State of California
The Resources Agency
Department of Water Resources
Bay-Delta Office

METHODOLOGY FOR FLOW AND SALINITY ESTIMATES IN THE SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN MARSH

TWENTY-FOURTH ANNUAL PROGRESS REPORT TO THE STATE WATER RESOURCES CONTROL BOARD
In Accordance with Water Right Decision 1485, Order 9

August 2003

Gray Davis
Governor
State of California

Mary D. Nichols
Secretary for Resources
The Resources Agency

Michael J. Spear
Interim Director
Department of Water Resources

FOREWORD

This is the twenty-fourth annual progress report of the California Department of Water Resources' San Francisco Bay-Delta Evaluation Program, which is carried out by the Delta Modeling Section.

It documents progress in the development and enhancement of the Delta Modeling Section's computer models and reports the latest findings of studies conducted as part of the program. This report was compiled by Michael Mierzwa, with assistance from Jane Schafer-Kramer and Nikki Blomquist, under the direction of Bob Suits, Senior Engineer, and Tara Smith, program manager for the Bay-Delta Evaluation Program.

On-line versions of previous annual progress reports are available at:

http://modeling.water.ca.gov/branch/reports.html

For more information contact:

Tara Smith
tara@water.ca.gov
(916) 653-9885

-or-

Michael Mierzwa
mmierzwa@water.ca.gov
(916) 653-9794

TABLE OF CONTENTS

FOREWORD ..... **iii**

1 INTRODUCTION **1-1**

2 REALM **2-1**
2.1 Introduction **2-1**
2.2 REALM Physical Modeling Requirements **2-2**
2.3 Numerical Methods and Grid **2-3**
2.3.1 Grid 2-3
2.3.2 Solution Techniques for Physical Processes 2-5
2.4 Analysis and Management Tools **2-8**
2.5 Collaboration **2-9**
2.6 Work Flow **2-11**
2.7 Example Problems **2-11**
2.7.1 Through Delta Facility 2-11
2.7.2 Particle Tracking 2-14
2.7.3 Real-Time Adaptive Delta Management 2-14
2.8 References **2-15**

3 EXTENDING DSM2-QUAL CALIBRATION OF DISSOLVED OXYGEN **3-1**
3.1 Introduction **3-1**
3.2 Background **3-1**
3.3 Data and Model Input **3-2**
3.4 Calibration and Validation **3-4**
3.4.1 Calibration Results 3-6
3.4.2 Validation Results 3-7
3.5 Summary **3-11**
3.6 Future Directions **3-12**
3.7 References **3-13**

4 MORROW ISLAND DISTRIBUTION SYSTEM CALIBRATION **4-1**
4.1 Introduction **4-1**
4.2 Background **4-1**
4.3 Location and Setup of Flow Study **4-1**
4.4 Data and Analysis **4-2**
4.5 Conclusions and Recommendations **4-6**
4.6 Websites **4-6**

5 USE OF CALVIN IN DSM2 PLANNING STUDIES **5-1**
5.1 Introduction **5-1**
5.2 CALVIN Overview **5-2**
5.3 Use of CALVIN to Provide Input to DSM2 ..... **5-4**
5.3.1 Inflow and Export Boundary Conditions 5-4
5.3.2 Delta Island Consumptive Use 5-6
5.4 Use of DSM2 to Provide Feedback to CALVIN **5-7**
5.5 Future Directions **5-7**
5.6 References **5-8**
5.7 Websites **5-8**

6 NEW BEHAVIORS AND CONTROL SWITCHES IN DSM2-PTM 6-1
6.1 Introduction 6-1
6.2 Stage Triggering 6-1
6.2.1 Vertical Positioning Example 6-2
6.2.2 Vertical Positioning Implementation 6-2
6.3 Seepage Switch 6-3
6.4 References 6-3

7 IMPLEMENTATION OF A NEW DOC GROWTH ALGORITHM IN DSM2-QUAL 7-1
7.1 Introduction 7-1
7.2 Implementation in QUAL 7-1
7.2.1 Activating DOC Growth 7-2
7.2.2 DOC Mass Growth Rate Parameters 7-2
7.3 Example Application of New Methodology 7-4
7.4 Conclusions 7-5
7.5 References 7-6

8 DSM2-HYDRO BINARY OUTPUT FILE READER 8-1
8.1 Introduction 8-1
8.2 Main Interface 8-1
8.3 File Editor Interface 8-2
8.4 Location Editor Interface 8-3
8.5 Graphing Binary Data 8-4
8.6 Future Development 8-4

9 DEVELOPING EC FOR INFLOWS FOR THE SAN JOAQUIN RIVER EXTENSION TO DSM2 FOR PLANNING STUDIES 9-1
9.1 Introduction 9-1
9.2 Sources of Inflow to the San Joaquin River from Vernalis to Bear Creek 9-1
9.3 EC in Stanislaus, Tuolumne, and Merced Rivers 9-1
9.4 EC in San Joaquin River at Upstream Boundary (near Stevinson) 9-5
9.5 EC in Orestimba Creek 9-7
9.6 EC in Salt and Mud Sloughs 9-8
9.7 EC in Westside Agriculture Return Flow 9-12
9.8 EC in Eastside Drainage 9-13
9.9 EC in Groundwater Flows 9-13
9.10 References 9-14

TABLES

Table 3.1: Summary of Continuous DO and Temperature Monitoring Stations 3-6
Table 4.1: DSM2 Sensitivity Runs and MIDS Downstream Flow Coefficients 4-3
Table 5.1: Summary of CALSIM and CALVIN Boundary Conditions Inputs to DSM2..... 5-5
Table 9.1: Equations for EC as a Function of Flow at Various Sources of Inflow on the San Joaquin River..... 9-3
Table 9.2: EC Added to Applied Agricultural Water before Modeling Accumulated Salts 9-12

FIGURES

Figure 2.1: Multiblock Using Several Rectangular Meshes to Cover a Model Domain 2-4
Figure 2.2: (left) Plan View of 2D Cartesian Cut Cells, with Boundary-Conforming Straight Line Cuts Across Cells. (right) Side view of a Single 3D Cut Cell, with a Planar Cut Representing Bottom Topography 2-4
Figure 2.3: The Volume of Fluid (and Therefore the Boundary) Moving with the Water Levels in a Computational Cell During Wetting and Drying 2-5
Figure 2.4: Adaptive Mesh Refinement.....2-5
Figure 2.5: Through Delta Facility 2-12
Figure 2.6: TDF-Controlled Salinity Within Range 2-13
Figure 2.7: Unoptimized vs. Optimized Operations.....2-14
Figure 3.1: Water Quality Stations near Stockton. 3-2
Figure 3.2: Interaction Between DO and Related Parameters.....3-3
Figure 3.3: DO and Temperature Water Quality Stations in the Delta.....3-5
Figure 3.4: DO in the Middle River at Howard Road.....3-6
Figure 3.5: DO in the Old River at the Tracy Wildlife Association.....3-7
Figure 3.6: DO in the Old River at DMC.....3-7
Figure 3.7a: DO in the San Joaquin River at Rough and Ready Island, 1996-1998 3-8
Figure 3.7b: DO in the San Joaquin River at Rough and Ready Island, 1999-2000 3-8
Figure 3.8a: Water Temperature in the San Joaquin River at Rough and Ready Island, 1996-1998 3-9
Figure 3.8b: Water Temperature in the San Joaquin River at Rough and Ready Island, 1999-2000 3-9
Figure 3.9a: DO in the Sacramento River at Mallard Slough, 1996-1998 3-10
Figure 3.9b: DO in the Sacramento River at Mallard Slough, 1999-2000 3-10
Figure 3.10a: DO in the San Joaquin River at Antioch, 1996-1998.....3-11
Figure 3.10b: DO in the San Joaquin River at Antioch, 1999-2000.....3-11
Figure 4.1: Morrow Island Distribution System Intake and Goodyear Slough 4-2
Figure 4.2: DSM2 and Observed Flow Through MIDS Intake on February 19, 2003.....4-3
Figure 4.3: DSM2 and Observed Flow in Goodyear Slough near MIDS Intake on February 19, 2003.....4-4
Figure 4.4: DSM2 and Observed Flow in Goodyear Slough near MIDS Intake on February 26, 2003.....4-4
Figure 4.5: Stage at MIDS Intake on February 19, 2003 (Neap Tide) 4-5
Figure 4.6: Stage at MIDS Intake on February 26, 2003 (Spring Tide) 4-5
Figure 5.1: CALVIN Inputs to DSM2 and DSM2 Feedback to CALVIN 5-2
Figure 5.2: Regions, Inflows, and Reservoirs Represented in CALVIN.....5-3
Figure 5.3: Sample DSM2 Text Boundary Condition Input File, Using Input from CALVIN 5-5
Figure 6.1: View of Stage Behavior GUI Showing Vertical Positioning Based on Rising and Falling Stage 6-1
Figure 6.2: Example of Positioning from Stage Triggering and Particle Position Associated with: (A) Rising Stage and (B) Falling Stage.....6-2
Figure 6.3: Example of How Stage Triggering is Implemented.....6-3
Figure 7.1: Sample scalar.inp File.....7-2
Figure 7.2: Conceptualization of Implementation of DOC Growth in QUAL 7-3
Figure 7.3: Example operation_schedule.dat File.....7-4
Figure 7.4: Example of DOC Growth in an Island Reservoir 7-4
Figure 8.1: DSM2 Binary File Reader Application Interface 8-2
Figure 8.2: DSM2 Binary File Reader File Editing Interface 8-3
Figure 8.3: DSM2 Binary File Reader Location Editing Interface 8-3
Figure 8.4: DSM2 Binary File Reader Graphing Interface 8-4
Figure 9.1: Sources of EC in Modeled Reach of San Joaquin River 9-2

Figure 9.2: Stanislaus River, EC vs. Flow 9-4
Figure 9.3: Tuolumne River, EC vs. Flow 9-4
Figure 9.4: Merced River, EC vs. Flow 9-5
Figure 9.5: San Joaquin River near Stevinson, EC vs. Flow 9-6
Figure 9.6: Orestimba Creek, EC vs. Flow 9-8
Figure 9.7: Salt Slough, EC vs. Flow 9-9
Figure 9.8: Mud Slough, EC vs. Flow 9-11
Figure 9.9: Combined EC for Westside Agricultural Return Flow 9-12
Figure 9.10: EC in Groundwater Flows to the San Joaquin River 9-13

1 Introduction

Over the last ten years, the Delta Modeling Section has been developing and enhancing the Delta Simulation Model 2 (DSM2) and its support tools. The following are brief summaries of work that was conducted during the past year. The names of contributing authors are in parentheses.

Chapter 2 – REALM

Even though the Section continues to enhance DSM2 in response to numerous hydrodynamic and water quality needs in the Delta, a growing number of these requests are beyond DSM2's ability to address. To continue to provide technical support to the Department for issues related to the Delta, the first phase of this project assessed the possibility of using existing tools to meet the current and future technical questions the Section would likely face. After surveying these existing decision-support tools, it was concluded that, like DSM2, many of these existing tools had their own limitations. REALM is the working title of a new multi-agency decision-support system for modeling in the Delta. This chapter introduces the early development of REALM. *(Eli Ateljevich and Ralph Finch)*

Chapter 3 – Extending DSM2-QUAL Calibration of Dissolved Oxygen

The Section has been reporting progress in dissolved oxygen (DO) and temperature modeling in its annual reports since 1994. The last DSM2-QUAL DO and temperature calibration was conducted near Stockton on the San Joaquin River in 2000. Since that time, new DO, temperature, and nutrient data in the South Delta have become available. Originally a part of a project to study the effects of increasing flow in the San Joaquin River, the calibration and validation of QUAL for DO have been spatially extended to include the South Delta. Furthermore, two years of additional data along the San Joaquin River was also used to extend the existing validation through the present. This chapter focuses on the results of the extension of the previous QUAL DO and temperature calibrations and validations. *(Hari Rajbhandari)*

Chapter 4 – Morrow Island Distribution System Calibration

The current DSM2 grid includes an extensive portion of the Suisun Marsh, which is near the model's current downstream ocean boundary at Martinez. In fall 2002, the Morrow Island Distribution System (MIDS) intake gate was replaced with a new structure. The Department's Suisun Marsh Planning Section was responsible for overseeing this extensive project, as well as monitoring the new intake's impact on both the surrounding channels and within DSM2. In February 2003, the Suisun Marsh Planning Section conducted two field studies near the MIDS intake, and later recalibrated the MIDS intake gate coefficients in DSM2 to account for the changes in flow associated with the new structure. This chapter covers the Suisun Marsh Planning Section's work related to MIDS. (*Kate Le*)

Chapter 5 – Use of CALVIN in DSM2 Planning Studies

Previous annual reports have focused on the connections between DSM2 and CALSIM; however, DSM2 planning studies can be conducted using any water resources model that can provide the required flow and operations information. The University of California Davis's CALVIN (CALifornia Value Integrated Network)—an economic optimization model that varies water resources by month-- was recently used in a series of climate change and sea level rise studies to provide input into DSM2. DSM2 then was used to provide feedback to CALVIN on how well the system operations suggested in the CALVIN operations meet Delta water quality standards. This chapter focuses on the integration of CALVIN output into DSM2 and the role DSM2 plays in providing feedback to CALVIN for improving its representation of the Delta. (*Jamie Anderson*)

Chapter 6 – New Behaviors and Control Switches in DSM2-PTM

This chapter introduces a new stage-triggering behavior and a seepage control switch that were added to DSM2-PTM. Sometimes aquatic organisms in the Delta behave differently when the tide is flooding or ebbing. The new stage-triggering behavior allows this type of behavior to be specified using the Particle Tracking Model (PTM) behavior graphical user interface described in the 2000 annual report. In the past, PTM did not treat seepage flows differently from other agricultural diversions or channel junctions. While the assumption that the particle fate associated with seepage flows may be appropriate for contaminate flows, it was necessary to change PTM so some particles (such as aquatic organisms) would not be removed from the Delta by seepage flows. (*Aaron Miller*)

Chapter 7 – Implementation of a New DOC Growth Algorithm in DSM2-QUAL

Last year's annual progress report described the implementation of a dissolved organic carbon (DOC) growth algorithm in DSM2-QUAL. This algorithm was utilized to characterize the growth of DOC on flooded Delta islands in support of DWR's Integrated Storage Investigations' In-Delta Storage (ISI-IDS) project. Feedback on the ISI-IDS project from CALFED and others recommended improving the field experiments from which this algorithm was based, thus ISI conducted new experiments to develop a better routine for QUAL. Chapter 7 summarizes the new DOC growth algorithm used by QUAL to represent DOC growth on a flooded island. An example comparing the behavior of this new algorithm to the behavior of the old algorithm is shown. (*Michael Mierzwa and Ganesh Pandey*)

Chapter 8 – DSM2-HYDRO Binary Output File Reader

The binary output file generated by DSM2-HYDRO links HYDRO to DSM2-QUAL and DSM2-PTM. This file is also used to provide additional information on flow and stage data after a HYDRO simulation has been completed. This chapter introduces a new easy-to-use tool that facilitates access to the flow and stage information at any location in the DSM2 grid. This binary output file reader is used by the Section to provide quality assurance / quality control (QA/QC) in its modeling studies. (*Aaron Miller*)

Chapter 9 – Developing EC for Inflows for the San Joaquin River Extension to DSM2 for Planning Studies

The Delta Modeling Section developed a method to assign Electrical Conductivity (EC) to inflows in the San Joaquin River during the recent expansion of DSM2 from Vernalis to Bear Creek. This methodology assumes CALSIM-generated flows are available and can account for the recirculation of Delta-Mendota Canal water through the San Joaquin River. (*Jim Wilde*)

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 2:
REALM

Author: Eli Ateljevich and Ralph Finch

2 REALM

2.1 Introduction

REALM - River, Estuary, and Land Model - is a project to develop a new modeling tool and decision support system for managing *short-term operations* in the Sacramento-San Joaquin Delta and its tributaries, and planning *long-term structural changes* such as a Through Delta Facility (TDF) or In-Delta Storage.

The REALM project is motivated by two concerns:

- The need to significantly improve the accuracy and speed of existing simulation models.
- The need to greatly increase the usefulness of models for decision-making and for solving complex water issues in the Delta, tributaries, and bays.

Like other models used in the water resources community such as DSM2, REALM will provide software for modeling physical, chemical, and biological systems in estuaries, rivers, bays, and eventually groundwater. The range of processes that can presently be modeled will be expanded, physical detail will be refined, and multi-dimensionality will be offered. Many of the simplifying assumptions that are currently made will be eliminated or made optional.

Besides better physics representations and numerical methods, REALM will offer improved support for analysis and decision-making. The user will be provided with ways to visualize and investigate tradeoffs between disparate objectives, implement adaptive operation strategies, fold field data into the model in real time, and "play" with the model interactively. The visualization and analysis tools will leverage experiments, providing information such as sensitivities and probabilities that will allowing modelers to steer their investigations towards promising operating strategies or designs.

REALM will become a vehicle for directly posing such scientific management decisions as:

- What is the most efficient flow schedule to meet the water quality standard at Rock Slough?
- How should island flooding be manipulated to obtain the best improvement of water quality?
- What is the error in this simulation due to uncertainty in the tide? What strategy best compensates for this uncertainty?
- What are the tradeoffs between pumping rate and scheduling, Clifton Court gate operations, salinity, and stage in the South Delta?

Current models merely provide the ability to simulate; and questions like the ones above can be answered only indirectly, using informal trial-and-error experiments with simplified (flat-lined) time series as input and *ad hoc* safety margins to deal with uncertainty. By augmenting the traditional water resources model with standard tools from disciplines such as optimal control, mechanical engineering, and statistics, REALM will be able to show users much more than just the simulated output associated with one choice of input. The user will learn in detail how the Bay-Delta will respond to variations in management decisions and how to better craft these decisions. Thus, REALM supports a broad range of Bay-Delta study, whether motivated by science and the need to learn about the estuary, or by practice and the need to manipulate the Delta as an engineered system.

Many problems of interest in the Delta are complex. To solve them with a usable level of accuracy requires considerable model resolution which comes at the expense of increased model run time. In addition, many of the exploratory techniques for decision support advocated in this document involve batches of related exploratory runs, not just a single simulation. As the output of analysis expands from the "single best shot" to a depiction of tradeoffs and sensitivities, computational costs will go up proportionally.

REALM addresses the need for efficiency in two ways. First, it allows adjustable or selectable computational density within a model grid. Mesh refinement is concentrated in the areas that need it most, including complex flow regions and the featured regions of the study. Second, REALM's design allows parallel processing if multiple processor units are available in the hardware. Each processor works on a separate part of the domain or problem, with sub-components arranged in such a way that the communication between them is minimal and efficient.

2.2 REALM Physical Modeling Requirements

REALM is intended to be a state-of-the-art estuary model. The model will simulate flow, water surface height, water quality, and particle movement in response to tides, upstream flows, and midstream diversions. In its first release, REALM will include hydrodynamics and water quality in one and two dimensions plus some important extensions such as wetting and drying of tidal mudflats, and non-conservative/reactive source terms for dissolved constituents. In addition, due to strong demand in the user community, REALM will, early on, also include accurate individual particle tracking with behavior.

In the follow-up releases of REALM, vertically layered flow and 3D water quality modeling, groundwater, and sediment transport will be introduced. Care will be taken to ensure that the 3D and 2D formulations are compatible, so that coupling between them is simple and physical and the two can coexist in the same simulation (an example of this is TRIM3D, whose representation with one vertical layer is equivalent to TRIM2D.)

The order in which physical processes will be added to REALM depends on user needs. The Delta Modeling Section has interviewed more than a dozen Delta workers, managers, and

stakeholders to determine their priorities. These priorities and associated development costs will continue to be assessed and balanced in a regular design cycle.

2.3 Numerical Methods and Grid

Like all estuary models, REALM will be based on conservation of mass and momentum in one, two, and three dimensions. The formulation is not discussed in any detail here, but the formulation and level of approximation will be comparable to that used in comparable international (MIKE, Telemac) and local (TRIM, RMA, DSM2) flow models. The portrayal of the physics will include hydrostatic assumption for pressure variations in the vertical direction, variable water density due to salinity (using the Boussinesq approximation), diffusion analogies for turbulent stresses and dispersion, and a variety of source and sink terms such as wind and friction stresses.

Numerical models are distinguished not only by their specification of the conservation laws but also by the numerical methods that are used to integrate the resulting equations. The REALM design will accommodate a variety of numerical schemes[1], but primarily targets Finite Volume Methods (FVM) on Cartesian cut cell grids. In FVM schemes, the study domain is divided into discrete computational cells or "volumes" and the exchange of mass and momentum between these cell is tracked over time. A great variety of finite volume methods arise from the methods for calculating intercell fluxes, the treatment of boundary conditions, the choice of grid used to represent the estuary, and the marching scheme used to advance the model in time.

2.3.1 Grid

One of the most significant choices for a FVM numerical model design is the choice of the spatial discretization or grid. The grid not only affects the accuracy, speed, and user-friendliness of the model; it also imposes a number of restrictions on the choices of specific numerical schemes and has repercussions on all aspects of the software design including data management and input/output. For one-dimensional modeling, REALM will continue to use a network of channels similar to the current DWR model DSM2. For 2D and 3D, REALM will use a hybrid mesh that combines several tools often associated with one another: multiblock rectangular meshes, Cartesian cut cells, and mesh refinement. These methods retain the excellent numerical properties that rectangular grids possess, but allow boundary-conforming geometry and concentration of computation in difficult or interesting regions.

Multiblock refers to the use of a number of rectangles instead of a single rectangle to cover the domain (Figure 2.1). "Cartesian cut cells" refers to the use of a regular mesh for most of the domain, with the irregular boundary embedded using a series of straight-line cuts (Figure 2.2). The description of the cuts can be complicated when the definition of the model domain changes with fluctuating water levels during wetting and drying (Figure 2.3). Adaptive Mesh Refinement (AMR) refers to an adaptive solution mechanism by which Cartesian grids of different levels of

[1] If any broad category of numerical formulation is excluded, it is finite element methods (FEM). Although reputable models such as RMA and Telemac use finite elements, these schemes are seldom used in new flow models. There is little generic software support for FEM in infrastructure libraries, and most of the innovations from FEM (including arbitrary grids) have been absorbed into the finite difference and volume methods.

refinement are nested to produce a grid with high resolution in some areas and lower resolution in others (Figure 2.4).

Cartesian cut cell and AMR methods are difficult to program but they are easy to use. To allow efficient model development, "infrastructure libraries" such as the Advanced Computational Testing and Simulation (ACTS) collection developed at the Department of Energy national laboratories, particularly LBL, will be used. LBL is expected to be a major collaborator on this project.

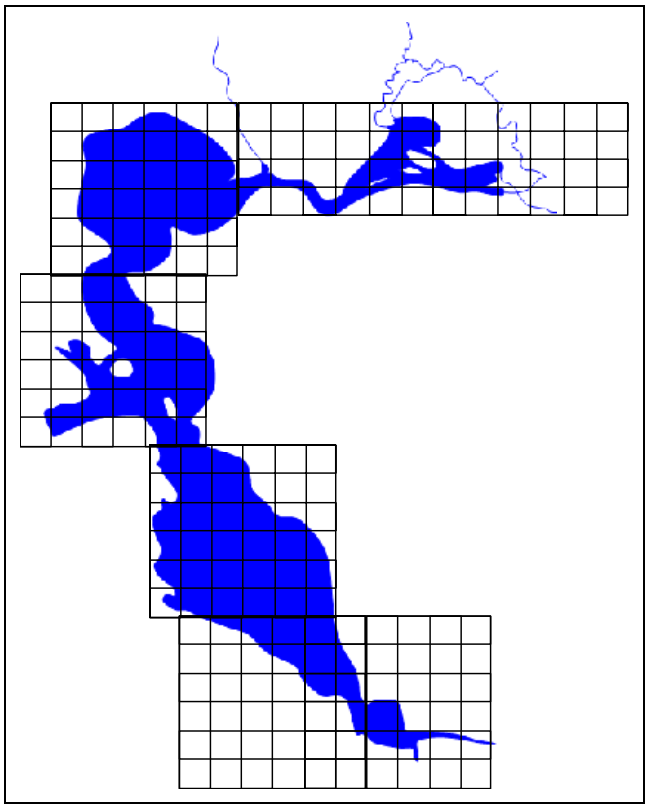

Figure 2.1: Multiblock Using Several Rectangular Meshes to Cover a Model Domain.

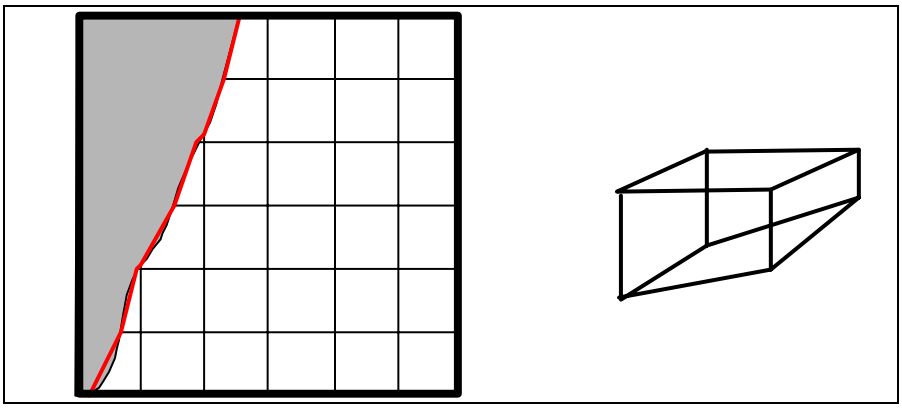

Figure 2.2: (left) Plan View of 2D Cartesian Cut Cells, with Boundary-Conforming Straight Line Cuts Across Cells. (right) Side View of a Single 3D Cut Cell, with a Planar Cut Representing Bottom Topography.

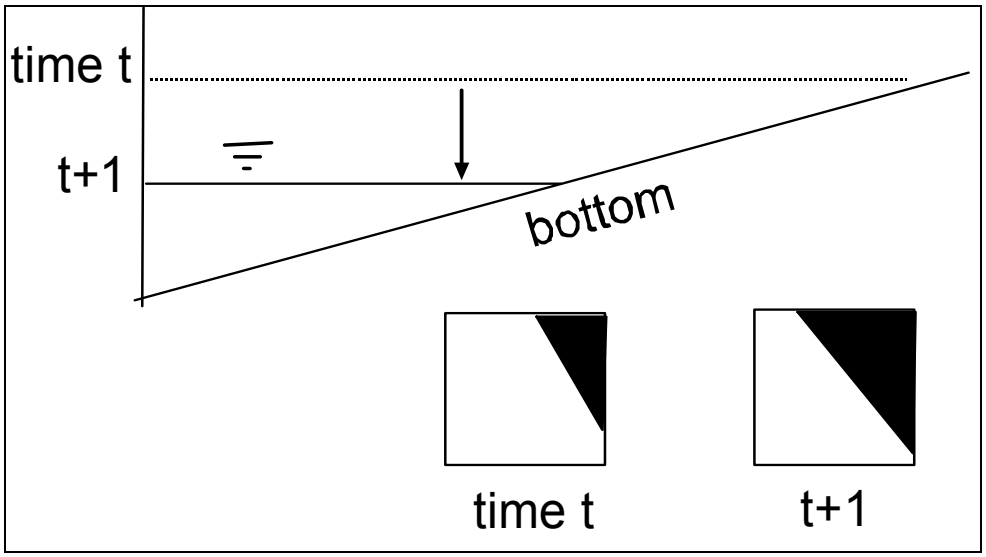

Figure 2.3: The Volume of Fluid (and Therefore the Boundary) Moving with the Water Level in a Computational Cell During Wetting and Drying.

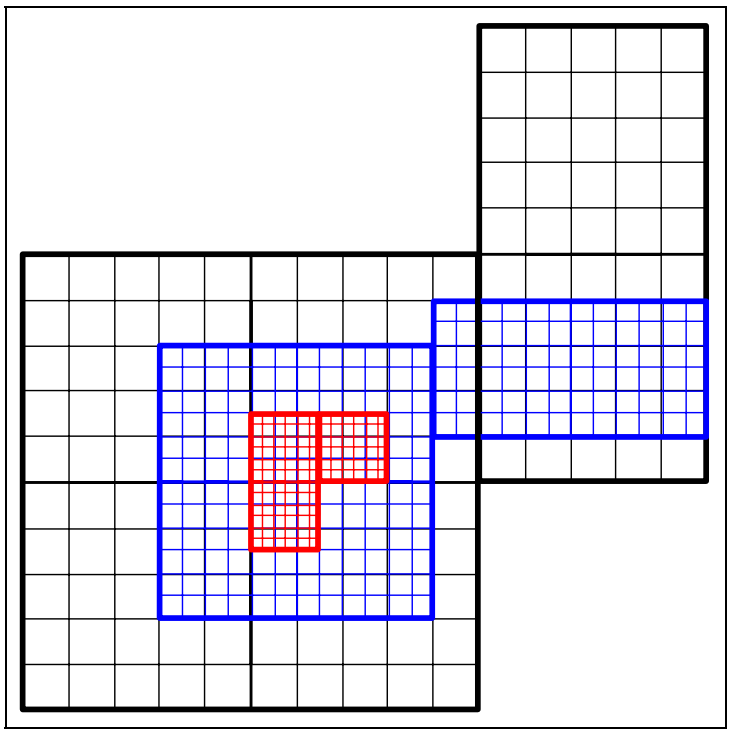

Figure 2.4: Adaptive mesh refinement.

2.3.2 Solution Techniques for Physical Processes

Aside from the grid, the numerical specifications for REALM provide for a great deal of flexibility. The design will allow the computational kernel (which describes the transfer of flux between cells) to be easily swapped, so that the solver to can be tailored to a particular flow

regime or geographical region. Further swapping is also needed to investigate tradeoffs between model performance and accuracy in the context of parallel processing. Some of the initial solution techniques that will be incorporated in the prototype for particular physical processes are described below.

Advection

Advection refers to the transport of a property (momentum, concentration) by the local fluid velocity. In the transport equations for water quality, this is the main mechanism for carrying a constituent from one point to another. In the hydrodynamic equations, the cell flux may be generalized to include the wavelike propagation of information at the characteristic speed of the medium, which is faster than fluid flow (see the special discussion on *gravity waves* below).

Advection is notoriously difficult to model well, and the challenge to do so is a driving force in research on numerical methods. Only in the last 10 years or so have robust, efficient solvers existed for multi-dimensional advection. The prototype of REALM will use second-order Godonov methods with approximate Riemann solvers for calculating fluxes between cells such as the ones described in LeVeque (2002). These methods are compatible with 1D and 2D shallow water formulations, and are valid for solving any problem to which the shallow water equations are applied – from estuary problems to floods and levee breaks.

High-resolution Godonov methods are computationally demanding, although they scale well under parallel computation. If, under experimentation, the prototype methods prove too expensive, simpler flux calculations will be adapted using reputable schemes like the MacCormack methods for estimating intercell fluxes for hydrodynamics and QUICK or QUICKEST method for advection of passive scalars/constituents.

Gravity Waves

Special consideration must be given to the *gravity wave* term in the momentum equation, which describes the pressure force due to the water surface slope. In a shallow estuary, propagation of waves by this mechanism is much faster than the fluid velocity.

Numerically, the time step of the model must be fine enough so that gravity waves do not travel too far in one time step relative to the spatial mesh – a situation which causes instability in explicit models and inaccuracy in implicit models.[2] Some models (such as the local RMA and TRIM models) treat the gravity wave implicitly for stability and deliberately use a larger time step. This treatment is thought to be justified physically under gentle estuary conditions when water surface changes are small and gradual. It is known to speed up model performance when serial processing is used for the computations.

The economy and legitimacy of this simplification will be revisited in the REALM project, since the computational context (parallel processing) and variety of applications for REALM are being

[2] An extensive discussion of explicit vs. implicit numerical methods is beyond the scope of this document. As a generalization implicit methods tend to be computationally expensive per time step and stable over long time steps; explicit methods are computationally inexpensive per time step but require short time steps. The competing factors (computation per time step vs. length of time step) provide a performance vs. accuracy tradeoff that is context dependent.

developed are somewhat different than the circumstances that originally led to the implicit gravity wave treatment. In fact, Godonov methods calculate the flux into a computational cell in a manner that does not readily decompose into separate gravity wave and advection components.

Diffusion

Diffusion plays a number of roles in tidal problems. In the hydrodynamic equations, the transport of momentum by turbulence is often approximated using a diffusion analogy. In the water quality equations, diffusion is used to represent both eddy diffusion (mixing due to circulating currents) and longitudinal dispersion (apparent mixing in a one-dimensional channel due to variations in convection velocity over a channel cross-section).

Diffusion is usually modeled implicitly – diffusion has a mathematical character (parabolicity) that requires more stability than does advection. Since both advection and diffusion appear in the same equations, the operators are often split, with implicit methods such as the Crank-Nicolson or the L_o – stable method of Twizell et al. (1996) used for the diffusion operator and explicit terms used for advection. REALM will initially use one of these two implicit methods for diffusion.

Source Terms

Source terms include a number of body forces defined at a point, such as friction, reactions of constituents, wind and other stresses, as well as sources and sinks of solute and flow. From a computational point of view these terms are mostly the same and only a few things matter, namely: 1) whether the sources are numerically "stiff", containing processes that change along very different time scales, or 2) whether they are singular (e.g., Mannings friction is not well-behaved when a water body is nearly dry).

Source terms can be split and treated separately, as can diffusion terms, and this will be the initial approach used in REALM. Higher-order Runge-Kutta explicit methods will be used for non-stiff source terms, particularly variants of Runge-Kutta that are known to be compatible with optimal control methods. The TR-BDF method, an implicit two-stage Runge-Kutta type scheme, will be used for stiff source terms.

2.4 Analysis and Management Tools

The crucial feature that will distinguish REALM from current models will be the incorporation of tools that will make decision support and policy analysis easier.

REALM will provide:

- Interactive "CD-player" user interaction. The user will be allowed to start, stop, rewind, adjust boundary conditions, and replay the time period.

- Model steering. The user may specify operating rules for boundary conditions and hydraulic devices that are managed adaptively (e.g. gates that are opened or closed depending on the state of the Delta such as water quality values).

- Automatic sensitivity calculations using the optimal control technique of adjoint modeling. Adjoint modeling is an efficient method of calculating the sensitivity of results to design decisions or to variations in boundary inflows (at every point in time).

- Data assimilation. The model will support statistical filters that can fold noisy field data into the model, achieving an appropriate balance between model and measurement error.

- Multi-objective analysis and visualization. Visualization tools will be provided not only to display the output of a single simulation on a map, but also to mine the data for trends and display tradeoffs between competing objectives, such as stage, releases, and exports.

- A data management model specifically designed for institutional modelers with GIS support. The data management will be based on an industry standard (ARC-HYDRO) database schema for storing hydrologic features, but will include innovations that make it easier to archive alternative versions of the same feature; e.g., a "historical" Stockton ship channel and a "dredged" Stockton ship channel.

Initially only a few of the features from this long list will be available to the user; however, the REALM design recognizes that the mathematical underpinnings of many of the features listed above are very similar. For instance, real time data assimilation models (Kalman filters) use the same "tangent linear model" as adjoint gradient calculations do. If these core abstractions are included in the design, a framework will result that can be filled out gradually and incrementally – without the daunting retrofit that would be required to add features later.

REALM will be interactive as the user will be provided an interface with controls much like the controls of a CD player. The user will have the ability to save a model state for a particular timestamp, run the model forward, rewind and try again with different boundary conditions. The interface will be visual, allowing the user to monitor the state of the model graphically. Another "interactive" feature is the support for user-designed operating rules. An example of this would be to ask the model to reduce pumping and/or operate gates when stage in the South Delta gets too low.

REALM will also make optimization and sensitivity analysis easier by incorporating adjoint model calculations into its design. Adjoint models can calculate in one pass sensitivities that would take vast numbers of "perturbation runs" to calculate by trial-and-error. REALM will not include hardwired solvers for particular optimization problems, but rather mathematical functionality that will make solving any large scale optimization problem easier. This functionality is exceedingly difficult to retrofit.

Finally, there is a class of decision support that lies partway between optimization and interactive modeling. This occurs under the discipline of multi-objective programming, where tradeoffs between hard-to-compare objectives are explored graphically. The user discovers solutions that are optimal or near-optimal according to some set of preferences, and then explores the tradeoffs between the objectives. The multi-objective algorithm provides guidance to avoid strategies that are inferior according to all of the objectives. These combinations are hard to avoid based on trial and error alone.

All of these interactive tools and a great many simpler applications require convenient, routine methods of initializing multiple simulations and collating or aggregating their results. The user might want to plot statistics over time from Monte Carlo experiments or display on an interactive map the differences between a base and alternative run. REALM will use Geographical Information System (GIS) software as its map interface for two reasons. First, it is well-developed, standard software that will greatly reduce development time. Secondly, and equally important, it will allow REALM to interact with other data and models much easier, especially biological and habitat data.

2.5 Collaboration

The REALM project ties together ideas from a number of different fields: water resources, numerical modeling, computer science, statistics, optimal control, and data management. DWR has expertise in a number of these areas, particularly in hydrodynamics, optimization, and aquatic systems. Nevertheless, a state-of-the-art project cannot be accomplished without significant contributions from experts in other fields. Areas in which outside assistance will be relied upon include:

- Infrastructure libraries for grid management and parallel computation.
- GIS for data management, grid development and visualization of results.
- Manipulation and visualization of time series data.

The idea of "infrastructure" for numerical models is not new, for there exists a veritable sub-industry of high performance infrastructure for numerical models, much of it locally produced by Federal Department of Energy labs and UC campuses. These libraries provide grid management, mesh refinement, embedded boundaries, and a great deal of solver support under parallelized solution schemes (domain decomposition and adaptive mesh refinement). For those versed in the underlying subject matter, the libraries have a parsimonious, elegant design, and provide hooks into other high quality open source resources. REALM will not only rely on these

software infrastructure libraries; but also extend this infrastructure for the support of multidisciplinary water resources models.

In addition to providing data management for the model, GIS will also be the front end for the application. GIS contractors will provide the following resources for the model:

- Tools for the assembly and control of model input, including the definition of model components, assignment of boundary conditions, and interaction with the model.

- Grid development tools, including:
  - Algorithms and tools for channel cross-section development in 1D channels, and
  - Tools for creating and managing hierarchies of Cartesian grids with embedded boundaries (defined below) – matching the data structures used in LBL libraries.

- Archival storage closely mirroring the ARC-HYDRO standard for (spatial) hydrologic data. The storage system will use the layering system developed for DSM2 (see Ateljevich and Pranger, 2002), so that multiple versions of model components can be stored and combined to form alternative scenarios.

- A system for producing mapped displays of the model state, both to display results and for use in the model controller. The model state will be retrieved from a native format, probably based on HDF5, an open source format and input/output library that is very common in high performance computing applications.

- A system for selecting time series data from a map for display using time series visualization tools.

Actual visualization of time series will be handled in a separate project called VTools, which is a rewriting and extension of the DWR's Vista suite (Sandhu, 1998). VTools will also bind the archival capabilities of Informix and the Informix TimeSeries Datablade (currently being used by DWR's Division of Environmental Services, or DES) with the loading format used the model, which will be based on HDF5 or the open source data storage tool BerkeleyDB. HEC-DSS storage will not be used for REALM in any significant way, although conversion utilities will be provided for HEC-DSS files.

2.6 Work Flow

REALM is expected to be developed in two major phases.

Phase 1 of the project will emphasize the initial design and creation of a functional prototype model for flow and transport. The phase is scheduled to take about 15 months from the start of contracted development. During this time, LBL will adapt their grid infrastructure and numerical solvers for estuarine hydrodynamics and water quality mass transport. At the same time, GIS contractors will work to develop a consolidated Delta bathymetry and a 1D/2D grid development tool. Towards the end of Phase 1, testing will take place on the link between the LBL grid and the GIS storage system. The conclusion of Phase 1 will see a working version of REALM with a few of the easier features implemented, such as model steering.

In Phase 2, model performance will be addressed and REALM will evolve into a production model. An initial Bay-Delta calibration will be undertaken and particle tracking will be added. Early in Phase 2, REALM will be ready for calibration, which will be followed by the first production release of the model. In parallel efforts, interactive control and optimal control will be added during Phase 2, and work will begin on numerical solvers for 3D vertically stratified flow. A second release of REALM is expected to take place about 12-18 months after the first containing some or all of these features. Thereafter, development will proceed in small design cycles rather than large pre-defined phases.

2.7 Example Problems

A few example problems gleaned from interviewing managers and workers in the Delta should serve to illustrate the type of problems that REALM will solve.

2.7.1 Through Delta Facility

The Through Delta Facility (TDF) is a proposed inter-Delta diversion to supplement the Delta Cross Channel (Figure 2.5). It would divert water from the Sacramento River (near Hood), to the Central Delta (near the Mokelumne River system), with the intent of improving water quality in the Delta.

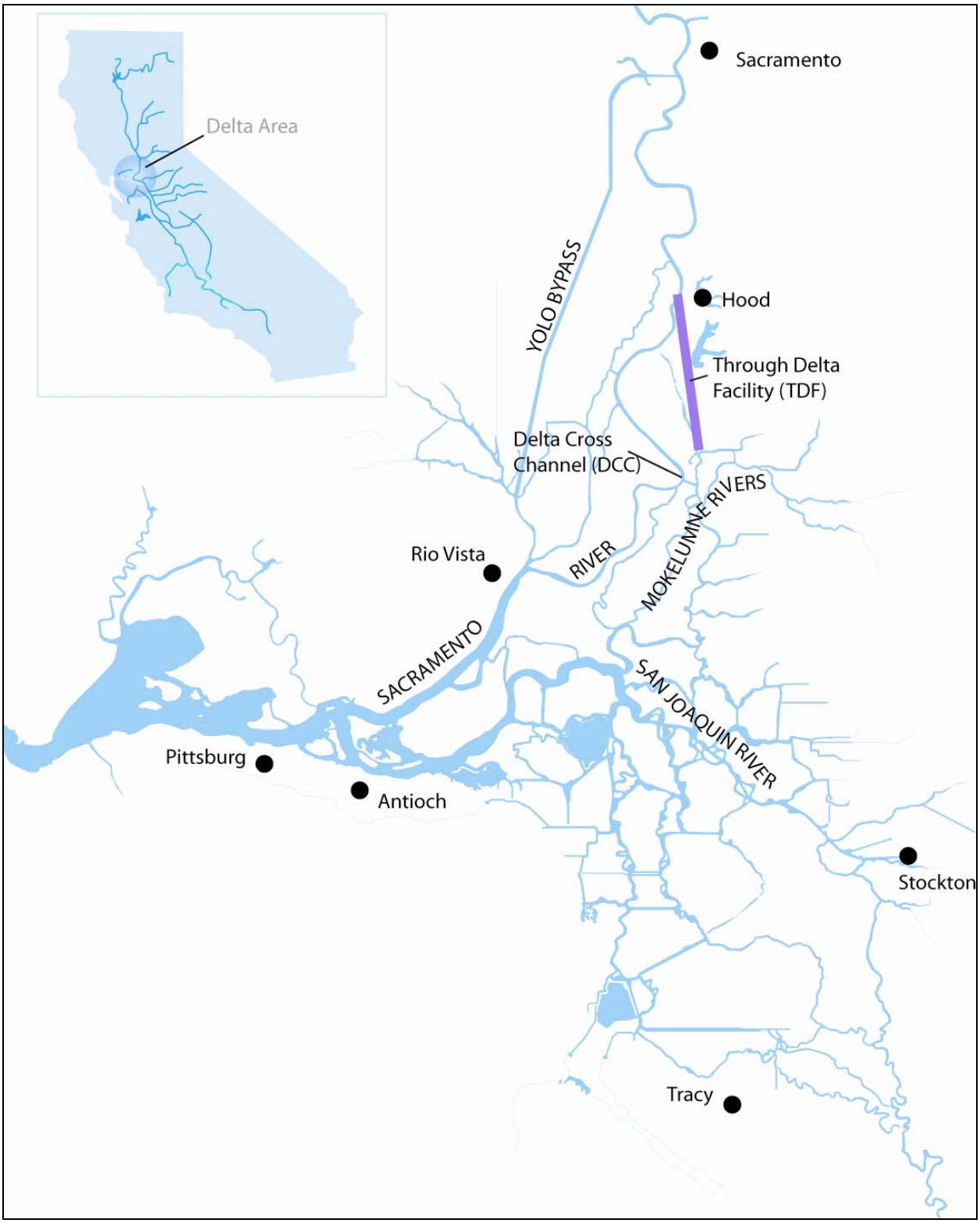

Figure 2.5: Through Delta Facility.

The Delta Modeling Section has conducted a series of studies using DSM2, a standard one-dimensional model, investigating different pumping rates and seasonal patterns of a TDF. The section was asked to run a study which would turn on the TDF when salinity at Rock Slough reached a certain level, then turn off the TDF when salinities dropped below another, lower target level.

Although this type of feedback from water quality to gate operation seems mechanically simple, on-the-fly manipulation of this sort is not available with DSM2 or any other model of the Delta now in common use. REALM's *model steering* feature will make it easy to make such a request by stipulating operating rules to guide the opening and closing of the TDF. Figure 2.6 shows how rules might be used to enforce salinity guidelines. The model anticipates the violation of user-imposed bounds and adjusts the TDF gates, export pumps, or upstream releases accordingly.

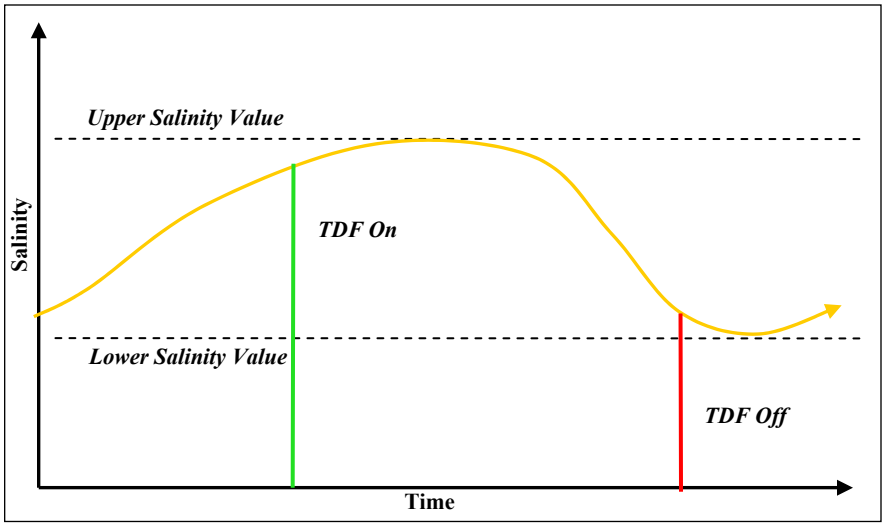

Figure 2.6: TDF-Controlled Salinity Within Range.

In the control scenario just described, the TDF or other device is operated to rules. The desired result is achieved, but perhaps at a price: too rapid a change in flow, too much water released upstream, or an unnecessarily large reduction in exports. If the controls (upstream releases and TDF flows) are considered to be continuously adjustable, REALM, with its *adjoint-supplied gradients*, could achieve the desired operation with an optimal water cost (Figure 2.7).

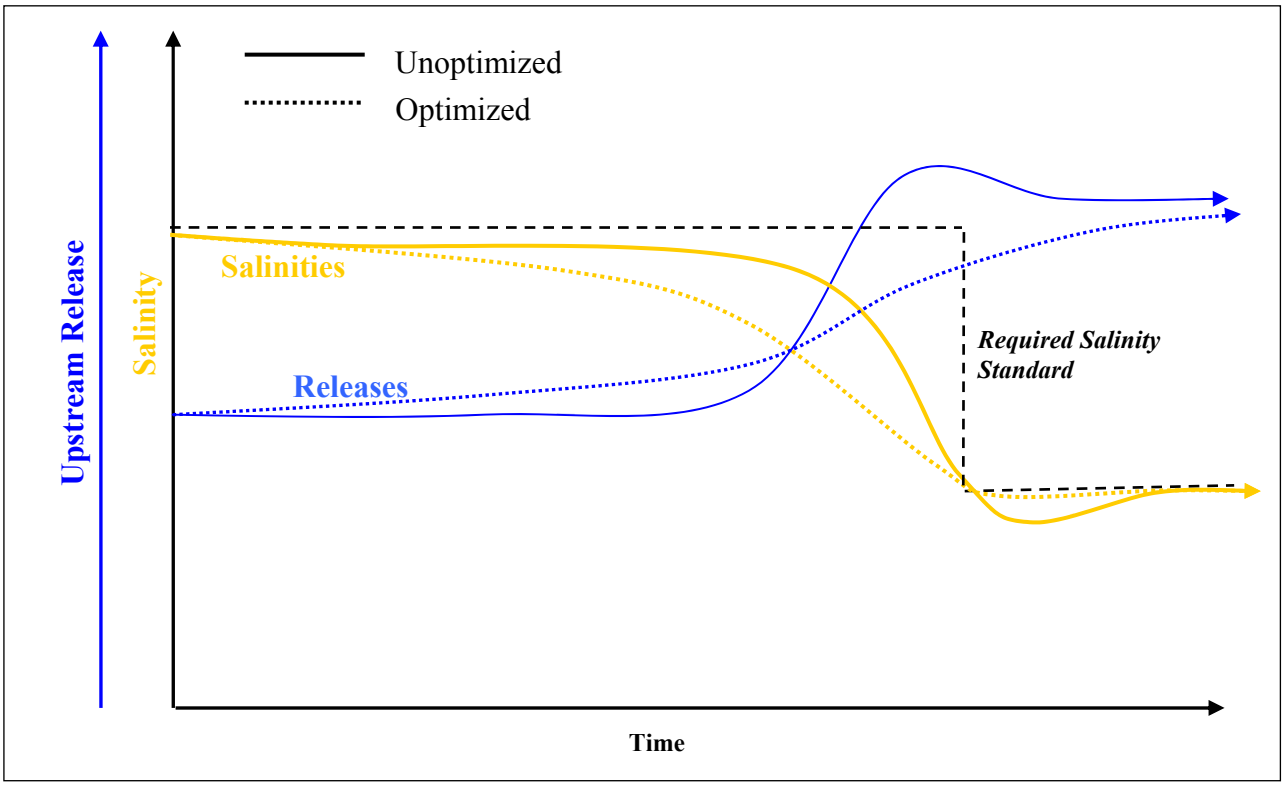

Figure 2.7: Unoptimized vs. Optimized Operation.

2.7.2 Particle Tracking

A number of Delta managers, engineers, and scientists were interviewed and asked to describe their model feature priorities. Virtually all of the environmental scientists interviewed said they needed accurate particle modeling and tracking. To do this, accurate velocity modeling in the junctions of channels is especially important, as well as accurate modeling of bays. This accuracy can be achieved only by using a 2- or 3-D treatment of junctions and bays, along with a fine-mesh grid in those areas.

Precise particle tracking will inevitably increase running time of the model. REALM's ability to vary the computational density of grid points and combine 1-, 2- and 3-D treatments, will allow the user to achieve the necessary level of accuracy where needed, without performing unnecessary computations within channels where high levels of accuracy would not be used.

2.7.3 Real-Time Adaptive Delta Management

Real-time, adaptive management of the Delta will play a more important role in coming years. Better and cheaper real-time data is available for traditional hydrodynamic and water quality values and biological and aquatic parameters, such as locations of endangered fish and counts. These data may enable adaptive management, but only if modeling tools are up to the task.

REALM will play a key role in this area because of its capability of real-time data assimilation. Data assimilation is the ability to incorporate observed data in a statistically correct manner into a model run. The observed data is compared to the computed data at the same time and location; inevitably the two values differ. Neither the observed or computed values are automatically accepted as "correct". Instead, using a process called Extended Kalman Filtering, their respective errors are compared from physical and mathematical principles, and the model adjusted accordingly. Data assimilation does more than adjust the single model value at the location of the observed data; it also correctly modifies neighboring points in the model. In this manner the statistically best possible forecast is developed using all possible data.

2.8 References

Ateljevich, E. and T. Pranger. (2002). "Chapter 13: DSM2 Input Database and Data Management System." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

LeVeque, R. J. (2002). *Finite Volume Methods for Hyperbolic Problems*. Cambridge University Press.

Sandhu, N. (1998). "Chapter 8: VISTA (Visualization Tool and Analyzer)." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Twizell, E.H., A. B. Gumel, and Arigu M.A. (1996). *Second order L_0 – stable methods for the heat equation with time dependent boundary conditions. Adv. Comput. Math.,* ***6*** *(333).*

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 3:
Extending DSM2-QUAL Calibration of Dissolved Oxygen

Author: Hari Rajbhandari

3 Extending DSM2-QUAL Calibration of Dissolved Oxygen

3.1 Introduction

DSM2 calibration was revisited with the objective of extending dissolved oxygen (DO) modeling to the South Delta region. Calibration of parameters was adjusted, based on the data collected at three locations in South Delta in 2000 by DWR, Central District. This work was a prerequisite for another project that investigated the effects of increased San Joaquin River (SJR) flow on dissolved oxygen DO levels in the Stockton Deep Water Ship Channel (DWSC) documented in Rajbhandari et al. (2002). This paper presents an overview of the assumptions and methodology for extending model calibration and validation to the Delta region beyond the DWSC.

3.2 Background

Low DO levels are of concern in the San Joaquin River Deep Water Ship Channel near Stockton (Figure 3.1). The DO levels frequently fall below the U.S. Environmental Protection Agency (EPA) standard of 5 mg/l for aquatic health and the Regional Water Quality Control Board standard of 6 mg/l for upstream migration of fall-run Chinook salmon. As one of several projects exploring ways of improving the ship channel's water quality, the Total Maximum Daily Load (TMDL) stakeholder process was created for this portion of the SJR to meet the water quality standards established by the Federal Clean Water Act. The stakeholder process is one of several projects exploring the ways of improving the ship channel's water quality.

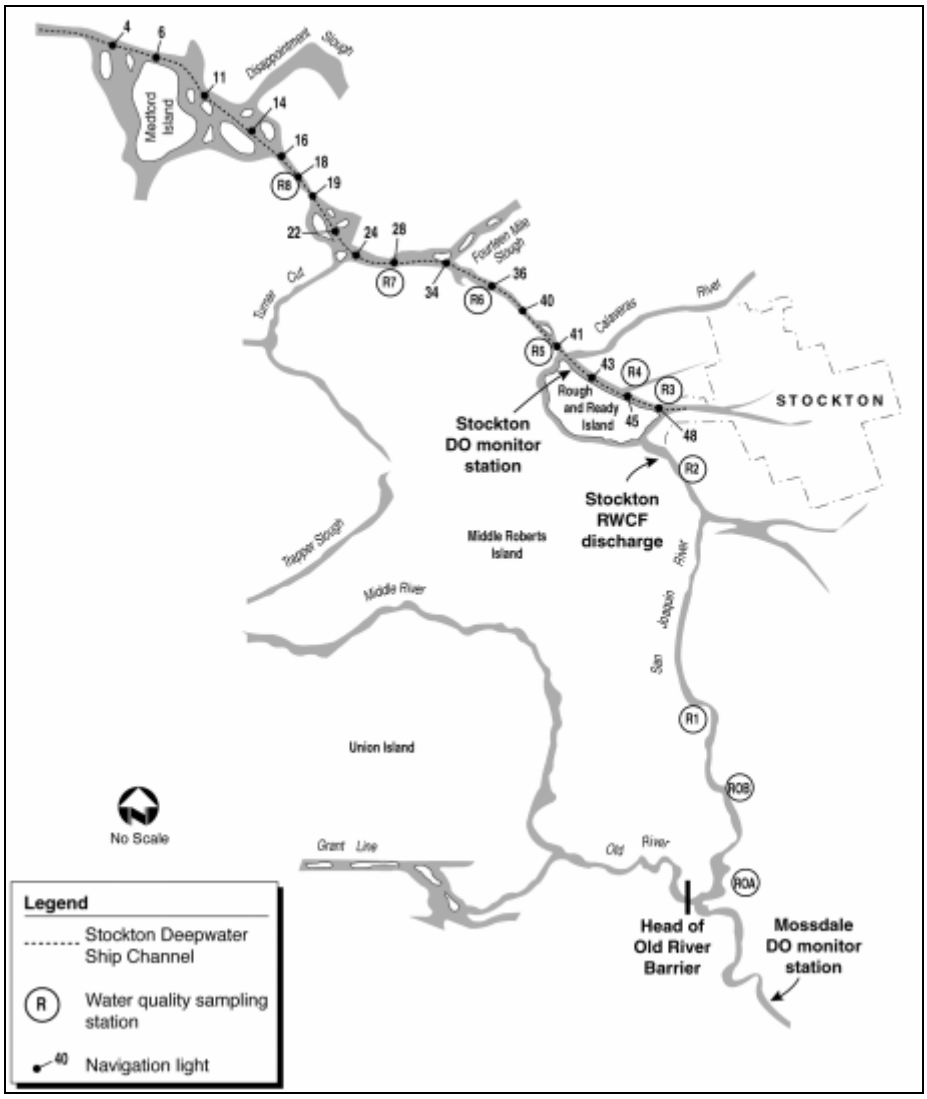

Figure 3.1: Water Quality Stations near Stockton.
(Adapted from Jones and Stokes, 2001)

3.3 Data and Model Input

The calibration and validation period covered July 1996 through December 2000. This period was chosen primarily because it provided the data needed for simulating DO. Unfortunately, this period does not include extreme dry periods, which are typically associated with extreme low DO levels in DWSC.

Simulation of DO by QUAL requires information on water temperature, biochemical oxygen demand (BOD), chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate) in the Delta. To simulate DO, a group of related variables has to be simulated at the same time. Interaction among water quality variables in DSM2 is shown in Figure 3.2. The rates of mass transfer

(shown by the arrows) are functions of temperature. It is important that temperature simulation be included in the DO simulation. The sources and sinks of DO are indicated in Figure 3.2. Rajbhandari (1998) discussed the DO kinetics used in QUAL in greater detail (this report can be found at: http://modeling.water.ca.gov/delta/reports/annrpt/1998/1998Ch3.pdf).

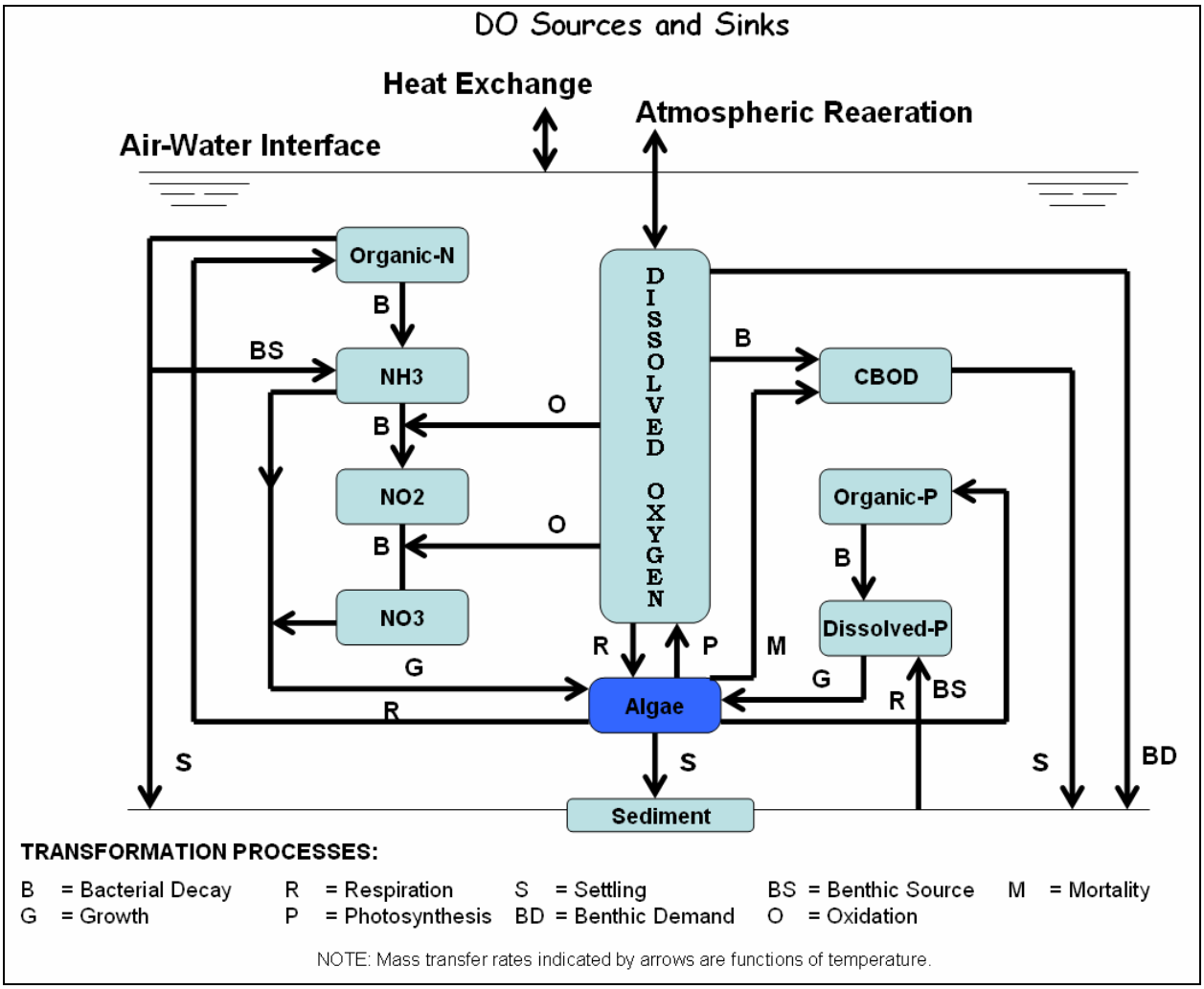

Figure 3.2: Interaction Between DO and Related Parameters.

DO and temperature data collected at hourly intervals provide boundary information needed by QUAL. A combination of hourly varying temperature and DO data in Sacramento River at Freeport (RSAC142) and Rio Vista (RSAC101) were provided for the Sacramento River model boundary. The historical record of DO and temperature at Martinez was used for the downstream model. Because continuous data were not available at Vernalis (RSAN112), hourly values of DO and temperature from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. Because the flows at Vernalis are primarily unidirectional and the hydraulic residence time is relatively short, this assumption seems appropriate.

Data on effluent flows from the City of Stockton's Regional Wastewater Control Facility were obtained from the City of Stockton Municipal Utilities Department (Huber, 2001). Flow, BOD, and temperature data were available on a daily basis. The data for ammonia nitrogen were available on approximately a two-day interval. These data were interpolated to obtain daily estimates. EC, organic nitrogen, nitrite nitrogen, and nitrate nitrogen data were available on weekly intervals, and interpolated to daily intervals. For most of these constituents, the values were sometimes given as "less than" a detection limit. Approximations were made based on the preceding and the subsequent known values.

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 DWR (1999). Estimates of flow and water quality of agricultural drainage returns at internal Delta locations were based on earlier DWR studies.

Hourly or 3-hour interval air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure data was provided by the National Climatic Data Center starting in July 1996 and was used as QUAL input to simulate water temperature. However, for most of 1996, only the minimum and maximum values for temperature and wind speed were available. For this period, hourly values for temperature and wind speed were approximated based on the daily maximum and minimum values.

3.4 Calibration and Validation

QUAL was previously calibrated and validated for simulating DO; however, it was based on data from 1998 to 1999 (Rajbhandari, 2001). At the time of this previous DO calibration and validation, hourly time series data were available only at the Rough and Ready Island (RRI); thus calibration and validation were limited to DO and temperature comparisons at that location. Under normal flow conditions, the DO levels in the SJR at RRI (RSAN058) depend mainly on SJR flow and quality. However, for the scenarios that may involve flows from the South Delta region, it is important to extend the validation of DO to include the South Delta region.

This extended calibration and validation was achieved by comparing model DO against field data available for the year 2000 at the three South Delta locations, two in Old River and one in Middle River (Figure 3.3). To compare the model and the field data, it was necessary to calibrate QUAL primarily in the South Delta region. During DO calibration, the rate coefficients for algae (growth and mortality rates) and sediment oxygen demand were adjusted. Calibrated coefficients are within the range suggested in the literature (Bowie et al., 1985; Brown and Barnwell, 1987; Thomann and Mueller, 1987). A more complete description of DO kinetics and model development is available in Rajbhandari (1995). Table 3.1 summarizes the continuous monitoring stations used in the calibration and validation of QUAL.

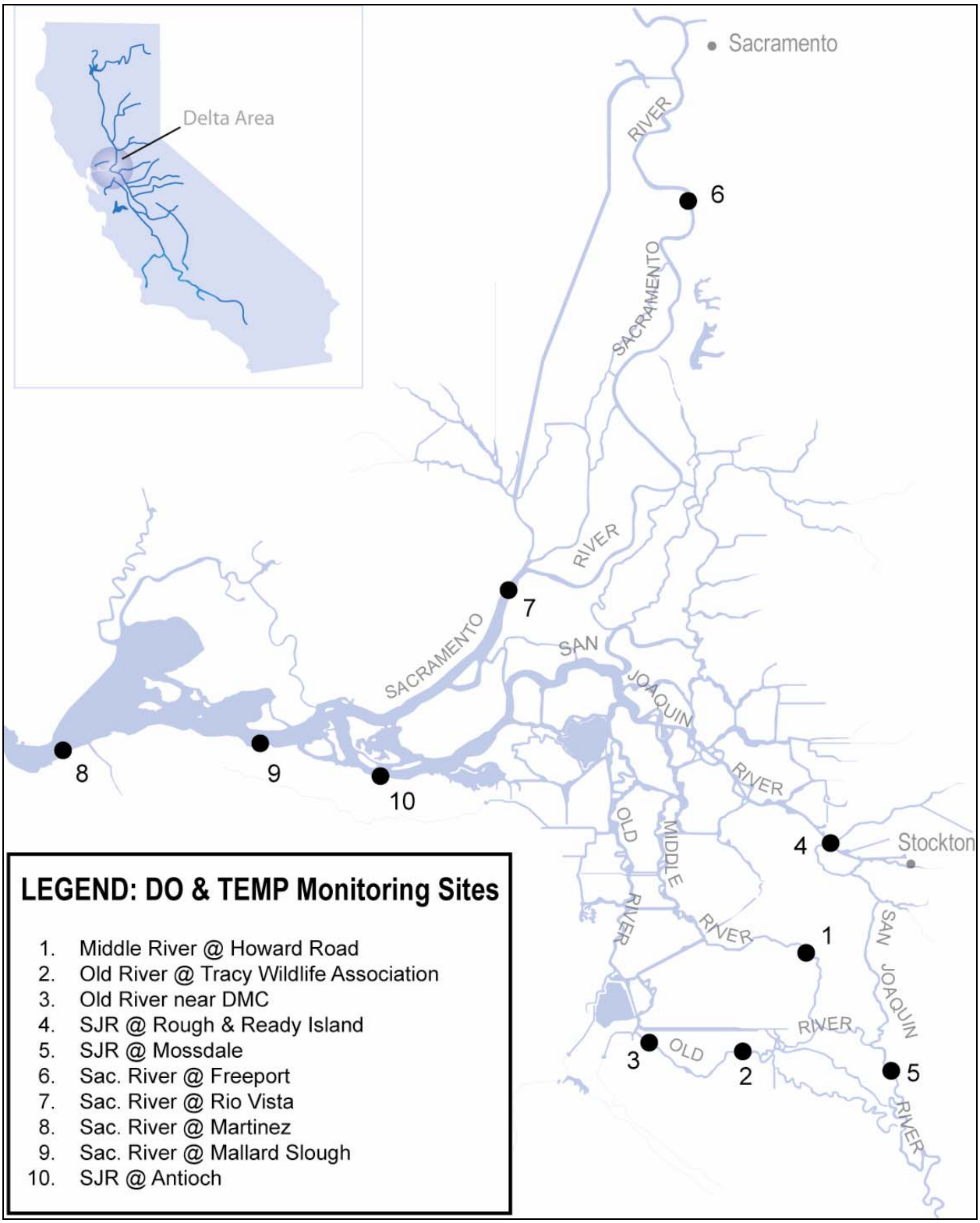

Figure 3.3: DO and Temperature Water Quality Stations in the Delta.

Table 3.1: Summary of Continuous DO and Temperature Monitoring Stations.

Map Location	Field Station Name	IEP RKI	Start Date	Figure
1	Middle River at Howard Road	-	2000	Figure 3.4
2	Old River at Tracy Wildlife Association	ROLD059	2000	Figure 3.5
3	Old River near DMC	ROLD047	2000	Figure 3.6
4	SJR at Rough & Ready Island	RSAN058	1983	Figure 3.7 Figure 3.8
5	SJR at Mossdale[1]	RSAN087	1983	-
6	Sacramento River at Freeport[2]	RSAC142	1999	-
7	Sacramento River at Rio Vista[2]	RSAC101	1983	-
8	Sacramento River at Martinez	RSAC054	1983	-
9	Sacramento River at Mallard Slough	RSAC075	1983	Figure 3.9
10	SJR at Antioch	RSAN007	1983	Figure 3.10

(1) Mossdale data was used to fill in missing values for the Vernalis boundary condition.
(2) Rio Vista data was used to fill in missing values for the Freeport boundary condition.

3.4.1 Calibration Results

Figure 3.4 compares modeled results with measured DO values in Middle River at Howard Road. For the spring and summer months the model diurnal range tends to be much shorter than the measured values, but the general trend and the low DO values appear to be in fairly good agreement. Supersaturated levels of DO observed in the field data in early June and at certain times in August and September were not reproduced in the model results.

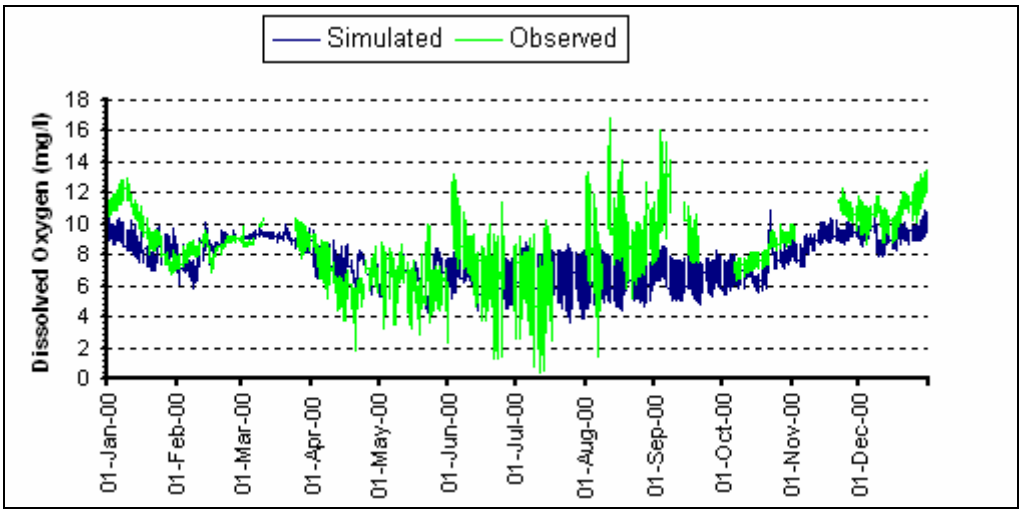

Figure 3.4: DO in the Middle River at Howard Road.

A comparison of model DO with field DO in Old River at Tracy Wildlife Association shows a fair agreement during most months (Figure 3.5). QUAL tends to under-predict the diurnal range. Highly supersaturated DO levels that occurred in early June and November were under-predicted by QUAL.

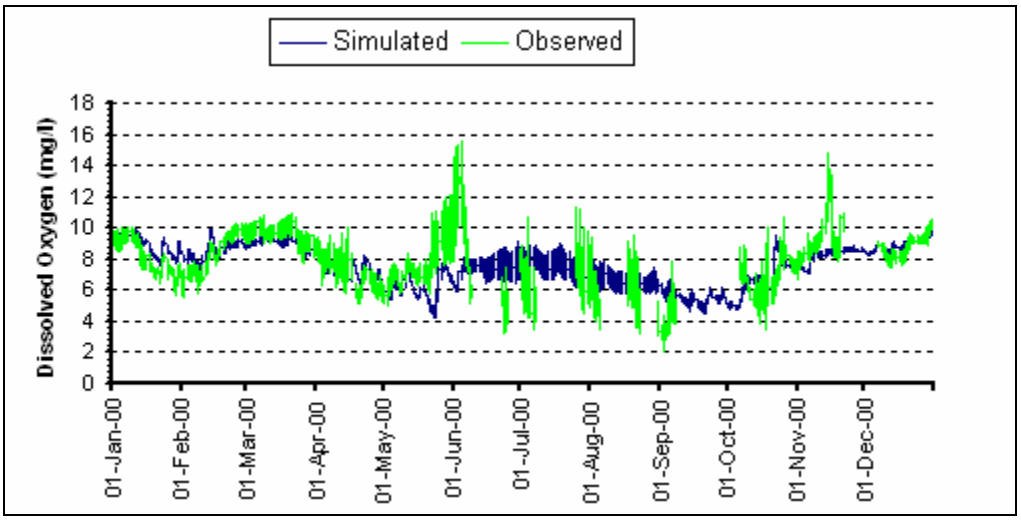

Figure 3.5: DO in the Old River at the Tracy Wildlife Association.

Field data for Old River at Delta Mendota Canal (DMC) is available only for May through November 2000 and is shown with the model results in Figure 3.6. The model tends to capture the monthly trend with better agreement in the lower range.

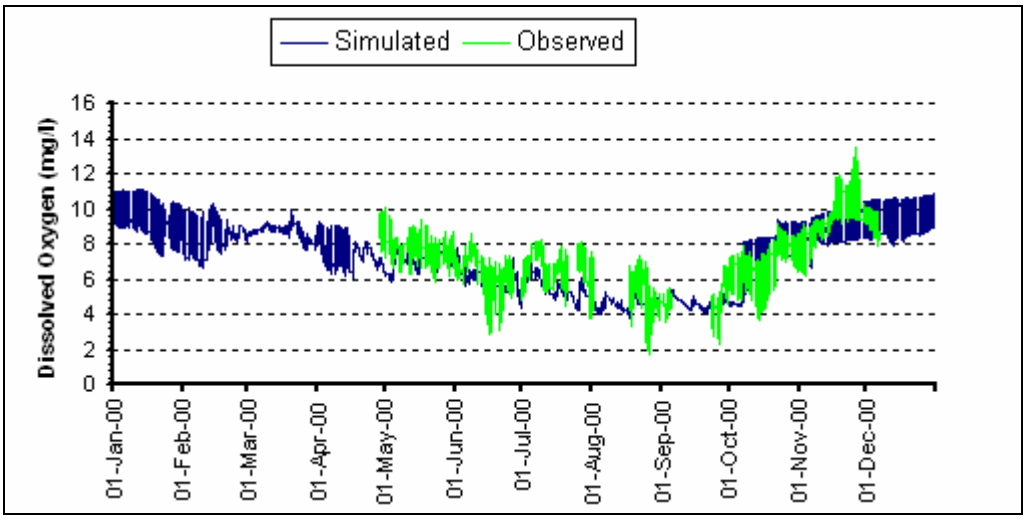

Figure 3.6: DO in the Old River at DMC.

3.4.2 Validation Results

Figure 3.7 presents the comparison of model DO and field observations in the San Joaquin River near Rough and Ready Island (RRI). The model represents the DO levels that fall below the required standard of 5 mg/l. In general, the differences between model and field DO were within 1 mg/l at the lower end of diurnal range and for the summer months. Seasonal highs and lows appear to be in phase. DSM2 was not able to reproduce the supersaturated values of DO observed during summer and fall 2000. The EPA requires that the DO must be greater than or equal to 5 mg/l throughout the year, while the Water Quality Control Board requires that the DO levels remain at 6 mg/l or above for the months of September through November. As a result, it

is desirable that the model be capable of predicting the low DO levels more accurately than the supersaturated DO values, so the under-prediction of supersaturated values of DO is not critical.

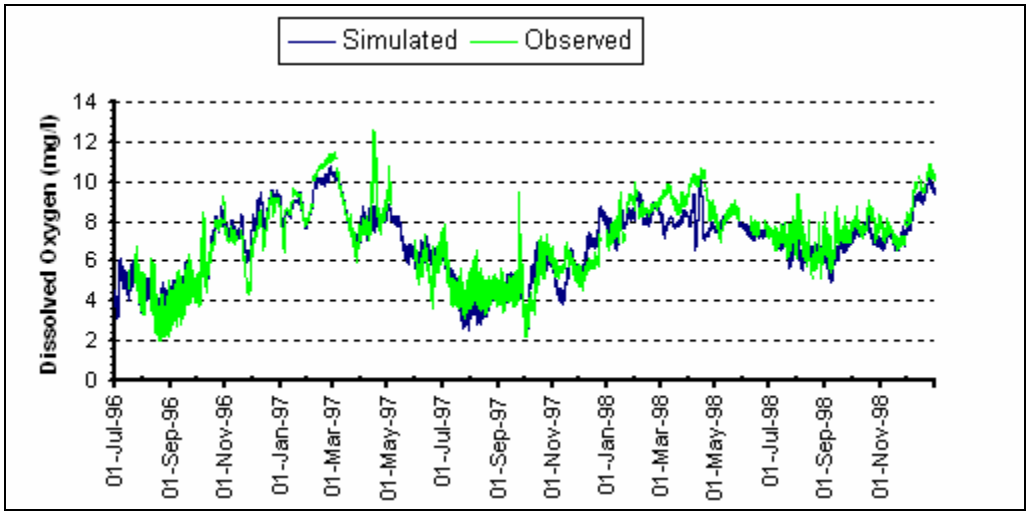

Figure 3.7a: DO in the San Joaquin River at Rough and Ready Island, 1996-1998.

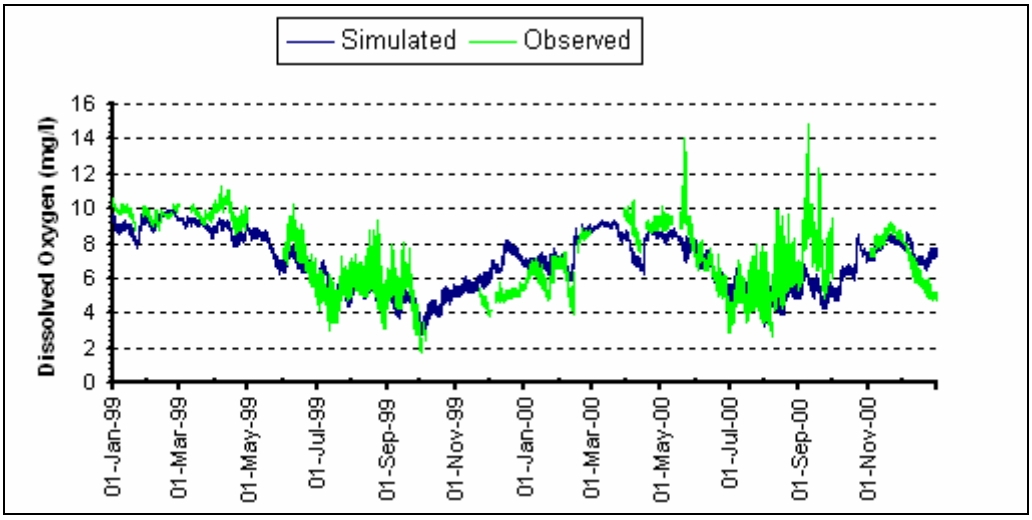

Figure 3.7b: DO in the San Joaquin River at Rough and Ready Island, 1999-2000.

Figure 3.8 compares simulated water temperature with field data at the continuous monitoring station at the San Joaquin River near RRI. In general, DSM2 seems to underestimate the observed data but the differences are generally less than 1° Celsius. The diurnal range in temperature simulation results is generally smaller than those for the field data, especially in the summer months; however, tests showed low DO sensitivity to small variations in temperature.

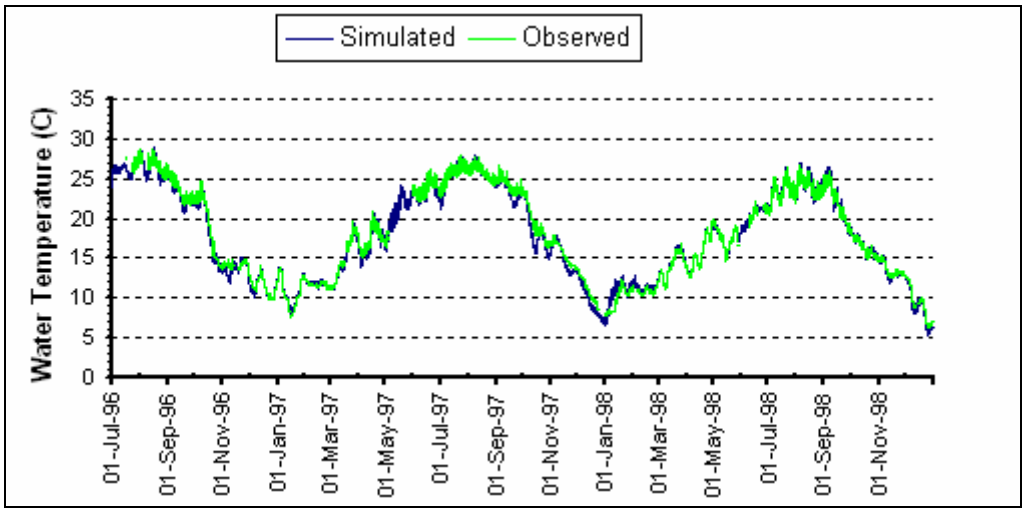

Figure 3.8a: Water Temperature in the San Joaquin River at Rough and Ready Island, 1996-1998.

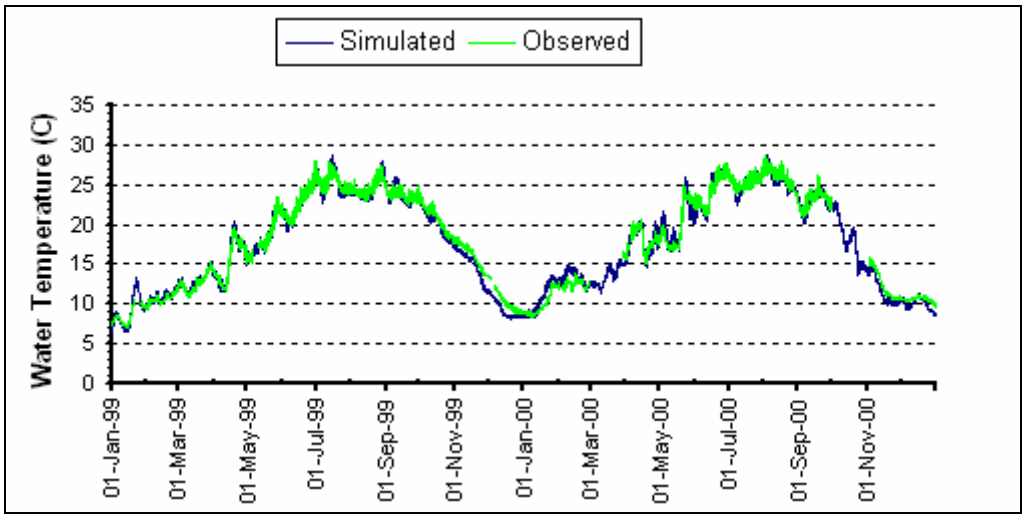

Figure 3.8b: Water Temperature in the San Joaquin River at Rough and Ready Island, 1999-2000.

Modeled DO at Mallard Slough (Figure 3.9) captures the seasonal variation of DO in the measured data. Except for summer through fall 1999, modeled DO was within 0.5 mg/l of the data for the low DO periods of summer months. Comparison of simulated and field DO in the San Joaquin River at Antioch is shown in Figure 3.10. The agreement was good and generally within 0.5 mg/l except for fall 1997 and winter 1998, when the model overestimated DO by up to 1.5 mg/l.

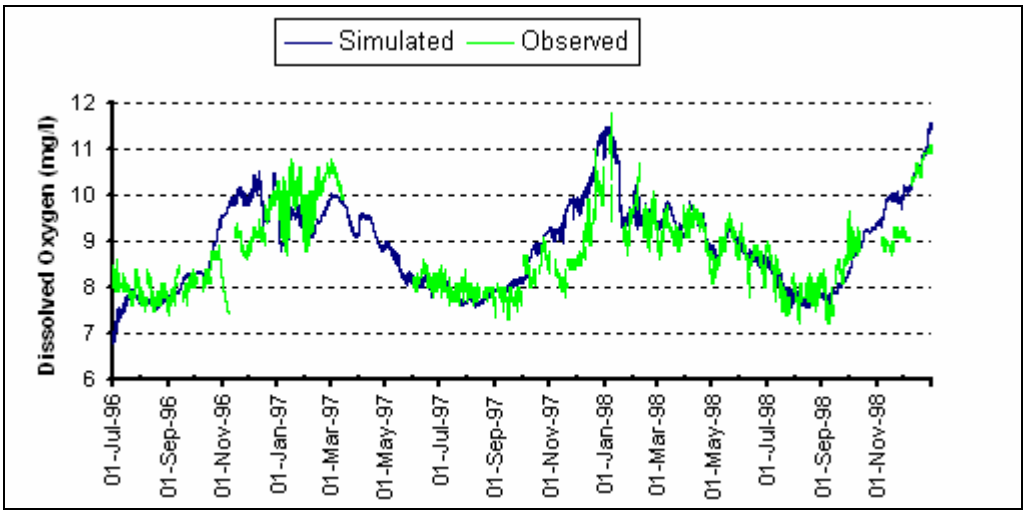

Figure 3.9a: DO in the Sacramento River at Mallard Slough, 1996-1998.

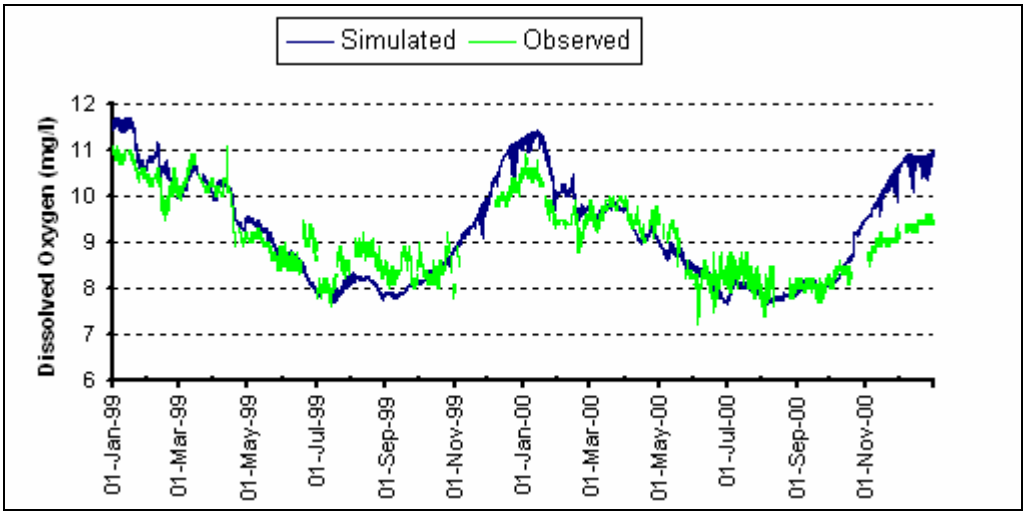

Figure 3.9b: DO in the Sacramento River at Mallard Slough, 1999-2000.

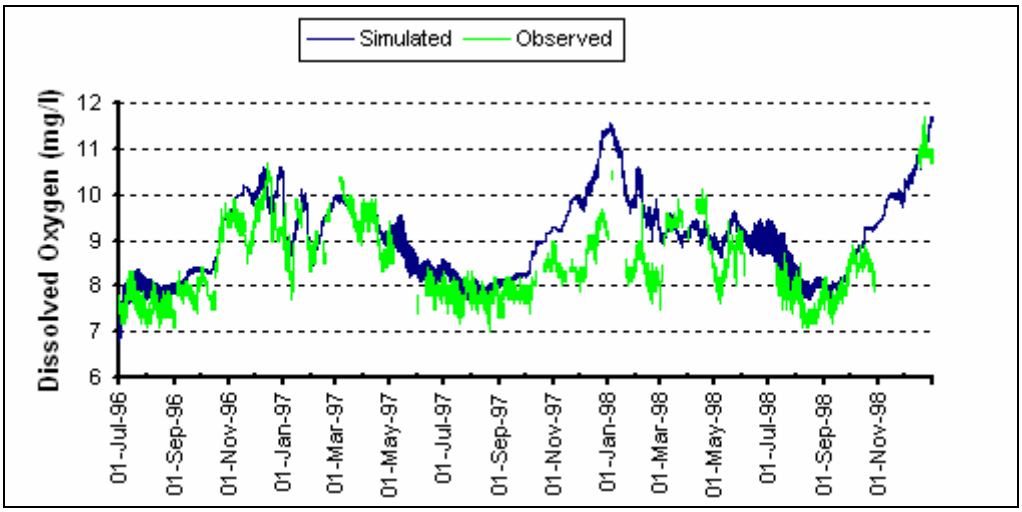

Figure 3.10a: DO in the San Joaquin River at Antioch, 1996-1998.

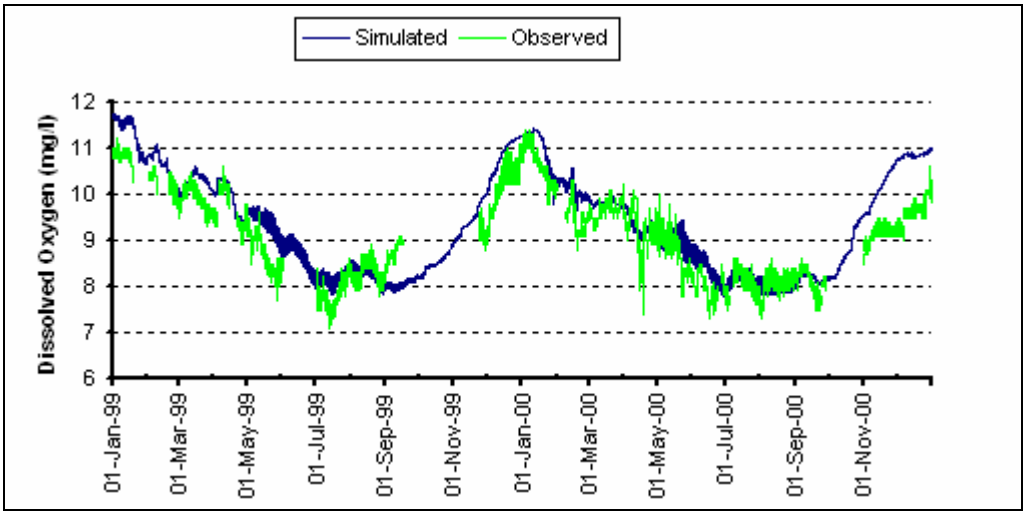

Figure 3.10b: DO in the San Joaquin River at Antioch, 1999-2000.

3.5 Summary

QUAL was previously calibrated and validated for simulating DO based on data from 1998 to 1999. During the past year, QUAL calibration of DO was extended to three South Delta locations. In addition, QUAL validation of DO was expanded to the western Delta and the RRI at DWSC for 1996 through 2000. Due to data inadequacy, several assumptions were made in specifying the boundary conditions. Model calibration can be further improved through a more detailed specification of the boundary conditions, including improving the estimates of the quality of agricultural drainage return. Nevertheless, the results were encouraging. The calibrated DSM2 was used to examine the effects of the proposed auxiliary pumps on DO levels of the DWSC. This is documented in Rajbhandari et al. (2002).

3.6 Future Directions

DWR's Delta Modeling Section is in the process of estimating the potential impacts of the Integrated Storage Investigations' In-Delta Storage (ISI-IDS) project operation on DO and temperature of the channels near Webb Tract and Bacon Island. In this study, DSM2 modeling of DO and temperature is based on the hydrologic information provided by DWR's operation model, CALSIM II.

Other potential applications of the extended DSM2-QUAL DO and Temperature modules may include the following projects:

- South Delta Improvements Program (SDIP) alternatives:

  Jones and Stokes, with assistance from DWR staff, are preparing the draft environmental impact report/environmental impact statement (EIR/EIS). The SDIP is designed to increase the diversion capacity of the State Water Project's intake to meet California water supply demands while providing adequate water quantity and quality to agricultural users in the South Delta and improving conditions for San Joaquin River salmon (Marshall, 2003). Different SDIP components may have varying impacts on DO levels in the South Delta. DSM2 can be a useful tool in assessing the potential impacts. DSM2 is being used to assess impacts associated with flow, stage, water quality (primarily simulated as conservative pollutants), and DO.

- SJR Modeling upstream of Vernalis:

  A proposal to develop and calibrate the DSM2-SJR model for DO and the related parameters, as a part of the Proposal for Upstream Monitoring 2003-2005, is being evaluated by CALFED. The DSM2-SJR model, a multi-agency effort, is expected to provide an essential link to understanding the SJR algae growth processes that create a substantial load of organic material that may contribute to DO decline episodes in the DWSC.

- Detailed/Multi-dimensional model analysis:

  Special studies may require a more refined analysis that would be best served by two-dimensional (2D) or three-dimensional (3D) models. DSM2 can be utilized in a way that would exchange information with the 2D/3D models that already exist, or are being developed by the other agencies, such as:

  - Stanford University. Using a CALFED grant, the university plans to develop a 3D hydrodynamic/DO model coupled to DSM2 that will provide a detailed understanding of the functioning of the DWSC and the South Delta and how these affect DO dynamics in the DWSC. By linking their region-specific 3D model to DSM2, the new Stanford 3D model will not have to simulate the entire Delta.

- Flow Science Inc. The company is using DYRESM (Dynamic Reservoir Model) to support the ISI-IDS project. DSM2 may be linked to their vertically stratified model.

3.7 References

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopt, G.L. Rupp, K.M. Johnson, P.W.H. Chan, and S.A. Gherini. (1985). *Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling, 2nd Ed.* US EPA. Athens, Georgia. EPA 600/3-85/040.

Brown, L.C. and T.O. Barnwell. (1987). *The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS; Documentation and Users Manual*. US EPA. Athens, Georgia. EPA 600/3-87/007.

California Department of Water Resources. (1999). *Water Quality Conditions in the Sacramento-San Joaquin Delta During 1995.* Division of Local Assistance.

Huber, L. City of Stockton Municipal Utilities Department. Personal communication..

Jones & Stokes Associates. (2001). "City of Stockton Year 2000 Field Sampling Program, Data Summary Report for San Joaquin River Dissolved Oxygen TMDL CALFED 2000 Grant."

Marshall, P. (2003). California Department of Water Resources, South Delta Improvements Program. Personal communication.

Rajbhandari, H. L., P. Nader and P. Hutton. (2002). *DSM2 Studies to Investigate the Use of Auxiliary Flow Pumps across South Delta Flow Structures*. Report to San Joaquin River Dissolved Oxygen TMDL Stakeholder Process Technical Advisory Committee. CALFED Directed Action Project.

Rajbhandari, H.L. (2001). "Chapter 6: Dissolved Oxygen and Temperature Modeling using DSM2." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Rajbhandari, H.L. (1998). "Chapter 3: DSM2 Quality." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Rajbhandari, H.L. (1995). *Dynamic simulation of Water Quality in Surface Water Systems Utilizing a Lagrangian Reference Frame.* Ph.D. Dissertation. University of California, Davis.

Thomann, R.V., and Mueller, J. A. (1987). *Principles of Surface Water Quality Modeling and Control.* Harper and Row, New York.

US Geological Survey. (1997). "Water Resources Data, California, Water Year 1997." Vol. 4.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 4:
Morrow Island Distribution System Calibration

Author: Kate Le

4 Morrow Island Distribution System Calibration

4.1 Introduction

In fall 2002, the Morrow Island Distribution System (MIDS) intake gate was replaced with a new combination gate (flap and screw combination). The 48-inch diameter high-density polyethylene pipes are significantly smoother than the previous corrugated, asphalt-coated pipes. The physical impact of this change was studied by conducting a field study in February 2003. This study was then used to calibrate the MIDS intake gate coefficient used in DSM2 by running a series of sensitivity runs using different MIDS intake coefficients. The study also provided insight on the tidal volume exchange between Goodyear Slough and the MIDS intake.

4.2 Background

Located west of the Sacramento-San Joaquin Delta, the Suisun Marsh lies near the DSM2 downstream tidal boundary at Martinez. The marsh is a vital wintering and nesting area for the waterfowl of the Pacific Flyway, representing approximately 12% of California's remaining wetland habitat. The majority of the wetland property in the marsh is privately owned and managed as waterfowl clubs. MIDS is responsible for maintaining one of these wetland habitats on Morrow Island.

MIDS functions by allowing less saline water to enter the distribution system from Goodyear Slough to the west, and then travel eastward by gravity flow through one of two ditches to the wetlands on the east side of Morrow Island. Water can exit the system from an outfall gate at the end of each of the two ditches. The flap gates on all of the MIDS culverts reduce the reverse flow through the system when the tide is flooding.

In DSM2, MIDS is represented by a series of gates with non-zero flow coefficients in one direction only, thus permitting flow to travel from Goodyear Slough to the west and through the two channels to the two outfall culverts in the east. The previous flow coefficient for the MIDS intake culvert was based on early DSM2 calibrations. When DWR replaced the MIDS intake structure, the Suisun Marsh Planning Branch of DWR's Division of Environmental Services developed a hydrodynamic study that was used to calibrate the DSM2 representation of the new culvert.

4.3 Location and Setup of Flow Study

MIDS is connected to Goodyear Slough through three 48-inch pipes. There is a large berm in Goodyear Slough to the west of the MIDS culverts. When operating, the tidal flap gates on the east side of the MIDS intake culverts prevent flow from leaving the MIDS ditch. The location of the MIDS is shown in Figure 4.1.

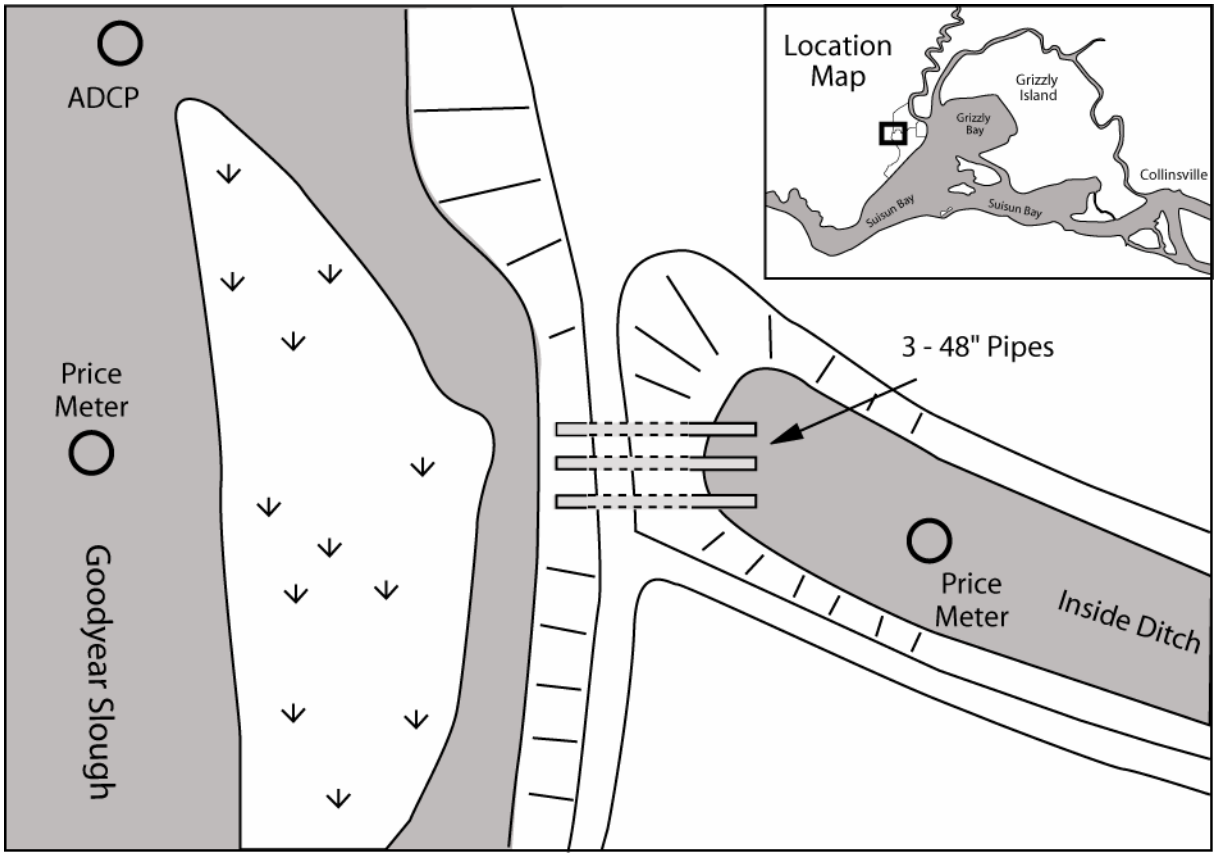

Figure 4.1: Morrow Island Distribution System Intake and Goodyear Slough.

Three flow monitoring devices were used to collect flow and stage data on either side of the new MIDS intake on February 19 and 26, 2003. During the neap tide on February 19, 2003, flow and stage data was sampled every 15 minutes beginning with the low-high tide and continuing through the high-high tide. A week later during the spring tide on February 26, data was sampled from the high-high through to the low-low tide.

As shown in Figure 4.1, two Price current meters were placed on either side of the MIDS intake pipes. An acoustic doppler current profiler (ADCP) was placed in Goodyear Slough north of the MIDS intakes. During the study period, the flap gates were tied fully open on the MIDS side to the east. The screw gates on the western side of the culvert (i.e., in Goodyear Slough) were only partially opened, allowing for an effective opening 18 inches in diameter.

4.4 Data and Analysis

Goodyear Slough flow data (collected by DWR's Central District staff) and stage data (collected by DWR's Delta Field Division) were compared with three DSM2 simulations. The current DSM2 flow coefficients for the MIDS intake pipes simulate one-way flap gates where flow can enter the MIDS from west to east (the assumed downstream direction for the MIDS in DSM2), but cannot reverse direction and move from east to west. A different flow coefficient was used

in each DSM2 run, as shown in Table 4.1. The results of these runs are shown along with the field observations in Figures 4.2 to 4.6.

Table 4.1: DSM2 Sensitivity Runs and MIDS Downstream Flow Coefficients.

Run	Downstream Flow Coefficient	Notes
1	0.5	Current DSM2 Coefficient
2	0.7	
3	0.2	

Figure 4.2 compares modeled and observed flow at the MIDS intake on February 19, 2003, for the three modeled flow coefficients from Table 4.1. The DSM2 results best matched the field observations when the MIDS downstream flow coefficient was set to 0.2 (i.e., run 3).

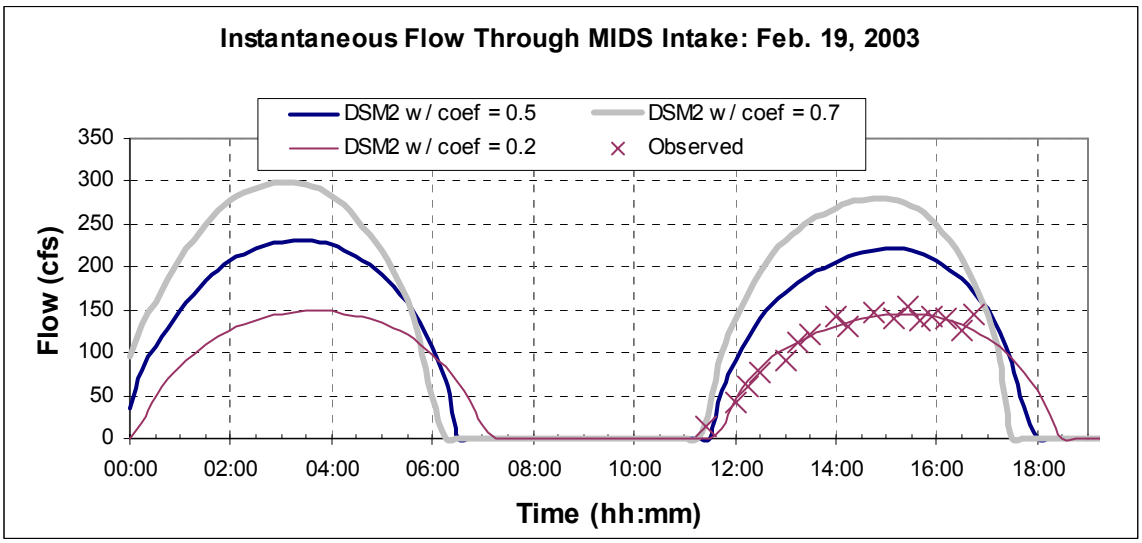

Figure 4.2: DSM2 and Observed Flow Through MIDS Intake on February 19, 2003.

A comparison of DSM2 and observed flow from February 19, 2003, to the north and south of the MIDS intake in Goodyear Slough shows how sensitive the new MIDS flow coefficient is to changes in the intake system (Figure 4.3). In this figure, negative flows in Goodyear Slough represent flow heading out towards Martinez (south). When the flow coefficient of 0.2 is used for the MIDS intake, DSM2 captured the magnitude of the tide ebbing back to sea. When the tide began to flood again at 18:30, the flap gate in the MIDS intake prevented flow from leaving the MIDS system, thus the flow north and south of the MIDS intake on Goodyear Slough was identical. No other changes were made to the geometry surrounding the MIDS intake or Goodyear Slough.

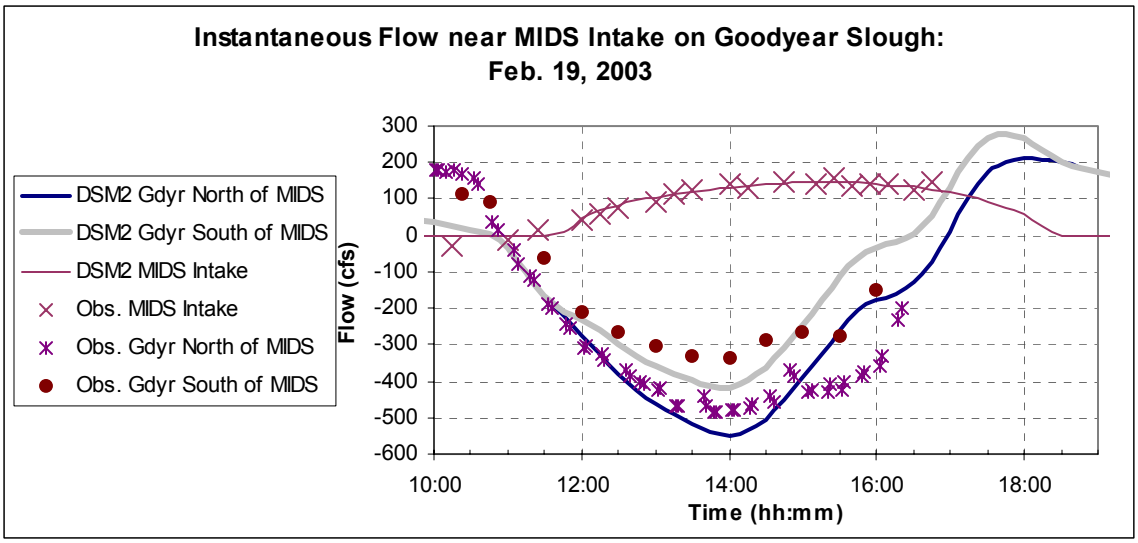

Figure 4.3: DSM2 and Observed Flow in Goodyear Slough near MIDS Intake on February 19, 2003.

Field measurements of the flow inside the MIDS intake and to the north and south of the intake on Goodyear Slough were taken a week later during the spring tide. These measurements were then compared with the new 0.2 flow coefficient used in DSM2 (Figure 4.4). While DSM2 accurately simulates the flow through the MIDS intake, the model underestimates the flow moving back and forth in Goodyear Slough by several hundred cfs. Though it is not shown, this underestimation of the flow magnitude in Goodyear Slough was the same in the runs where different MIDS intake flow coefficients were used. However, the 0.2 flow coefficient still represented the best fit of flow passing through the MIDS intake.

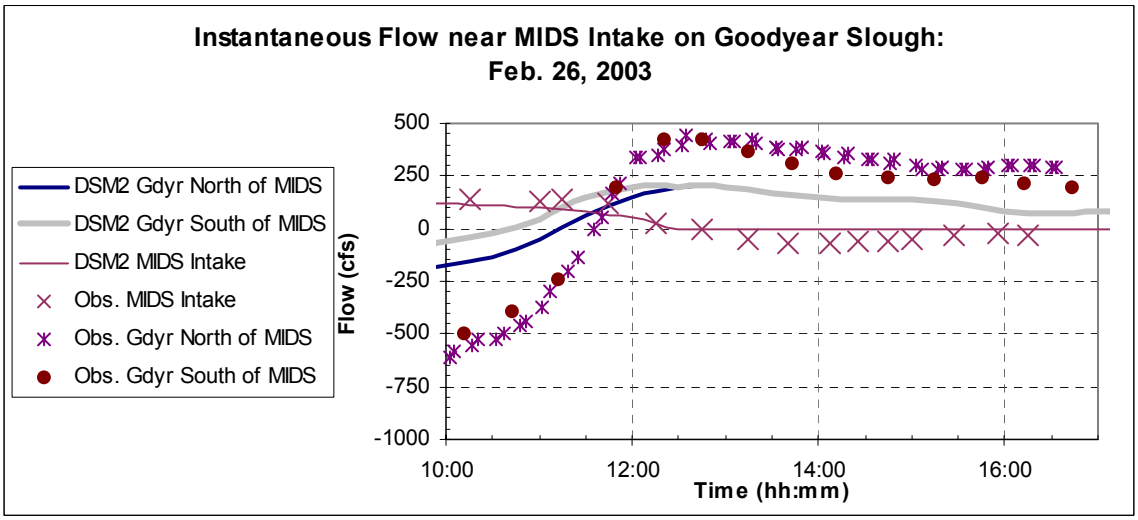

Figure 4.4: DSM2 and Observed Flow in Goodyear Slough near MIDS Intake on February 26, 2003.

Figures 4.5 and 4.6 illustrate the DSM2 and observed stage outside and inside the MIDS for both February 19 and February 26 respectively. The modeled and observed stage in Goodyear Slough to the west of the MIDS intake matched well on both days. However, the modeled stage inside the MIDS lags the field data by about 15 minutes for both days. The observed stage data east of the MIDS intake were flat prior to 8:00 AM because the intake flap gates were not yet tied open.

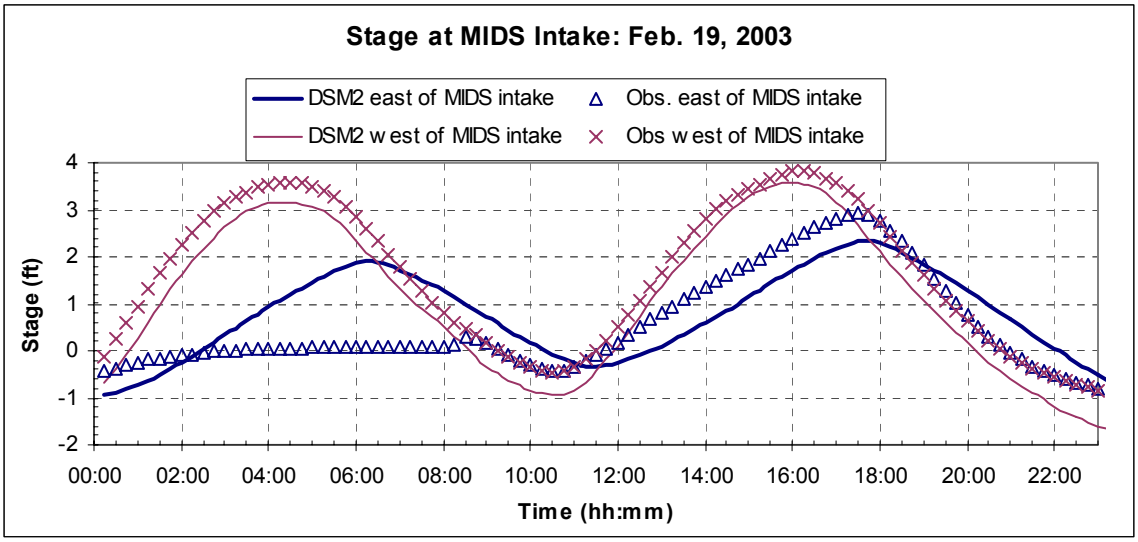

Figure 4.5: Stage at MIDS Intake on February 19, 2003 (Neap Tide).

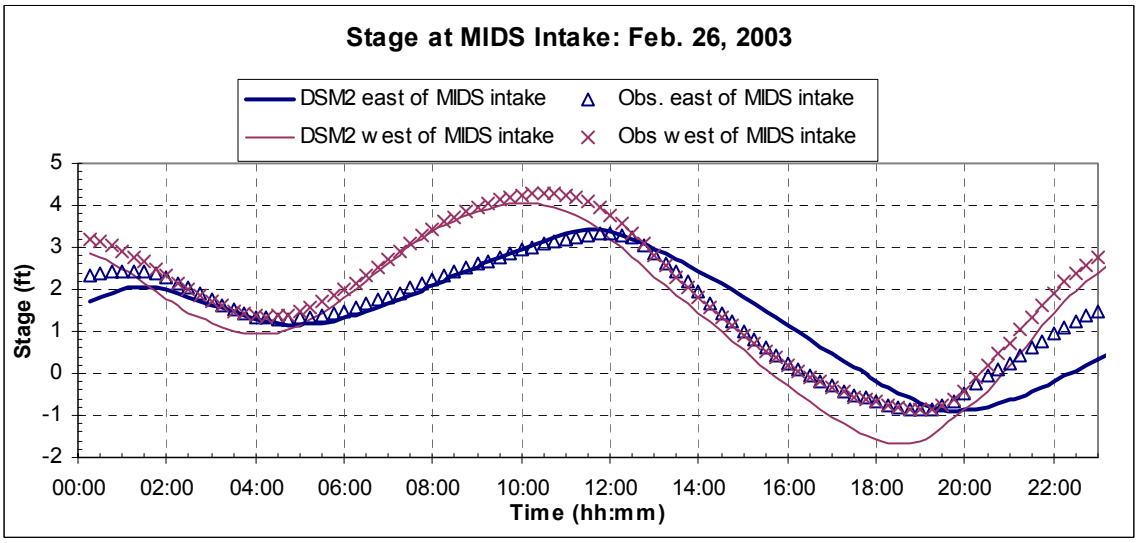

Figure 4.6: Stage at MIDS Intake on February 26, 2003 (Spring Tide).

4.5 Conclusions and Recommendations

- Because the 0.2 flow coefficient used in the DSM2 sensitivity runs fit the observed data better than the 0.5 flow coefficient used in the current calibrated version of DSM2, it is recommended that future DSM2 simulations use 0.2 as the flow coefficient for the MIDS intake.

- Modeled stage in Goodyear Slough matched both the amplitude and phase of the observed stage, while the modeled stage inside the MIDS lags the observed stage by about 15 minutes.

- Modeled flow in Goodyear Slough underestimated the observed tidal flow to the north and south of the MIDS intake during the spring tide; however, the modeled flow inside the MIDS matched the amplitude and phase of observed flow.

4.6 Websites

Additional information on the Suisun Marsh Program and Morrow Island Distribution System can be found at:
http://iep.water.ca.gov/suisun/dataReports/

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 5:
Use of CALVIN in DSM2 Planning Studies

Author: Jamie Anderson

5 Use of CALVIN in DSM2 Planning Studies

5.1 Introduction

DSM2 planning studies evaluate potential impacts of hypothetical changes to factors such as hydrologic regimes, water quality standards, system operations, and Delta configurations. To explore the impacts of a given alternative under various hydrologic conditions, DSM2 planning studies are typically run for a 16-year sequence (water years 1976-1991) of Delta inflows and exports derived from statewide water resources operations and storage simulations. Typically, the Delta boundary flows and exports for DSM2 planning studies have been provided by CALSIM, the Department of Water Resources' systems operations model.

Although CALSIM is typically used to provide boundary flows and exports for DSM2 planning studies, the input can be provided by any source or combination of sources that specify the following Delta inflows, exports, and flow control structures operations required to run DSM2:

- Inflows
  - Sacramento River at Sacramento
  - San Joaquin River at Vernalis
  - Eastside streams (Mokelumne and Cosumnes rivers, either separately or combined)
  - Calaveras River
  - Yolo Bypass
- Exports
  - State Water Project (Banks Pumping Plant)
  - Central Valley Project (Tracy Pumping Plant)
  - Contra Costa Canal and Los Vaqueros Reservoir (separately or combined)
  - North Bay Aqueduct and Vallejo (separately or combined)
- Delta Island Consumptive Use (diversions, drainage, and seepage)
- Flow Control Structures Operations
  - Delta Cross Channel
  - South Delta Fish and Agricultural Barriers

Another water resources model that can provide the required inflow and export information to DSM2 is CALVIN, the University of California at Davis' economic-water resources optimization model. This chapter provides a brief overview of CALVIN and describes how it is used to provide flow and export inputs for DSM2 planning studies (Figure 5.1). This chapter also discusses the use of DSM2 to provide feedback to CALVIN on how well the system

operations suggested in CALVIN meet Delta water quality standards and to suggest improvements in CALVIN's representation of Delta salinity requirements.

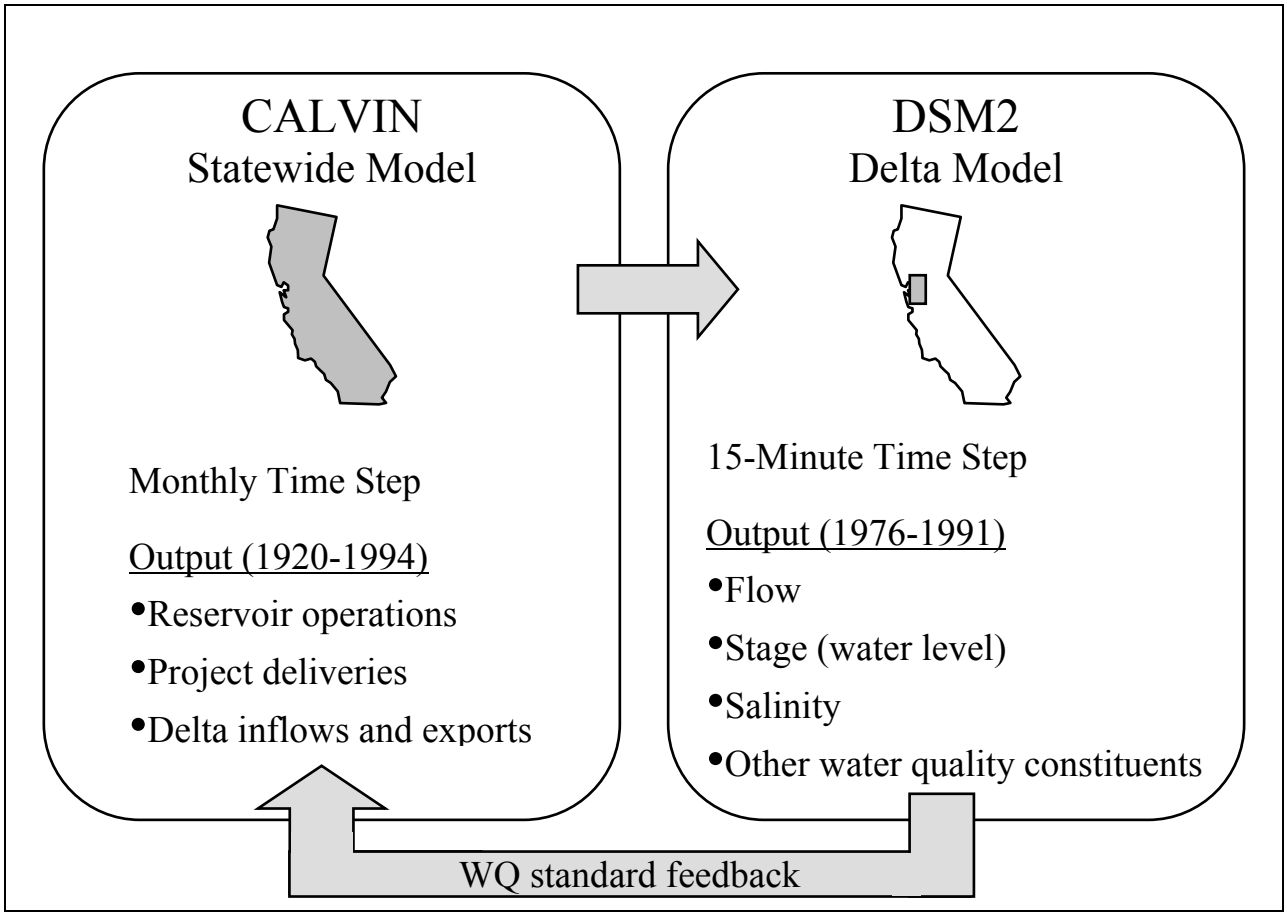

Figure 5.1: CALVIN Inputs to DSM2 and DSM2 Feedback to CALVIN.

5.2 CALVIN Overview

CALVIN (CALifornia Value Integrated Network) is an economic-engineering optimization model of California's water supply system (all information in this section is based on Jenkins et al., 2001 and Lund et al., 2003). A water resources optimization model is able to determine the "least cost" or optimal solution for water allocations given specified constraints. These constraints can be physical (such as facility capacities) or regulatory (such as water quality standards, delivery contracts, etc). Since CALVIN is an economically driven model, CALVIN allocates water and operates facilities to maximize the economic value of urban and agricultural water uses in the absence of other constraints. CALVIN simultaneously manages statewide surface water, groundwater, and water demands. CALVIN's spatial extent covers 88% of California's irrigated acreage and includes water demands from 92% of the current population.

An intricate network of approximately 1,200 elements represents California's complex water system (Figure 5.2) including:

- 51 surface reservoirs
- 28 groundwater basins
- 18 urban economic demand regions
- 24 agricultural economic demand regions
- 39 environmental flow locations
- 113 surface and groundwater inflows
- Numerous conveyance links

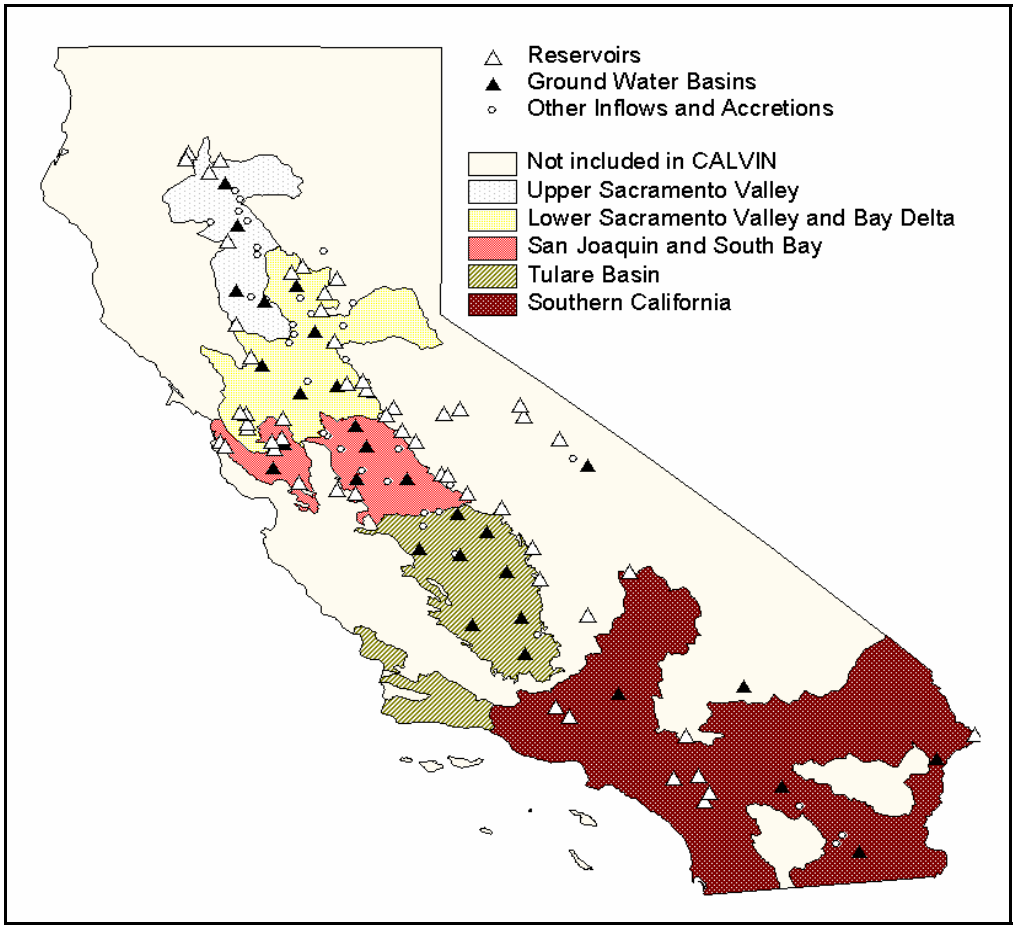

Figure 5.2: Regions, Inflows, and Reservoirs Represented in CALVIN (Lund et al., 2003).

Initial constraints incorporated into CALVIN include:

- Water availability
- Facility capacities
- Environmental restrictions
- Flood control restrictions

Additional constraints may also be incorporated into CALVIN simulations. An environmental constraint used in CALVIN is the minimum Net Delta Outflow (NDO) required to meet salinity standards in the Sacramento-San Joaquin Delta. DWRSIM simulation results for the 2020 level of development were used to calibrate the minimum Net Delta Outflow requirements used in CALVIN.

To incorporate a wide range of hydrologic conditions, CALVIN studies are typically run at a monthly time step for a 72-year period that spans calendar years 1920-1994. CALVIN simulations may be run at different levels of development to reflect projected changes in future water demands. For example, studies at the 2020 level of development assume that California's projected population of approximately 47.5 million people produces an average annual water demand of 10.06 maf/yr. In contrast, studies that project even further into the future to the 2100 level of development reflect an almost doubled water demand of 19.38 maf/yr to support a population of 92 million people. Information provided by the 72-year CALVIN studies includes evaluation of both economic and water supply impacts of proposed changes in facilities, operations, and water allocations.

5.3 Use of CALVIN to Provide Input to DSM2

5.3.1 Inflow and Export Boundary Conditions

Output from CALVIN can provide Delta inflow and export boundary conditions for DSM2 planning studies. The procedure for using CALVIN output to specify inflow and export boundary conditions in DSM2 are summarized below:

- Identify Delta inflow and export locations in CALVIN (Table 5.1)
- Convert CALVIN output from TAF/mo to cfs
- Put converted CALVIN output into a format that DSM2 can read (e.g., DSS)
- Smooth monthly Sacramento and San Joaquin river inflows
- Create a DSM2 boundary input file that refers to the input data from CALVIN

Table 5.1: Summary of CALSIM and CALVIN Boundary Condition Inputs to DSM2.

Boundary Condition	CALSIM Reference	CALVIN Reference
Sacramento River at Sacramento	C169	D44-D503
San Joaquin River at Vernalis	C639	D616-C42
Eastside Streams (Mokelumne and Cosumnes)	C504	D517-D515
Calaveras River	C508	C41-C42
Yolo Bypass	C157	C20-D55
State Water Project (Banks)	D419	D59-BANKS-PMP
Central Valley Project (Tracy)	D418	D59-TRACY-PMP
Contra Costa Canal	D408	D550-CC1-PMP
North Bay Aqueduct	D403B	D55-C22

The reference locations (e.g., model nodes) in CALSIM and CALVIN that correspond to the Delta inflows and exports are summarized in Table 5.1. CALSIM provides flow and export values in cubic feet per second (cfs), and CALSIM output can be used directly in DSM2. However, CALVIN provides flow and export output in units of thousand acre-feet per month (TAF/mo). Thus the output from CALVIN must be converted to cfs before it can be used in DSM2. In addition, the converted CALVIN output must be put into a format that DSM2 can read, such as properly formatted text files or the U.S. Army Corp of Engineers Hydrologic Engineering Center's Data Storage System (DSS) format.

For both monthly CALSIM or CALVIN inputs into DSM2, Sacramento and San Joaquin river flows must be smoothed during the transition from one month to the next to prevent numerical problems due to abrupt changes during the transitions. The Delta Modeling Section does this smoothing using a mass-conserving rational histopolation spline.

Note that for typical DSM2 planning studies, the stage input at Martinez (the downstream boundary condition) is provided by an adjusted astronomical tide regardless of the source of inflow and export boundary conditions (Shrestha, 2002). A sample DSM2 text boundary conditions input file (typically called boundary.inp) is shown in Figure 5.3. Note that in the sample input file, variable names that begin with a "$" are environment variables that are defined in different input files. These variables represent values that change from study to study such as the input file name (e.g., $CALVINFILE, $CALVINSMOOTH, or $TIDE) or the study designation (e.g., $STUDY). Further information on DSM2 input files can be found in Nader-Tehrani and Finch, 1998.

```
# HYDRO Time-varying boundary conditions with inflows and exports from CALVIN
# Created:  4-4-03 Jamie Anderson [jamiea]

#CALVIN boundary flow locations
#D44-D503        Sacramento at Hood
#D616-C42        San Joaquin at Vernalis
#C20-D55         Yolo Bypass
#C41-C42         Calaveras inflow to Delta
#D517-D515       East Side streams other than Calaveras
#D550-CC1-PMP    Contra Costa
#D59-TRACY-PMP   Tracy-CVP
#D59-BANKS-PMP   Banks-SWP
#D55-C22         North Bay Aqueduct

# Monthly boundary flows from CALVIN
INPUTPATHS
name     a_part        b_part        c_part e_part f_part fillin filename
sac      CALVIN-SMOOTH D44-D503      FLOW   1DAY   $STUDY last   $CALVINSMOOTH
sjr      CALVIN-SMOOTH D616-C42      FLOW   1DAY   $STUDY last   $CALVINSMOOTH
yolo     CALVIN        C20-D55       FLOW   1MON   $STUDY last   $CALVINFILE
cal      CALVIN        C41-C42       FLOW   1MON   $STUDY last   $CALVINFILE
eastside CALVIN        D517-D515     FLOW   1MON   $STUDY last   $CALVINFILE
ccc      CALVIN        D550-CC1-PMP  EXPORT 1MON   $STUDY last   $CALVINFILE
cvp      CALVIN        D59-TRACY-PMP EXPORT 1MON   $STUDY last   $CALVINFILE
swp      CALVIN        D59-BANKS-PMP EXPORT 1MON   $STUDY last   $CALVINFILE
nb       CALVIN        D55-C22       EXPORT 1MON   $STUDY last   $CALVINFILE
END

# MTZ stage
INPUTPATHS
Name  a_part     b_part   c_part  e_part  f_part   fillin  filename
MTZ   FILL+CHAN  RSAC054  STAGE   15MIN   PLANNING interp  $TIDE
END
```

Figure 5.3: Sample DSM2 Text Boundary Condition Input File, Using Input from CALVIN.

5.3.2 Delta Island Consumptive Use

There are several options for specifying Delta Island Consumptive Use (DICU) for DSM2 planning studies that use input from CALVIN, including:

- Using historical DICU for studies with historical precipitation and consumptive use demands
- Using the DICU for 2020 CALSIM studies for CALVIN studies at the 2020 level of development
- Separating total DICU computed by CALVIN into point DICU values throughout the Delta using DWR's processing program called ADICU

The representation of DICU in DSM2 planning studies depends on the type of CALVIN study and the amount of effort desired to represent DICU. If a CALVIN study reflects the current level

of development, the historical values for DICU that have already been computed from DWR's DICU model could be used. Additionally, if the CALVIN study represents the 2020 level of development, the DICU for the 2020 level of development used in CALSIM-based planning studies could be used in the DSM2 simulation. If the CALVIN study does not represent the current or 2020 levels of development, or if a more refined representation of DICU is desired, the total Delta consumptive use calculated by CALVIN could be divided into point DICU values throughout the Delta using DWR's processing program called ADICU (Adjusted Delta Island Consumptive Use). This is the only method presented that would provide DICU values based on the CALVIN output results.

5.4 Use of DSM2 to Provide Feedback to CALVIN

In addition to using CALVIN to provide inflow and export boundary conditions to DSM2 for planning studies, DSM2 can be used to provide feedback to CALVIN on how well it is meeting Delta water quality standards. Delta water quality standards in CALVIN are represented by minimum Net Delta Outflow requirements[1] that are intended to provide sufficient outflow to keep water quality constituent concentrations within allowable limits. CALVIN optimizes reservoir releases and exports based on these minimum Net Delta Outflow requirements, however CALVIN does not explicitly simulate water quality constituent concentrations. Thus CALVIN cannot verify that the minimum Net Delta Outflow requirements are associated with water quality constituent concentrations in the Delta that comply with Delta standards. Because DSM2 is a water quality simulation model that determines water quality concentrations throughout the Delta based on specified inflows and exports, DSM2 can be used to assess whether the inflows and exports computed by CALVIN actually meet water quality standards. In other words, DSM2 can be used to verify that the Minimum Net Delta Outflow requirements used in CALVIN are actually sufficient to meet Delta water quality standards. These results can be used in an iterative process to improve the representation of Delta water quality standards in CALVIN.

5.5 Future Directions

It is hoped that the cooperative relationship between DWR and UC Davis will be enhanced by continued use of DSM2 and CALVIN together in the future. Using input from CALVIN for DSM2 planning studies expands the types of studies to which DSM2 can be applied. One feature that distinguishes CALVIN from other system operations models is the economic optimization component; by coupling CALVIN and DSM2 it is possible to assess local impacts on hydrodynamics and water quality of system operations that CALVIN has determined to be economically efficient. DSM2 may also be used in the future to help refine the water quality

[1] Delta water quality standards in CALVIN are represented by minimum Net Delta Outflow requirements that were determined by calibration to the Department of Water Resource's DWRSIM simulation results for the 2020 level of development. DWRSIM is a statewide operations simulation model developed by the Department of Water Resources that was the predecessor to CALSIM. The Net Delta Outflow requirements specified in CALVIN were created prior to the release of CALSIM, thus those requirements are based on DWRSIM results.

constraints in CALVIN. Using DSM2 and CALVIN together provides a powerful set of analysis tools for exploring water resources issues in the Delta.

5.6 References

Jenkins, M., A. Draper, J. Lund, R. Howitt, S. Tanaka, R. Ritzema, G. Marques, S. Msangi, B. Newlin, B. Van Lienden, M. Davis, and K. Ward. (2001). *Improving California Water Management: Optimizing Value and Flexibility*. Report for the CALFED Bay-Delta Program. Sacramento, CA. October, 2001.

Lund, J, R. Howitt, M. Jenkins, T. Zhu, S. Tanaka, M. Pulido, M. Tauber, R. Ritzema, and I. Ferreira. (2003). *Climate Warming and California's Water Future*. Report for the California Energy Commission by the University of California at Davis Departments of Civil and Environmental Engineering and Agricultural and Resource Economics. Report 03-1 Center for Water Resources and Environmental Engineering, University of California, Davis, CA. March 20, 2003.

Nader-Tehrani, P. and R. Finch. (1998). "Chapter 5: DSM2 Input and Output." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Shrestha, B. (2002). "Chapter 11: 16-Year DSM2 Planning Studies with Adjusted Astronomical Tides and Daily Hydrology." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

5.7 Websites

Additional information on CALVIN can be found at:
http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/

Additional information on DSM2 can be found at:
http://modeling.water.ca.gov/delta/models/dsm2/index.html

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 6:
New Behaviors and Control Switches in DSM2-PTM

Author: Aaron Miller

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 7:
Implementation of a New DOC Growth Algorithm in DSM2-QUAL

Author: Michael Mierzwa and Ganesh Pandey

7 Implementation of a New DOC Growth Algorithm in DSM2-QUAL

7.1 Introduction

As part of DWR's Integrated Storage Investigations' In-Delta Storage project (ISI-IDS), DSM2-QUAL was modified to account for increases in dissolved organic carbon (DOC) concentrations due to the prolonged water contact with the peat soil on the proposed island reservoirs. The DWR Municipal Water Quality Investigations (MWQI) Program conducted the initial field experiments at DWR's SMARTS (Special Multipurpose Research and Technology Station) facility to develop the DOC growth algorithm to be used in QUAL (Pandey, 2002). Between 1998 and 2000, these experiments focused on measuring the production of DOC from peat soils in a series of eight tanks with different combinations of peat soil depth, water depth, and water exchange rates (Jung, 2001). However, while the SMARTS tank experiments did account for increases in DOC due to leaching and microbial decay, the experiments did not account for the additional production of organic carbon from algae and wetland plants. ISI conducted new studies that accounted for the production of organic carbon from algae and wetland plants in addition to the growth of DOC mass due to leaching and microbial decay of the peat soils (DuVall, 2003). This chapter summarizes the new methodology used in QUAL to simulate the increase in DOC mass in reservoirs due to interactions between water stored on a flooded Delta island and an island reservoir's peat soil bottom.

7.2 Implementation in QUAL

Based on the original SMARTS tank experiments (Jung, 2001), the concentration of DOC in the island reservoirs was modeled in QUAL using a logistic equation. Using this equation, island reservoir DOC would approach a fixed concentration after only a few months of storage. Since the implementation of this early equation, a few problems with this approach have been identified. First, the limited data from the SMARTS tank experiments suggested that after a few months, the DOC concentration in an island reservoir would approach a fixed value. However, the SMARTS tank experiments did not account for the production of organic carbon from algae and wetland plants, thus QUAL was underestimating the DOC concentration in the reservoirs. In situations where the DOC concentration of the diversions into one of the island reservoirs was higher than this fixed DOC concentration, QUAL would still use the logistic equation. In these situations the logistic equation would reduce the DOC concentration in the reservoir until it met the fixed DOC concentration.

In response to comments about the original SMARTS tank experiments and the implementation of the SMARTS data in QUAL, ISI conducted new experiments to develop stronger relationships from the new data (DuVall, 2003). These new studies accounted for the production of organic carbon from algae and wetland plants. Based on DuVall's work, the implementation of increasing DOC concentration in island reservoirs was completely redesigned in QUAL.

7.2.1 Activating DOC Growth

A new true / false flag, `storage_reservoir`, in the scalar.inp file (see Figure 7.1) allows anybody using the new QUAL executable to turn on / off the non-conservative growth of DOC in reservoirs. When the `storage_reservoir` flag is set to true, QUAL will look for a file called operation_schedule.dat in the directory were the QUAL run was initiated. In this file, constant monthly growth rates are specified only for the reservoirs where the user wants DOC concentrations to increase. When the `storage_reservoir` flag is set to false, DOC will be treated as a conservative constituent. DOC growth is limited to reservoirs.

```
# DSM2 input file
# ISI In-Delta Storage 2003 16-Year Planning Study
# Alternative B
# Updated: 2003.06.21, mmierzwa

# Various single-argument options (constants, coefficients, ...)
SCALAR
flush_output          10day          # interval to flush output
display_intvl         1day           # how often to display model time progress
checkdata             false          # check input data w/o simulation

# Note: all cont_* scalars are "true" or "false".
cont_unchecked        true           # continue on unchecked data
                                     # (use data value)
cont_question         false          # continue on questionable data
                                     # (use data value)
cont_missing          false          # continue on missing data
                                     # (use previous value)
cont_bad              false          # continue on bad data (use previous value)

warn_unchecked        false          # warn about unchecked data
warn_question         true           # warn about questionable data
warn_missing          false          # warn about missing data

printlevel            1                                g, 0 to 9,
                                                       umber.

temp_dir              e:/trash

# following all QUAL variables
Qual_time_step        15min          # Qual time step, in minutes
Dispersion            t              # true Activate dispersion
Init_Conc             0.0            # initial concentration value (not used)
storage_reservoir     t              # storage Reservoirs
tide_length           25hour         # tide length
END
```

Flag to activate (when set to true) DOC growth

Figure 7.1: Sample scalar.inp File.

7.2.2 DOC Mass Growth Rate Parameters

The data from the new ISI tank studies did not suggest the same leveling off of the DOC concentration after a few months of storage that was observed in the original SMARTS data. Instead, DuVall noted a steady linear increase in DOC concentration that began in the spring and ended in the early fall. QUAL now uses monthly growth rates for each reservoir. The monthly growth rate for each reservoir can be changed to reflect data collected from different sites.

In the previous implementation (Pandey, 2002), the DOC equation directly calculated increases in the DOC concentration. In the case of the ISI-IDS project, the additional organic carbon in the reservoirs comes from either the peat soil bottom surface or the algae and wetland plants

growing in the reservoir itself; thus QUAL's new growth mechanisms focus on adding organic carbon mass instead of DOC concentration. Because DSM2 treats reservoirs as tanks with constant surface areas, A, and variable depths, d_t, the amount of organic carbon added to the stored water, Δm, is a linear function of surface area (Figure 7.2). Though the new organic carbon, Δm, is shown below as coming from the peat soil base, the monthly growth rate is based on field observations that also included algae and plant sources. The new DOC concentration, C_t, will be calculated each time step using the current reservoir volume (except when the reservoir is below a specified depth, as described below), V_t, and the total mass of organic carbon, m_t', which includes both the mass already present in the reservoir, m_t, and new mass added to the system, Δm.

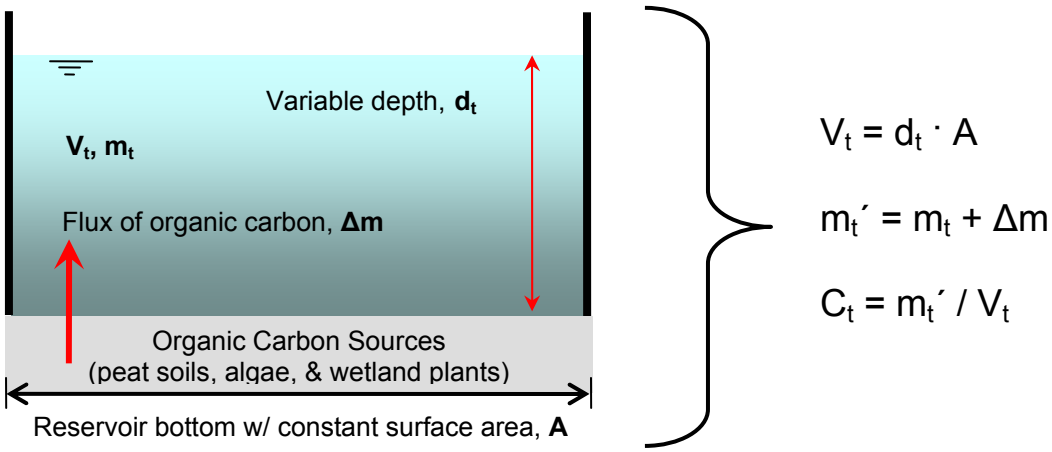

Figure 7.2: Conceptualization of Implementation of DOC Growth in QUAL.

Even though the flux of organic carbon is a constant value, the concentration may grow at a non-linear rate when the volume of the reservoir is changing. This can become problematic in situations when water is being released from a reservoir because the decreasing volume and constant flux of organic carbon into the reservoir will increase the rate of growth of the DOC concentration. An increase in the rate of DOC growth becomes a numerical problem as the volume of the reservoir approaches zero.

To prevent this, a minimum reservoir depth limit is specified in the operation_schedule.dat file (Figure 7.3). When the stage in a reservoir is equal to or less than this limit, QUAL no longer calculates a change in the DOC concentration in the reservoir.

The amount of new organic carbon is calculated as a function of the surface area of the reservoir, from QUAL's reservoirs.inp file, and the monthly growth rate parameters from the operation_schedule.dat file (see Figure 7.3). The monthly growth rate coefficients start in October and continue through the rest of the water year. The next parameter in the operation_schedule.dat file is a scaling factor. QUAL simulates DOC in ug/L, so the scaling factor is used to adjust the monthly growth rates accordingly. For the example operation_schedule.dat file shown below, the scaling favor is 1000.0. The final growth parameter is the minimum depth for growth limit described above.

```
Description of Input Variables
Line 1 Total Number of Reservoirs used for Storage Purposes
Line 2 Name of the Storage Reservoir followed by DOC Growth Parameters
Lines 2 should be repeated for each reservoir
2
webbtract    0.47 0.0 0.0 0.0 0.0 0.47 0.47 0.47 0.47 0.47 0.47 0.47 1000.0 2.0
baconisland  0.47 0.0 0.0 0.0 0.0 0.47 0.47 0.47 0.47 0.47 0.47 0.47 1000.0 2.0
```

Organic Carbon Monthly Growth Rate

Scaling Factor

Min. Depth for Growth

Figure 7.3: Example operation_schedule.dat File.

7.3 Example Application of New Methodology

This new method of DOC growth was tested in QUAL using the growth rate parameters shown in Figure 7.3, with the exception that the October growth rate constant was specified as 0.0 instead of 0.47. The hydrology and operation of the reservoirs were identical to a previous DSM2 study that used the old DOC growth logistic equation. The previous equation approach made use of different "bookends" for estimating the DOC growth parameters. Typically two bookends would be chosen to represent a high ultimate DOC concentration and a low ultimate DOC concentration. Finally, using the `storage_reservoir` flag shown in Figure 7.1, DOC growth was turned off to represent a no-growth base case.

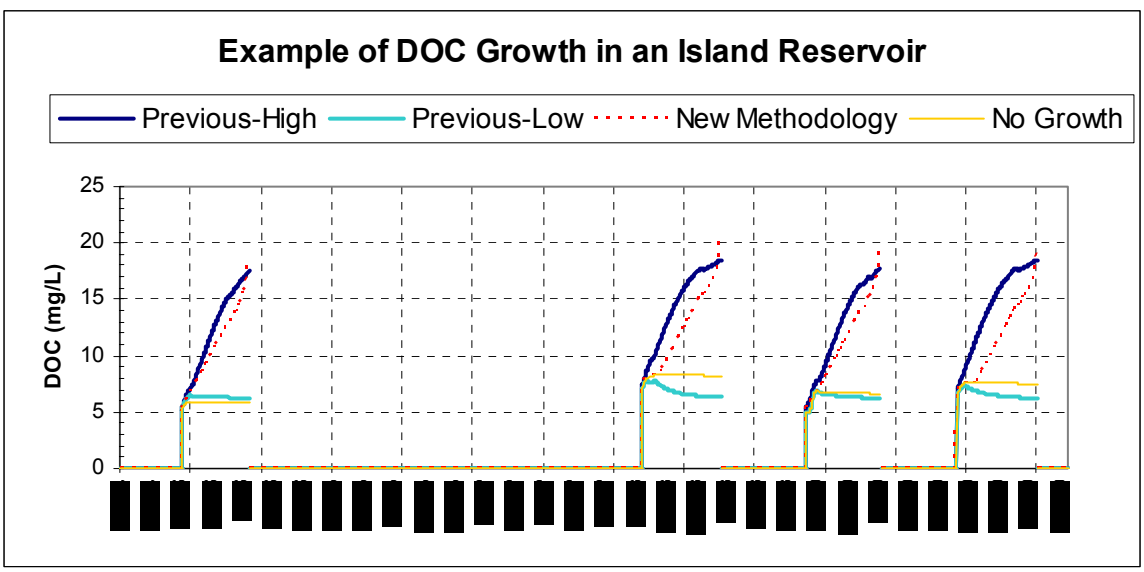

Figure 7.4: Example of DOC Growth in an Island Reservoir.

A comparison of the DOC concentrations from the previous equation high and low bookends, this new methodology, and a no-growth base case in an island reservoir is shown in Figure 7.4. DOC is shown only at times when the stage in the reservoir was greater than 1.0 ft. As can be seen by the no-growth results, the initial DOC concentration in the reservoir is a function of the

diversions from nearby channels and varied over the course of the study. Reservoir releases have no impact on the concentration inside the reservoirs.

During many of the diversion (fill) periods, the ultimate DOC concentration for the low bookend derived from the previous equation was lower than the incoming DOC concentration. Thus when the initial DOC concentration was greater than 6 mg/L, the low bookend equation reduced the DOC concentration in the reservoir. As described above, this problem is one of the reasons the DOC growth implementation in QUAL was redesigned.

The DOC concentration for the previous high bookend and the new methodology reached similar maximum values by the end of the four to five month storage periods. However, the DOC concentrations for the new methodology tended to have a sharp increase during the release period. As was described above in section 7.2.2, when the volume of the reservoir decreases, but the growth rate remains constant, the rate of change of the actual DOC concentration will rapidly increase. It is for this reason that a minimum depth required for growth limit is specified with the new DOC growth rate parameters. For this example, the minimum depth for DOC growth was set at 2 ft.

Although the previous high bookend and new methodology results were similar for this example, if the storage period was longer, the DOC concentration in the new methodology would continue to increase over time, while the DOC concentration using the previous high bookend method would quickly approach its ultimate DOC concentration (which for this example was around 19 mg/L). The difference between these two methodologies lies in the conclusions drawn from the field experiments. Because DuVall's field investigations were extended beyond the length of the original experiments, the new methodology is more effective at simulating the impacts of potential carry-over storage events (i.e., long-term storage).

7.4 Conclusions

By comparing the results of the new DOC growth implementation with the results of the previous implementation and no-growth studies, it has been confirmed that the actual implementation of the new DOC methodology in QUAL produces reasonable results, while avoiding some of the problems associated with the previous implementation. Though the above example only shows the DOC concentration at times when there is significant storage in the reservoirs (i.e., the stage is greater than 1 ft.), the proper indexing of the monthly growth rates was confirmed by looking at the DOC concentration of the new implementation for an entire six-year period.

However, it is important to note that although the implementation of the new DOC growth methodology in QUAL performed adequately when tested using a prior ISI-IDS study operation, the following points should be considered when using the new methodology:

- Non-conservative DOC growth is currently only available in QUAL for reservoirs. This non-conservative growth may be activated for specific reservoirs, while other constituents will be unaffected by the DOC growth parameters.

- A special QUAL executable was created for DOC growth. While this executable has been tested for DOC and other conservative constituents, it is not being distributed (i.e., it is only available upon request). Furthermore, the new `storage_reservoir` flag added to the scalar.inp file cannot be read in an older version of QUAL.

- The growth rate parameters are site specific. When using this version of QUAL to simulate DOC growth, the growth rate parameters should be valid for the reservoir to which they are applied.

7.5 References

DuVall, R. (2003). "In-Delta Storage Program Water Quality Field Investigations". Presentation on Jan. 22, 2003 to stakeholders committee meeting. Available at http://www.isi.water.ca.gov/ssi/indelta/docs/4%20FieldInvStakeholders012203.ppt. Sacramento, CA.

Jung, M. (2001). *Conceptual Model and Mathematical Relationships for Reservoir Island Release Water Quality Module in DSM2 for Organic Carbon*. Consultant's Report. Municipal Water Quality Investigations, California Department of Water Resources. Sacramento, CA.

Pandey, G. (2002). "Chapter 9: Implementation of DOC Growth in DSM2-QUAL." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board*. California Department of Water Resources. Sacramento, CA.

6 New Behaviors and Control Switches in DSM2-PTM

6.1 Introduction

This document describes the improvements that have been incorporated into DSM2's Particle Tracking Model (PTM). The improvements include some additional behaviors and control switches. First, a new stage triggering behavior was added so particles can be forced to certain areas of the channel based on whether the tide is flooding or ebbing. Second, a simple control switch to the input will allow or disallow particle removal by seepage flows (i.e., a flow through a levee or some other soil substrate).

6.2 Stage Triggering

A new stage triggering behavior was added to the PTM behavior module described by Miller (2000). This module allows the user to select particle-positioning criteria based on whether the tide is rising or falling. As is shown in an image of the behavior GUI (Figure 6.1), stage triggering is currently limited to the particle's vertical position. However, horizontal (transverse) positioning, along with additional longitudinal velocity, will be added in the future.

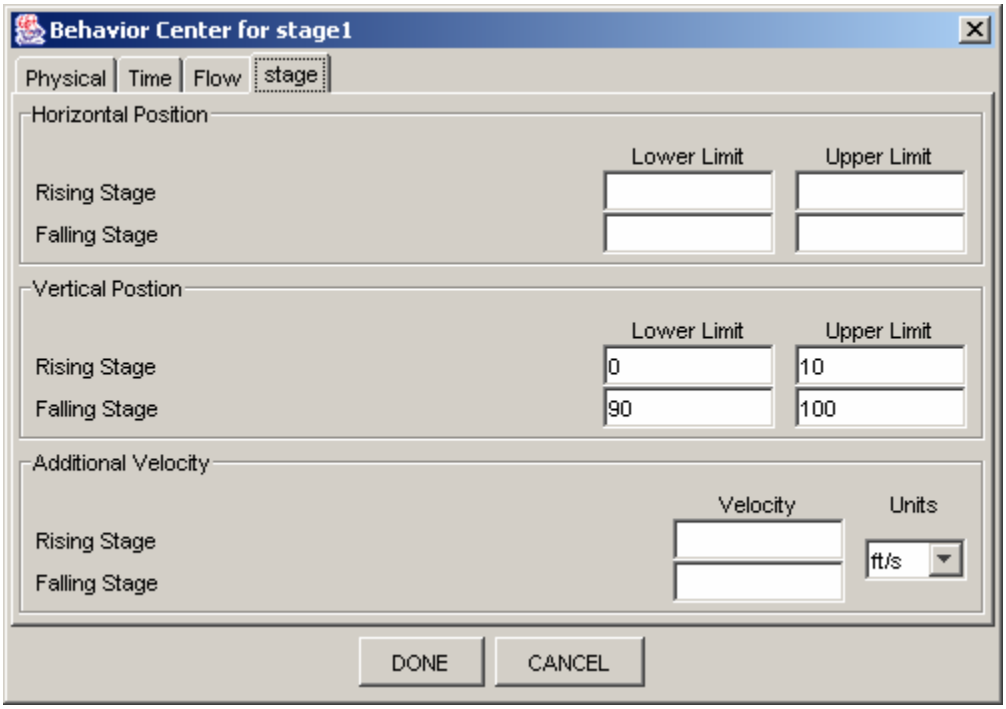

Figure 6.1: View of Stage Behavior GUI Showing Vertical Positioning Based on Rising and Falling Stage.

6.2.1 Vertical Positioning Example

The vertical positioning is based on percentage of channel depth with respect to the bottom of the channel. Using the example from Figure 6.1, during rising stage particles are instructed to stay between 0% and 10% of the depth as measured from the bottom of the channel. During the falling stage, the particles are instructed to stay between 90% and 100% depth as measured from the bottom.

Figure 6.2 shows diagrams of the particle vertical positioning based on rising and falling tides. For this example it is assumed that the rising tide is associated with upstream velocities, and that the particles will be constrained to the bottom 10% of the channel based on the user-established vertical positioning behavior (Figure 6.1). Similarly, the falling tide is associated with downstream velocities when the particles are limited to the upper 10% of the channel.

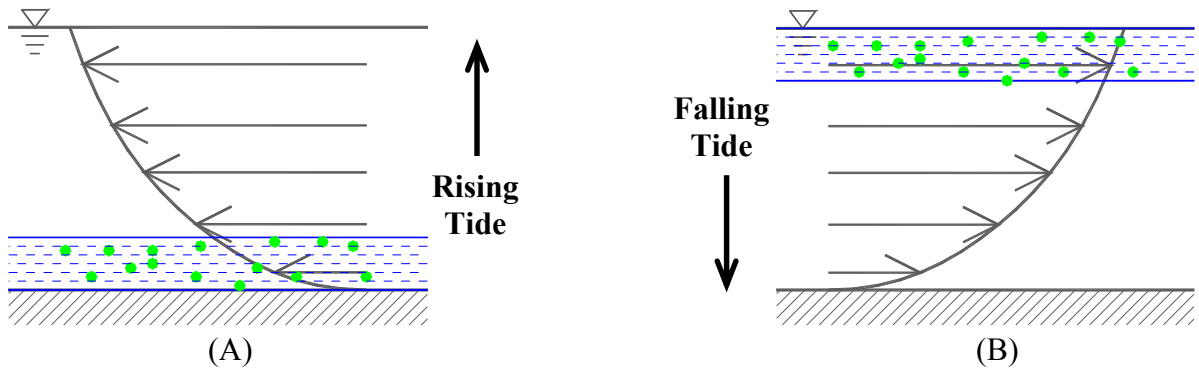

Figure 6.2: Example of Positioning from Stage Triggering and Particle Position Associated with: (A) Rising Stage and (B) Falling Stage.

6.2.2 Vertical Positioning Implementation

Whether the stage is rising or falling is determined using the change in stage between the last and current time steps. Since the time step is fixed, the gradient of the change will be based on the incremental stage. Currently the sensitivity of the stage determination logic is hard coded within PTM to a slope of 0.0001. When the absolute value of the change in stage exceeds 0.0001 ft/sec, the stage trigger occurs. Positive changes are associated with the rising stage limits, and negative changes in stage are associated with the falling stage limits.

As shown in Figure 6.3, stage triggering only occurs during periods when water levels are rapidly changing. During the intermediate periods (i.e., periods between stage triggers) the particles do not have any behaviors that are associated with stage triggering. During periods outside of this interval, the particles will not be constrained to any position in the channel.

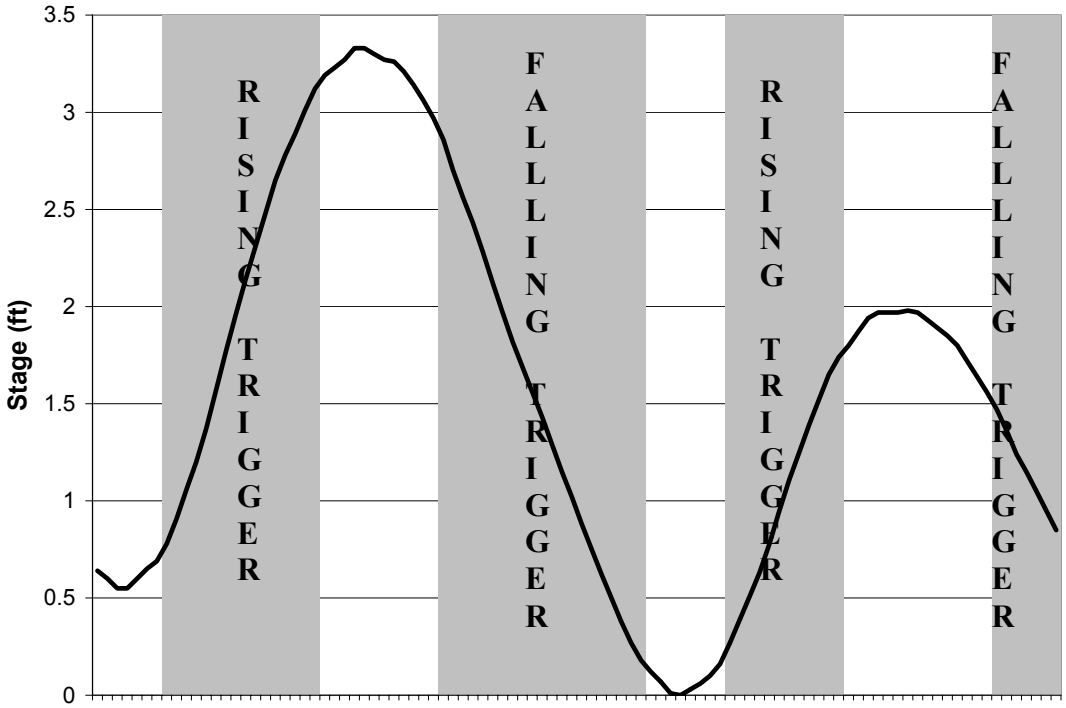

Figure 6.3: Example of How Stage Triggering is Implemented.

6.3 Seepage Switch

In PTM, particles are diverted based on flow splits at flow junctions. These junctions include intersections of multiple channels, agricultural diversion, and seepage nodes. As described by Miller (2002), PTM combines the flows at a given node to calculate the probability of a particle being diverted. In the past, PTM has not treated seepage flows differently than agricultural diversions or channel junctions. If PTM is simulating small particles, such as a water or a contaminate molecule, then having this option on would be appropriate, since the seepage flow simulates water lost to the islands or surrounding groundwater via permeable soil substrate. However, if PTM is simulating an aquatic organism, then no particles should be removed with seepage.

To allow users to decide if particles are lost to seepage, a new scalar flag was added to PTM. The scalar flag `particle_to_seep` determines whether the particles in the PTM may be diverted with the seepage flows.

6.4 References

Miller, A. (2000). "Chapter 5: DSM2 Particle Tracking Model Development." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 21st Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Miller, A. (2002). "Chapter 2: Particle Tracking Model Verification and Calibration." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 8:
DSM2-HYDRO Binary Output File Reader

Author: Aaron Miller

8 DSM2-HYDRO Binary Output File Reader

8.1 Introduction

The binary output file generated by DSM2-HYDRO contains flow and stage information for every channel and reservoir in the grid. Traditionally this file links HYDRO to DSM2-QUAL and DSM2-PTM. In the past, this file has been accessed to provide additional information on flow and stage data after a HYDRO simulation has been completed. However, early efforts to extract information from binary output files were not standardized and were difficult to perform on a regular basis.

Recognizing the value of having a standard tool to extract data from the HYDRO binary output files, staff began developing a graphical user interface (GUI) that would facilitate access to the flow and stage information at any location in the DSM2 grid. Though work on the output file reader is still underway, the current GUI can extract data, allow visual examination of the output, and write data in DSS format for further use.

The DSM2 Binary File Reader was written mostly in Java, with a small portion being written in FORTRAN and C. Java provides an easy and robust way to develop portable user interfaces, FORTRAN is used to most efficiently read the binary file, and C provides the interface between Java and FORTRAN.

8.2 Main Interface

The main interface (Figure 8.1) allows users to open and edit project files or create new ones. These project files use XML to store information on output preferences, including binary file names and requested output locations. Users can edit the project files, but will only be asked to save their changes when closing the binary file reader GUI.

Once a file is loaded, the binary data is exported to columns of text using the *Make Table* button, or to DSS format using the *Export to DSS* button. In addition, extracted data can be graphed by pressing the *Make Graph* button.

Instead of saving or viewing the entire binary data file, a starting and ending time can be set using the Timewindow feature. If used, both a start and an end time must be specified using the following convention:

DDMMMYYYY HHMM

For example, to look at hourly data only from 1976, the following value would be entered as the start time: `01JAN1976 0000`, and the end time would be entered as: `31DEC1976 2300`.

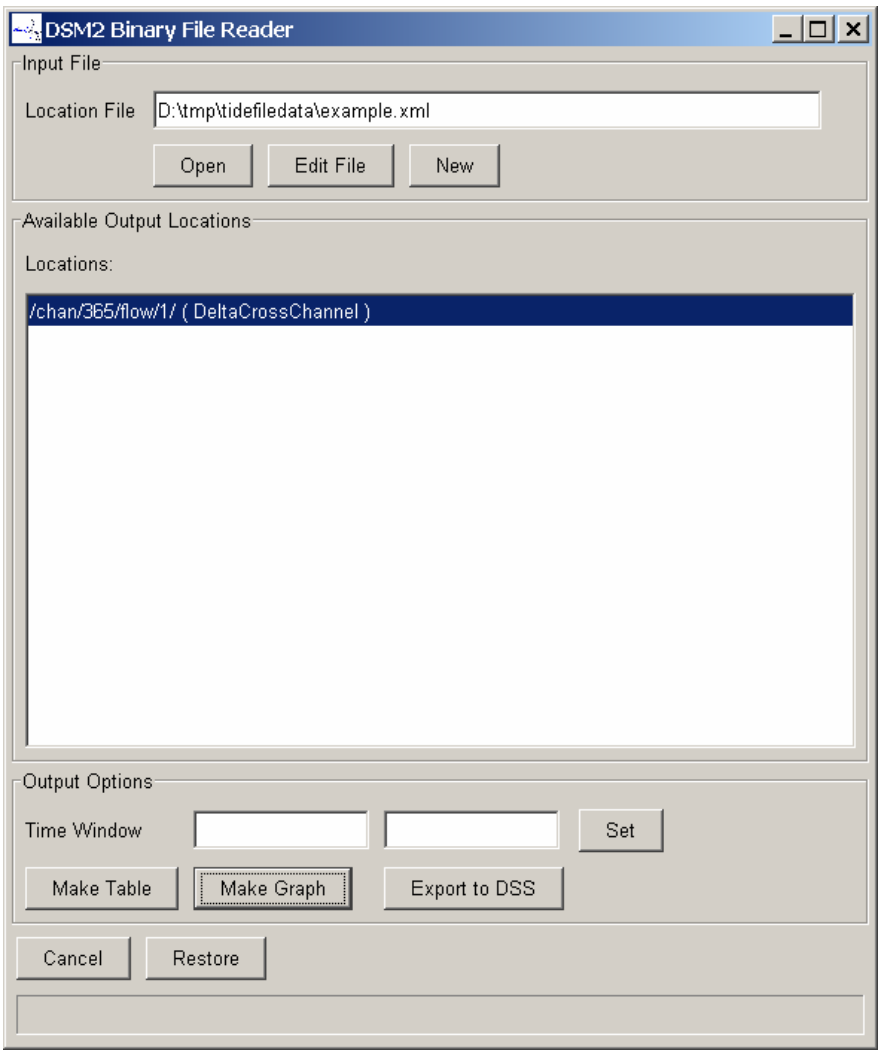

Figure 8.1: DSM2 Binary File Reader Application Interface.

8.3 File Editor Interface

Pressing the *Edit File* or *New* button will open the file editor interface (Figure 8.2). The file editor shows all binary files listed in the current project file and the output locations associated with each binary file. The editor displays this information in tree format and provides a number of ways for users to customize their output.

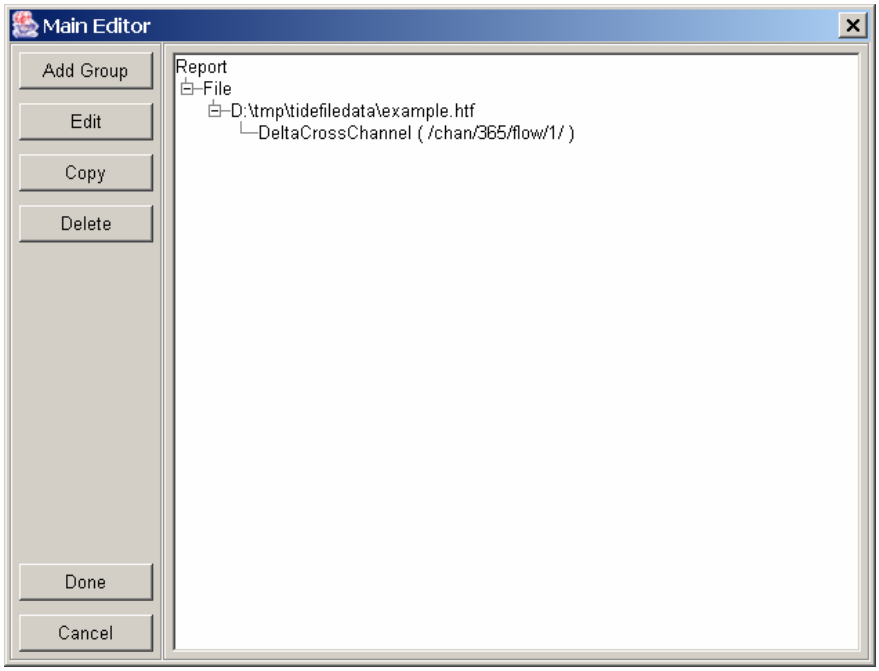

Figure 8.2: DSM2 Binary File Reader File Editing Interface.

8.4 Location Editor Interface

Pressing the *Add Group* or *Edit* button while in the main editor panel will open the location editor interface (Figure 8.3). The *Location Name* is the name of the output location and must be unique throughout the project file. The *Tidefile Location* is the path and filename the binary file will read.

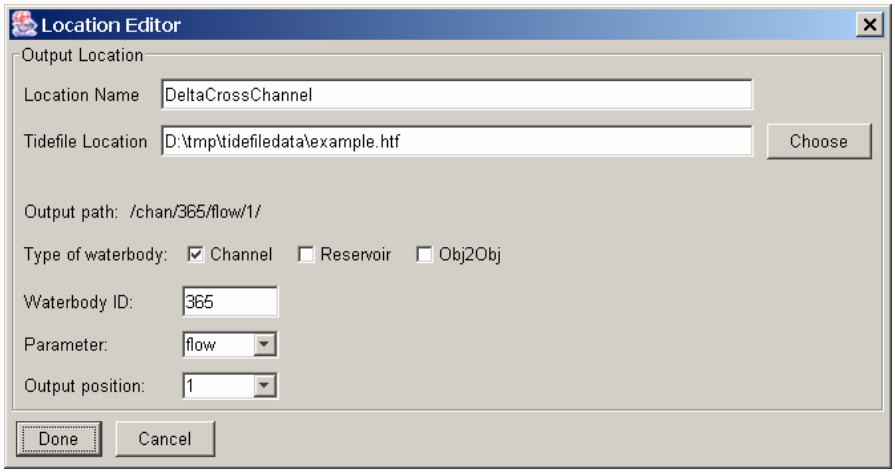

Figure 8.3: DSM2 Binary File Reader Location Editing Interface.

The remaining fields define a single location. The *Type of waterbody* defines one of three types currently available to DSM2 output: channel, reservoir, or object-to-object. The object-to-object waterbody type is used in DSM2 to simulate a transfer of water to and from either of the first two

waterbody types. The *Waterbody ID* defines the specific channel, reservoir, or object2object and must correspond with a waterbody simulated in DSM2. Channel numbers are defined in the DSM2 input files. Although reservoir and object2object are defined by names in the DSM2 input files, in the binary files they are assigned numbers based on the order they are listed in these input files.

Since every waterbody in the binary file has multiple parameters, the *Parameter* option defines which parameter to output. If both flow and stage values are to be examined, then separate output paths must be created for each parameter.

The *Output position* defines what part of the waterbody to output. On channels, "1" is for the upstream end and "2" is for the downstream end. On reservoirs this position is the gate number. Gate numbers are defined by order they are listed in the DSM2 input files.

8.5 Graphing Binary Data

After the binary data is loaded into the main interface (Figure 8.1) and a project file is selected, the user has the option to graph the data by pushing the *Make Graph* button. A sample graph is shown in Figure 8.4. The graphing ability was an add-on package Scientific Graphics Toolkit (SGT) developed by National Oceanic and Atmospheric Administration (NOAA). The graph window provides utilities to navigate, change, and print the data.

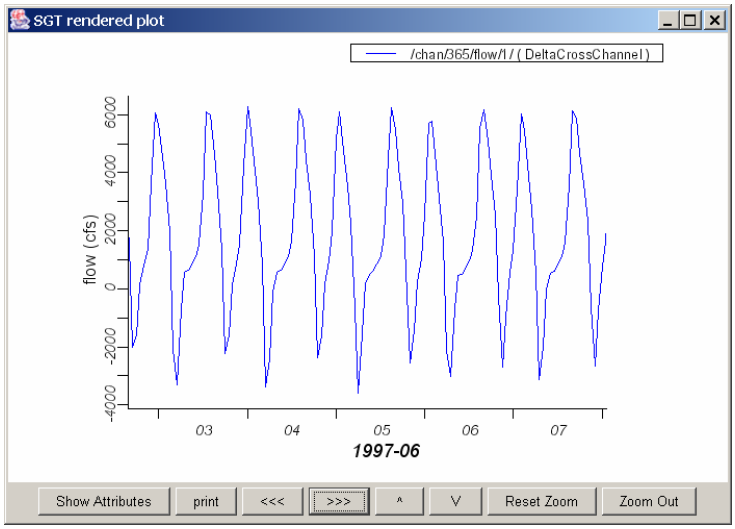

Figure 8.4: DSM2 Binary File Reader Graphing Interface.

8.6 Future Development

The binary output file reader will be expanded to read QUAL's binary file. It will also be linked to established QA/QC logic to enable a user to quickly evaluate a DSM2 simulation. Finally, it is anticipated that the reader will be linked to a report generator tool. This will entail reading from both the hydrodynamic and water quality output files and statistically manipulating these results into a useful format.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

24th Annual Progress Report
June 2003

Chapter 9:
Developing EC for Inflows for the San Joaquin River Extension to DSM2 for Planning Studies

Author: Jim Wilde

9 Developing EC for Inflows for the San Joaquin River Extension to DSM2 for Planning Studies

9.1 Introduction

The DSM2 extension up the San Joaquin River from Vernalis to Bear Creek, described by Pate (2001), has been used to simulate Delta hydrodynamic and electrical conductivity (EC) conditions based upon CALSIM-derived Delta inflows and exports. These simulations required modeling various inflows and associated EC in the extended reach of the San Joaquin River. The flows for these sources were provided by CALSIM directly, generated from post-processing CALSIM results via a methodology developed by Montgomery Watson Harza (2002), or taken from average values from the San Joaquin River Input-Output Model (SJRIO). As part of this effort, EC needed to be developed for the various sources of inflow to the San Joaquin River upstream of Vernalis. This chapter presents the assumptions and methodology for generating these EC values.

9.2 Sources of Inflow to the San Joaquin River from Vernalis to Bear Creek

EC is introduced into the San Joaquin River in the reach from Vernalis to Bear Creek from various sources: the upstream boundary near Stevinson; the tributary flows from the Stanislaus, Tuolumne, and Merced rivers; flows from Orestimba Creek and Mud and Salt Sloughs; westside agricultural drainage; eastside drainage; and groundwater flow (Figure 9.1). Monthly average flows from the Stanislaus, Tuolumne, and Merced rivers are obtained directly from CALSIM studies, as is the flow in the San Joaquin River near Stevinson. Agricultural drainage from the westside consists of runoff from applied water from Delta Mendota Canal (DMC) deliveries, riparian diversions, and groundwater pumping. Runoff from applied DMC water and riparian diversions is provided by CALSIM, and runoff from applied groundwater comes from SJRIO. Eastside drainage flows are provided by CALSIM, and groundwater flows into the San Joaquin River come from SJRIO.

9.3 EC in Stanislaus, Tuolumne, and Merced Rivers

Relationships between historic flows and EC were established (Figures 9.2, 9.3, and 9.4) to assign EC to flows from the Stanislaus, Tuolumne, and Merced rivers. No significant advantage was seen in developing relationships based upon time of year. The equations generated are presented in Table 9.1.

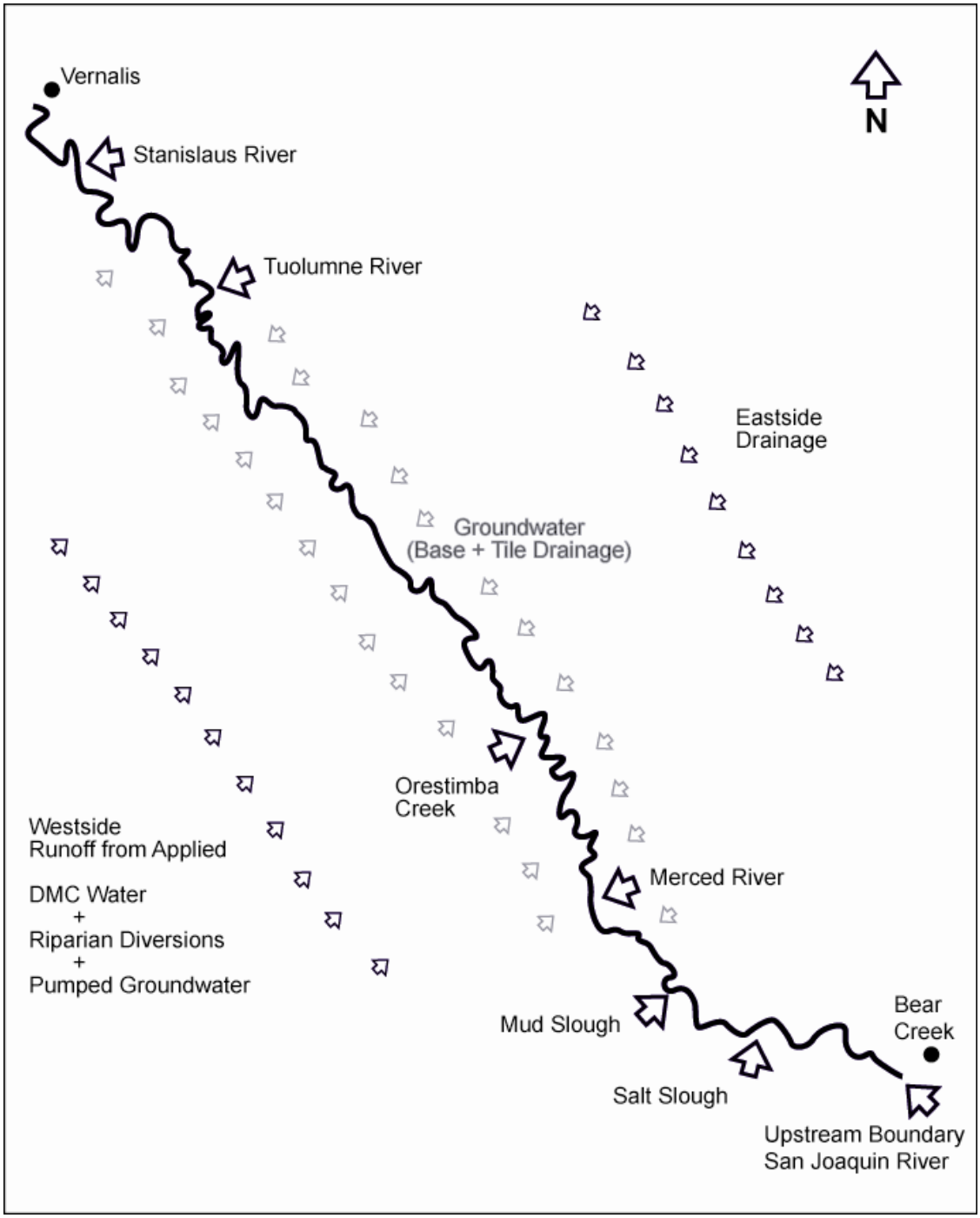

Figure 9.1: Sources of EC in Modeled Reach of San Joaquin River.

Table 9.1: Equations for EC as a Function of Flow at Various Sources of Inflow on the San Joaquin River.

EC Source	EC Equation	EC Limits	Period
Stanislaus River	$2400Q^{-0.48}$	EC>70	All
Tuolumne River	$2950Q^{-0.482}$	EC<350	All
Merced River	$-5E\text{-}07Q^3 + 0.0013Q^2 - 1.12Q + 384$	40<EC<350	All
SJR near Stevinson	$2440Q^{-0.305}$	EC<2000	January
	$3840Q^{-0.392}$	EC<1500	February
	$8690Q^{-0.465}$	EC<2000	March
	$5840Q^{-0.439}$		April
	-1.21Q + 1540	EC>100	May
	-2.30Q + 1720	EC>200	June
	1390		July
	$1570e^{-0.009Q}$		August
	$7100Q^{-0.600}$	EC<2000	September
	$1590e^{-0.0103Q}$	EC>50	October
	$3390Q^{-0.503}$	EC<1500	November
	$2910Q^{-0.355}$	EC<1500	December
Orestimba Creek	-0.15Q + 655		January-May
	-2.58Q + 710		June-August
	-3.76 Q + 710		September
	$800e^{-0.0053Q}$		October
	$690e^{-0.0042Q}$		November
	$570e^{-0.002Q}$		December
Salt Slough	1800		January
	1640		February
	1540		March
	1600		April
	-1.80Q + 1620		May
	-3.13Q + 1680		June
	-2.03Q + 1350		July
	-1.80Q + 1230		August
	-1.05Q + 1060		September
	1030		October
	-4.40Q + 2050		November
	-6.55Q + 2620		December
Mud Slough	-2.06Q + 2420		January
	-1.64Q + 2790		February
	3250		March-August
	2310		September
	-4.69Q + 2390		October
	-5.23Q + 2660		November
	-2.40Q + 2360		December
Q in cfs, EC in uS/cm			

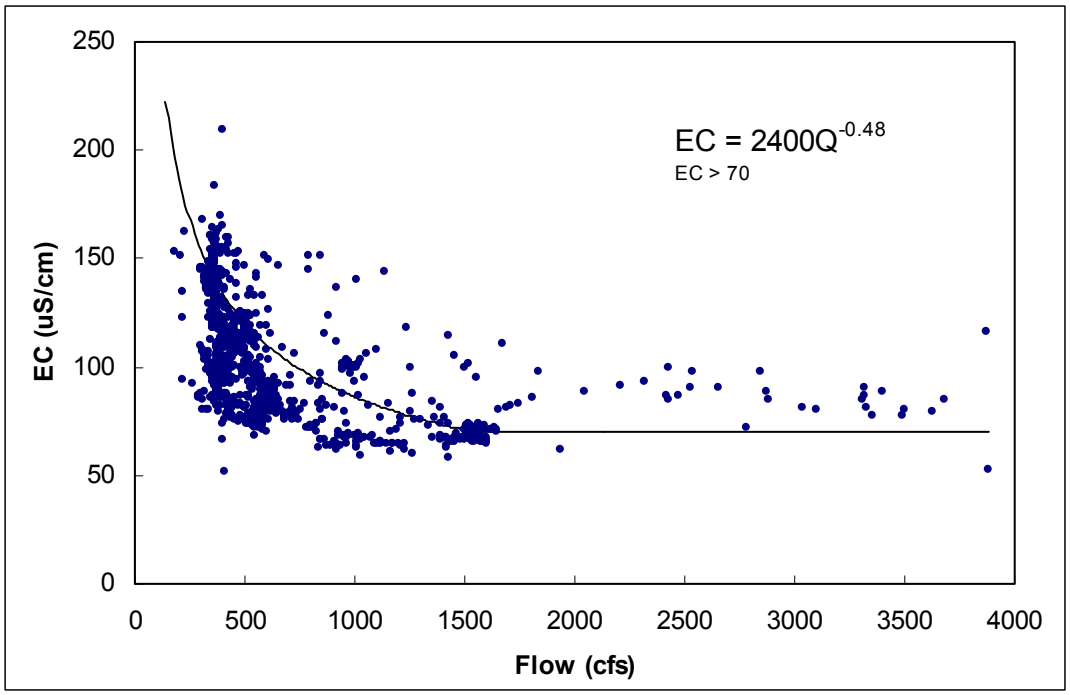

Figure 9.2: Stanislaus River, EC vs. Flow.

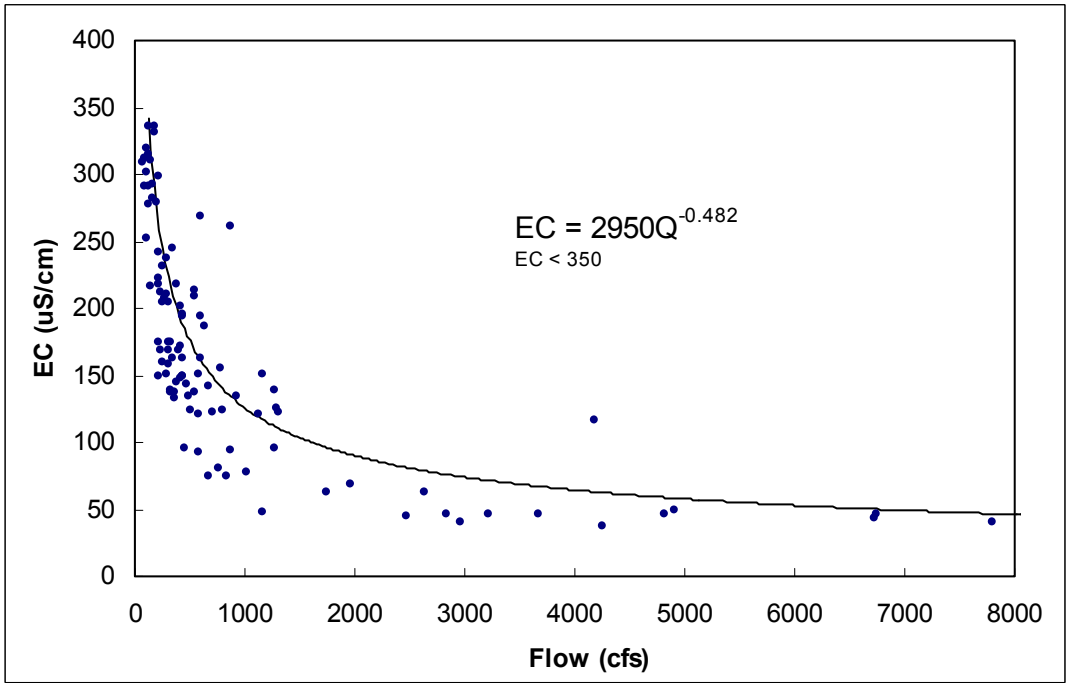

Figure 9.3: Tuolumne River, EC vs. Flow.

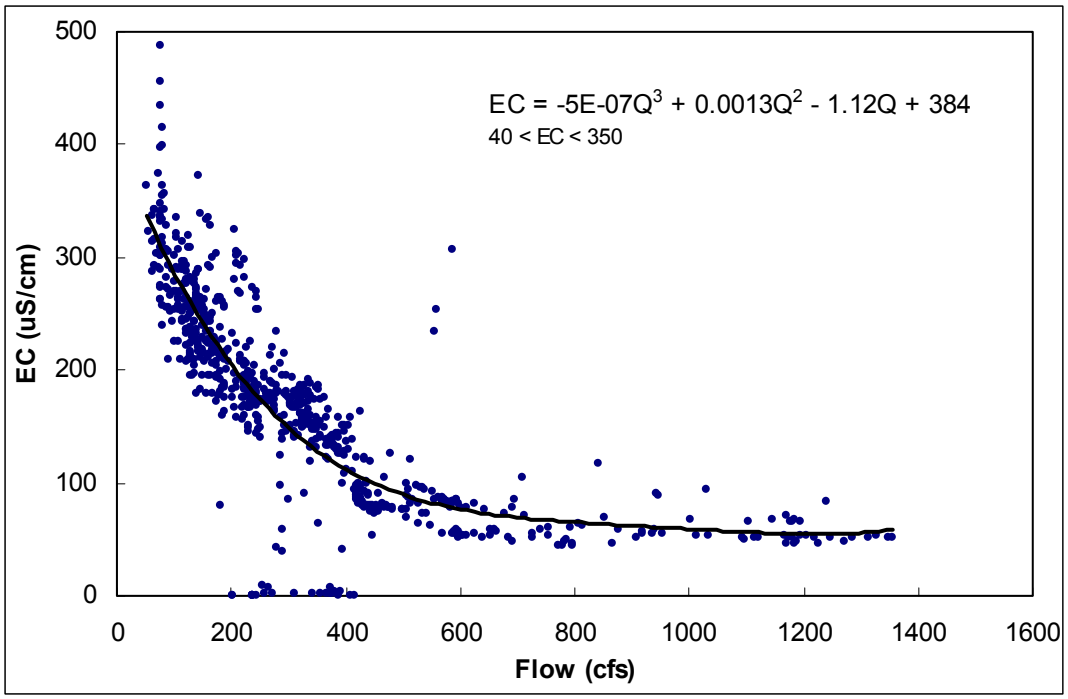

Figure 9.4: Merced River, EC vs. Flow.

9.4 EC in San Joaquin River at Upstream Boundary (near Stevinson)

To assign EC to flows from the San Joaquin River at the upstream boundary near Stevinson, relationships between historic flows and EC were established for each month (Figure 9.5). The equations generated are presented in Table 9.1.

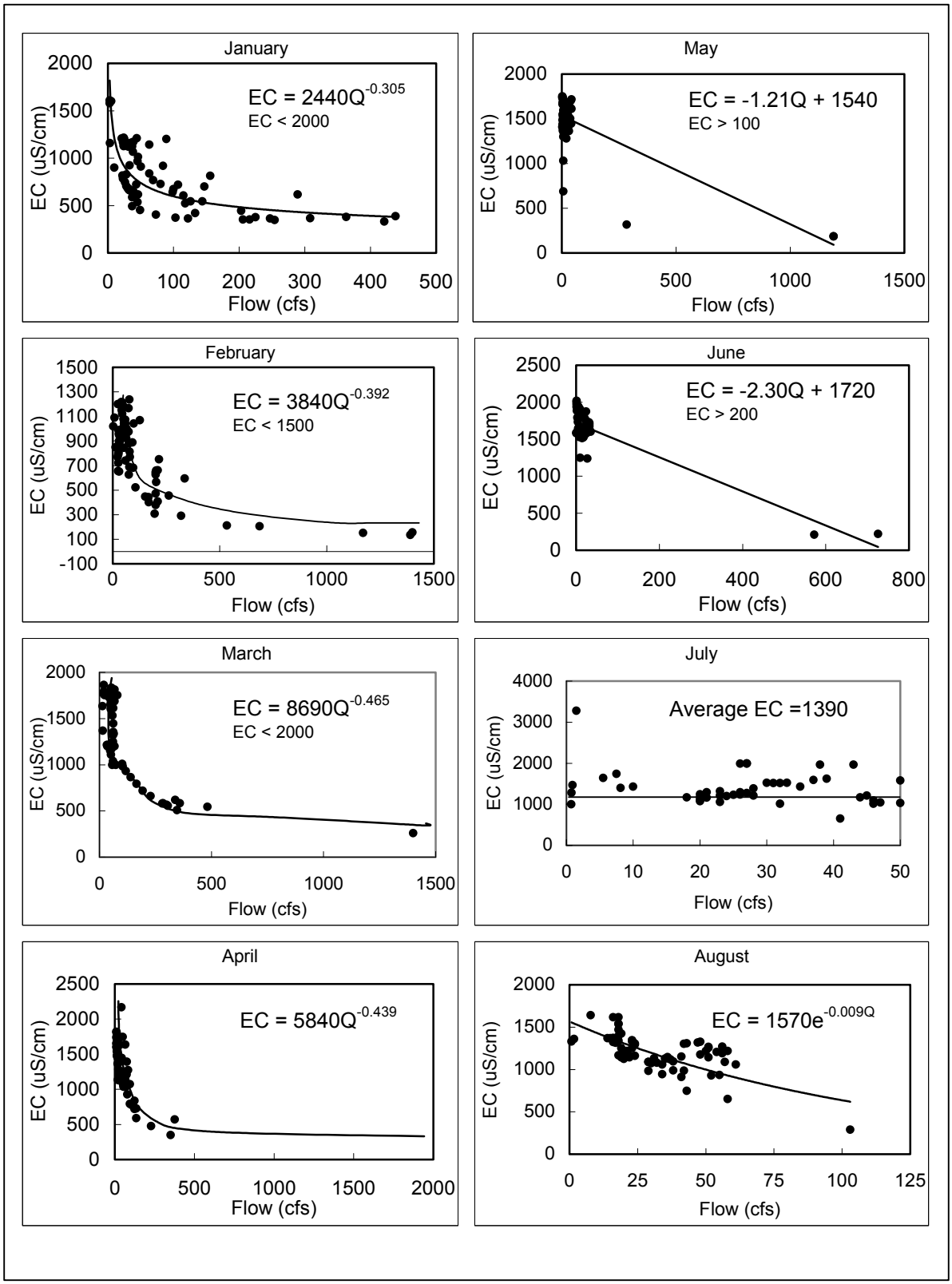

Figure 9.5: San Joaquin River near Stevinson, EC vs. Flow.

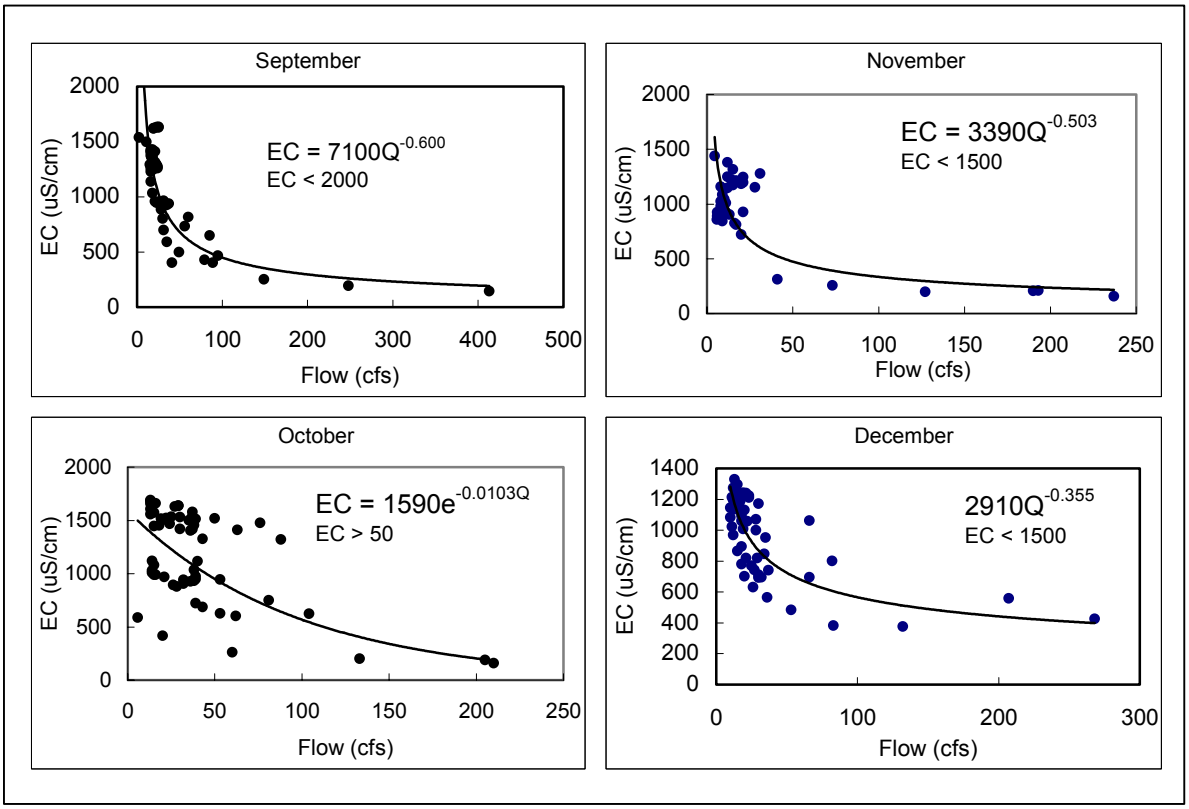

Figure 9.5 (cont.): San Joaquin River near Stevinson, EC vs. Flow.

9.5 EC in Orestimba Creek

To assign EC to flows in Orestimba Creek, relationships between historic flows and EC were developed for each of six intervals for any year: January-May, June-August, September, October, November, and December (Figure 9.6). The relationships are based upon data collected by USGS from January 1997 through February 2000. The equations generated are presented in Table 9.1.

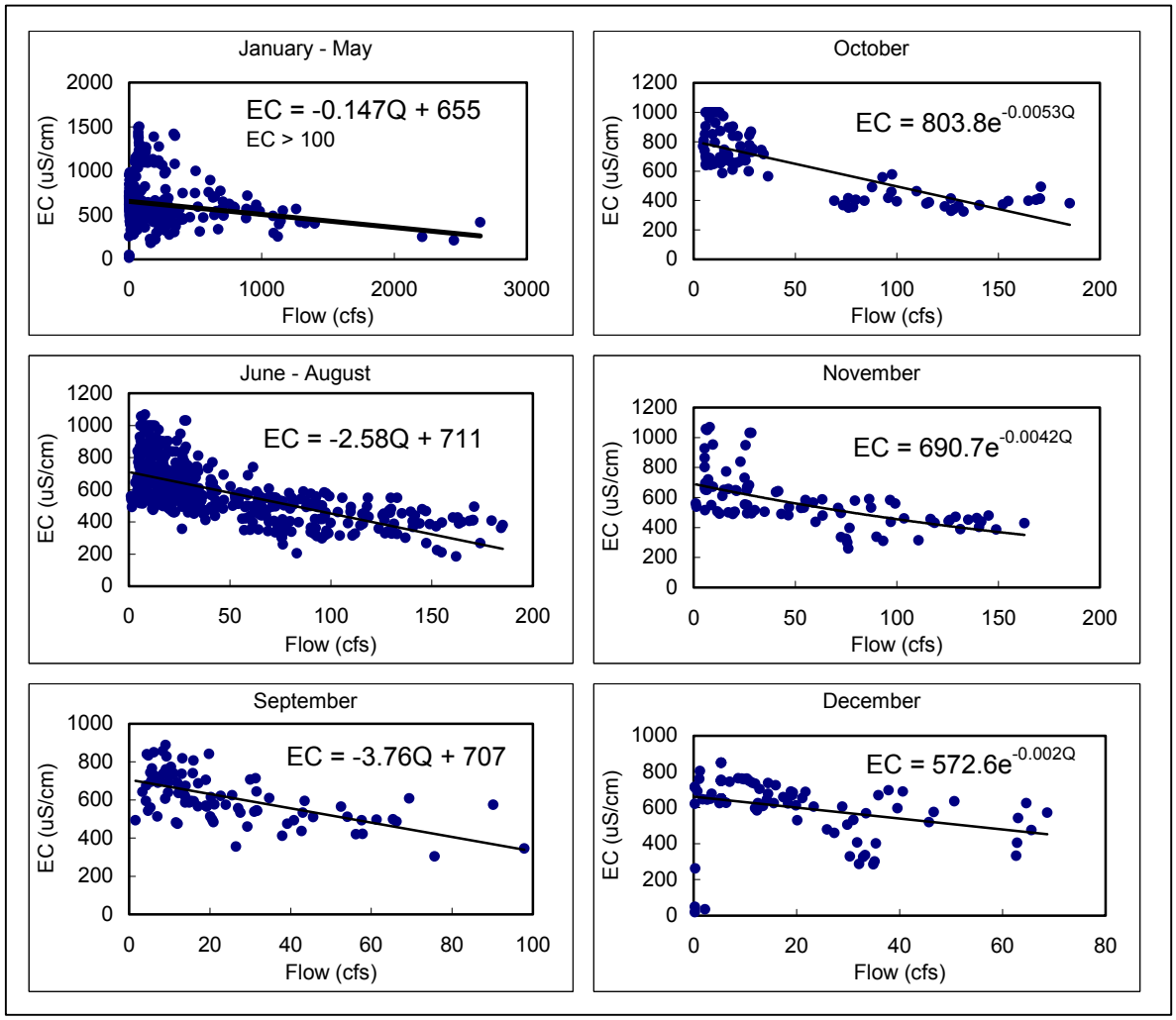

Figure 9.6: Orestimba Creek, EC vs. Flow

9.6 EC in Salt and Mud Sloughs

To assign EC to flows in Salt and Mud sloughs, relationships between historic flows and EC were developed for various intervals. For Salt Slough, relationships were developed for each month (Figure 9.7). For Mud Slough, one relationship was determined for the March-August period and individual relationships for other months (Figure 9.8). These relationships are based upon data collected by USGS from January 1997 through October 2000. The equations generated are presented in Table 9.1.

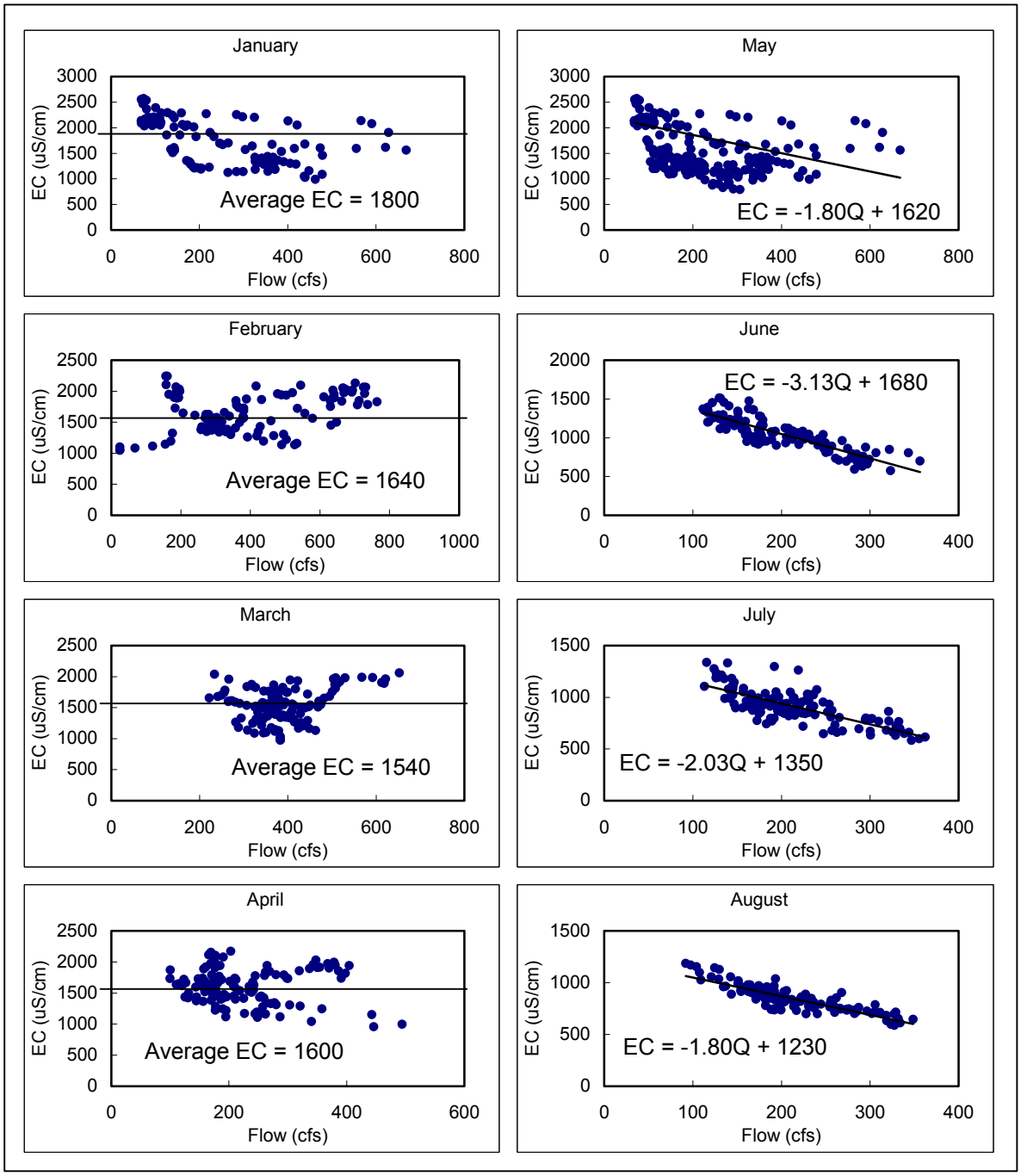

Figure 9.7: Salt Slough, EC vs. Flow.

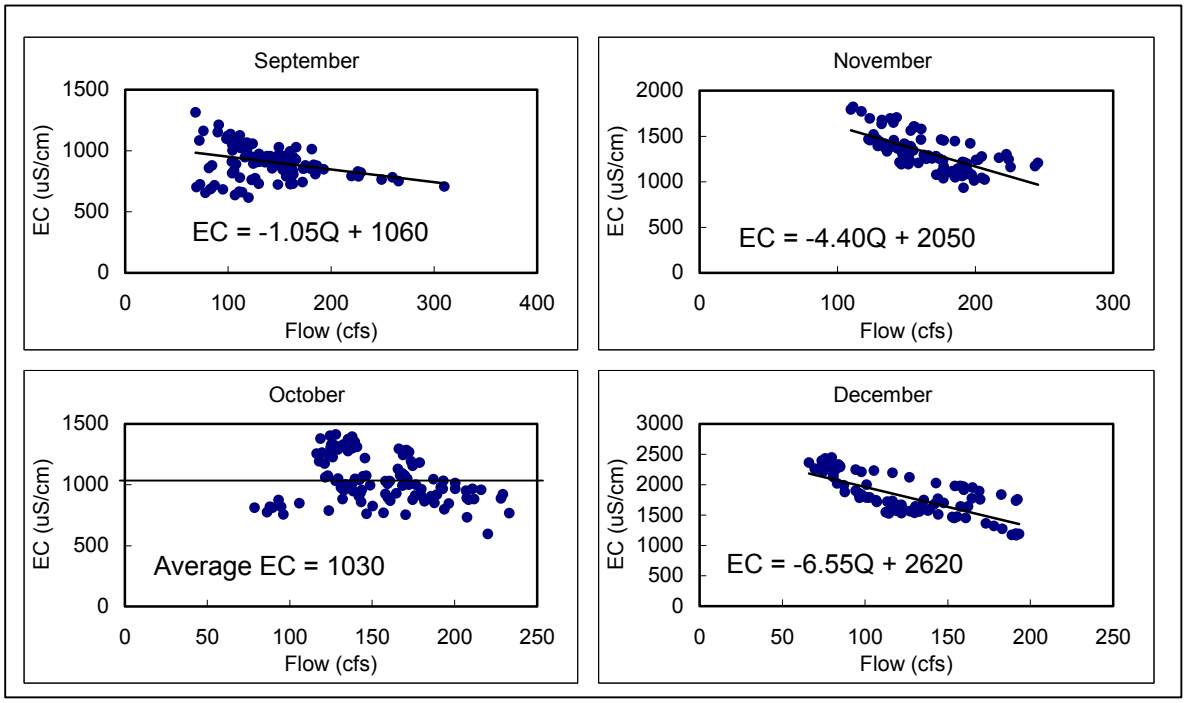

Figure 9.7 (cont.): Salt Slough, EC vs. Flow.

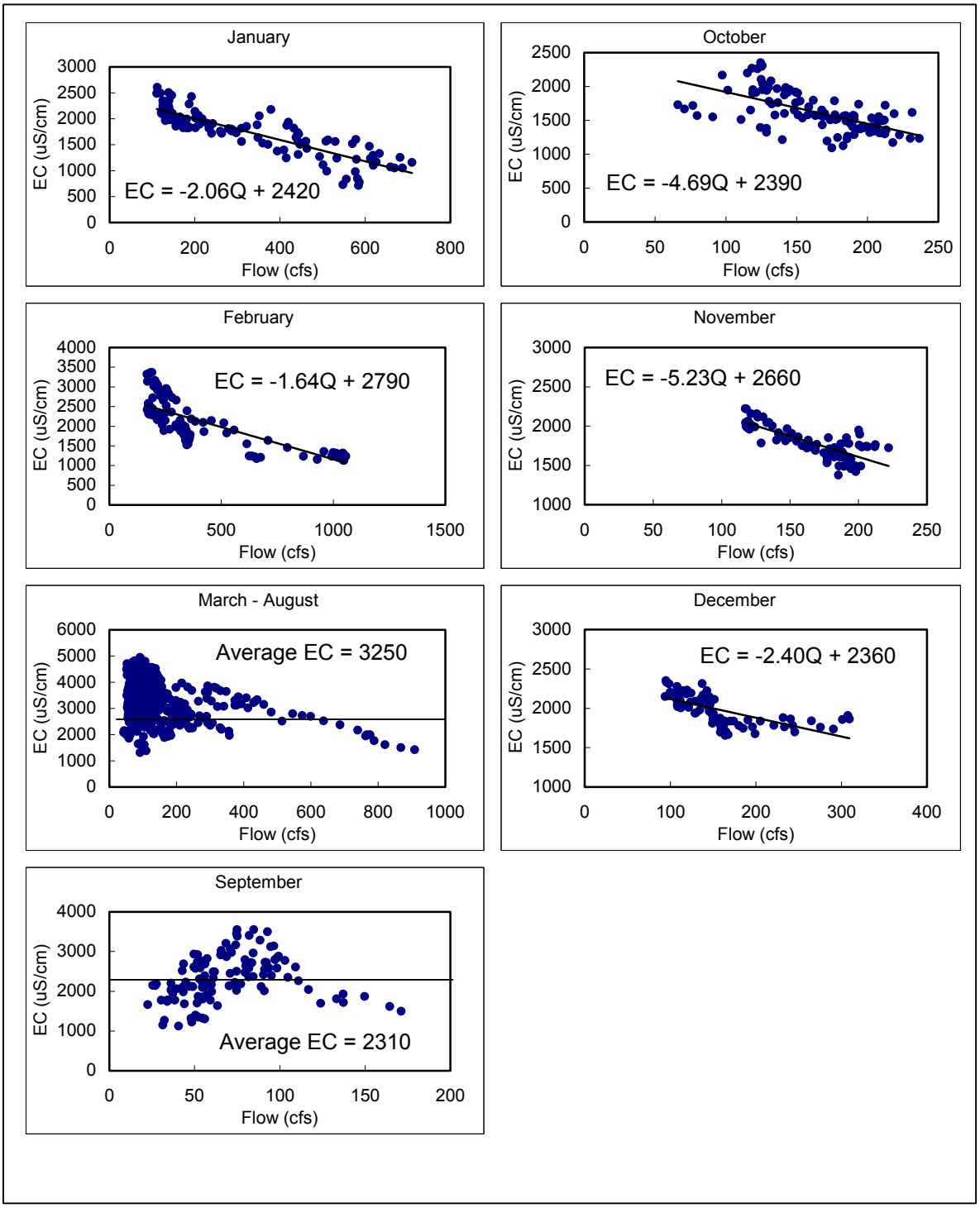

Figure 9.8: Mud Slough, EC vs. Flow.

9.7 EC in Westside Agriculture Return Flow

The agriculture return flow from the westside has three components: runoff from applied DMC water, runoff from riparian diversions, and runoff from applied groundwater. The EC in each source is estimated before the water is applied. The monthly average EC for the applied DMC water is provided by DSM2 from a previous simulation that reports the EC at DMC intake. The monthly average EC for the source of riparian water is derived by using a gross mass balance to estimate EC in the San Joaquin River at each point of modeled diversion. The time-constant EC in applied groundwater is provided by SJRIO, which varies the values along the reach of the San Joaquin River.

The accumulation of salts in each source of applied water is then modeled by increasing the EC according to Table 9.2. The EC added is the same regardless of source and does not vary from year to year. In DSM2, the three sources of westside agriculture drainage are combined and inserted at specific model nodes. The end result of this process is a monthly changing EC pattern for combined westside agriculture drainage that varies from 1,774 to 2,710 uS/cm over the 16-year sequence as shown in Figure 9.9.

Table 9.2: EC Added to Applied Agricultural Water before Modeling Accumulated Salts.

Period	Added EC (uS/cm)
October-February	1650
March-July	1500
August-September	1480

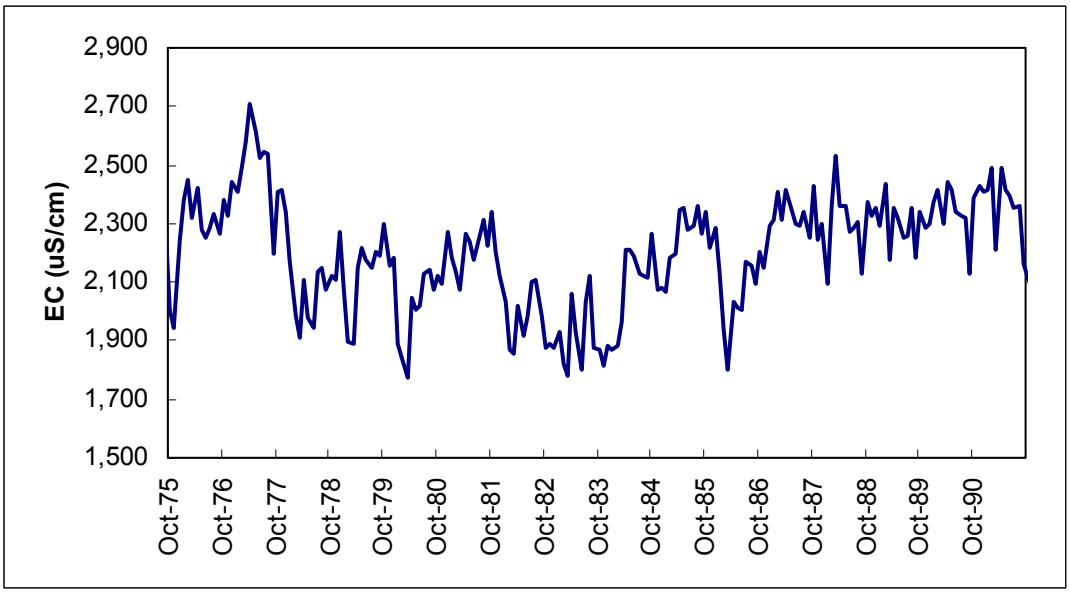

Figure 9.9: Combined EC for Westside Agricultural Return Flow.

9.8 EC in Eastside Drainage

The EC in eastside drainage was calculated from flow-salinity relationships embedded in CALSIM. These relationships do not vary by year and are expressed as:

$EC=7377.8Q^{0.4432}$ March-September

$EC=36273Q^{0.6507}$ October-February

where EC is in uS/cm and EC < 9,000 uS/cm
Q is monthly average flow in cfs

9.9 EC in Groundwater Flows

EC in groundwater flow is assigned to base flow and tile drainage. The EC values vary by reach in the San Joaquin River, but are constant for all months for all years (Figure 9.10). These values are based upon values in SJRIO with some minor modifications to better reproduce observed EC at Vernalis.

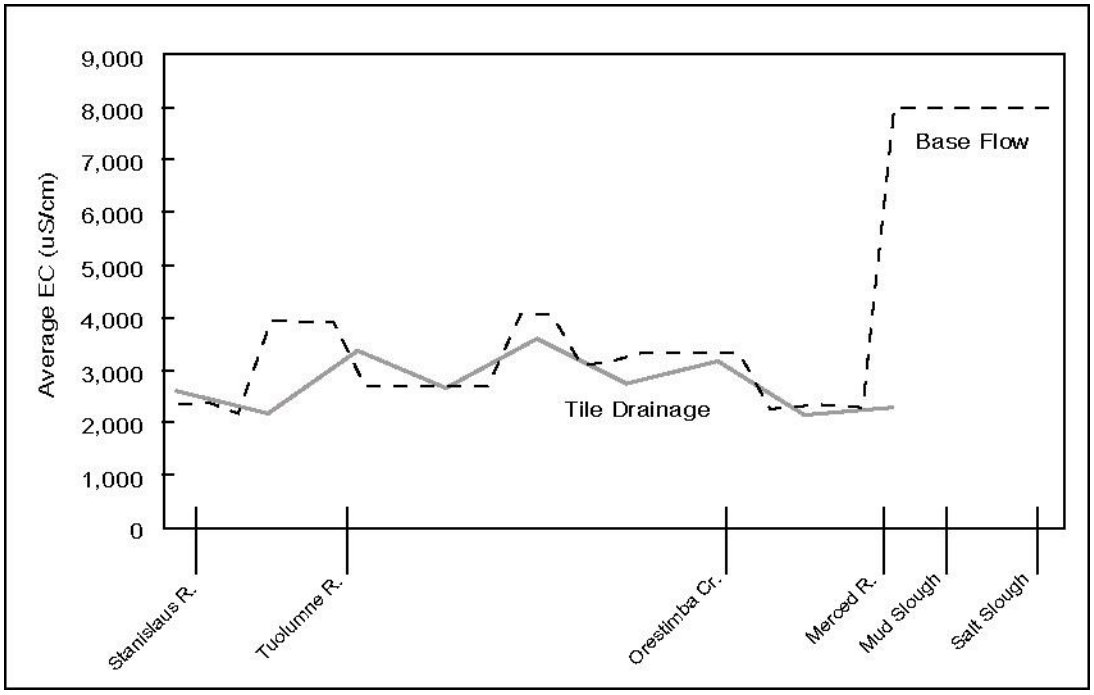

Figure 9.10: EC in Groundwater Flows to the San Joaquin River.

9.10 References

Montgomery Watson Harza. (2002). *Linking CALSIM and DSM2-SJR for Delta Mendota Canal Recirculation Study*. Technical Memorandum. Montgomery Watson Harza.

Pate, T. (2001). "Chapter 5: DSM2 San Joaquin River Boundary Extension." *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Acronyms and Abbreviations

1D – 1-dimensional
2D – 2-dimensional
3D – 3-dimensional
ACTS – Advanced Computational Testing and Simulations
ADCP – Acoustic Doppler Current Profiler
ADICU – Adjusted Delta Island Consumptive Use
AMR – Adaptive Mesh Refinement
API – Application Programming Interfaces
ARC-HYDRO – database designed to store hydrologic information
BOD – Biochemical Oxygen Demand
CALSIM – California Water Resources Simulation Model
CALSIM II – California Water Resources Simulation Model II
CALVIN – (CALifornia Value Integrated Network) U.C. Davis Economic Water Resources Optimization Model
cfs – cubic feet per second
DES – Division of Environmental Services (part of DWR)
DICU – Delta Island Consumptive Use Model
DMC – Delta Mendota Canal
DO – Dissolved Oxygen
DOC – Dissolved Organic Carbon
DSM2 – Delta Simulation Model 2
DSS – HEC's Data Storage System
DWR – California Department of Water Resources
DWRSIM – DWR's Monthly Operations Optimization Model (Predecessor to CALSIM)
DWSC – Stockton Deep Water Ship Channel
DYRESM – Dynamic Reservoir Model
EC – Electrical Conductivity
EIR/EIS -- Environmental Impact Report / Environmental Impact Statement
EPA – U.S. Environmental Protection Agency
FEM – Finite Element Methods
FVM – Finite Volume Methods
GIS – Geographic Information System
GUI – Graphical User Interface
HDF5 – file format for saving data
HEC – USACE Hydrologic Engineering Center
HYDRO – DSM2 Hydrodynamics Model
IEP – Interagency Ecological Program
ISI – Integrated Storage Investigation (part of DWR)
ISI-IDS – ISI In-Delta Storage Program
LBL – Lawrence Berkeley Laboratories
MIDS – Morrow Island Distribution System
MIKE – Danish Hydrology Institute's multi-dimensional hydrodynamic and water quality models
MWQI – Municipal Water Quality Investigations
NDO – Net Delta Outflow
NOAA – National Oceanic and Atmospheric Administration
PTM – DSM2 Particle Tracking Model
QUAL – DSM2 Water Quality Model
REALM – River, Estuary, and Land Model
RKI – River Kilometer Index
RMA – multi-dimensional hydrodynamic and water quality finite element models
RRI – Rough and Ready Island

SDIP – South Delta Improvements Program

SGT – Scientific Graphics Toolkit

SJR – San Joaquin River

SJRIO – San Joaquin River Input-Output Model

SMARTS – Special Multipurpose Research and Technology Station

SPAWAR – Space and Naval Warfare Systems Command

TAF – thousand acre-feet

TDF – Through Delta Facility

TMDL – Total Maximum Daily Load

TRIM2D – USGS and SPAWAR 2D, depth-averaged, finite-difference hydrodynamic model

TRIM3D – USGS and SPAWAR 3D, depth-averaged, finite-difference hydrodynamic model

USACE – U.S. Army Corps of Engineers

USGS – U.S. Geological Survey

VTools – time series visualization tool (under development)