Proposed Uses of DWSC Water Quality Models during Implementation of the San Joaquin River Dissolved Oxygen Total Maximum Daily Load

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Acronyms and Abbreviations

BOD	biochemical oxygen demand
CBDA	California Bay-Delta Authority
CBOD	carbonaceous biochemical oxygen demand
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
DO	Dissolved Oxygen
DWR	California Department of Water Resources
DWSC	Stockton Deep Water Ship Channel
GORT	Gate Operations Review Team
GUI	graphical user-interface
mg/l	milligrams per liter
msl	mean sea level
NH_3	ammonia
NPDES	National Pollutant Discharge Elimination System
RMA	Resources Management Associates
RRI	Rough & Ready Island
RWCF	Regional Wastewater Control Facility
RWQCB	Central Valley Regional Water Quality Control Board
SOD	sediment oxygen demand
State Water Board	State Water Resources Control Board
SWP	State Water Project
TMDL	Total Maximum Daily Load
TWG	Technical Work Group
USGS	U.S. Geological Survey
UVM	Ultrasonic Velocity Meter
VSS	volatile suspended solids
WARMF	Watershed Analysis Risk Assessment Framework

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Introduction

The Central Valley Regional Water Quality Control Board (RWQCB) Control Program for the San Joaquin River Dissolved Oxygen (DO) Total Maximum Daily Load (TMDL) requires that those responsible for the loads of biochemical oxygen demand (BOD) and nutrients that may stimulate algae growth in the San Joaquin River perform studies to evaluate the impacts of these source loads on DO in the Stockton Deep Water Ship Channel (DWSC). Water quality modeling is considered to be a necessary ingredient for these studies and evaluations. At least five water quality models of the DWSC have been developed in recent years and may be available for various comparative evaluations and investigations related to the low DO management activities.

A modeling plan is needed to guide the use of these models in the general tasks of integrating and interpreting the available field data from the San Joaquin River and the DWSC, as well as for evaluating various management alternatives and adaptive monitoring efforts. Examples of these general modeling purposes will be described, and the capabilities of the available models for achieving several specific modeling purposes will be discussed. The general modeling purposes can be classified as model calibration to match field data, model sensitivity to the major water quality processes within the DWSC, and model evaluation of the effects and consequences of various management options. Modeling is likely the best method available to separate the effects from multiple sources and processes in the DWSC and compare the effects and consequences of alternative management strategies.

Because there are several models that may be used, a comparison of the model capabilities may be useful. Each model is likely to have similarities to others, but with specific strengths and weaknesses. Because all models are likely to be "data-limited" in the sense that many model inputs and coefficients must be assumed or estimated from the same set of limited field data, a direct comparison of model accuracy and reliability may be difficult. The modeling plan will review the DWSC models generally, but will not compare the models for accuracy or reliability. The ability to easily access the models and make changes and comparative simulations will be described.

After reviewing the available models, and introducing the general uses for water quality models, ten potential categories of DWSC water quality modeling studies are described, and uses are suggested. Potential need for additional model features (model development) or field studies to identify missing processes and measure important rates and relationships within the DWSC (calibration data) will be described. This basic modeling plan should be used to guide modeling of the DWSC as an integral component of the DO TMDL Implementation Plan.

The basic sections of the DWSC modeling plan will:

- Summarize the capabilities of available water quality models. These include the DSM2-QUAL, the Systech link-node, the HydroQual 3-D, and the UCD/USGS/Stanford 3-D (under development). Major categories of model features are the user-interface for specifying inputs and displaying results, the geometry, the tidal hydraulics and physical mixing processes, the water quality variables and biochemical processes, and the range of conditions used for calibration.
- Identify various water quality modeling needs (uses) for future DWSC DO studies and evaluations. The basic uses can be classified as calibration, sensitivity to uncertain inputs and processes, and simulation of alternative management actions.
- Propose a plan for the future use of available models to address the identified future needs for modeling to support the DO TMDL investigations and implementations of management actions. Some future management actions that might be evaluated with modeling are the aeration/oxygenation facilities, the nitrification/treatment of the Stockton Regional Wastewater Control Facility (RWCF) discharge, the tidal gate at the head of Old River, upstream salinity management, and dredging or flow bypass options (Burns Cut).

This report has been written on a relatively short timeframe, but the current modeling group (California Department of Water Resources [DWR], LBL, Systech, Jones & Stokes) for the upstream monitoring and investigations project have been consulted. The current model development groups (HydroQual and UCD/USGS/Stanford) have been contacted for their ideas and suggestions. Other members of the Technical Work Group (TWG) who have been involved in previous DWSC modeling and measurements have been interviewed for their ideas about future modeling purposes and uses. A draft of the modeling plan was prepared for the May 16 TWG meeting, which was dedicated to modeling issues. This draft has been prepared incorporating the comments or suggestions received from the TWG members by the end of May 2006. The PowerPoint presentation given by Russ Brown at the May 16, 2006, TWG meeting is attached to this report as Appendix B.

The overall purpose of this report is to stimulate discussion among TWG members about future DWSC modeling. This paper is merely an introduction to more thorough development and refinement of modeling purposes and procedures. It provides a motivational bridge between the capable and energetic leadership support of Mark Gowdy (RWQCB) and Barbara Marcotte (California Bay-Delta Authority [CBDA]) and future staff and TWG members who will continue their dedicated and successful efforts to resolve this water quality and fish habitat restoration problem.

General Purposes of Water Quality Models

The basic model uses of water quality models can be classified as calibration, sensitivity to uncertain inputs and processes, and comparative simulation of alternative management actions. Calibrated models may be generally useful in several ways and can become more useful when applied according to a logical plan of comparative study rather than run randomly or intermittently. Models should be used iteratively and indefinitely as part of the adaptive management and environmental monitoring process.

Models serve to increase the information content of field data and monitoring records to improve the management of habitat or water quality conditions necessary for aquatic organisms. Modeling in this general sense is used as an information tool. Monitoring without model interpretation and integration may provide data but little useful information. Measurements with model interpretation of the results should be used to check original expectations and provide performance assessments and evaluations for future actions. Water quality models are an important component of the adaptive management of natural resources, as illustrated in Figure 1. Environmental planning requires looking ahead to avoid or mitigate environmental impacts. First, a general model of the water body is necessary to interpret and integrate the available field data and monitoring records. Management decisions can then be based on the modeled comparison of a series of alternatives. The alternative with the most promising performance and with the least environmental effects on other resources likely would be selected for implementation.

The ultimate purpose of developing and calibrating a water quality model of the DWSC is to allow reliable simulations of management alternatives. These comparative simulations can be used in a planning (i.e., future conditions) framework, or as part of an adaptive management (i.e., interactive) framework, as shown in Figure 1. Specifically, models can act like a microscope or telescope to focus attention on those aspects of the DWSC DO dynamics that are most important or more likely to provide the desired increase in measured DO concentrations. Models can be used as “dynamic hypothesis testers” to scrutinize the observed data and validate or adjust understanding of the physical and biochemical processes and variables that influence DO in the DWSC.

Previous Models of Dissolved Oxygen in the DWSC

At least five water quality models have been developed for the DWSC to evaluate the causes of low DO conditions. A short review of the development and application of each of these models will introduce the concepts of model formulation (i.e., geometry, flows, processes, variables), model calibration, model sensitivity, and management evaluations.

Resources Management Associates Link-Node Model

The first documented application of a water quality model of the DWSC was a link-node (i.e., mixed volume elements) tidal model developed by Resources Management Associates (RMA) for the Sacramento District U.S. Army Corps of Engineers (Corps) to investigate likely changes in DO concentrations in the DWSC resulting from the dredging of the channel to a depth of about 35 feet below mean sea level (msl). It was anticipated by the Corps that deepening of the DWSC by about 5 feet could have a potential negative effect on the DO concentrations. This development and application were documented in a technical report (Resources Management Associates 1988) and a Sacramento District office report (U.S. Army Corps of Engineers 1988).

RMA developed a link-node tidal hydraulic model of the Delta channels to allow the tidal mixing and transport as well as the water quality in the DWSC to be simulated. The objectives were to develop and calibrate a water quality model that would match observed DO conditions for 1-month periods in the fall of 1974 and 1978. The model had about 25 nodes between Mossdale (head of Old River) and Turner Cut (10 nodes between the turning basin and Turner Cut). The Delta tidal model extended to Antioch and used daily inflows provided in the DWR DAYFLOW database. Flows in the DWSC in the fall of both years were estimated to be high. A barrier at the head of Old River was installed in 1974, with estimated DWSC flows of about 1,500 cubic feet per second (cfs); State Water Project (SWP) pumping was moderate in fall 1978, with estimated DWSC flows of about 1,000 cfs.

The general goals for the calibrated model were to examine the effects of channel deepening from 30 to 35 feet on DO, and determine the most sensitive factors affecting DO. The initial model calibration was judged “good agreement with the DO data.” The most sensitive factors were algae growth and respiration, BOD and detritus decay. A maximum decline of 0.5 milligrams per liter (mg/l) was simulated from channel deepening; the consequence of increased residence time and reduced reaeration (from greater depth) and increased algal respiration (from reduced ratio of euphotic depth to total depth).

A second phase of modeling was conducted to refine these general results and apply the model to a wider range of conditions. The goal was to determine the amount of aeration that would be needed to offset the effects of the channel deepening on DO. Seven validation cases (including the two already calibrated) were simulated, each for about a 1-month period. Model coefficients were adjusted and used for all simulation periods. For example, the sediment oxygen demand (SOD) was set at 1 g/m^2/day. The light extinction was held constant, with 1% light level at 5 feet, equivalent to an extinction coefficient of about 1.0 ft^{-1}. The RMA model included detritus, BOD, SOD, ammonia, and two algae biomass variables (with different growth, respiration, and settling rates). Thirty-three coefficients were specified, and inflow concentrations were specified for each period. City of Stockton treated wastewater was added. Some periods were before tertiary treatment (begun in 1979) with high ammonia, BOD, and detritus values.

The minimum DO values were matched reasonably well, with minimum DO of about 2 mg/l observed between San Joaquin River miles 30 and 40 (channel point) in several low-flow years. The model results matched most days of observed longitudinal DO (DWR boat surveys or City of Stockton data) within 1–2 mg/l. The location of the DO sag was moved downstream with higher flow, and was generally less severe. However, the simulated response to the closure of the head of Old River gate (i.e., increased flow) was greater than observed data indicated.

A series of comparisons was made with a channel depth of 30 feet and 35 feet to determine the simulated effect on the minimum DO. At relatively low flows, the DO reduction from deepening was about 0.5 mg/l. At higher flows, the minimum DO location moved downstream, and the DO reduction from deepening was about 0.2 mg/l. However, it was determined that the amount of oxygen needed to compensate for the deepening was greater for the higher flows. A maximum of 2,500 lbs/day was determined to be required for the 1979 period, with a flow of about 1,500 cfs. This estimate was used as the design for the mitigation aeration facility, which was constructed by the Corps in 1993.

Don Smith (the model developer), who still works for RMA, should be congratulated on this initial DWSC modeling effort, conducted 20 years ago. The importance of net flows and accurate inflow concentrations for calibration, the effects of the channel depth and model coefficients on simulated DO, and the possibility of aeration and head of Old River flow controls were all explored. This is a good example of systematic model development, calibration, application, and recommendations for specific additional data collection. A management action was implemented (Corps/Port aeration device) for mitigation of the effects from deepening the DWSC, based on these model studies.

City of Stockton (Systech) Link-Node Model

A second link-node model of the DWSC was developed by Systech for the City of Stockton, to assist the City in preparing for their National Pollutant Discharge Elimination System (NPDES) discharge permit renewal from the RWQCB (Philip Williams and Associates 1993). The model also extends from the head of Old River to downstream of Turner Cut. Ten model segments were used between the turning basin and Turner Cut. The tidal embayments (i.e., Smith

Canal, Calaveras River Channel) near Stockton were included in the model. Daily DWSC flows and inflow concentrations, as well as daily Stockton RWCF discharge and effluent concentrations were used. The model was calibrated with 1990 and 1991 data collected by the City of Stockton. It was later verified with 1993 and 1996 data during the NPDES renewal applications.

The model was used to simulate the responses of ammonia concentrations (i.e., toxicity) and DO in the DWSC to various scenarios of Stockton RWCF effluent discharge. The model demonstrated the importance of upstream river flow and upstream river load of algae and carbonaceous biochemical oxygen demand (CBOD) for estimating the DO in the DWSC. Without accurate flow data, the model could not match the observed DO in DWSC. These model results confirmed the need for the installation of the U.S. Geological Survey (USGS) Ultrasonic Velocity Meter (UVM) tidal flow station near the Stockton outfall (Garwood Bridge) in 1996.

The City of Stockton model was used to provide several comparisons of RWCF effluent effects for the NPDES permit renewal application. The elimination of BOD and ammonia from the Stockton RWCF discharge alone could not meet the DO objective, because of the large river loads of oxygen-consuming materials. This model result led to the subsequent TMDL studies that evaluated the effects of upstream river conditions, Stockton RWCF discharges, and the DWSC geometry on DO in the DWSC. The model was used to evaluate alternative flow management strategies for improving low DO in the DWSC. Increasing the river flow from 250 to 1,000 cfs was found to eliminate the predicted DO deficit (Chen 1997). The model was also used to evaluate various aeration alternatives in the DWSC at flows of 0 cfs, 500 cfs, and 1,000 cfs.

The City of Stockton model was used to integrate and interpret more intensive DWSC data collected in 1999, 2000, and 2001 as part of two CALFED grants. In addition to DO, CBOD, nutrients (ammonia, nitrate, and phosphorus) and algae biomass, the model variable list was expanded to include detritus (measured as volatile suspended solids [VSS]) and phaeophytin (representing dead algae biomass). Wind-driven reaeration was added. Settling and resuspension of detritus (VSS) and inorganic sediment was added. Model changes were made to track and output the daily fluxes of various processes that contribute to the sinks or sources of DO (i.e., mass-balance terms). Only minor adjustments in the coefficients were needed to match the field data for 1999, 2000, and 2001. The model calibrations for temperature and concentrations of several water quality constituents were reasonably good as documented in the report (Chen and Tsai 2002). This report, available on the DO-TMDL website, provides a good introduction to DO modeling of the DWSC. The model was peer-reviewed by EPA staff and a CALFED review panel.

Sensitivity was performed with the model to evaluate the impact of a parameter value on the cumulative index of the predicted DO deficit (load) below 5 mg/l for the entire year. For example, a 5% change in the decay coefficients for nitrification and BOD decay produced a 5% to 10% change in the predicted DO deficit. A 5% change in the detritus decay produced a 20% change in the DO deficit, because there was more detritus in the river loads. A small change in the temperature adjustment factors produced a 35% to 70% change in the predicted DO deficit. A 5% change in flow produced a 15% change in the predicted deficit. A 5% increase in river algae load increased the DO deficit by 50%. A 5% decrease in river algae load can decrease the DO deficit by 35%. A 5% change in the Stockton RWCF load changed the DO deficit by 5%. Sensitivity is related to the baseline conditions; the dominant factors may shift between time periods.

The process of estimating daily inflow concentrations for the San Joaquin River illustrated the importance of frequent river measurements. The infrequent (bi-weekly or monthly) river concentration data was thought to be a major reason for model's inability to accurately capture some of the episodic low DO concentrations observed in the DWSC. To reduce the model uncertainty, it would be necessary to collect more frequent river measurements. Carl Chen (model developer) has remained active in the DO TMDL technical work group and participates in the upstream modeling team. The City of Stockton model is currently used as part of the Watershed Analysis Risk Management Framework (WARMF) model and user-interface for the San Joaquin River and DWSC.

DWR DSM2-QUAL Model

A third water quality model of the DWSC (and the entire Delta) is the DSM2-QUAL model developed by DWR. Hari Rajbhandari performed his Ph.D. research/thesis on adding a DO-BOD and nutrient-algae growth model to the DSM2 tidal hydraulic model. The DSM2 model is a link-node tidal hydraulic model, but the water quality calculations are made using a lagrangian (i.e., moving parcels) framework. This model is fully mixed vertically within each parcel and uses about the same variables as the two link-node models. The DSM2-QUAL uses many of the water quality variables and rate coefficients from the EPA River model, QUAL2K (latest version name). The DO model was documented in his thesis (Rajbhandari 1995) and in several chapters in the annual reports of the DWR Delta modeling section to the State Water Resources Control Board (State Water Board) on methodology for flow and salinity estimates in the Bay-Delta.

The DSM2-QUAL DO model has been applied for the 1996–2000 period. It has been calibrated with the hourly temperature and DO data from the Rough & Ready Island (RRI) station, using the Mossdale DO measurements as input. During calibration, it was sometimes hard to match the daily DO range; emphasis was placed on getting the minimum DO pattern to match the field data. However, model output was examined to verify some other data (chlorophyll, BOD, and ammonia [NH_3]) that are available on a weekly or biweekly basis at some nearby stations (i.e., City of Stockton or DWR data). The seasonal match with the RRI minimum DO data is reasonable, and similar to the match for the link-node models. The DSM2 model has not been used to evaluate flow changes or other management adjustment.

An advantage for the DSM2-QUAL model is that the tidal hydraulics are calculated for the entire Delta with the DSM2-HYDRO module. All of the other DWSC models require that the tidal flows below the head of Old River be specified; these are generally determined by first running the DSM2-Hydro module. Simulations for the 5-year period (1996–2000) included a wide range of flows and river loading conditions. The 1999 and 2000 conditions correspond to simulation periods for the City of Stockton model. Results have not been directly compared, nor have the coefficient or river and RWCF loading estimates been compared.

HydroQual 3-D Model (ECOMSED/RCA)

A fourth DWSC model was developed by HydroQual under a CALFED (CBDA) contract. They have just submitted their final report for the DWSC modeling task (HydroQual 2006). The objective of this model was to improve on the fully mixed link-node model results and allow the diurnal stratification and resulting surface DO increases from aeration and algal photosynthesis to be simulated. HydroQual used their standard 3-D estuary tidal hydraulic model, called ECOMSED. The model extended from Vernalis to Jersey Point. Ten vertical layers are simulated, and three lateral elements are specified within the DWSC. There were several tidal boundaries in their 3-D grid, so they used the hourly tidal stage and flow results from the DSM2-HYDRO tidal hydraulic model of the entire Delta for boundary conditions. The good matches with the DSM2-HYDRO tidal stages and tidal flows (used as inputs) were not surprising. A good match with the USGS Garwood station tidal flows was also expected, because the DSM2 tidal flows at the head of Old River were used as tidal boundary flows. However, they found that the DSM2 flows for the DWSC were considerably lower than the measured flows, and the Old River diversions had to be adjusted.

Potential new results from the 3-D ECOMSED tidal flow model might be a more accurate vertical distribution of tidal flows, and diurnal temperature stratification and tidal mixing patterns. However, there are only limited periods when stratification measurements have been collected (i.e., summer 2002) and HydroQual ran their model for 2000 and 2001, but not 2002. They have not provided comparisons with the hourly temperatures or DO measurements from the Mossdale or RRI stations. The ECOMSED model predicted a diurnal stratification of 1–2°C in July and August, but a discussion of how this stratification might affect DO was not given. The closest to a vertical DO calibration for the RRI station was Figure 30-C, showing the surface and bottom model result compared with the surface and mid-depth data from the City of Stockton's R5 station. The simulated surface and bottom DO concentrations were within 1 mg/l, and the simulated diurnal DO variation was less than 2 mg/l. This does not appear to match the surface DO monitoring at RRI, which often has a 3–4 mg/l diurnal variation.

The water quality model (RCA) is a combination of a eutrophication model (i.e., nutrients-light-algae) and an SOD model. The SOD rate is estimated from the flux of organic material deposition onto the bottom sediment, which is an assumed fraction of the detritus and algae in the DWSC. The RCA model is based on previous estuary modeling for Long Island Sound, Massachusetts Bay, and Chesapeake Bay. There are about 25 variables in the water column, including three algae groups, detritus, and organic matter variables split into refractory (slow decay), labile (moderate decay), and reactive (rapid decay) components for nitrogen, carbon, and phosphorus. The advantage of splitting variables into the chemical components by reaction rates (which are not measured) is not described.

Many new model parameters are needed to track the aerobic and anaerobic chemistry in the sediment layer, but no measurements for calibrating these assumed concentrations or chemical processes and fluxes. The only calibration described is a comparison of the calculated SOD rates with general values measured in other estuaries (maximum of about 1 g/m^2/day). The RCA model calculates the release of ammonia and phosphate, as well as the uptake of NO_3 by the sediments; however, these have very small effects on the relatively high nutrient concentrations in the DWSC. Resuspension of material from the bottom of the DWSC is not simulated in the RCA model.

The ECOMSED/RCA model was used to calibrate with 2000 and 2001 DWSC data. HydroQual presumably will demonstrate the ability of the model to evaluate different management conditions in the final task of their CALFED project.

University of California, Davis/Stanford/USGS Model

A fifth model is under development by USGS, University of California, Davis (UC Davis), and Stanford. This model development is also supported by a CALFED grant that included extensive data collection efforts in August 2004 and August 2005. These field data captured periods of stratification and water quality gradients (longitudinal, lateral, vertical) observed in the DWSC.

A 20-meter-grid hydrodynamic model is being applied by USGS, with 1-m depth elements. This allows the DWSC to be divided into approximately 80,000 volume elements (10 layers x 10 lateral elements x 10 miles x 80 segments/mile). Although the only continuous tidal flow measurements are collected at the USGS Garwood station near the RWCF discharge (upstream of the DWSC), the data collection efforts included tidal flow measurements (i.e., ADCP) at additional locations during the 1-month data collection periods. The hydrodynamic model is detailed enough to simulate the effects of flow eddies on lateral and longitudinal mixing and the effects of vertical stratification on the vertical flows and mixing processes.

The water quality calculations will be made using the same computational grid. Stratification and non-uniform vertical or lateral flow conditions might be simulated with this new model, but it seems like a lot of calculations for so few measurements. Calibration for the two intensive field study periods may be more challenging. There are some run-time issues (i.e., computer time required for a12-month simulation) related to using the model for a range of seasonal management options. This model might end up being more of a research tool to investigate extreme events or specific conditions in the DWSC.

Other Deep Water Ship Channel Dissolved Oxygen Models

Other models have been used to evaluate DO conditions in the DWSC. For example, a statistical model of the DO conditions as a function of the Vernalis and Mossdale river concentrations of algae, and the Stockton RWCF ammonia loads was developed (Jassby and Van Nieuwenhuyse 2005) from the historical monthly water quality samples collected by DWR at Vernalis, Mossdale, and Buckley Cove (located downstream of the RRI DO monitor). An application of the Streeter-Phelps Flow-BOD-DO model was included in the RWQCB staff report for the DO TMDL (Foe et al. 2002). A monthly mass-balance loading “box model” was included in the San Joaquin River DO Synthesis report (Lee and Jones-Lee 2002).

Suggested Water Quality Model Uses

This section identifies various general and specific uses of water quality modeling for future DWSC DO studies and evaluations. The basic model uses can be classified as calibration, sensitivity to uncertain inputs and processes, and comparative simulation of alternative management actions. Any particular series of comparative model results will likely provide information that may be hard to classify, but will certainly improve understanding of the DWSC and increase confidence in adaptive management decisions. One of the general recommendations from this review of DWSC models is that they should be "moved" from research tools to more general stakeholder applications, by providing direct access through a graphical user-interface (GUI) to the modeling data, assumptions (coefficients), and results.

Calibration

The ability of a model to match measurements for a range of variables is the primary method for testing the accuracy and completeness of a model formulation. A model that adequately simulates a wide the range of conditions can be used confidently for a comprehensive range of applications. Useful information can be obtained from simulating periods when the model results do not match the observed data, suggesting that inflows are not estimated correctly, or that variables are missing from the model, or that processes are not calibrated or linked properly.

One very important but often neglected step in model calibration is the estimation of model inputs that will "drive" the simulation results. The major inputs for a DWSC water quality model are the San Joaquin River flows, river concentrations of each model variable, and the RWCF discharge and effluent concentration for each modeled variable.

Sensitivity

Sensitivity studies involve systematic variations in the assumed model coefficients, inflow concentrations, RWCF effluent concentrations/loads, or river flows. Some sensitivity results for the summer of 2000 simulations of the DO deficit in the DWSC using the City of Stockton model have been reported (Chen and Tsai 2002). The following general suggestions for sensitivity studies could apply to any of the DWSC water quality models. Sensitivity studies involve two selected variables: the input or coefficient being changed, and the model result (output) being compared. The baseline conditions for the time period selected for sensitivity studies will control the sensitivity results. Possible sensitivity studies may therefore appear to be endless; careful selection of the modeling cases is needed to provide efficient and comprehensible sensitivity results.

One of the previous CALFED grant reports, "Evaluation of Stockton DWSC Water Quality Model Simulation of 2001 Conditions: Loading Estimates and Model Sensitivity," investigated the calibration and sensitivity of the improved City of Stockton Water Quality model. This previous report (attached as an appendix) describes the stepwise estimation of river flows, river concentrations, and RWCF concentrations for each modeled variable, as well as the comparison of field data with model results. It also shows comparative results from a series of sensitivity simulations used to evaluate the estimated model inputs and coefficients for 2001. Review of this previous report (appendix) may improve the reader's understanding of the following suggestions for uses of DWSC water quality modeling during the DO-TMDL implementation.

The sensitivity of each model input can be evaluated, although it is generally recognized that a few inputs are most important for changing the DO simulations. River flow, algae biomass, detritus, CBOD, and ammonia have the greatest impact on DO concentrations in the DWSC. A seasonal simulation will normally show that sensitivity is greatest during the warmest periods, which correspond to the highest algae biomass.

Secondary sensitivities can be investigated to better understand the primary sensitivity to algae biomass, for example. The effects of algae biomass may be less important if the light conditions in the DWSC allow relatively high algae growth. Higher algae decay will increase the sensitivity of DWSC DO to algae biomass. Although "everything affects everything else," there are dominant relationships that can be identified through these stepwise sensitivity studies.

Some of the physical and biochemical processes in the DWSC are important in determining sensitivity. The settling and resuspension of detritus (algae) and the reaeration rate are important physical processes that cannot be directly measured. The model itself may be the best method for estimating these processes. Sensitivity can help select an appropriate coefficient.

Because nutrients are so high in the San Joaquin River, particulate settling and light adsorption may be the most sensitive factors for algae growth in the DWSC. Diurnal stratification may reduce vertical mixing and allow algae to grow in the surface layer, while restricting the reaeration of the deeper water. The seasonal algae growth will be sensitive to temperature and solar energy variations, as influenced by the assumed mixing depth, light extinction coefficient, and growth rate light-limitation curve.

Sometimes the sensitivity results can be shown for a matrix of simple cases. For example, the results of the model-calculated DWSC algae growth and decay rates for the range of light extinctions and inflow algae concentrations could be given in a table showing monthly average DO or algae biomass results through the season for a given flow. The contribution of algae growth in the DWSC can be evaluated by setting the growth rate to zero, while allowing algae settling and decay to continue.

Comparison of Management Alternatives

The ultimate purpose of developing and calibrating a water quality model of the DWSC is to allow reliable simulations of management alternatives. These comparative simulations can be used in a planning (i.e., future conditions) framework, or as part of an adaptive management (i.e., interactive) framework, as shown in Figure 1.

Flow management options might be explored with a systematic comparison of constant Stockton flows of 250 cfs, 500 cfs, 750 cfs, and 1,000 cfs. This will generally indicate the importance of increased flow; however, the results would depend on the river concentrations assumed.

The City of Stockton is implementing nitrification facilities this summer (2006). So next fall and winter ammonia concentrations will be reduced, with RWCF effluent concentration of only 2 mg/l NH_3-N. The improvements in DO with this change in RWCF loads could be shown for each of the assumed constant flow cases, or shown in comparison with actual 2007 river conditions.

The oxygenation device is under construction and is expected to be operational in the spring of 2007. It is designed to add a maximum of 10,000 lb/day of dissolved oxygen into a side stream of 50 cfs pumped from the RRI monitoring station at a depth of 10 feet, and discharged at 40 mg/l above the ambient DO concentration through a diffuser located at a depth of 15 feet and about 1,000 feet upstream from the intake. The oxygenation device would be operated whenever the DO is less than 6 mg/l. Comparative simulations with and without the device would allow the performance of the device to be simulated and compared to actual operations and DO measurements. The effects for constant flows of 250 cfs, 500 cfs, 750 cfs, and 1000 cfs could also be compared.

River algae biomass is assumed to be the primary source of BOD into the DWSC. Evaluation of the effects of upstream controls on algae biomass could be based on systematic runs with summer algae and associated VSS BOD, and organic variables that are 50%, 100%, 150%, and 200% of those measured in 2001 (see Appendix).

DWSC Water Quality Modeling Plan

This section presents a preliminary plan for the future use of the available DWSC water quality models to support the DO-TMDL investigations and implementation of management actions. Some of the future management actions that might be evaluated and adaptively managed (i.e., operated) with modeling support are the aeration/oxygenation facilities, the nitrification/treatment of the Stockton RWCF discharge, operations of the tidal gate at the head of Old River (for DWSC flow management), upstream salinity management (and associated nutrients), and dredging or flow bypass options (Burns Cut).

Work developing and calibrating the upstream water quality model for the river and watershed upstream of Vernalis is ongoing. This model has been developed by Systech for other TMDL studies, and is called WARMF. The San Joaquin River model currently extends upstream to Lander Avenue. With continuing interest on restoration of the San Joaquin River below Friant Dam, the watershed and river water quality model could be extended upstream to Friant Dam. The San Joaquin River WARMF model includes the improved City of Stockton Water Quality Model. Obtaining a copy of the San Joaquin River WARMF is the easiest way for a stakeholder to obtain direct access to one of the DWSC water quality models. This modeling package includes a GUI that allows comparison graphs between two or more model runs, and calibration graphs of the field data. The WARMF model can be downloaded from the ftp site at:

ftp://systechengineering.com (username is sjriver, password is Vernalis).

The following ten categories of model simulations are recommended to the RWQCB staff and the San Joaquin River DO-TMDL TWG as they continue to work on San Joaquin River restoration investigations, water quality management, and DO-TMDL implementation activities.

(1) Historical Simulations of 1986–2005 and Beyond

A full set of daily flows and concentrations sufficient to produce annual simulations of the historical conditions in the DWSC for the previous 20 years should be prepared. (The DWR RRI DO monitoring began in 1986.) This will allow the full range of historical flows and RWCF loadings to be simulated with the calibrated models. This will require a consistent set of river water quality concentrations to be estimated and compared with the simulated DO concentrations. Water quality measurements may be limited for some years, however. For example, the USGS tidal flow measurements began in 1996. The San Joaquin River water quality data atlas provides a compilation of available data. Periods with extreme DO deficits (e.g., May 2004, February 2003) will provide the strongest test of the model ability to match measured DO concentrations.

Model inputs should be estimated for each new calendar year. The last year that was simulated with any of the DWSC water quality models was 2001. An updated historical simulation is being completed by DWR for each year with the Delta tidal hydraulic and EC model (DSM2). The DWSC modeling could use these tidal simulation results to supply the necessary tidal flow and tidal elevation boundary conditions.

Much can be learned from the periods of agreement as well as periods when the model results do not agree with the measured water quality conditions. The appendix provides an example of preparing the model inputs and conducting calibration and sensitivity for 2001.

(2) Sensitivity of Historical Simulations to Increased Deep Water Ship Channel River Flow (with Algae)

One of the "mysteries from the past" is the rather weak evidence from the DWR boat surveys that DO concentrations increase in response to increased flows, following the installation of the temporary rock weir at the head of Old River. The DWSC water quality model should be run with and without the barrier, for each year of historical record when a barrier was installed. For all years, a sequence of runs with increments of the Vernalis flow (i.e., 10%, 30%, 50%, 70%, and 90%) should be compared. Can the changes in DWSC DO be summarized or understood? Why has the response of DO to increased flow been relatively small—does the DO sag move downstream but with the same minimum DO? Is there an algae concentration that eliminates the DO benefit from higher DWSC flows?

(3) Sensitivity of Sun, Wind, and Tide on Stratification and Dissolved Oxygen in the Deep Water Ship Channel

The effects of solar energy, wind mixing, tidal flow, net flows, and geometry on the vertical temperature gradient and mixing processes (stratification) that affect algae growth, turbidity settling, and reaeration should be accurately modeled for the DWSC. This was one of the major goals for the 3-D model development by HydroQual and the UC Davis/USGS/Stanford team. The resulting differences in the vertical distribution of light, algae biomass, DO, and pH between the DWSC, the turning basin, and the downtown area (i.e., Weber Point blue-greens) should be reliably simulated (if the model formulations are adequate).

(4) Effects of Stockton RWCF Discharge on Dissolved Oxygen in the Deep Water Ship Channel

The DO conditions in the DWSC were extremely bad in the years prior to tertiary treatment (before 1979). BOD and VSS (algae) loads were much higher than current limits. The latest improvements in the RWCF processes are wetlands and nitrification towers (summer 2006). The effects of the RWCF effluent on DWSC DO should be simulated. Three additional cases could be run for each year; (a) secondary treatment (oxidation ponds) only, with no tertiary treatment (dissolved air flotation and filtering of algae), (b) nitrification to a maximum ammonia of 2 mg/l, and (c) complete elimination of the RWCF discharge.

It also might be interesting to see the comparison of the current discharge location and a discharge that enters the San Joaquin River at the downstream end of RRI (with a pipeline or by diverting the flow into Burns Cutoff). Are the tidal mixing and reaeration processes sufficiently different at this location that the DO sag would be substantially reduced?

(5) Effects of Reaeration and Oxygenation Devices on Dissolved Oxygen in the Deep Water Ship Channel

The effects of the Corps aeration facility on the San Joaquin River at channel point (now operated on an expanded schedule by the Port) and the DWR demonstration oxygen injection facility on RRI should be simulated. The tidal mixing of the additional DO and the ultimate improvement in the DWSC DO should be simulated. The planned demonstration monitoring at the two upstream and two downstream mid-depth stations, as well as the inflow (R2a—upstream of RRI bridge), will attempt to distinguish the DO increment produced by the oxygen injection. Model comparisons with and without the oxygen injection may be extremely helpful in the interpretation and evaluation of the efficiency of the device. The HydroQual model report included some examples of this type of performance modeling. Modeling might be used to interactively guide the operation of the oxygenation device, depending on the flow, measured DO, and simulated DO conditions.

(6) Effects of Deep Water Ship Channel Flow Management

The future tidal gate at the head of Old River will allow the fraction of the Vernalis flow that enters the DWSC to be interactively managed by DWR. In addition to increasing flow and DO in the DWSC, gate operations may affect San

Joaquin River fish movement (Chinook salmon) and entrainment losses (delta smelt), as well as water quality (salinity) in south Delta channels. The operations will be adaptively managed with a Gate Operations Review Team (GORT). Modeling of the likely effects of flow on the DWSC DO should be provided to the GORT during periods when DWSC flows would make a difference for DO compliance.

(7) Dissolved Oxygen Total Maximum Daily Load Implementation Credits and Responsibilities

The San Joaquin River DO-TMDL implementation plan goal is the elimination of the DO deficits (DO below objectives) in the DWSC. Upstream studies are required; the aeration demonstration project is being constructed by DWR, and the City of Stockton has upgraded RWCF treatment to include nitrification of ammonia—and each of these simultaneous actions may contribute to the TMDL goal of DO compliance. How will progress toward the goal be tracked? Who will receive credits for reducing BOD loads or augmenting the DWSC DO concentrations? A modeling framework will be needed because these changes in BOD and DO conditions will depend on flow, temperature, and other water quality conditions. This will require several model runs to track the credits and remaining responsibilities for compliance with the DO objectives in the DWSC.

(8) General Sensitivity to Flow and Algae Biomass

A series of simulations that compare the effects of various seasonal algae biomass and flows on the DWSC DO concentrations may be useful for adaptive management of the DWSC. Considering flow increments of 250 cfs from 250 cfs to 1,500 cfs [6 cases], and maximum seasonal algae concentration increments of 50 µg/l (5 mg/l biomass) from 50 µg/l (5 mg/l) to 250 µg/l (25 mg/l) [5 cases], would provide a "lookup table" of DO concentrations at various locations in the DWSC that would vary as a function of these two primary variables. A general pattern of DO sensitivity may be identified that will allow basic management decisions to be made about the operation of the head of Old River gate. When is more DWSC flow advantageous, and when does the increased algae biomass make the increased DWSC flow a liability for DO concentrations?

(9) Forecast Deep Water Ship Channel Conditions Likely to Occur Next Week

Perhaps the ultimate use of a calibrated model would be to make accurate projections about water quality conditions in the DWSC that will likely develop in the near future (forecast), based on projections of flow, weather, RWCF discharges, and existing conditions at the Mossdale and RRI monitoring stations. These forecasts would be the basis for adaptive management of the head of Old River flow gate, the Port of Stockton aeration device, and the demonstration oxygenation device.

(10) Future Planning Efforts

Work on habitat restoration and water quality management of the San Joaquin River has only just begun. There are other TMDL implementation plans are being developed, there is interest in restoring salmon populations upstream to Friant Dam, there are Reclamation studies of Delta-Mendota Canal–San Joaquin River recirculation, and the Corps may yet again deepen the DWSC from 35 feet to 40 feet. Each of these planning efforts will require evaluations of the likely effects on water quality conditions in the DWSC. An accurate and easily adaptable (i.e., user-interface) water quality model that can be shared and used collectively by all stakeholders in each of these planning efforts would be a great tool.

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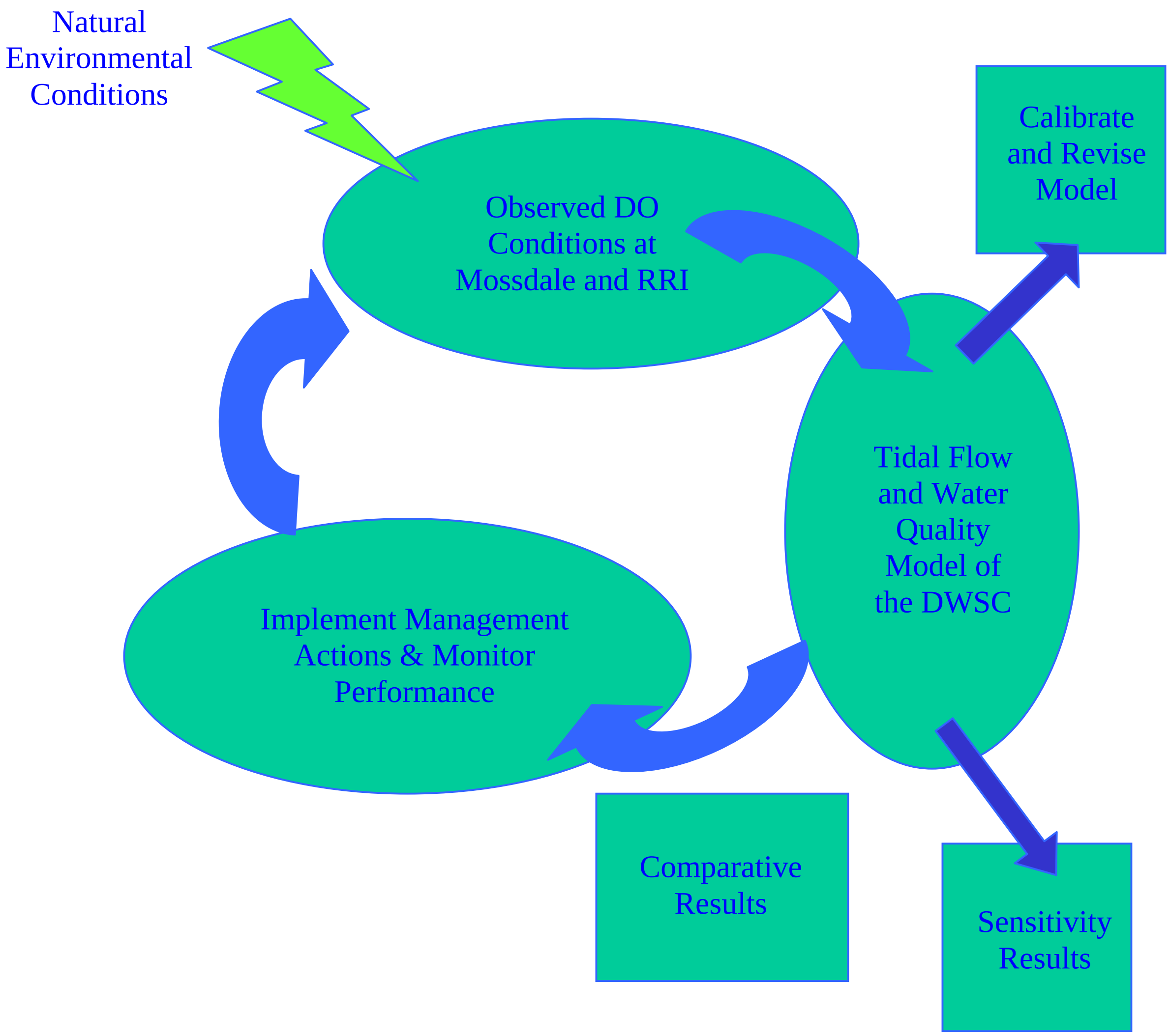

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Jones & Stokes

Figure 1

Adaptive Management of the DWSC with a Combination of Water Quality Modeling and Field Data Collection and Monitoring

Appendix A

Evaluation of Stockton DWSC Water Quality Model Simulation of 2001 Conditions: Loading Estimates and Model Sensitivity

Evaluation of Stockton Deep Water Ship Channel

Water Quality Model Simulation of 2001 Conditions:

Loading Estimates and Model Sensitivity

Prepared for

San Joaquin River Dissolved Oxygen TMDL
Technical Advisory Committee

and

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Introduction

The San Joaquin River (SJR) Dissolved Oxygen TMDL Technical Advisory Committee (TAC) directed some of the money in CALFED Directed Action Task 01-N61-06 "Downstream Tidal Exchange" (awarded to Jones & Stokes) to be used for preliminary data analysis and simulation of 2001 water quality conditions in the DWSC. The modeling was accomplished by Systech Engineering using the improved San Joaquin River water quality model developed under the 2000 CALFED Grant. The results from the 2001 simulations are described in this short technical report. This modeling work was accomplished in February 2002 by Systech Engineering to support the preliminary analysis of 2001 data that was requested by the TAC. This written documentation will be included as part of the final "Tidal Exchange" report to CALFED.

Modeling Task Description

The improved version (CALFED 2000 Grant) of the Stockton Water Quality Model, originally developed by Systech in 1993 for the City of Stockton, was used to simulate calendar year 2001 dissolved oxygen (DO) and other water quality conditions. The results show the validation of the water quality model for 2001 flows and concentrations, using the previously calibrated model coefficients. Additional simulations demonstrate the sensitivity of the DO concentrations to slightly different coefficient values and inflow concentrations during 2001. The simulated cases were:

1. Validation results for 2001 using the best estimates of river and Stockton Regional Wastewater Control Facility (RWCF) effluent flows, river and RWCF concentrations, and calibrated coefficients. Comparisons with DO, VSS, ammonia, chlorophyll and phaeophytin will be emphasized.

2. Sensitivity of DO to river flow will be demonstrated by comparison with two runs with slightly higher (i.e., 150%) and slightly lower (50%) net river flows. The summer low-flow period will be emphasized in the flow evaluation. Simulations with a constant steady flow of 250 cfs, 500 cfs and 1,000 cfs will be shown to indicate the flow sensitivity throughout the year.

3. Sensitivity of DO to light and resulting algae growth in the DWSC will be evaluated with two runs with slightly higher (150%) and lower (50%) euphotic depths (i.e., depth with 1% surface light). The effects of higher and lower algal growth rates will also be compared.

4. Sensitivity of DO to the RWCF effluent concentrations (loads) will be simulated. The CBOD load and the ammonia load will be reduced to 50% and increased to 150% to accomplish this comparison.

5. Sensitivity of DO to the SJR loads of CBOD, VSS, and algae biomass (chlorophyll) will be evaluated with a series of comparisons that will include increasing the concentrations to 150% and reducing the concentrations to 50%.

6. The sensitivity of DO to the settling rate coefficients for particulate organic materials (i.e. VSS and chlorophyll) will be shown with increased settling rates (150%) and decreased settling rates (50%).

Review of Model Assumptions and Coefficient Values

The Stockton Water Quality model is fully documented in the final report for the 2000 CALFED grant (Chen & Tsai, 2002). The model extends about 20 miles from the Head of Old River (HOR) to the City of Stockton River station 8 (Navigation Light 17/18) near Columbia Cut. The model calculates tidal flows between segments (approximately 0.5 to 1.0 mile long) and uses mass balance equations to simulate the concentrations of several water quality variables, including DO. The model includes several tidal sloughs (Fourteen Mile, Mormon, French Camp) and side channels that join the SJR in the vicinity of Stockton.

The water quality variables that are simulated include the following: temperature, DO, CBOD, chlorophyll (i.e., live algae) and phaeophytin (i.e., dead algae), VSS (i.e., detritus), TSS, ammonia, nitrate, total phosphorus, and EC (i.e., TDS). The original purpose of the model was to simulate the effects of RWCF effluent on DO concentrations in the DWSC. Some water quality variables that are not currently included in the model are pH, organic nitrogen, and TOC. The model processes that produce or consume oxygen include: atmospheric reaeration, sediment oxygen demand, detritus decay, algae growth, algae respiration/decay, nitrification (ammonia to nitrate), and CBOD decay. The model can also simulate artificial aeration from bubble columns or waterfall devices; the model properly simulates the amount of DO added as a function of the DO deficit from saturation at the location of the aeration device.

The model has been improved and calibrated as part of the CALFED 2000 Grant (99-B16). Several years have been simulated (i.e., 1991, 1996, 1999, and 2000) and a generally reasonable match to the measured water quality concentrations (i.e., temperatures, DO, nutrients and TSS) has been obtained with the model. Several additional parameters were measured in the special field studies during the summer of 1999, 2000, and now 2001 that allow more of the model variables (i.e., BOD, chlorophyll, phaeophytin) to be calibrated and validated. The calibrated coefficients are described in the final modeling report (Chen and TSAI, 2002).

Estimating Daily River and RWCF Flows

Daily SJR flows passing the HOR and entering the DWSC are generally provided by the USGS tidal flow meter (i.e., UVM) located near the Stockton RWCF. However, the UVM tidal flow device was not operational for a large portion of the summer in 2001, and estimates of DWSC daily flow were obtained using flow regression equations developed from Vernalis flow and Delta Export pumping (Jones & Stokes, 2001).

Figure 1 shows the measured and estimated DWSC flows during 2001. The Vernalis USGS flows are shown for reference. The measured UVM data generally follows the estimated range of Stockton flows at the beginning and ending of the summer period with missing records. The June-September Stockton flows are estimated to have ranged between 750 cfs and 1,000 cfs. The combination of measured UVM flow and estimated flow on days without UVM measurements were used in the modeling. The flows are very important in the water quality modeling because they control the dilution of the RWCF discharge, the travel time between Mossdale and the DWSC, and the residence time within the DWSC.

Figure 2 shows the Stockton RWCF daily discharge flows for 2001. Although the discharge is sometimes shut off on weekends and holidays, the monthly average discharge rate during the summer and fall was between 31 cfs and 47 cfs. The RWCF flow is important because it directly controls the effluent loads (e.g., ammonia and CBOD) discharged to the river. The river or discharge load can be calculated from the concentration and flow as:

Daily load (lbs/day) = 5.4 * concentration (mg/l) * flow (cfs)

Daily River Concentrations

A large amount of field data is needed to provide daily estimates of the model inflow concentrations for the river and the RWCF discharge. The DWR Mossdale water quality monitoring station provides hourly temperature, pH, conductivity, and DO measurements. These were used for estimating daily river concentrations. Weekly water quality measurements were available from Mossdale and Vernalis during the summer and fall TMDL sampling period. Concentrations for the winter period were only roughly estimated from assumed general seasonal patterns.

Figure 3 shows the daily average EC measured at Vernalis, Mossdale, and Rough & Ready Island (R&R). The Vernalis EC was relatively constant at about 600-650 uS/cm during the summer period, as required by the SWRCB 1995 WQCP Vernalis salinity objective of less than 700 uS/cm from April through August. The EC at Mossdale is slightly higher than at Vernalis during the summer period, suggesting the influence of agricultural drainage. The EC at R&R is not very much higher than Mossdale, although the RWCF discharge EC is about 1200 uS/cm. The expected increase in river EC at R&R would be about 25 uS/cm with a dilution of 20 (i.e., river flow of 760 cfs and

RWCF discharge of 40 cfs). The water quality model should match the observed EC changes in downstream segments. For example, the delayed reduction in EC at R&R following the October pulse flow event at Vernalis should be reasonably well simulated by the model. This simulated EC pattern was not evaluated, however, because the emphasis of this study was on the 2001 DO concentrations.

Figure 4 shows the temperatures in the SJR at Vernalis, Mossdale, and R&R. Temperatures were greater than 20 C from May through September, and were greater than 25 C for portions of June, July, and August. Temperatures of less than 10 C were measured only in January, early February, and December. Nitrification is greatly reduced at temperatures of less than 10 C. The saturated DO concentration declines from about 11.5 mg/l at 10 C to about 8.5 at 25 C. All of the model decay rates are assumed to be temperature dependent, so BOD and algae decay will have a stronger effect on DO in the summer.

Figure 5 shows the Mossdale minimum and maximum DO and the daily average value used in the model. The Mossdale average DO was greater than saturation and the diurnal range was greater than 2 mg/l from June through September, indicating significant algae concentrations because algae photosynthesis is the only process that can create this diurnal variation in DO. Mossdale DO was slightly less than saturation (i.e., 1-2 mg/l) and the diurnal range was less than 1 mg/l during the remainder of the year.

Figure 6 shows the minimum and maximum pH recorded at Mossdale. Although pH is not included in the water quality model, the pH data confirms the diurnal DO measurements and indicates a substantial algae concentration in the river from June through September. The Mossdale pH is greater than 8 from late May through September. The pH is generally lower at R&R (i.e., 7.5 to 8.0) suggesting that algae growth is still present but less active. The RWCF effluent pH is usually about 6.5

Figure 7 shows the measured and estimated turbidity values for Mossdale in 2001. The assumed seasonal pattern is somewhat arbitrary. A mathematical "sine-squared" shape has been assumed for the seasonal pattern. Summer concentrations of TSS and turbidity are higher than winter values, unless a large storm produces surface runoff to the river. The model uses the turbidity values to represent inorganic suspended solids (TSS) that may settle in the DWSC. The model estimates the light extinction coefficient and depth of algae growth (i.e., euphotic depth, 1% of surface light) from the TSS, as well as algae and VSS concentrations. TSS is settling and is re-suspended in the DWSC by the tidal velocity. Because the observed downstream decrease in turbidity is moderate, there must be substantial re-suspension of the clay particles, or else the settling rate is very slow.

Figure 8 shows the measured and estimated VSS (organic particles including algae and detritus) concentrations for 2001. The strong seasonal pattern follows the Mossdale diurnal DO and pH measurements that are strongly peaked (i.e., "sine-squared" shape) during the summer. The VSS measurements at Mossdale and Vernalis are very similar, declining rapidly in September at both stations. The seasonal estimate of river VSS concentration uses a minimum of 2 mg/l and a maximum of 12 mg/l. VSS is the simplest and most basic measurement of organic material entering the DWSC. However, the model will separately track the DO decay from algae respiration and decay, so the algae contribution to the VSS must be separated from the VSS estimate. This is a little involved and requires an important assumption about the pigment content of algae.

The primary algae measurements are the pigments, chlorophyll and phaeophytin, assumed to represent the live and decaying algae. To estimate algae biomass, the fraction of algae that is pigment molecules must be assumed. The water quality model assumes a constant pigment content of 1.25% of the biomass. With this assumption, 1 mg/l of algae biomass (VSS) would be equivalent to 12.5 ug/l of pigment (chlorophyll or phaeophytin). This basic assumption can be confirmed by comparing the total pigment concentration with the VSS measurements. The VSS (ug/l) concentration should always be greater than 80 times the total pigment (ug/l) concentration. The measured algae pigment at Mossdale and Vernalis has been converted to equivalent biomass with the assumed 1.25% pigment content. Figure 8 indicates that this ratio is a reasonable guess and that the algae biomass may represent a majority of the river VSS concentrations. The detritus variable in the model represents the non-algae organic particles that decay and settle. The estimated river detritus concentrations for 2001 obtained by subtracting the algae biomass from the VSS concentrations are relatively constant at between 2 mg/l and 4 mg/l.

Figure 9 shows the measured and estimated Mossdale chlorophyll concentrations used for the model input. The chlorophyll concentrations decreased rapidly in September. The weekly measurements at Mossdale and Vernalis were used to fit an assumed seasonal curve with a very strong peak (i.e., "sine-cubed" shape). Although both temperatures and light have seasonal sinusoidal shapes, the reason for this extremely seasonal peaked shape is not obvious. The maximum chlorophyll is assumed to be 80 ug/l (equivalent to 6.4 mg/l VSS) and the winter minimum is 0 ug/l.

Figure 10 shows the measured and estimated Mossdale phaeophytin concentrations that were assumed to be 50% of chlorophyll, based on the summer TMDL measurements. The maximum of 40 ug/l corresponds to a VSS concentration of 3.2 mg/l. The total algae biomass (live and dead) is the majority of the 10-12 mg/l VSS measured in June and July.

Figure 11 shows the estimates of ultimate dissolved CBOD at Mossdale. The 5-day total BOD measurements was used to estimate the dissolved, carbonaceous BOD values. Because the model separately tracks the BOD from ammonia oxidation, algae decay, phaeophytin decay, and detritus decay, only the dissolved carbonaceous BOD fraction of total BOD is simulated with CBOD in the model. The model assumes that 1 mg/l of detritus or algae biomass will produce 1.6 mg/l of BOD during decay. The model assumes that ultimate CBOD is 2.5 times the 5-day CBOD. The 2.5 factor is derived from long-term BOD measurements that indicate the 5-day BOD is about 40% of the ultimate (30-day) BOD. This ratio suggests that the daily BOD decay rate is about 0.10 day $^{-1}$. After accounting for the BOD equivalent of the measured VSS (detritus and algae), the data suggests that only about 1 mg/l is dissolved 5-day CBOD. The model therefore assumes the ultimate CBOD is about 2.5 mg/l throughout the year.

The model requires estimates of river ammonia, nitrate, and phosphate concentrations. The ammonia at Mossdale varied from 0 to 1.0 mg/l and was simulated as a constant 0.5 mg/l. This will have an ultimate BOD equivalent of about 2.5 mg/l. The SJR nitrate concentrations are very high at Mossdale and were simulated as a constant of 2.0 mg/l. The SJR phosphorus concentrations (assumed dissolved and available for algae growth) were assumed to be a constant of 0.15 mg/l.

There may be substantial variations in the daily river concentrations that are not included in these seasonal model estimates, which are based on weekly summer and fall grab samples. The daily changes in river concentrations caused by variations in river flows or variations in algae growth conditions were not simulated by the model for 2001.

Daily Stockton RWCF Effluent Concentrations

Daily (24-hour composite) measurements of CBOD, VSS, and ammonia-N in the RWCF effluent are routinely collected. These measurements provide very accurate RWCF load estimates for the model.

Figure 12 shows the daily measurements of 5-day CBOD, and the corresponding estimates of ultimate CBOD in the RWCF effluent. The first estimate of ultimate CBOD is assumed to be 2.5 times the 5-day CBOD measurements. The second estimate of ultimate CBOD is based on the assumption that each 1 mg/l of VSS will produce 1.6 mg/l of ultimate CBOD during decay. The two estimates of ultimate CBOD are similar throughout the summer and fall. Because the oxidation ponds and tertiary dissolved air flotation and sand filters are most effective in the summer, the CBOD concentrations are actually lowest in the spring and summer period.

The data suggest that the ultimate CBOD estimated from VSS (i.e., particulate) is often slightly greater than the ultimate CBOD estimated from 5-day CBOD. Therefore, very little RWCF effluent CBOD is dissolved. The total ultimate RWCF effluent CBOD (detritus and algae and dissolved) varies from about 5 mg/l to 25 mg/l during the summer and fall months, with the estimates from VSS being about 5 mg/l higher than the estimates from 5-day CBOD. The assumed 2.5 factor for 5-day CBOD or the 1.6 factor for VSS must be adjusted slightly to produce the same estimate of ultimate CBOD.

Figure 13 shows the daily ammonia-N concentrations for the RWCF effluent. The maximum ammonia-N concentrations of 25 mg/l during the winter are similar to the inflow concentrations to the RWCF, and indicate that very little removal of ammonia occurs during the winter. The majority of the ammonia is removed by algae uptake and growth during the spring and summer months. The RWCF performance during 2001 was not as good as most years, when ammonia has consistently been less than 2 mg/l from May through August (Jones & Stokes 1998). The total kjeldahl nitrogen (TKN), that includes ammonia and organic nitrogen, were measured weekly and are shown in Figure 13. The majority of the TKN concentration was ammonia-N.

Figure 14 shows the ultimate BOD equivalent for the TKN, assuming that 4.7 mg/l of oxygen are required to oxidize (i.e., nitrify) each 1 mg/l of ammonia-N. The maximum ultimate NBOD concentrations are about 150 mg/l during the winter, when the TKN concentration is 25 mg/l. However, the nitrification rate is less during the winter and may cease altogether at temperatures of less than 10 C. The ultimate NBOD dominates the ultimate CBOD, which was generally less than 25 mg/l. These high ultimate BOD concentrations from the RWCF effluent are, however, diluted by the SJR flow before entering the DWSC.

Combined SJR River and RWCF BOD Loads to DWSC

A simple way to visualize the two sources of BOD loading (i.e., river and RWCF) is to consider the total ultimate BOD concentrations entering the DWSC each day. The river load at Mossdale will change (i.e., decay) as it flows to the DWSC. The RWCF load will be diluted by the river flow before entering the DWSC. The model simulates the decay of BOD and decline of algae biomass during the travel time from Mossdale to the DWSC. At a flow of 500 cfs the travel time is about 2.5 days, and at a flow of 1000 cfs the travel time is only 1.2 days. Field measurements of VSS and chlorophyll indicate that the R3 concentrations are generally less than 50% of the Mossdale concentrations. A considerable reduction in the Mossdale load of particulate organics (i.e., ultimate BOD) apparently occurs in the river between Mossdale and DWSC, although the travel time was generally only 1-2 days during 2001.

The ultimate BOD concentration entering the DWSC will be increased by the RWCF effluent BOD concentration after dilution by the river flow. The fraction of the effluent concentration of ultimate BOD that will enter the DWSC in the river flow can be estimated from the ratio of the combined river flow and effluent discharge to the effluent discharge:

Dilution Factor = (River flow + RWCF Discharge) / RWCF Discharge

A higher river flow will provide a greater dilution of the RWCF discharge. The river and diluted effluent water will then move through the DWSC more quickly, and exert less of the ultimate BOD within the DWSC volume, when the river flow is higher. A 5-day moving average of the river flow and discharge has been assumed to account for tidal mixing in the SJR.

Figure 15 shows the resulting dilution factor pattern for 2001. The model assumed the higher flow estimate shown in Figure 1. The dilution factor was generally greater than 20 through out the summer. During December the dilution factor declined to less than 10 for several days. The assumed ultimate BOD concentration that enters the DWSC from Mossdale was assumed to be 50% of the Mossdale ultimate BOD. The ultimate BOD concentration entering the DWSC from Mossdale follows a seasonal pattern that is a minimum of 5 mg/l in the winter and a maximum of 12 mg/l in the summer.

The ultimate BOD concentrations from the RWCF effluent were high when ammonia-N concentrations were greater than 10 mg/l (i.e., 50 mg/l ultimate NBOD). However, because the dilution of effluent by the river flow was generally greater than 20, the contribution of ultimate BOD from the RWCF discharge to the DWSC was almost always less than 5 mg/l. Only in January and December were the ultimate BOD concentrations entering the DWSC from the diluted RWCF effluent higher than 5 mg/l. The contribution of ultimate BOD from the RWCF discharge to the DWSC was therefore almost always less than the contribution of ultimate BOD from the river.

Figure 16 shows the measured daily DO deficit (i.e., saturated DO - average DO) at the Rough and Ready Island monitoring station operated by DWR. The DO deficit pattern already accounts for the change in DO saturation that depends directly on the water temperature. The DO deficit reflects the total BOD decay that was exerted in the river downstream of Mossdale or in the DWSC during the travel time of the water to the Rough & Ready station. The longer the travel time, the more of the ultimate BOD will actually decay within the DWSC and cause the DO concentrations at R&R to decline. The total ultimate BOD entering the DWSC assuming 50% of the Mossdale BOD and the diluted RWCF BOD is also shown in Figure 16. The two patterns show a strong similarity and suggest that the seasonal ultimate BOD concentration entering the DWSC accounts for the majority of the observed DO deficits at the R&R Island station.

The DO deficit indicates that the ultimate BOD loads exceeded the ability of reaeration and algae production to add DO to the DWSC. Reaeration of the DWSC increases as the DO deficit increases, and reaeration also increases as the residence time increases, but the net effects of reaeration on the effective BOD loads are difficult to evaluate without a model to perform the calculations. A model is also needed to track the net effects of algae growth in the DWSC. Algae photosynthesis is assumed to produce as much DO as algae respiration and decay will subsequently consume, but the net effects on DO in the DWSC does not appear to be balanced. These more complicated and involved calculations can only be performed with a water quality model.

Validation of Model Results for 2001 DO Conditions

The Stockton DWSC water quality model was used to simulate 2001 conditions without any changes in model coefficients. The inflow concentrations were specified as described in this report, and the field data collected at the City of Stockton river sampling stations in the DWSC were compared with the model predictions. Because the river concentration estimates do not include daily variations, only the basic seasonal patterns of river water quality can be simulated with the model. The daily changes in river flow and the daily changes in RWCF effluent concentrations and flows will produce some daily variations in simulated water quality in the DWSC. Daily fluctuations in water temperatures will also slightly change BOD decay rates in the DWSC. Figure 4 indicates that temperature between Mossdale and R&R are very similar. The model is able to reproduce the short-term temperature fluctuations caused by meteorology, but the seasonal effects of temperature on DO saturation and BOD decay processes are the dominant effects for DO simulation.

Figure 17 shows the simulation of ammonia concentrations at R3 and R5 compared with Mossdale. Mossdale ammonia was assumed to be 0.5 mg/l, although the data indicates considerable variation in ammonia. The highest summer ammonia concentration of about 1.0 mg/l was measured at R3 during August. The concentrations had decreased to about 0.75 mg/l at R5. The model concentrations were a little less than measured at R3, and the simulated decline at R5 was smaller, suggesting that the simulated decay rate may be slightly too fast. The green line represents the expected ammonia concentration entering the DWSC without any ammonia oxidation. The DWSC ammonia values would have been about 1.5 to 2.0 mg/l during the summer. The model appears to be simulating about the right amount of nitrification, although reducing the rate slightly from 0.05 day^{-1} to 0.04 day^{-1} might improve the match with field data. The model could also be modified to include organic nitrogen, which would allow the TKN measurements to be used and would allow the complete nitrogen cycle to be simulated. The TKN concentrations at Mossdale were about 1.0 to 1.5 mg/l during the summer, and this additional organic nitrogen will decay to ammonia and then nitrify, thereby increasing the oxygen demand.

Figure 18 shows the measured and simulated VSS concentrations at Mossdale, R3 and R5 for 2001. The water quality model had a re-suspension term added that is a function of the river velocity that includes a strong tidal component within the DWSC. The re-suspension term for VSS is unlimited (i.e., total VSS is not tracked) and therefore acts as a net source of VSS. The model is simulating too much re-suspension of VSS in the river and DWSC, with model R3 concentrations of 5 to 15 mg/l. The measured VSS at R3 is about 5 mg/l. The simulated decrease of about 1 mg/l VSS between R3 and R5 is properly simulated. But the simulated tidal signal (i.e., spring-neap tidal energy) in VSS is much greater than indicated by the VSS data. Field measurements suggest a more constant resuspension source of VSS within the DWSC that counteracts the settling of VSS (Litton, 2002). The VSS simulation for 2001 is not adequate because the average VSS is too high (from the simulated re-suspension source of VSS) and the tidal variation within each month is too strong.

Figure 19 shows the measured and simulated chlorophyll concentrations at Mossdale, R3 and R5 for 2001. The simulated net decline in chlorophyll (i.e., algae) between Mossdale and R3 is apparently too slow in the model because the simulated chlorophyll at R3 is about 3x higher than measured. As Figure 19 indicates, the model simulates the R3 chlorophyll to decline to about 75% of the Mossdale chlorophyll, but the data indicate that the R3 chlorophyll is only about 25% of the Mossdale value. The algae simulations at R5 are also too high compared with the data. The model does simulate a 50% decline in chlorophyll between R3 and R5, which is similar to the observed decline. The chlorophyll simulation for 2001 is not adequate because the net decline in chlorophyll between Mossdale and the DWSC is not enough to match the R3 algae data. The modeled algae growth rate may be too high, or the decay rate might be too slow.

Figure 20 shows the measured and simulated phaeophytin concentrations at Mossdale, R3 and R5 for 2001. The net decline in phaeophytin (i.e., dead algae) between Mossdale and R3 is apparently too slow in the model because the simulated phaeophytin at R3 is higher than measured in June, July, and August. The data indicate that phaeophytin at R3 and R5 was higher than at Mossdale in September and October. The model decay rates for both chlorophyll and phaeophytin may be too low. Some special algae decay rate experiments suggest that the dark decay of chlorophyll was about 0.5 day^{-1} and the dark decay of phaeophytin was about 0.25 day^{-1} (Litton, 2002). The model is currently using a chlorophyll decay rate of 0.13 day^{-1} and a phaeophytin decay rate of 0.10 day^{-1}. Increasing these coefficient values may improve the match with field data. The simulated growth rate of algae in the light conditions typical of the river below Mossdale (i.e., 10-15 feet depth) and in the DWSC (i.e., 25-35 feet depth) should also be verified with field measurements.

Figure 21 shows the simulated and measured DO concentrations at R3 and R5. The minimum daily DO concentration from the DWR R&R monitoring station are also shown. The saturation DO concentration for the R&R station temperature is shown for comparison. The seasonal decline in DO at R3 and R5 is simulated. The simulated DO at R5 is about 1 mg/l below the measured R5 data and below the R&R minimum DO concentrations during the spring and summer. The measured DO was nearly saturated during April and May when the flows were at least 3,000 cfs during the VAMP period. The simulated DO at R5 was about 2 mg/l lower than the R&R data during this event.

The general magnitude of the simulated DO deficit at R5 matches the field data quite well during the summer and fall period of June through October 2001. However, the simulated DO at R3 was considerably less than the measured DO data at R3, suggesting that the model is simulating too much BOD decline in the river between Mossdale and DWSC. The model therefore simulates too little BOD remaining at R3 to lower the DO between R3 and R5. The simulated settling and decay processes between Mossdale and R3 should be better balanced with the simulated settling and decay processes within the DWSC from R3 to R5.

Figure 22 shows the cumulative travel time between Mossdale and R3 and then to R5. The DO deficit measured at R5 appears to be generally related to this pattern. As described in Figure 16, the highest concentrations of CBOD and NBOD from the river and the RWCF effluent occurred during the June-September period. The travel time to the DWSC was about 3 days, and the cumulative travel time to R5 was about 10 days, with a corresponding dilution factor of about 20 for the RWCF effluent. The model is not able to track the short-term fluctuations in the measured DO at the R&R station that were observed during this summer period. Some of the suggested changes in the VSS, ammonia, and algae simulations will also likely improve the DO simulations.

Sensitivity Results

The model was also used to demonstrate sensitivity of simulated DO concentrations in the DWSC to changes in RWCF effluent and river concentrations, as well as to changes in river flow and some important model coefficients. These sensitivity results will increase confidence in the model if the sensitivity simulations bracket the measured data. The sensitivity results also emphasize the importance of the measured river and RWCF concentrations of the ultimate BOD components (i.e., algae, TKN, detritus, and dissolved CBOD).

Sensitivity of DO to Flow in 2001

Figure 23 shows the simulated daily average DO concentrations at R3 for the base case with actual flows in 2001 compared with a reduced (50%) flow case and an increased (150%) flow case. The base simulation used the high flow estimate shown in Figure 1. The same seasonal Mossdale river concentrations and the same RWCF effluent flows and concentrations were used in each simulation. The higher flow case gave shorter travel times (67% of base) and greater dilution of the RWCF effluent so the effective BOD concentrations entering the DWSC were less than the base. The reduced flow case gave longer travel times (2x base) and less dilution (50% of base) for the RWCF effluent. The simulated changes in DO concentrations at R3 were greater for the reduced flow case than for the increased flow case. A large difference (i.e., 2-3 mg/l) in the simulated DO concentrations at R3 was predicted during the summer period, indicating that flow is a very important variable for accurately simulating DO concentrations. The measured DO data at R3 appears to be better matched with the increased flow (150%) case.

Figure 24 shows the simulated daily average DO concentrations at R5 (Rough & Ready) for the base case with actual flows in 2001 compared with a reduced (50%) flow case and an increased (150%) flow case. The simulated changes in DO concentrations at R5 were greater for the reduced flow case than for the increased flow case. A difference of 1-2 mg/l in the simulated DO concentrations at R5 was predicted during the summer period, indicating that flow is a very important variable for accurately simulating DO concentrations. The measured DO data at the R&R monitoring station appears to be better matched with the increased flow (150%) simulation case. This does not mean that the flows should be increased, because the flows are accurately measured. Rather, the model coefficients need to be further adjusted to match the DO data with the measured base flows.

Sensitivity of DO to VSS and Algae Settling Rates in 2001

Figure 25 shows the simulated daily average DO concentrations at R3 for the base case compared with reduced settling rates (50%) for algae and VSS and with increased settling rates (150%). The same seasonal Mossdale river concentrations of algae and VSS and the same RWCF effluent flows and concentrations of VSS were used in each simulation. The reduced settling produced lower DO concentrations (i.e., 1 mg/l less during the summer period), presumably because of greater concentrations of VSS and algae remaining in the flow entering the DWSC. Figure 26 shows the simulated results at R5 (Rough & Ready). The effects of the increased settling rates (150% base) were not as great at either R3 or R5. These results suggest that VSS settling is a very important coefficient for simulating DO in the DWSC. The settling rates should not be reduced, however, because the simulated DO concentrations with the reduced settling rates were much lower than the measured DO data at R3 and R5. The increased settling rates case gave a better match with the measured DO, but the settling rates should only be adjusted if comparison with the measured VSS and algae (i.e., chlorophyll and phaeophytin) concentrations suggests a change is necessary. The model VSS settling and re-suspension formulations might need to be revised to track to total VSS and limit the mass of VSS that is available to be re-suspended from the bottom.

Sensitivity of DO to Algae Growth Rates in 2001

Figure 27 shows the simulated daily average DO concentrations at R3 for the base case compared with reduced algae growth rate (50%) and increased algae growth rate (150%) cases. The reduced algae growth rate produced slightly higher DO concentrations at R3. The reduced algae growth rate only slightly reduced the algae biomass, suggesting that the majority of the algae originated from Mossdale, rather than growing in the river between Mossdale and the DWSC. The increased algae growth rate had a dramatic effect on the simulated DO at R3, reducing the DO concentrations by 2 mg/l during the summer period. This indicates that the simulated growth rate should not be raised. Any additional algae biomass grown in the river will enter the DWSC and reduce the DO as the algae decays. Figure 28 shows the simulated results at R5 (Rough & Ready). The effects of the increased algae growth rate (150% base) on DO at R5 was very strong, causing a decrease of 2 mg/l during the summer period. Because this is the same effect as simulated at R3, the mechanism appears to be growth of algae in the river between Mossdale and the DWSC.

Conclusions

These sensitivity results suggest that the model needs additional calibration of the algae growth, decay and settling processes that occur between Mossdale and the DWSC. Similarly, the VSS settling and re-suspension processes that occur between Mossdale and the DWSC need additional calibration. Model simulations of the moderate decline in algae, VSS, and DO concentrations between R3 and R5 appear to be much closer to the measured data.

The Stockton DWCS water quality model is our most useful existing tool for integration and systematic analysis and evaluation of alternative management actions. The existing model should continue to be used to increase our understanding of the DWSC water quality processes. The model equations and coefficient values have been improved from the original model developed in 1993 for the City of Stockton. However, additional simulations and integration of results from recent experiments performed by the CALFED funded projects (e.g., Litton, 2002 and Lehman, 2002) should be made. The recent peer review panel wondered why the existing model was not being used to provide integration of field data and analysis of potential management actions. The existing water quality model should be used until a more comprehensive alternative model are available.

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Peggy W. Lehman (2002). Oxygen Demand in the San Joaquin River Deep Water Channel, Fall 2001. Prepared for CALFED Bay-Delta Program 2001 Grant 01-N61.

Gary M. Litton (2002). Sediment Deposition Rates and Oxygen Demands in the Deep Water Ship Channel of the San Joaquin River, Stockton, California. Prepared for CALFED Bay-Delta Program 2001 Grant 01-N61-005.

Figure 1. Measured and Estimated SJR Flows entering the Stockton Deep Water Ship Channel in 2001.

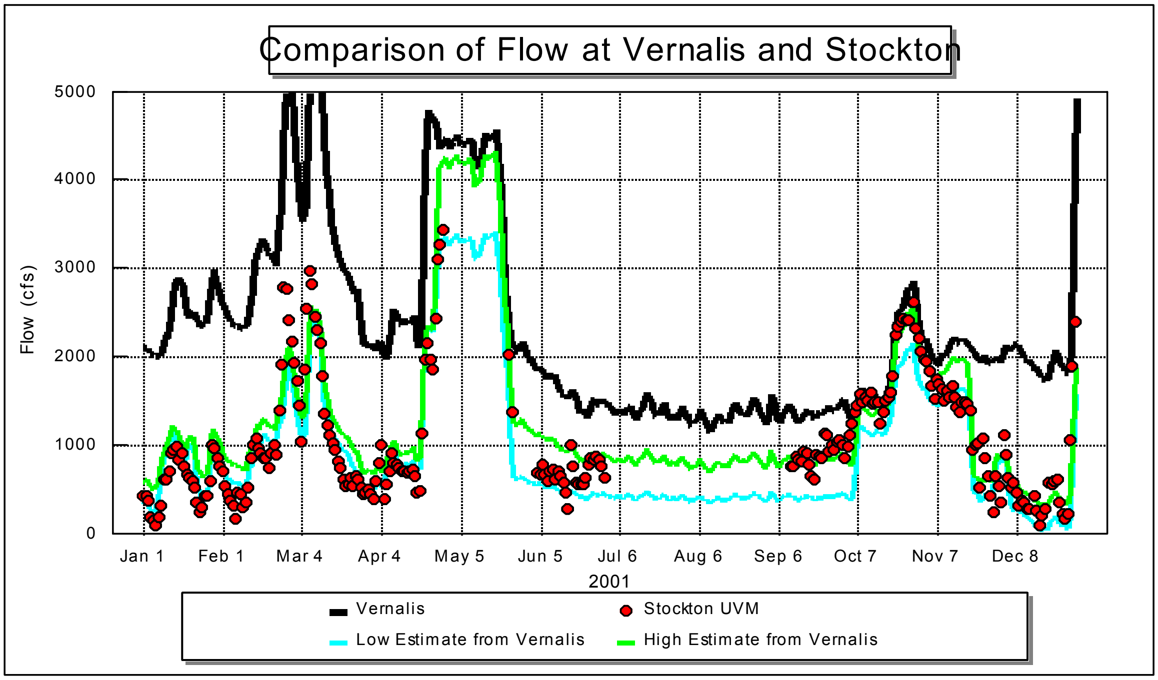


Figure 2. Stockton RWCF Daily Discharge During 2001.

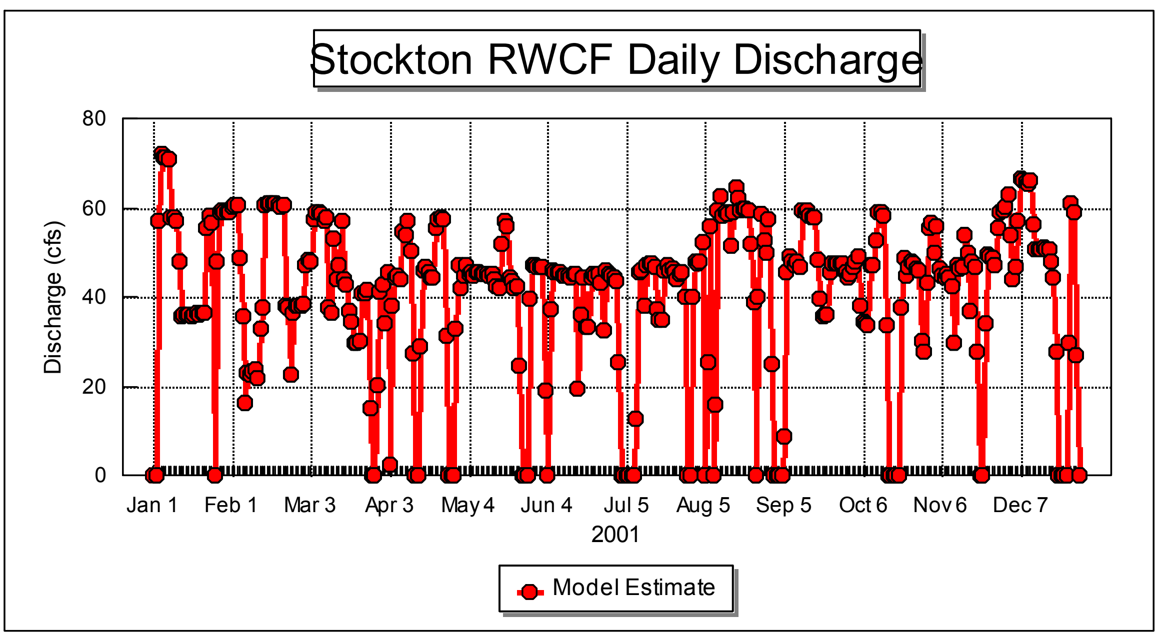


Figure 3. San Joaquin River Mean Daily EC Measurements for 2001.

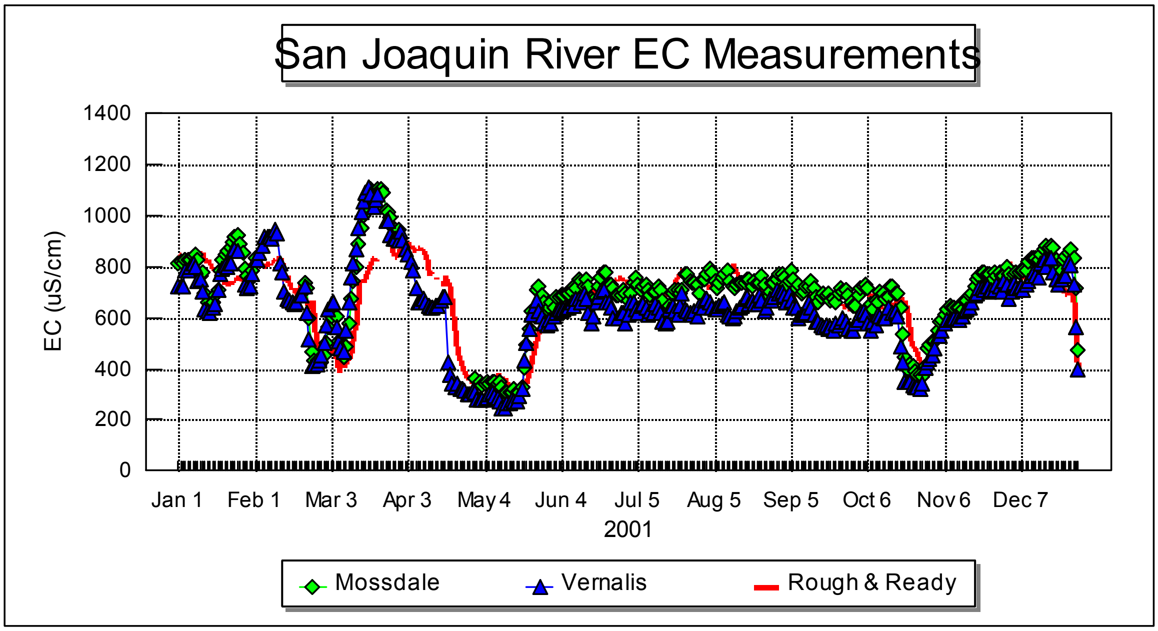


Figure 4. San Joaquin River Mean Daily Temperature Measurements for 2001.

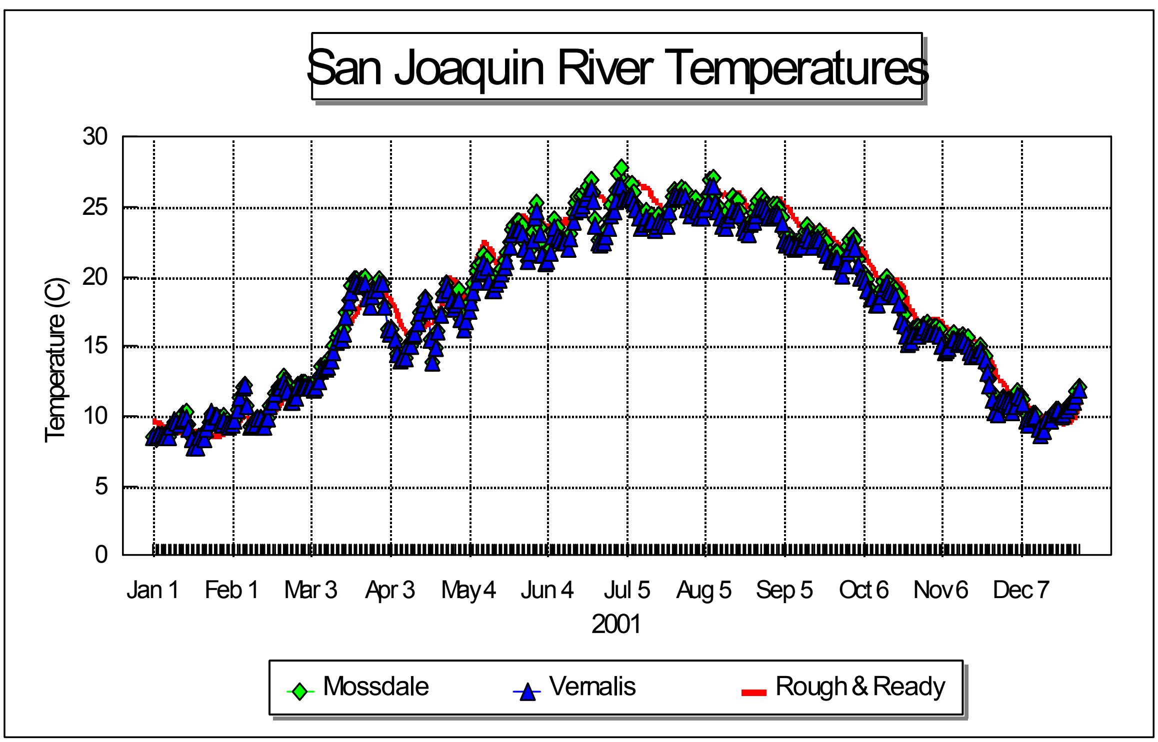


Figure 5. Mossdale Daily Average DO Compared to Saturated DO and Minimum and Maximum DO Measurements for 2001.

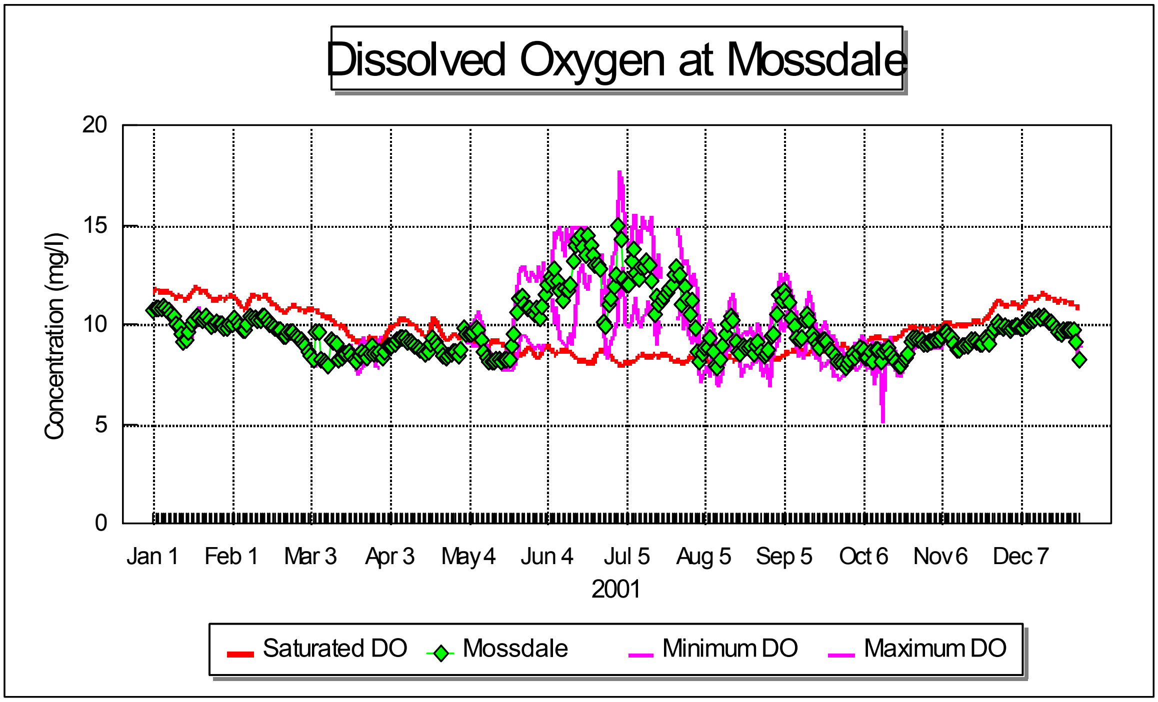


Figure 6. Daily Minimum and Maximum pH at Mossdale and Rough & Ready Island

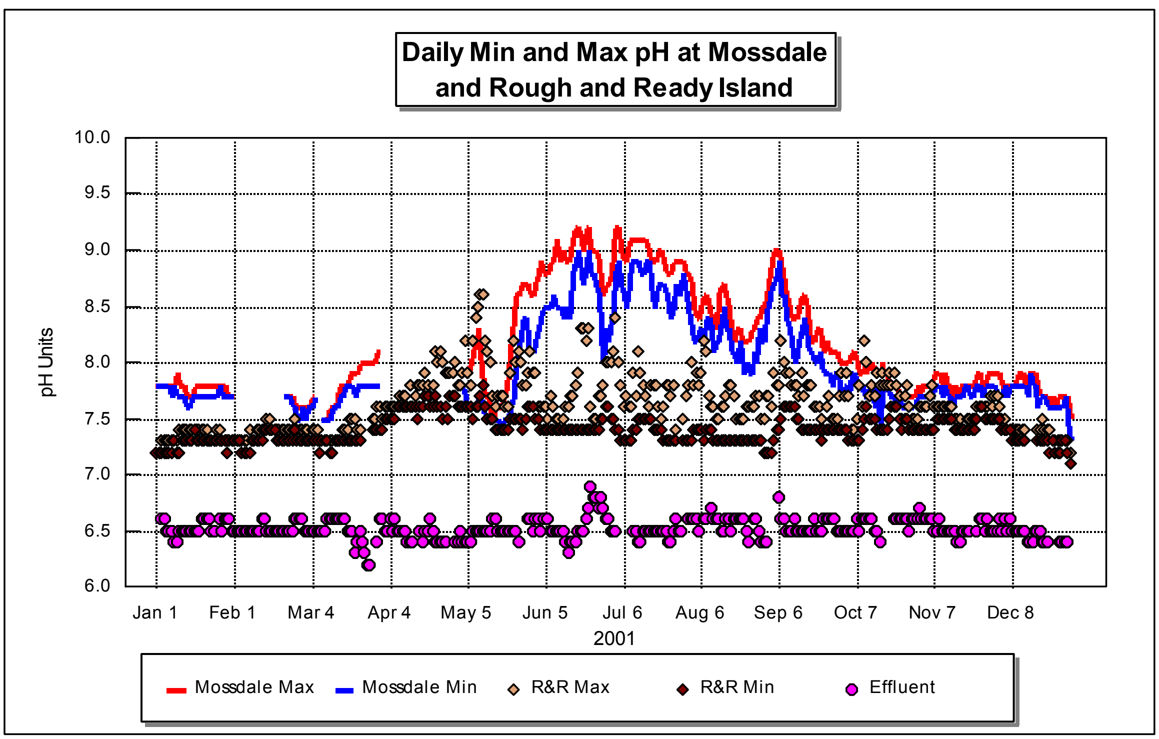


Figure 7. Measured and Estimated Turbidity (TSS) Values at Mossdale in 2001.

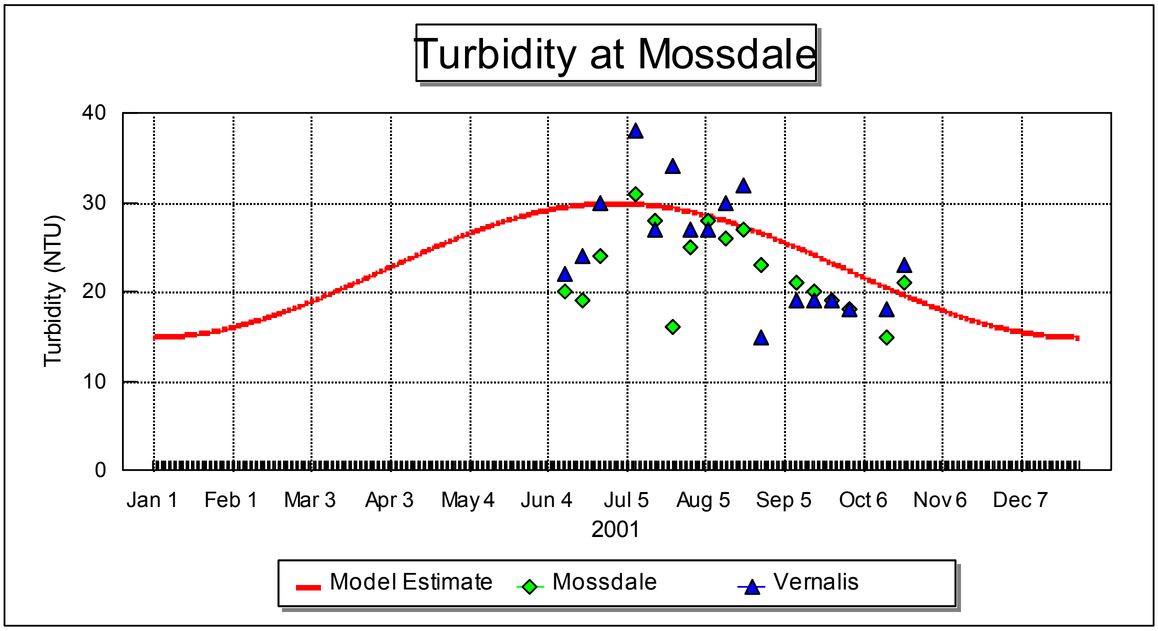


Figure 8. Measured VSS and Estimated Detritus and Algae Concentrations for 2001.

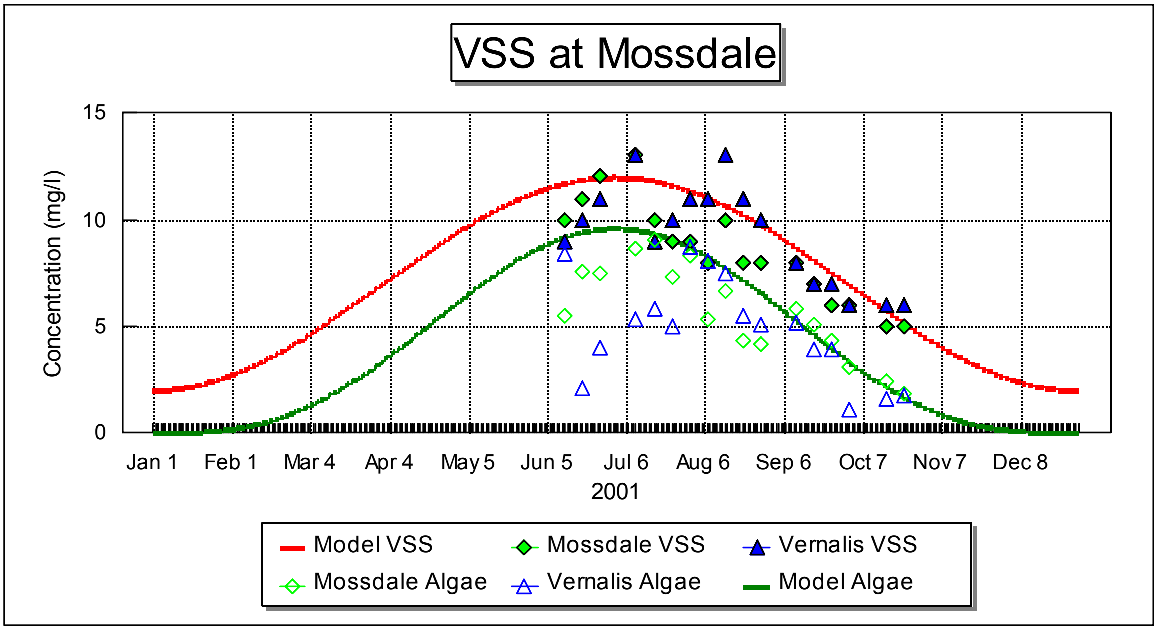


Figure 9. Measured and Estimated Chlorophyll Concentrations for 2001.

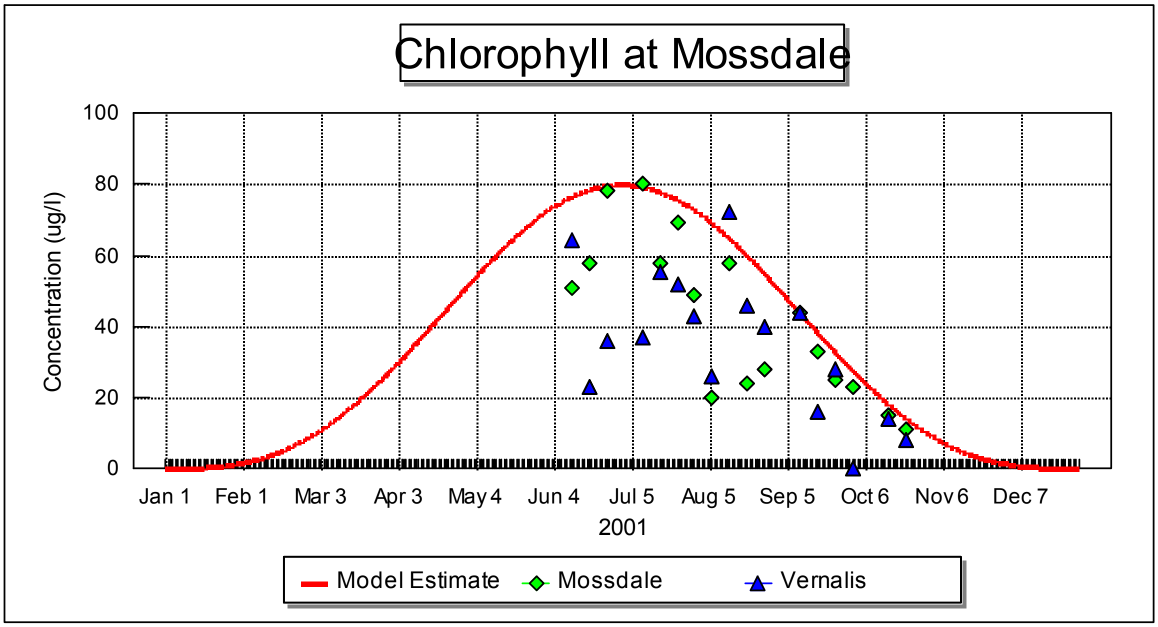


Figure 10. Measured and Estimated Phaeophytin Concentrations for 2001.

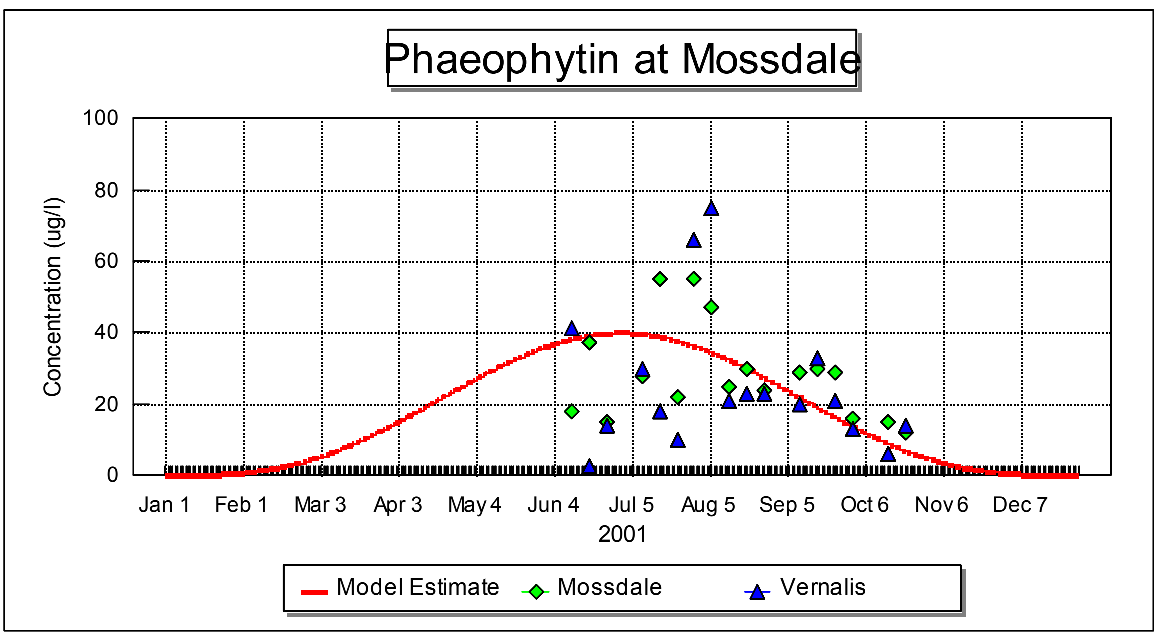


Figure 11. Measured and Estimated 5-day BOD and 5-day CBOD Estimates for 2001.

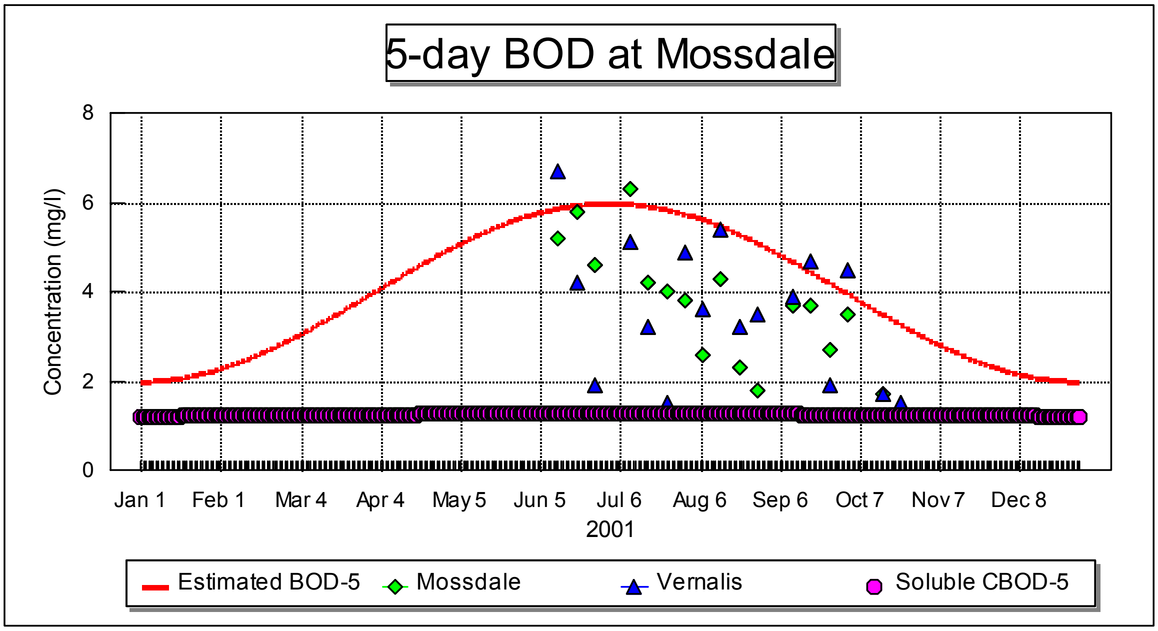


Figure 12. Estimated Stockton RWCF Ultimate CBOD from 5-day CBOD and VSS Data

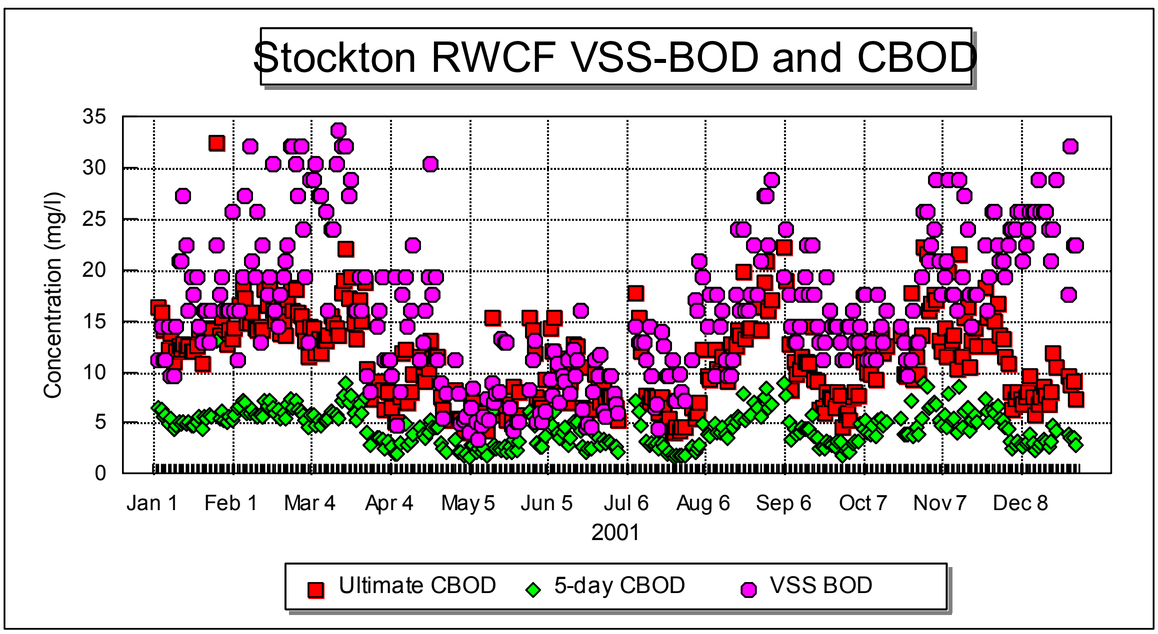


Figure 13. Daily Measurements of RWCF Ammonia-N and TKN Concentrations for 2001

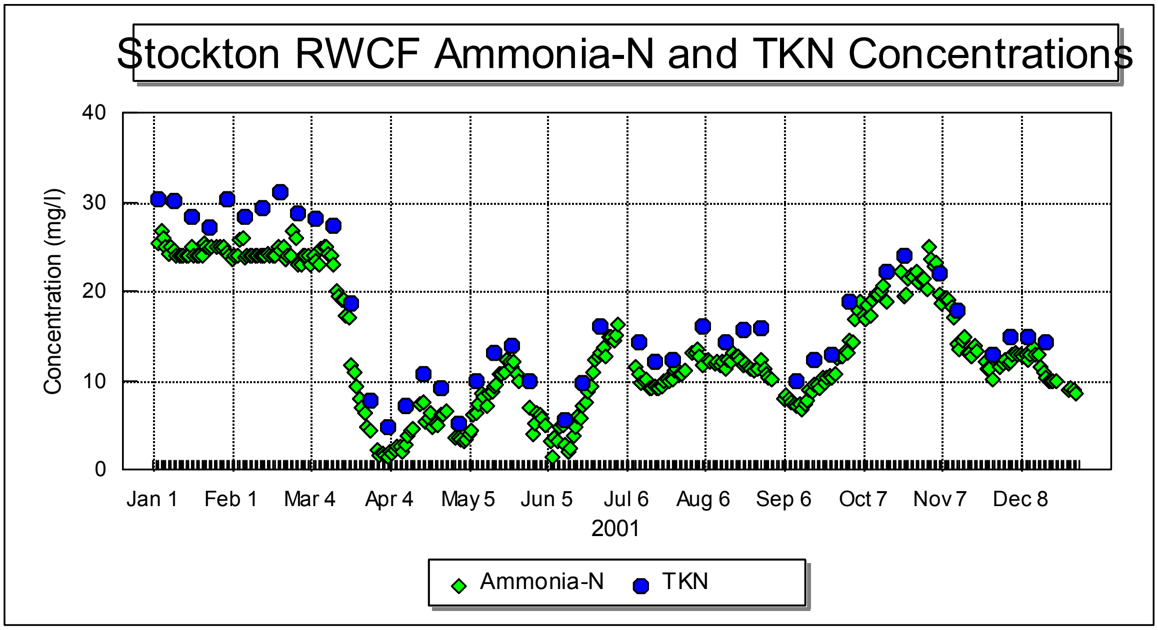


Figure 14. Comparison of Ultimate CBOD and Ultimate NBOD from RWCF

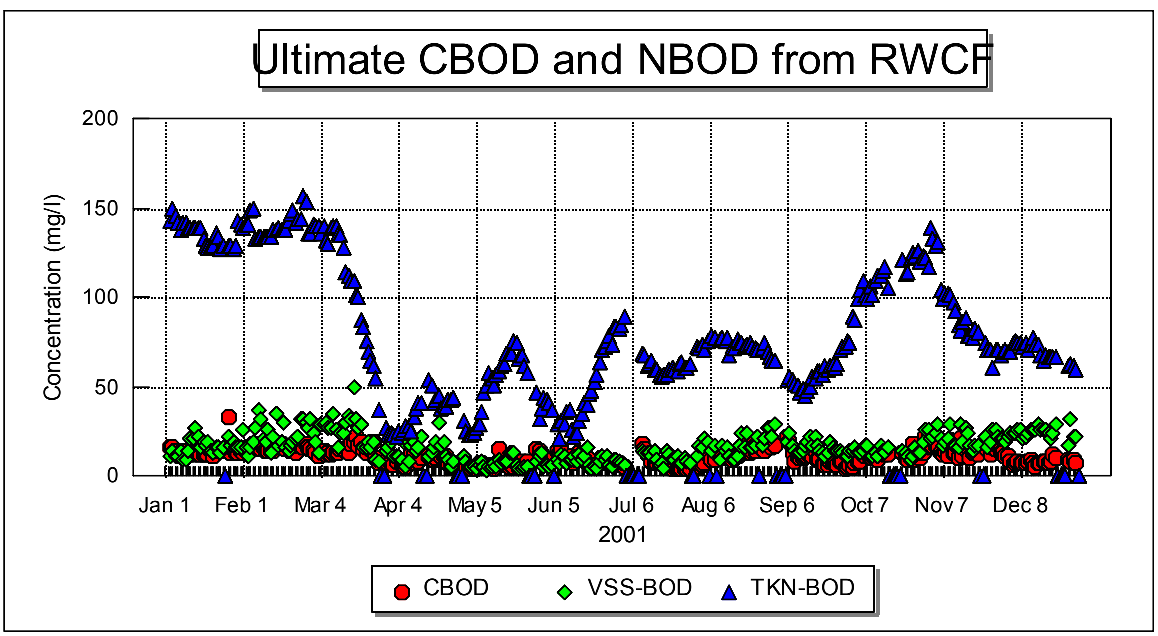


Figure 15. Estimates of Total Ultimate BOD concentrations entering DWSC from RWCF Discharge.

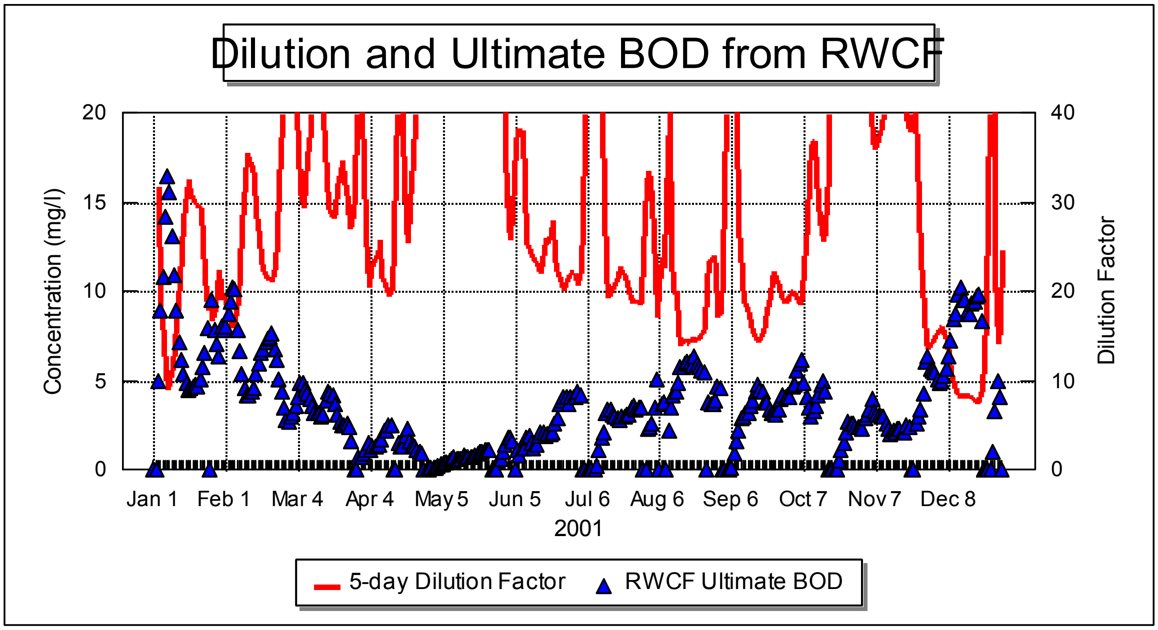


Figure 16. Daily DO Deficit at Rough & Ready Island in 2001 Compared to Ultimate BOD Entering DWSC from Mossdale and RWCF.

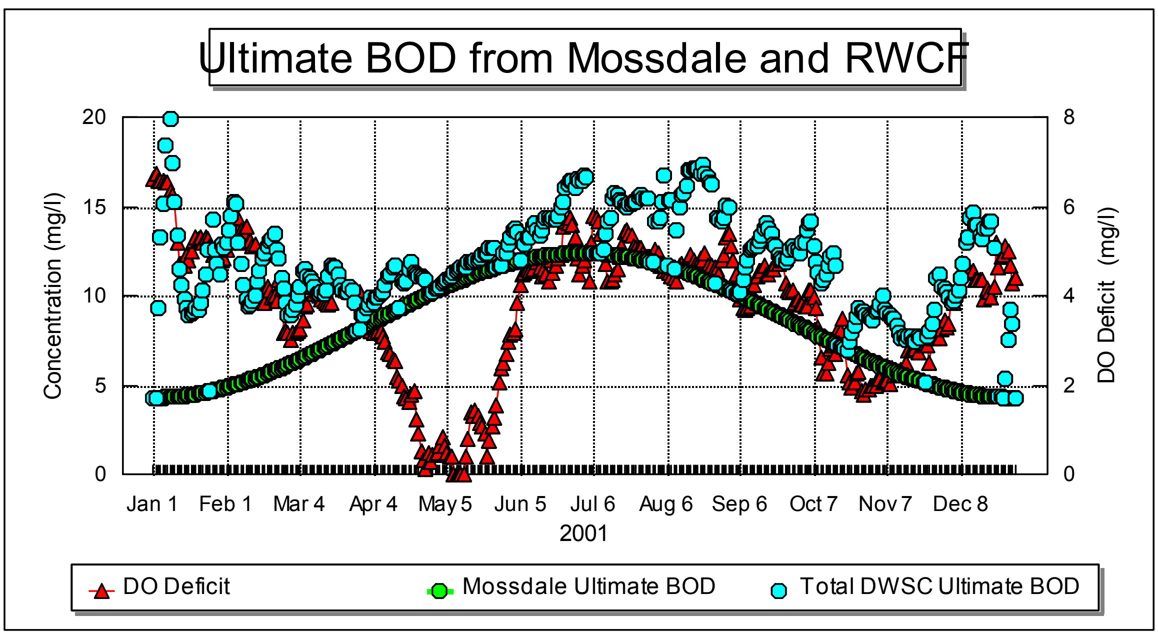


Figure 17. Model Simulated Ammonia-N Concentrations Compared with Ammonia-N Measurements in DWSC at R3 and R5 in 2001.

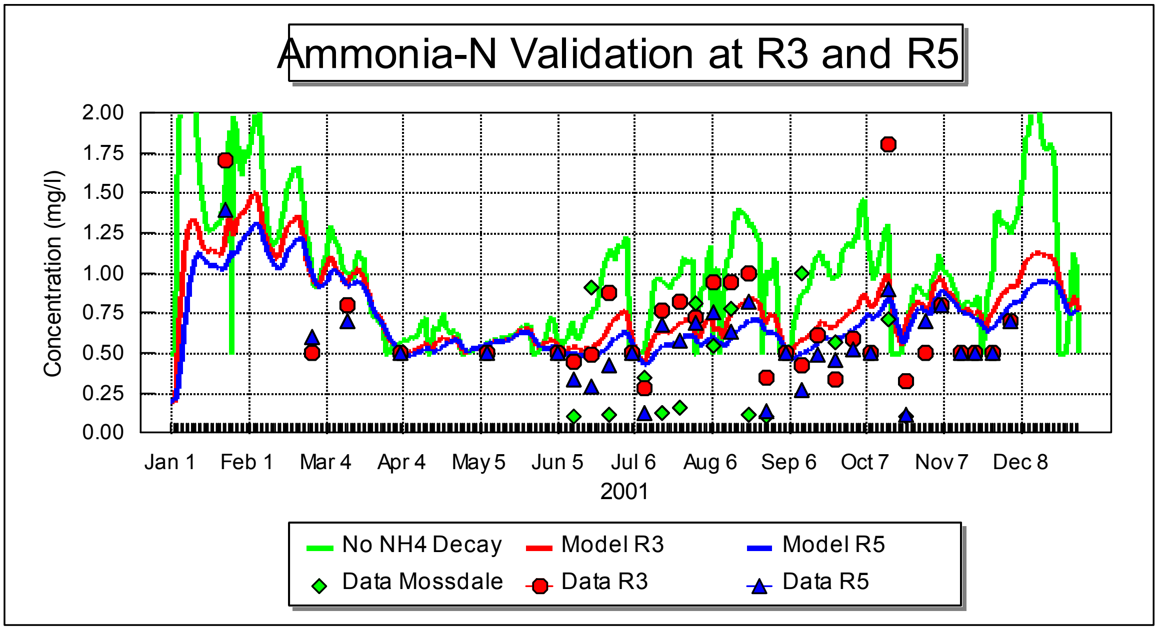


Figure 18. Model Simulated VSS Concentrations Compared with VSS Measurements in DWSC at R3 and R5 in 2001.

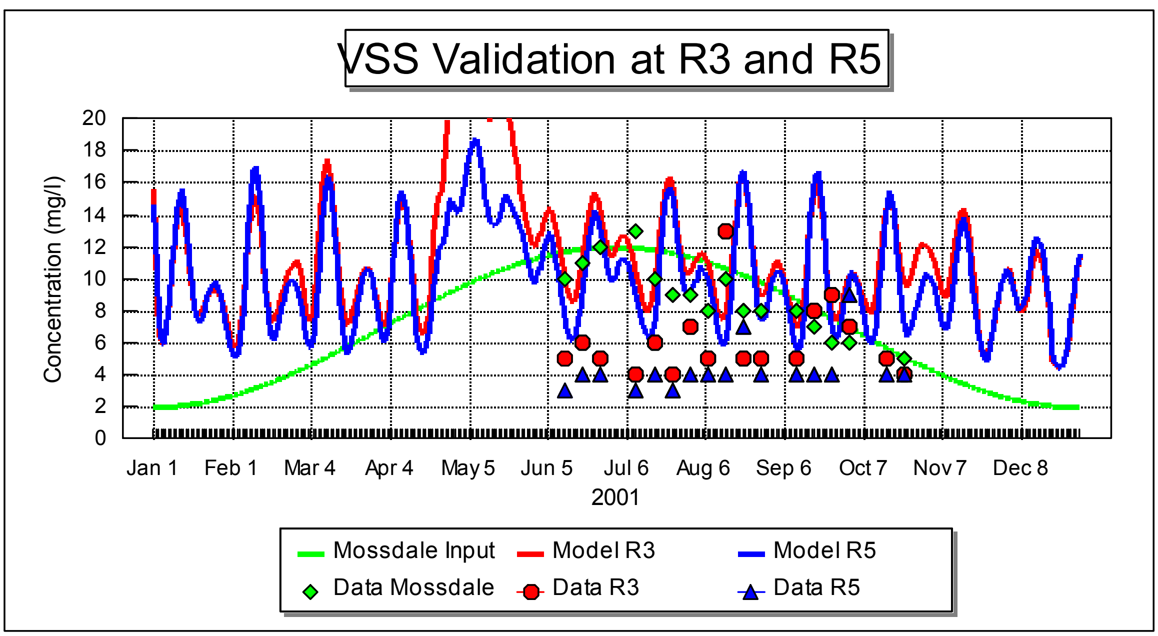


Figure 19. Model Simulated Chlorophyll Concentrations Compared with Chlorophyll Measurements in DWSC at R3 and R5 in 2001.

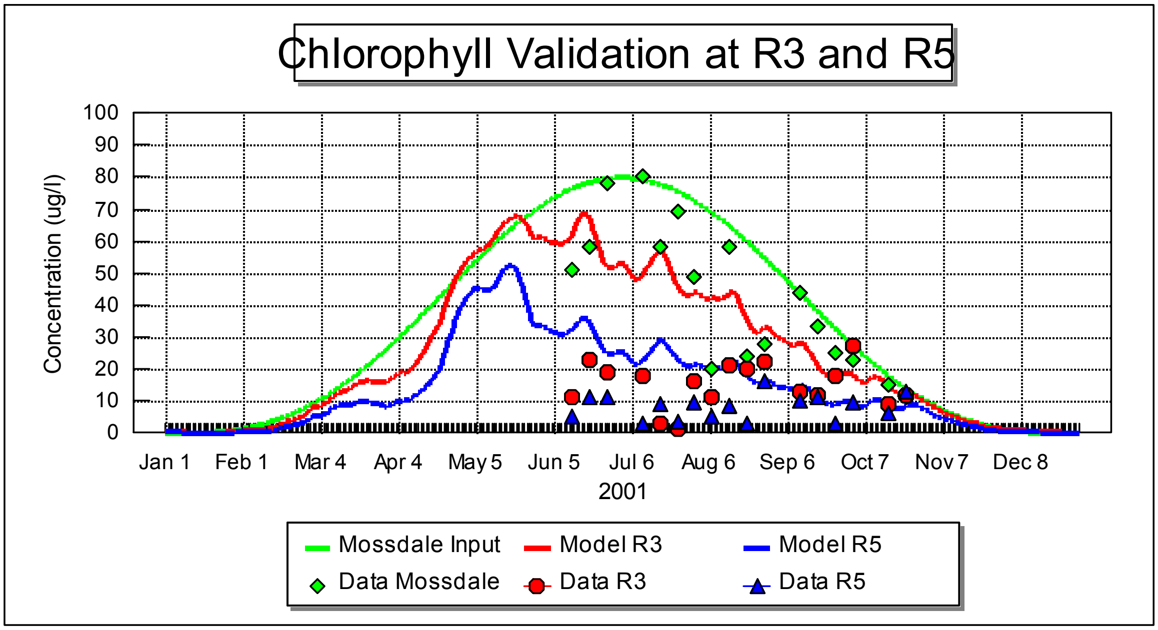


Figure 20. Model Simulated Phaeophytin Concentrations Compared with Phaeophytin Measurements in DWSC at R3 and R5 in 2001.

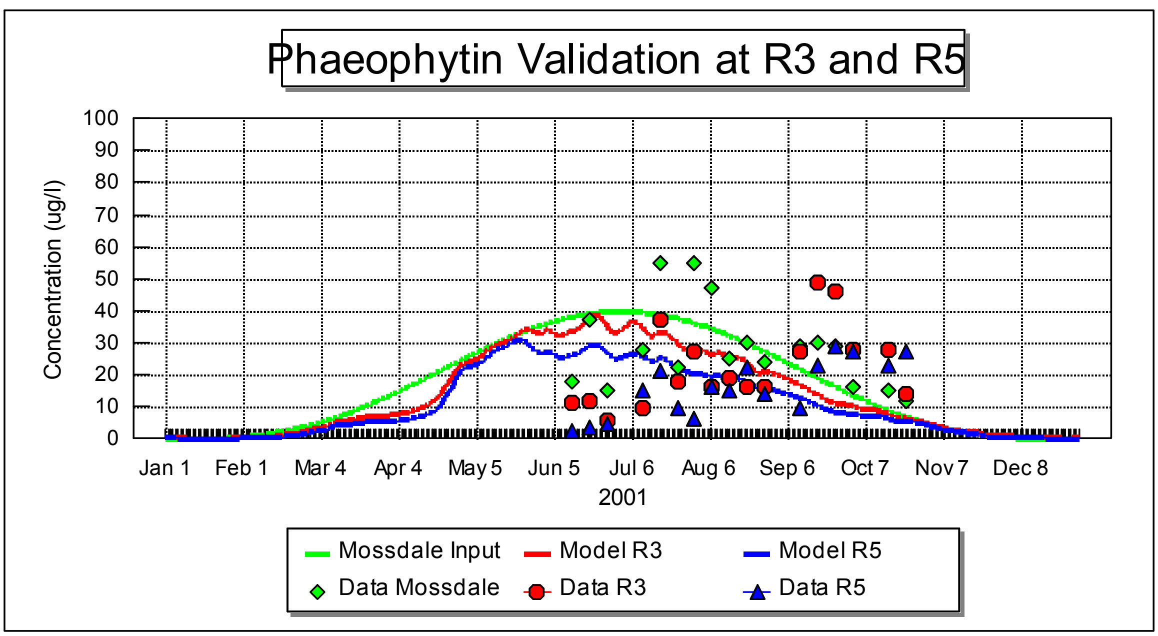


Figure 21. Model Simulated DO Concentrations Compared with DO Measurements in DWSC at R3 and R5 (Rough & Ready Island) in 2001.

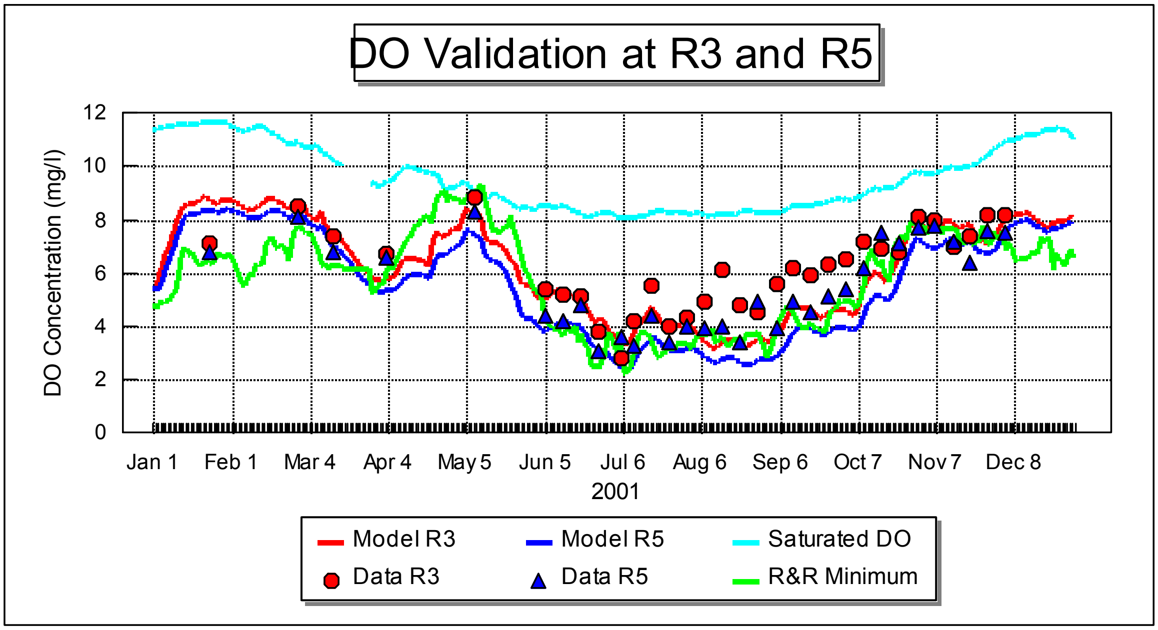


Figure 22. Simulated Travel Time Between Mossdale and DWSC at R3 and R5.

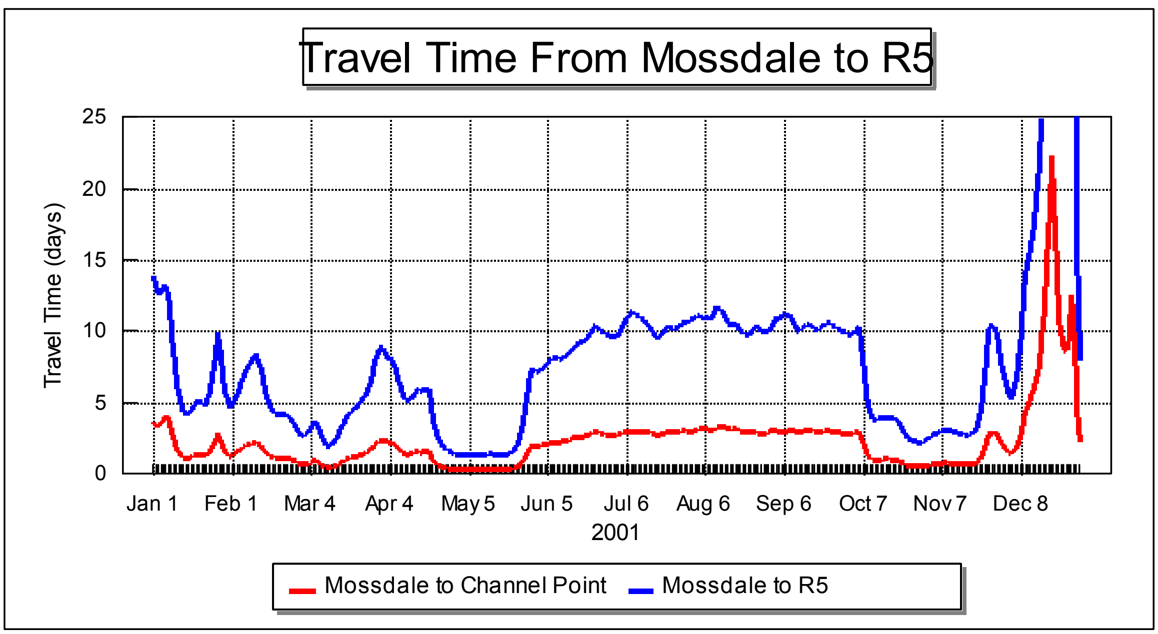


Figure 23. Sensitivity of Simulated DO at R3 to DWSC Flows.

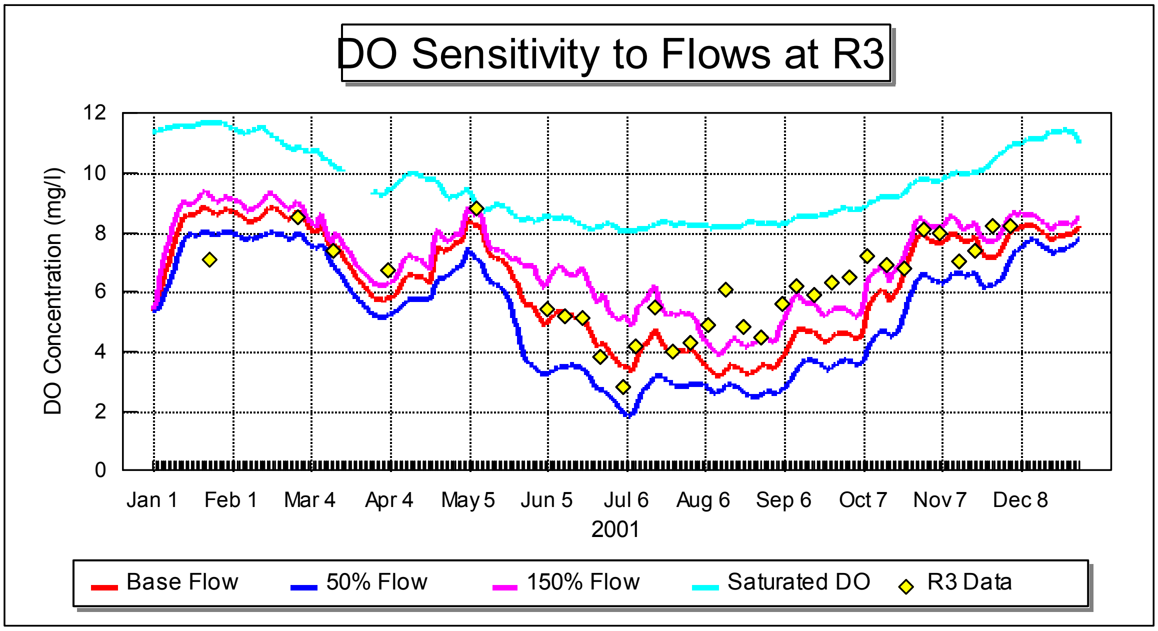


Figure 24. Sensitivity of Simulated DO at R5 (Rough & Ready) to DWSC Flows.

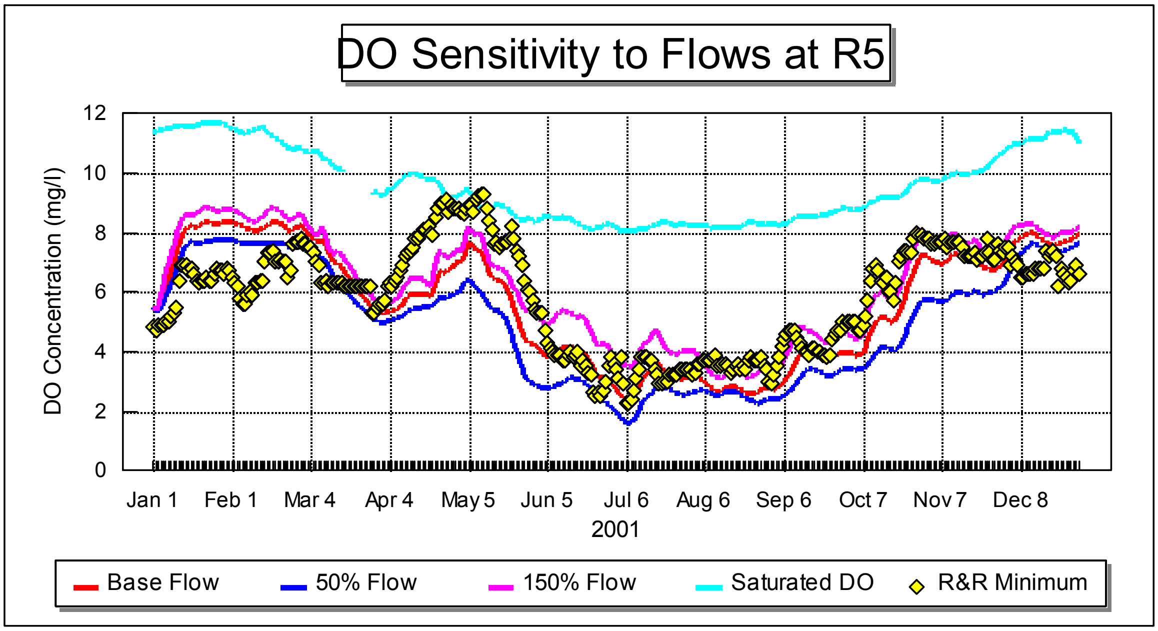


Figure 25. Sensitivity of DO at R3 to VSS and Algae Settling Rates.

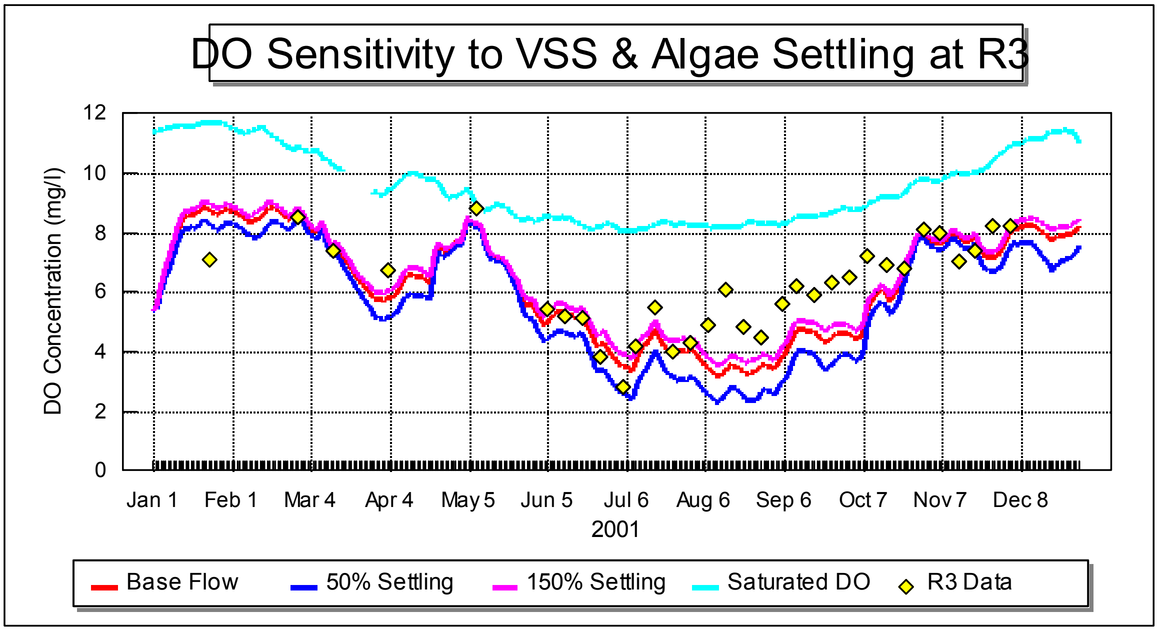


Figure 26. Sensitivity of Simulated DO at R5 to VSS and Algae Settling Rates.

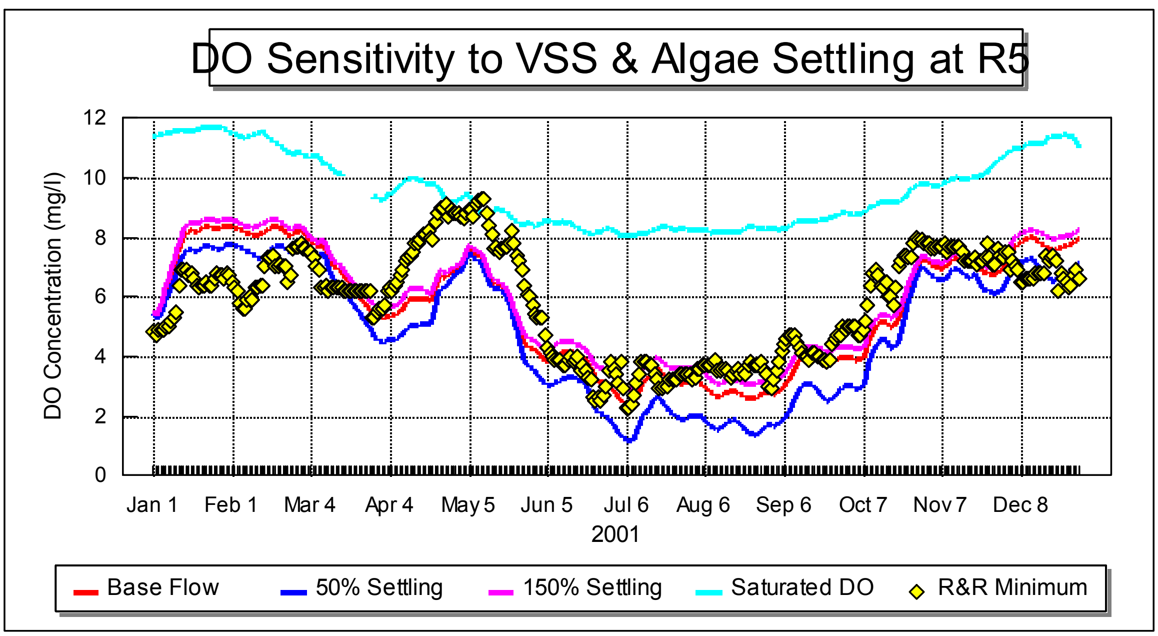


Figure 27. Sensitivity of Simulated DO at R3 to Algae Growth Rate.

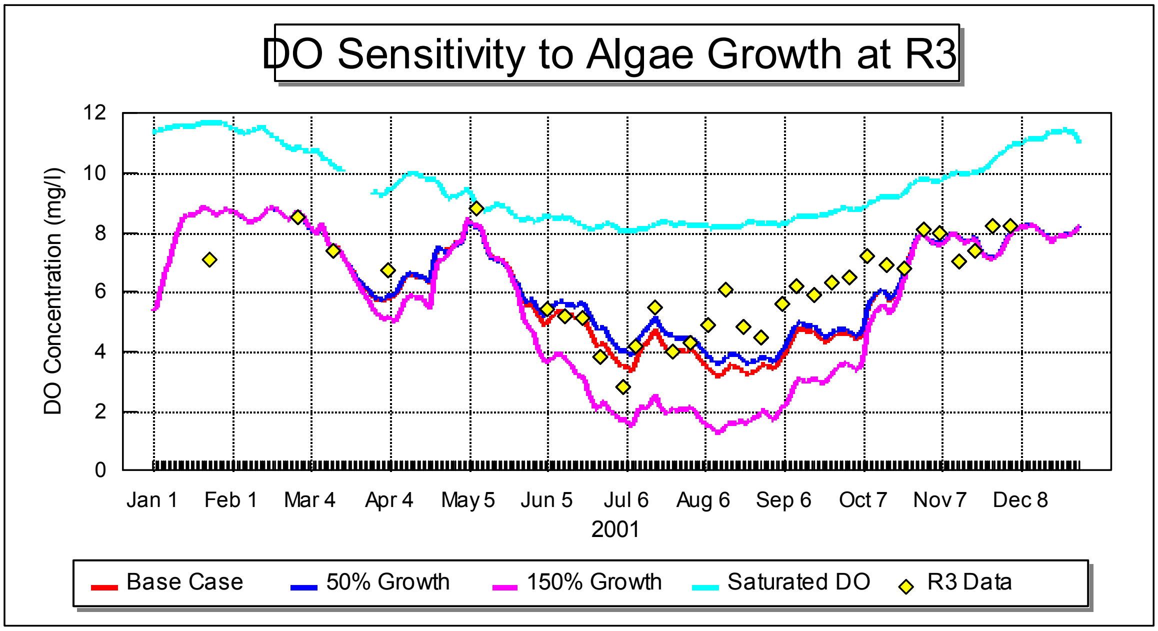
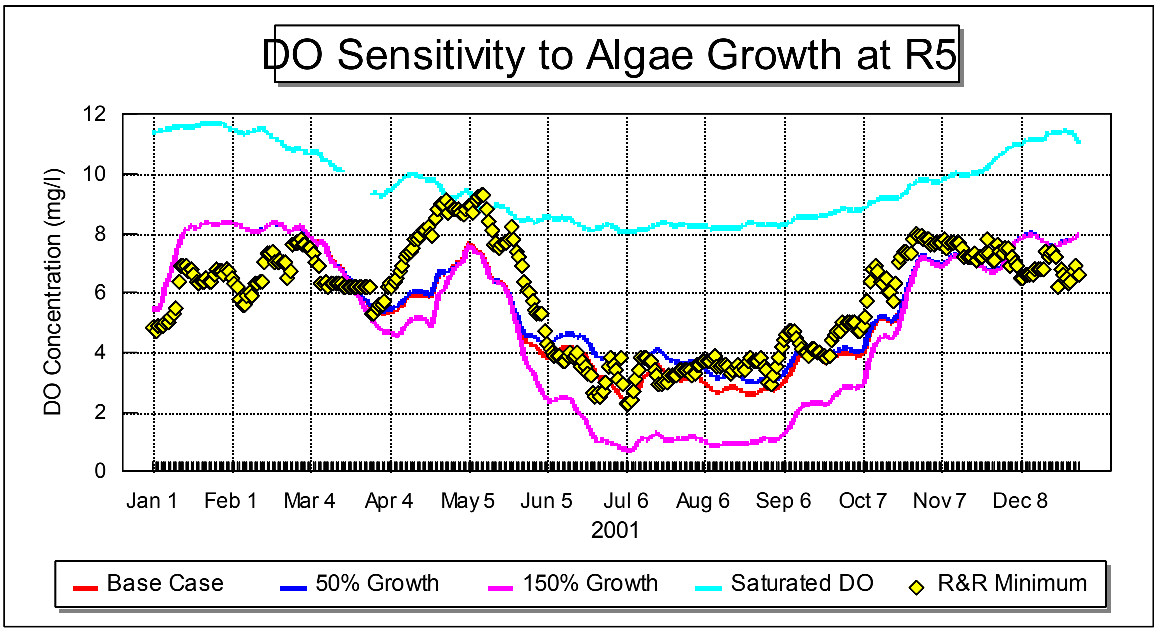


Figure 28. Sensitivity of Simulated DO at R5 to Algae Growth Rate.



Appendix B

Review of DWSC Modeling—What Should We Do Next?

PowerPoint Presentation by Russ Brown at SJR DO-TMDL Technical Work Group May 16, 2006.

Review of DWSC Modeling- what should we do next?

Russ Brown, Jones & Stokes

DO-TMDL Technical Work Group
May 16,2006

DO Modeling Ingredients

- Temperature (rates & DO saturation)
- Geometry (area, depth, width)
- Flow (cfs) and Travel Time (or movement)
- BOD: CBOD, NBOD, SOD, Detritus
- Algae: N/P/light/C-photosynthesis-pH
- Re-aeration f(wind) & aeration/O_2 injection

Calibration of DO Models

- Matching seasonal DO does not validate assumptions about model relationships, rates, responses, and inputs
- CBOD decay f(temperature,settling)
- SOD f(temperature, settling)
- NBOD f(temperature, nitrifying bacteria)
- Algae f(temperature,N,P, light,settling)
- Detritus f(algae decay, settling)

Purposes for DWSC DO Models

- Basic Understanding of DWSC Processes
- Evaluate flow and algae inflow effects
- Determine TMDL responsibility & credits
- Determine effects of management actions
  - Evaluate wastewater permit limits
  - Mitigation for DWSC deepening
  - Evaluate performance of oxygenation

DWSC Models Galore!!

- RMA 1-D link-node
- City of Stockton 1-D link-node
- DSM2-QUAL 1-D Lagrangian Transport
- HydroQual 3-D with sediment fluxes
- USGS/UC Davis/Stanford 3-D Hydro+WQ
- Statistical long-term relationships: DO=f( )
- RWQCB strawman report: Streeter-Phelps

Review of DWSC DO Models-Corps of Engineers-RMA 1988

- RMA Delta tidal hydraulic model for flows
- RMA link-node WQ model with Algae (N/P/light), Detritus, CBOD, Ammonia, SOD, temperature, DO
- 15 1-mile segments;1 month simulations for 7 years; time-series and longitudinal plots
- Sensitivity of inputs and coefficients; deepening
- WQ model suggested mitigation of 2,500 lb/day (0.2 mg/l) for deepening from 30 to 35 feet

Review of DWSC DO Models- City of Stockton-Systech 1993

- Link-node tidal hydraulic and WQ
- Algae (N/P/light), detritus, CBOD, ammonia, SOD, temperature, DO
- 23 segments from HOR to Turner Cut; July 90-Dec 91 calibration; time-series and long plots
- Verified for 1993, 1996; CALFED improvements (detritus, phaeophytin, re-suspension) for 1999, 2000, and 2001
- Used to evaluate effects of flows, wastewater loads (ammonia), and aeration in DWSC

Review of DWSC DO Models-DSM2-QUAL- DWR 2001

- DSM2-QUAL model based on 1995 PhD Thesis of Hari Rajbhandari
- Algae (N/P/light), CBOD, ammonia, SOD, temperature, DO
- DSM2-HYDRO Delta grid; 25 segments from HOR to Turner Cut; 1998-1999 calibration; 1996-2000 validation; time-series plots of Temp & DO
- 1976-1991 DSM2 planning studies can use selected river inputs from 1996-2000 for SJR

Review of DWSC DO Models-ECOMSED/RCA- HydroQual 2006

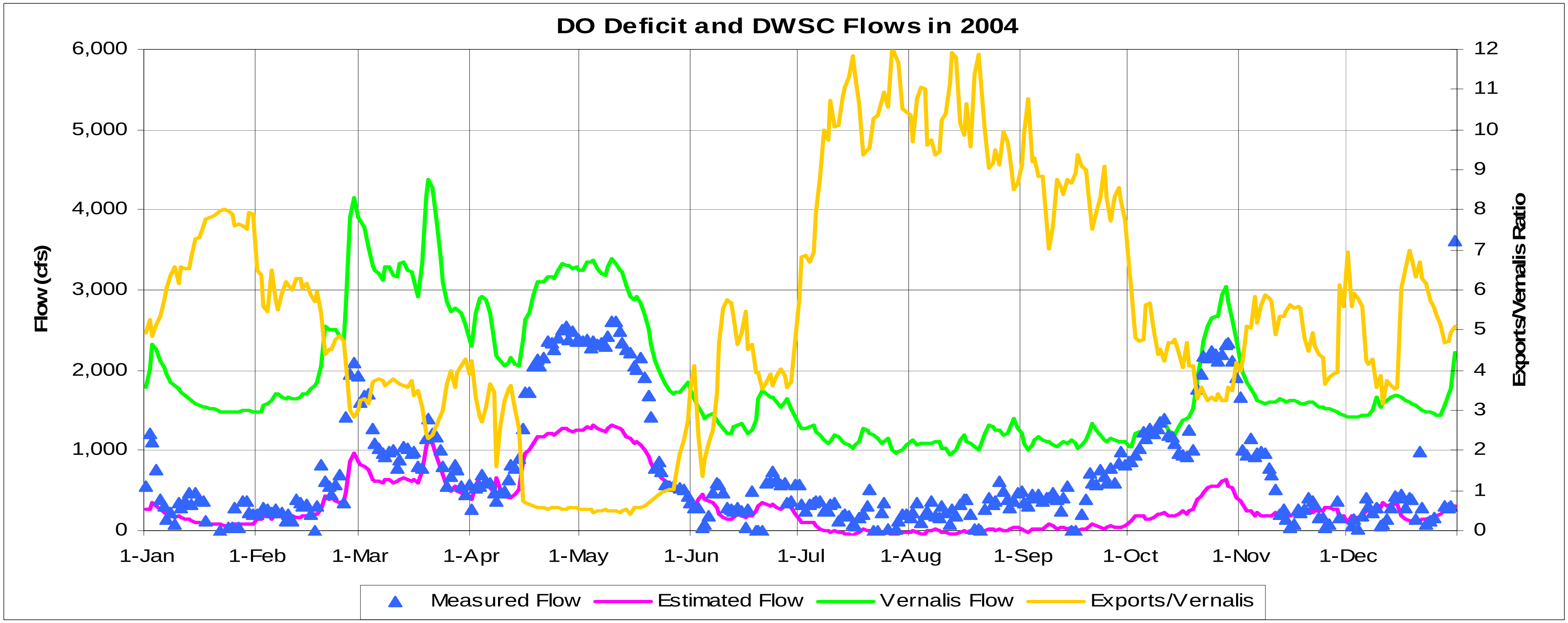
- HydroQual model based on 3-D ECOMSED/RCA with sediment flux
- Algae (N/P/light), CBOD, detritus, ammonia, sediment nutrient flux/SOD, temperature, DO
- DSM2-Delta results for tidal stage & flow; 25 segments from HOR to Turner Cut; 3 lateral sections with 10 layers; 2000-2001 calibration; time series plots of stage, flow, and water quality parameters at various stations (top and bottom)

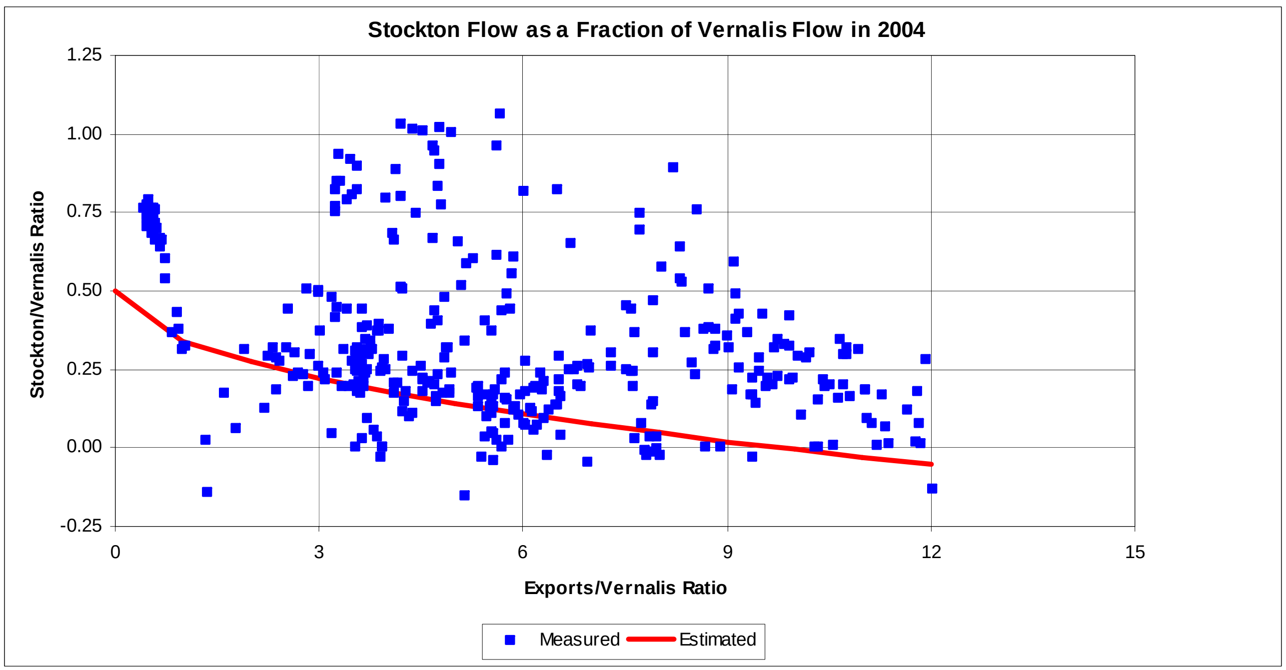
Review of DWSC DO Models-USGS,UC Davis,Stanford 2007

- 20-m 3-D Hydrodynamics by Pete Smith,USGS; 1-m layers (800,000 cells)
- Tidal flows and temperature stratification, DO model within 3-D flow computations to be developed by UC Davis
- Three 1-month intensive hydrodynamic and water quality surveys throughout DWSC by UC Davis and Stanford; August 2004 and August 2005

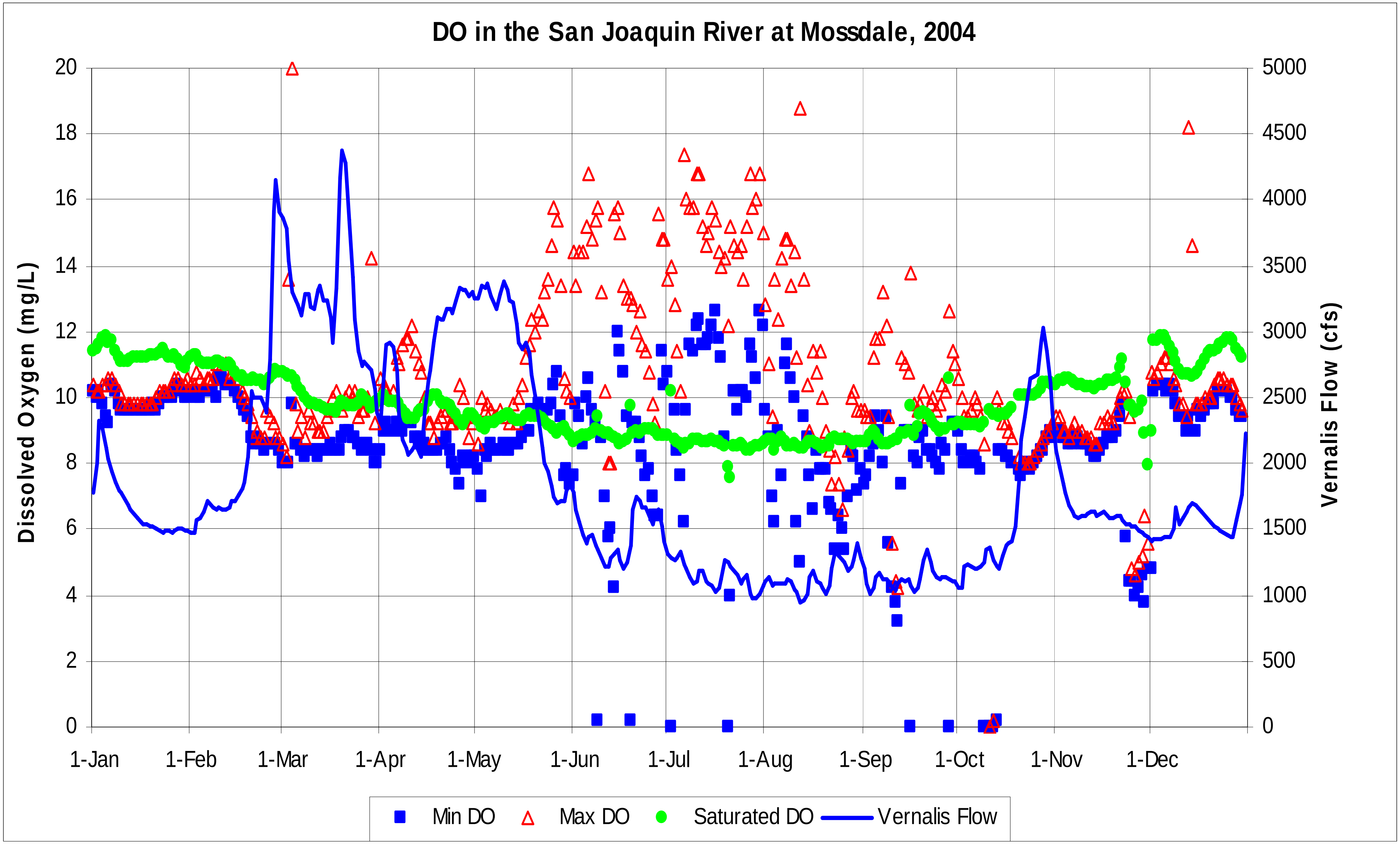
DWSC Data Atlas

- 1984-2005 daily flow, EC, pH, T, SS, DO
- RWCF effluent concentrations
- Provide comparisons between years
- Show patterns of flow, EC, DO, and algae
- Identify basic relationships for DWSC
- Provide model inputs and calibration data

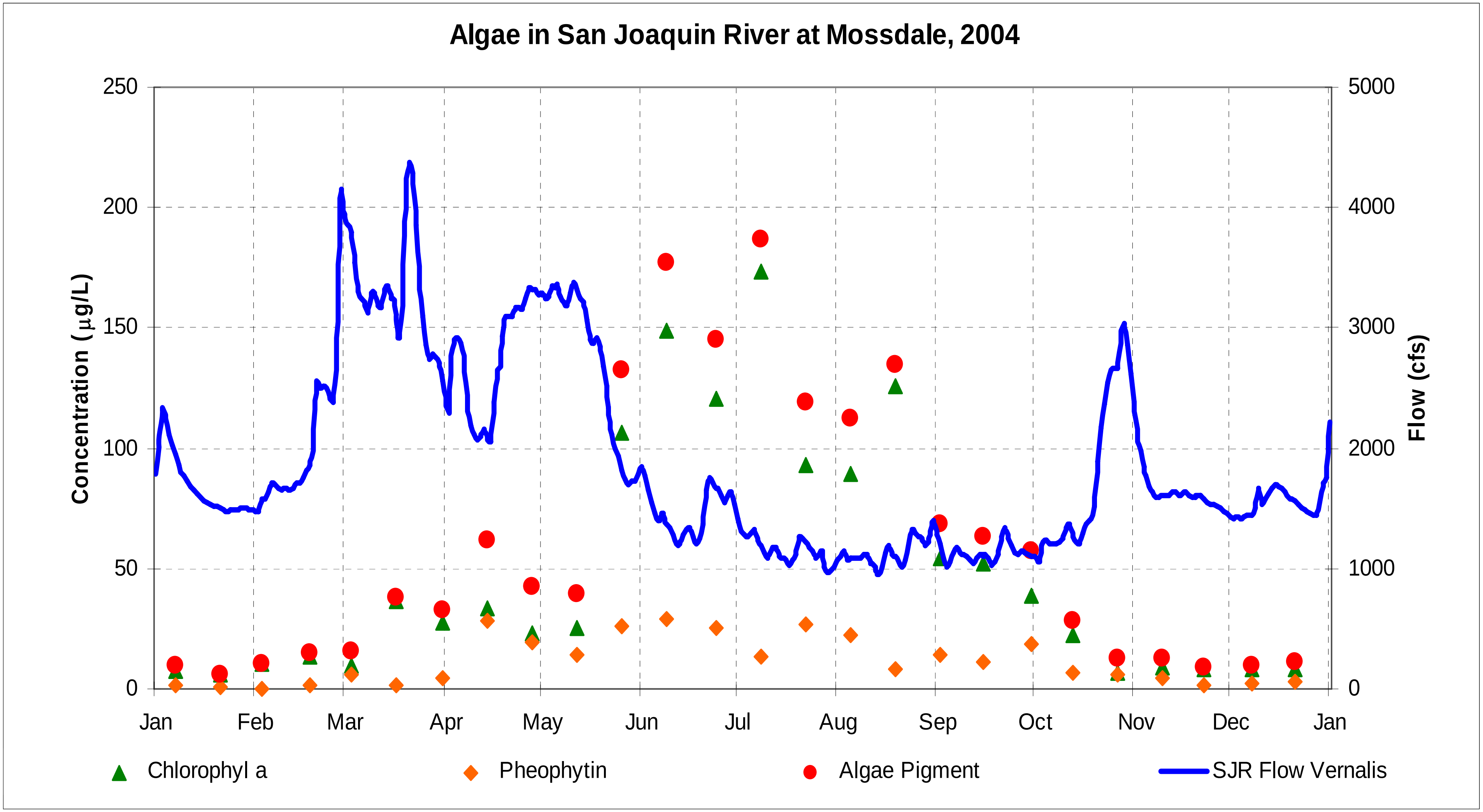




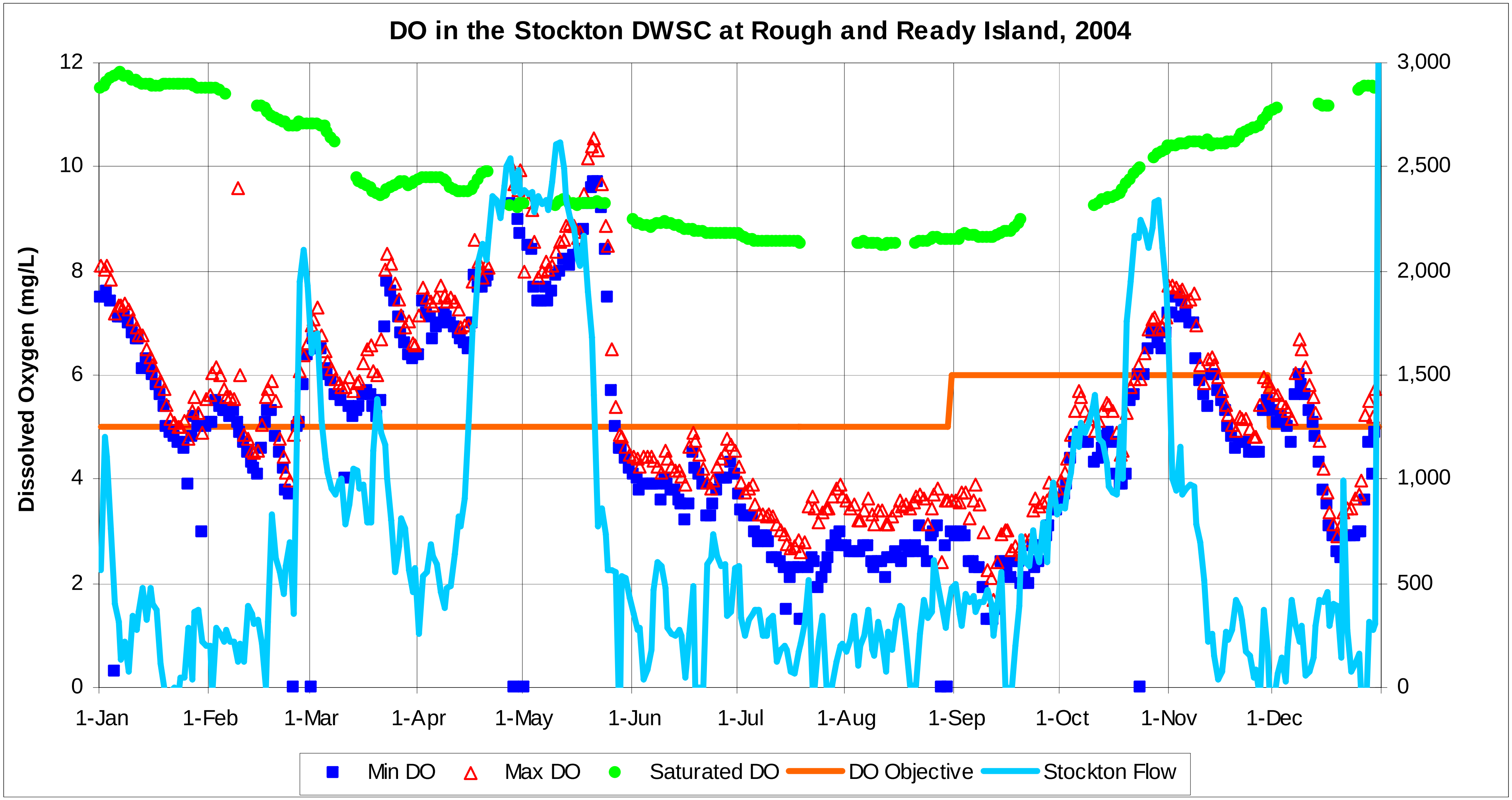
Measured Stockton flow data is very important, and difficult to estimate or model accurately



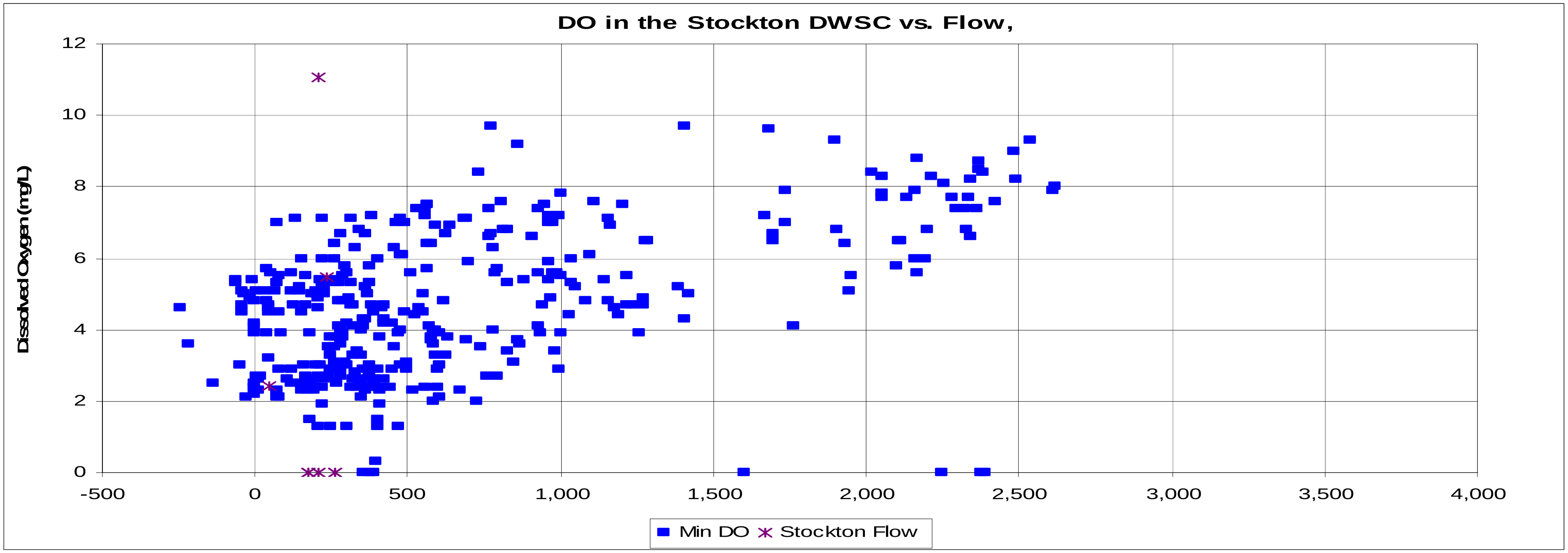
DO at Mossdale is usually saturated or supersaturated in summer- can we estimate algae biomass from diurnal DO and pH?

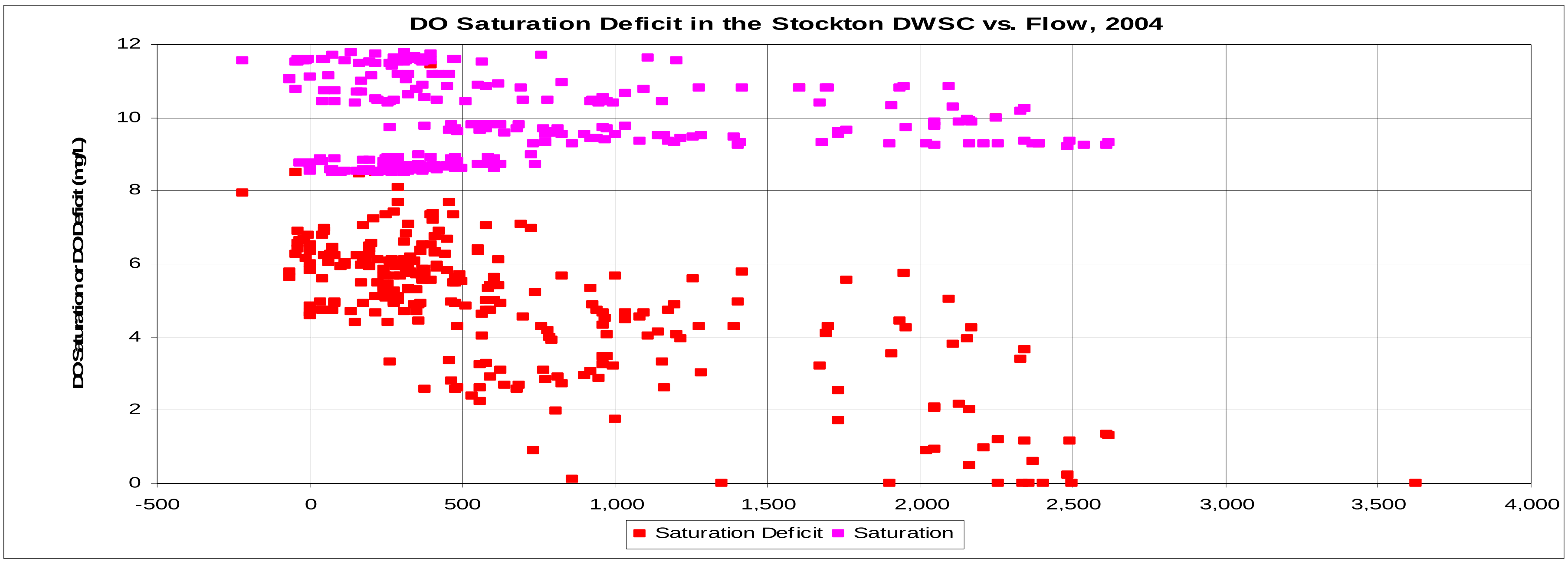


How will the DWSC respond to SJR flow and algae? What else would you like to know about to make a better prediction of DWSC DO?



DWSC DO is often lowest during winter and summer low flows



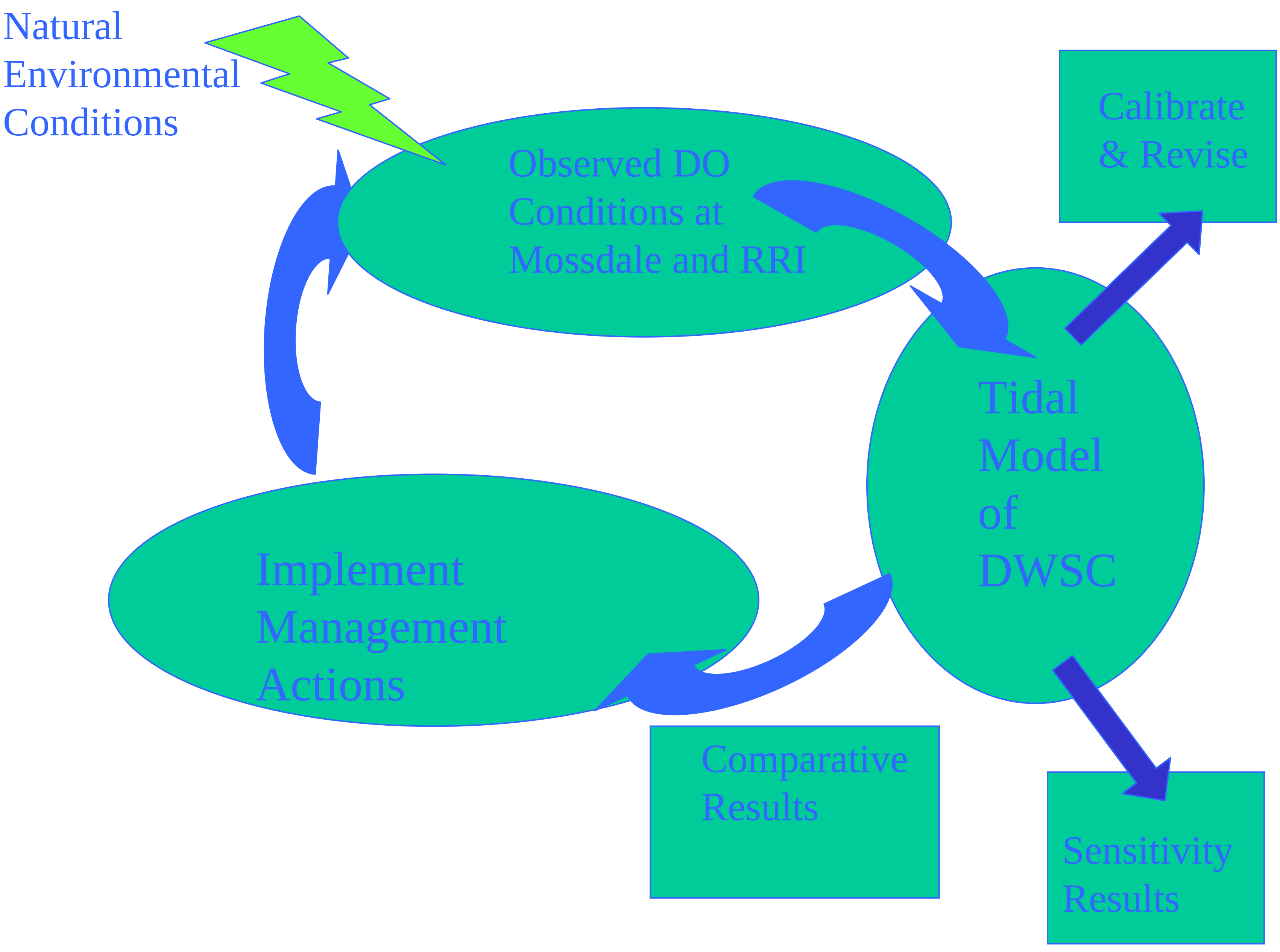


DO Deficit in the DWSC appears to decrease at higher flows

DWSC Modeling of Flow, Stratification, Turbidity, Algae and DO

- There should be more direct interaction between data collection efforts and modeling integration and interpretation
- All potential controls of flow and sediments and nutrients and algae on the SJR and DO in the DWSC should be integrated and adaptively managed by a team

Adaptive Management of the DWSC



Suggested Future DWSC Modeling Efforts

- Estimate daily inputs needed for DWSC
- Historic simulations of 1984-2005 (RRI)
- Update inputs & simulation for each year
- Sensitivity of stratification and DO to wind, sun, tides, and flow
- Determine algal dynamics (movement, photosynthesis, respiration) in the DWSC

Suggested Future DWSC Modeling Efforts

- Effects of increased flow (with algae)
- Effects of RWCF ammonia on algae & DO
- Effects of aeration and oxygen injection
- Forecast DWSC DO for the next week
- Your best idea goes here
- Your other ideas go here