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

Originally
prepared by Jones & Stokes
(now ICF International)
Contact: Russ Brown
916-737-3000
rbrown@icfi.com

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Introduction

The Central Valley Regional Water Quality Control Board (RWQCB) Control Program for the San Joaquin River (SJR) dissolved oxygen (DO) total maximum daily load (TMDL) requires that those responsible for the loads of BOD and nutrients that may stimulate algae growth in the SJR perform studies to evaluate the impacts of these source loads on DO in the 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 SJR 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 our best hope 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.

A modeling capability matrix will be used to show the overall match between the specific purposes of models and the basic capabilities of the available models. Potential needs 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:

- 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.

- 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 would be 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.

- 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 of the 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 Cutoff).

- Identify missing model features or field data that may prevent accurate evaluations of some TMDL issues or management options. Examples of modeling gaps might be re-suspension of detritus and sediments from the bottom, zooplankton and benthos grazing effects on algae, algae death/decay (chlorophyll/phaeophytin ratio) or episodic light response, and the nitrifying bacteria biomass.

This report has been written on a relatively short time-frame, but the current modeling group (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 SJR DO-TMDL technical working 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, 2006, 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 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 (CALFED 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 for Water Quality Models

Water Quality models are an important component of the adaptive management of natural resources, as illustrated in Figure 1. A general model of the water body is necessary to provide interpretation and integration of the available field data and monitoring records. Management decisions are based on the modeled comparison of a series of alternatives. The alternative with the most promising performance and with the least environmental effect on other resources likely would be selected for implementation. Measurements with model interpretation of the results should be used to check the original expectations and provide performance assessments and evaluations for future actions. Modeling in this general sense is used as an information tool. Monitoring without model interpretation and integration may provide data but little useful information.

Models should serve to increase the information content of the field data and monitoring records. 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 our understanding of the physical and biochemical processes and variables that influence DO in the DWSC.

Calibrated models are appropriate tools for comparative analysis. Environmental planning requires us to look ahead to avoid or mitigate environmental impacts. Environmental restoration attempts to improve the habitat water quality conditions necessary for aquatic organisms. Models may be generally useful in several ways; models can become more useful when applied according to a logical plan of study rather than run randomly or intermittently. Models should be used iteratively and indefinitely as part of the adaptive management and environmental monitoring process.

Previous Models of Dissolved Oxygen in the Deep Water Ship Channel

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 and 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 ft above mean sea level (msl). It was anticipated by the

Corps that deepening of the DWSC by about 5 feet (ft) could have a potential negative effect on the DO concentrations. This development and application were documented in a technical report (RMA 1988) and a Sacramento District office report (Corps 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 between the turning basin and Turner Cut). The Delta tidal model extended to Antioch and used daily inflows provided in the California Department of Water Resources (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 the fall of 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 ft 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, biochemical oxygen demand (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 month-long period. Model coefficients were adjusted and used for all simulation periods. For example, the sediment oxygen demand (SOD) was set at 1 gram per square meter per day (g/m^2/day). The light extinction was held constant, with 1% light level at 5 ft, equivalent to an extinction coefficient of about 1.0 ft^{-1}. The RMA model included detritus, BOD, SOD, ammonia (NH_3), and two algae biomass variables (with different growth, respiration, and settling rates). A total of 33 coefficients were specified, and inflow concentrations were specified for each period. City of Stockton treated wastewater was added. Some periods were prior to tertiary treatment (began 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 SJR 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 (i.e., increased flow) was greater than observed data indicated.

A series of comparisons was made with a channel depth of 30 ft and 35 ft 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 pounds per day (lb/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 all were 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 of 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 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 from 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 also was 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 provide integration and interpretation of more intensive DWSC data collected in 1999, 2000, and 2001 as part of two CALFED Grants. In addition to DO, carbonaceous biochemical oxygen demand (CBOD), nutrients (ammonia, nitrate, and phosphorus), and algae biomass, the model variable list was expanded to include detritus (volatile suspended solids [VSS]) and phaeophytin (representing dead algae biomass). Wind-driven reaeration was added. Settling and re-suspension of detritus (VSS) and inorganic sediment were added. Model changes were made to track and output the daily fluxes of various processes that contribute to the sink or source 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 US Environmental Protection Agency (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 SJR illustrated the importance of frequent river measurements. The infrequent (bi-weekly or monthly) river concentration data were 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 TWG and participates in the upstream modeling team. The City of Stockton model currently is used as part of the Watershed Analysis Risk Management Framework (WARMF) model and user interface for the SJR 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 Quality 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 RRI stations 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) 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 Rough and Ready Island (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 of 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 generally are determined by first running the DSM2-Hydro module. Simulations for the 5-year period (1996–2000) include 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 contract. They have just submitted their final report for the DWSC modeling task (May 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 (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 simulated surface and bottom DO 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 of diurnal variation.

The water quality model (RCA) is the combination of an eutrophication model (i.e., nutrients-light-algae) and a sediment model. The SOD rate is estimated from the flux of organic material deposited 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. There are many new model parameters 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 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. There is no re-suspension of material from the bottom of the DWSC simulated in the RCA model. The ECOMSED/RCA model was calibrated with 2000 and 2001 DWSC data.

UC Davis/Stanford/USGS Model. A fifth model is under development by USGS, UC Davis, and Stanford. This model development is also supported by a CALFED grant that included extensive data collection efforts in August of 2004 and August 2005. These field data captured periods of stratification and water quality gradients (longitudinal, lateral, vertical) observed within the DWSC. A 20-meter (m) 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., acoustic doppler current profiler [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 within the DWSC.

Other DWSC DO 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 R&RI 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 SJR 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 certainly will improve our 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 (i.e., 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 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 SJR 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 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 therefore may 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* (Jones & Stokes 2002) investigated the calibration and sensitivity of the improved City of Stockton

Water Quality model. This previous report 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 may increase 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 normally will 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 within the DWSC are important in determining sensitivity. The settling and re-suspension 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 SJR, 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 generally will 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). 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 demonstration 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 DO into a side stream of 50 cfs pumped from the RRI monitoring station at a depth of 10 ft, and discharged at 40 mg/l above the ambient DO concentration through a diffuser located at a depth of 15 ft and about 1,000 ft 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 1,000 cfs also could 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.

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 Cutoff).

There is ongoing work developing and calibrating the upstream water quality model for the river and watershed upstream of Vernalis. This model has been developed by Systech for other TMDL studies, and is called WARMF. The SJR model currently extends upstream to Lander Avenue. With continuing interest in restoration of the SJR below Friant Dam, the watershed and river water quality model could be extended upstream to Friant Dam. There is a version of the SJR WARMF that includes the improved City of Stockton Water Quality Model. This is the easiest way for a stakeholder to obtain direct access to one of the DWSC water quality models. This modeling package includes a graphical user interface that allows comparison graphs between two or more model runs, and calibration graphs of the field data.

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

(1) Historical simulations of 1986–2005

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. For example, the USGS tidal flow measurements began in 1996. The SJR 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.

(2) Updated simulations for future years

A new set of annual inputs should be estimated for each calendar year. The last year that has been simulated with any of the DWSC water quality models is 2001. A similar historical simulation is being completed by DWR with the Delta tidal hydraulic and electrical conductivity (EC) model (DSM2). The DWSC modeling can use the tidal simulation results produced by DWR 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. .

(3) Sensitivity of historical simulations to increased DWSC river flow (with algae)

One of the "mysteries from the past" is the rather weak evidence from the DWR boat surveys that there is any increased DO response from 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 the 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?

(4) Sensitivity of sun, wind, and tide on stratification and DO

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 of 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).

(5) Effects of Stockton RWCF discharge on DWSC algae and DO

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 of 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 (i.e., 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 SJR 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?

(6) Effects of reaeration and oxygenation devices on DO in the DWSC

The effects of the Corps aeration facility 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 R&RI 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 the oxygenation device, depending on the flow, measured DO, and simulated DO conditions.

(7) Effects of DWSC 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 SJR 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.

(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 (six cases) and maximum seasonal algae concentration increments of 50 micrograms per liter (µg/l) (5 mg/l biomass), from 50 µg/l (5 mg/l) to 250 µg/l (25 mg/l) (six 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 DWSC 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 likely will develop in the near future (i.e., 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 SJR has only just begun. Other TMDL implementation plans are being developed, there is interest in restoring salmon upstream to Friant Dam, there are Reclamation studies of DMC-SJR recirculation, and the Corps of Engineers may yet again deepen the DWSC from 35 ft to 40 ft. 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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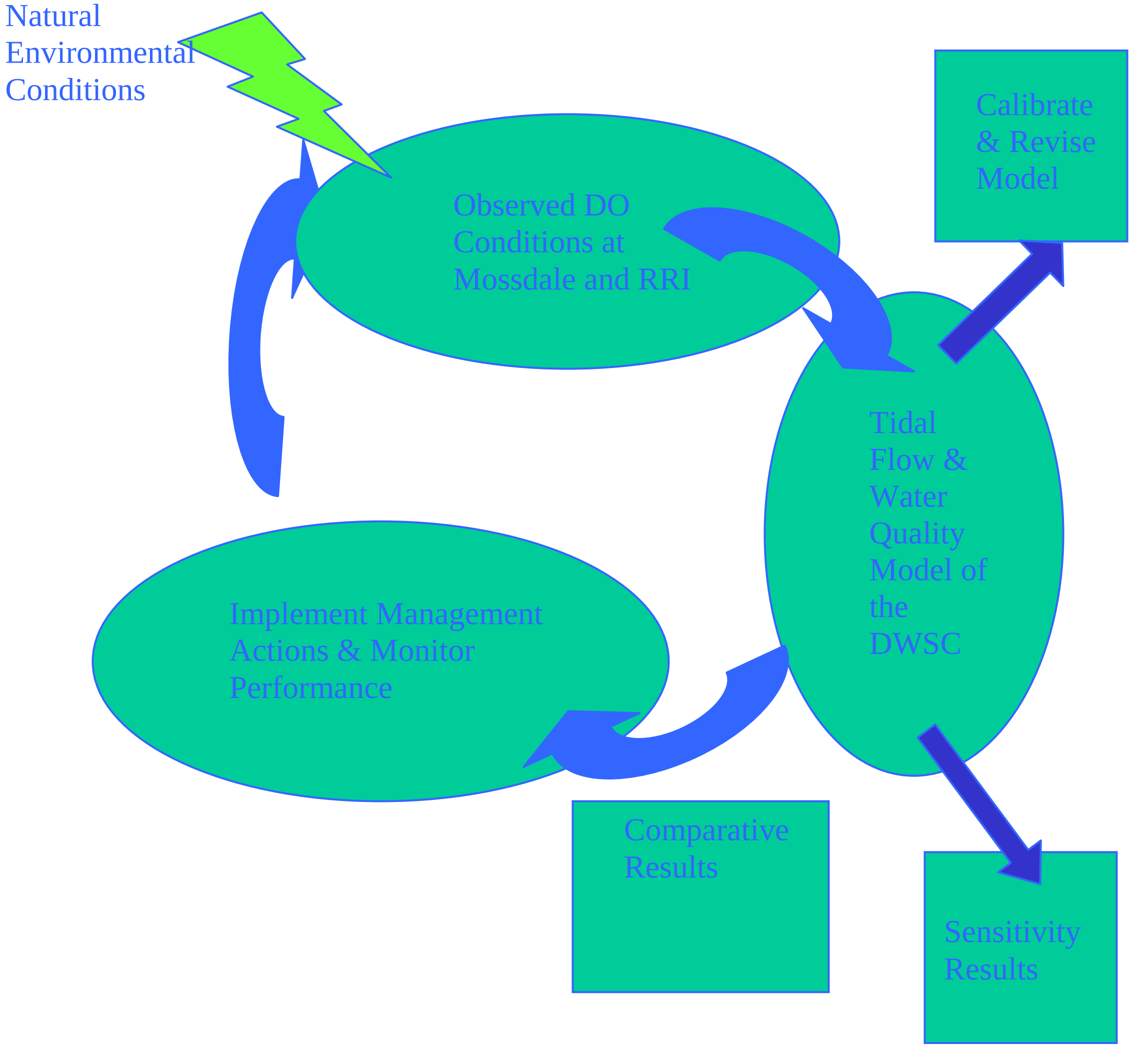

Figure 1. Adaptive Management of the DWSC with a combination of Water Quality Modeling and Field Data Collection and Monitoring