Review Panel Report

Ecosystem Restoration Program Independent Review Panel

The San Joaquin River Stockton Deep Water Ship Channel Dissolved Oxygen Total Maximum Daily Load - WARMF and Link-Node Models

Panel Members

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EXECUTIVE SUMMARY

This review of the Watershed Analysis Risk Management Framework (WARMF) and Link-Node models provides information and recommendations intended to help the Central Valley Regional Water Quality Control Board (Regional Board) make appropriate use of the models to implement the dissolved oxygen (DO) TMDL. The major findings and recommendations of the review include:

(1) The data gathering elements of the project have been impressive. Extensive and well planned efforts have been guided by identified data needs and knowledge gaps. Further, these efforts have had clearly identified approaches, quality assurance and control methods, and have been well documented.

(2) The model implementation and application process has been an ongoing effort, with initial findings guiding additional work. This process of ongoing model development through model application and additional data collection increases model representation, decreases model uncertainty, and increases model confidence.

(3) The WARMF model representation encompasses a large portion of the San Joaquin River (SJR) basin below the rim dams on the major tributaries. The amount of data and information required for such an application is remarkable: assumptions regarding model inputs, boundary condition and calibration data, model coefficients and parameters, and model performance metrics to name the principal needs. Given these conditions, the Review Panel (Panel) recommends:

   a. Improvement of certain data sources and comprehensive model documentation.
   b. Calibration of component inputs, such as, westside tributaries and groundwater.
   c. An extensive uncertainty analysis to provide a quantitative means to convey model uncertainty to decision-makers such that identified TMDL actions and prescriptions can be dependably developed and implemented.

While the WARMF model needs several improvements to be useful as a TMDL tool for assigning responsibility to upstream discharges, it is probable that such improvements are possible. However, while WARMF has been identified as a tool to “facilitate easy use by stakeholders who have little or no familiarity with modeling watersheds or water quality” (ref 8), this outcome has not been realized in the San Joaquin Basin application. This is a complex application of WARMF and only a small cadre of modelers is qualified and capable of applying the model and fully interpreting the output.

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(4) The Link-Node model represents a portion of the southern and central Delta, including the Stockton Deep Water Ship Channel (DWSC). This region experiences complex morphology, hydrology, meteorology, and water quality. The Link-Node model does not appear to be appropriate to sufficiently address all the questions that are before the Regional Board regarding DO impairments and appropriate prescriptions to remedy the impairments. In particular, the DO impairments and associated processes in the DWSC are characterized by both longitudinal and vertical gradients, which are driven by tidal hydrodynamics, among other processes. The Panel feels that the one-dimensional characteristics of the Link-Node model restrict the use of this tool in developing screening level analyses alternatives, which are most likely insufficient to support TMDL required actions.

(5) The Panel considers the reduction of nitrogen inputs in the upstream watershed to be a desirable management plan for the DO TMDL. Despite uncertainty over what the actual algal reduction and DO improvement per unit of nitrogen removal might be, the Panel is convinced that such actions would yield measureable improvement in downstream reaches.

(6) Although the topic of phytoplankton contributions from the upper SJR watershed (Mud Slough and Lander Avenue) was part of the review, the discussion of management plans to reduce this source of algae was not. Nevertheless, the Panel feels it is worth mentioning a seemingly plausible plan to reduce a portion of this algal source. In the summer months, the SJR at Lander Avenue typically has very low flow (<10 cfs) with a very high algal content. The land adjacent to the SJR in this reach is owned by the State Department of Parks and Recreation and managed as the Great Valley Grasslands State Park. If a portion of the parklands could be turned into a flow-through, managed wetland to reduce the algal content of the water, this could reduce the algal contributions from the upper watershed.

FOREWORD

This Review was sponsored by the Ecosystem Restoration Program (ERP) and was facilitated by UC Davis. The Review required substantial time and effort from the staff and consultants of the Regional Board. The Panel evaluated a great deal of reference material on the models provided by the Project Team. The Panel appreciates the wealth of information and detail that the Project Team has assembled on the models and their application to the DO issue in the DWSC. The Panel carefully reviewed the materials to provide a Review commensurate with the important role of the models in the regulation of oxidizable substances and other factors and processes that may affect DO through a TMDL. This Review Report provides the thoughts, suggestions, and recommendations of the Panel.

Funding for this Review was provided by the ERP. The ERP was established to fund and implement fish and wildlife restoration efforts in California's Bay-Delta. A major objective of the ERP is to improve the health of the Bay-Delta ecosystem by restoring and protecting habitats and native species. The ERP is implemented cooperatively by the California Department of Fish and Wildlife, the US Fish and Wildlife Service, and National Marine Fisheries Service.

BACKGROUND FOR REVIEW AND REPORT

San Joaquin River Watershed

The SJR is the largest river in Central California. The 366-mile long river starts in the high Sierra Nevada mountain range and travels northwest through the San Joaquin Valley where it meets the Sacramento River at the Sacramento-San Joaquin Delta and then flows out toward the Pacific Ocean (fig. 1). The SJR is relatively shallow (~8-15 feet) upstream of the City of Stockton. Starting at Stockton and heading west to San Francisco Bay, the river has been dredged and forms the Stockton DWSC (fig. 2).

Figure 1. San Joaquin River Watershed

The Stockton DWSC is a navigation channel used by ocean going cargo vessels to transport goods to and from the Port of Stockton. It begins at Stockton and heads westward where it merges with the John F. Baldwin Channel near Antioch (fig. 2). Depths in the DWSC can vary between 35-45 feet depending on location.

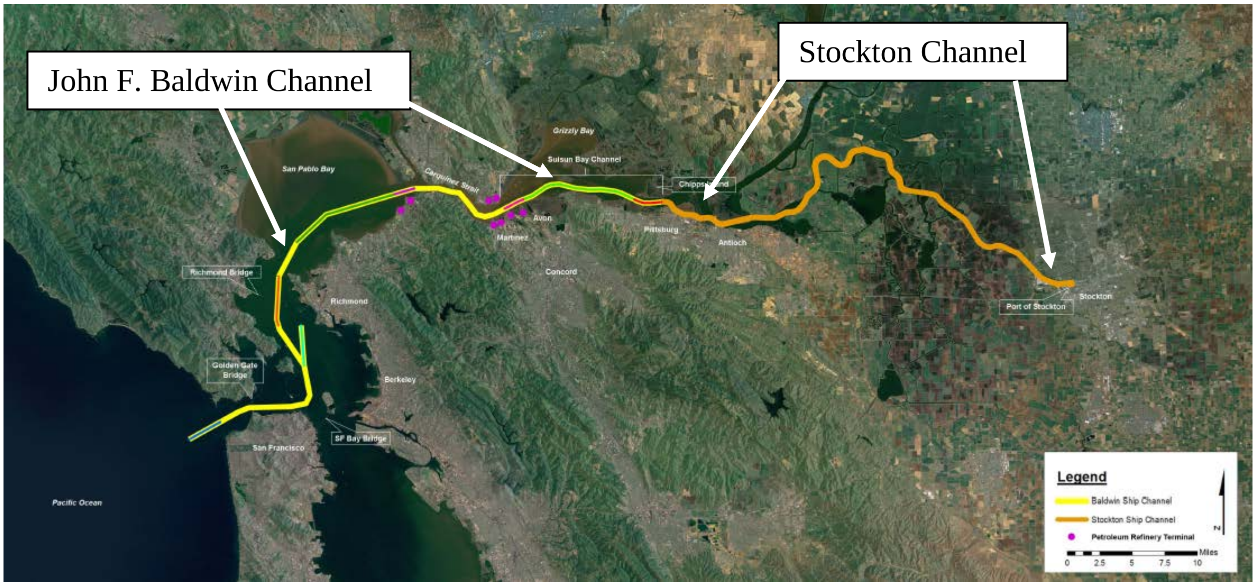

Figure 2. Deep Water Ship Channels of the lower San Joaquin River

Dissolved Oxygen Impairment

Historically, the lower SJR in the first 14 miles of the Stockton DWSC experienced regular periods of low dissolved oxygen (DO) concentrations from the City of Stockton to Disappointment Slough (fig. 3). More recently with upgrades to the City of Stockton's wastewater treatment plant, the impairment now occurs only within the first 7 miles of the DWSC from the City of Stockton downstream to Turner Cut. The location where the DO depression is greatest is downstream of Stockton next to Rough and Ready Island.

The low DO conditions in the Stockton DWSC often violate the DO water quality objectives. The objectives are contained in the *Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin* (Basin Plan, Fourth edition - 1998). There are two parts to the Basin Plan DO objectives that apply to the lower SJR. The first part of the objective is 5.0 milligrams per liter (mg/L) at all times in the river within the Delta (excluding the section of the river west of the Antioch Bridge). The second part of the objective is a site specific objective of 6.0 mg/L, applied only in the fall from 01 September to 30 November to the stretch of river from Stockton downstream to Turner Cut.

TMDL Control Program

In January 1998, the State Water Resources Control Board first adopted a Clean Water Act Section 303(d) list that identified the low DO impairment and ranked it as a high priority for correction. This initiated the need for the Regional Board to develop a Total Maximum Daily

Load (TMDL) to identify the factors contributing to the impairment and apportion responsibility for correcting the problem. In January 2005, the Regional Board adopted a TMDL that identified three contributing factors:

- Loads of oxygen demanding substances from upstream sources and from the City of Stockton Wastewater Treatment Plant
- Geometry of the DWSC
- Reduced flow through the DWSC

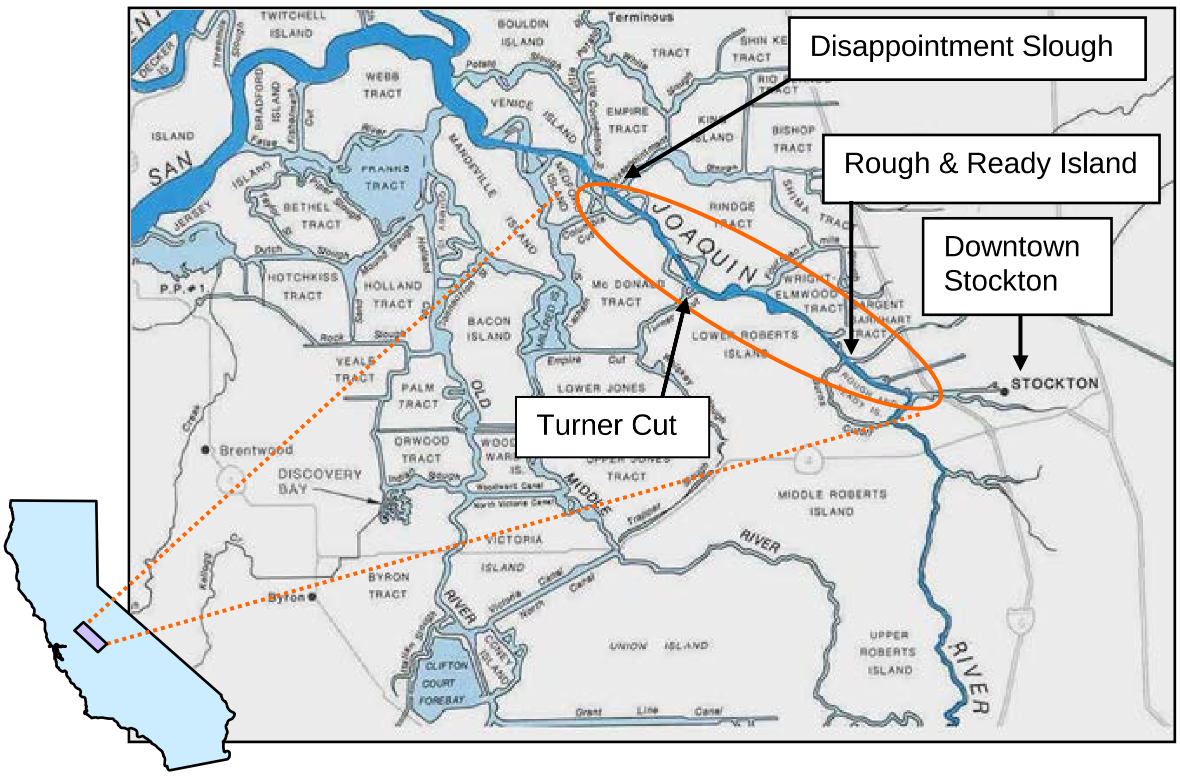

Figure 3. Map of the Impaired Reach of the lower San Joaquin River

The TMDL recognized that more studies were necessary to better understand the sources, transport and fate of the oxygen demanding substances from the upstream watershed, and the downstream impacts once these substances were transported into the DWSC. The first of these studies were initiated in 2005 and the final studies were completed in 2012.

TMDL Control Program Studies

For the TMDL studies, the SJR watershed was broken down into two sections – the upstream, riverine watershed from Mossdale to its confluence with Bear Creek at Lander Avenue, and the downstream, estuarine watershed from Mossdale to Disappointment Slough (fig. 4). The watershed upstream of Mossdale is non-tidal, while the downstream portion is tidally-influenced.

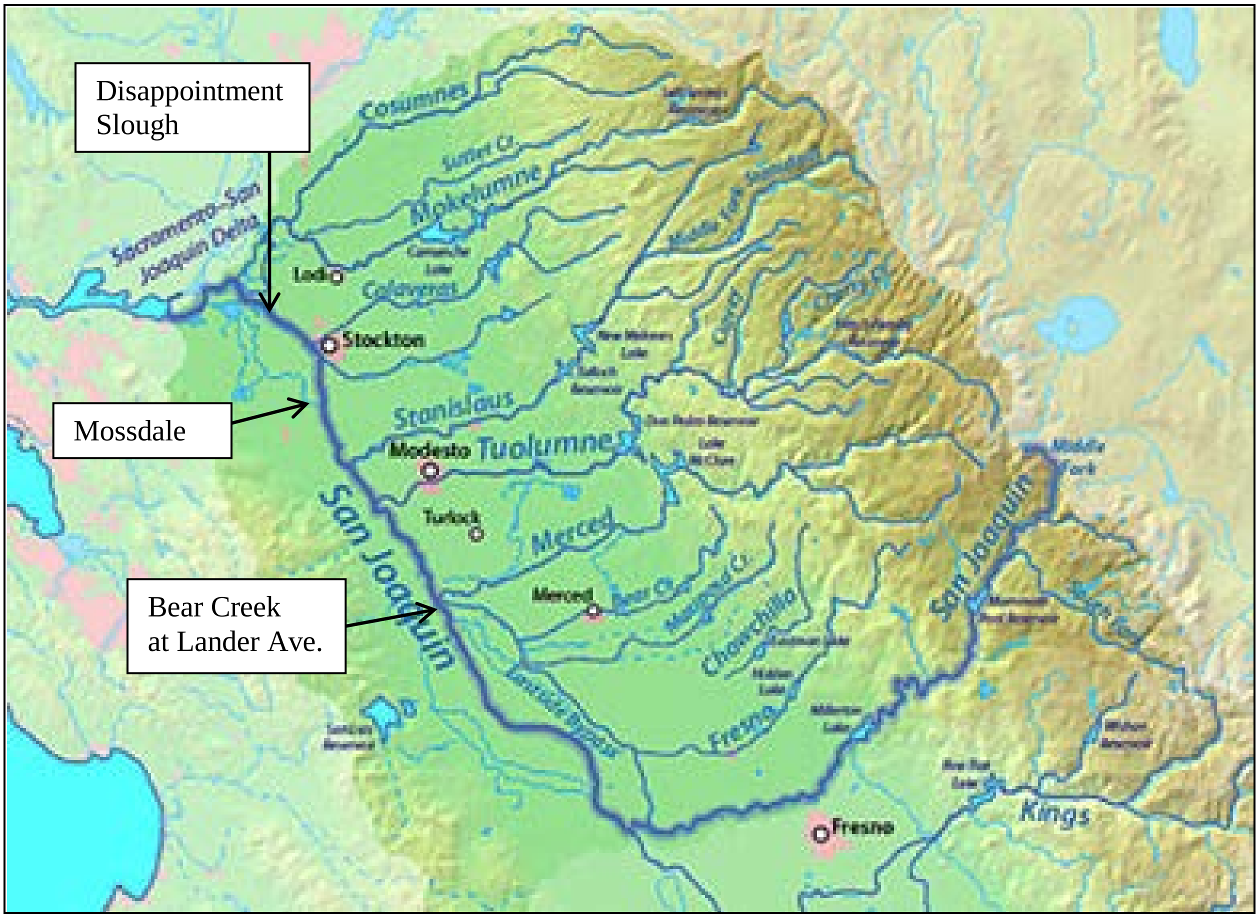

Figure 4. Upstream and Downstream Sections of the TMDL Watershed Studies

The upstream studies focused on measuring all major and most minor non-point source discharges to the SJR, identifying and quantifying oxygen demanding substances and their precursors and developing a water quality model (WARMF) to describe their fate and transport from the upper basin to Mossdale. This included a description of changes in algal biomass as it moved down river.

The downstream studies focused on collecting and analyzing data on the sources of nutrients, phytoplankton, and oxygen-consuming materials, and developing a water quality model (Link-Node) describing how the decay of all oxidizable material influenced DO concentrations in the tidal river between Mossdale and Disappointment Slough.

TMDL Models – WARMF and Link-Node

Two models were applied to the SJR and DWSC watershed as part of the DO TMDL – the WARMF model and the Link-Node model.

The WARMF model is a USEPA-supported model that was developed as a decision support system for watershed management (ref 8). The scientific underpinnings of the model have undergone several peer reviews by independent experts under USEPA guidelines and the model has been used by the States as a tool to calculate TMDLs for most conventional pollutants (e.g., nutrients, BOD, TSS, and coliform). The WARMF model is a GIS-based watershed model that calculates daily runoff, shallow groundwater flow, hydrology, and water quality of a river basin.

Link-Node hydrodynamic models have been used in the Bay-Delta since the 1960's. A Link-Node model was first developed and used by Water Resources Engineers and the California Department of Water Resources (DWR) for the San Francisco Bay-Delta in the late 1960's. In 1983, the Sacramento District of the U.S. Army Corps of Engineers used a Link-Node model to determine the effects on water quality from deepening the Stockton DWSC. In 1993, Systech Water Resources, Inc. developed a Link-Node model for the City of Stockton to assist them in developing their National Pollutant Discharge Elimination System (NPDES) permit renewal for the Regional Board. Since then, Systech has continued to refine the model for TMDL purposes to track and output the daily fluxes of various processes that contribute to the sink or source of DO in the DWSC.

One of the primary goals of completing the watershed studies was to develop a unified water quality modeling framework encompassing the SJR from its confluence with Bear Creek to Disappointment Slough in the Delta. The unified model is the integration of the WARMF model and the Link-Node model. The vision was that this fully integrated model would be useful for evaluating TMDL loads, determining waste load allocations, and identifying prescriptions to manage DO. In addition, the Regional Board is hoping to use the integrated model to forecast periods when the DO would be less than DO objectives so as to inform aeration operations, and to ascertain the effects on DO concentrations with proposed future channel deepening projects or potential changes in river flow.

Goals of this Report

This report begins with a summary of the review process. The major findings and recommendations of the Panel are then presented, followed by discussion and responses relevant to the questions posed in the Panel's charge.

PANEL CHARGE AND PROCESS OVERVIEW

Panel Membership

The Panel consists of four scientists and engineers who together cover the breadth of relevant issues needed to ensure a thorough evaluation of the models and their use. The members were selected for their expertise and reputation in freshwater and estuarine phycology, water quality modeling, estuarine hydrodynamics, nutrients, and local hydrodynamics. Panel members were screened for conflict of interest and bias to ensure a balanced and objective review.

Panel Charge

The upstream and downstream studies represent five years' worth of data collection in the SJR. Thus, the purpose of this independent scientific review is to examine the integrated model that was created from both the upstream and downstream studies, and evaluate if it is scientifically sound and adequately robust to be used in managing the DO TMDL control program.

The Regional Board staff would like to know from the Panel if the integrated model is sufficient to answer specific questions related to loads, assimilative capacity, future alterations to the geometry of the channel, and flow through it. It is also important to Regional Board staff that the Panel evaluate the validity of using a single compliance point in the DWSC to represent DO concentrations throughout the channel, and using the model to forecast periods of excursion from the DO objective to inform aeration operations.

Review Process

The ERP and the Regional Board developed the panel charge shown above. This charge called for the Panel to respond to 15 questions, grouped into six categories.

In its review, the Panel was charged to consider:

- Materials presented to them in oral and written forms.
- Prior documentation concerning the WARMF and Link-Node models.
- Other information sought and received by the Panel members.

The Panel was not charged with discovering or reviewing materials available on other models of the system or other applications of those models. Instead, the WARMF and Link-Node models were considered on their own merits. Similarly, the Panel did not undertake application of the models, nor did they review the actual computer code or algorithms.

REFERENCE MATERIAL

The Panel used the materials provided by the Project Team before, during, and after the review meeting for its review of the models. These materials are identified by reference number in the Review and additional materials used by the Panel are referenced in the text of the report *(in italics)* immediately following its first mention. The materials provided by the Project Team include the following:

Required Reading Provided for Review before Meeting:

(1) 2005 Staff Report and Basin Plan Amendment and Control Program for the San Joaquin River DO TMDL. 104 p. Chapters 1, 2, and 4 (http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/central_valley_projects/san_joaquin_oxygen/final_staff_report/do_tmdl_final_draft.pdf)

(2) Draft San Joaquin River DO TMDL Studies Report, July 2013 (Downstream Studies report) including the following sections:

a) Gulati 2013 DO Load Report
b) Jue 2013 WQ&Flow WARMF-2008
c) Sheeder and Herr 2013 Link-Node Calibration 071013
d) Spier 2013 BGA

e) Spier 2013 RRI DO Profiling DWSC
f) Stringfellow 2013 Synthesis
g) Stubblefield 2013 Mass Balance
h) Weissman 2013a Gowdy Output WARMF-2012
i) Weissman 2013b Link-Node Analysis

(3) Final Report Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project. 2010. 144 p. http://baydeltaoffice.water.ca.gov/sdb/af/docs/Stockton%20DWSC%20DO%20AF%20Final%20December%202010.pdf

Additional Reference Material Provided for Review before Meeting:

(4) 2005 Staff Report and Basin Plan Amendment and Control Program for the San Joaquin River DO TMDL. 104 p. Remaining Chapters (http://www.waterboards.ca.gov/centralvalley/water_issues/tmdl/central_valley_projects/san_joaquin_oxygen/final_staff_report/do_tmdl_final_draft.pdf)

(5) Stockton Deep Water Ship Channel Operations Report. 2008. 84 p. http://baydeltaoffice.water.ca.gov/sdb/af/docs/2008%20Operations%20Performance%20Report.pdf

a) Stockton Deep Water Ship Channel Operations Report. 2008. Appendix A. *San Carlos* DO Surveys and the DWSC Dissolved Oxygen Model. 42 p. http://baydeltaoffice.water.ca.gov/sdb/af/docs/2008%20Operations%20Performance%20Report%20Appendix%20A.pdf

b) Stockton Deep Water Ship Channel Operations Report. 2008. Appendix B. Monitoring of the Aeration Facility Effects and Calculated DO Increments in the Stockton DWSC. 56p. http://baydeltaoffice.water.ca.gov/sdb/af/docs/2008%20Operations%20Performance%20Report%20Appendix%20B.pdf

(6) Effects of the Head of Old River Barrier on Flow and Water Quality in the San Joaquin River and Stockton DWSC. 2010. 65 p. http://baydeltaoffice.water.ca.gov/sdb/af/docs/HORB_Report_Final_3-17-2010.pdf

(7) Synthesis and Discussion of Findings on the Cause and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel Near Stockton, CA. 2003. G. Fred Lee and Associates, El Macero, CA. http://cdm16658.contentdm.oclc.org/cdm/singleitem/collection/p267501ccp2/id/1374/rec/11

(8) The User's Guide for the WARMF Model

(9) The User's Guide for the Link-Node Model

(10) Upstream Studies Reports (2008):

a) Task4 Monitoring Report

b) Task5 Station Upgrade
c) Task6 Modeling Study Final
d) Task7 Isotopes Report
e) Task9 Phytoplankton Grazing
f) Task10 New Stations
g) Task11 Local Database
h) Task12 Final Report

(11) Estuary Project Additional Reports (2013):

a) Report4-1 Field Report-Station Maintenance
b) Report4-1 QA Report
c) Report4-2 Temporal Plots
d) Report4-2 Data Summary Tables
e) Report4.3 Old and Middle River
f) Report5.2 Agricultural Drainage
g) Report5.6 Link-Node Zooplankton Routine
h) Report5.2 Sediment Report

Additional Resource Material Provided for Review after Meeting:

(12) Calibrated Coefficients.xls
(13) Hanlon Chlorophyll Correlation Memo 092513.pdf
(14) Link-Node Calibration Update.docx
(15) Link-Node Technical Documentation.pdf
(16) Memo PPR Questions response 092513.pdf
(17) Stubblefield Salinity Memo 092513.pdf
(18) Task2 Technical Memorandum.pdf
(19) Task6 Calibration Parameters.pdf
(20) Task6 WARMF Model Inputs.pdf
(21) WARMF Forecasting WY2012 Final Report.pdf
(22) WARMF TechDoc.pdf
(23) Watershed boundary delineation.pdf
(24) 12-20-12-Final WSA Water Budget TM-plates.pdf
(25) 12-30-12-Final WSA Salt and Nitrate Budget-TM.pdf
(26) 12-30-12-Final-ATT-A-WSA Salt and Nitrate Budget TM.pdf
(27) ASABE WARMF Calibration and Validation.pdf

MAJOR FINDINGS

The major findings of the Panel are summarized here. Details of these findings and other observations follow.

Overall

The process of developing a regulatory TMDL for the Stockton DWSC DO impairment requires a successful upstream and downstream model. The upstream model must be capable of not only predicting the flows and water quality at Mossdale, but also defining the sources of the flows and the transport and fate of constituents that lead to that water quality condition. This is necessary in order to use the model to assign responsibility for reducing inputs to the SJR of oxygen-demanding substances or constituents that lead to oxygen demands. Subsequently, the downstream model needs to be able to correctly account for the movement of flow and the transport and fate of water quality constituents through the DO problem area. This capability is needed to evaluate the causes and extent of the DO problem.

The upstream model used in this study and being evaluated by the Panel is the WARMF model. The downstream model being evaluated is the Link-Node model. Together, these models have been termed the unified model.

WARMF model

The WARMF model should be capable of being applied to the TMDL process for DO impairment in the Stockton DWSC, as it has been used in several other TMDLs across the country. However, applying WARMF to the upstream SJR will require many additions, improvements, and simplifications. Some of the major concerns of the Panel were:

- the data sources used,
- the model version to be used (2008 versus 2012),
- calibration of nutrient source inputs, and
- uncertainty analysis.

While the WARMF model has been used for TMDLs, this SJR application is quite complex. A critical element in analytical assessment that the Panel did not discover among the documents was a clear presentation of model reviews and model selection. Specifically, projects that are to use numerical models for analysis would start with a problem statement and conceptualization of the entire system such that the modeling needs can be identified. Simply because WARMF is an USEPA-approved model and has been used in other TMDLs is not an appropriate reason to select the model for use. Model selection is important in developing “feasible, defensible, and equitable TMDLs and load allocations” (USEPA, 2005). While WARMF is an acceptable model, the process of developing a problem statement; system conceptualization; multiple model review (spatial and temporal data needs, appropriate dimensional representation, etc.) would have identified strengths and limitations initially and ensured that all parties were on the same page prior to a large and complex modeling (and data collection) effort.

USEPA, 2005, TMDL model evaluation and research needs, Prepared by L. Shoemaker, T. Dai, and J. Koenig, Tetra Tech, EPA/600/R-05/149, November.

Link-Node Model

The Link-Node model represents a portion of the southern and central Delta, including the Stockton DWSC. This region experiences complex morphology, hydrology, meteorology, and water quality. The Link-Node model does not appear to be appropriate to sufficiently address the questions that are before the Regional Board regarding DO impairments and appropriate prescriptions to remedy the impairments. In particular, the DO impairments and associated processes in the DWSC are characterized not only by longitudinal gradients, but also vertical gradients, both of which are driven by tidal hydrodynamics, among other processes. The Panel feels that the one-dimensional characteristics of the Link-Node model restrict the use of this tool in developing screening level analyses alternatives, which are most likely insufficient to support TMDL required actions.

The selection of the model appears to be one of convenience – there was already an existing Link-Node model representation of the project area that could be modified for the TMDL. As noted above, the step of system conceptualization and model review in light of project objectives did not appear to occur. Given that the tidally-driven region where the DO impairments occur is a multidimensional problem, a conceptualization of the system and key processes (thermal stratification, vertical variations in DO, vertical variations in primary production, sediment oxygen demands, etc.) would have identified that a one-dimensional representation of the DWSC was insufficient to characterize the system and develop effective analyses, TMDLs load allocations, and prescriptions. Interestingly, Stringfellow (ref 10h) stated "[C]urrently, the Tidal Estuary reach is modeled by the Link-Node model, which is a two-dimensional model" (page 6). This was an incorrect characterization of the system.

The Link-Node model was developed over 30 years ago (ref 15). Much has been learned about processes in the model area since its development. Thus, there are currently other models available for the study area which would be more appropriate and defensible, for use in this TMDL process. Some of the major concerns with the use of the Link-Node model for application in the DWSC were the ability to model the water movement and volumes, the longitudinal calibration on temperature, nutrients, and phytoplankton, and the treatment of model uncertainty.

Model Formulation and Assumptions

The Panel finds the WARMF model to be over-parameterized for the application to the SJR. Many of the parameters included in the model have no local data available as input to the model or for verification. The use of national datasets for these parameters is questionable at best. In many cases the data used by the Project Team is either inadequate or not specified. The 2008 version uses more actual data on tributary inputs while the 2012 version relies more on modeling inputs based on land use and other GIS layers along with the transport functions within WARMF.

The Link-Node model uses a simplistic series of well-mixed nodes connected by links to represent a system that has significant vertical stratification. As noted above, this one-dimensional, longitudinal representation of the system is insufficient to answer critical questions about the DWSC with regard to hydrodynamics and water quality, including DO. Further, the longitudinal calibration of the model is not sufficiently presented for the Panel to evaluate. Finally, model uncertainty was not characterized in a manner that allowed the Panel to evaluate model performance. Such information is critical to allow a stakeholder, resource manager, or regulator to quantify results in a manner that would allow, for example, the determination of load allocations.

With regard to a "unified" model, the Panel found it difficult to identify the mechanism for model information sharing from WARMF to the Link-Node model. It was unclear if time steps were always consistent; how simulated constituents in WARMF, but not in the Link-Node model were addressed (flow was well documented); how uncertainty was propagated from one model to another; and explicitly how the unified model would be used to (a) assign upstream load allocations and (b) forecast future conditions. Important in this discussion is that forecasting is a remarkably different task than simulation and scenario testing. Model representation, model uncertainty, data uncertainty, stochastic processes (in hydrology, water quality, meteorology), and other considerations are imperative in forecasting.

Model Documentation

The WARMF model has been used in several TMDLs and is well-documented from a user's manual perspective. However, the specific adaptation of the model to the SJR is not completely documented. While there are a plethora of documents, there is no single, coherent structure that documents the model for the TMDL application. Further, the data sources and model uncertainty for the SJR application are not incorporated into the documentation in a comprehensive manner. The references provided do not indicate what data were actually used in the SJR model. In fact, the documentation provided for this review included several applications of the WARMF model to different areas within the valley for a variety of constituents and purposes (refs 10c, 18, 21, 24-26). One of the most important application reports was inadvertently left off the list (CV-SALTS, 2010). This method of model documentation was both disjointed and confounding to the reviewers. In addition, during the review there were two distinctly different versions of the model discussed, the 2008 and the 2012. It was not made clear which version was to be used for the TMDL process.

CV-SALTS, 2010, Salt and nitrate sources pilot implementation study report, submitted by Larry Walker Associates; Luhdorff and Scalmanini Consulting Engineers; Systech Water Resources, Inc.; Newfields Agriculture and Environmental Resources, LLC; Department of Land, Air, and Water Resources, UC Davis.

The Link-Node model, like WARMF, is also well-documented from a user's manual perspective. The modeling report provided on the Link-Node model (ref 15) is dated and appears to pre-date the concept of a unified modeling framework. The Link-Node model calibration update (ref 2c) does not detail the role of model unification, but only briefly presents results of hydrodynamic and water quality simulations. Concerns with the recent calibration document (ref 2c) include:

- Discharge calibration, which notably overestimates flow (fig. 3). Ideally nodal volumes and calibration coefficients would be provided throughout the model domain.
- Oxygen-demanding constituents (ammonium, BOD) or constituents that may affect DO (phytoplankton) are not replicated by the model. Summary statistics are not provided for these constituents. Yet, DO simulations appear to track observed values fairly well (fig. 12; fig. 13 is unreadable). This suggests that perhaps DO simulations are "right" for the wrong reason.
- The most recent grid and nodes are not identified in this document.

Databases and Data Sources

Several of the data sources for WARMF inputs are not referenced, outdated, or otherwise inadequate. The categories of questionable inputs are: watershed delineation, land use, atmospheric deposition, diversions, groundwater, fertilizer application, and manure production. Recommendations for each of these data sources are made later in this report.

The data sources for the Link-Node model are also incompletely documented. The challenge here is that there is an initial 2002 report (ref 15) and a follow up 2013 report (ref 2c). While the initial report appeared to address many elements of a typical "modeling report" (e.g., model domain, modeling concepts, simulated constituents and processes, boundary conditions (flow, water quality, meteorology) and loads calibration, sensitivity analyses, summary statistics), the 2013 update is limited to a the presentation of a few results. Discussions with the Project Team suggest that changes have been made between 2002 and 2013. The development of an updated comprehensive modeling report would be a requisite element of a TMDL model. Note, review of the 2002 (ref 15) report suggests that a more comprehensive calibration and statistical analysis to quantify uncertainty would be useful. Surprisingly, the 2002 report (ref 15) is not referenced in the 2013 report (ref 2c).

Uncertainty in Model Results

Model results are always somewhat uncertain. All models have a general level of error or "noise" in model results, below which it is not particularly useful to interpret results. Additional modeling studies should be able to better define this range and give a firmer and more transparent basis for an uncertainty assessment for some important locations and conditions. Such error estimates of model results should be especially useful in guarding against over-interpreting model results and identifying assumptions in greatest need of additional refinement and data.

At a minimum, error analyses should be conducted, combining a sensitivity analysis of critical model results to some of the largest and least well-supported model assumptions with an assessment of the likely range of error in these major model parameters and assumptions. Ultimately, a more sophisticated Monte Carlo type of error analysis would be a worthwhile undertaking, if cross-correlation of input and parameter errors can be assessed. However, at this point, the main intent of simple error analysis is to provide a direct and interpreted assessment of the likely uncertainty in major model outputs resulting from estimated uncertainties in major model parameters and assumptions. An example is provided in figure 5, below, that utilizes a simple perturbation-response curve to identify how individual parameters may be sensitive, as well as combinations. In this fictitious example, parameter A is changed +/-20% and the outcome at a downstream location is assessed for change in DO. This is repeated for parameter B, and then a combined effect is assessed. "Parameters" may include model coefficients, flow or water quality boundary conditions, meteorology, channel geometry, or other modeling elements.

As far as the Panel can tell, neither the WARMF nor the Link-Node models have undergone even this initial level of uncertainty analysis in the SJR application. Once this initial stage of uncertainty analysis is completed, a more rigorous Monte Carlo approach may be in order.

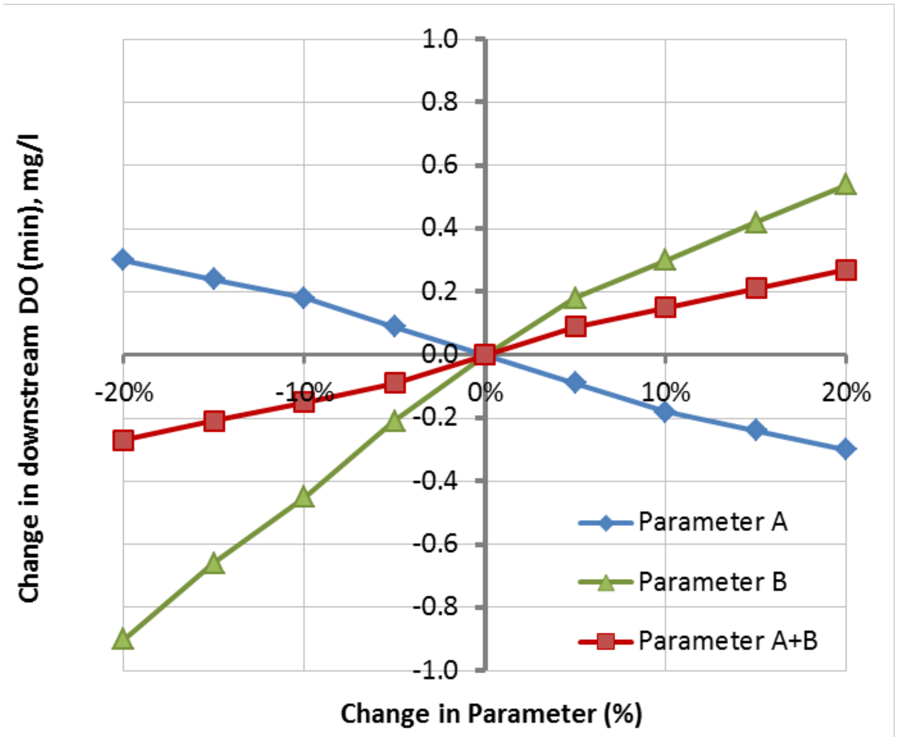

Figure 5. Example of an initial uncertainty assessment approach to estimate change in state variable (DO concentration) as a result of a perturbation in parameter A, parameter B, and a combined perturbation of parameters A and B.

Application of Models to Future Scenarios

The data in the models being reviewed are for the current level of development and the model applications are for such conditions. However, policy and planning applications of the model will include potential future conditions. To reduce confusion and increase transparency, protocols should be developed to establish assumptions and methods for estimating future demand, operational, meteorological (e.g., climate change) and hydrologic conditions. Such an effort will be challenging and controversial, but is necessary to produce greater consistency and transparency in model results, with a greater likelihood of consensus and buy-in.

MAJOR RECOMMENDATIONS

The major recommendations presented here are separated into the WARMF model and the Link-Node model. Some of these recommendations should be fairly easy to implement; others will require substantial commitments. In either case, it is the overall recommendation of this Panel that neither model is ready to be applied to the TMDL task in its current state.

WARMF model

The major recommendations for the WARMF model are grouped into the following categories: database improvements, calibration needs, uncertainty analysis, and clarification of model version.

Database Improvements

The documentation of data sources used for the WARMF model needs to be transparent. The data sources for the SJR application need to be in one document, including the references for the data, the assumptions required in using the data, and the limitations of the data. Currently, the data sources are spread over several reports (refs 10c, 18, 21, 24-26, CV-SALTS 2010) and it is not clear which sources are used in the SJR application of WARMF-2008 or WARMF-2012 or neither. In addition, many of the data sources need to be updated and improved. The needed improvements or clarification of data sources will be discussed by component here.

Watershed Delineation:

The WARMF model uses DEM data to define the watersheds in the SJR area. However, the lack of topography near the SJR makes this very difficult to do. Plus, in many cases in the valley, water is transported across topographic lines by pumping water in canals and ditches. The USGS NAWQA program defined most of the watersheds of interest in the 1990's. More recently, a nationwide effort to improve watershed delineations took place called Watershed Boundary Dataset (WBD). A USGS report was prepared to document the process used to develop the WBD (USGS and USDA, NRCS, 2012). For California, the state stewards of the WBD are Lorri Peltz-Lewis (USFS, lpeltzlewis@fs.fed.us, 916-640-1049), Donna Knifong (USGS, dknifong@usgs.gov, 916-278-3081), and Scott Splean (NRCS, scott.splean@ca.usda.gov). The WBD is available through the GeoSpatial Data Gateway at http://datagateway.nrcs.usda.gov).

In the separate report on Orestimba Creek by the Project Team, there is a question about whether the CCID Main Canal is part of the watershed. Several USGS NAWQA reports, as well as the WBD, clearly identify the canal as part of the watershed. Later in the Orestimba report, the Project Team seems to realize that the DEMs may not be producing proper watershed boundaries.

The Panel recommends using the WBD watershed boundaries.

USGS and USDA, NRCS, 2012, Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD)(3rd ed.): U.S. Geological Survey Techniques and Methods 11-A3, 63 p. (http://pubs.usgs.gov/tm/tm11a3/)

Land Use:

In the WARMF-2008 model, the land use is pulled from 1980 shape files from USGS. In the WARMF-2012 model, it appears that the detailed, field-level DWR land use was substituted for the 1980 land use, although it is hard to tell from the documentation what was actually used. Again, the USGS NAWQA program digitized the detailed DWR land use as early as the 1990s and used it in several reports.

The DWR land use should be used in both versions of WARMF.

Atmospheric Deposition:

The WARMF model uses wet deposition from the National Atmospheric Deposition Program (NADP) site in Yosemite NP and dry deposition from the USEPA Clean Air Status and Trends Network (CASTNET) site in Yosemite NP. While the Project Team acknowledged that Yosemite air quality is very different from the valley, they choose to use the Yosemite site. In a recent study of nutrient trends in the SJR, a USGS study used the NADP site at Davis and California Acid Deposition Monitoring Program (CADMP) sites in Sacramento and Bakersfield for wet deposition, and the CADMP sites in Sacramento and Bakersfield for dry deposition (Kratzer et al, 2011).

The Panel recommends that the WARMF application for the SJR also use sites in the valley for atmospheric deposition instead of sites in Yosemite NP.

Kratzer, C.R., Kent, R.H., Saleh, D.K., Knifong, D.L., Dileanis, P.D., and Orlando, J.L., 2011, Trends in nutrient concentrations, loads, and yields in streams in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975—2004: USGS Scientific Investigations Report 2010-5228, 112 p., http://pubs.usgs.gov/sir/2010/5228/

Diversions:

The WARMF model only uses three diversions between Lander Avenue and Vernalis – Patterson Irrigation District, West Stanislaus Irrigation District, and El Solyo Water District. However, in the development of SJRIO these three diversions only account for about half of the diversions from the river in this reach. How does WARMF account for the other diversions? Are some users of SJR irrigation water specified directly (big three diversions) while others are specified indirectly?

Groundwater:

Although the Project Team indicated that groundwater inflows to the SJR were specified by Darcy's Law, there was no mention of where the water table elevations were obtained. This is necessary to define the hydraulic gradient between the water table and the river. In one document it states that the water table is assumed to follow the slope of the overlying land. If this is the case, how is groundwater pumping near the river accounted for? In the Task6 Modeling Study Report, table 1.26 and figure 1.122 show the groundwater contribution to be 700 cfs or 25% of the river flow for the given scenario. The field studies of groundwater inflows to the river have come up with a probable range of 1-3 cfs/rivermile or about 80-240 cfs for this reach of river (Phillips 1991, Zamora et al, 2013).

In addition, the Zamora et al (2013) study shows that denitrification in the anoxic sediments of the SJR converts most of the groundwater nitrate to nitrogen gas. However, an appreciable amount of ammonium from the anoxic mineralization of streambed sediments could contribute dissolved inorganic nitrogen (DIN) to the SJR. Overall, the DIN from groundwater contributed about 9% of the river DIN during synoptic surveys from Lander Avenue to Vernalis (Zamora et al., 2013).

The Panel recommends a re-evaluation of the groundwater component in WARMF.

Phillips, S.P., Beard, S., and Gilliom, R.J., 1991, Quantity and quality of ground-water inflow to the San Joaquin River, California: USGS Water-Resources Investigations Report 91-4019, 64 p., *http://pubs.usgs.gov/wri/1991/4019/report.pdf*

Zamora, C., Dahlgren, R.A., Kratzer, C.R., Downing, B.D., Russell, A.D., Dileanis, P.D., Bergamaschi, B.A., and Phillips, S.P., 2013, Groundwater contributions of flow, nitrate, and dissolved organic carbon to the lower San Joaquin River, California, 2006—2009: USGS Scientific Investigations Report 2013-5151, 105 p. *http://pubs.usgs.gov/sir/2013/5151/*

Fertilizer Application:

The source of the fertilizer application data used in both WARMF-2008 and WARMF-2012 is not clearly identified. The data for the 2012 version has more variation by month and crop than the 2008 version, but still no clearly-identified reference. The CV-SALTS (2010) report refers to fertilizer application numbers coming from the CDFA fertilizer sales reports. However, there are some necessary assumptions in using sales data, such as timing of application and location of application.

The Panel recommends that the references and assumptions used for the fertilizer data be supplied. Also, the data should be compared with other fertilizer application data (see Kratzer et al, 2011; Gronberg and Spahr, 2012; Ruddy et al, 2006). In Ruddy et al (2006) the county-level fertilizer application data was distributed to the field level based on specific land uses.

Gronberg, J.M., and Spahr, N.E., 2012, County-level estimates of nitrogen and phosphorus from commercial fertilizer for the conterminous United State, 1987-2006: USGS Scientific Investigations Report 2012-5207, 20 p. *http://pubs.usgs.gov/sir/2012/5207/*

Ruddy, B.C., Lorenz, D.L., and Mueller, D.K., 2006, County-level estimates of nutrient inputs to the land surface of the conterminous United States, 1982-2001: USGS Scientific Investigations Report 2006-5012, 17 p. *http://pubs.usgs.gov/sir/2006/5012/*

Manure Production:

The source of manure production data is also not clearly-referenced. The CV-SALTS (2010) report refers to information on dairy sources coming from the Regional Board, Dairy CARES, UC Cooperative Extension, and Western United Dairymen. However, the methodology of developing manure production numbers based on numbers and location of cows and average per cow waste is not identified.

The Panel recommends that the methodology for the manure production data be supplied. Also, the data should be compared with other manure production data (see Kratzer et al, 2011; Ruddy et al., 2006). In Ruddy et al (2006), the county-level manure production data was distributed to the field level based on specific land uses.

Other Data Issues:

The Regional Board needs to get to the bottom of the data sources issue, as it is confounding. For the TMDL to get acceptance there needs to be transparency in the tools being used. The data sources and data assumptions are a very important part of the use of WARMF to potentially allocate loads in the upstream watershed. In one of the documents provided to the Panel it showed the use of CDEC data for flows and water quality in some tributaries. This use of CDEC data needs to be reviewed, as CDEC data is meant for real-time usage only, unless there is no other data available.

Calibration Needs

In addition to calibrating the WARMF model at the downstream boundary, it is important to calibrate at upstream sites in the SJR and also by individual inputs/tributaries. It would be useful to present model calibration performance at major westside tributaries in addition to the in-stream sites at Crows Landing, Patterson, Maze, and Vernalis. Currently, the 2008 version of WARMF provides better simulations for TDS, NH4, BOD, and phytoplankton than the 2012 version. The Project Team did not provide such a direct comparison or discussion. Although the Project Team and the Regional Board seem to prefer the more predictive nature of the 2012 version where the westside is simulated based on model parameters instead of boundary inflows, the results are not nearly as good. The other difference in the 2012 version is the improved land use and groundwater link. This seems to cast some doubt on the ability of the 2012 version to properly simulate the westside inputs. This was not explained by the Project Team.

Uncertainty Analysis

All models and input data contain errors and simplifications which affect results. This leads to some level of uncertainty or noise in model results. It is highly desirable to have a basic error analysis completed as part of the model-development phase. Without such a basic error analysis, general model result applications and general impressions of model accuracy will be uninformed regarding the likely levels of error and sensitivity.

The SJR application of WARMF does not appear to have undergone any extensive uncertainty analysis. The Panel recommends that the Project Team implement a process to identify the likely errors in data inputs and the impact of that uncertainty on model outputs. Ideally, a Monte Carlo simulation would be done using realistic assessments of uncertainties in model inputs and parameters.

Clarification of Model Version

In the required reading prior to the meeting, the Panel was under the impression that the WARMF-2008 model was being reviewed. However, during the meeting the WARMF-2012 model was also presented. The Project Team was not clear on which version was to be used for the TMDL.

Link-Node Model

The major recommendations for the Link-Node model are grouped into the following categories: model formulation, calibration needs, and uncertainty analysis.

Model Formulation

The Link-Node model provides a simplistic series of well-mixed nodes connected by links to represent water movement and water quality in the DWSC. The first major assumption of this approach is that the system is well-mixed vertically and laterally. Examination of data demonstrates that the stretch of the DWSC of concern does stratify daily, even under mild meteorological conditions. Further, the Turning Basin strongly stratifies for most of the period of highest concern. It has been demonstrated in field work and three-dimensional modeling that the tidal interaction with the Turning Basin accounts for a large percentage of the oxygen load in the near DWSC. A second major assumption of the model is that the upstream boundary location, Mossdale, is not tidally influenced. Mossdale experiences a 2-foot tidal range and strongly bi-directional flow during the low-flow periods of concern, raising strong questions on the validity of this assumption. Further, the upstream node shown in the documentation is actually located at the head of Old River barrier location which is 4.5 kilometers downstream of Mossdale. Since there are 11 nodes in the 16.4 kilometer stretch from the upstream boundary to the confluence with French Camp Slough, it is highly unlikely that the upstream node is properly accounting for the volume from Mossdale to the head of Old River.

Calibration Needs

The calibration information shown for the Link-Node model does not include accounting for water volumes. The most important criteria for modeling water quality constituents is for the flow to first be accurately simulated. The flow comparison curves presented in the calibration documentation demonstrate tidal changes significantly higher than the observed data. Once this type of error is accepted, it will require water quality coefficients to be specified that are not actually corrected to compensate for the flow errors. The documentation suggests that the flow errors are related to improper representation of the channel dimensions in the link connection to the nodes. It is unclear why these errors weren't addressed. There have been reasonably good bathymetry data available for several years and some even higher resolution data have been developed more recently.

Additionally, calibration results should be presented graphically and statistically. Typical graphical analysis can include time series presentation of simulated versus observed values for flow and stage, constituent concentrations or flow calculated loads, and scatter plots of simulated versus observed values. Statistics can include a range of parameters, including mean bias, mean absolute bias, root mean squared bias, as well as other statistics (e.g., Nash-Sutcliff model efficiency coefficient, R^2 for simulated versus observed scatter plots). Often, these statistics can be reduced to seasonal values to focus on challenging periods of the year (e.g., summer, fall) or examine specific statistics (e.g., minimum daily DO, 7-day average of the daily minimum DO) to ensure the model is effectively representing important constituents well. Documentation should identify if simulated results are depth and laterally averaged (as they are in the Link-Node and WARMF models). Similarly, observed or measured data should be identified as spot samples at discrete locations, or if appropriate, vertically and/or laterally integrated samples. A challenge with the current Link-Node model is that vertically and laterally averaged simulated conditions are compared with spot measurements.

Uncertainty Analysis

All models and input data contain errors and simplifications which affect results. This leads to some level of uncertainty or “noise” in model results. To supplement, substantiate, and test this experience-based understanding of error or “noise” in model results, there should be formal numerical error analysis based on realistic assessments of uncertainties in model inputs and parameters. These might take the form of simple single-parameter sensitivity studies or more elaborate Monte Carlo studies. While such studies would represent simplifications of known errors and uncertainties in the model, they would provide a source of understanding of model uncertainty which everyone could understand. It is highly desirable to have a basic error analysis completed as part of the model’s development phase. Without such a basic error analysis, general model result applications and general impressions of model accuracy will be uninformed regarding the likely levels of error and sensitivity.

When assessing uncertainty within a single model, the aforementioned approaches can be effective in quantifying uncertainty such that decision makers can responsibly develop actions for remediation, regulatory compliance, and interim- and long-term planning. When multiple models are utilized, such as the proposed integration of WARMF and the Link-Node model, an analytical framework should be implemented to characterize and propagate uncertainty from the upstream model to the downstream model. That is, while both individual models include uncertainty, the transfer of uncertainty from WARMF to the Link-Node model is an additional uncertainty introduced into the Link-Node model. Whether the errors compound or offset are both important outcomes to quantify and document.

RESPONSES TO QUESTIONS IN PANEL CHARGE

For each area of this review, the Panel presents a discussion of our impressions and concerns, followed by more focused responses to the questions posed in the charge.

San Joaquin River DO TMDL Model (WARMF/Link-Node): Development, Assumptions, Calibration, and Error

The integrated SJR DO TMDL Model (integrated model) is composed of both the upstream, non-tidal WARMF model and the downstream, estuarine, tidally-influenced Link-Node Model. This integrated model will be used by the Regional Board for four main purposes – 1) Better understand the factors that control DO concentrations in the DWSC, 2) Develop final TMDL load and waste load allocations for responsible parties, 3) Determine if the model can be used to improve the operations plan for the Aeration Facility at Rough and Ready Island, and 4) Use the model to understand changes in DWSC DO concentrations caused from specific actions such as the BDCP that will change flow through the channel, US Army Corps deepening the channel, and implementation of best management practices in the upstream watershed.

<u>Question #1 for Panel:</u>

Discuss the scientific basis for the integrated model. Has the model identified all the major potential sources of oxidizable material in the basin and the processes responsible for its fate and transport into the DWSC?

Panel Response to Question #1:

Yes, the major sources are identified in the WARMF model, although it is questionable if the proper loads are assigned to the sources or if the fate and transport of oxidizable material (e.g., NH4) is effectively modeled. In fact, the WARMF model is probably over-parameterized, with many parameters included that have no supportable source of data inputs.

The Link-Node model includes the basic processes responsible for transport in the DWSC. However, the Panel could not fundamentally assess how successful the model was in properly describing transport.

The process of using multiple models in different hydrologic settings is common in flow and water quality analyses. Discrete river models are used in conjunction with discrete reservoir models to assess the different river and reservoir hydrodynamic and water quality responses. Similarly, different models have been used for river and estuary applications – as is the case in this SJR application. These models may differ in dimensionality (one-dimensional, two-dimensional, three-dimensional), spatial averaging (laterally-averaged versus depth-averaged representations), governing equations, spatial and temporal resolution, or other factors. The handshake between different models is critical to define, test, and document. Discontinuities in geometric representation, space and time steps, constituents modeled, relative levels of uncertainty and other factors should be fully explored and documented to allow decision makers to interpret output in a meaningful and useful manner.

Question #2 for Panel:

Discuss whether in the future the model can be used to calculate changes in the assimilative capacity of the DWSC as a result of changes in flow, channel morphology, location and operation of the aeration facility, and loads from population growth.

Panel Response to Question #2:

Most of this question concerns the abilities of the Link-Node model. While the WARMF model requires more comprehensive documentation of assumptions and model performance, the Panel does not support the selection of the Link-Node model for the Delta and DWSC portion of the domain. Thus, the Panel is not convinced this integrated model could be used to evaluate future changes.

Apportioning Responsibility

A key finding of the TMDL studies is that the upstream watersheds contribute to low DO in the Stockton DWSC by exporting oxidizable material, including algae, to the estuarine SJR. Some of this organic material decays as it is transported down river through the DWSC. In addition, downstream monitoring has assessed the organic load from the Stockton urban sloughs and from the Stockton Wastewater Treatment Plant (WWTP) to the DWSC. The other factor contributing to low DO is the dredging of the SJR in the DWSC, which increases retention time and decreases reaeration per unit volume. The integrated model has been used to calculate the fraction of DO depletion contributed by all responsible parties above the assimilative capacity of the DWSC. This fraction is important as it may be used to assign responsibility for funding the operation and maintenance of the aeration device and implementation of best management practices to reduce loading.

Question #3 for Panel:

Discuss whether the upstream monitoring and the integrated model have accurately characterized the relative contribution of oxidizable loads from each sub watershed to the downstream DWSC DO problem.

Panel Response to Question #3:

Due to the many outstanding questions about the WARMF model data sources, calibration, uncertainty analysis, and model version, the Panel cannot make a determination on this.

Question #4 for Panel:

Discuss whether the model accurately represents the effect of DWSC channel deepening on DO concentration.

Panel Response to Question #4:

While increasing the depth of the DWSC will clearly increase residence time and stratification — a condition that the Link-Node model clearly demonstrates — due to the many outstanding questions about the Link-Node model representation of the Delta and DWSC reach, the Panel cannot make a determination on this question.

Question #5 for Panel:

In 2002, an Independent Review Panel for the original TMDL concluded that algal concentrations entering the DWSC could not be effectively controlled by nutrient reductions in the upper San Joaquin Basin because the nutrient concentrations were too high. Does this Panel still agree with that assessment?

Panel Response to Question #5:

The Panel feels that although there is considerable uncertainty about the expected improvements, it still would be worthwhile removing nitrogen (N) from the system. In addition, this removal could be tied to other Regional Board regulatory functions in the valley, such as, protection of groundwater nitrate levels, nitrogen plans for the Irrigated Lands Program, and CV-SALTS. Since phytoplankton are major contributors to BOD and N has been shown to be the most limiting nutrient, N reductions throughout the watershed (focusing on largest contributors) would be a prudent and potentially effective approach to reducing BOD in the DWSC. The second factor is probably “geometry” of the DWSC, but altering geometry to minimize bottom water hypoxia is unlikely to be a feasible and practical alternative.

Nutrient Limitation/Reduction:

There seems to be confusion as to how to relate high nutrient concentrations to potential phytoplankton community responses, including control of phytoplankton production. Not all phytoplankton species (or even genera) respond to specific nutrient concentrations similarly. There are often profound kinetic differences in terms of how individual taxa respond to a range of concentrations. In this regard, the dominant cyanobacterial bloom forming genus in the DWSC, *Microcystis*, has a relatively high saturation response to nitrate, while small flagellates, diatoms and <3 um picoplankton are very good competitors for nitrate at quite low levels. Therefore, it is difficult to assume that nitrate concentrations are "too high" for N to be limiting and potentially control phytoplankton production in the general sense. In addition, making such conclusions simply based on *concentrations* is probably inappropriate and potentially flawed, both conceptually and technically. A more realistic and relevant way to interpret nutrient-phytoplankton growth and bloom relationships is to relate *supply rates* or *loads* (i.e. fluxes) to rates of utilization by phytoplankton. It is true that phytoplankton "see" concentrations at any one instant. However, it is the *rate* of use vs. the *rate* of supply that best defines these relationships over time and space. In some (early) reports and previous panel summary it is stated that "nutrients are supplied in excess" (presumably of algal growth requirements — but this has not been substantiated with experimental evidence). There appears to be another line of thought that stresses N as being the *most* limiting nutrient (ref 2f). This interpretation is probably most realistic to follow with regard to potential relationships between nutrient availability and their effects on phytoplankton growth potentials in the SJR and DWSC (ref 2f). Once nutrients start to be reduced (hopefully due to management actions) or vary in time and space due to episodic events, such as droughts, rainfall-driven pulses, as well as internal cycling processes such as uptake (which under bloom conditions can lead to quite large variations in both concentrations and availability), nutrient-limited growth can occur over a range of time frames or in specific horizontal and vertical regions/zones of the system.

In addition, there is likely to be a strong interaction between nutrient (N) and light limitation in the system, and this could change over time scales from minutes to weeks to months, and on the order of a few cm in the water column. This is dependent on turbidity and flow changes in the system in response to events or seasonal rainfall patterns, episodic events, etc. Furthermore, some motile or buoyant taxa, such as the bloom-former *Microcystis* can circumvent light limitation (and hence optimize nutrient uptake) by remaining in surface waters. The fact that ammonium seems to stimulate algal production and resultant BOD more than nitrate indicates that such strong light-nutrient interactions exist in the system and that N is the most limiting nutrient. More experimental work would need to be done using *in situ* bioassay experiments (using different irradiance levels) to establish the nutrient (N) and light limitation interactions and N-limitation (of algal growth) thresholds for different taxa, but it is safe to say that N loading is a strong determinant of algal growth potential (and hence algae-related BOD) throughout the SJR and in the DWSC, as well as downstream in the Delta.

In all instances, there seems to be reasonably good agreement that phosphorus is not limiting, especially in the more estuarine portions of the system, including the DWSC. Therefore, efforts at controlling algal production should focus on N. For non-point sources, "best management" efforts aimed at N reductions will also lead to phosphorus reductions, and *vice versa*. With regard to reducing N, TOTAL N load should probably be considered (with an emphasis on biggest targets---such as excessive N runoff from agricultural lands—which contain high nitrate concentrations). Going after specific N sources based on relative "reactivities" of phytoplankton species (e.g., specifically reducing ammonium relative to nitrate because of the so-called "ammonium inhibition of nitrate uptake" in diatoms), is not likely to yield much more benefit than total N removal (besides, diatoms are not a water quality issue as opposed to cyanobacterial bloom taxa). There is enough residence time in the system to recycle and regenerate N, so going after specific N sources based on biological reactivity differences seems like a waste of effort and money. In the case of large ammonium sources that could consume oxygen in nitrification, that is another matter. Such sources may be worth targeting if they are accessible and treatable.

Nutrient attenuation:

In order to be effective as a management tool, the model should be able to estimate nutrient (most importantly N) attenuation along the length of the SJR down to the DWSC. If and when N input reductions are enacted, it will be essential to be able to estimate the attenuation of dominant N inputs. It will be important to determine the relative roles and importance of uptake, nitrification, and denitrification along the SJR. The same will be true of organic carbon sources that are either discharged into or formed *in situ* (via phytoplankton production) along the SJR.

The stoichiometric relationships between N inputs (ammonium and nitrate) and CO_2 fixation (or organic matter production) should be determined and modeled so that we can gauge the relative importance of algal production in removing DIN (vs. its input) and its role as a source of oxidizable organic matter. Algae is generally considered to be a more “reactive” form of organic matter for microbial utilization and depletion of oxygen than allochthonous carbon sources such as humics, organics derived from soils, wood and decaying higher plant materials.

Lastly, the fact that the main harmful cyanobacterial bloom genus in the SJR and DWSC is the non-N_2 fixer *Microcystis* is indicative of N over-enrichment. Reduction in *Microcystis* biomass aimed at lowering the SJR’s BOD must include constraints on N loading from the abovementioned sources. Furthermore, control of downstream harmful algal blooms in the N limited regions of the Bay Delta and San Francisco Bay will be dependent on N input restrictions as well. Therefore, there are multiple reasons over a range of scales to reduce N inputs, starting with the very high levels of nitrate currently being discharged into the SJR.

Question #6 for Panel:

Discuss whether it is appropriate to use the estimates of DO depletion from these sources as a basis for calculating the relative responsibility of all parties to fund aeration?

Panel Response to Question #6:

The Panel feels that the models are not sufficiently developed yet. The current models are best used as more of a screening tool than a tool capable of assigning responsibility. This question also involves relative costs and political considerations that are beyond the scope of this Panel. Some specific issues with regard to the DO depletion issue:

The model results indicate that removal of the oxygen-demand originating from the geometry of the DWSC during low DO events resulted in the greatest improvement with respect to the baseline scenario for both the May 2013 and November 2012 models. Thus, the altered channel geometry due to formation and maintenance of the DWSC was predicted to be contributing more to DO violations than the other oxygen-demanding load contributions from the SJR, the WWTP, and the tributaries. However, it’s not clear how the artificial oxygenation is incorporated in the model and how its dynamics (in terms of DO introduction) are linked to the DO consuming processes, especially if the DWSC is ephemerally-stratified. How much (more) effective might oxygenation be if the oxygen is introduced at the bottom as opposed to some distance above the bottom in the DWSC? Also, the changes in diffusional dynamics under stratified vs. mixed or disturbed conditions (and how they impact DO levels) need to be clarified. Lastly, the balance between oxygen production and consumption by phytoplankton needs to be incorporated into the ability of the model to accurately depict and predict oxygen dynamics in the DWSC.

TMDL Compliance Point(s)

The final TMDL will require a telemetered compliance point(s). The purpose of the compliance point(s) would be to mandate collection of the water quality information needed to run the integrated model and predict the amount of aeration needed to meet the water quality objective. A water quality monitoring station was established in 1983 at the western end of Rough & Ready Island to measure water quality parameters such as temperature, pH, DO, chl-a, and turbidity. This monitoring station is located in the section of the channel where the lowest DO concentrations have historically been observed (aside from the Turning Basin). Since 2008, two additional DO sondes have been added to the station. The original DO sonde was located 1-meter below the surface and the new sondes are at 3-meters and 6-meters. In addition, since 1983 DWR has conducted twice monthly boat cruises usually between June and November along the length of the channel (Antioch to the Turning Basin) and measured oxygen concentrations at 1 meter below the surface and 1 meter off the bottom. The demonstration project for the Aeration Facility and DWR's boat cruises have demonstrated that some locations in the DWSC, including the Turning Basin, do not meet the water quality objective even under aeration.

Question #7 for Panel:

Discuss whether Rough and Ready Island is a suitable compliance point. Is the monitoring being conducted at Rough and Ready Island in combination with model output predictive of the amount of oxygen needed from the aeration device to ensure that the DO objective is met throughout the DWSC?

Panel Response to Question #7:

A fundamental purpose of the TMDL modeling work is to identify source loads, assess alternative prescriptions, and allocate responsibility to regulated entities. While this is clearly a valid approach, a confounding element is the concept of a single compliance point for an essentially fixed DO concentration (the compliance value changes from a DO minimum of 5 mg/l to 6 mg/l seasonally). This single compliance location is intended to be representative of all possible locations at all times. This "everywhere, always" requirement is, for all intents and purposes, unachievable. An unachievable compliance requirement leads to lack of buy-in from stakeholders and can actually result in a delay in restoring beneficial uses to regions of the project area. While beyond the scope of this review, regulatory flexibility that would provide for adaptive management elements to allow temporal and spatial recovery rates to vary could provide benefits sooner in some areas than other areas.

In the interim, the Panel feels that the only way to address this question as posed would be to install additional data sondes at other potentially important compliance sites for the first year or two and then evaluate the data to answer this question. Sufficient vertical and lateral variability should also be defined through field monitoring to identify an appropriate metric to guide compliance. The Project Team has already suggested that the introduction of oxygen at the aeration facility will not be able to meet the DO objective at all sites and all times (see below).

<u>Question #8 for Panel:</u>

What modifications in the location and size of the aeration facilities might be made to ensure that the entire DWSC is in compliance with the water quality objective?

<u>Panel Response to Question #8:</u>

After collection of the data recommended in the previous question, it would be easier to determine where additional aeration facilities might be needed. Clearly having separate diffusers for the two oxygen systems would increase the amount of oxygen that can be delivered. Additional data collection would also help to identify specific locations for a facility (e.g., locate the sites at the bottom of the channel instead of only at mid-depth in the water column). The use of air instead of pure oxygen should be considered at the additional sites due to cost considerations.

TMDL Margin of Safety

The final TMDL will require a margin of safety to ensure that the DWSC will not be impaired for fish migration after implementation of the TMDL and load allocations. The Margin of Safety may be accounted for explicitly as a part of load allocations, or it may be included implicitly in the assumptions of the TMDL process.

<u>Question #9 for Panel:</u>

Is the previously calculated Margin of Safety appropriate for a TMDL and load allocation calculated with the Link-Node and WARMF models?

<u>Panel Response to Question #9:</u>

The 20 percent MOS included in the 2005 Staff Report (ref 1) is undoubtedly too low. An appropriate MOS can't be answered without uncertainty analysis of both the WARMF and the Link-Node models. The MOS is really dependent upon how much uncertainty there is in the models themselves and the data that goes into the models. The uncertainty in the model results versus the observed values needs to be added to the uncertainty in the measured data (e.g., typical relative percent difference criteria from production laboratories are 20% for chemical constituents (e.g., nitrate, ammonium, orthophosphate)). Thus, even if the model accurately predicts the observed, there is still a 20% uncertainty in the input data and the data used in model calibration. So, 20% is undoubtedly too low.

<u>Question #10 for Panel:</u>

How do modeling errors relate to errors in TMDL and load allocation? Would errors in load allocations lead to non-attainment of water quality criteria?

Panel Response to Question #10:

See answer in #9. Errors in observed data and model results could propagate through each of the system models and from the WARMF model to the Link-Node model. If uncertainty is effectively quantified for the models, then an appropriate MOS can be determined at, for example, some exceedance criteria (e.g., 90% or confidence interval (e.g., 95%)). This could be incorporated into the load allocation determination, and attainment of water quality criteria when load allocations are met could be statistically presented. A MOS is not a guarantee that compliance will always be attained – such an assurance would require setting a MOS at a value that may overly constrain certain beneficial uses. Instead, non-attainment events could be identified by magnitude (ideally manageably small) and frequency (ideally infrequent). Rather than considering non-attainment as an infraction in this complex system, non-attainment could be viewed as an opportunity to gain additional knowledge that could be used in an adaptive management framework to refine prescriptions and improved water quality over the long-term. The Panel feels that specific quantification of a MOS (explicit) versus the "conservative assumptions" (implicit) approach used in certain TMDLs is a markedly more robust pathway towards attainment of actual water quality improvements and compliance.

Question #11 for Panel:

What are other sources of error and implicit components of Margin of Safety?

Panel Response to Question #11:

Errors occur throughout analytical processes, including:

- Data collection and analytical methods used to collect data in support of modeling (e.g., could the USGS provide a better estimate of the uncertainty in the flows from their UVM station upstream of the Stockton RWCF instead of relying on an estimate from G Fred Lee from 2000? (ref 7)),
- Data collection and analytical methods used in compliance monitoring,
- Model formulations (governing equations, process representations, spatial and temporal scale issues in model representations, lateral and depth averaging of governing equations, incomplete or absent model representations (or understanding of how processes should/could be modeled)),
- Limited data sets (that do not represent or under-represent the range of natural conditions such as droughts and floods), and poorly characterized non-linearity in system response, etc.,
- Model output interpretation,

For data collection, quality assurance processes can be put in place to minimize uncertainty, but not eliminate it. Model uncertainty can be characterized through calibration and sensitivity analysis, as discussed previously. However, in addition to these quantifiable elements, basic system conceptualization limitations are prevalent in many systems, and the SJR is no exception. The various field and modeling efforts clearly illustrate that while much has been learned, there is a long way yet to go. While scientists, researchers and others may never know all aspects of a natural system, additional knowledge will be acquired through time. A fundamental goal of an adaptive management program could include an ongoing effort to reduce the MOS through time via ongoing studies, research, and analysis.

Using the Model

The TMDL assigned load and waste load allocations to parties responsible for contributing oxygen demanding substances. The City of Stockton WWTP was assigned a 30% waste load allocation. Since adoption of the TMDL the City of Stockton has upgraded its facility to include advanced nitrification. The model was used by the contractors to determine if the City of Stockton is meeting its waste load allocation.

Question #12 for Panel:

Should discharge data or model simulations be used to determine if the City of Stockton is meeting its waste load allocation?

Panel Response to Question #12:

The Panel's opinion is that measured data from the WWTP discharge should be used to determine if the waste load allocation is met or not. Ultimately, this question needs to be answered by the Regional Board. The allocation should be for a discharge from the WWTP. Thus, the actual discharge data should be used.

Question #13 for Panel:

If modeling is to be used to assess compliance with the load allocation, discuss whether the model results are scientifically robust and accurately assess the impact of the City of Stockton WWTP discharge.

Panel Response to Question #13:

The Panel believes that measured data should be used instead of model results. Ultimately, the models are used to come up with the load allocation for the WWTP. If that allocation was established before the WWTP improvements, the allocation should be easy to meet. In this case, the Regional Board may want to revisit the overall load allocations for meeting the water quality objectives. Nevertheless, measured data should be used to determine compliance.

Question #14 for Panel:

Discuss the limitations of the Integrated Model. What should it not be used for?

Panel Response to Question #14:

With the current models, the Panel feels they can be used as screening tools, but not for allocating responsibility. The many data-related limitations of WARMF have been elaborated on above. Likewise, the formulation limitations of the Link-Node model have been discussed.

Predicting Blue-Green Algae in South Delta

Blue-green algae blooms have been documented to periodically occur in the Delta since 1999 and recent research indicates that the blooms may be originating in the SJR (Central Delta) between June and September. Ambient microcystin concentrations during bloom conditions may impact the growth and survival of zooplankton and fish in the estuary and could contribute to the pelagic organism decline by reducing the amount of high quality food at the base of the food chain. Data were to be collected to assess the abundance and distribution of blue green algae and their toxins in the South Delta, but blue-green algae are not explicitly simulated by the model.

Question #15 for Panel:

Discuss the limitations of the integrated model's simplified representation of phytoplankton and whether additional measures should be taken to consider the impact of blue-green algae on the TMDL and load allocations.

Panel Response to Question #15:

Is this an issue of DO or of toxicity? If it is not a DO issue, should it be addressed in some other way than this DO TMDL? For the purpose of estimating upstream (of the DWSC) DO consumption associated with phytoplankton production, the model is sufficiently well developed to not have to add special considerations and terms for the blue-green algae. For slow-flowing regions that exhibit periodic vertical stratification that enables blue-green algal (BGA) blooms to become established and significant from a system-level production and BOD perspective, some modification of the model may be needed. Models must not only capture nutrient supply versus BGA growth potential, but also flow, stratification, and residence time in order to estimate impacts on doubling rates of the BGA bloom and its ability to uptake nutrients and its role in BOD dynamics. Also, buoyancy behavior needs to be captured by the model, because the biomass is concentrated near the surface, affecting multiple processes, including light penetration, O2 production/consumption and water column diffusional characteristics.

However, before embarking on more complicated versions (and interpretations) of the models, it must be determined how important BGA is as a fraction of the BOD-generating biomass in the SJR and DWSC, and this has not yet been done (it is not obvious from ref 2d). If this fraction turns out to be relatively small (say <10% of total phytoplankton biomass) the BGA impact on BOD will not be significant enough to warrant the time, trouble and expense of doing so.

One way to quantitatively estimate and distinguish BGA from other phytoplankton groups in the SJR and DWSC is to use high performance liquid chromatography (HPLC)- derived diagnostic photopigments, in conjunction with cell counts, to partition the biomass into these groups (see Wright et al. 1996; Jeffrey et al. 1999; Pinckney et al. 2001; Paerl et al., 2003). This will enable more comprehensive (and efficient) assessments of the relative contributions of these groups to the total phytoplankton biomass (as chlorophyll *a*) throughout these systems.

Jeffrey, S.W., Wright, S.W., Zapata, M., 1999. Recent advances in HPLC pigment analysis of phytoplankton. Marine and Freshwater Research 50, 879–896.

Paerl, H.W., L.M. Valdes, J.L. Pinckney, M.F. Piehler, J. Dyble and P.H. Moisander. 2003. Phytoplankton photopigments as Indicators of Estuarine and Coastal Eutrophication. BioScience 53(10) 953-964.

Pinckney, J. L., T. L. Richardson, D. F. Millie, H. W. Paerl. 2001. Application of photopigment biomarkers for quantifying microalgal community composition and in situ growth rates. Org. Geochem. 32:585-595.

Wright, S.D., Thomas, H., Marchant, H., Higgins, M., Mackey, D., 1996. Analysis of phytoplankton of the Australian sector of the Southern Ocean: comparisons of microscopy and size frequency data with interpretations of pigment HPLC data using the **"***Chemtax***"** *matrix factorization. Marine Ecology Progress Series 144, 285–298.*

Zooplankton, a recent addition to the model and a potentially important element in phytoplankton dynamics, requires additional assessment prior to implementation. Model performance was counterintuitive and data to sufficiently test the model were not available.