 when DOC < 4 mg/L,
C_2 = 9.2 when DOC ≥ 4 mg/L,
DOC = raw water dissolved organic carbon (mg/L) from DSM2, and
Br = raw water bromide concentration (mg/L) from EC.

The bromide concentration used in Equation 5.19 was calculated from EC based on its location using the same equations used when calculating TTHM (see *Section 2.5.4*).

The 16-year minimum, average, and maximum daily averaged bromate concentration at the four urban intakes for study 1 (base case) and study 4b is shown below in Table 2.5.15. The bromate concentration associated with the 10th, 25th, 50th, 75th, and 90th percentile at each location is also shown. These percentiles were calculated in the same manner as the chloride percentiles (see *Section 2.5.2*).

Table 2.5.15: Summary of Daily Averaged Bromate (ug/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles				
					10th	25th	50th	75th	90th
RS	Study 1	0.1	5.7	14.3	2.3	3.0	5.2	7.9	10.0
	Study 4b	0.2	6.0	14.9	2.4	3.2	5.5	8.5	10.4
LVR	Study 1	0.2	7.3	18.9	2.4	3.5	6.8	10.3	13.0
	Study 4b	0.1	7.5	19.1	2.4	3.7	6.9	11.0	13.3
SWP	Study 1	0.1	6.9	17.4	2.4	3.7	6.5	9.7	11.8
	Study 4b	0.1	7.1	17.1	2.4	3.8	6.8	10.1	11.9
CVP	Study 1	0.1	7.9	18.4	2.4	5.3	8.0	10.6	12.6
	Study 4b	0.1	8.0	18.4	2.4	5.4	8.1	10.9	12.8

The 14-day average bromate constraints called for by the Delta Wetlands WQMP were calculated every day as the average of the 14 previous days (WQMP, 2000). This was done not only to remain consistent with CALSIM, but also under the assumption that forecasting and operations would make use of the previous 14 days worth of field and modeling data. A summary of the 14-day average bromate constraints is shown in Table 2.5.16.

Table 2.5.16: Summary of 14-Day Average Bromate (ug/L) at Urban Intakes.

Urban Intake	Study	Min	Ave	Max	Percentiles 10th	25th	50th	75th	90th
RS	Study 1	0.6	5.7	13.6	2.3	3.0	5.2	7.9	9.9
	Study 4b	0.7	6.0	14.6	2.4	3.2	5.5	8.5	10.2
LVR	Study 1	0.8	7.3	18.5	2.4	3.5	6.7	10.3	12.9
	Study 4b	0.6	7.5	18.1	2.4	3.8	6.9	11.0	13.2
SWP	Study 1	0.7	6.9	17.1	2.4	3.7	6.5	9.7	11.8
	Study 4b	0.7	7.1	16.8	2.4	3.8	6.8	10.1	11.9
CVP	Study 1	0.3	7.9	16.9	2.4	5.2	8.0	10.5	12.5
	Study 4b	0.3	8.0	17.5	2.4	5.4	8.1	10.9	12.7

Time series plots of the 14-day running average bromate at all four urban intakes are shown below in Figures 2.5.35 – 2.5.38.

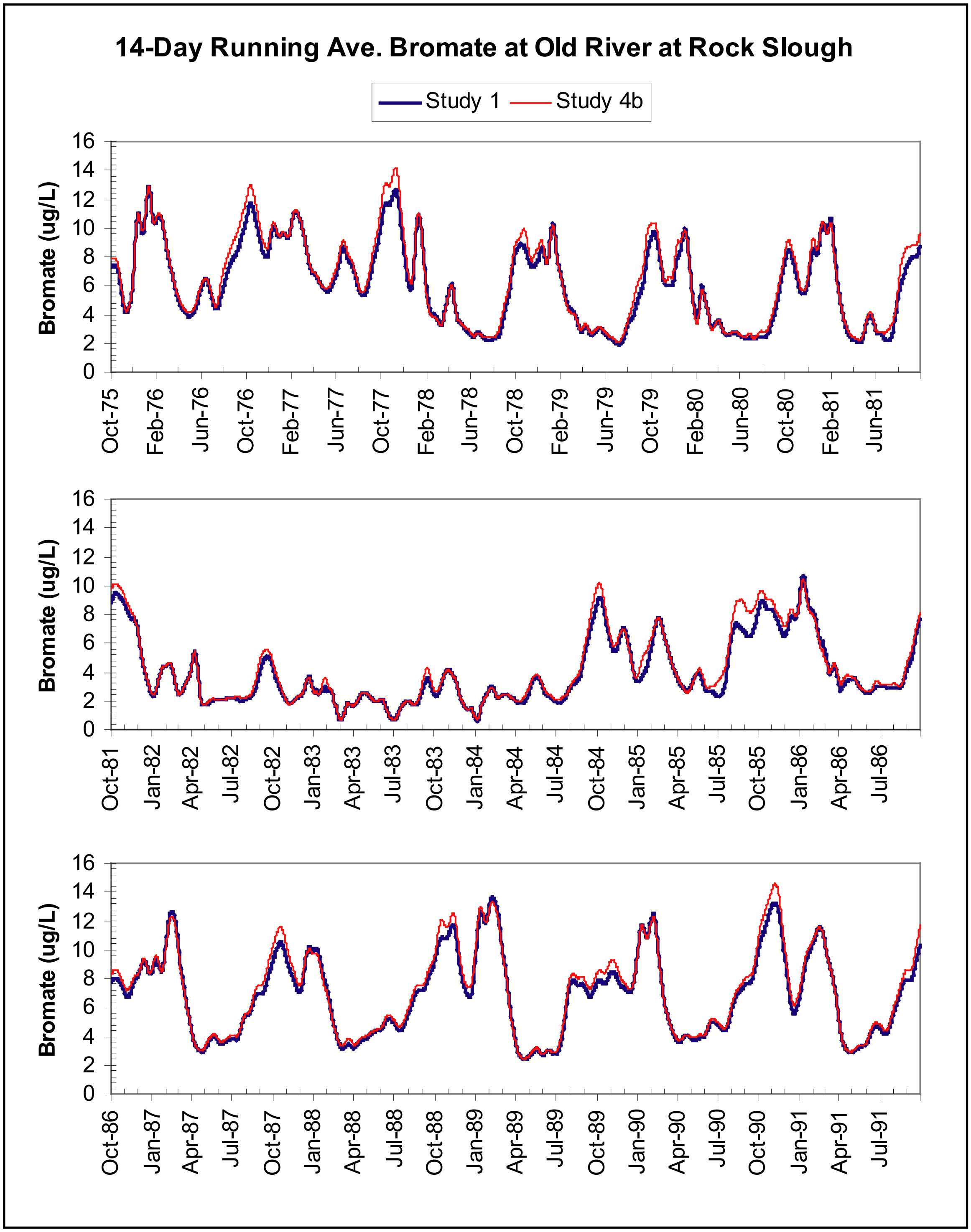

Figure 2.5.35: 14-Day Average Bromate (ug/L) at Old River at Rock Slough (RS).

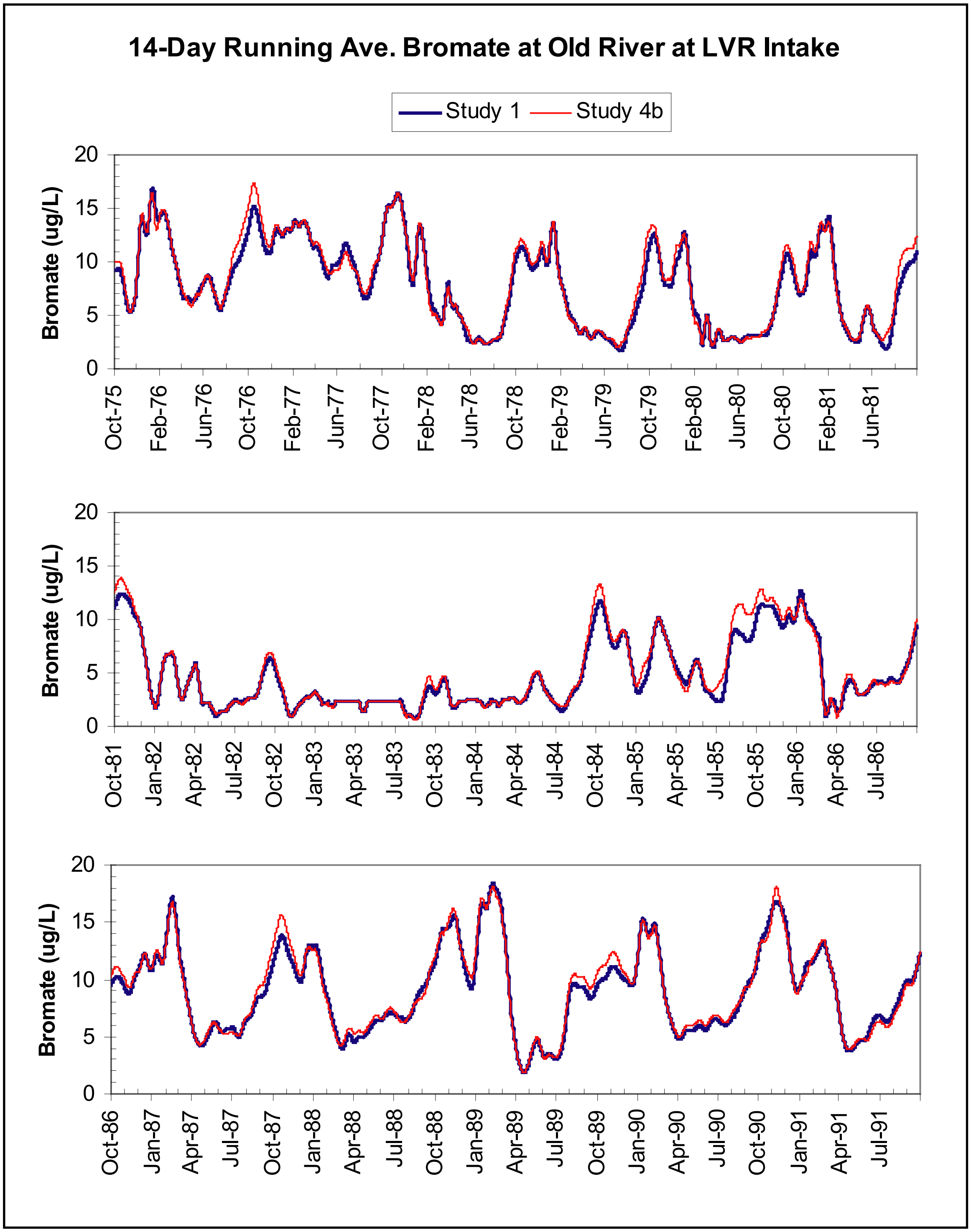

Figure 2.5.36: 14-Day Average Bromate (ug/L) at Old River at LVR Intake (LVR).

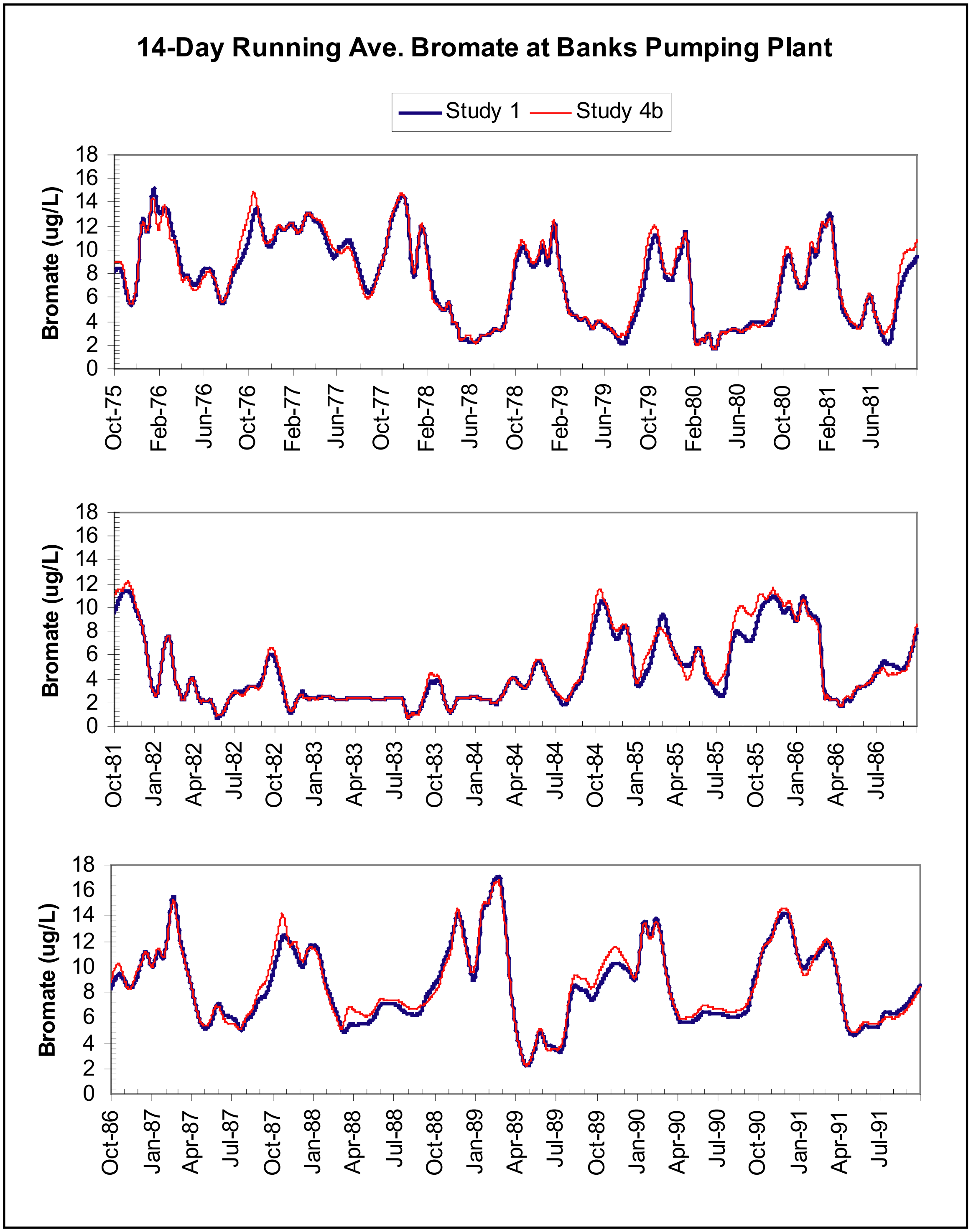

Figure 2.5.37: 14-Day Average Bromate (ug/L) at Banks Pumping Plant (SWP).

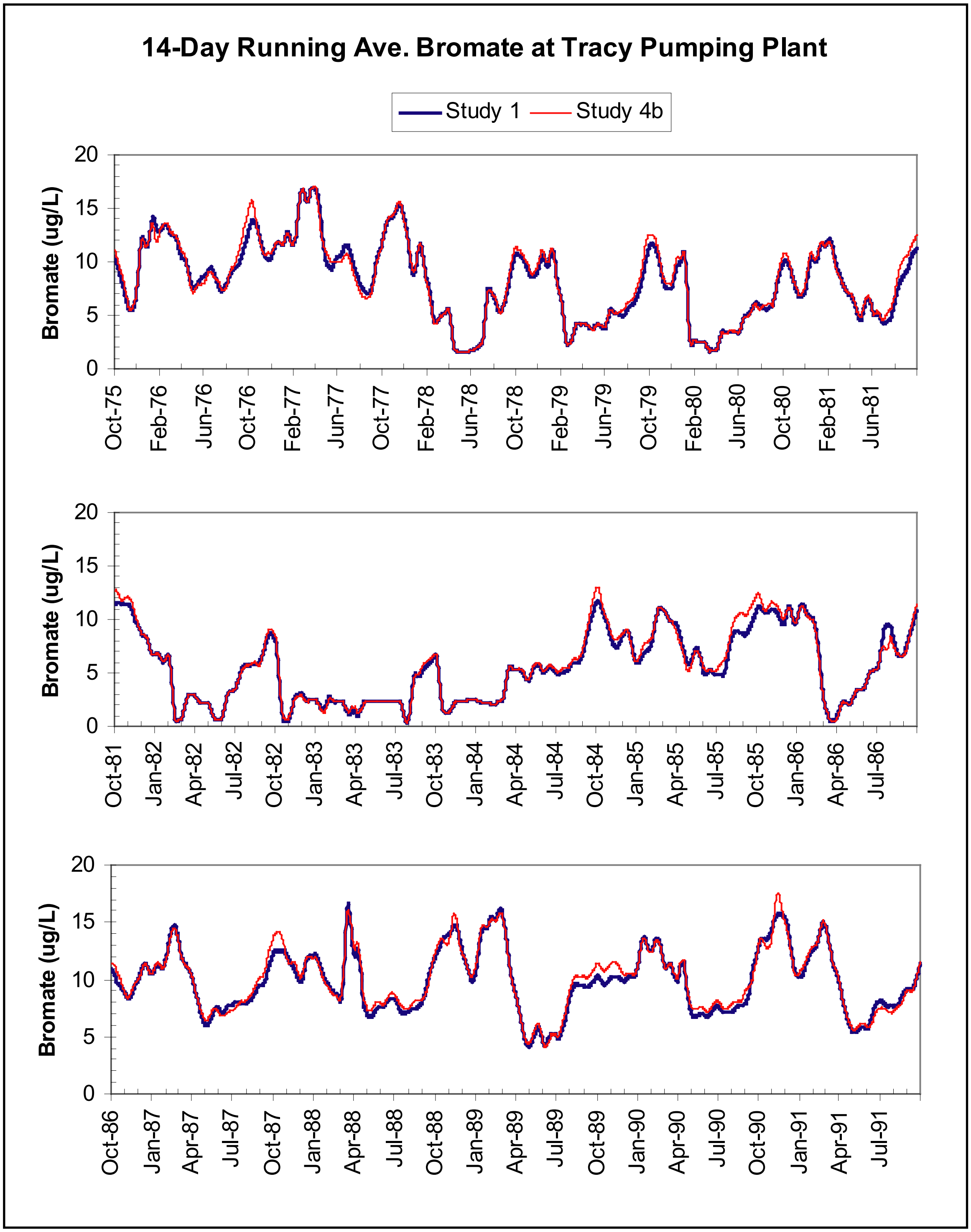

Figure 2.5.38: 14-Day Average Bromate (ug/L) at Tracy Pumping Plant (CVP).

Violations of the Water Quality Management Plan (WQMP) bromate standard are not based on the 14-day averages, but instead on the difference between the new IDS operation and the modeled base case (WQMP, 2000). According to the WQMP, when the modeled base case bromate is less than or equal to 8 ug/L, the modeled project (alternative) bromate can not exceed 8 ug/L. When the base case bromate already exceeds 8 ug/L, the 14-day average increase in bromate concentration at any urban intake can not exceed 0.4 ug/L. The incremental WQMP constraint is illustrated below in Figure 2.5.39.

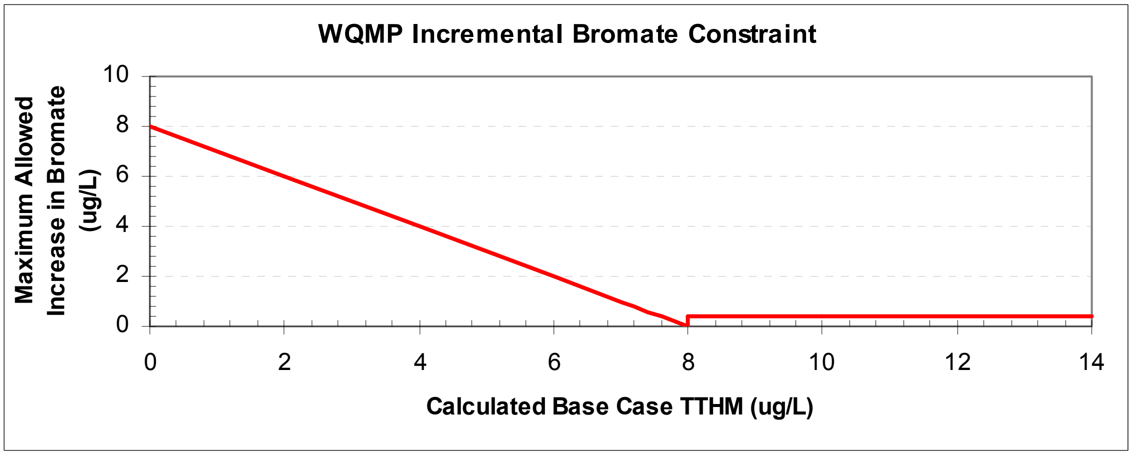

Figure 2.5.39: WQMP Incremental Bromate Constraint.

The 16-year minimum, average, and maximum change (study 4b - study 1) in the 14-day average bromate at the urban intakes is shown in Table 2.5.17.

Table 2.5.17: Summary of Change in 14-Day Bromate (ug/L) at Urban Intakes.

Urban Intake	Min	Ave	Max	Percentiles				
				10th	25th	50th	75th	90th
RS	-0.6	0.3	2.0	-0.1	0.0	0.2	0.5	0.9
LVR	-1.6	0.2	2.8	-0.4	-0.1	0.1	0.5	1.0
SWP	-1.7	0.2	2.5	-0.4	-0.1	0.1	0.4	0.8
CVP	-2.2	0.2	2.0	-0.3	-0.1	0.1	0.4	0.7

The number and frequency of days out of the 5,844 day simulation when the variable WQMP bromate constraint was exceeded were calculated using the modeled base case (study 1) to find the WQMP standard and the change in 14-day average bromate (Table 2.5.18).

Table 2.5.18: Number and Frequency of Days the WQMP Bromate Constraint is Exceeded.

Urban Intake	# Days > Standard	% Days > Standard
RS	1,098	19%
LVR	1,248	22%
SWP	966	17%
CVP	1,161	20%

Time series plots of the change (study 4b – study1) in 14-day running average bromate at all four urban intakes are shown below in Figures 2.5.40 – 2.5.43. The WQMP D1643 change in TTHM standard is also shown.

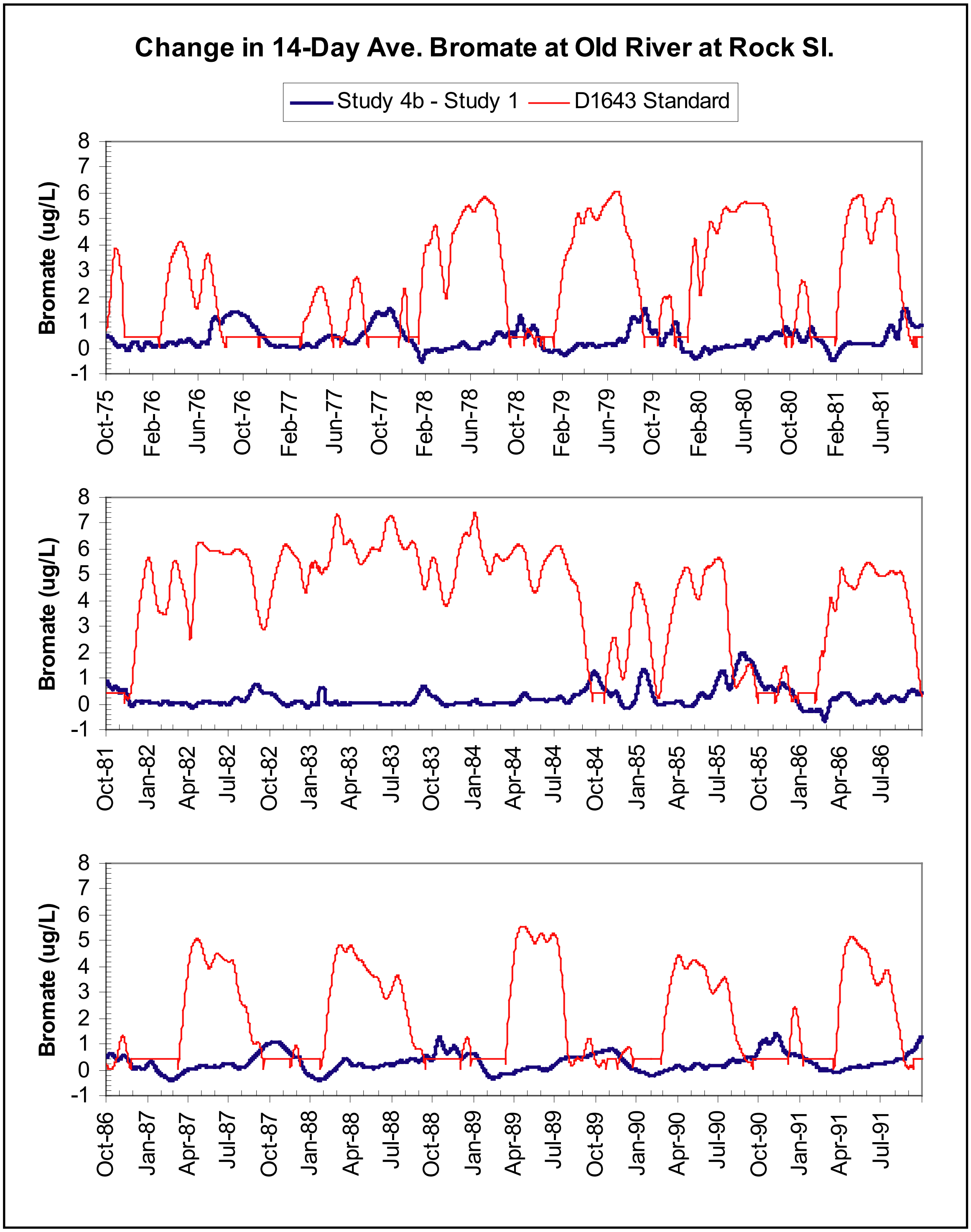

Figure 2.5.40: Change in 14-Day Average Bromate (ug/L) at Old River at Rock Slough (RS).

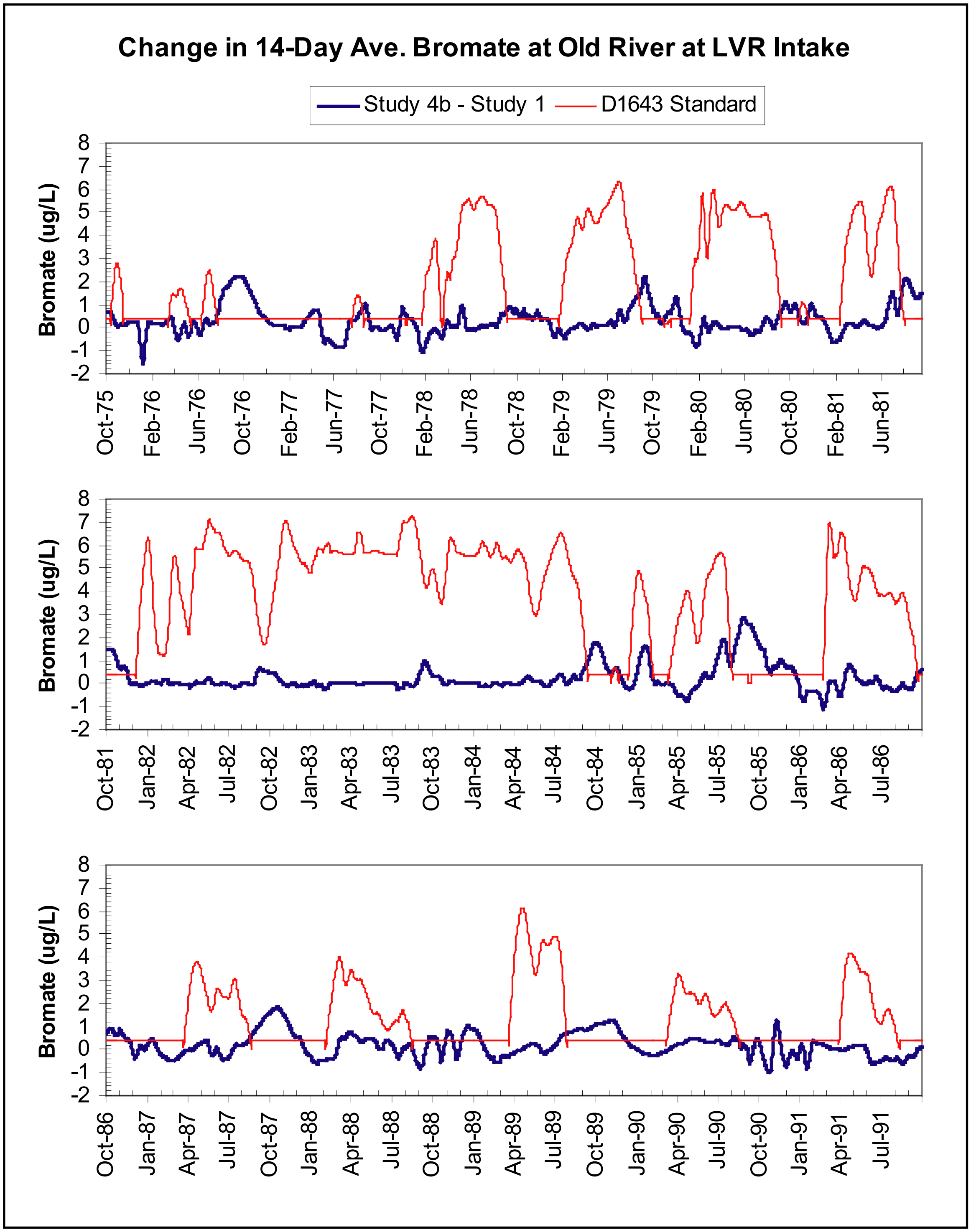

Figure 2.5.41: Change in 14-Day Ave. Bromate (ug/L) at Old River at LVR Intake (LVR).

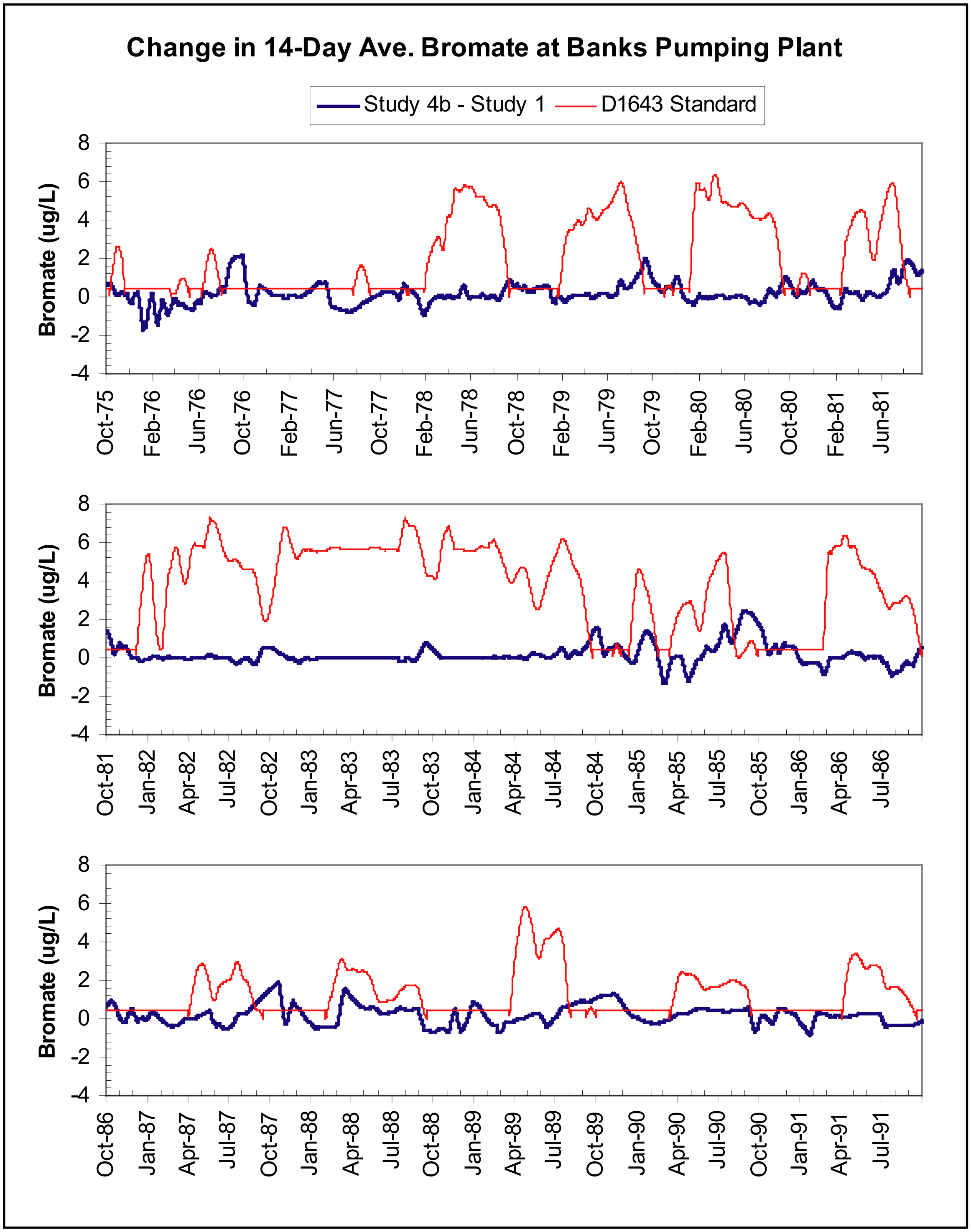

Figure 2.5.42: Change in 14-Day Average Bromate (ug/L) at Banks Pumping Plant (SWP).

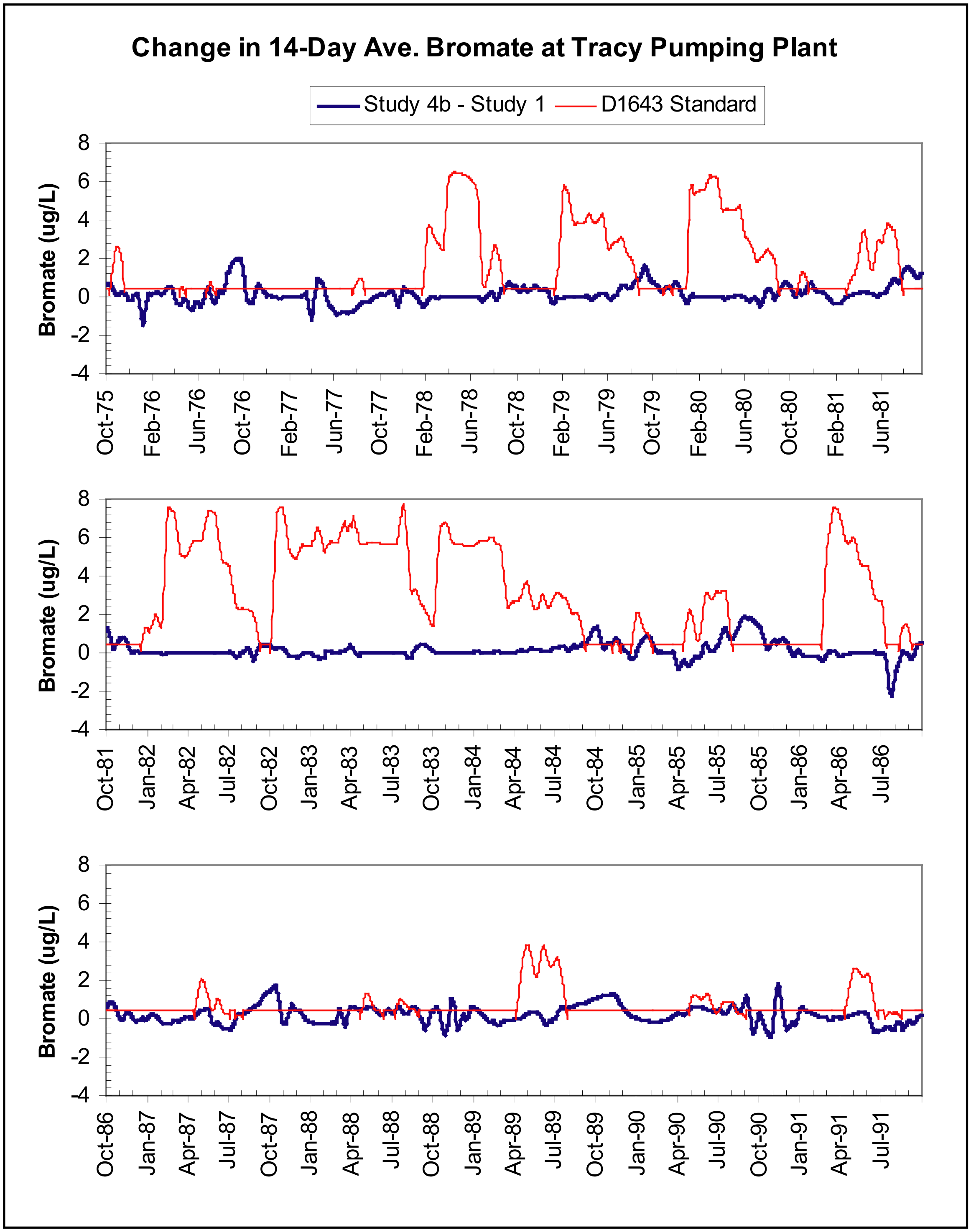

Figure 2.5.43: Change in 14-Day Average Bromate (ug/L) at Tracy Pumping Plant (CVP).

2.6 Conclusions

In general, the DSM2-QUAL results not only reflect changes to Delta water quality due to operation of the project, but should be viewed as responding to larger system wide changes made within CALSIM II due to not just the immediate short-term operations of the project, but also the long-term presence of the IDS project. In other words, DSM2 will show a water quality response when the CALSIM II inflows and exports are changed regardless of the immediate diversions or releases. Although CALSIM II simulated a 72-year period, DSM2 planning studies are still limited to a standard 16-year period. This 16-year period (water years 1976 – 1991) was chosen because a mix of critical, wet, and normal years exist in the historical (and hence CALSIM) hydrology. Though it would be interesting to extend to the DSM2 water quality simulation to the full length of the CALSIM II operations, two constraints still exist:

- Extending the downstream ocean stage boundary condition; and
- Developing practical data storage and processing system to handle 72 years work of hourly tidal data throughout the Delta.

The 16-year minimum, average, and maximum daily average values are presented for most of the DSM2 inputs and all of the water quality constituents: chloride, DOC, TTHM, and bromate. However, the usefulness of these three time-series statistics is extremely limited when analyzing as complex a system as the Sacramento - San Joaquin Delta. Though cumulative frequency distributions have proved useful in prior IDS DSM2 reports, time constraints prevented the generation of these statistics and plots distributions. Instead, 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile states are provided for many of the flow and water quality parameters related to the operation of the IDS project. These percentile values can be used to fill in the general shape of the missing cumulative frequency distributions, and provide valuable insight into change in frequency of events.

Another useful statistic is the change in daily average concentrations (measured as the difference of study 1, the no action base case, from study 4b, the alternative with circulation). Since the differences are calculated before the percentiles are calculated, they preserve the temporal character of the CALSIM operations. In other words, not all of the decreases or increases in water quality parameters are directly related to an immediate operation of the IDS islands. The only changes made within DSM2's description of the Sacramento – San Joaquin Delta were the addition of the project islands and the spatial characterization of the island operations (via the simulation of two integrated facilities per island). In fact, global Delta wide processes such as consumptive or the operation of the South Delta permanent barriers use were not changed, thus the primary possible sources for differences (alternative – base) in water quality are related to:

- Differences in CALSIM II's alternative and base flows and exports;
- Local effects due to circulation and the physical placement of the integrated facilities;
- Temporal effects due to differences in how CALSIM II and DSM2 treat the long-term sinks of organic carbon in the Delta; and
- The amount of organic carbon produced (via the wetted surface area) in each island.

A general summary of the range (16-year min and max), median (50^{th} percentile), and percent time that the WQMP constraints were exceeded (regardless of the magnitude of the difference) for all four urban intakes combined is shown in Table 2.6.1 for the following water quality parameters. The lowest and highest values for all four urban intakes are shown for each of these three statistics. The lowest and highest values frequently come from different locations.

Table 2.6.1: Summary of Change in Water Quality Constituents for all Urban Intakes.

Water Quality Constituent	Range	Median	% Days > WQMP Standard
Chloride	-21.8 – 40.7 mg/L	0.1 – 0.4 mg/L	1 – 8%
DOC	-0.6 – 4.4 mg/L	0.3 – 0.5 mg/L	9 – 33%
TTHM	-4.8 – 42.5 ug/L	2.6 – 3.2 ug/L	3 – 6%
Bromate	-2.2 – 2.8 ug/L	0.1 – 0.2 ug/L	17% - 22%

Again, it is important to not focus on generalized statistics covering all of the locations for the entire simulation period, but rather to spend time reviewing the percentile results for both the change in water quality and absolute results for each individual location. However, though the range of values shows a highly varied response to the various water quality parameters, the median values show a very slight increase in all four water quality parameters covered in this study. The estimate of the percent days that the WQMP standards adopted in D1643 were exceeded does not take into account the magnitude of each exceedence of the standards. At times, the differences between D1643 compliance and a violation are minor. The time series plots for each water quality parameter provide a crude estimate of the magnitude of these differences.

2.7 Recommendations

Though the current study was designed to accommodate a fairly complete simulation of several of the key physical processes (see Figure 2.4.2) unique to the operation of the IDS project, the magnitudes and details associated with some of these processes are not completely understood. Often types of scaling or sensitivity analysis have been used to bookend or justify assumptions made when developing boundary conditions or mechanisms to represent these processes. In most cases, the DSM2 simulations were designed such that these assumptions can be easily repeated and/or tested in future studies. The following are suggestions for improvements to future DSM2 simulations:

- Either remove seepage flows if the reasoning for assigning a fixed concentration to the seepage return flows is insignificant or make use of the current DSM2 setup and conduct an actual sensitivity test on the seepage return flow concentrations;
- Estimate the long-term mass flux of the various water quality constituents passing through the urban intakes;
- Improve the project island volume – flow relationships used in the CALSIM II DOC constraints by rerunning the DSM2-QUAL fingerprinting simulation for conditions similar to the proposed circulation operations;
- Conduct and present a formal scale analysis of the project island volume – flow relationships;
- Develop and apply flow – organic carbon relationships for the flow boundaries;
- Develop and apply a daily ANN or other EC / chloride constraint in CALSIM II to better match the current DSM2 salinity simulations;
- Quantify the difference in organic carbon produced by the project islands in DSM2 to the amount of organic carbon produced in CALSIM II, and if the values are significantly different, rethink the way DSM2 is representing DOC in the project islands; and
- Extend the DSM2 analysis (post-processing) time frame such that cumulative frequency distributions and closer analysis between the CALSIM and DSM2 results may be conducted.

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Chapter 3: WATER QUALITY FIELD INVESTIGATIONS

3.1 Introduction

Disinfection byproducts (DBPs) such as trihalomethanes are an issue of concern for the California water system and the In-Delta Storage Program. Maximum contaminant levels and operational criteria are set by regulatory agencies (e.g., D1643 and WQMP) to protect public health and research is being conducted better understand and manage DBP precursors like total and dissolved organic carbon (TOC and DOC) at their source. Field investigation during the feasibility stage of the study focused on better understanding the reservoir biological processes concepts and variations in organic carbon due to peat soils and biological productivity. The field investigations included the following specific tasks to estimate the organic carbon loading from peat soils and biological productivity.

- Reviewed the literature on organic carbon loading in the Delta for information that may be applicable to In-Delta storage.
- Evaluated likely Organic Carbon (OC) concentrations and loads expected in storage water using mesocosms or physical models of the proposed reservoir islands. The experiments were extended to simulation of water circulation in reservoirs to resolve the water quality issues.
- Integrated results from field studies with mathematical models (CALSIM II, DSM2, and DYRESM) to resolve water quality issues and develop desired operations for overall system benefits.

This section is organized to present general information on the development of a conceptual model and the experimental physical model (mesocosms) in the rest of this introductory Section 3.1. Section 3.2 describes the materials and methods used in the mesocosm experiment and Section 3.3 presents and discusses the results. How the data from the experiment were used in the mathematical models is described in Section 3.4. Section 3.5 lists references.

3.1.1 Development of Conceptual Model

DOC and particulate organic carbon (POC) in surface water can come from external or internal sources. For reservoir construction in wetlands, soil could be a dominant source of OC loading, at least initially. In order to adequately predict and mitigate both short-term and long-term impacts associated with flooding peat soils, it is important to understand not just the likely quantity of OC loading but also the quality or sources of that loading. A simplified conceptual model showing the sources of major biological and physical factors in the reservoir DOC is shown in Figure 3.1.

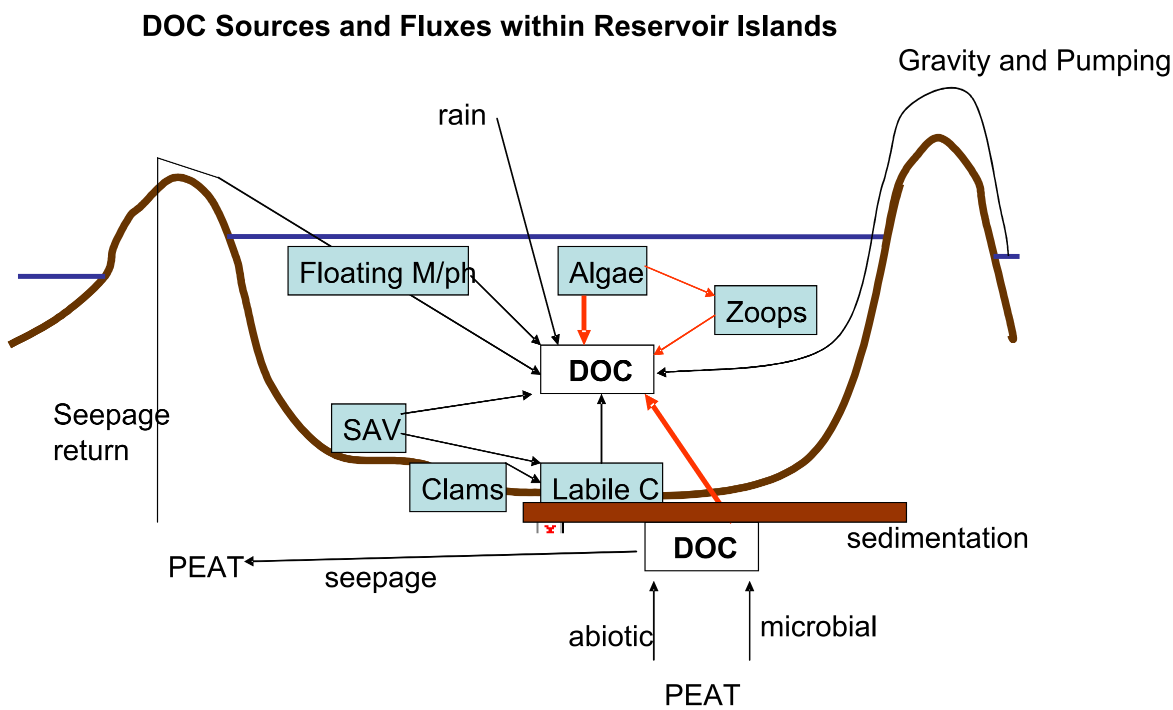

Figure 3.1: Conceptual Model Showing the DOC Sources in Project Island

3.1.2 Development of Physical Models (Mesocosms)

Mesocosms or physical models of the proposed reservoir islands were created to study the ecological processes driving OC loading. This mesocosm study was designed to meet specific needs and timelines of the program. The focus of the study was to reduce uncertainty surrounding estimates of likely rates for the process of OC loading in the proposed reservoir islands. The mesocosms were put together using naturally occurring water and biota. The objective of the experimental design was to include as many complex and interacting ecological factors that drive carbon dynamics in the Delta as possible. Study results in terms of net OC loading rates (such as interacting processes like abiotic leaching, microbial degradation, photooxidation and macrophyte growth and death decomposition) were considered together. Nevertheless, the use of water depth as a treatment variable with the mechanism of light attenuation driving submersed macrophyte growth in a replicated, controlled mesocosm experiment provided a start for fleshing out qualitative and quantitative differences in OC sources.

3.2 Materials and Methods

Mesocosm studies were conducted from March through December 2002 at the Municipal Water Quality Investigations Field Support Unit in Bryte, California (Plate 3.1). Four 3300 L (shallow) and four 6100 L (deep) mesocosms were put together using fiberglass tanks (1.5 m diameter and 1.8 or 3.4 m height respectively). The eight tanks (mesocosms) were filled with 820 L (0.5 m depth) of peat soil, classified as Rindge series muck (Plate 3.2), collected from Bacon Island, California, the site for one of the proposed reservoirs, on March 5, 2002. Before adding the soil to the tanks, living plant material was removed and the soil was well mixed using a front end loader and backhoe (Plate 3. 3). The Division of Natural Resources Analytical Laboratory at the University of California, Davis analyzed the soil for the following analytical groups: salinity, fertility, extractable micronutrients and exchangeable cations. Information on the lab and their analytical methods is available at (http://danranlab.ucdavis.edu/). In addition to these analyses, the % carbon (C), % hydrogen (H) and % nitrogen (N) content of the soil was determined using a Perkin-Elmer model 2400 CHN analyzer with acetanilide used as a standard. Soil fresh weight (fw) % moisture, % ash and % organic matter (OM) as well as dry weight (dw) % ash and % OM and loose soil bulk density were also determined before the soil was added to the tanks (Table 1). The soil was compacted somewhat once inside of the tanks by walking on it as it was applied, leveled and adjusted to the 0.5 m depth.

Plate 3.1: Fiberglass Mesocosms

Plate 3.2: Peat Soil (Rindge Muck) Sample

Plate 3.3: Backhoe and Dump Trucks at Bacon Island

3.2.1 Simulated Hydrology

On March 12, 2002 the tanks were filled with Sacramento River water collected at West Sacramento using a 11,355 L water truck. Once filled, the depth of water over the peat soil was approximately 1.4 m in the shallow mesocosms and 2.9 m in the deep mesocosms. An additional 6,100 L tank was filled with river water only (no soil) and served as a control mesocosm. The water was baffled during filling to reduce soil disturbance. Nevertheless, some mixing of the soil with the overlying water occurred for a few days after the tanks were filled as gas bubbles escaped from the soil and entrained soil particles in the water column. Secchi disk visibility was less than 0.3 m in the days following filling. Two weeks after filling most of the suspended soil particles settled out and Secchi disk visibility increased to one meter (data not shown). Turbidity measurements of water in the mesocosms are presented in Figure 3.2.

Table 3.1: Physical and Chemical Properties of the Peat Soil

Table 1. Physical and chemical conditions of the peat soil used in the experiment.

Analyte	Result	Unit	Reporting Limit
SP[a]	126	%	1
EC	2.98	mmhos/cm	0.01
pH	4.3	pH units	0.1
Ca (SP)	17.5	meq/L	0.1
Mg (SP)	12.1	meq/L	0.1
Na (SP)	5.8	meq/L	0.1
Cl (SP)	3	meq/L	0.1
HCO_3 (SP)	0.6	meq/L	0.1
CO_3 (SP)	<0.1	meq/L	0.1
SO_4-S (SP)	356	ppm	1
NH_4-N	37.5	ppm	0.1
NO_3-N	156	ppm	1
P-Olsen	73	ppm	0.1
Fe (DTPA[b])	688	ppm	1
Mn (DTPA[b])	10.4	ppm	0.1
Cu (DTPA[b])	0.6	ppm	0.1
Zn (DTPA[b])	1.6	ppm	0.1
X[c]-K	1	meq/100g	0.1
X[c]-Na	1.4	meq/100g	0.1
X[c]-Ca	19.6	meq/100g	0.1
X[c]-Mg	6.8	meq/100g	0.1
Soil Density[d]	0.743	Kg/L	1
Soil Moisture	40	%	NA
Organic Matter (dw)[e]	45	%	NA
Ash (dw)[e]	55	%	NA
Carbon[f]	26	%	NA
Nitrogen[f]	1.4	%	NA

[a] The saturation percentage (SP) method involves saturating the soil with water and subsequent extraction under partial vacuum of the liquid phase for the determination of dissolved salts. Soil moisture at the point of complete saturation is the maximum amount of water held when all the soil pore space is occupied by water and when no free water has collected on the surface of the paste.

[b] The DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method is a non-equilibrium extraction for estimating the potential soil availability of Zn, Cu, Mn and Fe.

[c] Equilibrium extraction of soil for plant available exchangeable potassium, sodium, calcium and magnesium using 1 Normal ammonium acetate (pH 7.0) and subsequent determination by atomic absorption/emission spectrometry

[d] The mass (743g) of 1L of fresh (not oven dried) non-compacted soil divided by 1KG

[e] By combustion of oven dried (70 C) soil in muffle furnace

[f] By CHN analyzer

The mesocosms were filled and drained according to typical modeled reservoir operations. Based on modeled operations, January is the most typical month in which sufficient water is available in the Delta to fill the reservoirs. Filling the tanks in early March was less representative of typical operations than a January fill but the unavoidable result of logistics constraints. The theoretical reservoirs are usually emptied in June and July to a minimum depth of 0.3 meters. The minimum depth is maintained by topping-off diversions. Filling and draining of the reservoirs usually takes two to four weeks depending on the pumping plant design (number of pumps and capacity). Because of logistics constraints and the late start, the tanks were filled in one day on March 12, 2002. The mesocosms were emptied by the same volume each day from July 29 through August 7 until a minimum depth of 0.3 m was reached, to better simulate how the reservoirs will be drained. As the mesocosms were drained, water pressure on the peat soil at the bottom was reduced and gas bubbles again escaped from the soil, mostly in the deep mesocosms. Note the dramatic increase in turbidity in the deep mesocosms after draining to a depth of 0.3 m (Figure 3.2). It was not clear if the gas was from air trapped in the soil when the tanks were initially filled or if the gas was from microbial activity or other sources. The mesocosms were maintained at a Depth of 0.3 m through the end of December except for the addition of rain water which increased the drained depth from 0.3 m to about 0.5 m in the last few weeks of the study. Rain did not have an obvious effect on the mesocosms during must of the study especially when the mesocosms were full and precipitation was only a small fraction (on the order of 1%) of tank volume. Rainfall data for Bryte, CA in are shown in Figure 3.3. River water was added at least monthly to make up for evaporation loss. The tanks were refilled in January 2003 and a second year of this study is currently underway. Similar reservoir operations with winter filling and summer draining were used in the second year's study but a small circulation flow (approximately 15% of reservoir water volume exchanged per month) was simulated in the mesocosms.

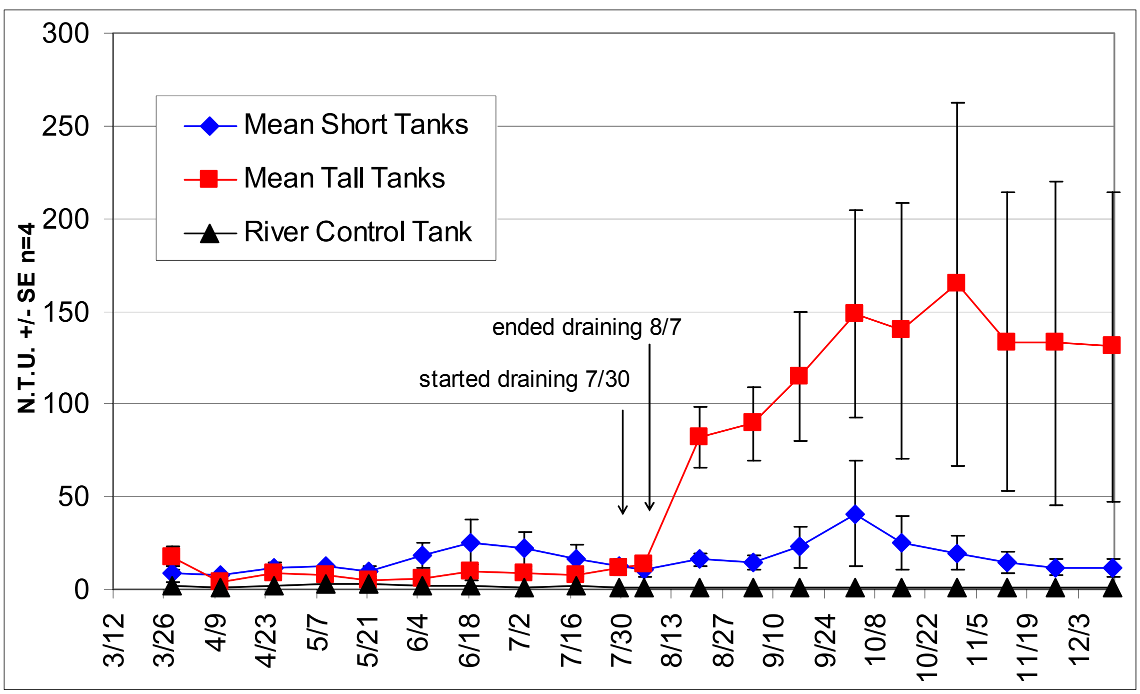

Figure 3.2: Mean Turbidity in Mesocosms in 2002

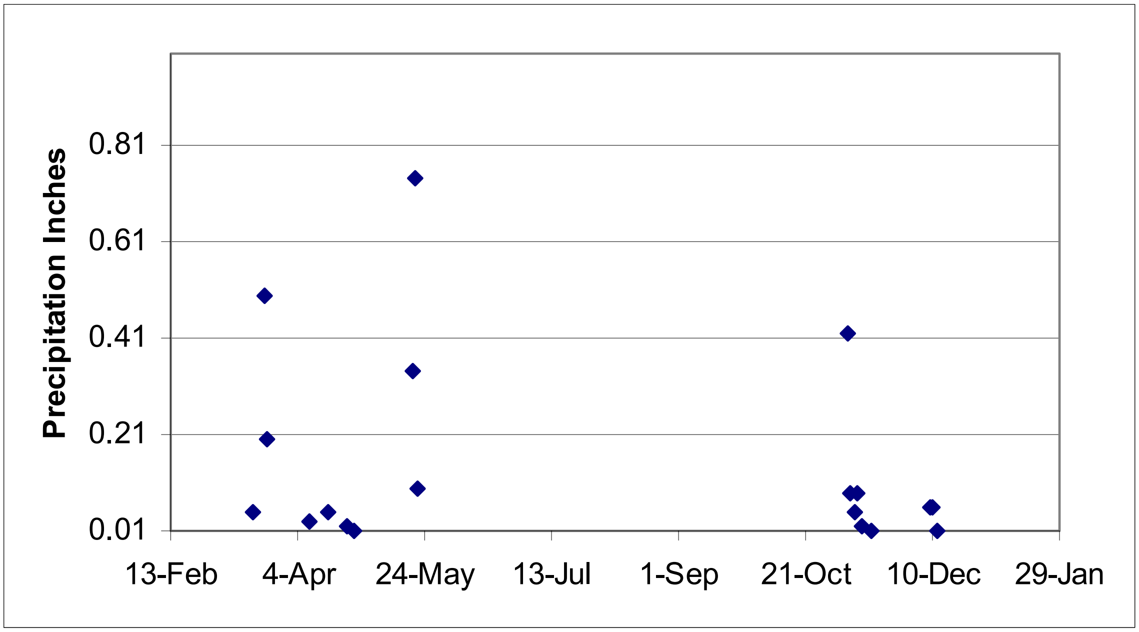

Figure 3.3: Daily Precipitation Totals for Bryte Station for 2003-2003

3.2.2 Soil Disturbance

Disturbance or manipulation of the soil used to fill the mesocosms was not considered a problem in this study. The objective of the study was to physically model conditions in the proposed reservoir islands after flooding. Of the proposed reservoir islands' land areas, 85% to 90% is in production agriculture and subject to the disturbance of annual tilling. Tilling turns over approximately the top 30 cm of soil, the same surface layer of soil collected for this study. Note the vast area of tilled peat soil in the agricultural fields of Bacon Island shown in Plate 3.3. Peat soil on the reservoir islands will also be disturbed during construction of the integrated facilities, levee modification and excavation for borrow material (sand) located under the peat soil. This disturbed peat soil will form the soil/water interface when the islands are flooded. Gas bubbles will also escape from the reservoir soils when the islands are first flooded. In addition, the reservoirs will be filled through pumping facilities at a rate of 1500 cfs. This flowing water together with wind waves will cause some erosion and mixing of soil and water during filling. Nevertheless, the same soil and mesocosms were used in the second year's study. Other than the simulated reservoir diversions and discharges and the resulting release of interstitial gas bubbles, which will also occur in the real reservoir islands, disturbance did not occur in this subsequent year's study.

3.2.3 Biota

Soil from Bacon Island (one of the proposed reservoir islands) together with naturally occurring biota in the Sacramento River water as well as macrophytes, invertebrates and fish collected from the Delta were used in this study to create physical models (mesocosms) of the reservoir islands. Soil from one of the proposed reservoirs was used and provided inoculation of the mesocosms with appropriate seeds, eggs and organisms.

The Sacramento River will be the source of most of the water diverted to the reservoir islands. Untreated water from this river was added to the tanks within an hour of collection in order minimize plankton mortality. The most common zooplankton that developed in the mesocosms were (in order of abundance): cyclopoid nauplii, *Acanthocyclops vernalis*, *Bosmina*, *Daphnia* and rotifers. Common phytoplankton included: *Ankistrodesmus, Synedra, Cryptomonas, Melosira, Chlorella, Chlamydomonas* and unidentified flagellates.

Egeria densa is probably the most abundant submersed macrophyte in the Delta although good diversity and abundance data do not exist for submersed or other aquatic plants in the Delta (Jassby and Cloern 2000). After observing the onset of active growth of *Egeria* in the Delta, fragments were collected from Franks Tract and added to the mesocosms that same day, April 17, 2002. Ten fragments (total 80 g f.w.) were added to each mesocosm. Naturally occurring invertebrates, epiphytic algae, eggs or other organisms on the *Egeria* fragments were not removed and the fragments were transported in coolers filled with Delta water to minimize mortality. Light levels in the mesocosms were approximately 550 and 150 µmol m^{-2} s^{-1} at depths of 0.3 and 1.0 m respectively in the mesocosms. In the deep mesocosms, light levels were less than 50 µmol m^{-2} s^{-1} at depths over two meters and were probably too low to support *Egeria* growth. In May 2003 however, an *Egeria* stem was observed growing up to the surface in one of the deep mesocosms. Light levels may have been higher, high enough to support growth of any surviving *Egeria*, when the mesocosms were in a drained (0.3 m depth) condition from August 2002 to January 2003.

On May 1, eleven adult Threespine stickleback were added to each mesocosm. These fish were selected because they are naturally occurring in the Delta and they satisfied mosquito concerns of the County vector control district. *Gambusia* populations unexpectedly appeared in the mesocosms and it is not clear if these recruits got in with the Threespine stickleback, the river water, *Egeria* fragments or otherwise. Minnow traps were used to remove the fish from the mesocosms before draining. Trapping was stopped when fish were no longer caught. More *Gambusia* than threespine sticklebacks were caught in the traps. Some adult threespine sticklebacks died before trapping and were removed when found. Trapping did not completely remove all of the fish because additional threespine stickleback juveniles were caught in 2003.

3.2.4 Temperature and Dissolved Oxygen

Maximum and minimum water temperatures in the mesocosms were recorded every two weeks and ranged from 8 to 34 C during the study. Temperature changes between day and night were enough to keep the mesocosms from permanently stratifying. Diurnal stratification did develop in the mesocosms, especially on hot summer afternoons, but cool nights resulted in homogeneous temperatures and DO concentrations early in the morning. To simulate wave action and mixing on the surface of the reservoirs and to ensure dissolved oxygen (DO) concentrations remain high enough for fish, small aquarium air stones (4 cm-length x 1.3 cm width) were placed five cm under the water surface on the same day that the fish were added. On September 4, 2002 a kink in the air line to one of the short tanks was observed. Without aeration, DO concentrations dropped to 4.6 mg/L. After the kink was removed, DO concentrations returned to nearly saturated concentrations. Otherwise, the lowest DO concentration observed in the mesocosms was 5.7 mg/L and occurred before the aeration stones were installed. With aeration, DO concentrations remained close to or above saturation. The size and placement of the air stones were such that approximately the top 20 cm of water were mixed but mixed gently enough so not to disturb the sediment/water interface which was about 140 and 290 cm below the surface in the shallow and deep mesocosms, respectively. Low turbidity measurements through April and May show that the sediment was not stirred when the airstones were installed on May1, 2002 (Figure 3.2). As mentioned, the jump in turbidity following draining was probably due to the loss of head pressure and the observed gas bubbles escaping from the peat soil. Diurnal temperature stratification was less obvious after installation of the air stones but was still observed on hot afternoons.

3.2.5 Water Sampling

Water samples were taken from a depth of 0.3 m from each mesocosm every two weeks using a Van Dorn sampler. Samples were analyzed using standard methods by the Department of Water Resources Bryte Analytical Laboratory (http://wq.water.ca.gov/bryte/) for the following water quality parameters: Total Organic Carbon by combustion (TOC), Dissolved Organic Carbon by combustion (DOC), UV Absorbance at 254nm (UV254), Turbidity, pH, Total Mercury, Total Kjeldahl Nitrogen (TKN), Dissolved Ammonia, Dissolved Nitrite and Nitrate, Total phosphorus and Ortho-phosphate. In addition to these water quality measures, the following field data were collected at the time of sampling: Temperature, Dissolved Oxygen (DO) and Secchi Depth. Sub-samples of juvenile fish trapped in 2002 were analyzed for whole fish total mercury concentrations by the California Department of Fish and Game Water Pollution Control Laboratory in Rancho Cordova, California. These analyzed fish hatched in the mesocosms, were observed as fry and were later trapped and analyzed at a juvenile length of approximately two to three cm.

3.2.6 Salinity

Salinity in the mesocosms was not monitored in 2002. However, at the end of the study, specific conductance (SC) was 194 uS/cm in the deep mesocosms and 243 uS/cm in the shallow mesocosms. Specific conductance in the Sacramento River at West Sacramento ranges from 124 to 241 uS/cm, and is 161 uS/cm on average (DWR 2003). During the study period, March through December 2002, evaporation less precipitation was approximately 50 cm in the mesocosms. The water lost to evaporation was replaced with Sacramento River water collected from the same West Sacramento location. In the deep mesocosms which contain approximately 290 cm of water, this 50 cm of water loss is about 18% of the volume. Specific conductance of the water used to fill the mesocosms in early 2003 was about 170 uS/cm. Assuming a starting SC of 170 uS/cm, an 18% increase in SC would have resulted in an increase of SC from about 170 to 201 uS/cm, consistent with the measured SC at the end of the study which ranged from 180 to 204 uS/cm in the four mesocosms. Similarly in the shallow mesocosms which contain slightly less than half the water volume as the deep mesocosms, a 36% increase in SC would have resulted in an increase of SC from about 170 to 231 uS/cm, consistent with the measured SC at the end of the study which ranged from 234 to 257 uS/cm in the four mesocosms. Other factors that could have affected salinity include the potential release of salt from the soil and the fact that precipitation fell in the mesocosms not just when they were full but also when they were drained to a depth of one foot which would increase dilution of salts. Nevertheless, increases in salinity were consistent with what would be expected from evaporation and dramatic changes in salinity were not apparent.

3.3 Results and Discussion

Using mesocosms or physical models of the proposed reservoir islands allowed for a better understanding of some ecological processes that will influence project operations and be influenced by operations. Phytoplankton biomass at the time of reservoir release was lower than expected considering that nutrient rich agricultural peat soils were flooded. Further understanding of the mechanisms likely to control phytoplankton dynamics and the development of predictive models for the proposed reservoirs will require additional small, medium and large scale studies. Nutrient concentrations in the mesocosms are presented in Figures 3.4 through 3.8. Chlorophyll *a* and pheophytin *a* concentrations are presented in Figures 3.9 and 3.10, respectively. Zooplankton developed visible clusters in the clear-brown water of the mesocosms and may have controlled algal populations, but again many additional studies are needed, on many scales, to flesh out all the complex and interacting ecological processes controlling the processes of phytoplankton dynamics and their effects on the process of OC loading. Another factor, among many, that may be in part responsible for lower than expected phytoplankton contributions to OC concentrations could be a negative interaction between DOC and phytoplankton (Carpenter et al. 1998). Plate 3.4 shows a sample of the clear-brown, DOC rich, water in the mesocosms.

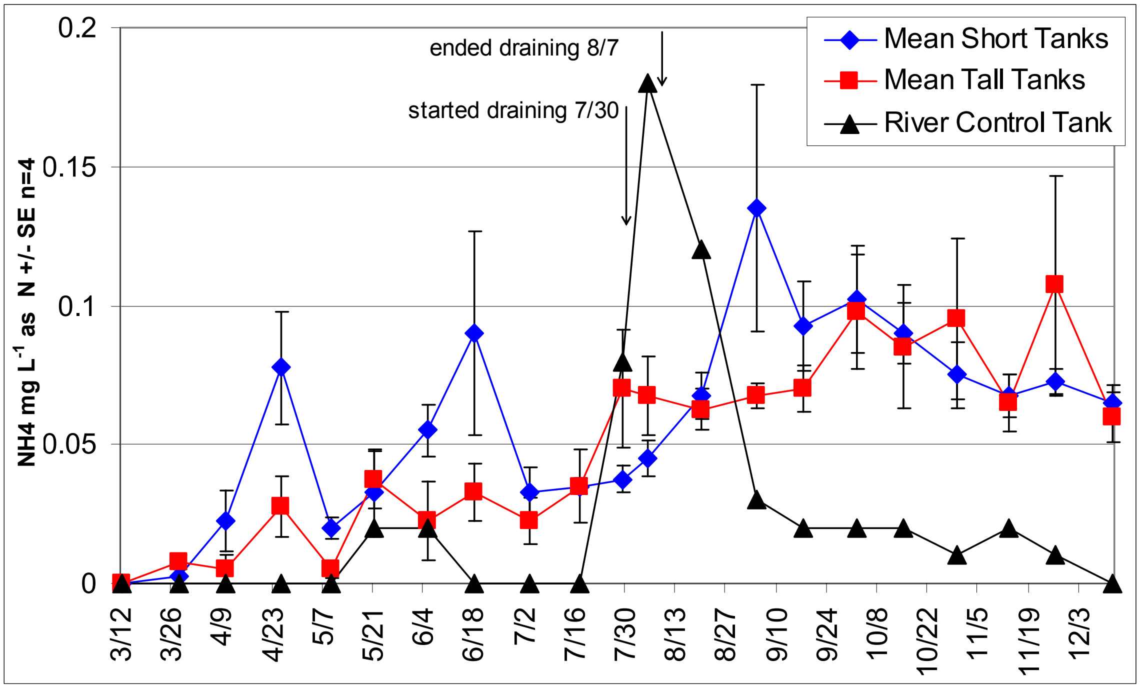

Figure 3.4: Mean Dissolved Ammonia in Mesocosms

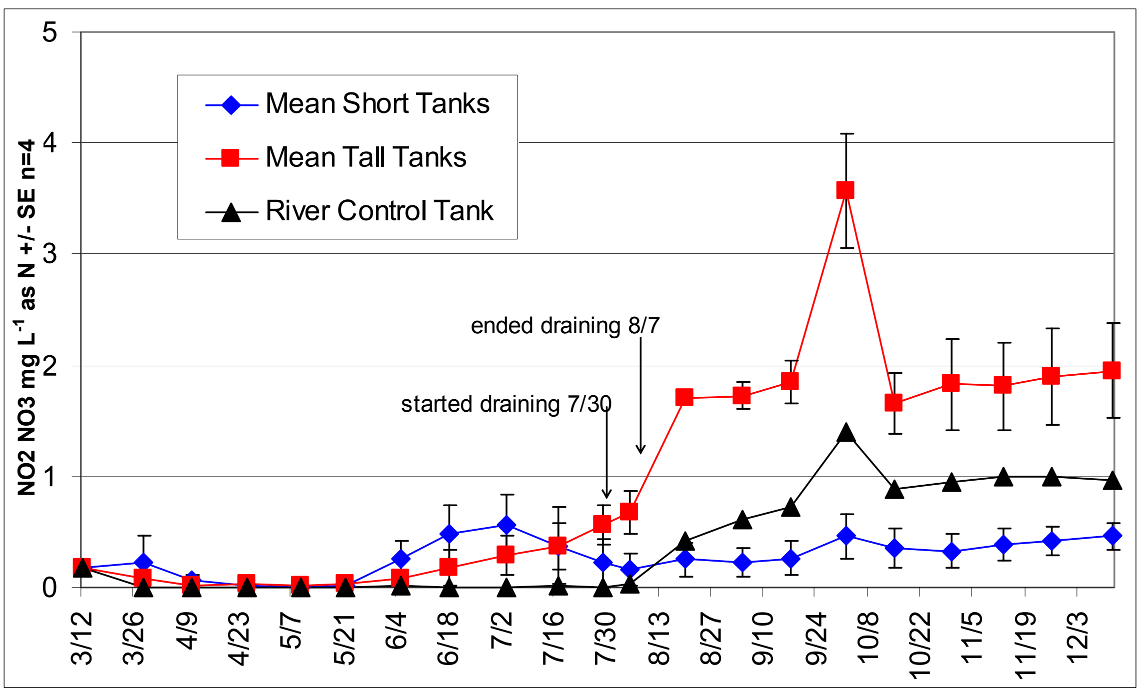

Figure 3.5: Mean Dissolved Nitrite and Nitrate in Mesocosms

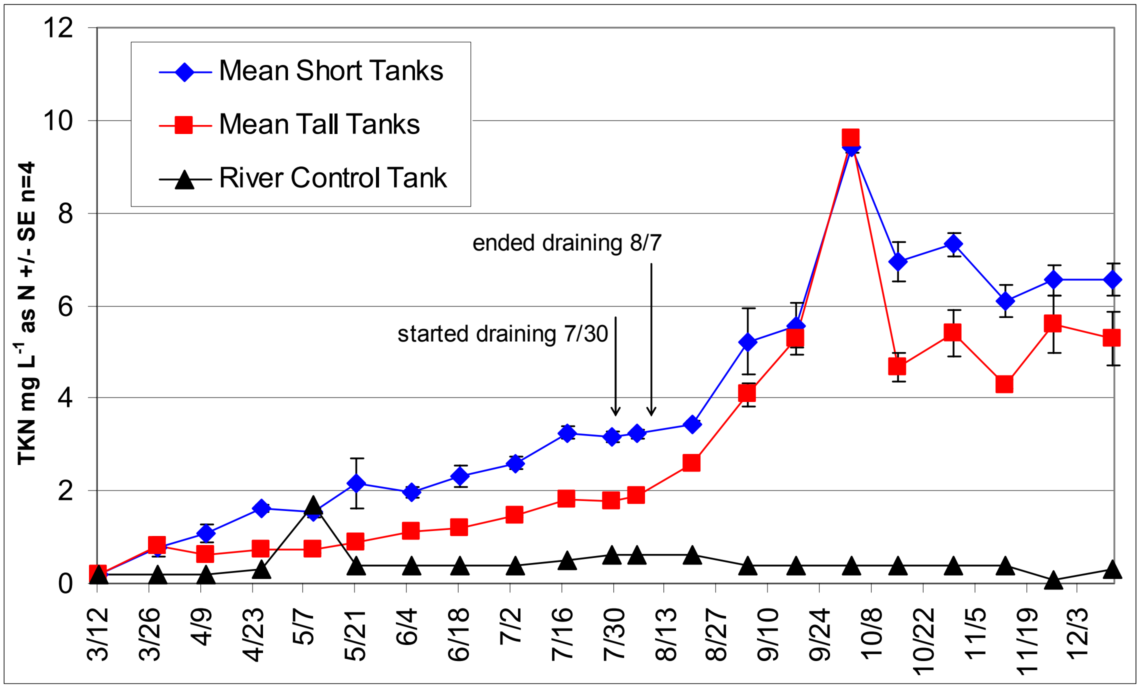

Figure 3.6: Mean TKN in Mesocosms

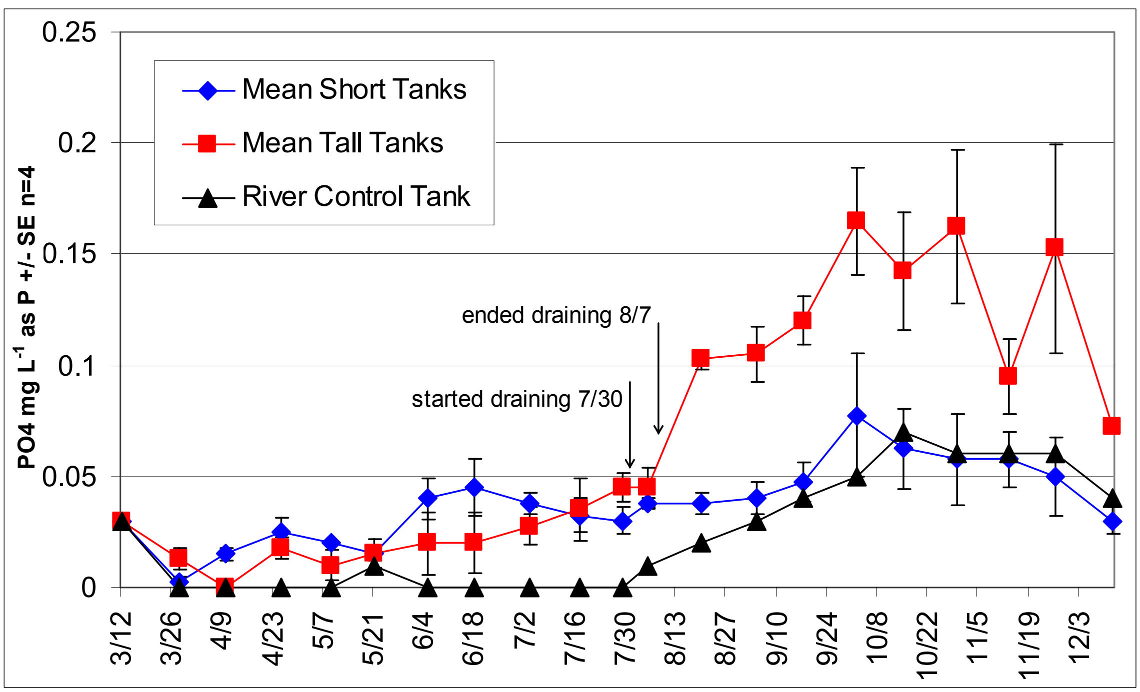

Figure 3.7: Mean Dissolved Orthophosphate in Mesocosms

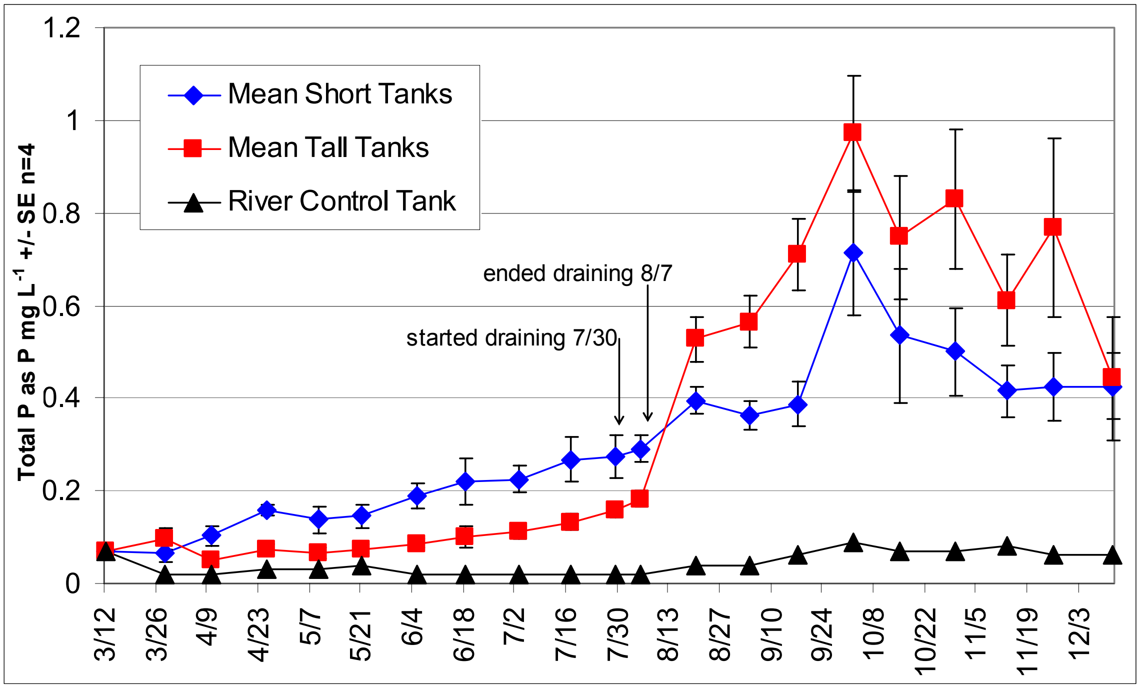

Figure 3.8: Mean Total Phosphorus in Mesocosms

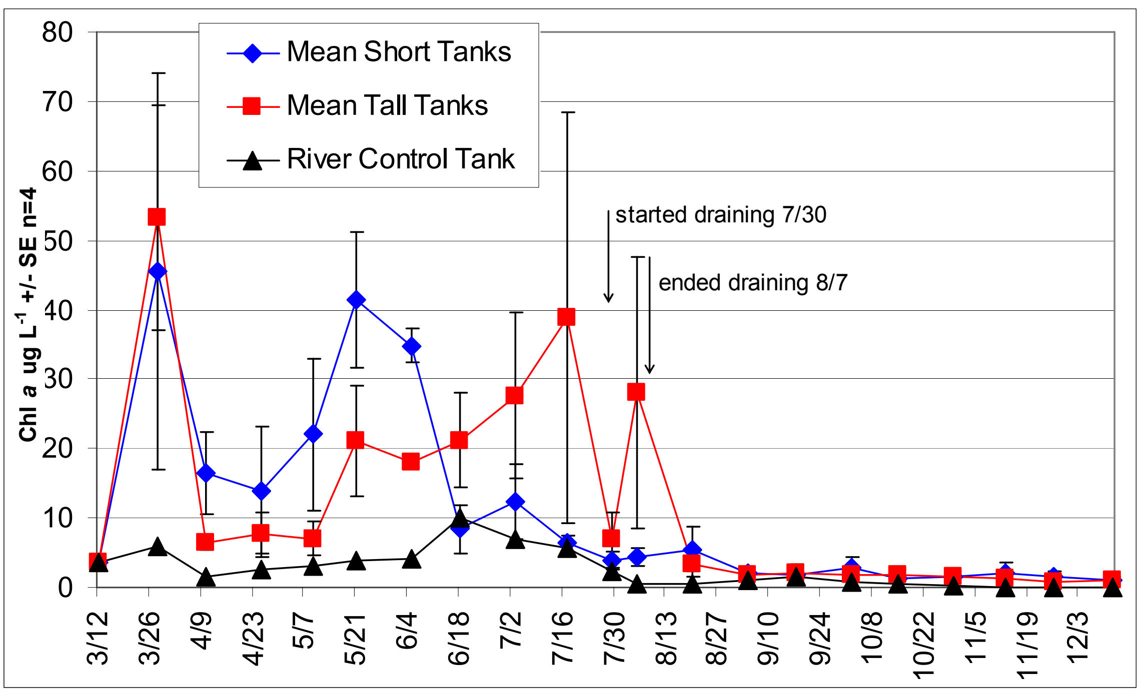

Figure 3.9: Mean Chlorophyll a Concentrations in Mesocosms

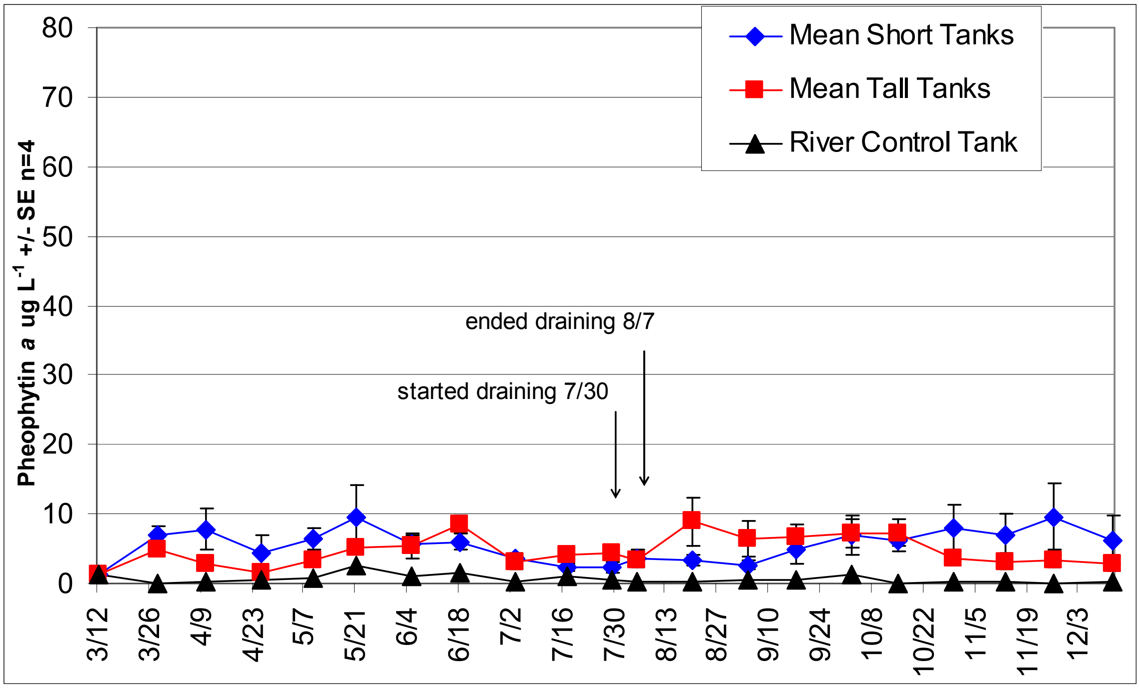

Figure 3.10: Mean Pheophytin a Concentrations in Mesocosms

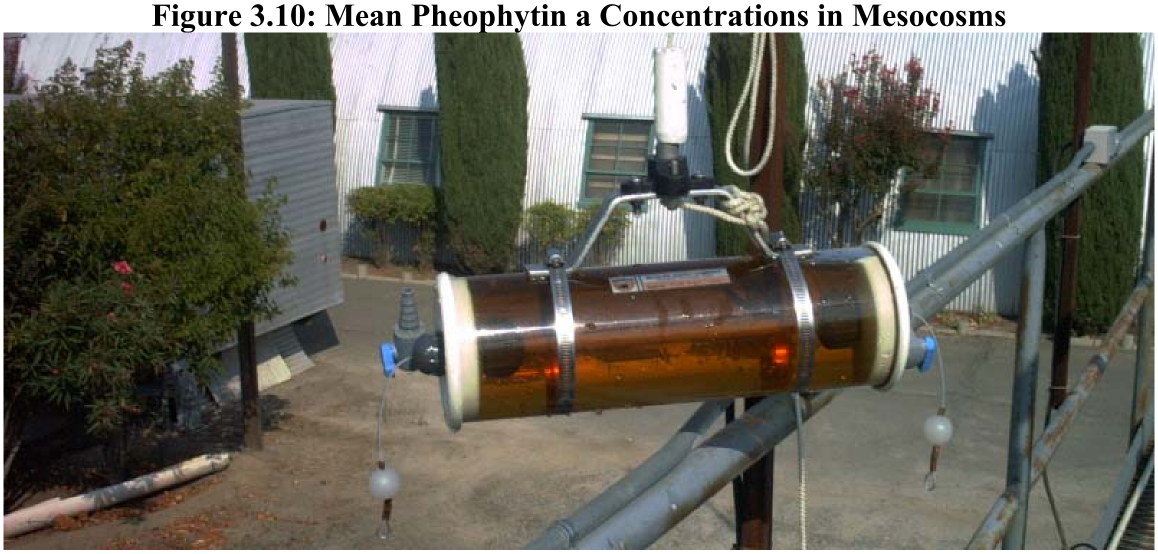

Plate 3.4: Sample of Mesocosm Water in the Van Dorn Sampler

3.3.1 Egeria densa

While Egeria appears to have increased OC loading rates, especially after the mesocosms were drained, differences between loading rates in the deep versus shallow mesocosms (Figures 3.14 trough 3.17) were not dramatic like the observed differences were between submersed macrophyte biomass. After draining, there was zero biomass observed in the deep mesocosms while dense beds of plants filled the shallow mesocosms (Plates 3.5 and 3.6). The plants were not destructively sampled for quantitative biomass measurements but there was so much *Egeria* that grew in the shallow mesocosms that terrestrial grass plant was able to get a root-hold and grow out of one of the shallow mesocosms (Plate 3.5). Similar loading rates between shallow and deep mesocosms despite dramatic differences in *Egeria* biomass (Figures 3.14 trough 3.17) suggest that peat soil is the overwhelming source of OC loading.

3.3.2 Organic Carbon

Figures 3.11 through 3.13 show the mean TOC, DOC and POC concentrations in the mesocosms during the study. The TOC loading rates presented in Figures 3.14 through 3.17 were calculated by standardizing the rate of TOC concentration increase over time to a one meter water depth by multiplying by the water depth in the mesocosms. This calculation removed the effect of dilution by depth and produced aerial loading rates. DOC loading rates (not shown) calculated the same way were almost identical to those calculated from TOC concentrations. The low concentrations of POC shown in Figure 3.13 were indirect measures, calculated as the difference between TOC and DOC. Nevertheless, chlorophyll *a* and pheophytin *a* concentrations were also low relative to the high OC concentrations in the water and further suggest that the peat soil was the dominant source of OC loading in the mesocosms. Observations from 2003 suggest that *Egeria* biomass is increasing relative to 2002 and results may show that biological productivity has a larger contribution to OC loading in years following initial flooding. DOC has been extracted from water from the both shallow and deep mesocosms for carbon dating and should be another indirect tool for comparing loading from peat vs. primary productivity. Results from the carbon dating are expected soon.

Plate 3.5: Inside one of the Shallow Mesocosms after draining
(Note the dense bed of *Egeria* and the grass growing at the surface of the water (not in the soil) supported by the Egeria)

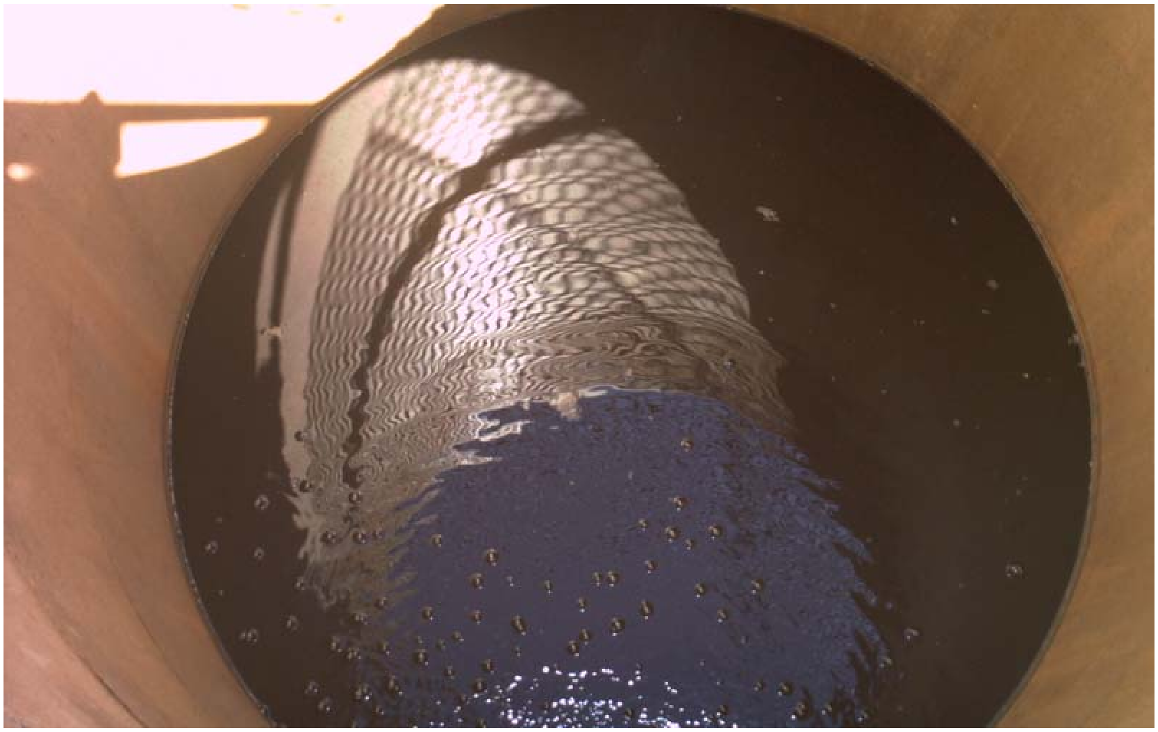

Plate 3.6: Inside of a Deep Mesocosm after Draining to a Depth of 0.3 m

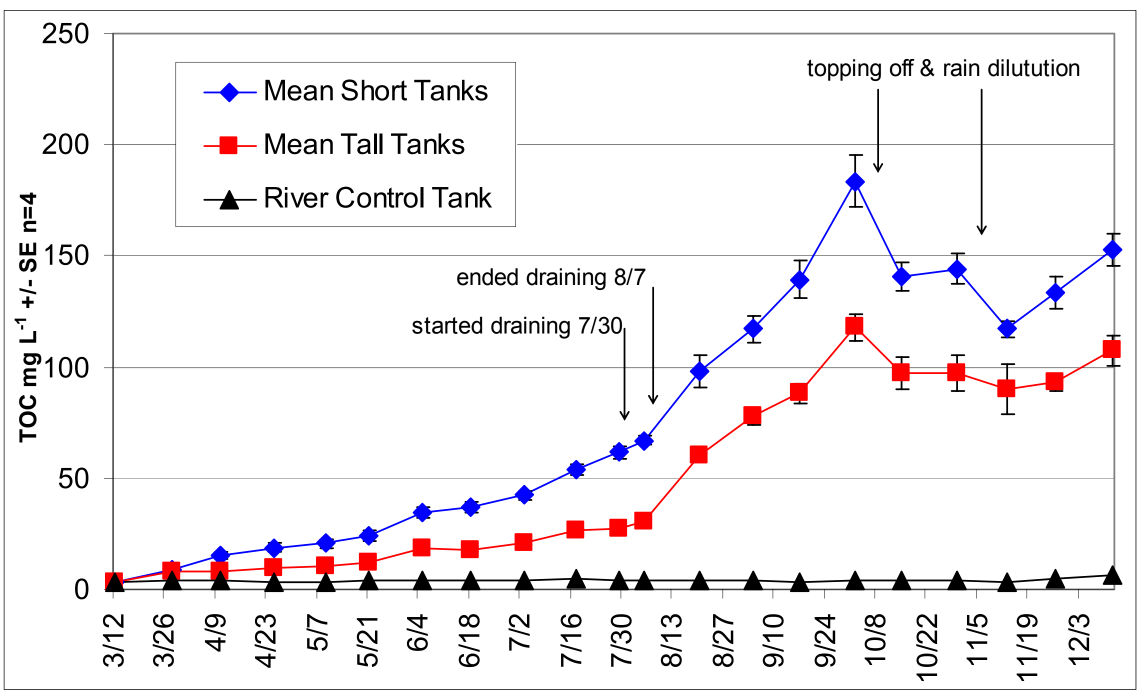

Figure 3.11: Mean TOC Concentrations in the Mesocosms

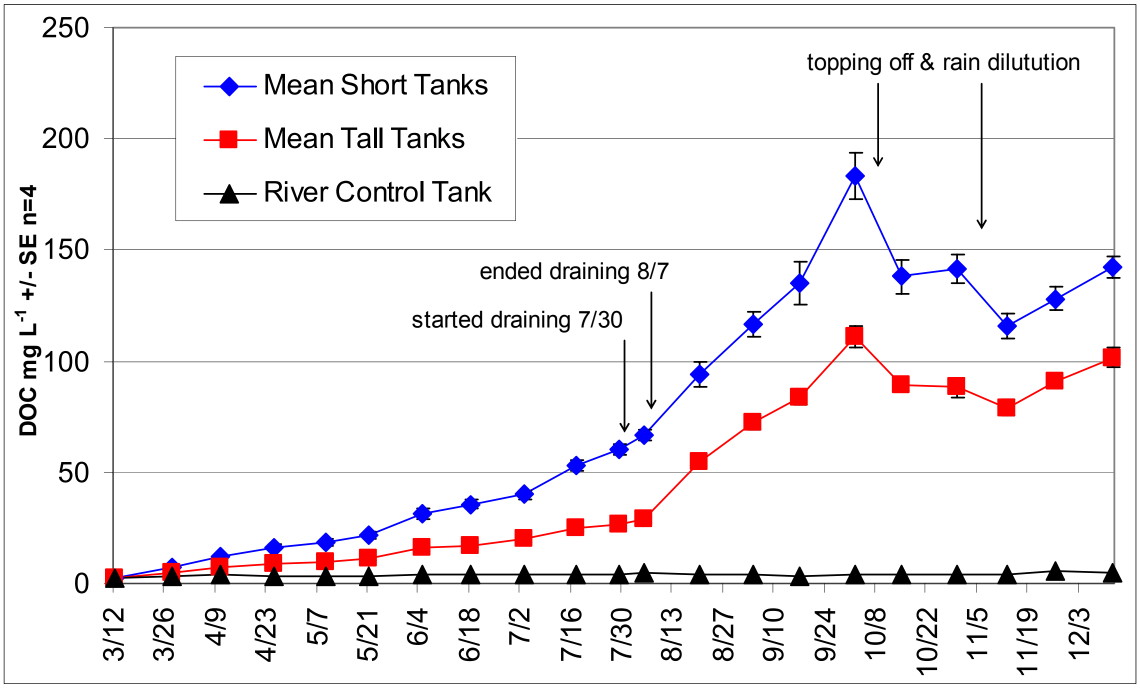

Figure 3.12: Mean DOC Concentrations in Mesocosms

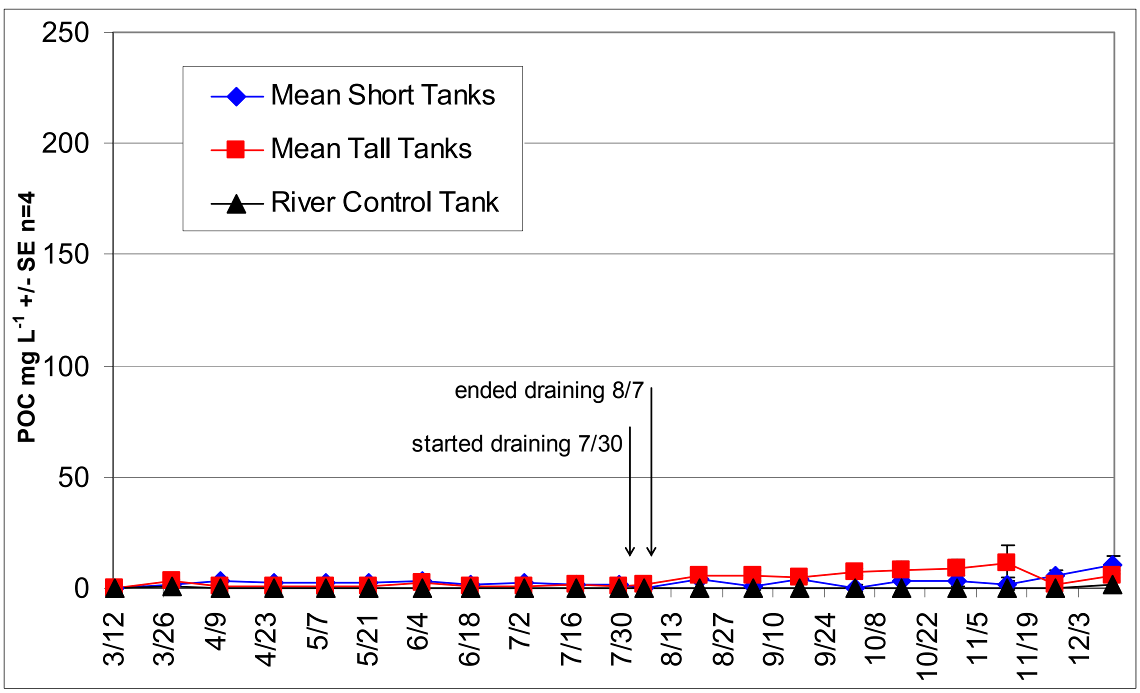

Figure 3.13: Mean POC Concentrations in Mesocosms

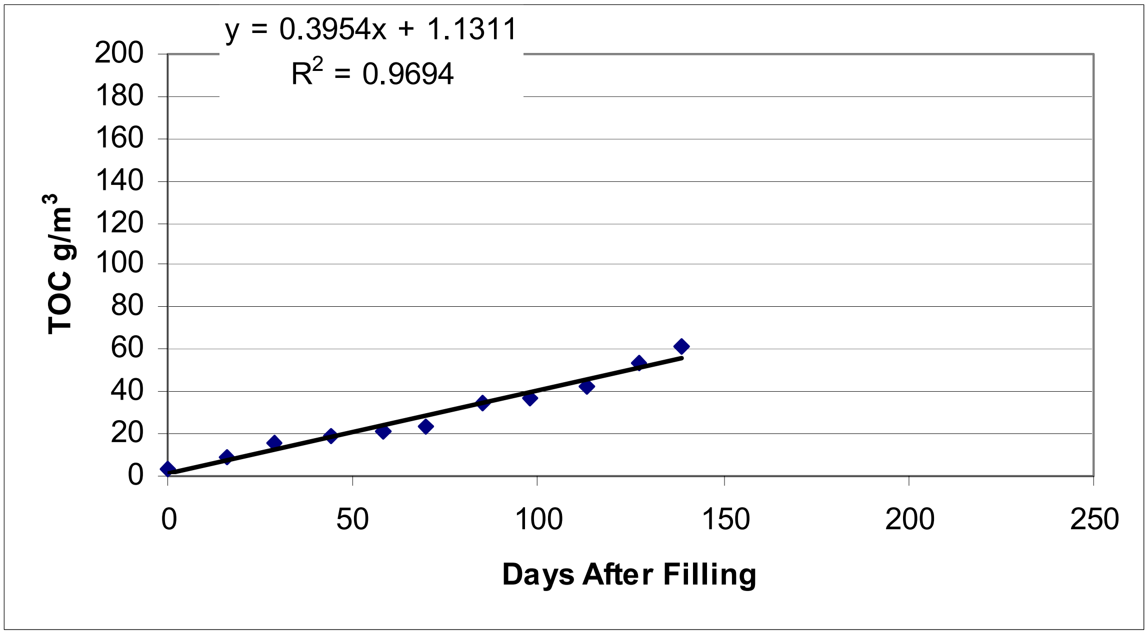

Figure 3.14: Total Organic Carbon in full Shallow, 1.4 m, Mesocosms
(Note: Standardized for 1 meter, m*1.4 = 0.554 gC/m2/d.)

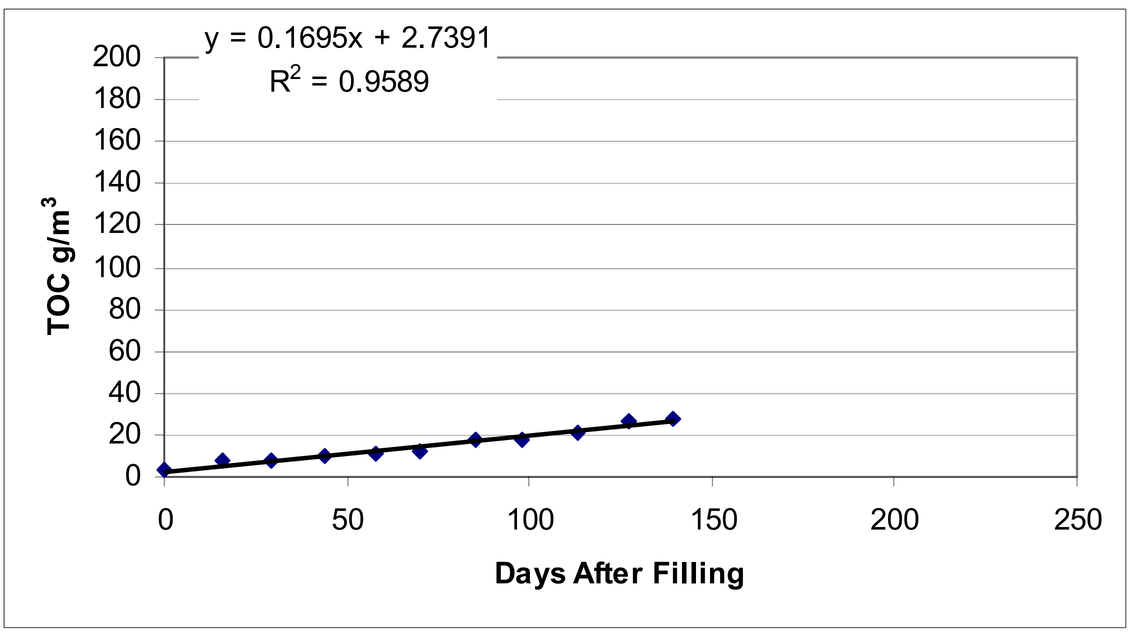

Figure 3.15: Total Organic Carbon in Full Deep, 2.9 m, Mesocosms
(Note: Standardized for 1 meter, m*2.9 = 0.492 gC/m2/d)

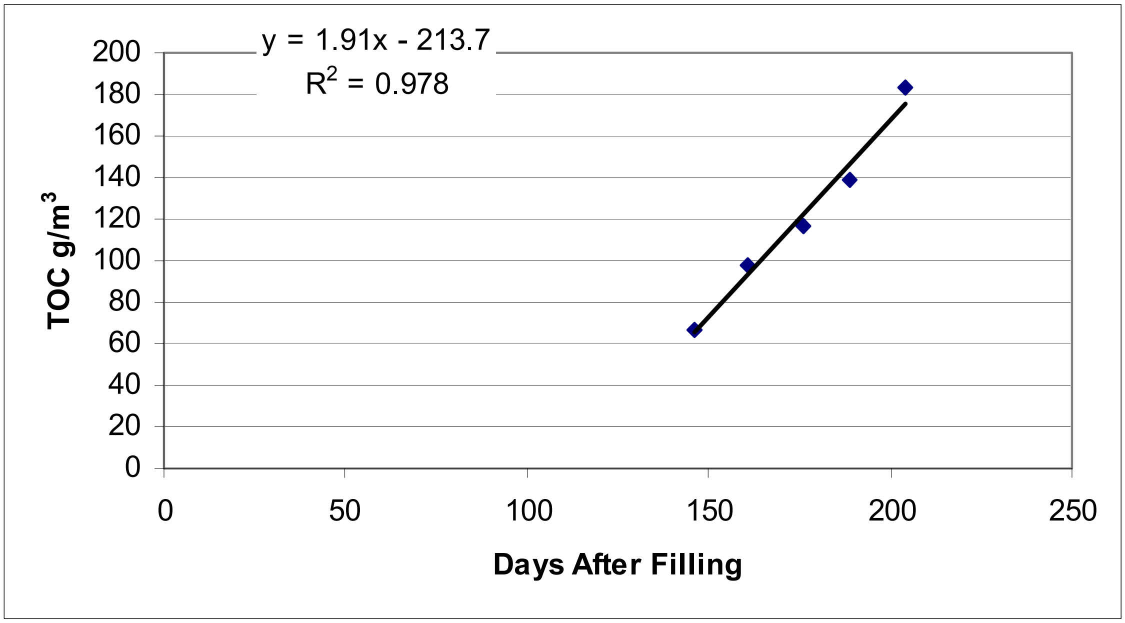

Figure 3.16a: Total Organic Carbon in drained shallow, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.573 gC/m2/d)

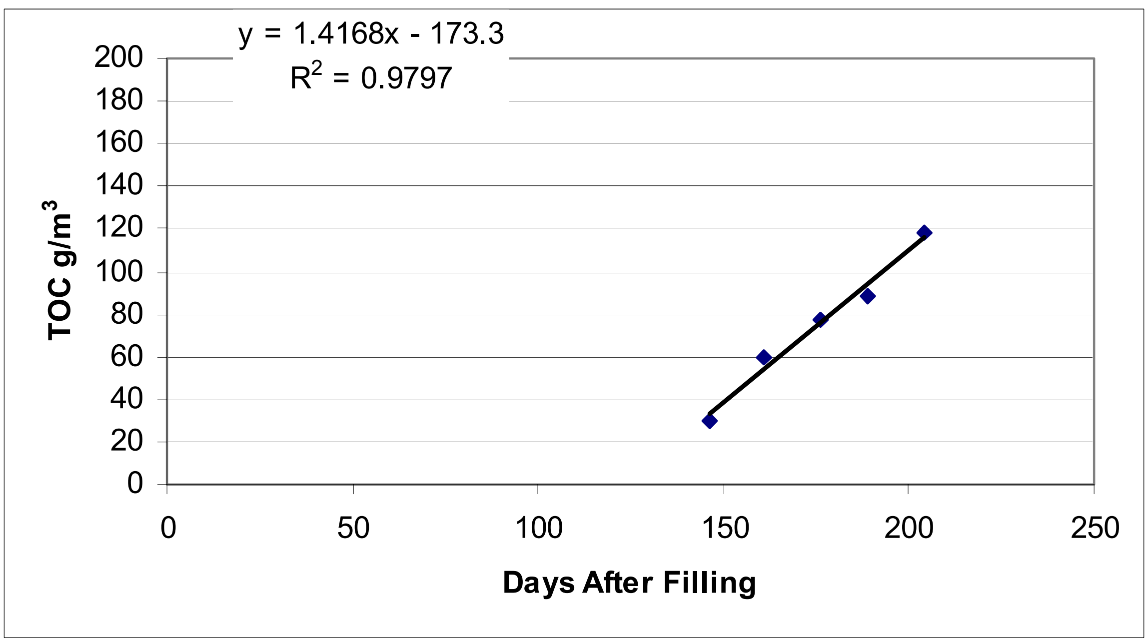

Figure 3.16b: Total Organic Carbon in Drained Deep, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.425 gC/m2/d)

3.3.3 Precipitation and Evaporation

Rain falling in the mesocosms (Figure 3.3) from November 7th through November 10th had a noticeable dilution effect on water quality in the drained mesocosms (Figures 3.11 and 3.12). A similar amount of rain fell in May but had a minor if noticeable effect on water quality because the mesocosms were full then. The November rain was about 10% of the volume of the drained mesocosms but in May when mesocosms were full this amount of rain was only about 1 % of the volume of the water in the full mesocosms. Similarly, dilution effects from topping off the mesocosms to make up for evaporation losses are obvious when the mesocosms were drained to a depth on 0.3 m but not apparent when the mesocosms were full.

3.3.4 Mercury

Mean total mercury (Hg) concentrations in fish from the mesocosms were 0.03 ug/g (ppm) for threespine stickleback samples and 0.01 ug/g for *Gambusia* samples collected from the mesocosms. The detection limit was 0.01 ug/g. All the fish analyzed were born and reared in the mesocosms and were approximately three months old when collected. Total Hg analyses of mesocosm water never resulted in detection of Hg but the detection limit was 0.2 ug/L. This detection limit is probably an order of magnitude above the concentrations at which methylmercury dynamics operate in the Delta.

3.3.5 Biological Productivity

The treatment variable in this study was water depth. Varying water depth and hence the light available for submersed macrophyte growth facilitated the identification of the effects of submersed macrophytes on the process of organic carbon loading. The mechanism controlling macrophytes and their effects on water quality was light attenuation. Submersed macrophytes were not destructively harvested in this study because it is a multiple year study. Nevertheless qualitative and quantitative descriptions of the *Egeria* productivity are possible. Approximately 100% of the surface area of the shallow mesocosms became covered with *Egeria* by the end of July when the mesocosms were drained to simulate reservoir discharge while 0% or no *Egeria* was observed in the deep mesocosms before or after draining (Plates 3.5 and 3.6, respectively). Published data on the standing biomass of submersed vegetation vary widely because of inconsistencies in excluding or including underground organs, epiphytic algae and inorganic matter. However a reasonable range for estimates of submersed macrophyte biomass for species such as *Ceratophyllum demersum, Potamogeton pectinatus* is about 100 g d.w. m^{-2} to 1000 g d.w. m^{-2} (Sculthorpe 1967). In the spring and early summer of 1996, Anderson et al. 1996 measured *Egeria* in Sandmound Slough and Seven Mile Slough by physically removing *Egeria* from under a quadrant. Their measurements were about, 1800 g d.w. m^{-2} and 2100 g d.w. m^{-2} respectively, and suggest that *Egeria* biomass in the Delta is at the upper end or above Sculthorpe's range. Filamentous algae and periphyton growing intertwined in the plant beds and on the plants can result in higher biomass estimates however. By early August 2002 when the mesocosms were drained, *Egeria* biomass was probably around 200 to 300 g d.w. m^{-2}.

Higher OC loading rates were observed in the mesocosms with *Egeria* but a linear relationship between DOC and TTHMFP (Figure 3.17) suggests that peat soil and not primary productivity was the overwhelming, or effectively the single source, of OC. A linear relationship between DOC and THMFP has been related to a single source of OC because OC from vegetation has two to five times higher THM reactivity than other sources of OC, such as peat, in reservoirs (USGS 2001). Changes in formation potential for TTHM, chloroform and bromodichloromethane are shown in Figures 3.18 and 3.19. However, a problem was identified in the data used to generate Figures 3.17 through 3.20. Samples collected before October 15, 2002 were not properly diluted by the analytical lab before dosing with chlorine and at least some THMFP data are suspect (Agee 2003 personal communication). Without proper dilution, all of the chlorine is used up and the THMF maxes out prematurely. A flat spot in the data from August 20 through October 2, 2002 is obvious in Figures 3.18 and 3.19. These data were not used in the DOC and TTHMFP regression (Figure 3.17). Analyses completed before August 20, 2002 appear to be valid because they were in the 'transition zone' where the method might have worked, but were above the prescribed DOC concentration of 10 mg/L and should be considered invalid. Figure 3.21 shows TTHMFP data only for samples collected October 15, 2002 or later when proper dilutions were made by the lab prior to chlorination. Other researchers have identified a problem with the dose-based method for THMFP analysis because results are highly dependent on sample dilution (Fujii et al. 1997). Mean dilutions used by the analytical lab are presented in Figure 3.22.

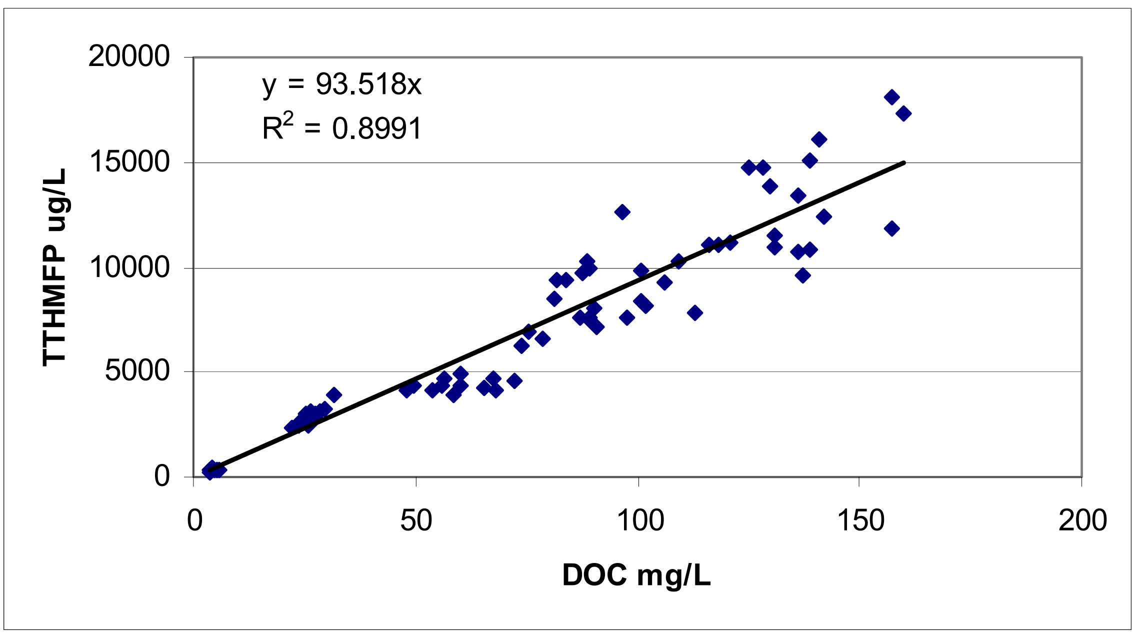

Figure 3.17: Relationship between THMFP and DOC for Mesocosms Water

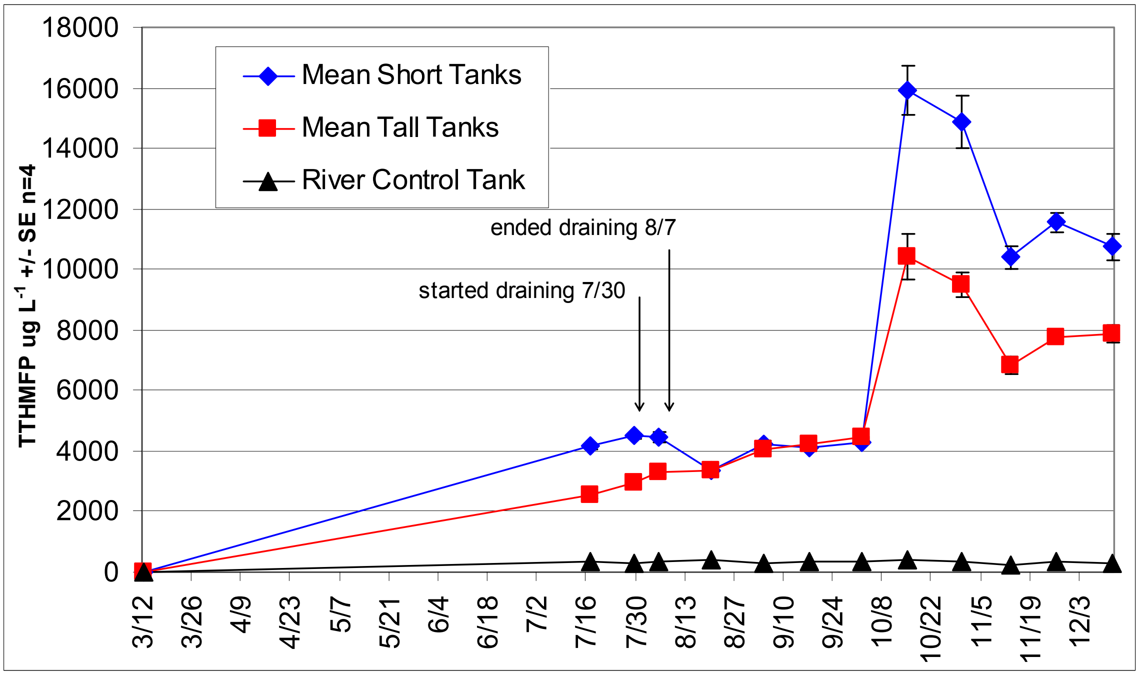

Figure 3.18: TTHMFP for Mesocosm Water

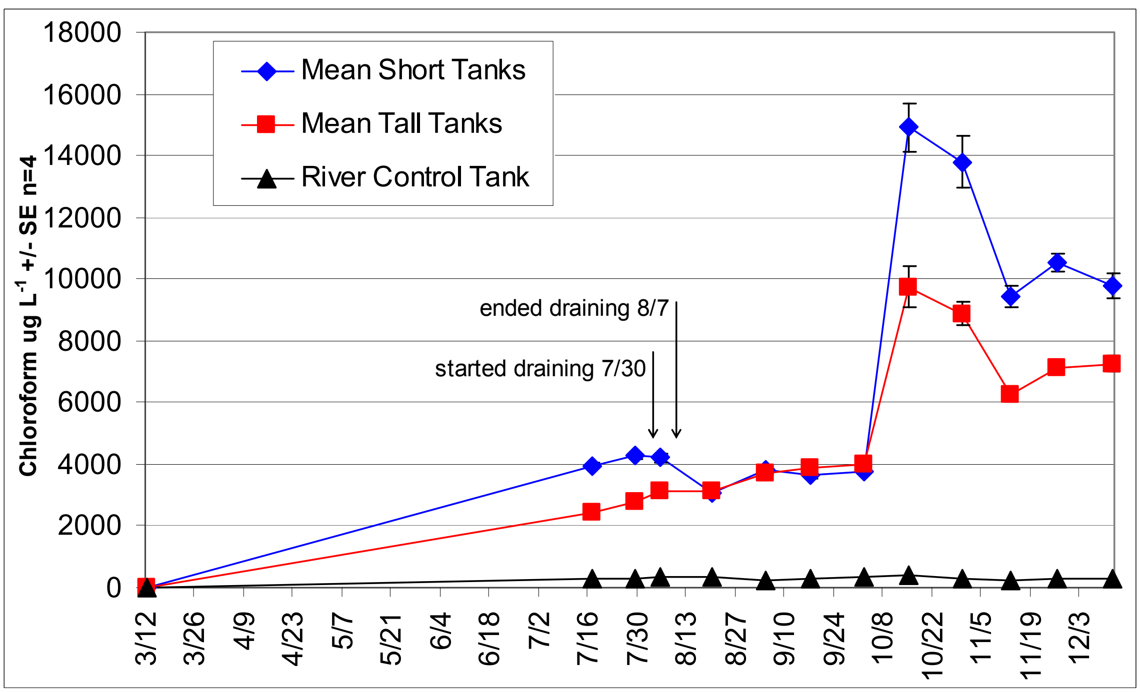

Figure 3.19: Chloroform Formation Potential for Mesocosm Water

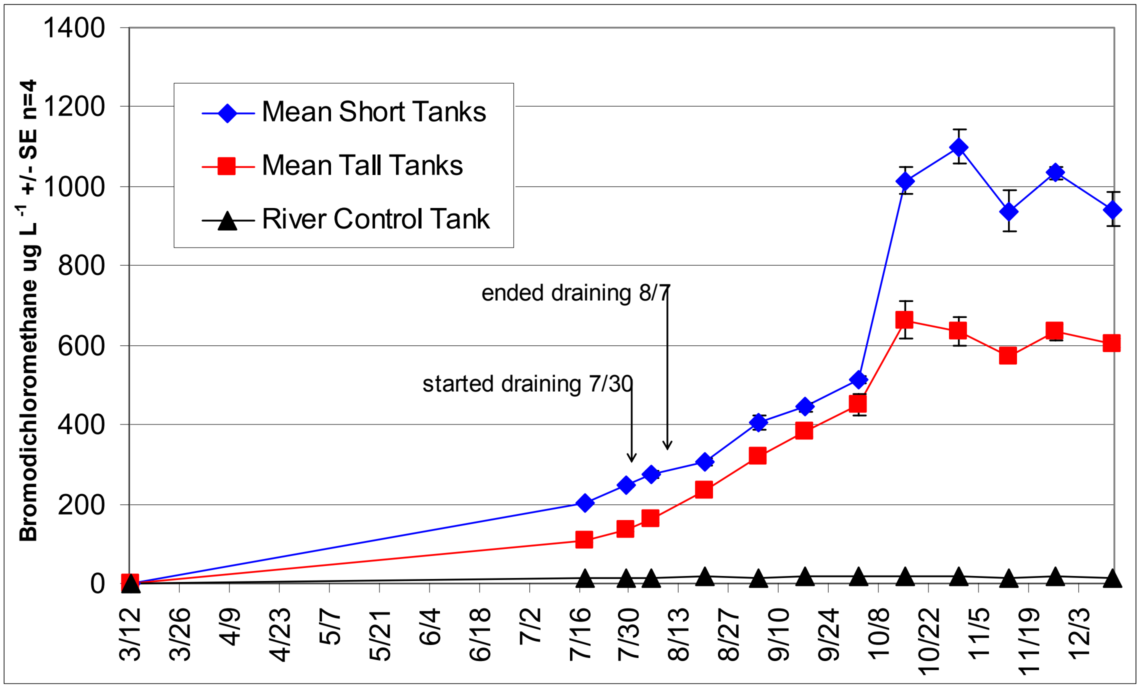

Figure 3.20: Bromodichloromethane Formation Potential for Mesocosm Water

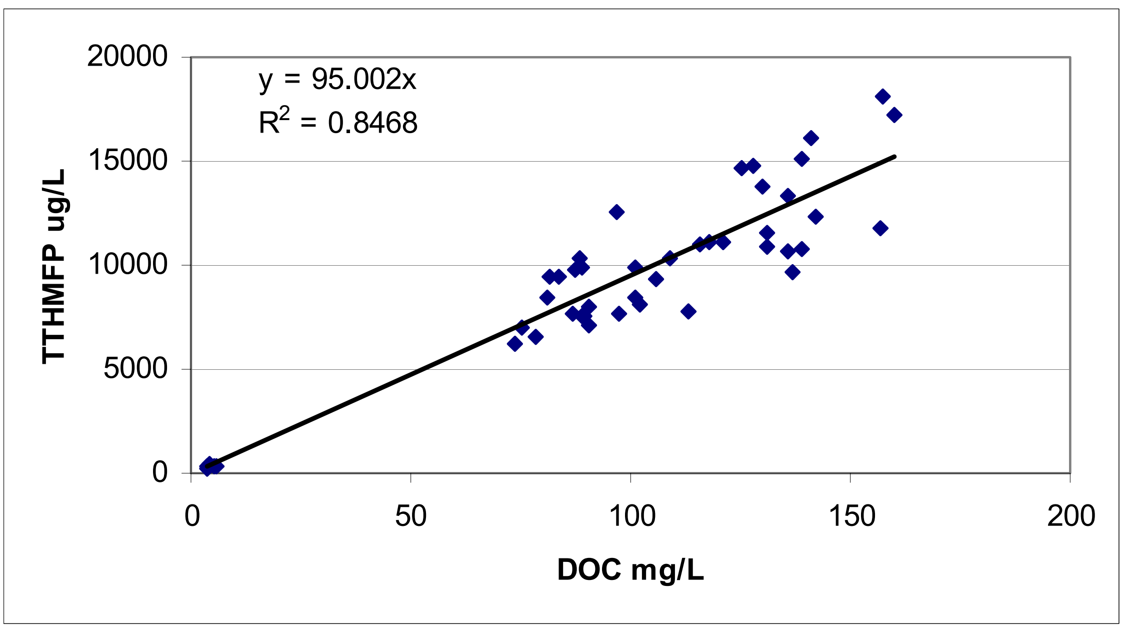

Figure 3.21: Relationship between DOC and TTHMFP
(Note only for samples collected October 15, 2002 or later)

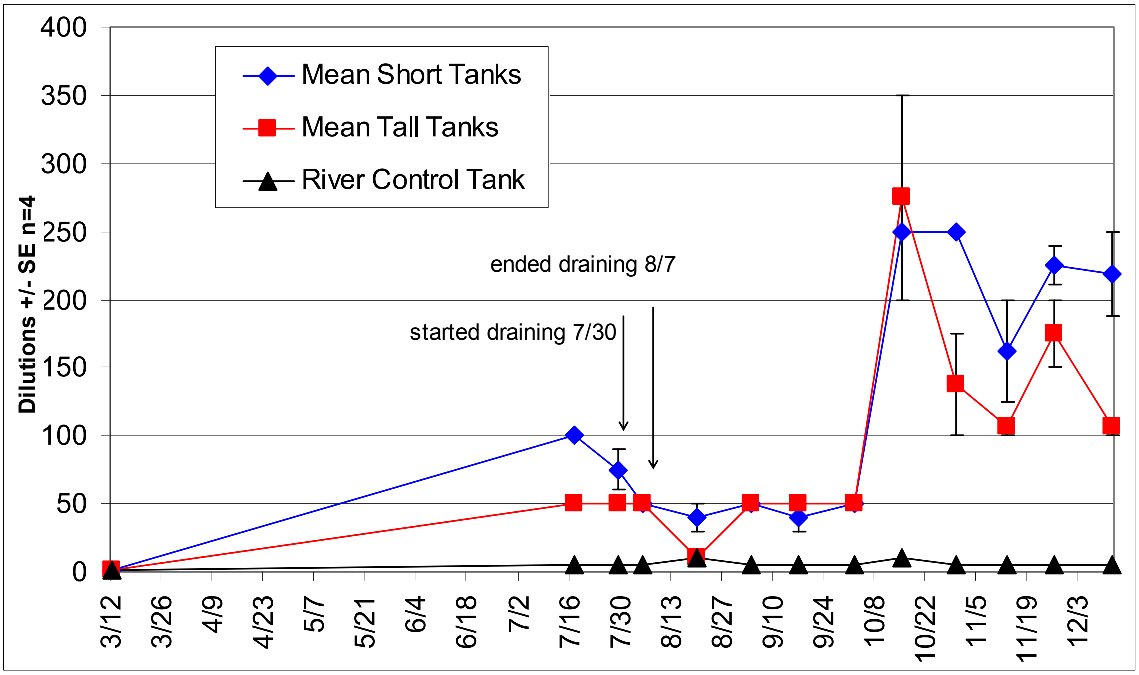

Figure 3:22: Mean Dilutions used in Analyses of THMFP

3.3.6 Trihalomethane Formation Potential

Despite the problem with the THMFP analysis, the linear relationship between DOC and TTHMFP shown in Figures 3.18 and 3.21 is strong ($r^2 = 0.899$ and 0.847) and suggests that the peat soil was effectively the single source of OC (USGS 1998). There might be indirect mechanisms that can explain why *Egeria* appeared to increase carbon loading but not result in a non-linear increase in THMFP. The *Egeria* could have facilitated higher peat-derived DOC loading by oxidizing the peat soil near the soil-water interface or otherwise increasing microbial activity or degradation of the peat. Labile *Egeria* exudates or decomposing biomass may have been rapidly metabolized by bacteria and not been a mechanism responsible for higher DOC concentrations in the mesocosms with *Egeria*. Similarly, bacteria may have used phytoplankton exudates and prevented phytoplankton from increasing OC loading relative to the peat soil. Kamjunke et al. (1997) found that phytoplankton exudation, not allochthonous DOC can be the main source of DOC used by bacteria in eutrophic waters. This phytoplankton derived DOC may be easily and rapidly consumed by bacteria and therefore not contribute significantly to overall OC loading relative to peat soil.

3.3.7 Phytoplankton

Phytoplankton productivity or biomass might also have been limited by the high concentrations of DOC. Carpenter et al. (1998) showed that increasing DOC concentrations substantially reduce chlorophyll concentrations, primary production and their variability. Bioavaliable POC in the Delta is derived primarily from autochthonous phytoplankton production but this production is a small component of the ecosystems mass balance (Sobczak et al. 2002). Phytoplankton-derived DOC is probably an important source of bioavaliable carbon to bacteria in the Delta but may also be ephemeral and in short supply. Therefore, phytoplankton in the mesocosms, in the proposed reservoir islands and in the Delta may not be a significant source of OC loading relative to peat soil. Nutrient supply is another factor that affects phytoplankton dynamics and OC loading. Additional studies are needed to further identify and quantify the complex and interacting sources of OC.

3.3.8 Specific Ultraviolet Absorbance

Specific ultraviolet absorbance (SUVA) is calculated by dividing ultraviolet absorbance (UVA) by DOC and provides information about the aromatic structure of DOC in water (USGS 1998). UVA and SUVA results are shown in Figure 3.23 and 3.24, respectively. There was another problem at the analytical lab, this time in the measurement of UVA. During July and early August, samples were not properly diluted before analysis and again resulted in readings that were too low. This problem primarily effected samples from the shallow mesocosms. Only one data point was compromised in the deep mesocosm series. It was possible to interpolate estimates for the bad readings from the relationship between UVA and DOC concentrations (Figure 3.25). The bad data points are shown by the missing UVA and DOC data around 3 abs/cm and mg/L in Figure 3.26. Interpolated estimates were used to create the data points identified by four pointed stars in Figure 3.23. The actual and estimated data were then used to generate the SUVA data shown in Figure 3.24. Mean SUVA values were similar between the deep and shallow mesocosms and remained relatively constant during the study. However, SUVA values were dramatically lower in the river water only mesocosm.

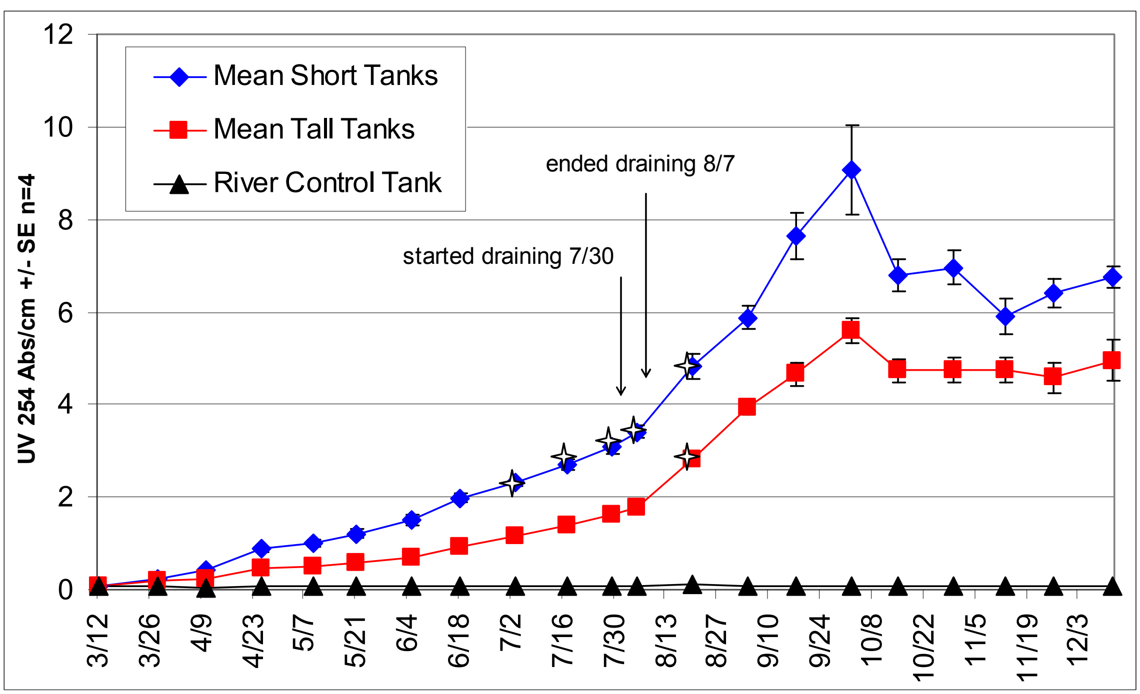

Figure 3.23: UV 254nm Absorbance
(Note estimated data indicated by four-pointed stars)

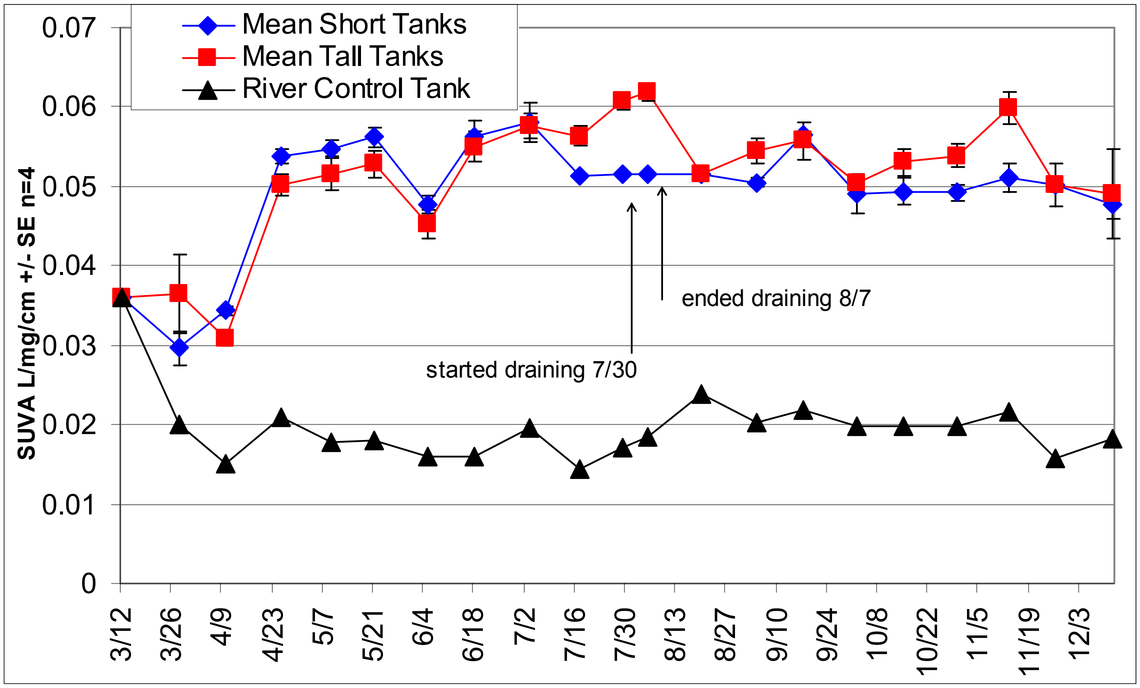

Figure 3.24: Mean Specific UV Absorbance (UVA/DOC)

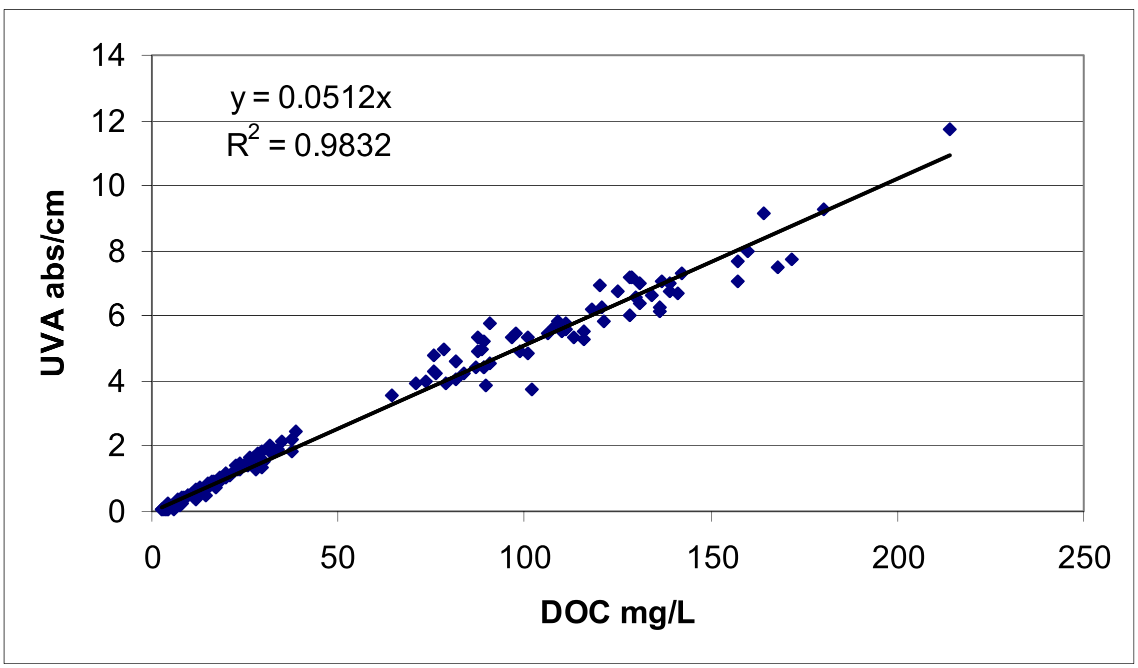

Figure 3.25: Relationship between UVA and DOC for Mesocosm Water

The relationship between UVA and TTHMFP is also linear (Figure 3.26). If the TTHMFP data that were identified as potentially invalid, those data for before October 15, 2002, are removed from Figure 3.27 the relationship stays mostly the same but the r^2

value declines slightly from 0.884 to 0.82 but the linear relationship does not change (Figure 3.27). The strong linear relationships between THMFP and DOC and UVA together with the lack of a linear relationship between SUVA and STTHMFP (Figure 3.29) provide both quantitative and qualitative information about the processes of OC loading that will be important to the in-Delta storage. These relationships suggest that not only was DOC overwhelmingly from a single source, the peat soil, but also that non-aromatic forms of DOC were probably the dominant THM precursors in the water (USGS 1998).

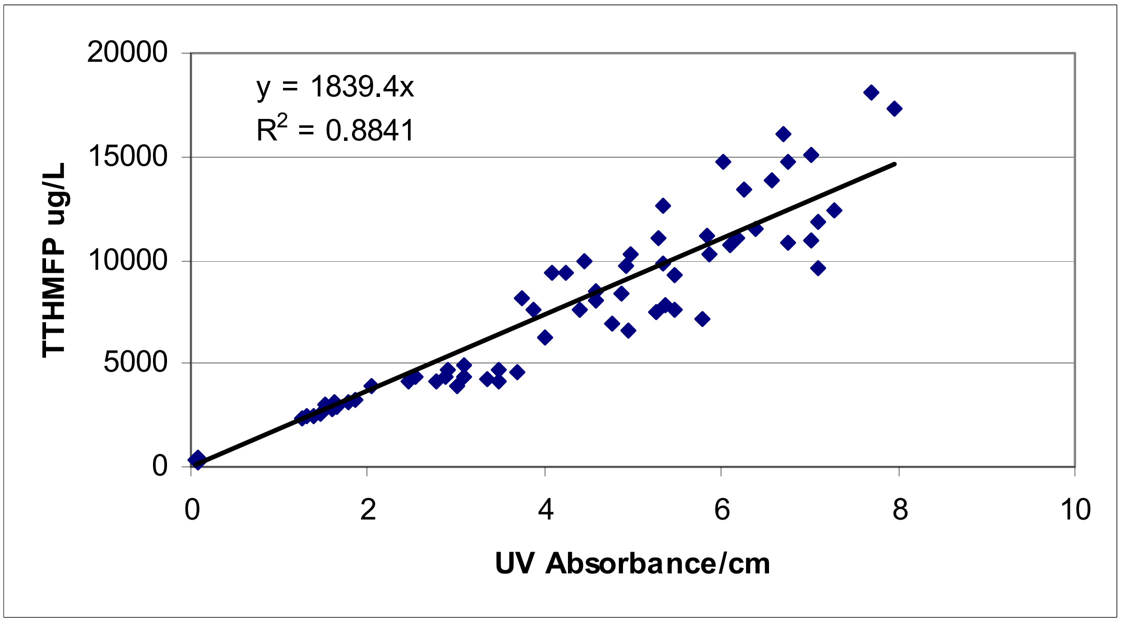

Figure 3.26: Relationship between UV Absorbance and THMFP

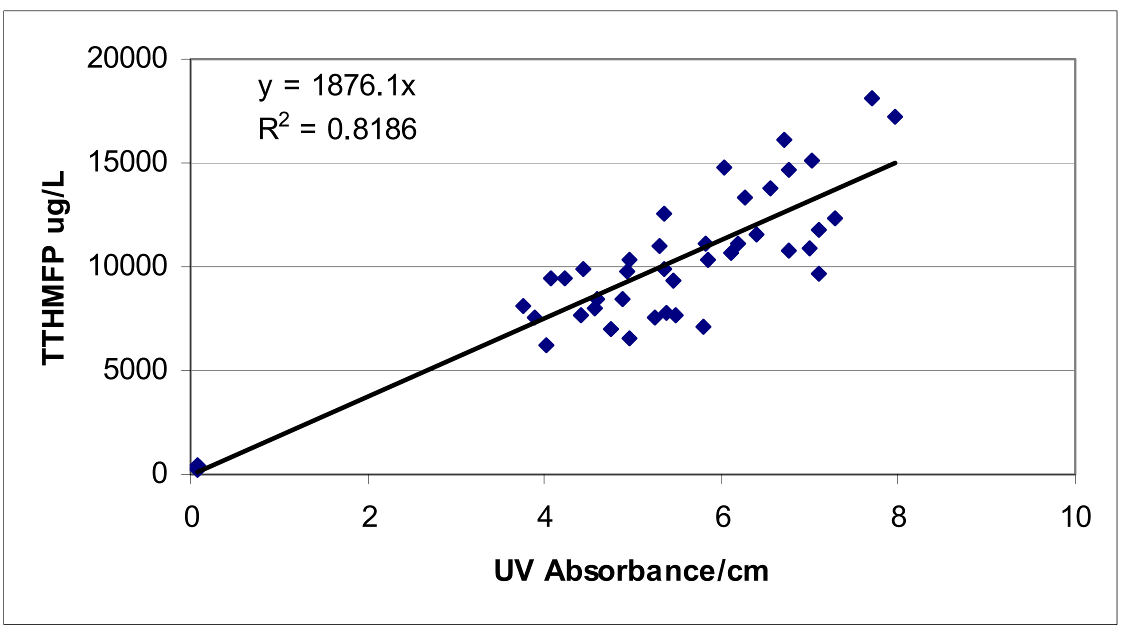

Figure 3.27: Relationship between UV Absorbance and THMFP
(Note: using only data from October 15, 2002 or later)

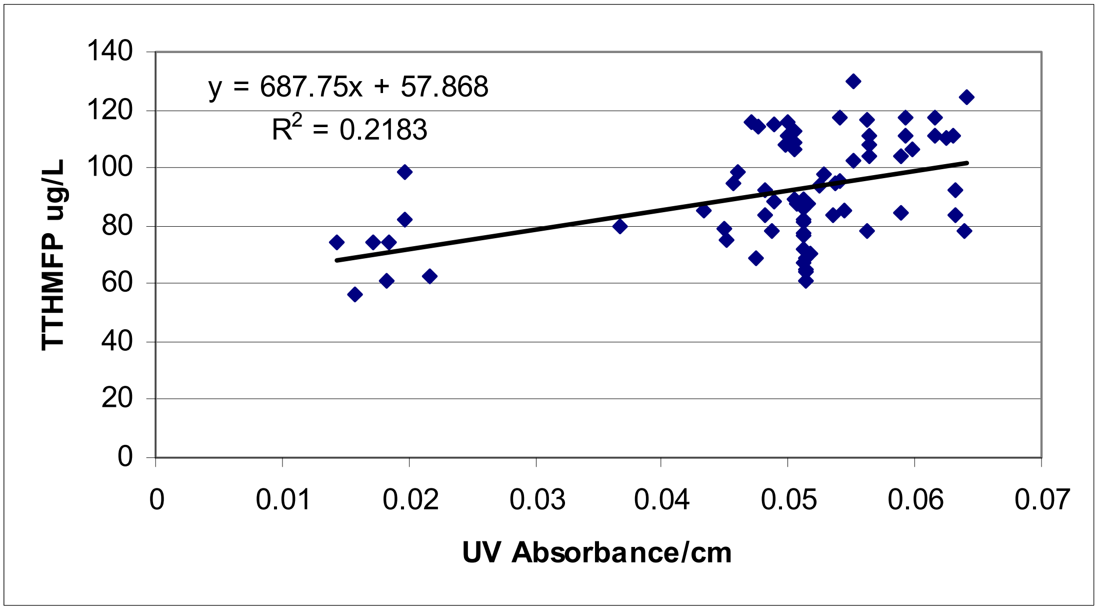

Figure 3.28: Relationship between SUVA and STTHMFP

In the 2003 study, the new circulation operation for the reservoir islands was simulated in the operation of the mesocosms. Figure 3.29 shows DOC concentrations in the mesocosm water (preliminary data). Declines in DOC are due to dilution from filling and circulation. The tanks were filled in thirds over a three month period starting in January 2003. For example if there was 2.1 m head space at the beginning of the study in late January, 0.7 m or 1/3 of the storage capacity was added. Then at the end of February the second third (0.7 m) was added and at the end of March the final third was added and the mesocosms were then full. The percent (%) of water circulated or exchanged in the mesocosms is shown by the arrows in Figure 3.29. For example, if there was one meter of water in a mesocosm and 0.25 meters of water was drained and replaced with Sacramento River water this was a 25% circulation. Figure 3.29 shows relatively flat organic carbon concentrations during the March through July storage period because the exchange or circulation rate was approximately in balance with OC loading rates.

While the circulation operation in 2003 was different than 2002 mesocosm hydrology, preliminary results from the 2003 study suggest that organic carbon loading rates are consistent with 2002 rates. Also, little POC was observed in 2003 as in 2002 i.e., the TOC:DOC ratio appears to be close to one in both years (TOC and other water quality data have not yet been fully tabulated and analyzed). Figure 3.30 shows the DOC concentrations during the March through July storage period as in Figure 3.29 but standardized to a one meter water depth to account for dilution effects from refilling and circulation operations. These preliminary data are consistent with the OC loading algorithm used in DSM2**.** The OC loading algorithm as implemented in DSM2 assumed a zero rate for OC loading in the winter months. The preliminary 2003 data shown in Figure 3.31 for the winter months of January and February are also consistent with this assumption. After the tanks were drained to a depth of 0.3 meters water was no longer circulated, i.e. the mesocosm hydrology was the same as in 2002 after draining. Therefore, the 2003 January-February data do not need to be standardized for comparison with 2002 data. Figure 3.32 shows DOC concentrations as measured (not transformed) for the non-storage or drained period. Again, preliminary 2003 results are consistent with the OC growth rate developed from the 2002 study. Additional 2003 data like trihalomethane formation potential and UV absorbance have not yet been analyzed for the 2003 data.

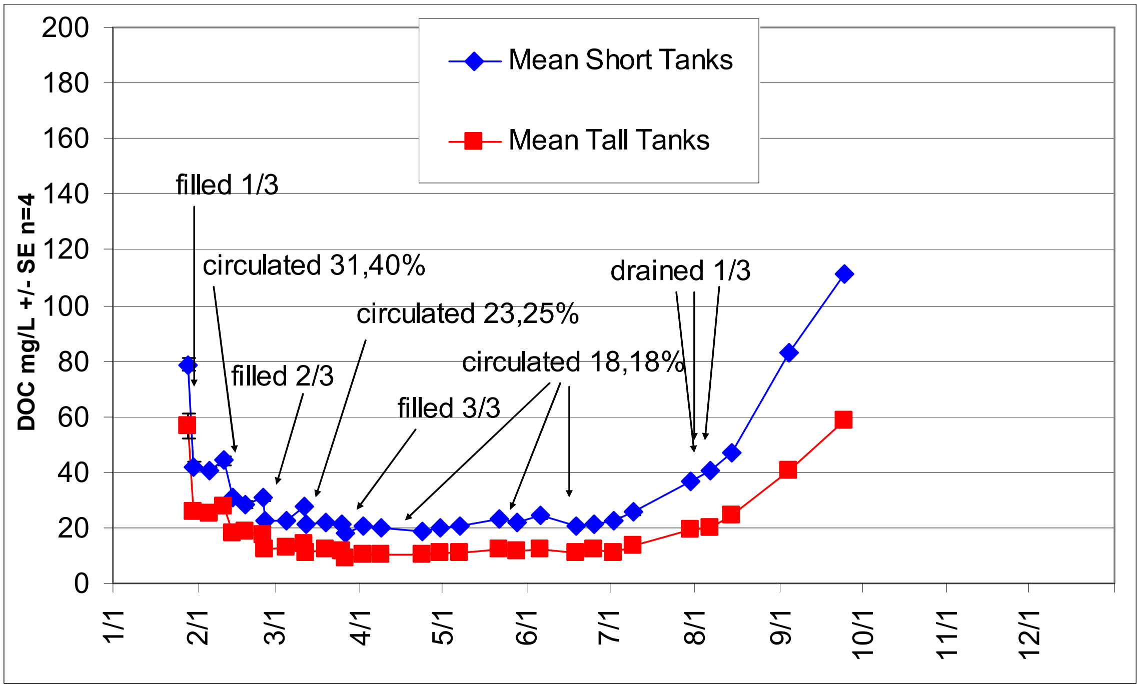

Figure 3.29: Mean 2003 DOC concentrations in mesocosms.

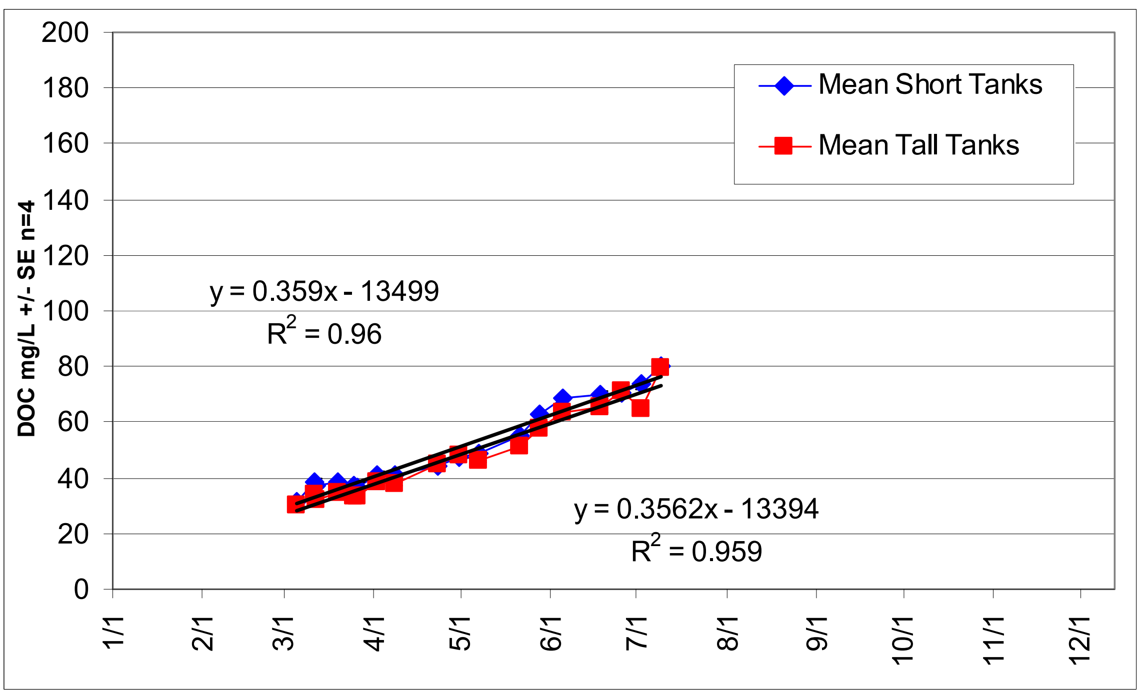

Figure 3.30: 2003 March-July storage period DOC concentrations in mesocosms (Means standardized to a one-meter water depth).

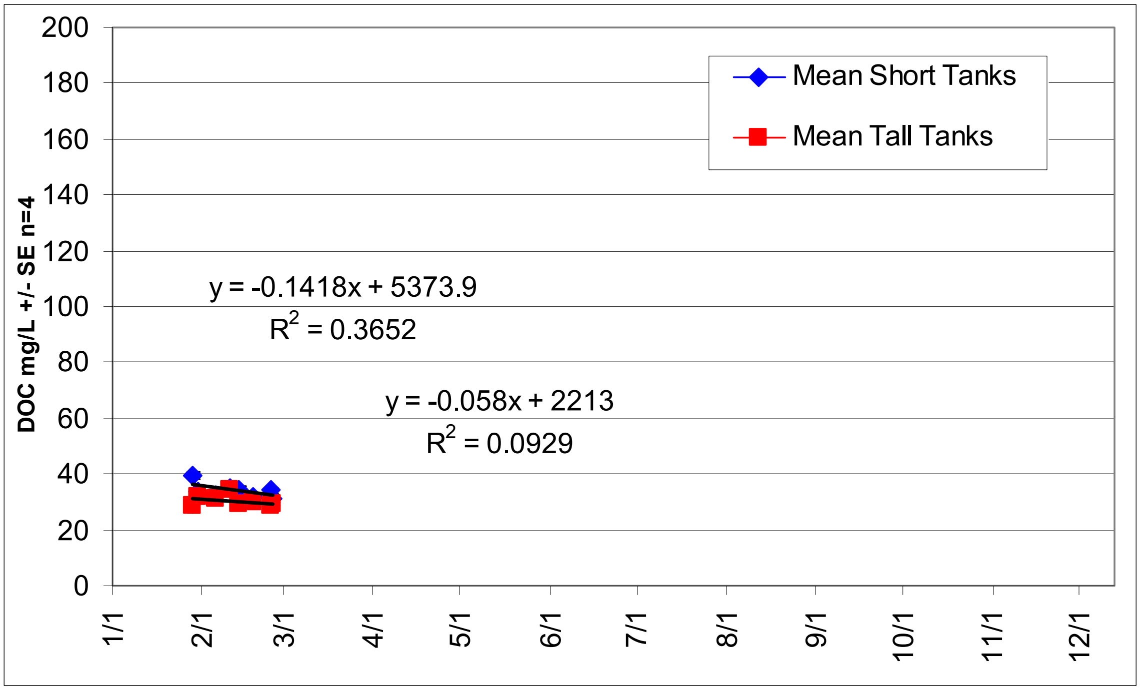

Figure 3.31: 2003 winter DOC concentrations in mesocosms
(Means standardized to a one meter water depth).

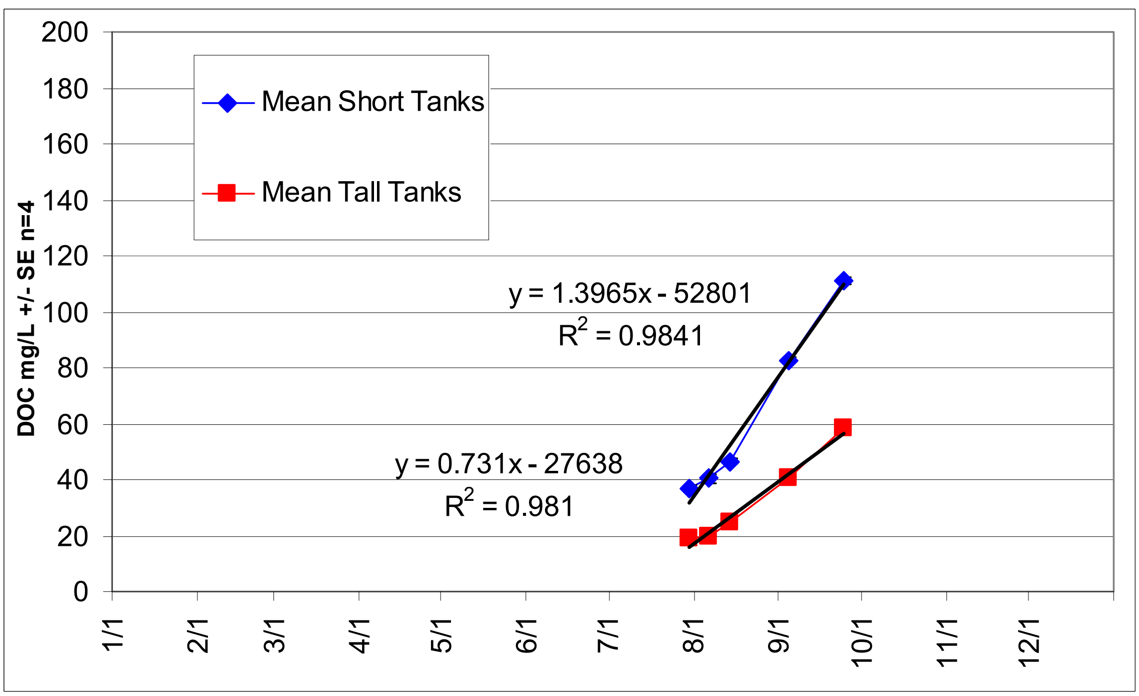

Figure 3.32: 2003 drained period DOC concentrations in mesocosms.
(These means are DOC concentrations as measured i.e. not standardized because no circulation flows during this period. In order to standardize slopes as in Figures 3.11 through 3.16 m*0.3 = 0.42 and 0.22 $gC/m^2/d$ respectively.)

Predicting organic carbon loading in the proposed in-Delta reservoir islands has been a challenge for over a decade. The first estimates were a part of a 1990 Delta Wetlands Inc. draft EIR (DW 1990), mostly qualitative and based on comparisons to Delta island agricultural drainage. Estimates in this and subsequent EIRs were also limited in that algal and vascular aquatic plant productivity (bioproductivity) was not adequately considered. In recent years, DWR has conducted studies in order to reduce uncertainty and make a recommendation on the project. Much still needs to be done in order to develop process-level, mechanistic models of the reservoirs especially ones that can be used to accurately predict water quality in the reservoirs and at downstream drinking water intakes. Nevertheless, this mesocosm study is the latest step in an ongoing and integrative process to reduce uncertainty.

3.4 Use of OC Field Data in Modeling

Comparison of the mean 2002 and 2003 OC concentrations in the mesocosms shown in Figures 3.11 through 3.16 and Figures 3.29 through 3.32 (respectively) indicates similar OC values in both years. The annual average areal loading rate is on the order of $100gC/m^2/yr$. The OC growth rates shown in Table 3.2 were used in the DSM2 model runs. These rates vary over the course of the year and are consistent with this annual average areal loading rate of about 100 $gC/m^2/yr$.

Table 3.2: Project Island Organic Carbon Growth Rates (gC/m2/day)

Island	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Bacon Island	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59
Webb Tract	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59

3.5 References

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Chapter 4: SIMULATION OF TEMPERATURE AND DISSOLVED OXYGEN

4.1 Introduction

Two DSM2 planning studies were run in HYDRO and QUAL with and without the proposed the In-Delta Storage (IDS) reservoirs in the SWP and CVP systems. The objective of the study was determine whether the In-Delta Storage Reservoir operations would meet the Dissolved Oxygen (DO) and temperature standards at the outlets or not. Both of the scenarios were simulated with the CALSIM II Daily Operations Model. A basic description of the DSM2 / CALSIM II scenarios and their identification is described in Table 4.1. Detailed descriptions of the operation scenarios are given in the December 2003 Draft Report on Operations. Detailed descriptions of the DSM2 hydrodynamics scenarios are given in Mierzwa (2003). The interaction between CALSIM II and DSM2 is illustrated in Figure 4.1.

Table 4.1: DSM2 and CALSIM study scenarios

DSM2 Study	CALSIM II Study	Description
Base	Study 1	No Action Base
Project Operation	Study 4b	In-Delta Storage project islands with DOC constraints and island circulation

4.2 Modeling Approach and Boundary Conditions

There is a close interaction between the DO and other water quality parameters. In particular, DO interacts with water temperature, BOD, chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate). In order to simulate DO, a group of related variables has to be simulated at the same time.

A conceptual model showing the interaction among water quality variables in DSM2 model is shown in Figure 4.2. In Figure 4.2, the rates of mass transfer are functions of temperature. It is important that the temperature simulation be included in the DO simulation. Further information on DSM2 kinetics is given in a 1998 report by the Department of Water Resources (Rajbhandari 1998), also available at the Delta Modeling Section web site http://modeling.water.ca.gov/delta/reports/annrpt/1998/chpt3.pdf.

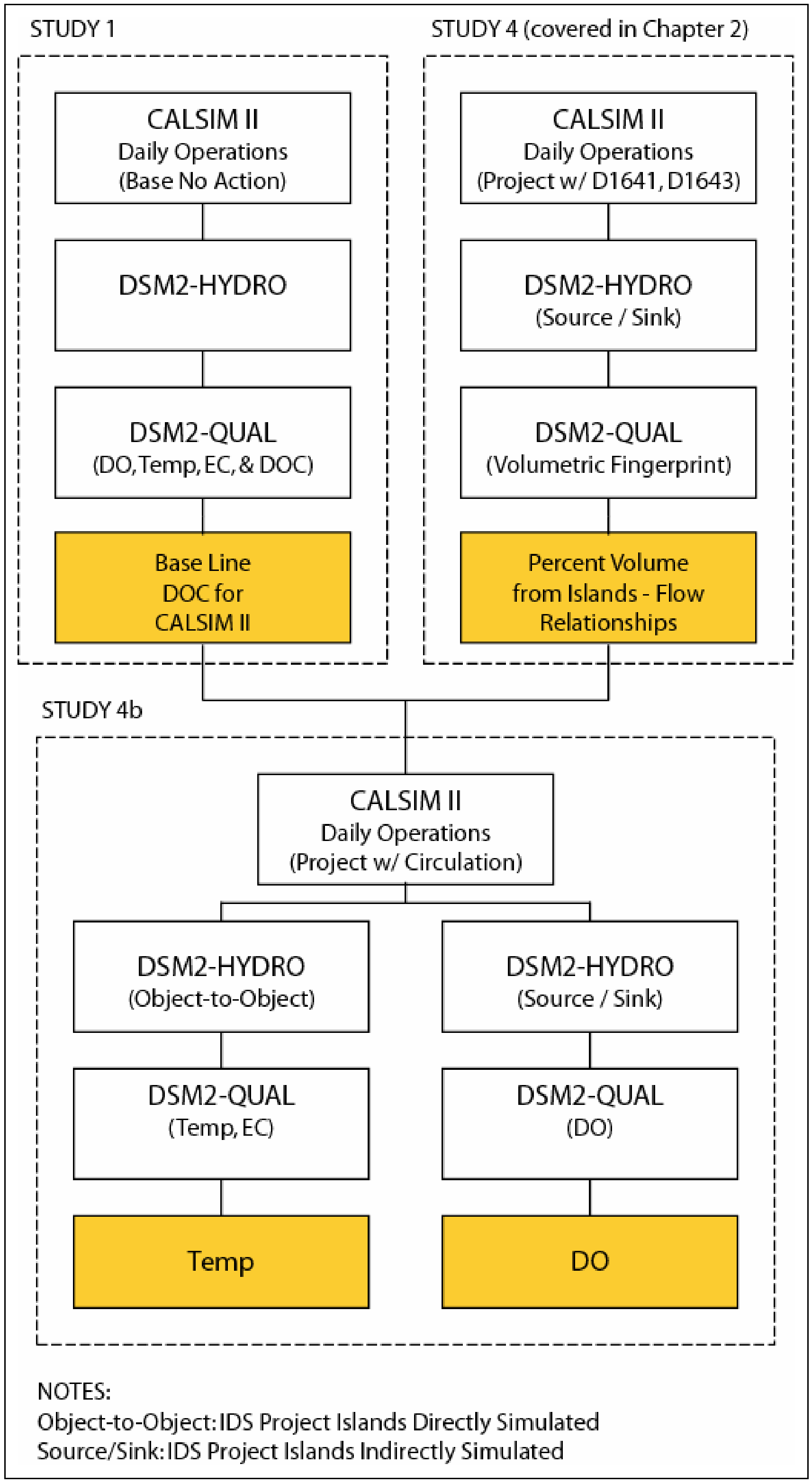

Figure 4.1: Study Methodology

The representation of project islands and the island release points as modeled in the DSM2 model is shown in Figure 4.2. Recent works on calibration and validation of DSM2 for DO are documented in Rajbhandari et al (2002). The conceptual and functional descriptions of constituent reactions represented in DSM2 are based generally on QUAL2E (Brown and Barnwell 1987), and Bowie et al. (1985). The DO concentration in the island reservoir is both a function of mixing associated with diversions to the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. DSM2 can be used to model all of the effects except for stratification.

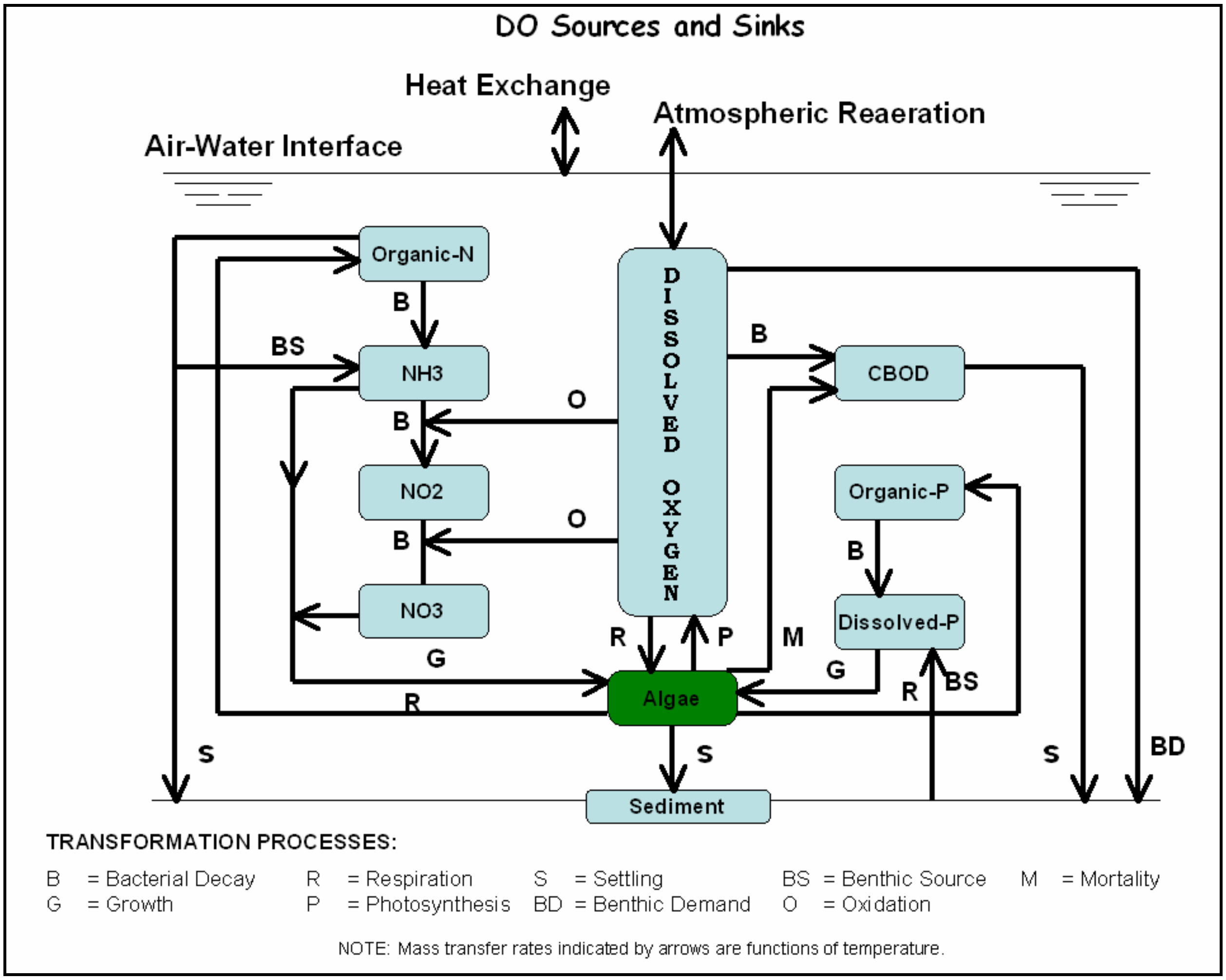

Figure 4.2: DO and Interaction among Water Quality Parameters

Data collected at hourly intervals for DO and temperature provides boundary information needed by DSM2. Estimated DO data in Sacramento River at Freeport were provided for the Sacramento River model boundary. The historical record of DO and temperature, available from May 1993 at Martinez including estimates for missing data, was used for the downstream boundary. The estimates were based on extrapolations of 1997-2000 data, averaged to daily averages, and extended to 1975-1983. Since continuous data were not available at Vernalis (RSAN112), hourly values of DO and temperature available from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. For 1975-1983, estimates based on extrapolation of data were used. Since the flows at Vernalis are primarily unidirectional, and the hydraulic residence time is relatively short, this assumption seems appropriate.

Nutrient data at Vernalis were approximated from the San Joaquin River TMDL measurements sampled at weekly intervals in 1999. The nutrient data at Freeport on the Sacramento River were approximated from the latest publication of the U.S. Geological Survey report (USGS 1997) and chlorophyll data were approximated from the statistical analysis study by Nieuwenhuyse, 2002. Estimates of flow and water quality of agricultural drainage returns at internal Delta locations were based on earlier DWR studies. Estimates of data were also based on other sources such as Jones and Stokes (1998).

Climate data at hourly or 3-hour intervals representing air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure (source: National Climatic Data Center) provided DSM2 input for simulation of water temperature. An electronic version of the data available for the period of 1997-2000 were extrapolated to cover the 16 years period from 1975-1991.

Model simulations were based on 15 minute time-steps. However, analysis of model results was based on daily averaged values because hydrodynamics information and water quality conditions were based on daily averaged values.

4.3 Project Island DO and Temperature

Temperature and DO were simulated using two different approaches, see Figure 4.1. Temperature was simulated using an object-to-object approach, where the IDS project islands were directly simulated. Water was diverted to or released from either island at one or two of its integrated facilities. The IDS project islands were simulated indirectly for DO by using a source / sink approach similar to the DSM2 treatment of the inflow / export boundary conditions. Time series were used to describe the concentrations to associate with releases from the islands. Since diversions were treated as sinks, the concentration of water diverted to the islands had no impact on the channels.

4.3.1 Temperature

Temperature inside of either island is both a function of mixing associated with diversions/releases to/from the islands, wind effects, heat exchange from atmosphere, and stratification. DSM2 modeled all the effects except for stratification. Therefore, the model results discussed below applies to cases where the stratification effects are negligible. One significant assumption is that DSM2 simulates reservoir as completely mixed.

4.3.2 Dissolved oxygen

The concentration of DO inside of either island (see, Figure 4.2) is both a function of mixing associated with diversions/releases to/from the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. Because DSM2 has never been calibrated or validated for modeling DO in reservoirs, at this time it was not possible to simulate reservoir DO. More importantly there is no data for even attempting to calibrate DO in the project islands. As an alternative approach, preliminary assessment of reservoir release impact on channels was based on the source/sink approach described above. Based on the discussion among Water Quality Team members [Duvall, 2003], the following water quality parameters were assigned for island release.

Three scenarios were chosen:

High chlorophyll	BOD 20-25 mg/l	Chlorophyll = 100 ug/l
Low chlorophyll	BOD 20-25 mg/l	Chlorophyll = 10 ug/l
Low BOD;Mid chlorophyll	BOD 8-10 mg/l	Chlorophyll = 40 ug/l

Other parameters were kept at the following values for all three scenarios.

Ammonia as nitrogen	0.05 mg/l
Nitrate as nitrogen	0.5 mg/l
Nitrite as nitrogen	~0.0
Organic nitrogen	2.0 mg/l
Dissolved ortho-phosphate	0.025 mg/l
Organic phosphorus	0.2 mg/l

Because discharge of stored water is prohibited if the DO of stored water is less than 6.0 mg/L, it was assumed that DO of island water would be at 6 mg/l at all times. In reality, this may require some aeration or application of other DO improvement technology which is beyond the scope of this study. EC (daily varying) input for release was used from the simulations by Mierzwa (2003). Temperature input (daily varying) was used from the simulations described in Section 4.5.

The difference in DO between the high chlorophyll and low chlorophyll scenarios typically was less than or equal to 0.4 mg/L. Though the DO results for the low chlorophyll scenario are somewhat better than those from the high chlorophyll scenario, a 0.4 mg/L difference is small enough that a time series plot of the low chlorophyll results would look similar to the high chlorophyll results. Furthermore, due to modeling and analysis time constraints, only the high chlorophyll and intermediate (low BOD, middle range chlorophyll) scenarios are plotted and discussed below.

The difference in DO between the high chlorophyll and low chlorophyll scenarios typically was less than or equal to 0.4 mg/L. Though the DO results for the low chlorophyll scenario are somewhat better than those from the high chlorophyll scenario, a 0.4 mg/L difference is small enough that a time series plot of the low chlorophyll results

would look similar to the high chlorophyll results. Furthermore, due to modeling and analysis time constraints, only the high chlorophyll and intermediate (low BOD, middle range chlorophyll) scenarios are plotted and discussed below.

4.4 DO and Temperature Requirements

The following DO and temperature constraints were utilized in evaluating the studies:

DO: Discharge of stored water is prohibited

- If the DO of stored water is less than 6.0 mg/L,
- If discharges cause the level of DO in the adjacent Delta channel to be depressed to less than 5.0 mg/L, or
- If discharges depresses the DO in the San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L September through November

Temperature: Discharge of stored water is also prohibited if,

- The temperature differential between the discharged water and receiving water is greater than 20º F, or
- If discharges will cause an increase in the temperature of channel water by more than:
    - 4º F when the temperature of channel water ranges from 55º F to 66º F,
    - 2º F when the temperature of channel water ranges from 66º F to 77º F, or
    - 1º F when the temperature of channel water is 77º F or higher

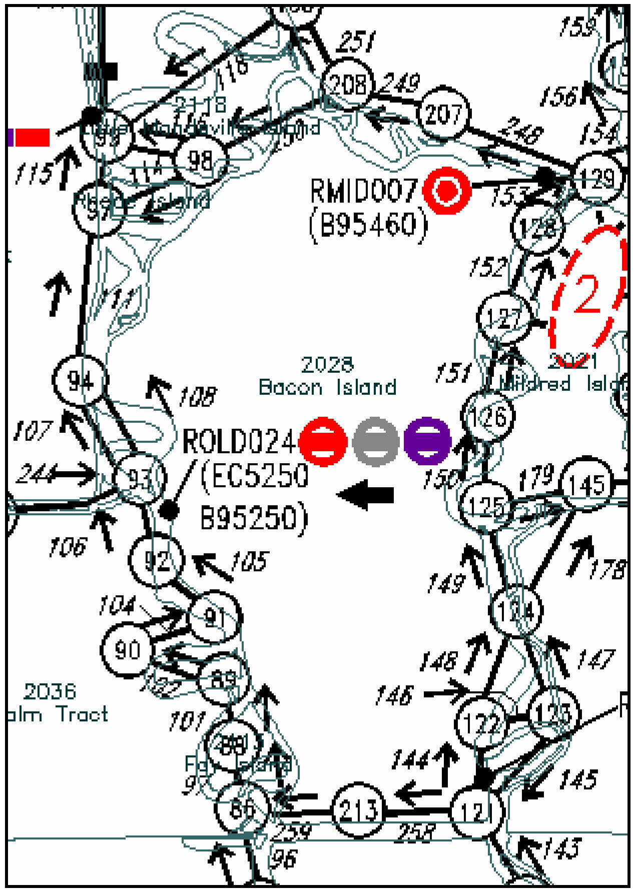

Figure 4.3(a): Representation of Bacon Islands in DSM2

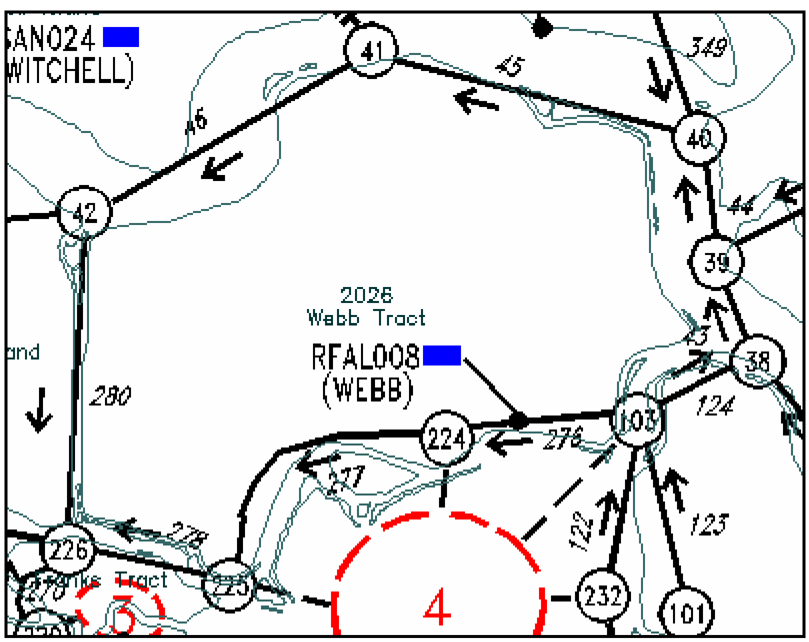

Figure 4.3(b): Representation of Webb Tract in DSM2

4.4.1 Output Location

To examine the impacts of project reservoirs on the channel DO and temperature, DSM2 output were requested for two locations. The first output was requested for the DSM2 Node 40. This location is close from the Webb Tract San Joaquin intake structure of the In-Delta Storage reservoir. The second output location was node 128, which is close to the release point from the Bacon Island.

4.5 Simulation Results

4.5.1 DO near the Islands

4.5.1.1 High Chlorophyll Scenario

This scenario considers island release at high BOD and high chlorophyll levels. Variations in the DO near project islands are shown in Figures 4.4a through 4.4d for channel near Bacon Island and Figures 4.5a through 4.5d for channel near Webb Tract. For the sake of clarity, the 16 year simulation time series plots are broken into four plots covering equal time period. For most times, the DO with the project is above 6 mg/l. For the Webb Tract the DO remains always above 6 mg/l. For Bacon Island the DO goes below 6 mg/l, however for about 15 days for 16 years simulation period. For the planned project operations, the variations of DO in the channels with and without project follow similar trend.

For both scenarios, channel DO is higher during winter months and lower during summer months because of higher DO saturation values at lower temperatures. Among the two output locations, Bacon Island intake (Node 128) has lower DO than Webb Tract (Node 40) intake. Although the operation lowers the channel DO, the plots show no violation since the DO is always above 5 mg/l level. The minimum DO seems to occur near Bacon Island intake during March 1988. The bar plot of the differences in the channel DO with and without project is shown in Figure 4.6. In general, the DO values decrease with the project operations. However, the change is lower than the one that would cause DO to be less than permissible value of 5mg/l. Among the two locations, the change in DO (with and without project) is more in Bacon Island which may be attributed to lesser amount of mixing near the intake structure.

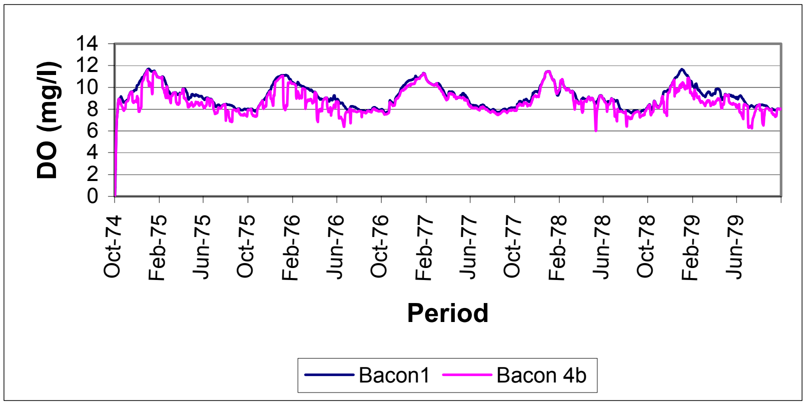

Figure 4.4a: Concentration of DO for WY 75-79

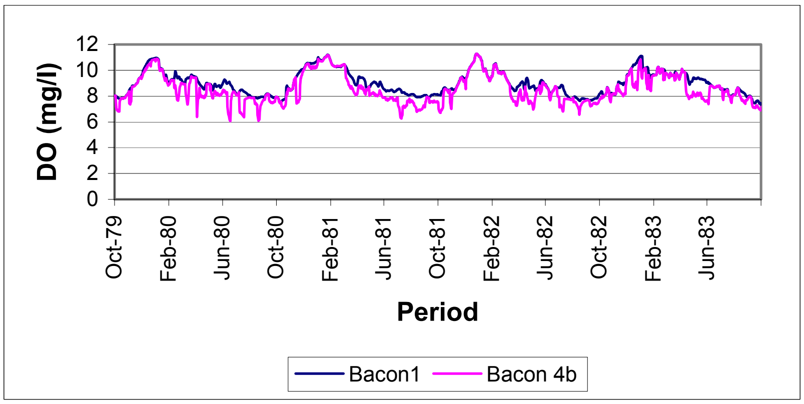

Figure 4.4b: Concentration of DO for WY 79-83

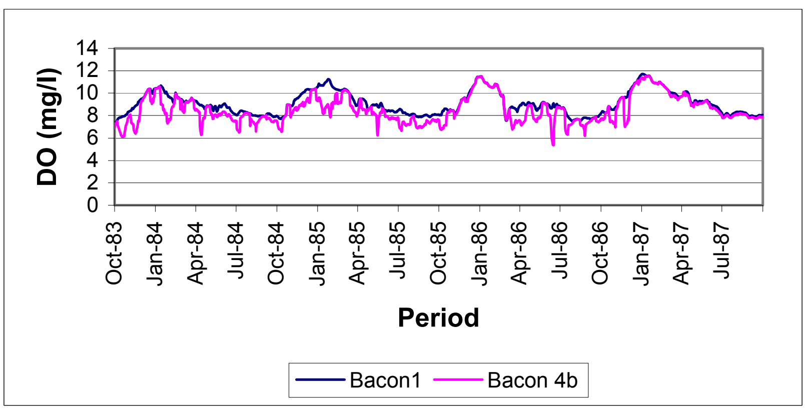

Figure 4.4c: Concentration of DO for WY 83-87

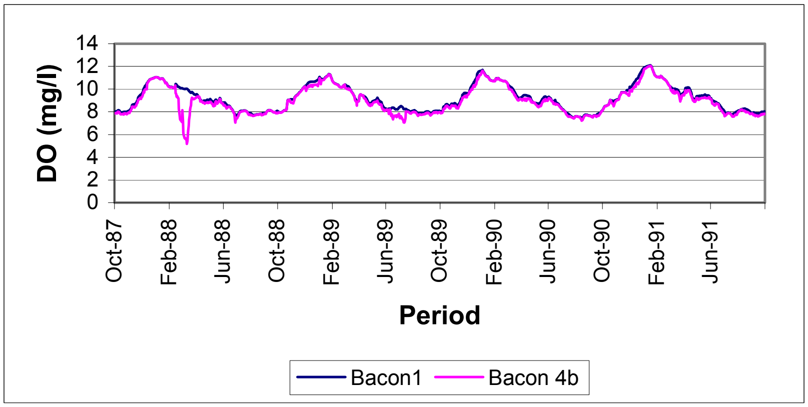

Figure 4.4d: Concentration of DO for WY 87-91

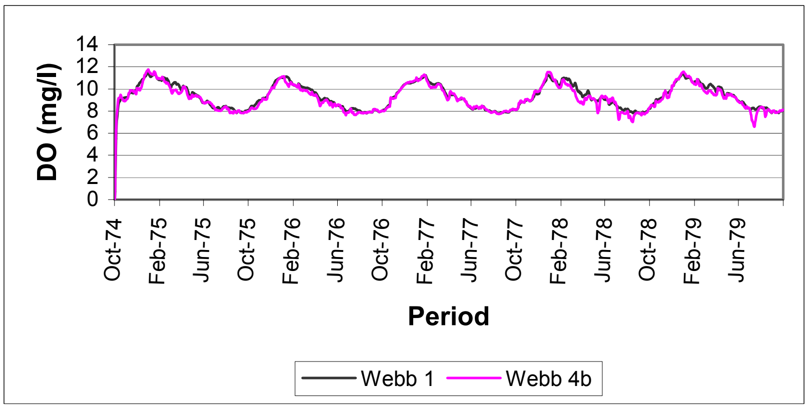

Figure 4.5a: Concentration of DO for WY 75-79

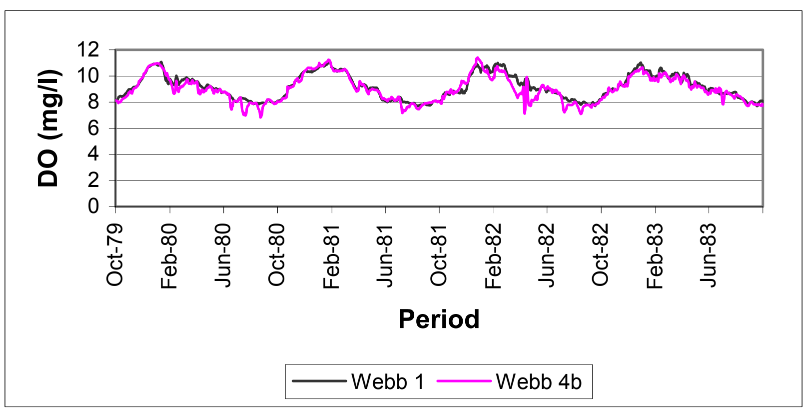

Figure 4.5b: Concentration of DO for WY 79-83

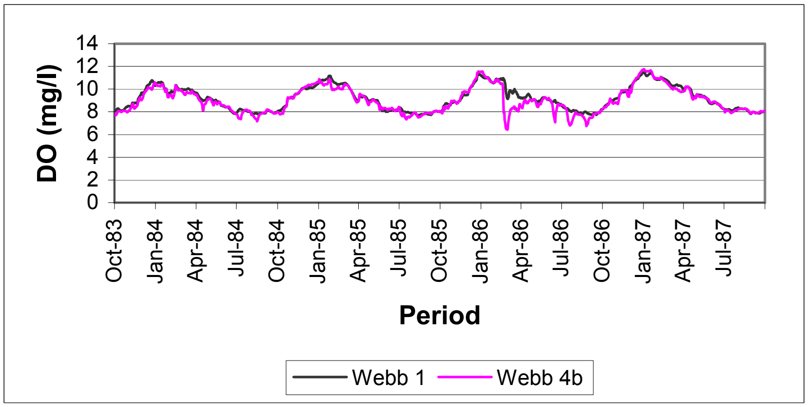

Figure 4.5c: Concentration of DO for WY 83-87

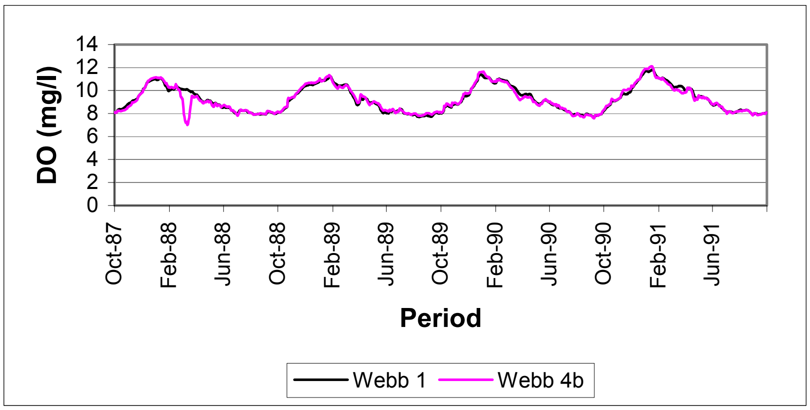

Figure 4.5d: Concentration of DO for WY 87-91

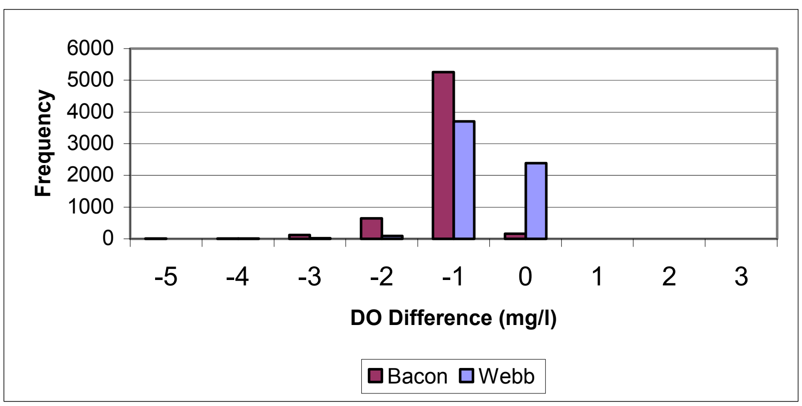

Figure 4.6: Bar plot of channel DO differences with and without project (High chlorophyll).

4.5.1.2 Intermediate Scenario

This scenario considers island release at low BOD and middle range of chlorophyll levels. DO near the project island integrated facilities (i.e. release points) is shown for

Bacon Island in Figure 4.7 and Webb Tract in Figure 4.8. Compared to the high chlorophyll scenario (Figures 4.4 – 4.5), the impact on channel DO due to project releases is smaller. The daily average difference in DO (high DO - intermediate DO) on the Middle River near the Bacon Island release point is shown in Figure 4.9, along with the actual daily average DO for the high and intermediate scenarios. The sensitivity of DO to the different chlorophyll and BOD as measured by the difference between the two scenarios ranged between 0.05 to -2.05 mg/L.

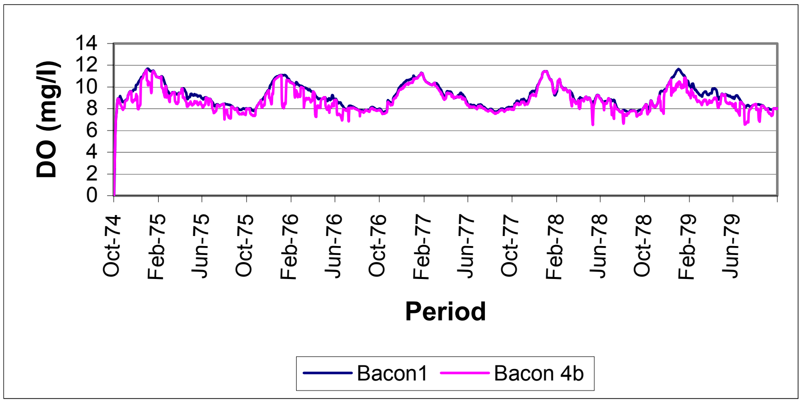

Figure 4.7a: Concentration of DO for WY 75-79

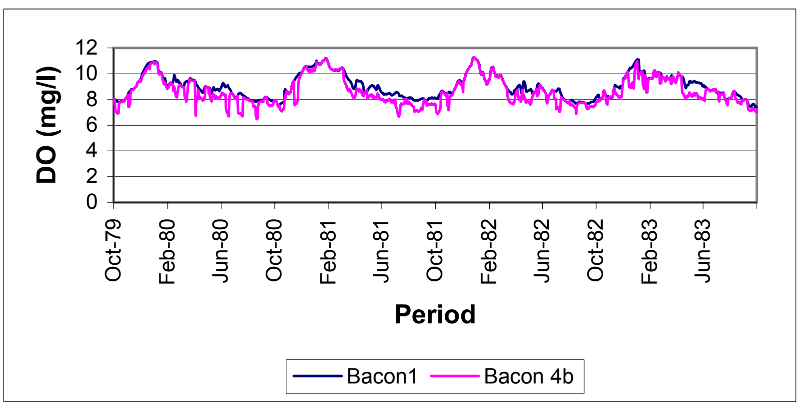

Figure 4.7b: Concentration of DO for WY 79-83

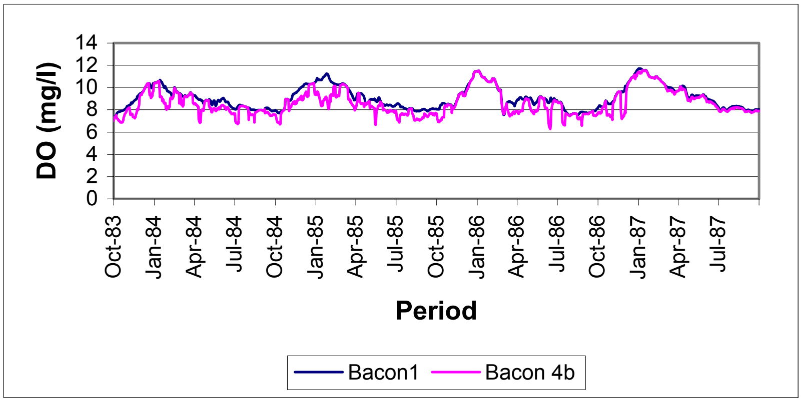

Figure 4.7c: Concentration of DO for WY 83-87

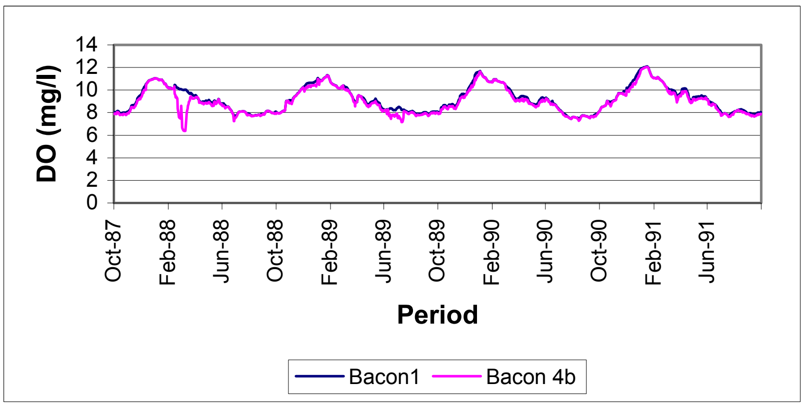

Figure 4.7d: Concentration of DO for WY 87-91

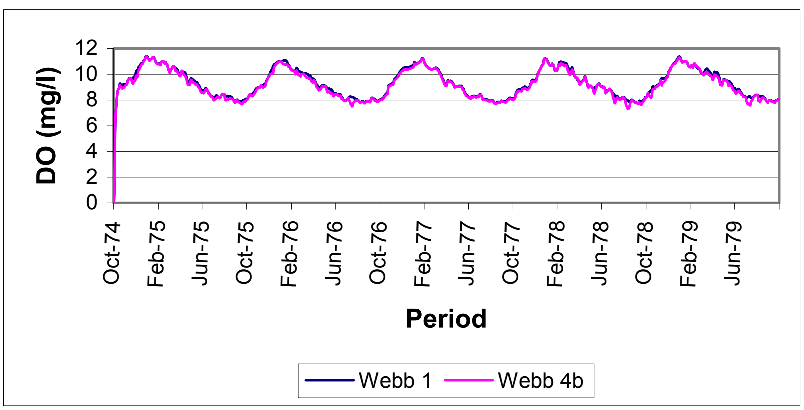

Figure 4.8a: Concentration of DO for WY 75-79

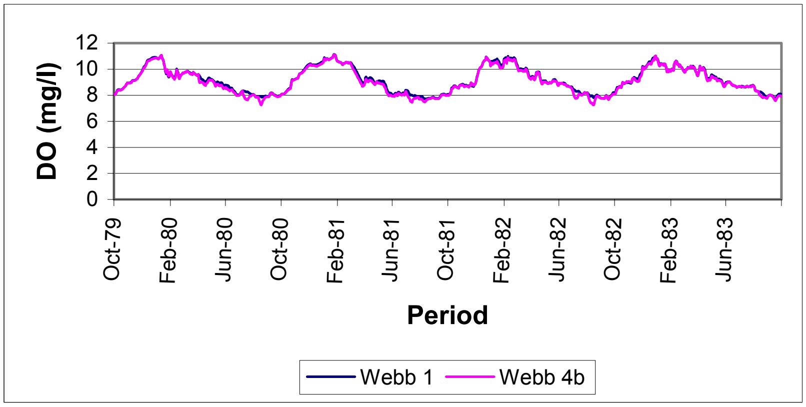

Figure 4.8b: Concentration of DO for WY 79-83

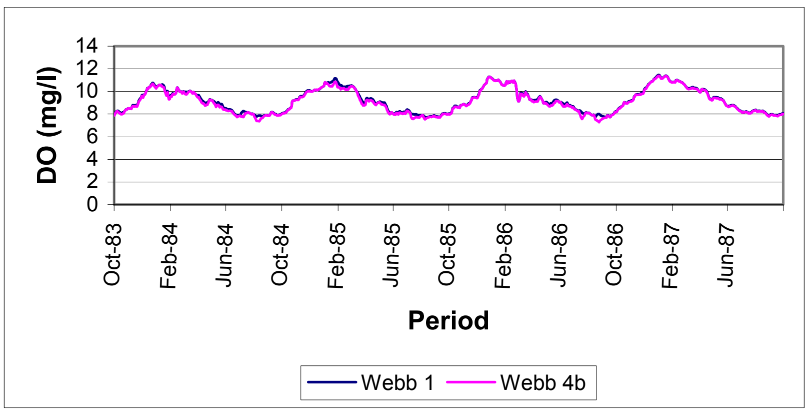

Figure 4.8c: Concentration of DO for WY 83-87

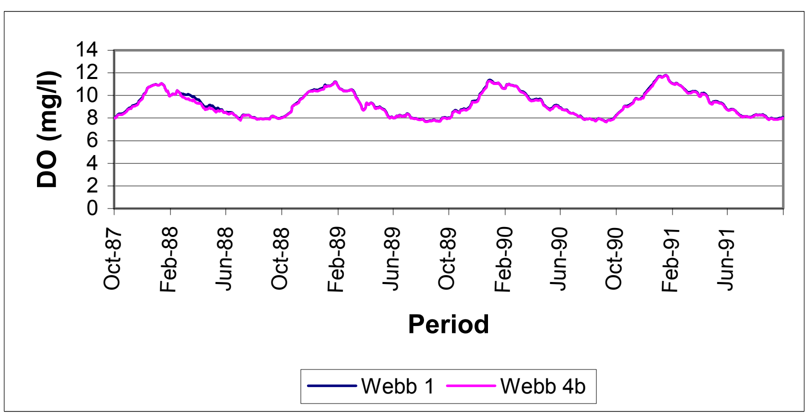

Figure 4.8d: Concentration of DO for WY 83-87

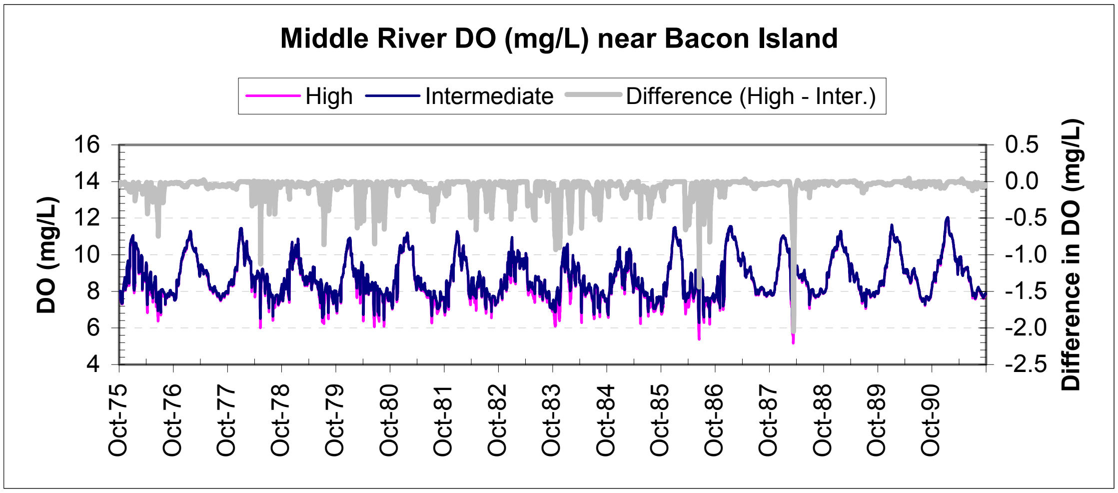

Figure 4.9: Sensitivity of DO for high and intermediate chlorophyll scenarios

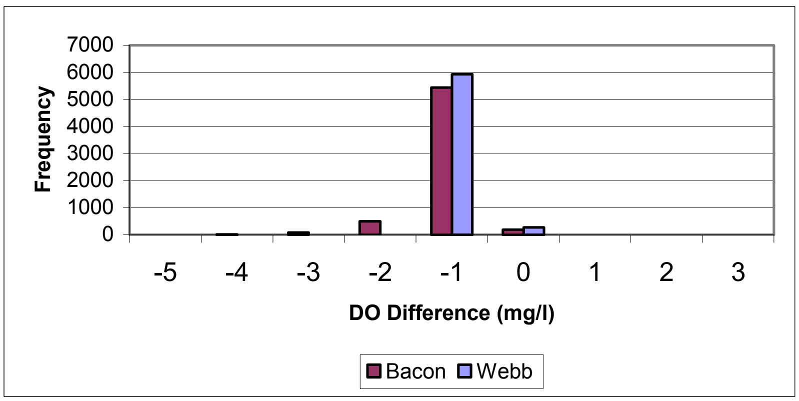

Figure 4.10: Bar plot of channel DO differences with and without project (Intermediate)

4.5.2 Temperature near the Islands

Channel water temperature for base and project operation scenarios are shown in Figures 4.11 a through d for channel near Bacon and Figures 4.12a through 4.12d for channel near Webb. For both scenarios, the channel temperatures follow similar seasonal pattern. Under the revised operation rules, violations in the channel water temperature are minimal. For a total of 16 years simulation period, the violation occurred for about 5 and 2 days for Bacons Island and Webb Tract, respectively. As summarized in Table 4.2, these violations only occur during summer times when one degree or lower temperature differential requirement applies. Considering the simulation period of 16 years, this can be attributed to inherent noise within the model. Frequency distribution of the temperature differentials between Study 1 and Study 4b releases for both output locations are shown in Figure 4.13. It can be seen that for most of the time the differential lies between -1 through 1 ^{0}F.

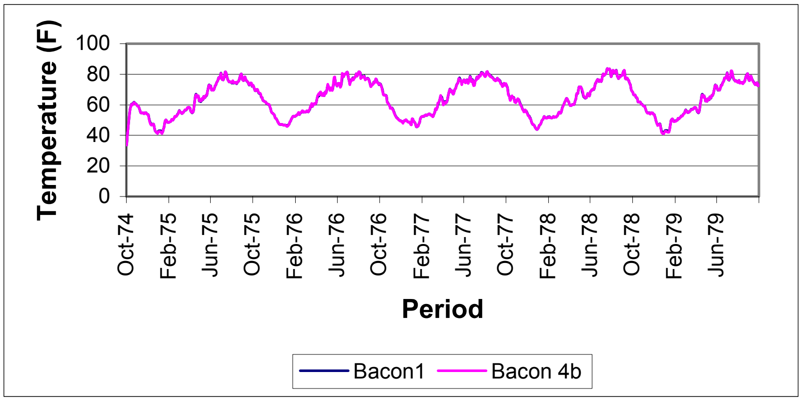

Figure 4.11a: Channel Water Temperature for WY 75-79

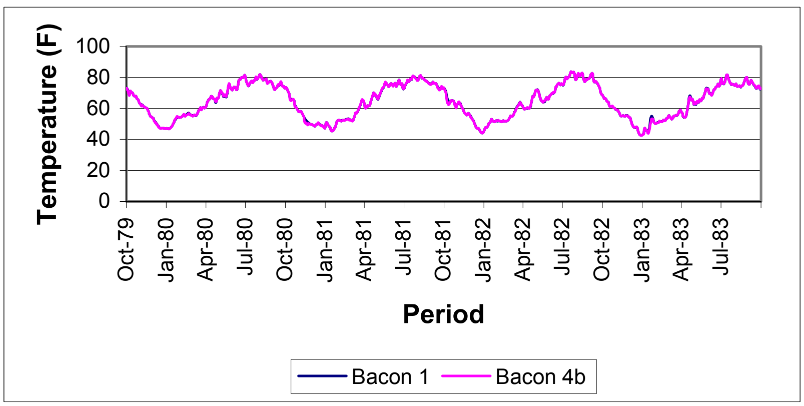

Figure 4.11b: Channel Water Temperature for WY 79-83

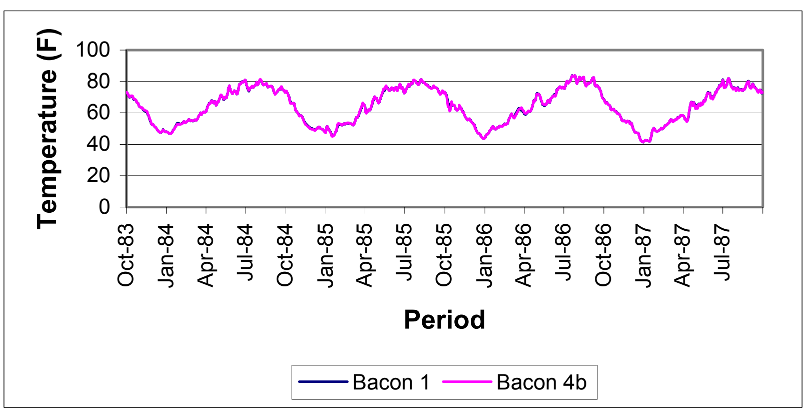

Figure 4.11c: Channel Water Temperature for WY 83-88

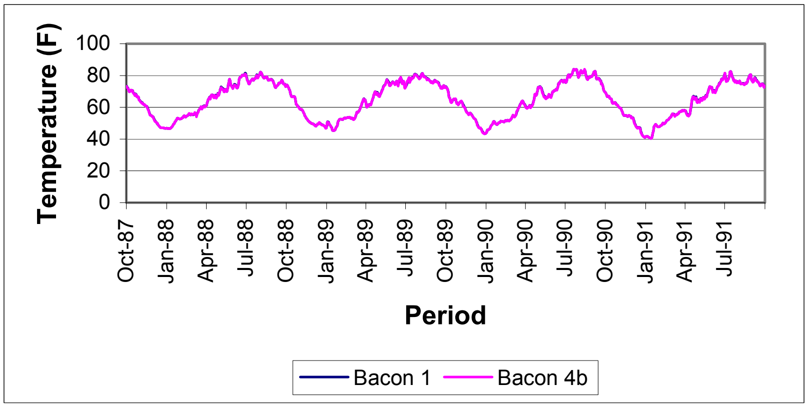

Figure 4.11d: Channel Water Temperature for WY 87-91

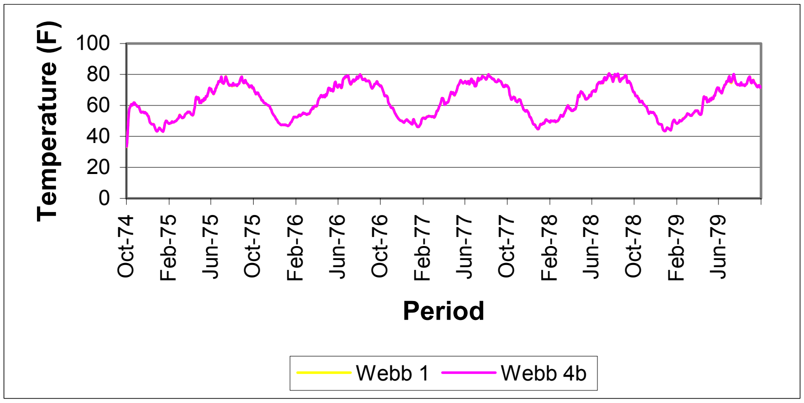

Figure 4.12a: Channel Water Temperature for WY 75-79

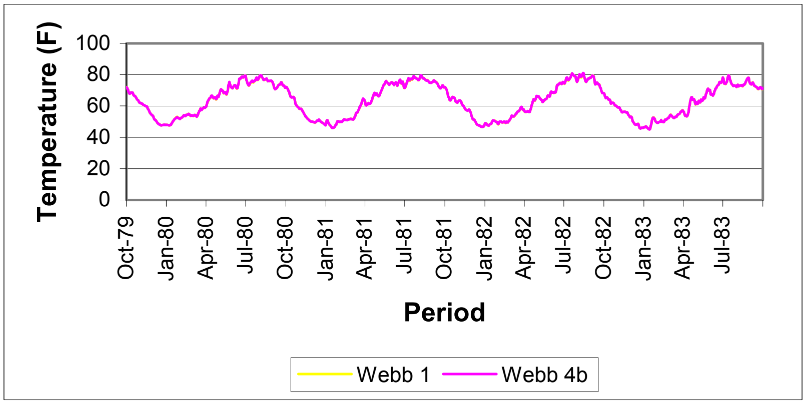

Figure 4.12b: Channel Water Temperature for WY 79-83

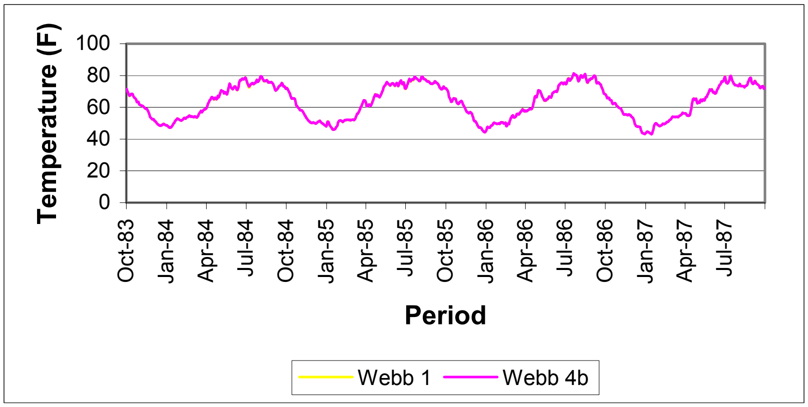

Figure 4.12c: Channel Water Temperature for WY 83-88

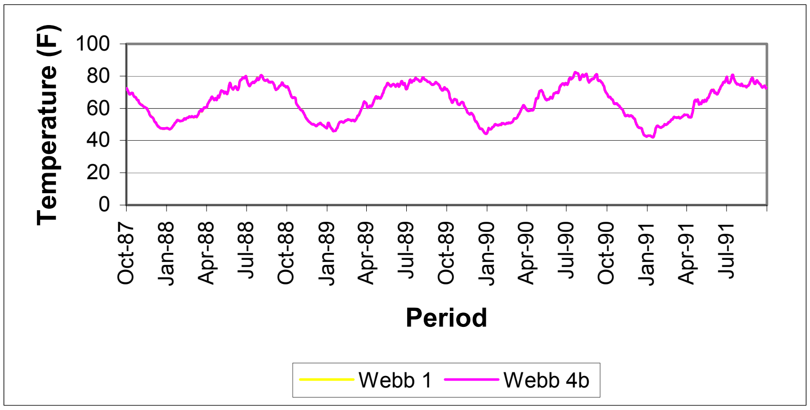

Figure 4.12d: Channel Water Temperature for WY 87-91

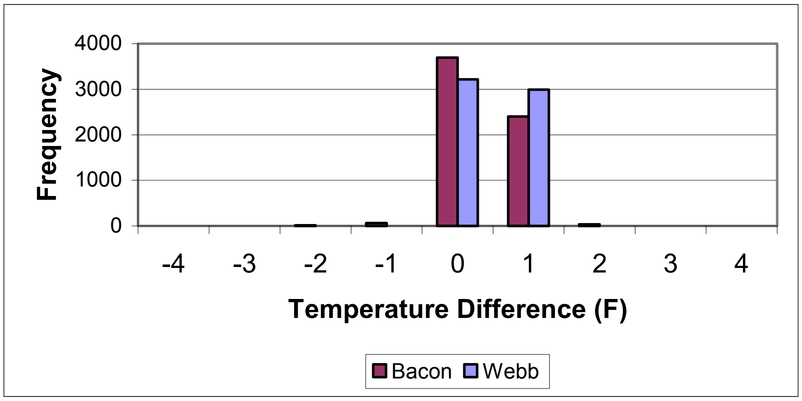

Figure 4.13: Temperature Difference at Outlets with and without Projects

Table 4.2: Summary of Violation Period in Water Temperature

Release Island	Channel Temperature (0F)	Violation (0F)	Time Period
Bacon	t>77	>1	June 15-16, 1976
Bacon	t>77	>1	July 11-12, 1979
Bacon	66<t<77	>2	June 14, 1976
Webb Tract	t>77	>1	June 12-13, 1976
Webb Tract	66<t<77	>2	None

4.6 Summary and Recommendation

4.6.1 Summary

In general, the DSM2-QUAL results not only reflect changes to Delta water quality due to operation of the project, but should be viewed as responding to larger system wide changes made within CALSIM II. In other words, DSM2 will show a water quality response when the CALSIM II inflows and exports are changed regardless of the immediate diversions or releases. Although CALSIM II simulated a 73-year period, DSM2 planning studies are still limited to a standard 16-year period. This 16-year period (water years 1976 – 1991) was chosen because a mix of critical, wet, and normal years exist in the historical (and hence CALSIM) hydrology.

Based upon the daily average results from DSM2 studies of DO and temperature, the following conclusions could be inferred.

- DSM2 modeling indicates that for the set of island water quality parameters used in this study, proposed IDS operation will not violate the DO condition in the channel assuming that the DO (and not other parameters) associated with releases meets the WQMP DO objectives. Under the planned operation rules, the island DO level was set at 6 mg/l. If this required criterion for island DO is not met, or changed, the study conclusions will not be valid.
- For the chosen scenarios of high chlorophyll, low chlorophyll, and intermediate organic load in the island release, no violation was indicated in the channel DO differentials with and without project islands. Due to lack of data, the assumed parameters may not include all the variations that could occur through complex interaction of plants and peat soil in the islands.
- A few days violations could occur for the temperatures that are higher than 77 degrees.
- Model simulation did not indicate that differences in water temperature between the island and the channel would exceed 20^0 F.
- DSM2 assumes that the reservoir is fully mixed and there is no stratification. Therefore, the model results will not be valid when sufficient stratification occurs.

4.6.2 Recommendation

- Water quality data needed for boundary conditions for the planning study were based on extrapolation of available data, when historical data were not available. Inclusion of more observed data is likely to improve the study analysis.
- A detailed investigation of island dynamics should be conducted to result in more confidence in the water quality of reservoir release. It may require further mesocosm studies, and calibration and validation of a reservoir model.
- Because of the inherent complexity of the reservoir dynamics, more time should be given for DSM2 analysis and post-processing so that sensitivity analysis could be conducted.

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Appendix A: Reservoir Stratification Study by Flow Science Inc.

Final Report
In-Delta Storage Program
State Feasibility Study
Reservoir Stratification Study
by
Flow Science Incorporated
(Under Separate Cover)