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

24th Annual Progress Report
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Chapter 3: Extending DSM2-QUAL Calibration of Dissolved Oxygen

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3 Extending DSM2-QUAL Calibration of Dissolved Oxygen

3.1 Introduction

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

3.2 Background

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

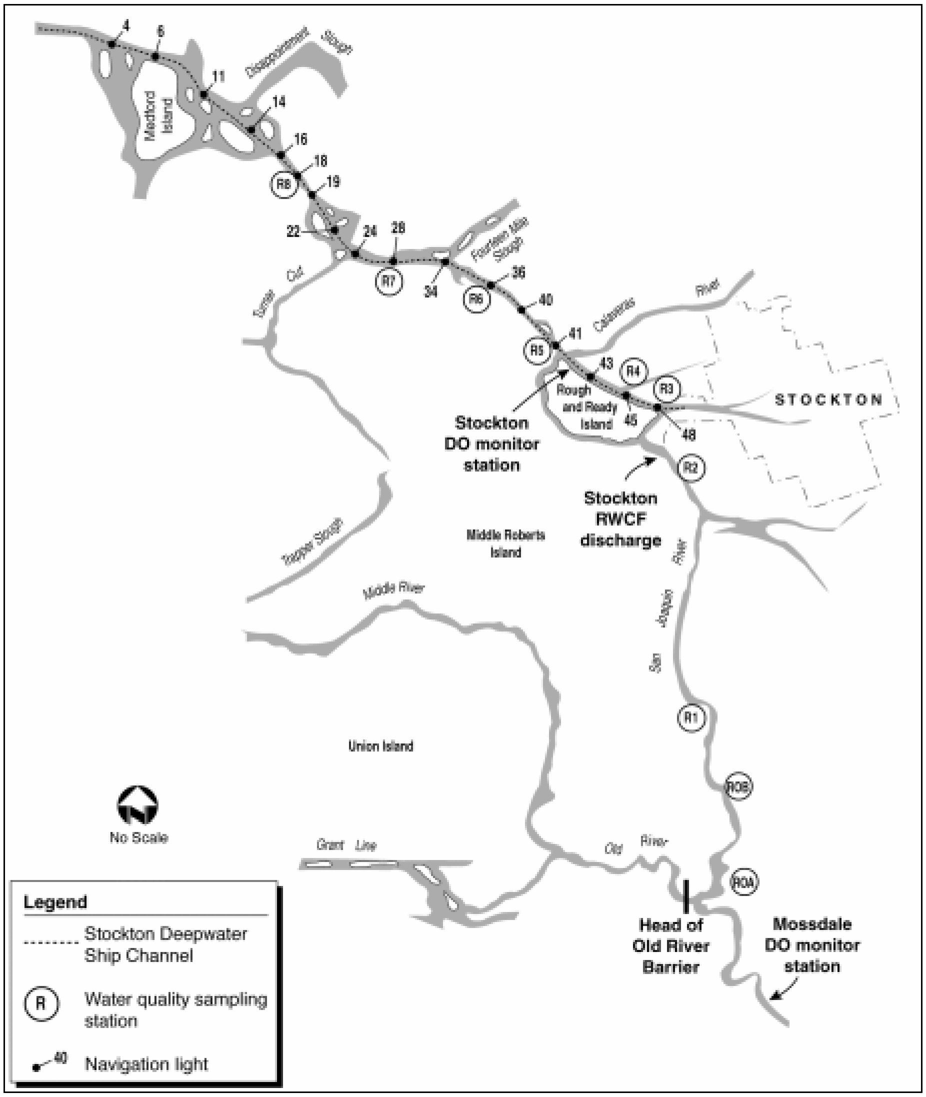


Figure 3.1: Water Quality Stations near Stockton.
(Adapted from Jones and Stokes, 2001)

3.3 Data and Model Input

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

Simulation of DO by QUAL requires information on water temperature, biochemical oxygen demand (BOD), chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate) in the Delta. To simulate DO, a group of related variables has to be simulated at the same time. Interaction among water quality variables in DSM2 is shown in Figure 3.2. The rates of mass transfer (shown by the arrows) are functions of temperature. It is important that temperature simulation be included in the DO simulation. The sources and sinks of DO are indicated in Figure 3.2. Rajbhandari (1998) discussed the DO kinetics used in QUAL in greater detail (this report can be found at: http://modeling.water.ca.gov/delta/reports/annrpt/1998/1998Ch3.pdf).

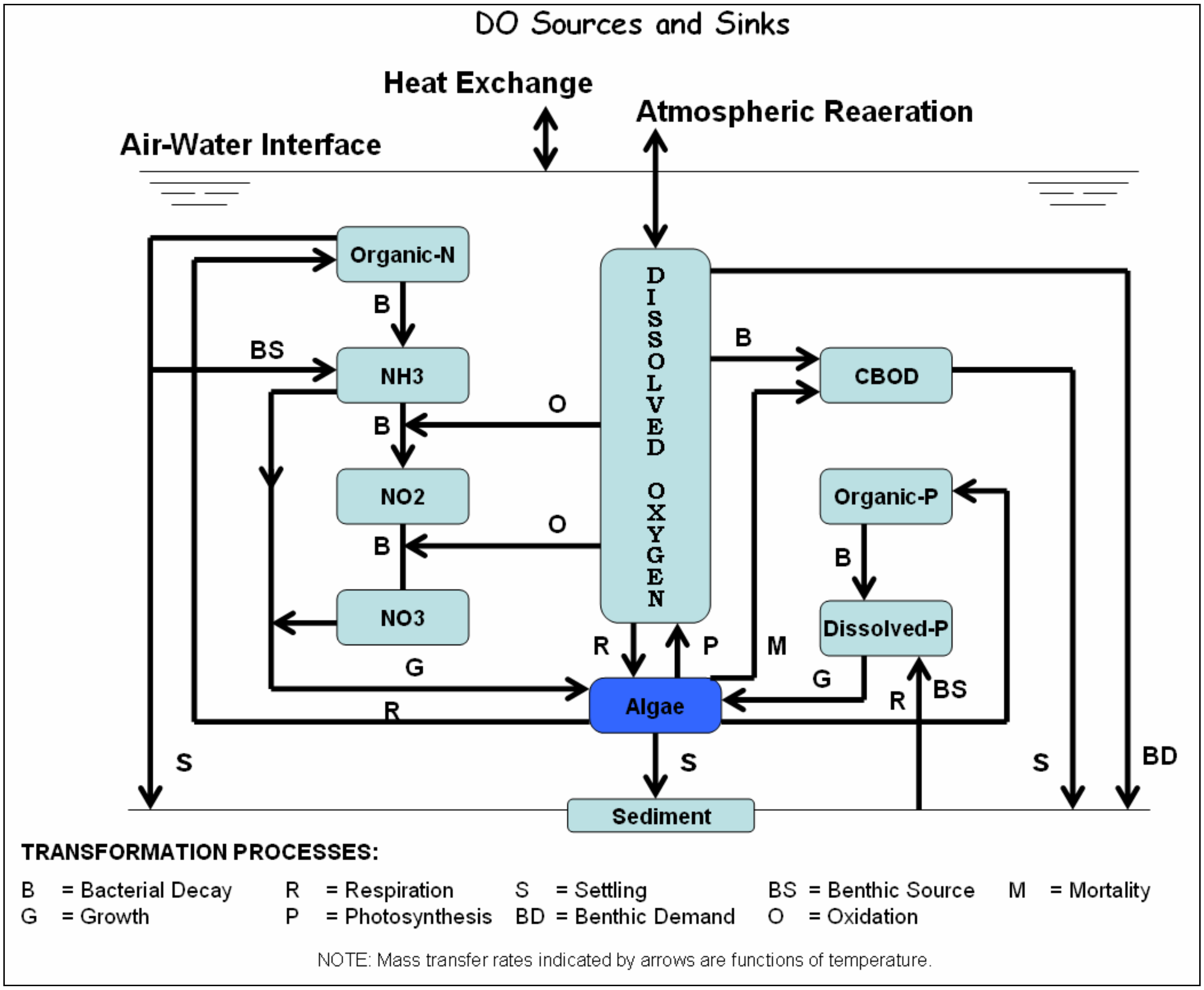
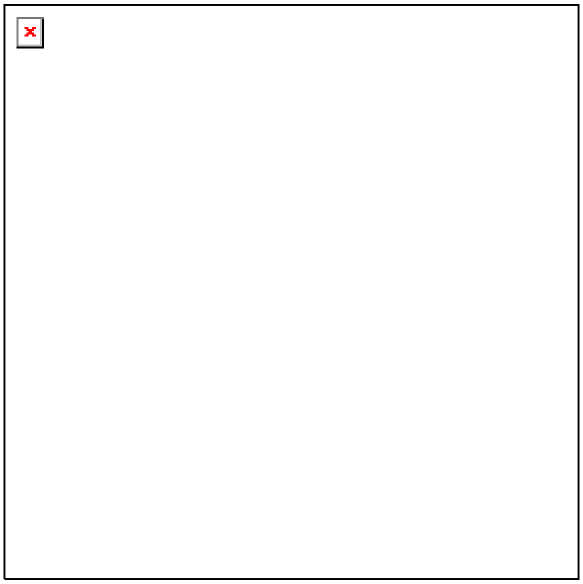


Figure 3.2: Interaction Between DO and Related Parameters.



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

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

Nutrient data at Vernalis were approximated from the San Joaquin River TMDL measurements sampled at weekly intervals in 1999. The nutrient data at Freeport on the Sacramento River were approximated from the latest publication of the U.S. Geological Survey report (USGS, 1997) and chlorophyll data were approximated from DWR (1999). Estimates of flow and water quality of agricultural drainage returns at internal Delta locations were based on earlier DWR studies.

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

3.4 Calibration and Validation

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

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

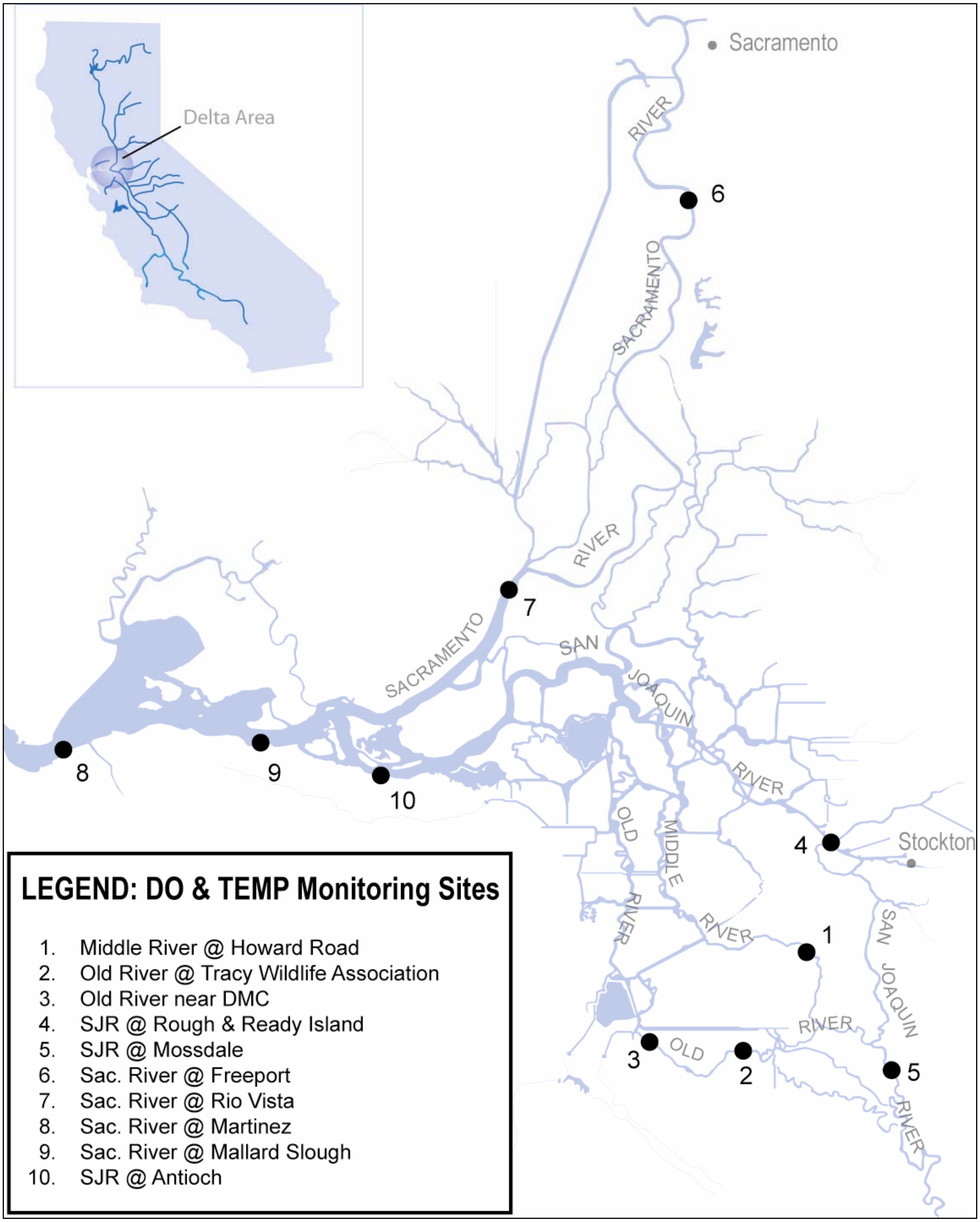


Figure 3.3: DO and Temperature Water Quality Stations in the Delta.

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

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

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

3.4.1 Calibration Results

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

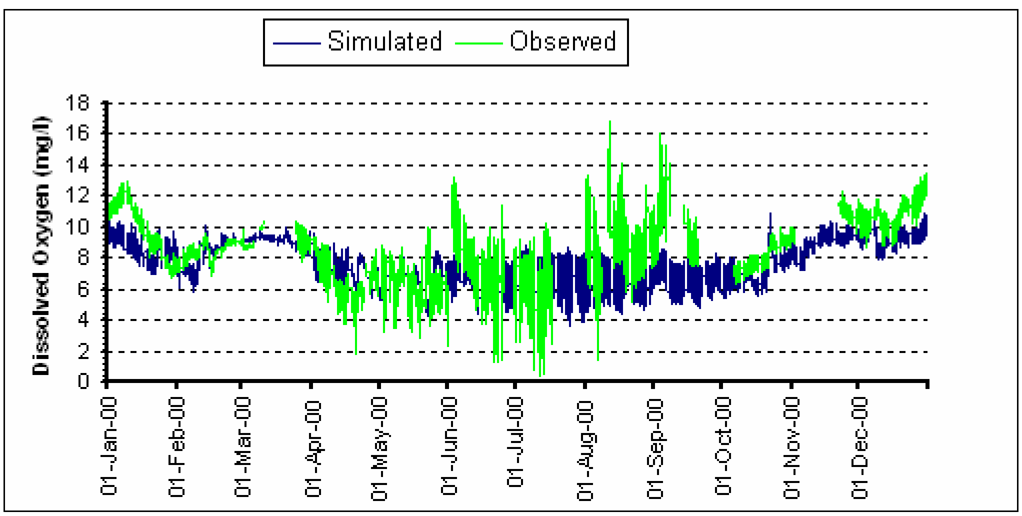


Figure 3.4: DO in the Middle River at Howard Road.

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

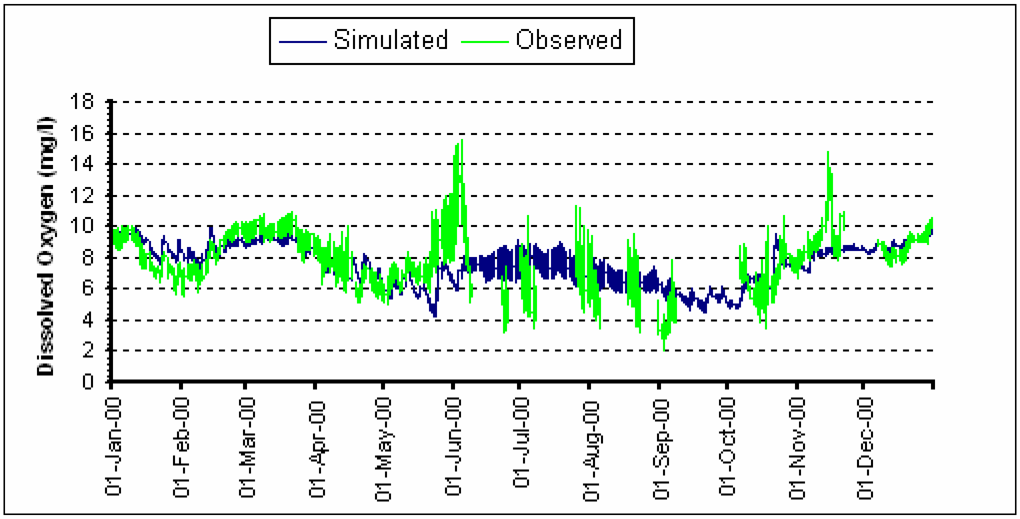


Figure 3.5: DO in the Old River at the Tracy Wildlife Association.

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

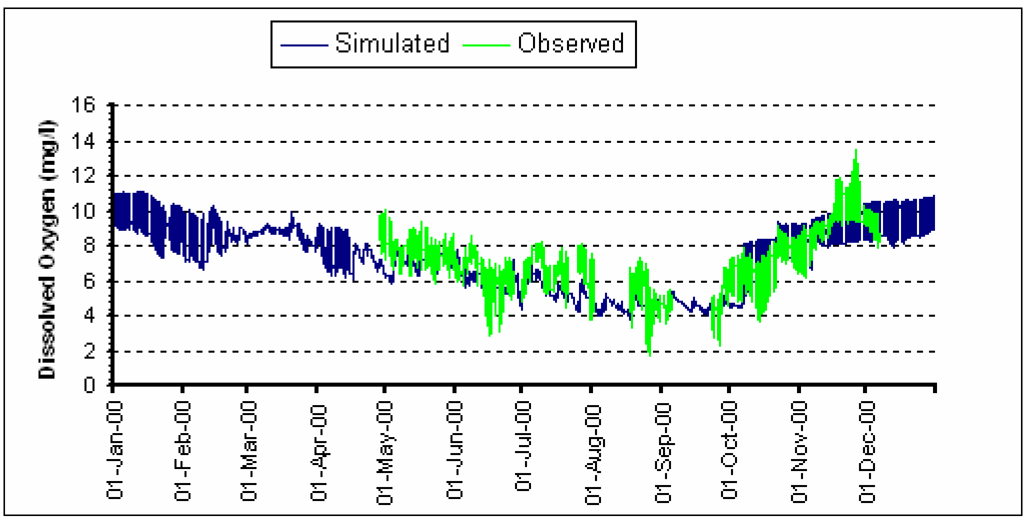


Figure 3.6: DO in the Old River at DMC.

3.4.2 Validation Results

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

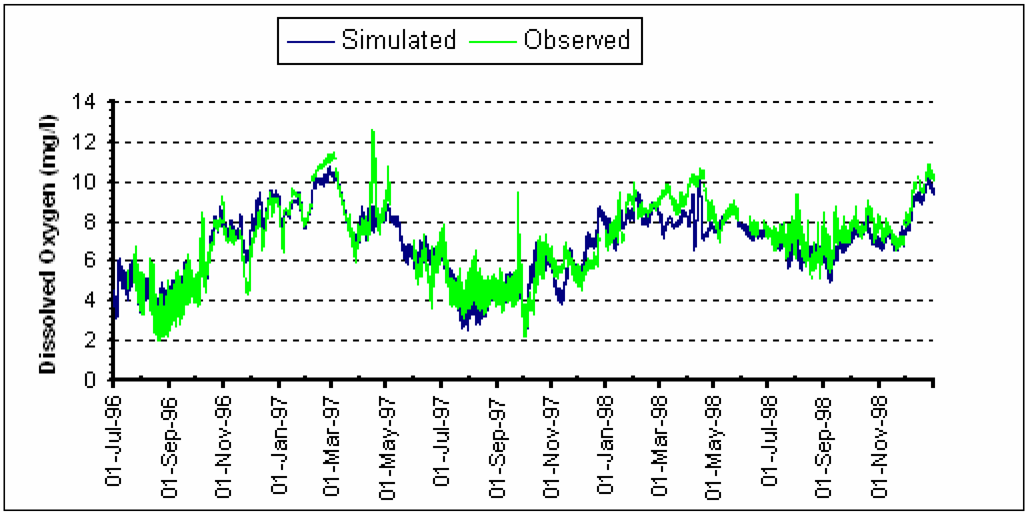


Figure 3.7a: DO in the San Joaquin River at Rough and Ready Island, 1996-1998.

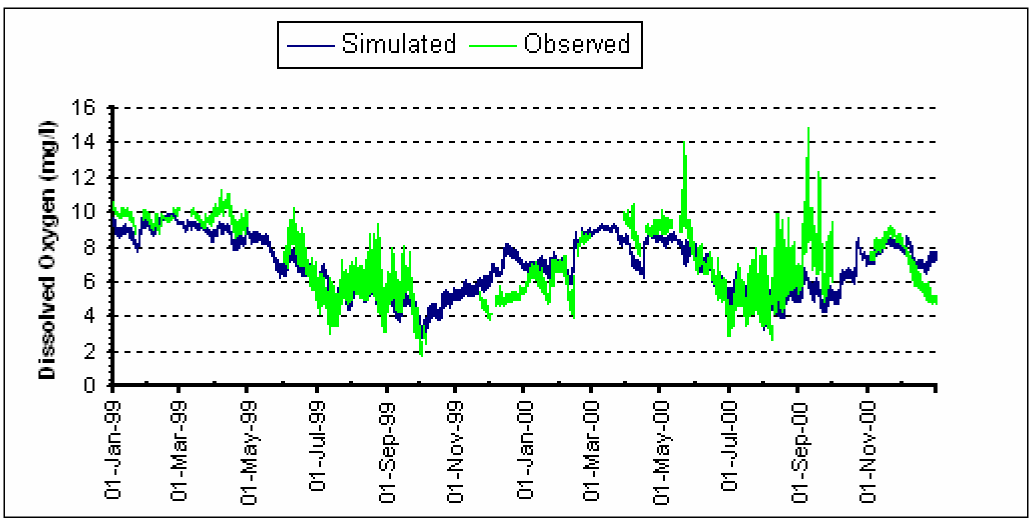


Figure 3.7b: DO in the San Joaquin River at Rough and Ready Island, 1999-2000.

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

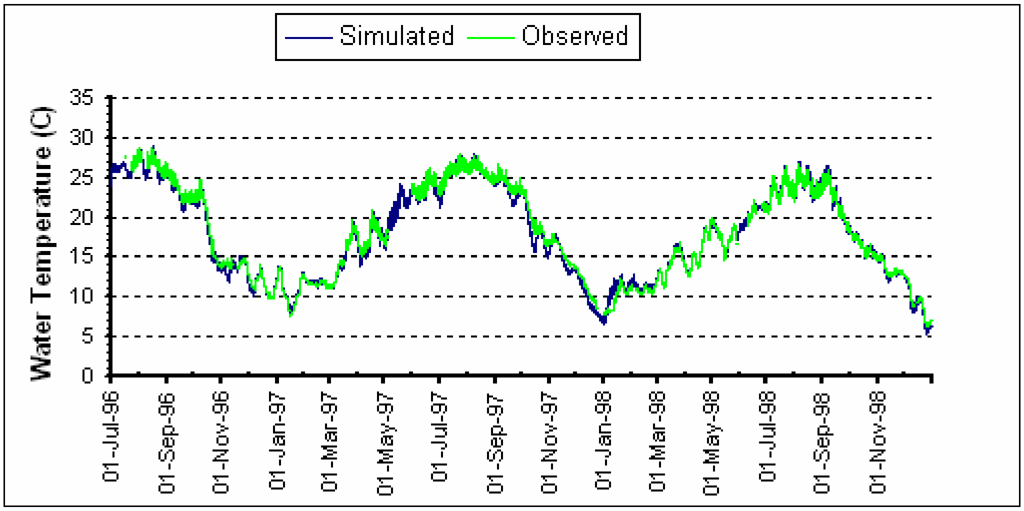


Figure 3.8a: Water Temperature in the San Joaquin River at Rough and Ready Island, 1996-1998.

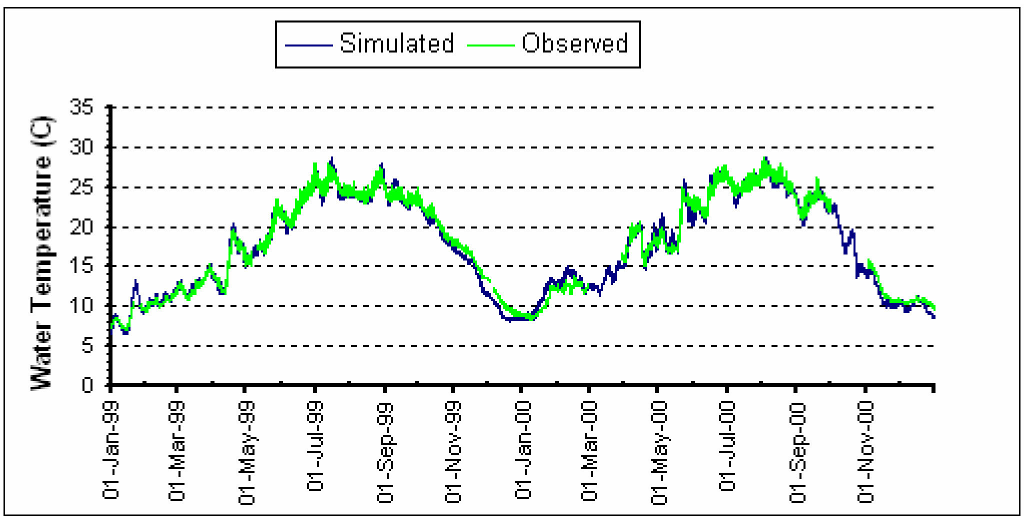


Figure 3.8b: Water Temperature in the San Joaquin River at Rough and Ready Island, 1999-2000.

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

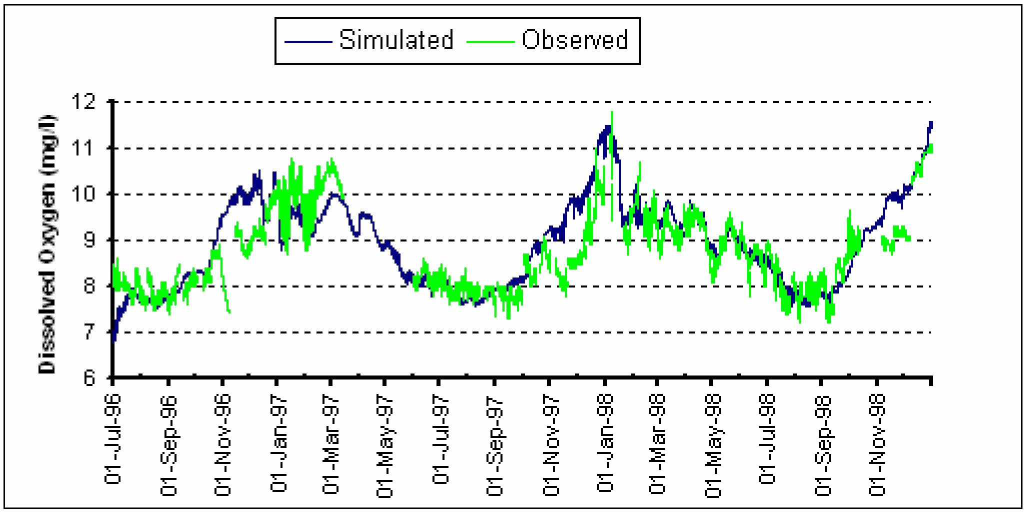


Figure 3.9a: DO in the Sacramento River at Mallard Slough, 1996-1998.

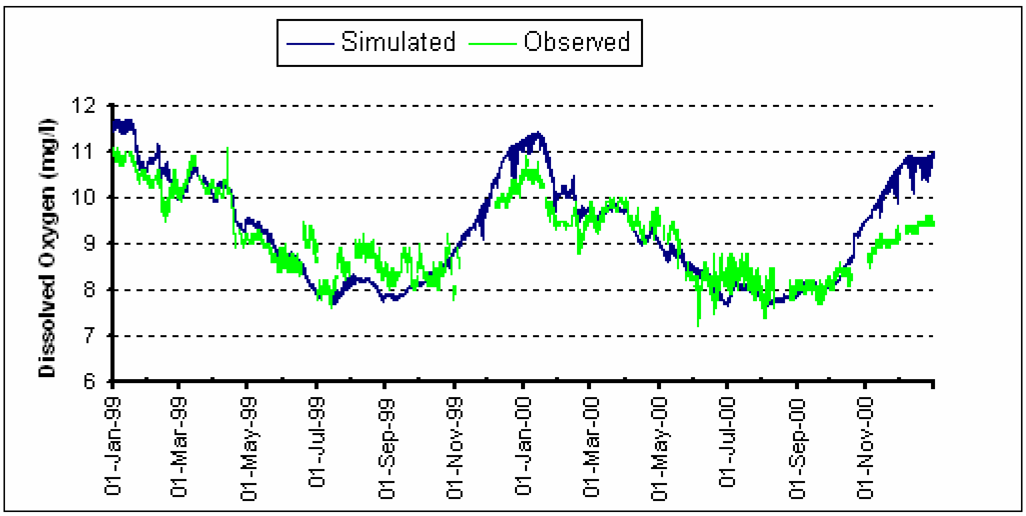


Figure 3.9b: DO in the Sacramento River at Mallard Slough, 1999-2000.

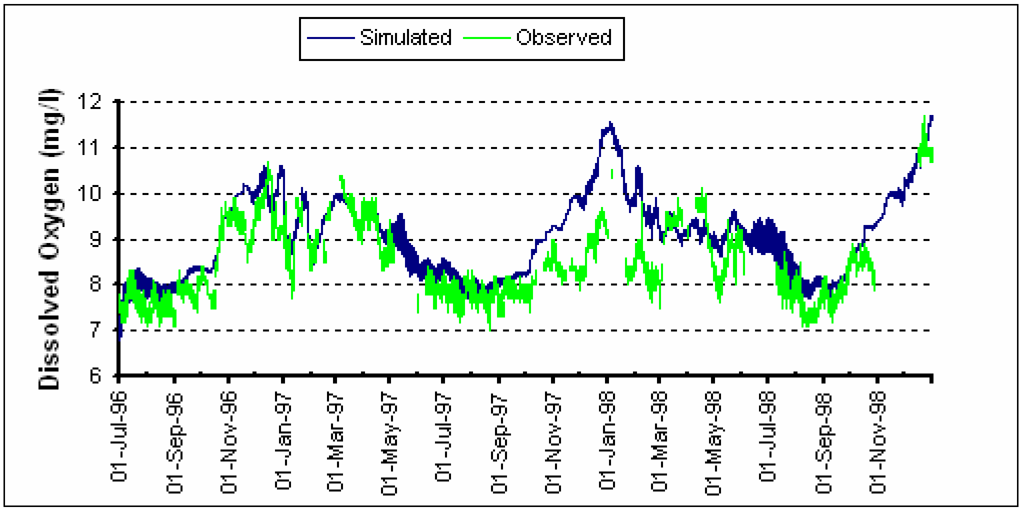


Figure 3.10a: DO in the San Joaquin River at Antioch, 1996-1998.

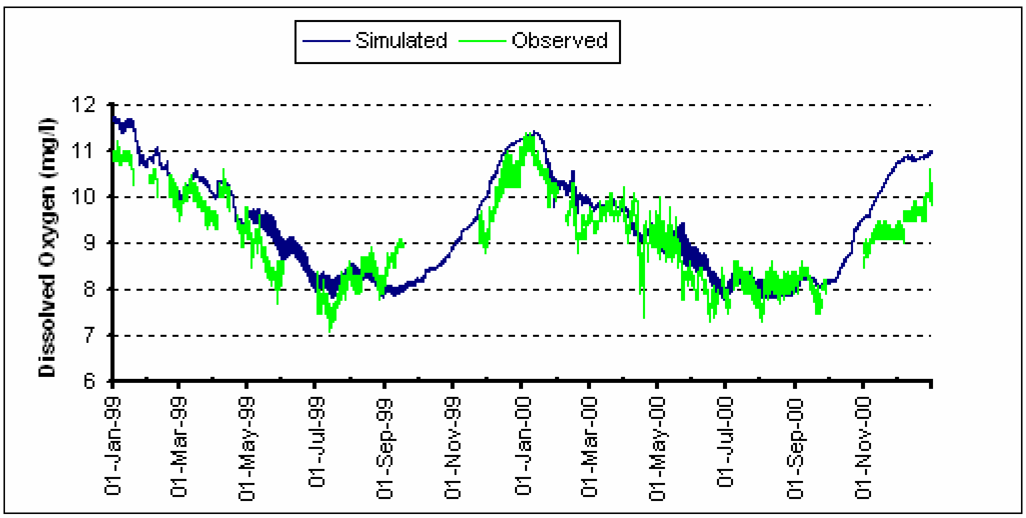


Figure 3.10b: DO in the San Joaquin River at Antioch, 1999-2000.

3.5 Summary

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

3.6 Future Directions

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

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

- South Delta Improvements Program (SDIP) alternatives:

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

- SJR Modeling upstream of Vernalis:

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

- Detailed/Multi-dimensional model analysis:

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

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

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

3.7 References

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

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

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

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

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

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

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

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

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

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

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

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