DSM2 Studies to Investigate the Use of Auxiliary Flow Pumps Across South Delta Flow Structures

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Table of Contents

List of Figures

EXECUTIVE SUMMARY

The purpose of this project was to investigate the effects of increasing the flow in San Joaquin River (by adding auxiliary pumps over the Grant Line Canal Barrier) on dissolved oxygen (DO) levels in the Stockton Deep Water Ship Channel (DWSC). The fundamental assumption for this project was that all three permanent flow structures in South Delta region would operate from April through November (For the location of the three barriers, refer to Figure 2). The primary purpose for these flow structures is to protect the water levels at the times when both State and Federal pumps are working near capacity. The proposed auxiliary pumps transfers water from the downstream side of the Grant Line Canal (GLC) Barrier to the upstream. This water transfer leads to reverse flows at the head of Old River, thus increasing the flow in the San Joaquin River downstream of the head of Old River.

The required magnitude of the auxiliary pumping was determined by achieving a certain target flow rate in San Joaquin River downstream of head of Old River. Furthermore, it was assumed that no auxiliary pumping is required if the flow targets were already met.

In the first phase of the project, the DO module of DSM2 was re-calibrated on a regional level, based on the 2000 South Delta DO data collected at three locations by DWR, Central District. Refer to Figures 7 through 12 for a comparison of model predictions with the field data.

In the second phase, DSM2 was used to simulate DO levels for the following three alternatives:

I) Base case (Three South Delta Barriers operating April through November)
II) Base case augmented with enough auxiliary pumping to maintain 1500 cfs target flow rate in San Joaquin River below head of Old River.
III) Same as II, but with 2500 cfs target flow rate.

Ideally, The hydrologic period selected should contain the extreme hydrologic events, however, the simulation period was limited to July 1996, through December 2000, mainly due to availability of the DO related data. Unfortunately, this hydrologic period does not contain the extreme dry periods.

Model results showed that DO levels improved significantly with 2500 cfs target flow rate, while only marginally with 1500 cfs (see Figures 13 and 14). Compared to the historic simulation, the base case scenario produced higher dissolved oxygen levels for all low DO periods that occurred during the summer and Fall months from 1996 through 2000 (Figure 13). Even without the auxiliary pumps, DO levels improved because of the three permanent flow structures.

It was concluded that there are potentially significant benefits to the DO concentrations in the SJR DWSC through the use of auxiliary pump flows. The incremental benefits would have been more significant, if the simulation period included the extreme dry events.

Introduction

Low dissolved oxygen (DO) levels are of concern in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) in the vicinity of Stockton (see Figure 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. 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 purpose of this project was to investigate the potential water quality benefits of adding auxiliary flow pumps across the Grant Line Canal flow structure (shown in Figure 2) to supplement San Joaquin River flow during low flow conditions.

The original scope of work (SOW) called for analyzing four different barrier configurations using DSM2:

- I- Base Case- No South Delta flow control structures
- II- Plan A- One Barrier Configuration (Head of Old River)
- III- Plan B- Three Barrier Configuration (Grant Line Canal, Middle River, Old River)
- IV- Plan C- Plan B with auxiliary pumping downstream of Grant Line Canal

The analysis for task 2 centered on creating a hydraulic barrier at the head of Old River. Changes to the SOW were proposed by Parviz Nader (based on ideas expressed by Mr. Alex Hildebrand, South Delta Water Agency) as follows:

1- Only two configurations will be analyzed:
   Plan A - Three Barrier Configuration (Grant Line Canal, Middle River, Old River)
   Plan B – Plan A with the addition of auxiliary pumping

2- The objective for the auxiliary pumping changed from creating a hydraulic barrier at the head of Old River to meeting a San Joaquin River flow target downstream from the Head of Old River.

The rationale for the change reflected in item 2 is as follows. On one hand, when the San Joaquin River flow is around 3000 cfs, creation of a hydraulic barrier at the head of Old River would be unnecessary. On the other hand, when the San Joaquin River flow drops to around 1000 cfs, creation of the hydraulic barrier at the head of Old River does not provide enough help to improve the dissolved oxygen levels in the Stockton Ship Channel.

Two flow targets at the San Joaquin River below the head of Old River were considered: a) 1500 cfs and b) 2500 cfs. Furthermore, it was assumed that the three barriers would be installed April through November. None of the model runs include the installation of the barrier at the head of Old River. The fundamental assumption is that with the inclusion of the three barriers and the auxiliary pumping at Grant Line, there would be no need for the Head of Old River Barrier. Considering the area enclosed between the three barriers extending to the head of Old River and the San Joaquin River between Vernalis up to the head of Old River, conservation of mass requires:

$$Q_{Target} = Q_{Vernalis} + Q_{aux} + Q_{barrier} - Q_{chdep} \quad (1)$$

Q_{Target} = Flow target on the San Joaquin River downstream from the head of Old River

$Q_{Vernalis}$ = Flow in the San Joaquin River at Vernalis (DSM2 boundary)

Q_{aux} = Amount of auxiliary pumping required at the Grant Line Canal Barrier site to achieve a flow target at the San Joaquin River below the head of Old River

$Q_{barrier}$ = Sum of gravity driven flows (net tidally averaged) through the barriers (+ for west to east).

Q_{chdep} = The sum of net channel depletion in the area bounded between east of the barriers and the head of Old River and the San Joaquin River between Vernalis and the head of Old River[1].

Equation (1) can be solved for Q_{aux} :

$$Q_{aux} = Q_{Target} + Q_{chdep} - Q_{Vernalis} - Q_{barrier} \quad (2)$$

All the parameters appearing on the right side of the equation are user input with the exception of $Q_{barrier}$. Several DSM2 runs were conducted to get estimates for the term $Q_{barrier}$ for various hydrologic conditions. Model results indicated that for the hydrologic conditions with $Q_{Target} > 1500$ cfs, the term $Q_{barrier}$ turns out to be a negligible amount. This is due to the fact that with the addition of auxiliary pumping, stage upstream (east) of the barriers is always greater than the stage downstream (even at high tide), thus stopping any natural gravity driven reverse flow. Thus equation (2) reduces to:

$$Q_{aux} = Q_{Target} + Q_{chdep} - Q_{Vernalis} \quad (3)$$

It should be noted that for high San Joaquin River flow ($Q_{Vernalis}$) conditions, equation (3) may lead to a negative number, suggesting that no auxiliary pumping would be necessary to meet the target flow. Figure 5 shows the magnitude of the required auxiliary pumping on the GLC barrier to maintain 1500 cfs and 2500 cfs flow targets. Since the selected hydrologic period happens to be one with somewhat higher flows than would normally occur in the SJR, the target flows are met except for the four summer-fall time periods shown. The year 1998 especially had significantly higher flows, so flow targets were already met for the entire period without auxiliary flows.

The simulation period was selected to cover July 1996 through December 2000. The main reason for selecting this period was the availability of data needed for DO simulation including electronic versions of hourly climate data. Unfortunately, this period does not include extreme dry periods, which are typically associated with the extreme low DO levels in DWSC. However, at this point, extension of the modeling period prior to 1996 is impractical.

[1] This definition of Q_{chdep} is different from the previous definition shown in the first quarterly report.

Three sets of hydrodynamic runs were conducted for

a) (Plan A) Base condition using hydrology based on historical conditions (No auxiliary pumping)
b) (Plan B) Alternative 1 auxiliary pumping based on Q_{Target} = 1500 cfs
c) (Plan B) Alternative 2 auxiliary pumping based on Q_{Target} = 2500 cfs

The three barriers are assumed to be operating April through November (auxiliary pumps operate only during the months when all three barriers are present). These runs were followed by three sets of water quality runs (EC based).

Salinity Simulations

Analysis of DSM2 hydrodynamic and salinity simulations showed water quality improvements in the main stem of the San Joaquin River between the head of Old River to the Turner Cut and to a lesser extent in the South Delta region. Areas close to Middle River and Old River leading to Clifton Court Forebay and CVP experienced a slight degradation. The changes to the rest of the Delta appear to be minimal. These were the expected results. The following factors support these findings:

1) Without auxiliary pumping, the major source of water in the South Delta is the San Joaquin River. Auxiliary pumping transports the better quality water coming from the North (primary source: Sacramento River) to the South Delta.
2) Without auxiliary pumping, poor water circulation patterns are created, which lead to stagnant conditions.[2] The agricultural drainage flows from nearby farms contribute to the water quality problems, as they are not flushed out of the system. The auxiliary pumping creates better water circulation and helps eliminate the stagnant conditions.
3) Maintaining a high flow rate in the main stem of San Joaquin River prevents any direct salinity intrusion into San Joaquin River.
4) Since the Net Delta Outflow is unaffected by the auxiliary pumping, the salinity intrusion patterns are not altered elsewhere, explaining why the changes in the water quality for the rest of the Delta are minimal.

Dissolved Oxygen Simulations

Simulation of DO by DSM2 requires information on water temperature, BOD, chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate) in the Delta. In order to simulate DO, a group of related variables has to be simulated at the same time. Interaction among water quality

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[2] It has long been recognized that maintaining three barriers in the South Delta region creates water quality issues due to poor circulation patterns. To improve the circulation patterns, a special gate operation has been introduced. Under this 'special operation', Grant Line Canal Barrier is closed a few hours before and after the low tide, and is allowed to remain open during the rest of the tidal cycle. The purpose of this type of operation is to protect the water levels during the low tide, and to create better circulation patterns, aiming at improving water quality. Under such operation, the net tidal flows tend to be from west to east in Middle River and Old River, and from east to west in Grant Line Canal. Such 'special operation' was not practical for this study, since the addition of auxiliary pumping requires full barrier operation during the entire tidal cycle.

variables in DSM2 is shown in Figure 3. 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 the figure. Further information on DSM2 kinetics is given in reference (Rajbhandari 1998), also available at the Delta Modeling web site "http://modeling.water.ca.gov/delta/reports/annrpt/1998/chpt3.html."

Available data collected at hourly intervals for DO and temperature provides boundary information needed by DSM2. A combination of hourly varying temperature and DO data in Sacramento River at Freeport and Rio Vista were provided for the Sacramento River model boundary. The historical record of DO and temperature at Martinez was used for the downstream model. Since continuous data were not available at Vernalis (RSAN112), hourly values of DO and temperature available from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. Since the flows at Vernalis are primarily unidirectional, and the hydraulic residence time is relatively short, this assumption may be less critical.

Data on effluent flows from the City of Stockton's Regional Wastewater Control Facility were obtained from the City of Stockton Municipal Utilities Department. Flow, BOD and temperature data were available usually on a daily basis. The data for ammonia nitrogen were available at approximately two-day interval. These data were interpolated to obtain daily estimates. EC, organic nitrogen, nitrite nitrogen and nitrate nitrogen were available at approximately weekly intervals. These were also interpolated to daily intervals so that a regular time-varying input file could be generated. For most of these constituents, the values were sometimes given as "less than" a detection limit. Approximations were made generally based on the values for the preceding and the subsequent dates.

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.

Climate data at hourly or 3-hour intervals representing air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure (source: National Climatic Data Center) provided DSM2 input for simulation of water temperature. An electronic version of the data was available only from July 1996. 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.

Comparison of Simulated and Measured DO

Previously DSM2 was calibrated and validated for DO simulation, however it was based on a few months' data in 1998 and 1999 (Rajbhandari 2001). Because hourly time series data were available only at the Rough and Ready Island (RRI) in the region of interest, calibration was primarily based on comparisons in that location. Under normal flow conditions, the DO levels in the SJR at RRI depend mainly on SJR flow and quality. However for the scenarios that are based on auxiliary pumping, it was important to validate DSM2 simulation of DO in the South Delta region. In the present context this was achieved by comparing model DO against field data available for the year 2000 at the three locations, two in Old River and one in Middle River as shown in Figure 4. This necessitated calibrating DSM2 but required changes to rate coefficients 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). The interested reader is referred to Rajbhandari (1995) for a more complete description of DO kinetics and model development.

Figure 6 compares simulated water temperature with field data at the continuous monitoring station at SJR near RRI. In general, DSM2 seems to underestimate the observed data but the differences are generally less than 1 degree Celsius. The diurnal range in DSM2 results is generally shorter than those for the field data, especially in the summer months. However tests showed that DO sensitivity to small variations in temperature is low.

Figure 7 presents the comparison of model DO and field observations in the San Joaquin River near RRI. The model seems to do well in representing 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 highly super-saturated values of DO observed during summer and fall of 2000. From the TMDL perspective it seems desirable that the model be capable of predicting the lower DO levels more accurately.

Data for most of year 2000 was available for three locations in the South Delta, as shown in Figure 4. Figure 8 shows comparisons of DSM2 DO with measured values in the 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.

Comparison of model DO with field DO in Old River at Tracy Wildlife Association shows a fair agreement during most of the months (Figure 9). Similar to the other locations the model tends to underpredict the diurnal range. Highly supersaturated DO levels that occurred in early June and November were grossly underpredicted by the model. It is relevant to note that the objective here is not to calibrate DSM2 to the South Delta region but rather to ensure that the model is able to make generally satisfactory prediction for the region. As for the RRI location emphasis was placed more on getting the low DO levels represented more accurately. This would ensure that DO simulation of auxiliary flows is good and allow a conservative estimate of its impact on DWSC. Field data for Old River at DMC is available only for the seven months and is shown with model results in Figure 10. The model tends to capture the monthly trend with better agreement in the lower range as with the other locations.

Figure 11 representing DO simulation at Mallard Slough shows that simulated DO captures the seasonal variation of DO in the measured data. Except for the summer - fall of 1999, modeled DO were within 0.5 mg/l for the low DO periods of summer months. The DO levels are maintained above the minimum standards of 5 and 6 mg/l for summer and fall months in the Delta. Comparison of simulated and field DO in the SJR at Antioch is shown in Figure 12. The model was able to represent the field DO fairly well for most of the simulation period. 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. Based on the above six locations, DSM2 was considered calibrated for the DWSC and the South Delta region.

DO Simulations for Base and Auxiliary Flow Scenarios

DSM2 was used to simulate DO levels at Rough and Ready island (RRI) for all four scenarios: historic, base, and auxiliary pumping of 1500 cfs and 2500 cfs. Compared to the historic scenario, the base scenario produced higher dissolved oxygen levels for all low DO periods that occurred during the summers from 1996 through 2000 (Figure 13). Even without the auxiliary pump flows DO levels got improved because the three permanent barriers for the eight months (April-November) of each year were able to let flows remain in the SJR. While the scenario with auxiliary flows designed for a target flow of 1500 cfs showed higher DO levels at RRI, the DO benefits compared to the base scenario was noticeable only for the summers of 1997 and 2000 (Figure 14). This is because for the rest of the period flows in SJR were already at or above 1500 cfs range. It is expected that in dry years when SJR typically has flows at about 1000 cfs or lower, the impact will be more evident. As expected, the scenario with auxiliary flows designed for a target flow of 2500 cfs resulted the highest DO benefits.

In the base scenario, DO levels fall below 5 mg/l from July – Oct, 1996 and 1997 thus violating both summer and fall DO standards. For 1998 the standard is maintained throughout the year whereas for 1999 and 2000 the standard is violated for parts of summer and fall, although to a lesser degree compared to 1996 and 1997.

Recommendations for Future Studies

A program to supplement the existing monitoring program and develop the needed database for future calibration is desirable. A minimum data collection program should include both spatial and temporal characterizations of the primary quality constituents, e.g., dissolved oxygen, temperature, chlorophyll-a, and nitrogen species, under at least two distinct hydrologic and hydrodynamic conditions.

Surveys should be conducted of sediment deposits along the DWSC to determine spatial variations in benthic/sediment oxygen demand (SOD), and the nitrogen and phosphorus content in the sediments to improve calibration of the model. Subject to a consistent expansion of the database, future extensions in the model to add additional variables, such as zooplankton and benthic algae, are likely to result in improvement in model performance. Extension of model should include a dynamic interaction of sediments with simulated constituents. Extensions could also include the ability to simulate additional species of algae and silica, if data availability and specific needs so indicate.

Summary

1. DSM2 was used to evaluate DO improvements in Stockton DWSC by adding auxiliary pumping across GLC barrier. The net effect of auxiliary pumping is to increase flows in the San Joaquin River.

2. DSM2 was recalibrated based on the DO data at three South Delta locations and the SJR near RRI. Model predictions are shown in Figures 7 through 12.

3. DSM2 was used to simulate DO levels (July 96 - Dec 2000) for three alternatives: I) Base case, II) Base case + 1500 cfs target flow in main stem of San Joaquin, III) Base case + 2500 cfs (for locations, refer to Figures 1, 2 and 4)

4. Model showed some improvement with 1500 cfs and significant improvement with 2500 cfs (see Figures 13 and 14). Even for the scenario with 2500 cfs target flows, the DO levels occasionally fell below the fall standard of 6 mg/l.

Acknowledgments

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Bijaya Shrestha of DWR for conducting DSM2 hydrodynamic and salinity runs,
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List of Abbreviations

BOD – Biochemical Oxygen Demand
CVP – Central Valley Project
DO – Dissolved Oxygen
DMC – Delta Mendota Canal
DSM2 – Delta Simulation Model 2
DWR – Department of Water Resources
DWSC – Deep Water Ship Channel
EC – Electrical Conductivity
GLC – Grant Line Canal
NDO - Net Delta Outflow
RRI – Rough and Ready Island
SJR – San Joaquin River
SOD – Sediment Oxygen Demand (Benthic Oxygen Demand)
TMDL – Total Maximum Daily Load
USGS – US Geological Survey

Appendix – Figures

The figures are presented in the following pages.

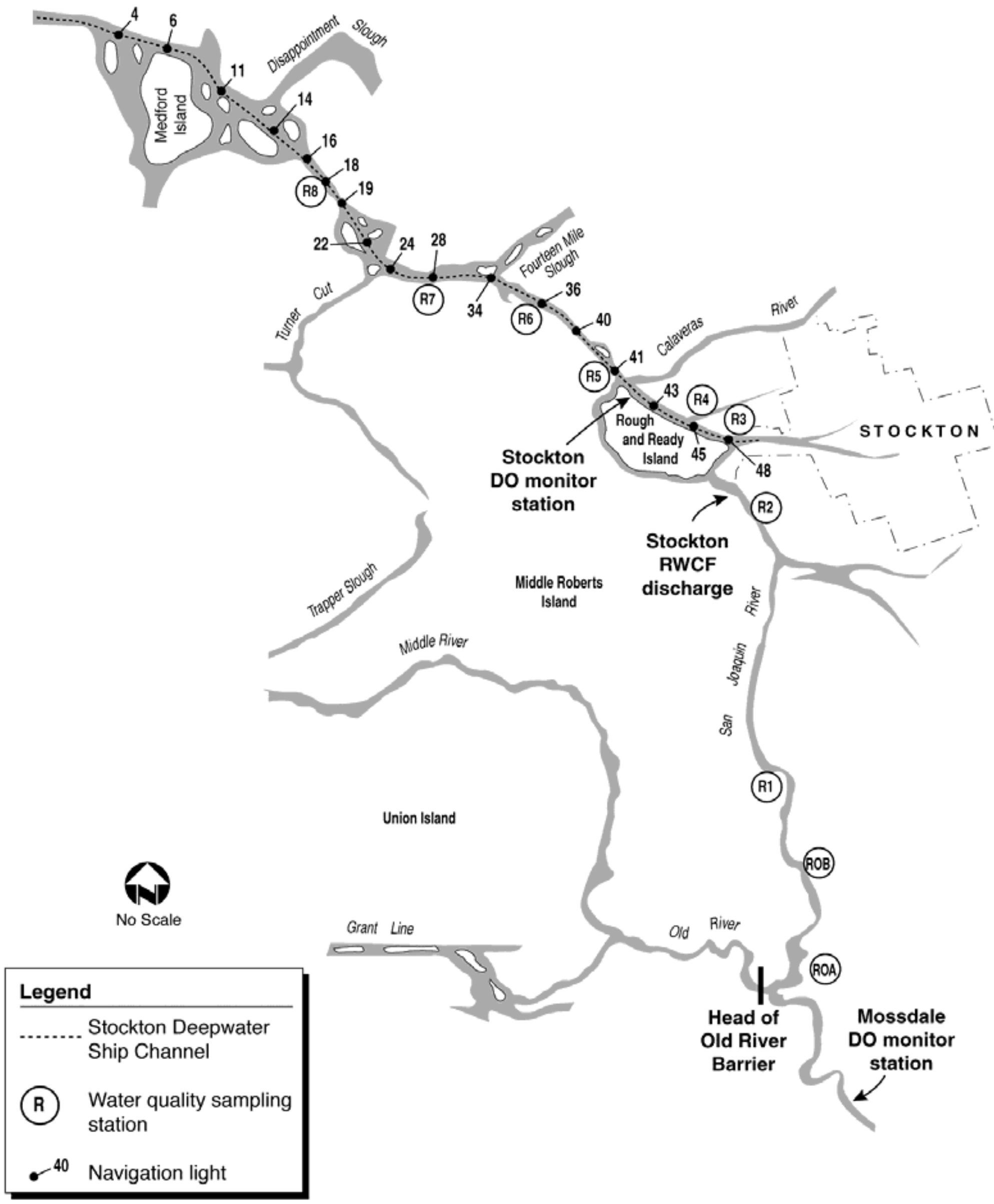

Figure 1. Water Quality Stations in the Vicinity of Stockton

(Adapted from Jones and Stokes, 2001)

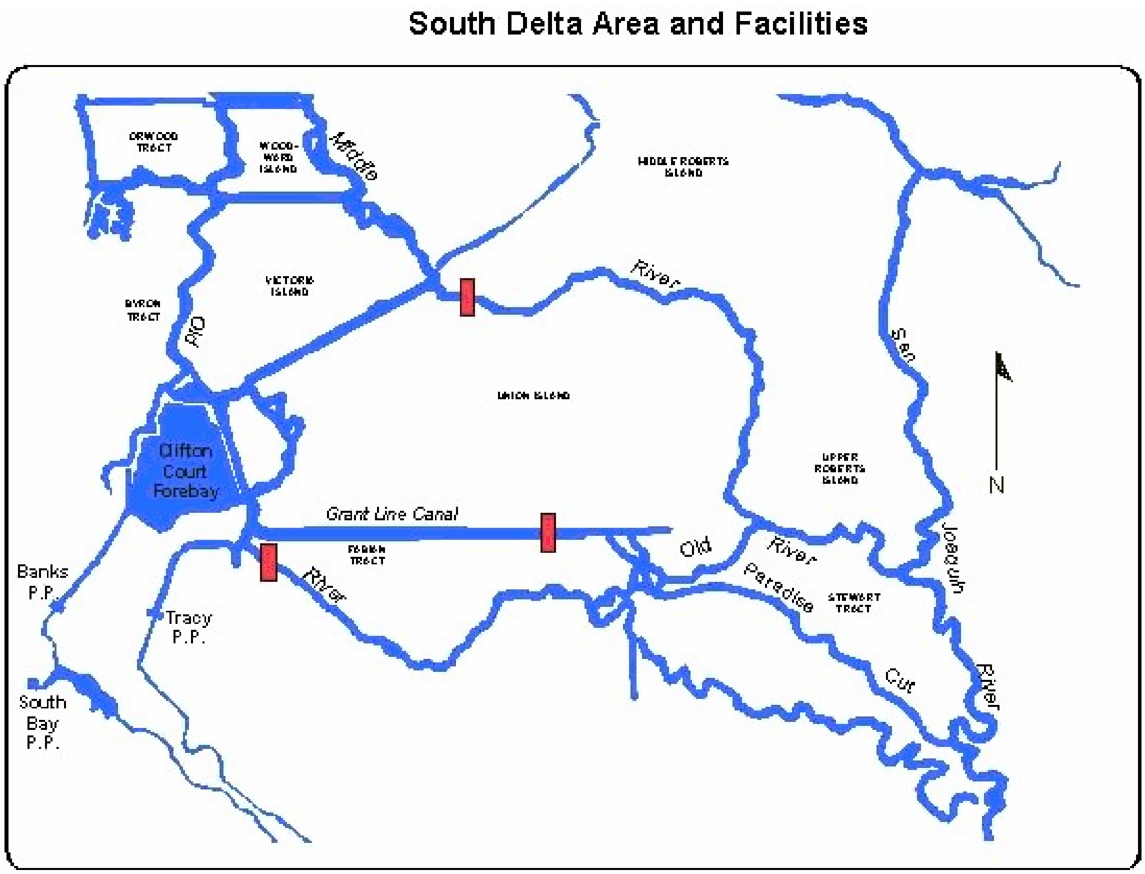

Figure 2. South Delta Flow Control Structures (indicated by rectangles)

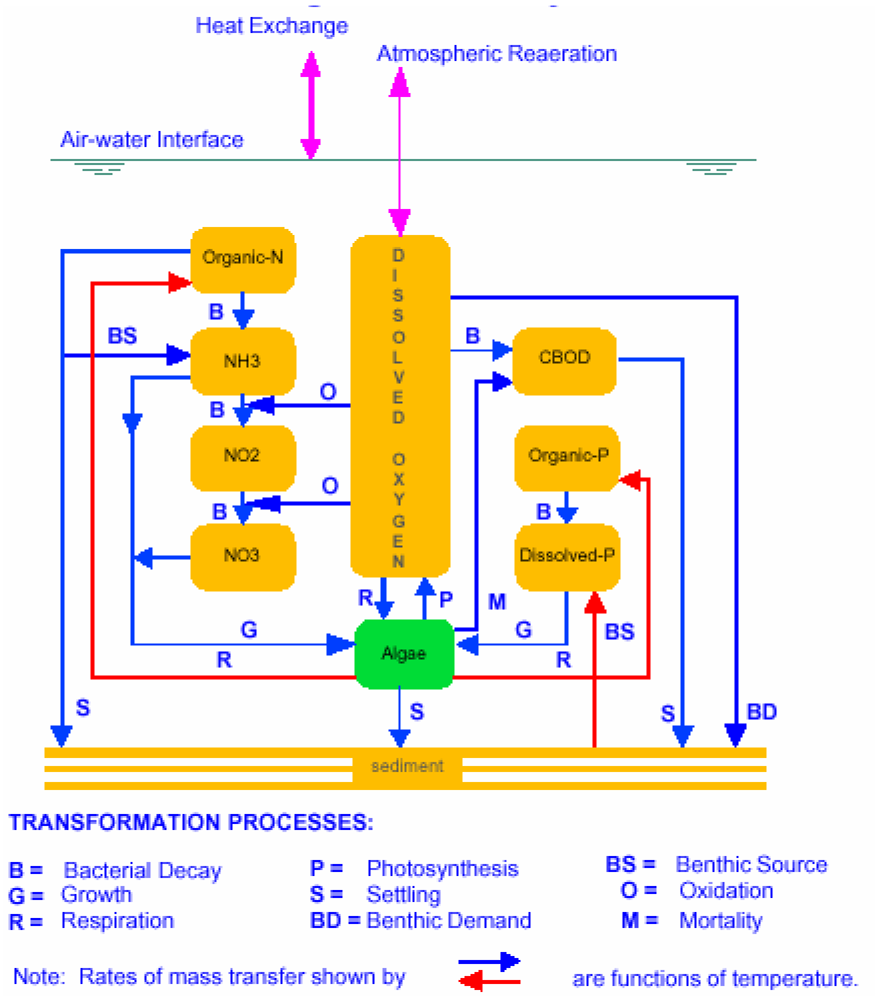

Figure 3. Interaction Among DO and the Related Parameters

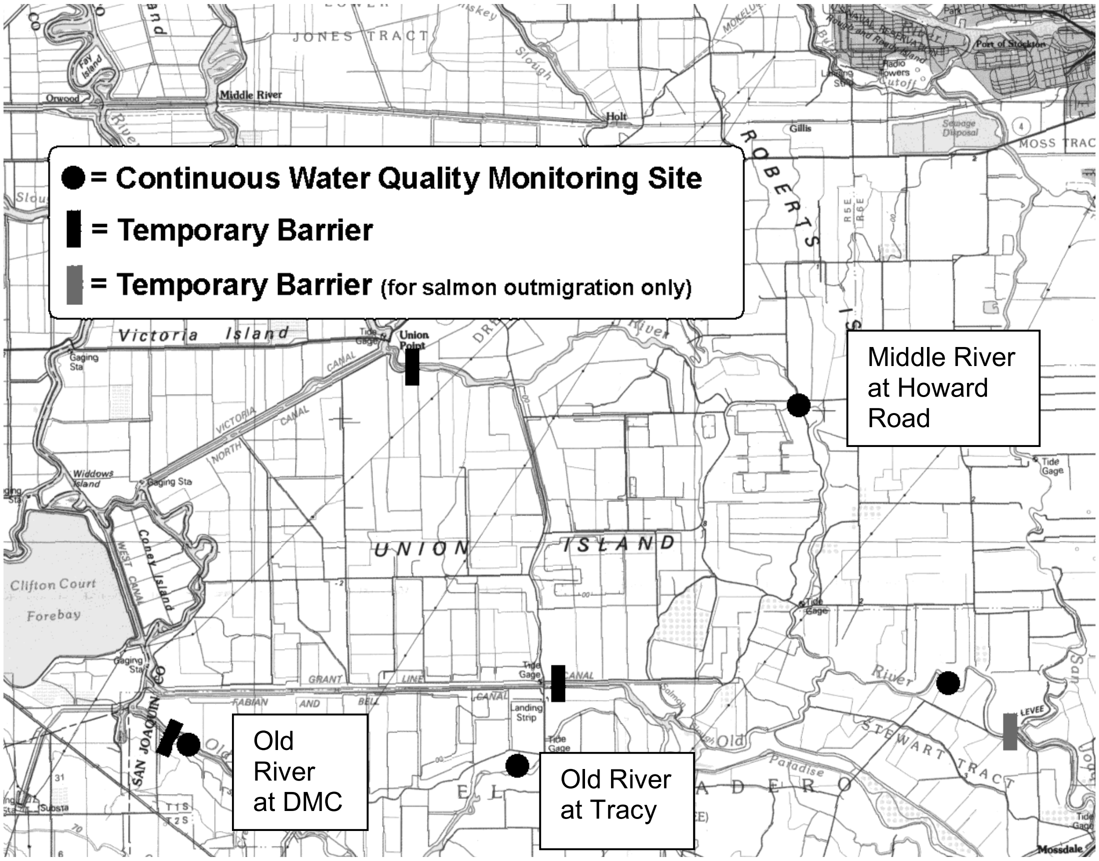

Figure 4. Water Quality Stations in the South Delta

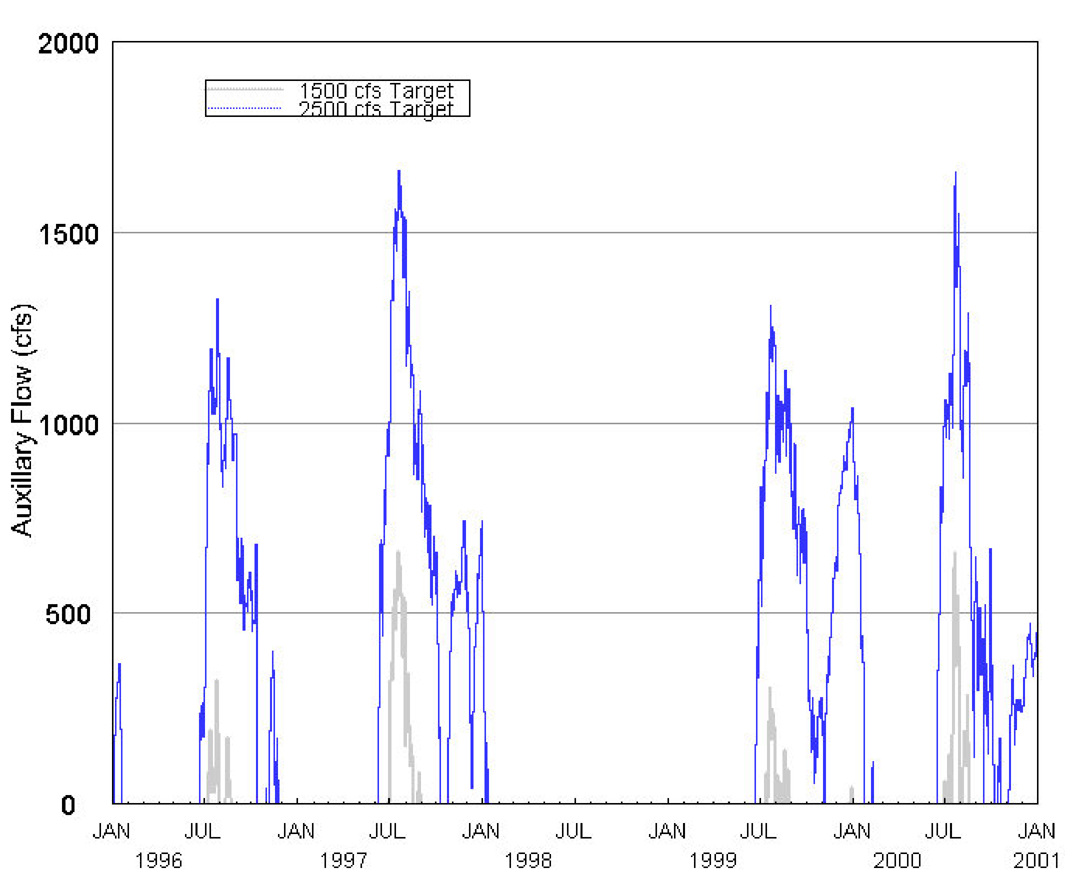

Figure 5. Auxiliary Flows over the Grant Line Canal Barrier

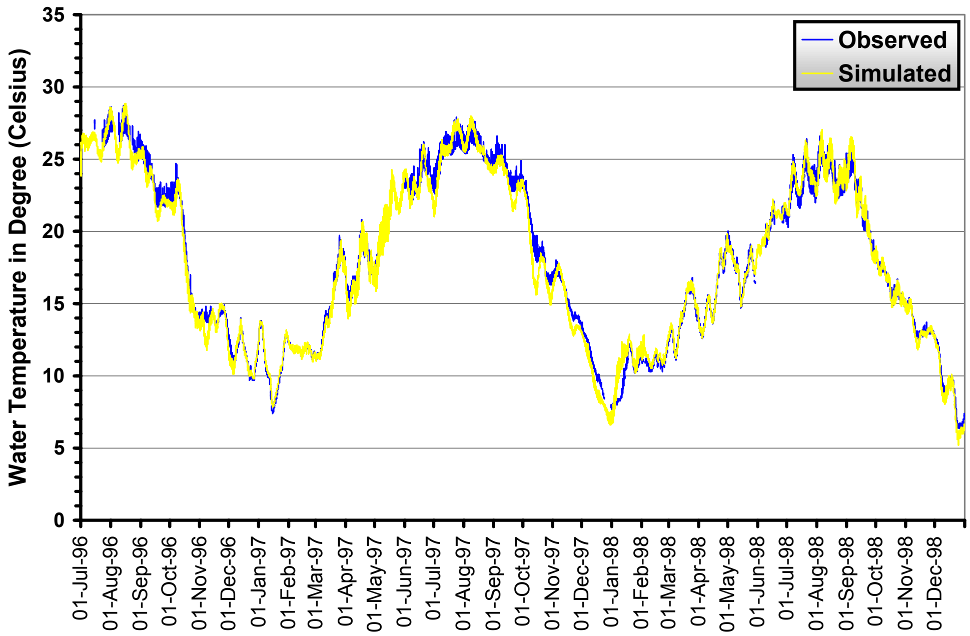

Figure 6 A. Water Temperature in the San Joaquin River at RRI

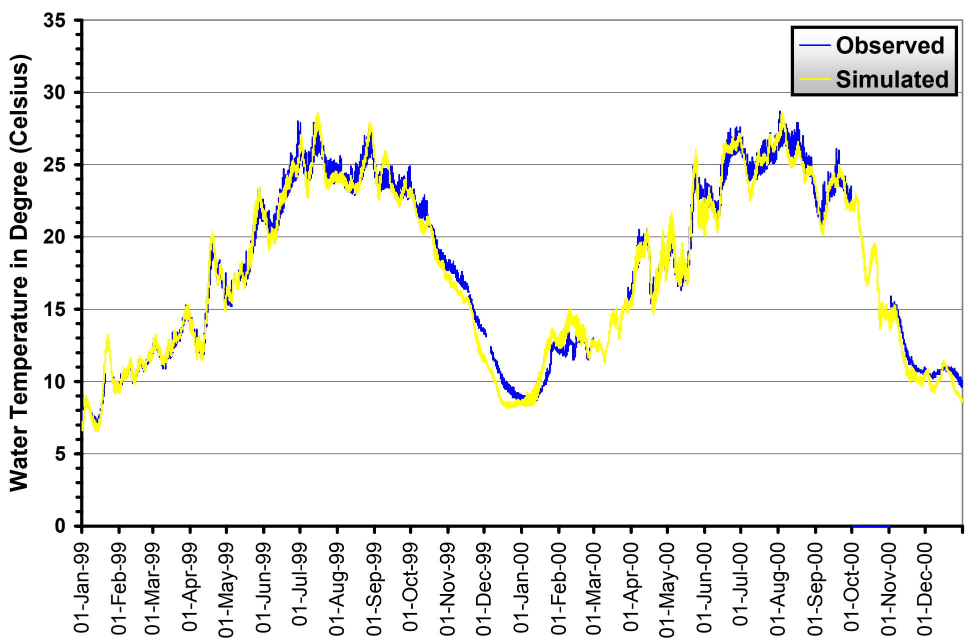

Figure 6 B. Water Temperature in the San Joaquin River at RRI

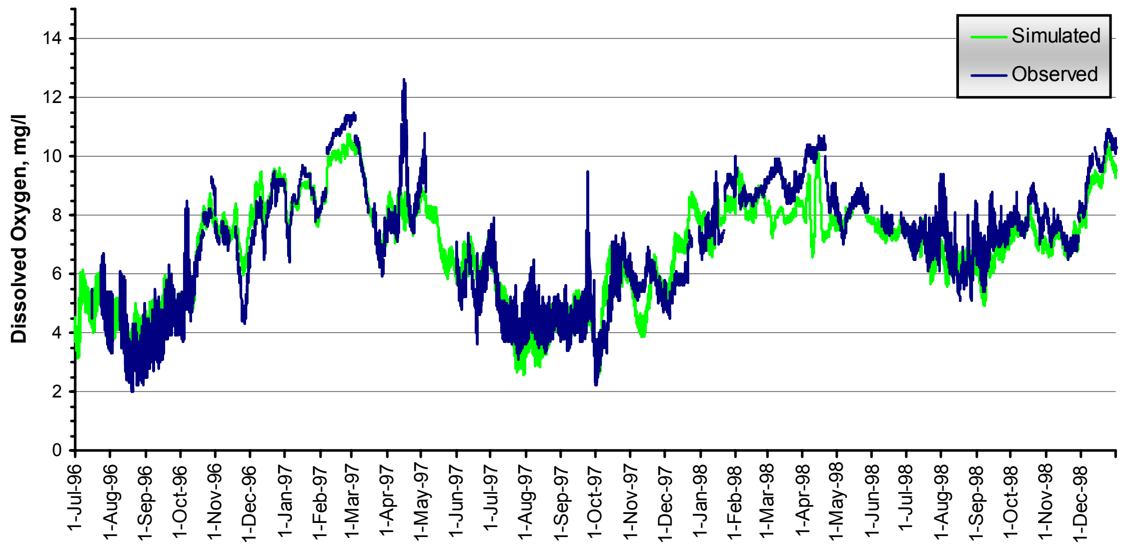

Figure 7 A. Dissolved Oxygen in the San Joaquin River at RRI

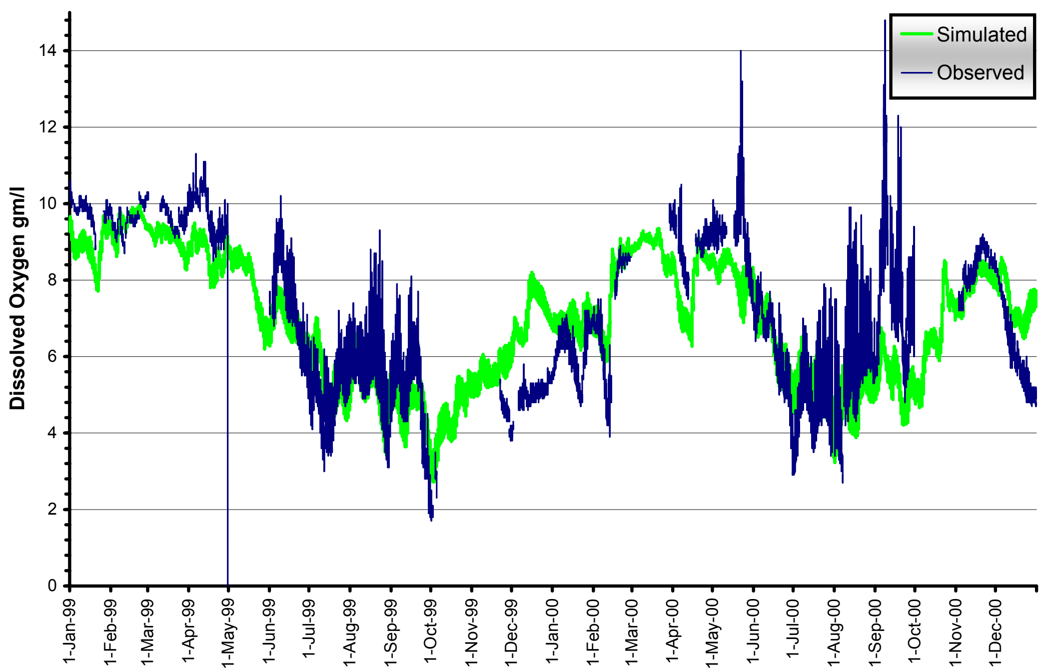

Figure 7 B. Dissolved Oxygen in the San Joaquin River at RRI

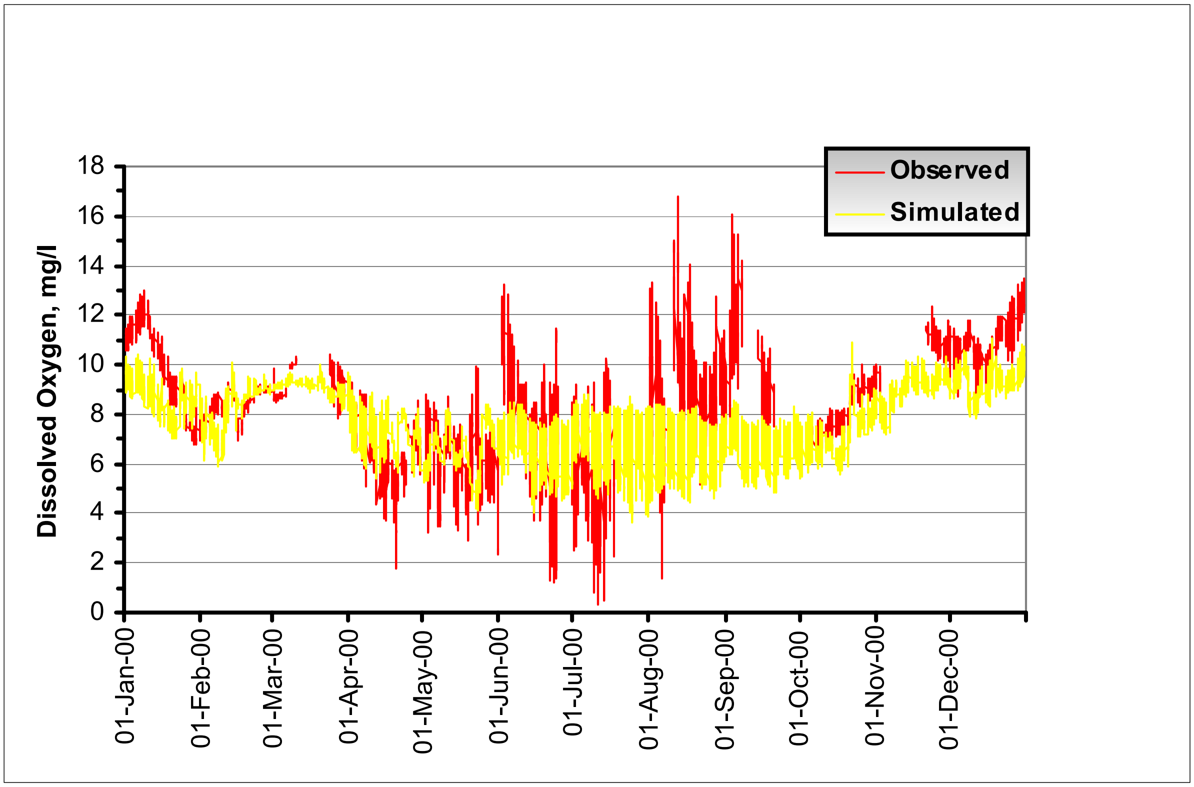

Figure 8. Dissolved Oxygen in the Middle River at Howard Road

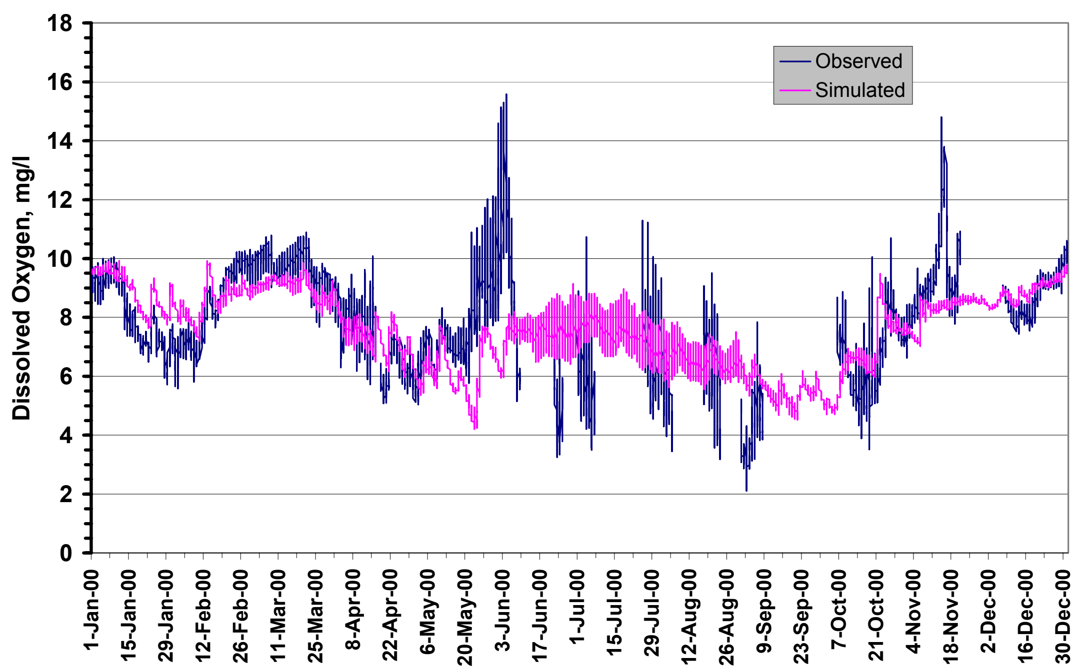

Figure 9. Dissolved Oxygen in the Old River at Tracy Wildlife Association

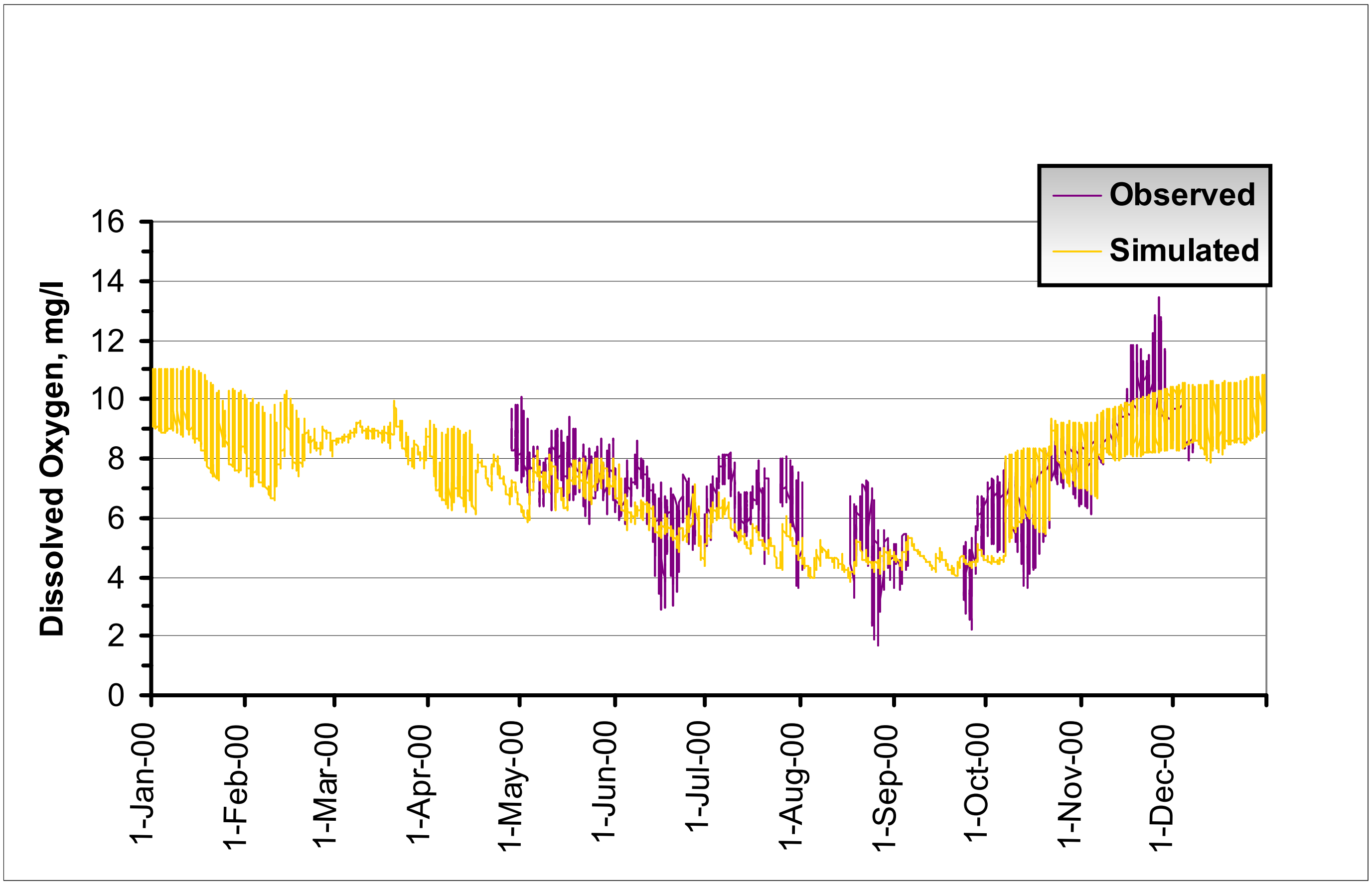

Figure 10. Dissolved Oxygen in the Old River at DMC

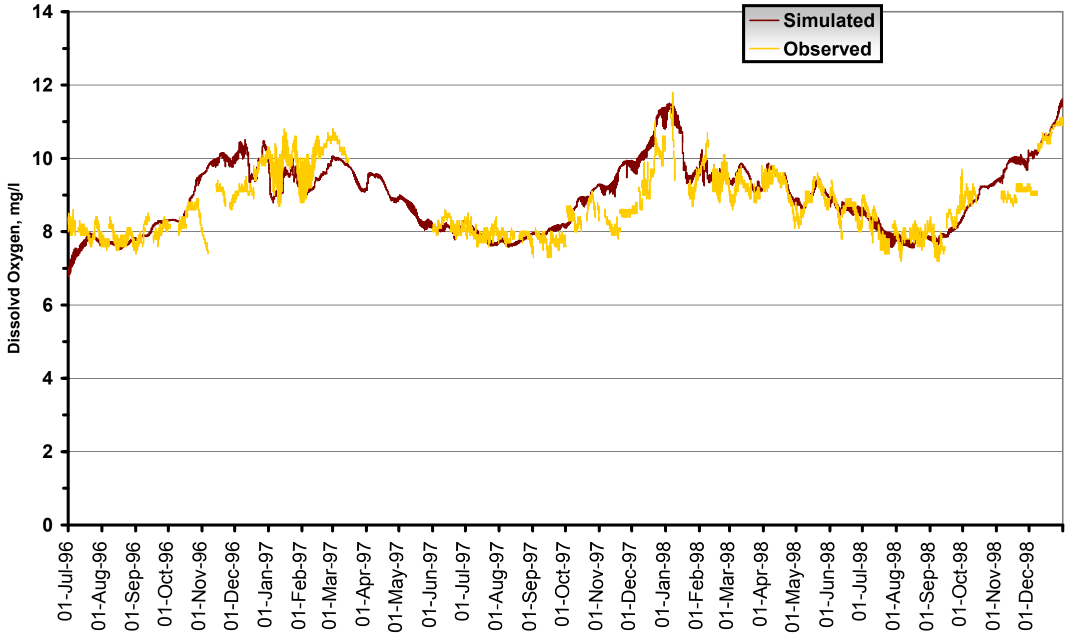

Figure 11 A. Dissolved Oxygen in the Sacramento River at Mallard Slough

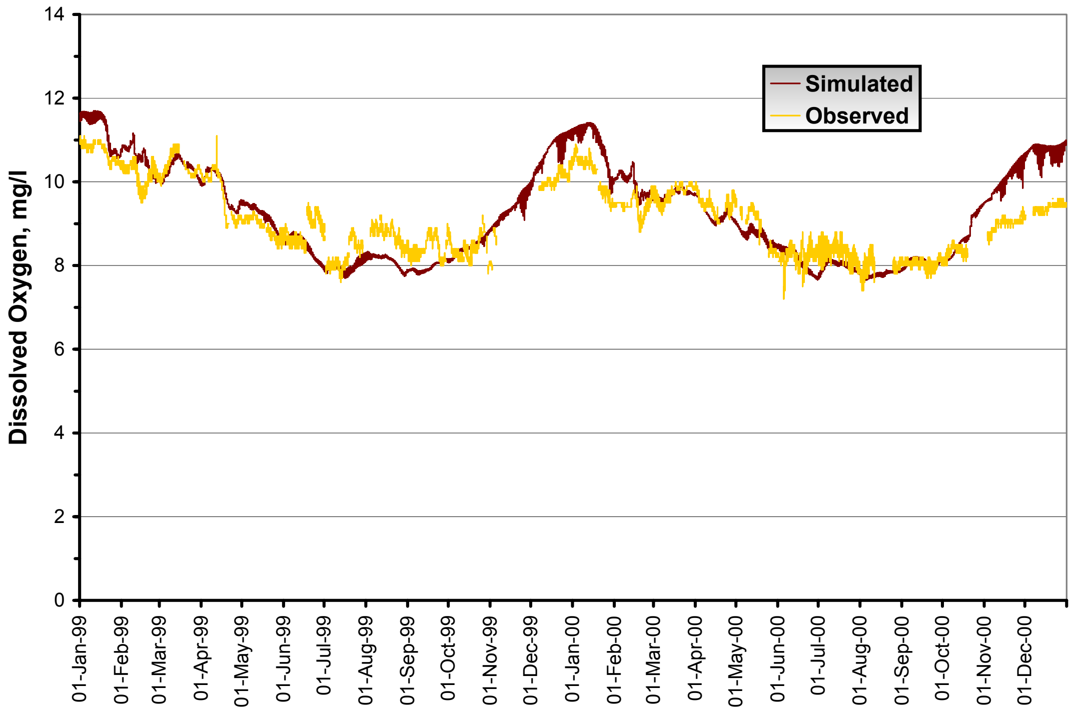

Figure 11 B. Dissolved Oxygen in the Sacramento River at Mallard Slough

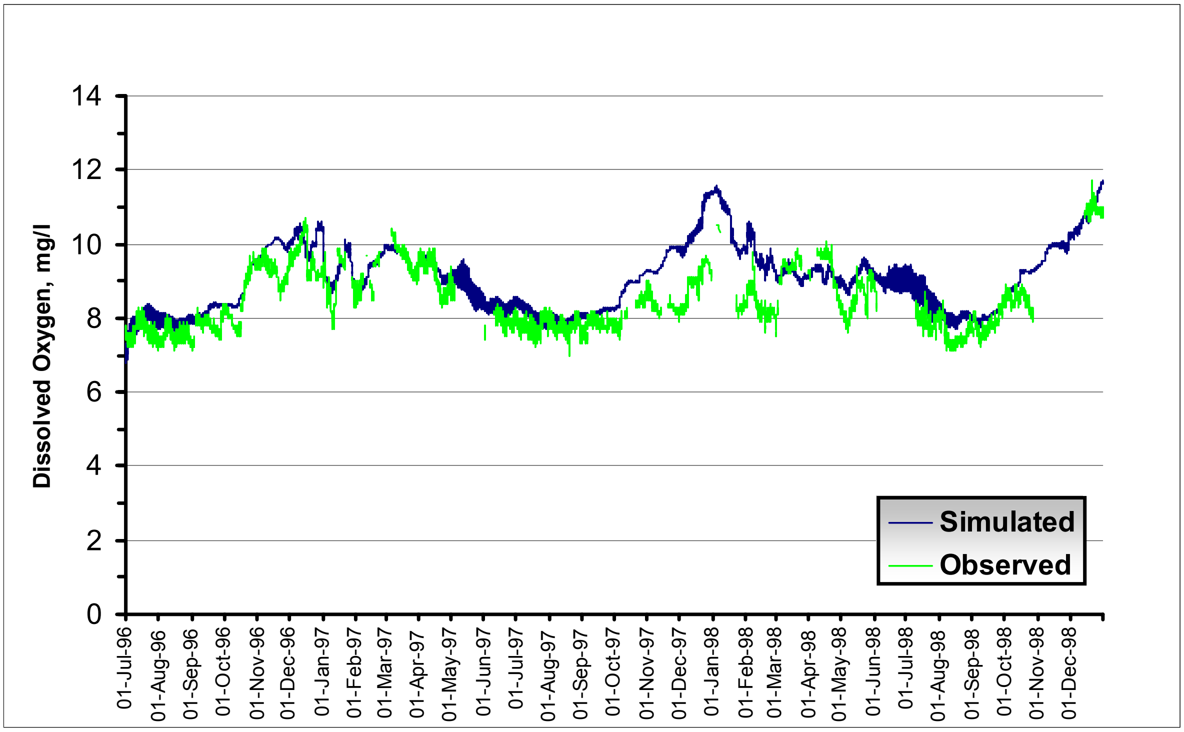

Figure 12 A. Dissolved Oxygen in the San Joaquin River at Antioch

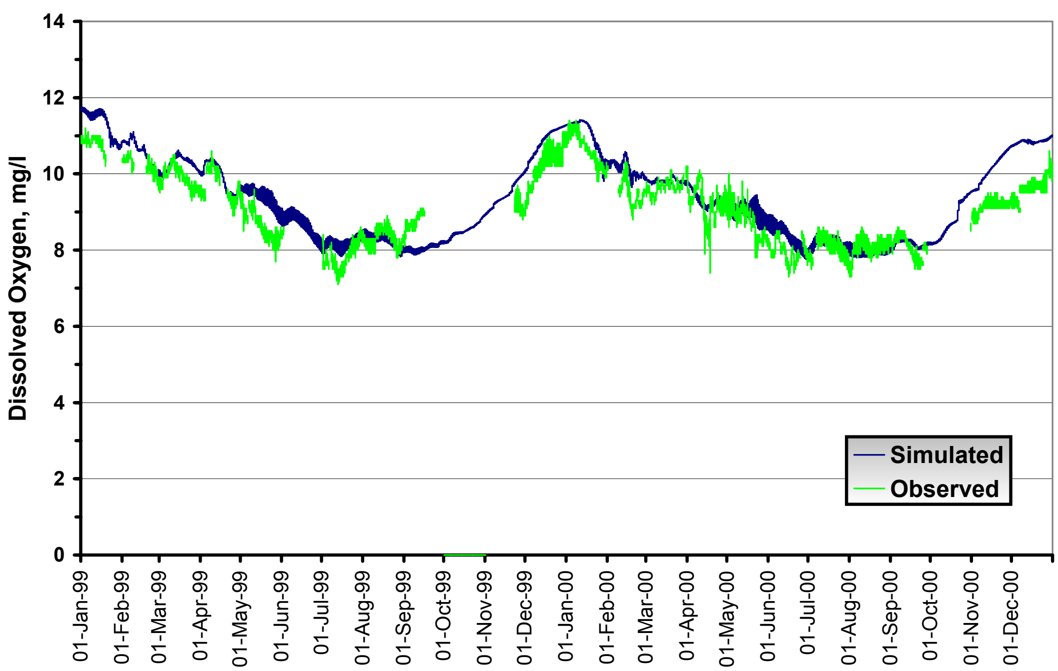

Figure 12 B. Dissolved Oxygen in the San Joaquin River at Antioch

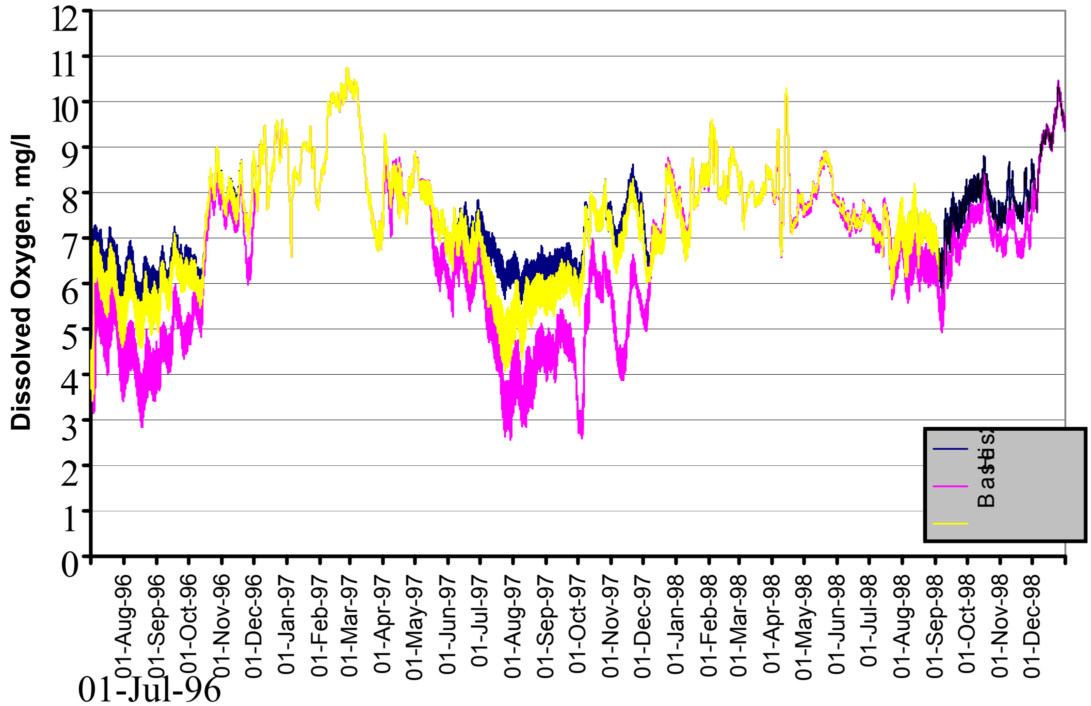

Figure 13 A. Impact of Auxiliary Flows on San Joaquin River DO at RRI

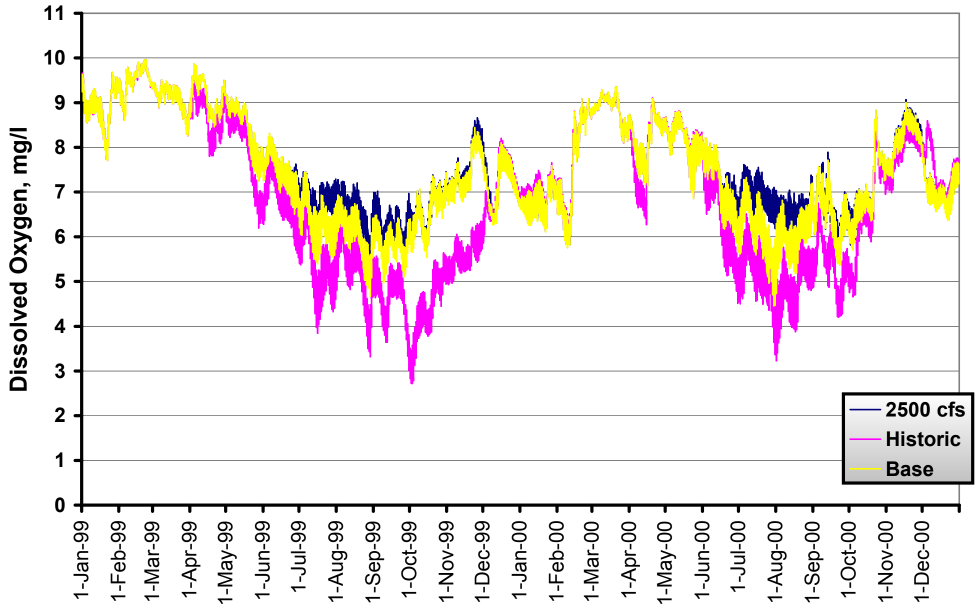

Figure 13 B. Impact of Auxiliary Flows on San Joaquin River DO at RRI

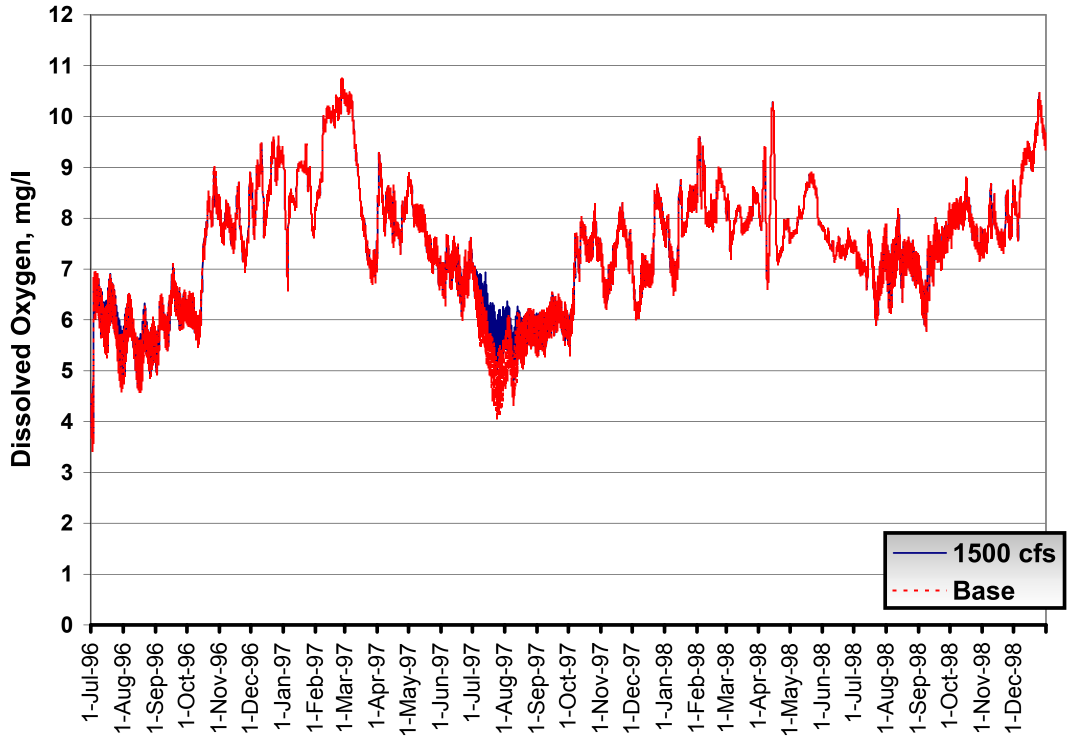

Figure 14 A. Impact of Auxiliary and Base Flows on San Joaquin River DO at RRI

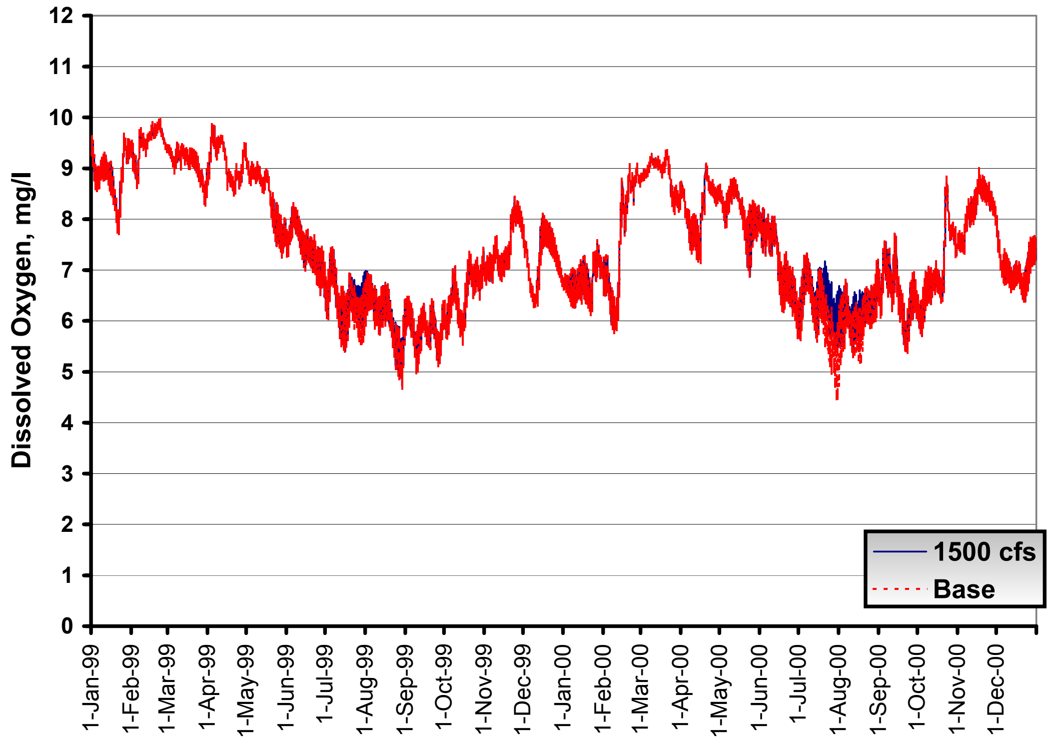

Figure 14 B. Impact of Auxiliary and Base Flows on San Joaquin River DO at RRI