San Joaquin Valley Drainage Authority

San Joaquin River
Up-Stream DO TMDL Project
ERP - 02D - P63

Task 12: DO Project Final Report

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Author:
William Stringfellow[1,2]

Affiliation:
[1]Ecological Engineering Research Program
School of Engineering & Computer Sciences
University of the Pacific
3601 Pacific Ave, Sears Hall
Stockton, CA 95211

[2]Ecology Department
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

Project Background Information:

This Project identified as Recipient Agreement No. ERP-02D-P63 was funded by a grant of funds from Proposition 13, Article 3 Bay-Delta Multi-purpose Water Management Programs (Water Code Sections 79196.5 (b) and (e)) for the purpose of implementing the CALFED Ecosystem Restoration Program (ERP). The project is part of the long-term comprehensive plan to restore the ecological health and improve water management for beneficial uses of the Bay-Delta system ("CALFED Plan"). The ERP is the principal component of the CALFED Plan designed to restore the ecological health of the Bay-Delta ecosystem.

The project is located on the San Joaquin River (SJR) upstream of the Stockton Deep Water Ship Channel (DWSC) and below the confluence of the SJR with Bear Creek. The monitoring location at the upstream limit of the project is where the SJR intersects State Highway 165 (Lander Avenue) and the furthest downstream monitoring location is Channel Point, where the SJR enters the DWSC (Figure 1). The project was conceived and executed to support the development of a scientifically based response to the dissolved oxygen (DO) total maximum daily load (TMDL) issued by the Central Valley Regional Water Quality Control Board (Regional Board) in 2003. It was determined in prior studies that suspended algae (phytoplankton) entering the SJR from upstream sources was a major contributing factor to oxygen demand in the DWSC.

The purpose of this report is to provide a summary of the results of the SJR Upstream DO TMDL Project (DO Project) in the context of the project objectives as defined in Recipient Agreement No. ERP-02D-P63. Project objectives were established in 2003, based on peer review of prior DO TMDL Directed Action projects, stakeholder recommendations, and input from the Technical Advisory Committee (TAC), the Steering Committee, and members of the Regional Board. The project was organized into Administration, Data Collection, Scientific, and Modeling efforts and executed as a number of Tasks. Table 1 presents a summary of the project by Task. A complete discussion of the project background and documentation of all project scientific activities can be found in the individual ***Task Final Reports***, posted for public distribution on the University of the Pacific Ecological Engineering Research Program website (www.eerp-pacific.org).

For the purposes of discussion, the study area for DO Project can be divided into three environmentally distinct regions based on hydrology and other factors:

1) the ***Southern Reach***, south of the confluence with the Merced River, dry season flow consists almost entirely of drainage from agricultural and wetlands;

2) the ***Mainstem Reach***, where flow is dominated by generally high quality water entering from the Eastside rivers, which drain the Sierra-Nevada Mountains; and

3) the ***Tidal Estuary Reach***, where flows are tidal and significant flow may be diverted out of the San Joaquin River to South Delta pumps via Old River.

Figure 1 shows the extent of the DO TMDL Project study area and major tributaries. Figure 2 shows a hydrologic map, designates the environmental regions, and shows the key monitoring locations defining each reach. The project area is located in the Central Valley ERP region and ecozone.

Objectives:

The objectives of the Upstream SJR DO TMDL Project as specified in the Recipient Agreement were as follows:

1. Objective 1: Establish a comprehensive monitoring program to characterize the loading of algae, other oxygen-demanding materials, and nutrients from individual tributaries and sub-watersheds of the upstream SJR.
2. Objective 2: Characterize the transformation and fate of algae and other oxygen-demanding materials between their sources in the watershed and the DWSC.
3. Objective 3: Characterize the fate of nutrients and the impact of nutrients on algal growth between their sources in the watershed and the DWSC.
4. Objective 4: Characterize the temporal variability of water quality parameters on a daily and seasonal basis.
5. Objective 5: Provide input and calibration data for water quality modeling associated with the low DO problems in the SJR watershed, including modeling on the linkage among nutrients, algae, and low DO.
6. Objective 6: Provide stakeholder confidence in the information that will be used to support the DO TMDL allocation and implementation process.

In addition to these objectives, specific research questions were formulated:

1. What are the sources of algal inoculum in the watershed?
2. What are the sources of nutrients in the watershed?
3. What is the relative importance of inoculant size and nutrient sources in determining the algal biomass load reaching Channel Point?
4. What would be the impact of reducing either inoculum or nutrients or both on algal biomass loads at Channel Point?
5. What other sources of BOD (besides algae) are in the SJR watershed and are these sources important to the SJR BOD load to the DWSC?

Results and Findings:

Objective 1: Establish a comprehensive monitoring program to characterize the loading of algae, other oxygen-demanding materials, and nutrients from individual tributaries and sub-watersheds of the upstream SJR.

A comprehensive monitoring and scientific program was established to characterize the loading of algae (phytoplankton), oxygen demanding materials, and nutrients from individual tributaries and sub-watersheds in the upstream SJR study area. Studies were conducted in an above normal year (2005), a wet year (2006), and a dry year (2007) (http://cdec.water.ca.gov/cgi-progs/iodir/wsihist). Activities conducted under Tasks 3, 4, 5, 7, 8, and 10 were conducted in support of this objective. The location of all sites where flow or water quality data were collected in the Upstream SJR DO TMDL Project study area are shown in Figure 3.

In the Southern and Mainstem areas, twenty stations for the measurement of flow were installed or improved as part of the DO TMDL Project. The details of flow station installation and improvements are found in the Task 5 Final Report. Eighteen of the stations were maintained by the University of the Pacific Ecological Engineering Research Program (EERP) as part of the DO TMDL Project (see Task 4 Final Report Appendixes B, C, and D). Other flow measurement stations were maintained by cooperating water and irrigation districts and publically available data from Department of Water Resources (DWR) and US Geological Survey (USGS) were also used in this project. Seasonal flow data was collected and compiled from a total of 52 flow monitoring stations for use in this project. Additional flow data was collected using appropriate methods, such as weir-sticks, at smaller drainages during sampling events.

Water quality and/or flow data was collected at 188 locations in the Upstream DO TMDL study reach (Figure 3). A list of 56 locations identified by the DO TMDL Steering Committee were investigated and additional locations were sampled as drainages in the region were identified and scientific studies were conducted. Thirty individual locations upstream of Vernalis and below Lander Avenue were identified as "primary" locations on drainages, meaning that water passing a primary (sampling) location did not pass another sampling location before entering the SJR. The locations of the primary water quality monitoring locations are shown in Figure 4. Data from primary stations can be used to calculate a mass loading to the SJR without counting any drainage contribution twice.

Flow in the Mainstem and Southern reaches of the DO TMDL study area is riverine and a comparison can be made between the flow measurements made at primary locations on tributaries entering the SJR and the total flow observed at Vernalis, before the river enters the tidal estuary. A seasonal analysis of SJR flow for 2007 is presented in Figure 5, which compares mean monthly flows observed at individual tributaries and drains to the flows observed at Vernalis. There is an average balance of 93%, which demonstrates that the DO TMDL Project has succeeded in developing a comprehensive program for monitoring surface flows and diversions to and from the SJR. The monitoring and measurements of surface flow is a fundamental step in the development of a mass balance to characterize the loading of algae, oxygen demanding materials and nutrients in the upstream SJR.

An accurate watershed model, as was developed in Task 6, provides the most comprehensive understanding of the complex factors governing the interactions of nutrients and phytoplankton and the fate of oxygen demanding materials in a complex river system like the SJR. However, direct loadings of materials from individual contributing drainages can be calculated from data collected as part of this project. Although there are numerous approaches that may be used to calculate the mass loading of algae, oxygen demanding materials, and nutrients from individual tributaries and sub-watersheds, in this report, seasonal patterns in loading by drainage were calculated by combining 2007 flow data for the primary stations with mean water quality results from the 2005 to 2007 project study period. Water quality data from all three study years is included to improve statistical confidence (increase number of measurements per month of year) and temporal coverage. Flow data from 2007 was used because the 2007 flow data set was complete and 2007 was a dry year, which are typically more problematic for low DO conditions. Similar calculations could be made using 2005 (above normal year) and 2006 (wet year) flow data. Flow (and therefore loads) from many drainages will vary with water year type, but summertime flows from agricultural drainages are not dependent on water year type. [For a discussion of the influence of water year type (WSI) on tributary and drain flows, see Task 4 Final Report Appendix G]. The calculated loading of chlorophyll (a measure of algal biomass), selected nutrients, and biochemical oxygen demand (BOD) are presented in Tables 2, 3, 4, and 5, respectively. The loadings are provided to illustrate the utility of the data collected by the DO TMDL Project and are not meant to be comprehensive. There are over 50 water quality parameters, measured as part of this project which can be used to calculate a mass balance (Table 6).

In summary, the first objective of the DO Project was achieved. Technological improvements in flow monitoring in the watershed, combined with a spatially and temporally comprehensive data gathering effort, resulted in the collection of sufficient water quality and flow information to calculate a mass balance on all the major and many of the smaller tributaries and drains in the study area.

Objective 2: Characterize the transformation and fate of algae and other oxygen-demanding materials between their sources in the watershed and the DWSC.

Characterization of the transformation and fate of algae and other oxygen demanding materials between the sources in the watershed and the DWSC involved multiple approaches. In the riverine area upstream of Vernalis, the SJR-WARMF model was developed, calibrated with water quality data collected throughout the Mainstem and Southern reaches, and applied to predict the fate of algae in the river under different management conditions. In the Tidal Estuary study area, direct measurements of algae and environmental conditions were conducted to elucidate the fate of algae between Vernalis and Channel Point. The studies in the Tidal Estuary area (Task 8, 9, and 10) were supplemented with some modeling using the existing version of a SJR Estuary model (Link-Node model) as part of Task 6.

A mechanistic model is necessary for characterizing the fate of non-conservative substances, such as phytoplankton and other oxygen demanding materials, in complex river systems. Even though direct measurements can be used to calculate flow and loads entering the river (Figure 5, Tables 2, 3, 4, and 5), processes such as absorption and settling; biological uptake and transformation; biological growth and decay; and many other processes determine the fate of material after they enter the river. For example, loads of phytoplankton entering the SJR are only a fraction of the phytoplankton load observed at Vernalis (Figure 6). This is due to the seasonal growth of algae in the river, particularly in the Mainstem reach (Figure 7). The particularly dynamic nature of the interactions between nutrients, phytoplankton, and the loading of oxygen demanding materials makes the development of a scientifically based DO TMDL especially challenging.

Objective 2 included the development of a hydrodynamic model for the SJR above Vernalis which includes the Mainstem and Southern reaches (Figure 2). One criteria for determining the accuracy of a model is the use of relative and absolute error calculation (see Appendix A of this document). The SJR-WARMF model is able to predict river flows at key locations in the watershed (Table 7) with a bias (relative error) typically less than 5% and a precision of less than 20%, which is equivalent to the error associated with many direct measurements. The error at Patterson was unusually high (27% absolute error), meaning there was not good agreement between the measurement of flow at Patterson (as reported by CDEC) and the model prediction. Field investigations were conducted and it was determined that the data posted on CDEC (which is not certified data) was not corrected for a change in station calibration, suggesting that the observed discrepancy between CDEC data and the model prediction may be due to data error as much as modeling error .

The model was found to be accurate for the prediction of "conserved" substances, including salts (results for sodium are given in Table 8). The SJR-WARMF model is believed to give as good an estimate of phytoplankton at key river locations as can be achieved with a two-dimensional model (Table 9). Absolute errors are high (>40%), but relative error is low (<15%, excluding Patterson), indicating that predicting the concentration of chlorophyll at an particular moment in time is difficult, but that the overall pattern for phytoplankton growth is well described. The magnitude of the absolute error needs to be considered in the context of the large natural variation in chlorophyll concentrations, which can vary by 50% on a daily cycle (see discussion of Objective 4, below). The SJR-WARMF model is considered to be a fully developed river model, useful for scientific management in the TMDL context.

For phytoplankton, the SJR-WARMF model can account for the differences between input loads and observed loads at Vernalis (Figure 6) by calculating the interactions between the loads of phytoplankton entering the system; the available solar radiation; temperature; hydraulic residence time; diatom and other phytoplankton nutrient requirements; nutrient loadings from different drainages; and a variety of other chemical and physical factors known to affect phytoplankton growth rates. The model was used to calculate the sources and sinks of phytoplankton in the SJR above the tidal estuary. Model mean mass balance results for water years 2000 to 2005 are presented in Table 10. Direct measurements of phytoplankton load during 2007 (Table 2) are consistent with the model predictions (Table 10). Using the SJR-WARMF model, the transformation and fate of algae and other oxygen demanding materials between Lander Avenue and Vernalis (the Southern and Mainstem reaches, Figure 2) can be characterized.

The transformation and fate of algae and other oxygen demanding materials in the Tidal Estuary study area is not completely understood and the tidal reach of the SJR between Mossdale and Channel Point does not have a fully developed model. Currently, the Tidal Estuary reach is modeled by the Link-Node model, which is a two-dimensional model originally commissioned by the City of Stockton to investigate the impact of the city wastewater on the dissolved oxygen in the DWSC. The Link-Node model is integrated with the SJR-WARMF model via a graphical interface, so that the output of the SJR-WARMF model serves as the input to the estuary model.

Improvement of the Link-Node model, including data collection activities and calibration, were proposed to be included in the Upstream SJR DO TMDL Project during planning of the directed action scope of work in 2003, but further development the Link-Node model was specifically excluded from this project, pending an analysis of a three-dimensional (3-D) model under development by other CALFED funded projects. In late 2006 it was determined by the Technical Working Group (TWG), an advisory group to the DO Project that replaced the TAC and Steering Committee, that the 3-D model was not going to be useful for modeling needs specific to the development of a scientific DO TMDL. In 2007, under the project adaptive management program, a limited amended scope of work was added to Task 6, which included adding flow and water quality from other state projects to the Link-Node model and performing an initial calibration of the model with this data. The result is a preliminary model for the Tidal Estuary study region; however, the model is not yet considered a completely developed tool for watershed management.

Included in the DO Project original scope of work were monitoring and experimental investigations conducted with the objective of providing basic scientific information concerning processes governing the fate of phytoplankton and oxygen demanding materials in the Tidal Estuary reach. A Lagrangian approach was used to characterize the transport and fate of algae by tracking a parcel of water from Vernalis to where the river transitions from non-tidal to tidal (approximately Mossdale Landing), past the confluence with Old River, to Channel Point, where the SJR deepens to form the DWSC. It was determined that there is a consistent loss of phytoplankton in the Tidal estuary reach between Mossdale and Channel Point (Figure 9). Measurements were made of zooplankton biomass and grazing rates and it was determined that grazing losses were significant, particularly where river morphology provided habitat conducive for zooplankton.

A plug-flow reactor model was developed to describe and estimate the relative contribution of potential mechanisms believed to be responsible for the decline of algal populations upon entry into the tidal reach and subsequent transport to the DWSC. This numerical model consists of three coupled ordinary differential equations describing the mass concentrations of chlorophyll a, pheophyin a, and zooplankton in a parcel of water traveling down the San Joaquin River. The model takes into account diel effects, light limitation associated with increased river depth, decay of chlorophyll a to pheophyin a, and grazing of zooplankton as described on Page 25 of the Task 8 report. The two dominant mechanisms for the decrease of phytoplankton below Mossdale appear to be zooplankton grazing and the reduction of available light associated with increased river depth, which limits the rate of algal growth. Settling during slack tide periods and dispersion associated with tidal flows may also contribute to phytoplankton declines, but are much less important. The results of these studies will be used in the development and calibration of the Link-Node Model in the future.

In summary, the second objective of the DO Project was achieved. The development of a calibrated SJR-WARMF model allows the calculation of a mass balance on phytoplankton and other oxygen demanding materials in the Mainstem and Southern reaches of the SJR. A model for the Tidal Estuary reach was not included in the scope of work for the DO TMDL Project, but scientific studies were conducted in the estuary. Those studies showed that there were consistent phytoplankton losses between Mossdale and Channel Point and that the losses could be attributed, in majority, to grazing pressure and decreased phytoplankton growth rates due to light limitation that occur as the river deepens as it enters the DWSC. Measurements of zooplankton biomass and grazing rates were made and a simple plug-flow model developed to estimate growth and loss parameters. These studies will provide a foundation for the development of a more complete estuary model in future studies.

Objective 3: Characterize the fate of nutrients and the impact of nutrients on algal growth between their sources in the watershed and the DWSC.

In order to accurately calculate the growth of phytoplankton in the SJR (Objective 2), the SJR-WARMF and Link-Node models must simulate a broad array of physical and water quality parameters (see Table 1.1 in the Task 6 Final Report) including nutrients required for the growth of phytoplankton. The major nutrients required for phytoplankton growth include nitrogen and phosphorous. In addition to modeling, direct measurements of nutrients were made at key location in the watershed, as described under Objectives 1 and 2, above.

A mass balance of nitrate and soluble reactive phosphate loads from tributaries and observed loads at Vernalis shows that there is a loss or transformation of nutrients in the river (Figure 10). Transformations occur in both wet and dry years and are typically less pronounced in the cooler months when losses due to biological transformation are less. Stable isotope studies demonstrate a relation between the nitrogen isotopic compositions of nitrate and phytoplankton, suggesting that nitrate is being transformed to organic nitrogen by phytoplankton growing rapidly in the Mainstem reach. The SJR-WARMF and Link-Node models are calibrated for the calculation of a mass balance on total phosphorous and total nitrogen, and results from the model identify settling and entrapment in river sediments as the most important loss mechanism for phosphorus and a significant loss mechanism for nitrogen. The other important loss mechanism for both nitrogen and phosphorus is diversion. All analysis, from both modeling and measurement efforts, identify agricultural inputs as the major sources of nitrogen and that nitrate is by far the most common source of nitrogen. There are significant sources of phosphorous from agricultural sources, but particularly high loadings of soluble reactive phosphate are found in drains impacted by urban wastewater discharge (Figure 11 and Table 4, see Task 4 Final Report for details on individual drainages).

In order to evaluate the impact of nutrients on phytoplankton growth, a sensitivity analysis was performed on the SJR-WARMF model. The model was used to test the hypothesis that halving nitrogen and phosphate inputs would reduce phytoplankton growth in the river. To test this hypothesis, a model simulation was run in which the loading of ammonia, nitrate, and phosphate to the river from all tributary inflows, drains, and point sources was reduced by 50%. The model predicts that these 50% load reductions will result in a decrease in river nutrient concentrations (33% for ammonia, 51% for nitrate, and 27% for phosphate), but that this reduction will only result in a 9% overall reduction in phytoplankton load entering the Tidal Estuary area.

The finding of the model simulation was consistent with the current understanding about the overabundance of nutrients in the Upper San Joaquin River. The minimal impact of a significant (50%) reduction in nutrient loads on phytoplankton yield is a consequence of the non-linearity between algal growth rates and nutrient concentrations, where nutrients must be decreased below a concentration threshold before algal growth rates will decrease in response to decreases in nutrient concentrations. Nutrient concentrations in the mainstem of the SJR are typically well above these concentration threshold (see Task 4 Final Report Appendix H).

These results do not mean that there are never periods or areas of nutrient limitation in the SJR. Studies of algae growth in the San Luis Drain, a tributary of Mud Slough, show that rapid algal growth slows as phosphate is depleted from the water column (see Task 4 Final Report Appendix P). In many years, there is a mass balance in the Southern Reach between phytoplankton loads measured at primary tributaries and the phytoplankton load at Crows Landing, indicating phytoplankton growth may be sometimes limited by nutrients or other factors in the Southern area. There is no indication that nutrient concentrations ever become limiting in the Tidal Estuary reach. It is well established that loads of phytoplankton from the Southern reach are combined with fresh nutrients and good physical conditions for growth in the Mainstem and, consequently, growth between Crows Landing and Vernalis is typically rapid. Based on this relationship, the SJR-WARMF model predicts that a reduction in phytoplankton loading to the river from the Southern reach would reduce the phytoplankton loading at Vernalis (Figure 12).

In summary, the third objective of the DO Project was achieved. The SJR-WARMF model was used to make a mass balance on nutrients, explore interactions between nutrients and algal growth, and to explore the impact of changing nutrient loads on phytoplankton in the SJR. Results from model simulation runs suggest that reducing nutrient loads from all sources will have a lesser impact on phytoplankton exports from the Mainstem than the reduction of phytoplankton loads entering the Mainstem from the Southern reach. Field studies indicate that nutrient limitation to phytoplankton growth may occur in areas of the Southern reach (Task 4, Appendix P).

Objective 4: Characterize the temporal variability of water quality parameters on a daily and seasonal basis.

The temporal variability of the water quality parameters was characterized on a daily and seasonal basis. Continuous flow monitoring stations installed as part of Task 5 typically included instruments for the continuous measurement of specific conductance (EC) as well. In Task 4, Task 8 and Task 10, continuous measurements of chlorophyll, EC, pH, DO, and turbidity were made using water quality sondes. Water quality sondes were deployed at fixed locations or were mounted on boats and were used to measure diurnal and weekly fluctuations in these water quality parameters, particularly chlorophyll and parameters related to photosynthesis (oxygen concentration and pH).

At many locations, flow, electrical conductivity, and temperature were measured continuously (typically at 15 minute intervals). EC was reported from temperature corrected electrical conductivity measurements. A complete record of EC and flow data from these locations is provided in Task 4 Final Report Appendix V. Seasonal and yearly trends for flow are presented in Task 4 Final Report Appendix F and Appendix G, respectively. An analysis of year-to-year and seasonal trends in EC is included in the Task 6 Final Report. Not surprisingly, EC in the SJR varies annually and is related to environmental factors such as irrigation practices, snowmelt and reservoir releases. The data collected by this project have also been provided to scientists at the US Bureau of Reclamation, who are calculating a mass balance on salt in the SJR basin. Results from those studies have not yet been made available.

Two flow trends were observed that are worth noting for establishing a basic understanding of the temporal relation between flow and water quality in the DO Project study area. The first trend is that flow patterns for ephemeral streams in the western and southern areas of the DO Project are determined largely by the relative dominance of agricultural or wetland land-use in the drainage. Agriculturally dominated drainages are influenced by irrigation events during the growing season and tend to have high summer flows and low winter flows. Seasonal wetlands are typically filled in the fall and drained in the spring, so wetland dominated drainages have higher winter flows and lower summer flows (Figure 13). Drainages on the eastside of the SJR that are dominated by agricultural land use show similar flow trends as westside drains, particularly in dry years, but also show stormwater patterns in wet years (see Task 4 Final Report Appendix F). The second trend is that there is an over-all, year-to-year decline in return flows from both westside and eastside agricultural drainages from 2000 to 2006 (Figure 14, Task 4 Final Report Appendix G). The implications of this trend for the management of the DO TMDL are not fully understood, but since the influence of agricultural activity on the hydrology and water quality in the SJR is great, the impact, either positive or negative, of long-term changes in agricultural water use should be evaluated in future studies.

Stable isotope data provided useful information on seasonal and year to year trends. The major east-side tributaries show a steady decrease in carbon isotopes and an increase in C:N ratio during the study period, consistent with an increase in terrestrial sources of POM in these rivers. Seasonal and spatial changes in nitrate concentrations could be related to different sources of nitrate (e.g., fertilizer vs. animal/human waste) that have distinctive isotopic compositions. In the Merced, Tuolumne, and mainstem SJR, higher nitrate concentrations are generally associated with higher nitrogen isotope values, suggesting a higher proportion of nitrate derived from human/animal waste. However, no such pattern was observed in either the Stanislaus or many of the minor drains, creeks, and wetlands sites. In general, there is a downstream decrease in nitrogen isotopes in the SJR, indicating higher proportions of nitrate derived from soil and fertilizer from the major tributaries downstream. However, during low flow conditions in the mainstem SJR in summer and fall 2007, the nitrogen isotope ratio of nitrate of the SJR increased downstream. The high nitrogen isotope values cannot be explained by known inputs and strongly suggests that there was addition of nitrate from human or animal waste from an unidentified and unsampled source or sources along this reach, especially downstream of Vernalis.

The isotope ratios also provide information about the dominant biogeochemical processes affecting water quality in the subwatersheds. For example, the nitrate isotope signatures of watersheds where the dominant control on nitrate concentrations appears to be nitrification (e.g., Orestimba, Del Puerto, and Ingram Creeks), algal uptake of N (e.g., Mud Slough and San Luis Drain), or contributions of nitrate from human/animal waste (e.g., Harding Drain, Westport Drain, and TID Lateral 6 & 7) are distinguishable.

Stable isotope data provide useful information about the causes of the seasonal and spatial changes in BOD concentrations because different sources of BOD (e.g., dissolved and particulate organic matter derived from algae vs. terrestrial detritus) often have distinctive isotopic compositions. For example, the isotopic signatures of particulate organic matter (POM) from watersheds where the dominant source of POM is fresh algae (e.g., Ramona Lake) or refractory terrestrial matter (e.g., MID Lat 5) are also distinguishable. POM from the upstream wetlands sites (e.g., Los Banos, Mud Slough) is dominated (~80%) by fresh and old algae, whereas POM from Salt Slough, like Del Puerto Creek, is dominated by old algae and more refractory sources of POM. The carbon isotope data suggest that more of the dissolved organic carbon (DOC) in the major and minor tributaries is of terrestrial origin, whereas more of the DOC in the mainstem SJR is derived from algae. Whether the algal-derived DOC is a byproduct of algal productivity (e.g., "leaked" from algae) or respiration of algae or algal sediments is currently unknown.

Water quality parameters related to phytoplankton (chlorophyll, pH, and DO in particular) were measured at 15 minute intervals at key locations in the DO TMDL study area. Water quality parameters related to phytoplankton follow year-to-year, annual, seasonal, and diurnal trends (see Task 4, 6, and 8 Final Reports). An example of observed trends in chlorophyll is shown for the SJR at Patterson for 2007 (Figure 15). Similar data were collected at seven river locations in the Southern and Mainstem reaches as part of Task 4, four fixed Tidal estuary locations as part of Task 8, and during Lagrangian studies as part of Task 8. A complete analysis of the Tidal Estuary data is provided in the Task 8 Final Report. The data collected as part of Task 4 have been included in the SJR-WARMF model and have been used to calibrate the ability of the model to predict diurnal fluctuation in phytoplankton and other water quality parameters in response to temperature, daylight, and season. A discussion of these trends is found in the Task 6 Final Report and all data are presented in the Task 4 Final Report Appendix N.

The wide diurnal variance in chlorophyll concentration presents a real challenge to the establishment of target water quality criteria for phytoplankton in the SJR. Previous studies have shown that chlorophyll concentration is significantly correlated with biochemical oxygen demand (BOD) for waters entering the DWSC at Stockton, a relationship that was confirmed in the current studies (Task 8 Final Report). However, a cause and effect relationship between phytoplankton loading at Vernalis and low DO conditions in the DWSC has not been established. Two factors complicating the development of a simple relationship between phytoplankton load exiting the Mainstem and development of low DO conditions in the estuary are the hydraulic split of the SJR at the confluence with Old River and the presence of other oxygen demanding materials entering the DWSC from sources adjacent to the City of Stockton. In the absence of a fully developed estuary model, a predictive relationship between chlorophyll loads at Vernalis and low DO events in the DWSC has not been established.

In summary, the fourth objective of the DO Project was achieved. High resolution flow and water quality measurements were made throughout the DO TMDL Project study area. The high resolution data have been provided to the SJR-WARMF model and used for testing the ability of the model to predict daily fluctuations in phytoplankton at key locations along the SJR. High resolution data have also been provided to scientists and managers from other projects, who are using the data for watershed evaluations and calculation of mass balances, particularly on salt. Chlorophyll concentrations show a high diurnal variance, which complicates the establishment of a cause and effect relationship between phytoplankton load from the Mainstem and the development of low DO conditions in the Tidal Estuary. A mechanistic model for the Tidal Estuary reach is needed to establish a predictive relationship between phytoplankton loads and low DO events.

Objective 5: Provide input and calibration data for water quality modeling associated with the low DO problems in the SJR watershed, including modeling on the linkages among nutrients, algae, and low DO.

As discussed above, flow and water quality data were collected throughout the study area (e.g. Figures 3, 4, 13, and 15). These data were compiled, quality checked and entered into multiple databases. Data were organized geographically and each location was assigned a unique location number (DO number). Data from each location, independent of type of data, were tagged with the appropriate DO number. The DO number was used to link data and analysis by statistical and geographical information system methods.

Data were first compiled into Excel spreadsheets. Excel files were distributed to Systech Water Resources for importation into the SJR-WARMF database; to DWR for importation into the Interagency Ecological Program and SWAMP databases; to CALFED as electronic deliverables; and to managers and scientists who requested data. Cooperating stakeholders were provided organized and quality checked electronic or print files of data, as requested. Recently, final data were provided to Jones and Stokes for inclusion in their SJR Data Atlas, a valuable storehouse of water quality and flow data collected throughout the SJR and estuary. The data collected by the DO Project were used to calibrate the SJR-WARMF model and were included in the Link-Node model.

In summary, the fifth objective of the DO Project was achieved. Data collected throughout the DO Project study area were quality checked, organized, and delivered to modeling groups and other scientist investigating various aspects of water quality and hydrodynamics in the SJR and estuary. The data collected in this study were used to develop, calibrate, and test the SJR-WARMF model. Data were also provided to the Link-Node estuary model.

Objective 6: Provide stakeholder confidence in the information that will be used to support the DO TMDL allocation and implementation process.

Stakeholders in the DO TMDL allocation and implementation process include the Regional Board, Federal and State resource agencies, water and drainage authorities, private landowners, ranchers, growers, agricultural coalitions, and municipalities. Specific steps taken to develop stakeholder confidence in the information collected and the scientific results produced as part of the Upstream SJR DO TMDL Project include public meetings, presentations to stakeholder groups, and the open dissemination of data and results between the DO Project and stakeholders.

Public meetings were the major mechanism for the dissemination of information, solicitation of stakeholder comments, and efforts to build stakeholder confidence. Project scientists attended TWG meetings and presented their findings to technical audiences and water managers in this forum. The TWG meetings provided a public and on-going review of the project. Outreach meetings were held annually, which targeted a more general public audience. Presentation of the SJR-WARMF model at a 2006 public meeting prompted one of the water agencies to commission an outside review of the model. The results of that review were used to improve the model and establish a dialog between the stakeholder community and the Task 6 modeling group.

The participants in the Project also made other formal and informal presentations to stakeholders. Field crews were a very public representative of the project. Field crews were instructed to respond to all stakeholder inquiries as to their activities in a clear and informative manner, even if the work schedule was delayed. All vehicles were clearly marked and landowner requests were accommodated. Any request for follow up information was noted and the requested information was provided (typically by phone or e-mail). The Project Chief Principal Investigator made formal and informal technical and programmatic presentations to various stakeholder groups, including to Regional Board staff, Federal Agencies, and various agricultural organizations, as requested.

The open dissemination of data and analysis between the project scientists, the TWG, and stakeholders was an important element for increasing overall confidence in the quality of the science and technical effort executed by the DO Project participants. Draft technical reports, which included a complete description of project activities and quality control results, were written at least annually and disseminated electronically. Hard copies of reports were provided on request. Comments from stakeholders and the public on Draft Reports were incorporated in Final Reports. Task Final Reports are now available for download from the EERP website (www.eerp-pacific.org).

A key feature of the DO Project was the development of a central water quality and flow dataset for dissemination to all project participants and stakeholders. In prior studies, not all data were available to stakeholders and scientific reviewers. It was not clear if differences in interpretation of results (between scientists) had been due to differences as to which data were used in each analysis. Lack of a complete data set was seen as a major impediment to development of a comprehensive understanding of factors controlling DO concentration in the estuary and data transparency is an obvious requirement for increasing confidence in the DO TMDL allocation process. Aspects of the data collection and dissemination effort are described in the discussion of Objective 6, above. The primary mechanism for transferring data was the distribution of the current version of the SJR-WARMF model, approximately quarterly, as it was improved or populated with new data. Data were also distributed annually via an FTP site set up for that purpose. Specific requests for data were accommodated throughout the year and transfers were typically made by e-mail or FTP posting for large data sets.

In summary, every effort has been made to achieve the sixth objective of the Upstream SJR DO TMDL Project. Technical and programmatic meetings were held to disseminate information concerning the project. Reports and data were widely distributed. Beta-versions of the SJR-WARMF-Link-Node model were posted for testing by project participants and stakeholders. Individual requests for information were accommodated and all activities were executed in a transparent manner.

Research Questions

The key research questions proposed for this project have been answered. Sources of algal inoculum in the watershed have been identified (e. g. Tables 2 and 10; Figure 8; Task 4 Final Report). The sources of nutrients have been identified (e. g. Table 3; Figure 11; Task 4 Final Report). The relative importance of inoculant size and nutrient sources in determining the algal biomass in the SJR has been determined and the impact of reducing either inoculum or nutrients has been evaluated (e.g. Figure 12). How loading from the SJR Mainstem relates to loads at Channel Point has been investigated (e.g. Figure 9), but in the absence of a mechanistic estuary model, the impact of reducing loads in the Mainstem on loads entering the DWSC cannot be determined at this time. Other sources of BOD have been identified in the SJR watershed, including dissolved organic carbon from sources other than algae (see Task 4 and 7 Final Report for details), but ammonia concentrations are low. In the Mainstem and Tidal Estuary reaches, phytoplankton are the major contributors of BOD (see Task 4, 7, and 8 Final reports for details).

Conclusions/Recommendations

The DO TMDL Project has met the objectives and answered scientific questions specified in Recipient Agreement No. ERP-02D-P63. As part of this project, a vast amount of information concerning water quality and hydrology in the SJR basin was collected, organized, and distributed to project scientists. Much of the data was compiled from on-line public data sources, but collection of data and supporting quality assurance information from existing data distribution sites was problematic and time consuming. The DO Project data-set has not been exhaustively analyzed under the scope of this recipient agreement. It is recommended that future directed action projects should be organized to include continued analysis of data collected in the SJR Upstream DO TMDL Project. Given the scope of data collected, specific research questions should be formulated to guide analysis. The impacts of land use changes and water conservation efforts on water quality could be a fruitful area of investigation. The use of the data for the scientific support of restoration activities and other TMDLs should be considered. Improvement or replacement of existing State funded on-line data distribution centers should be a priority.

The modeling effort under the DO project was largely limited (by contract) to the riverine portion of the SJR. The SJR-WARMF modeling effort is considered very successful and was subject to peer review by stakeholders. A key component of the success of the SJR-WARMF model was the development of the model in an open forum, including beta-type distributions and public presentation of the model to the TWG and other groups. There is a clear need for the further development of the estuary portion of the model. The TWG has a general consensus that the 2-D Link-Node model is the best identified candidate for the development of a usable DO TMDL model. Directed action funding should be considered for continued development of the Link-Node model and the integration of the Link-Node and the SJR-WARMF models into one SJR model. Data collected as part of the DO Project, particularly data on zooplankton, hydrology, and bathometry collected as part of Tasks 8 and 9, should be included in the estuary model. New data on zooplankton, flow, and water quality should be collected for the specific purpose of calibrating the model, as needed.

A successful component of the DO Project was the installation, calibration, and operation of new flow monitoring stations throughout the SJR basin. Collection of water quality data at key locations in the watershed was required for the measurement of mass loading and the successful development and calibration of the SJR-WARMF model. As of June 2008, long-term funding for the continued operation of the flow stations has not been identified. Continued monitoring in the basin will be important to the success of the DO TMDL implementation and long-term funding for monitoring and station maintenance should be found.

Finally, methods for the practical implementation of the SJR DO TMDL and other SJR TMDLs should be evaluated. The DO Project resulted in the development of a monitoring network which provides a verifiable mass balance on in-flows to the SJR. A QA/QC program on flow and water quality data has been established. The SJR-WARMF model can be used to sort out the complex biogeochemical and hydrological interactions that contribute to the buildup of phytoplankton in the SJR. It appears that many of the basic elements required for a water quality trading program now exist for the SJR. Emissions and water quality trading programs are gaining acceptance with the public and are believed to be a costeffective method to achieve environmental goals. The application of a water quality trading program to the implementation of SJR TMDL objectives should be investigated.

Figure 1. Upstream San Joaquin River Dissolved Oxygen Total Maximum Daily Load Project (DO TMDL Project) study area. Only major tributaries are shown. Key river locations are marked for reference.

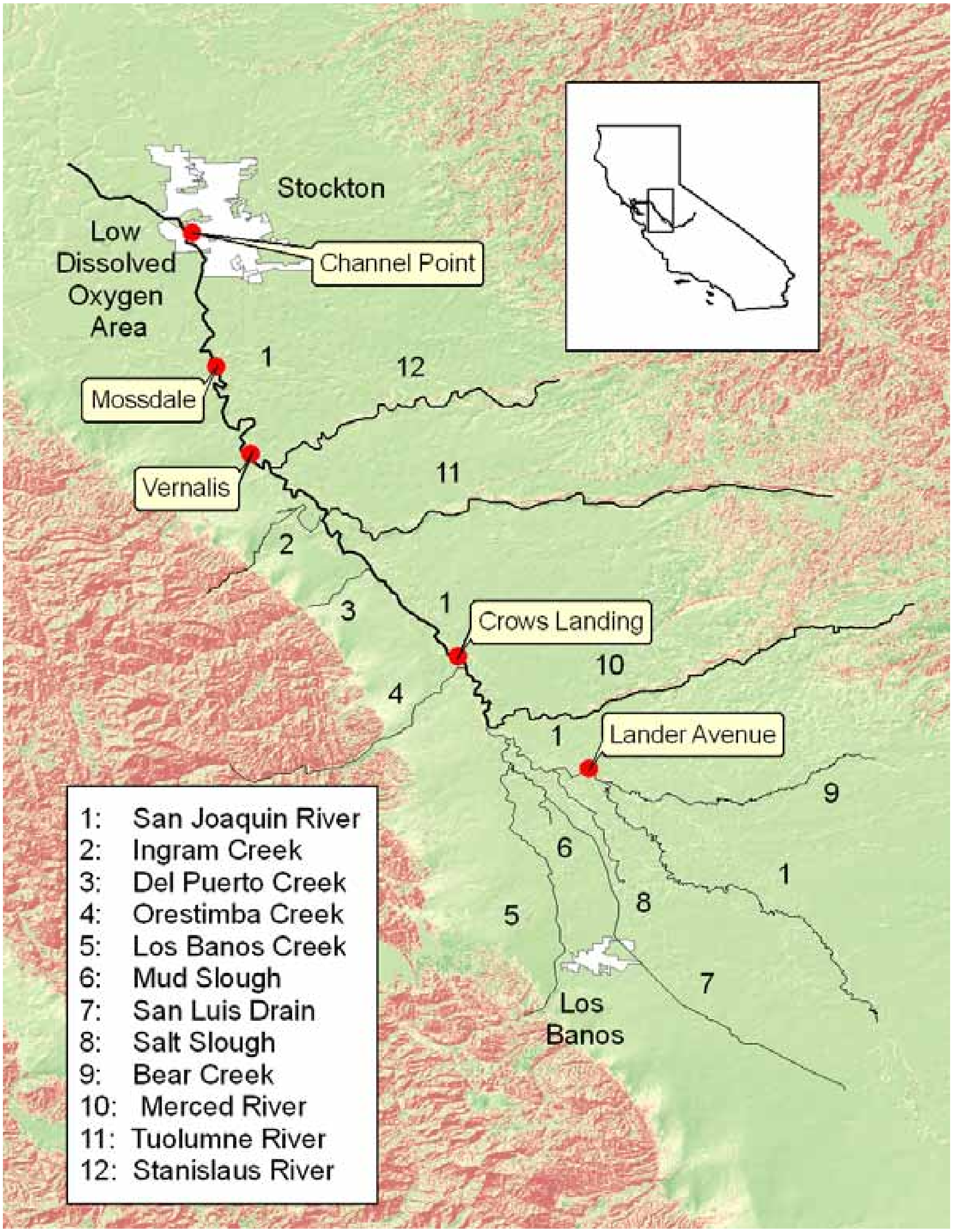


Figure 2. The San Joaquin River can be divided into three environmental regions based on hydrology and other factors: 1) the Southern Reach, south of the confluence with the Merced River, where dry season flow consists almost entirely of drainage from agricultural and wetlands; 2) the Mainstem Reach, where flow is dominated by generally high quality water entering from the Eastside rivers, which drain the Sierra-Nevada Mountains; and 3) the Tidal Estuary, where flows are tidal and significant flow may be diverted out of the San Joaquin River to South Delta pumps via the Old River. Numbers correspond to site codes.

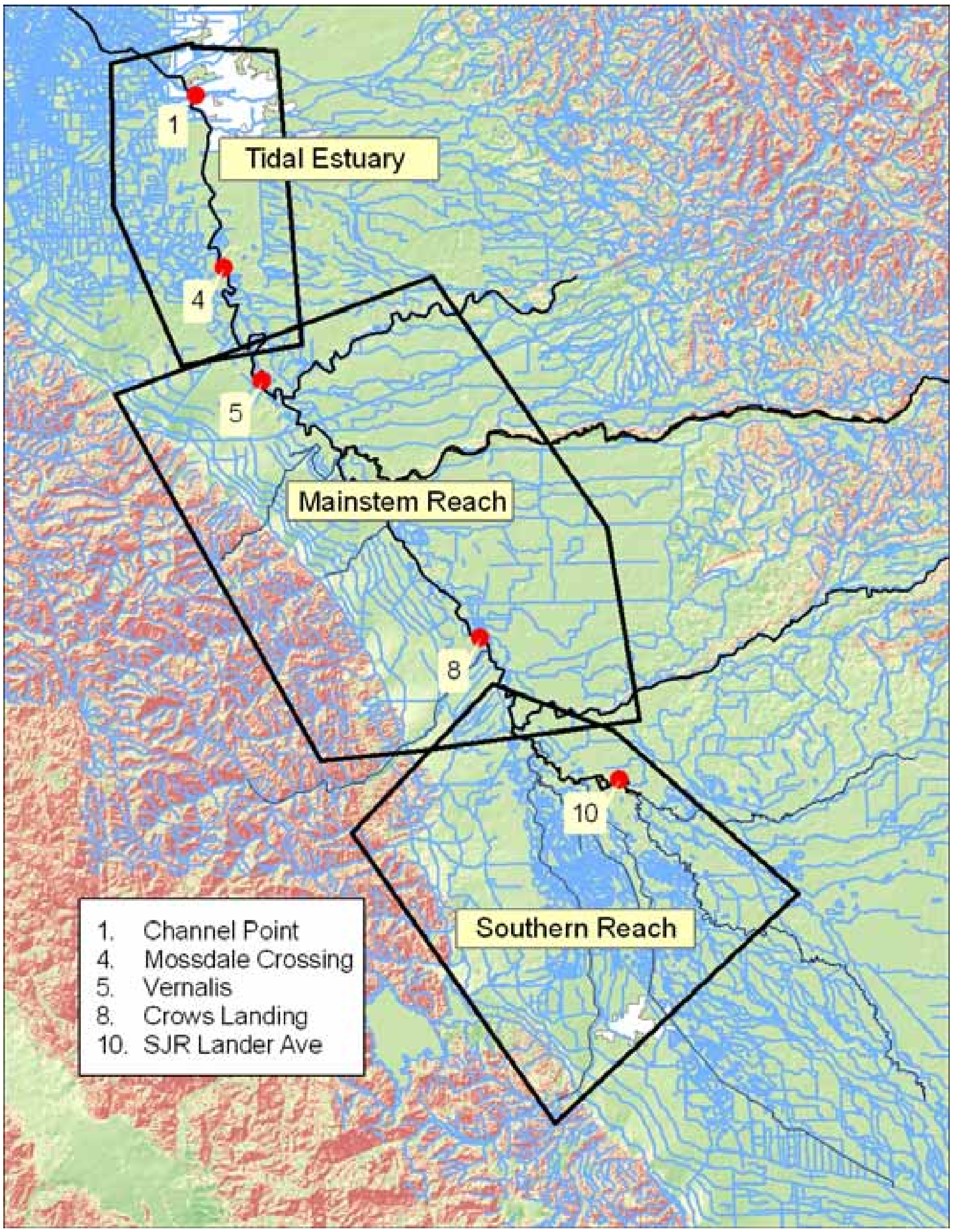


Figure 3. Map of all locations where physical, chemical or biological data were collected as part of the Upstream DO TMDL Project.

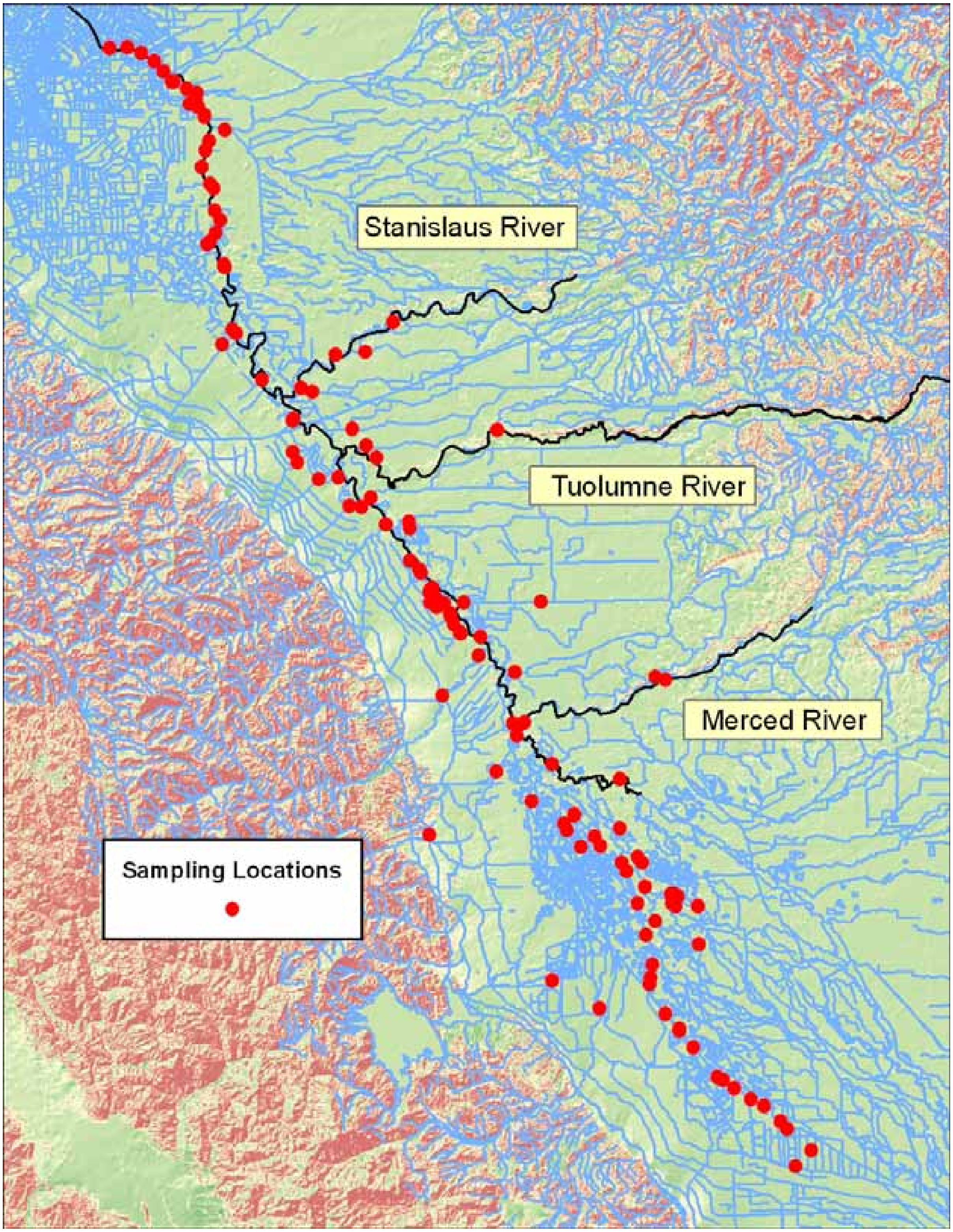


Figure 4. Map of primary stations used for mass balance of flow and load to the SJR at Vernalis (DO-5) and Crows Landing (DO-8). Numbers shown correspond to "DO" location designations, as shown in Tables 2 - 5 and the Task 4 Final Report.

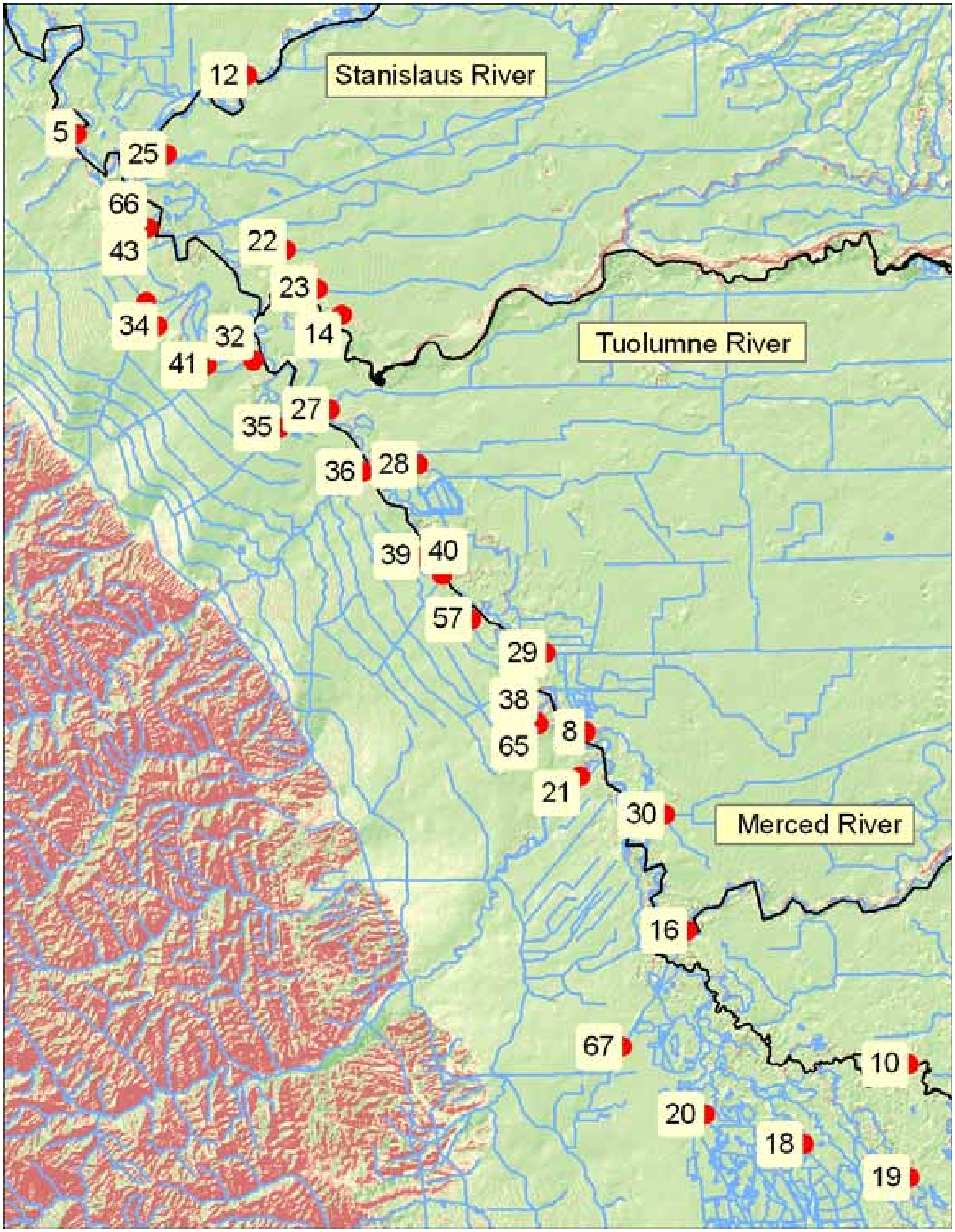


Figure 5. During 2007, between 80% and 110% of mean monthly flows observed at Vernalis could be attributed to specific tributaries measured as part of the DO TMDL Project. The results indicate that all significant surface flows entering the SJR from tributaries are now being measured. Results from the SJR-WARMF model suggest that discrepancies between measured surface flows at tributaries and flows at Vernalis can be attributed in large part to groundwater inputs. In 2007, measured flows at Vernalis averaged 1,892 cfs. Lines are polynomial fits to the data.

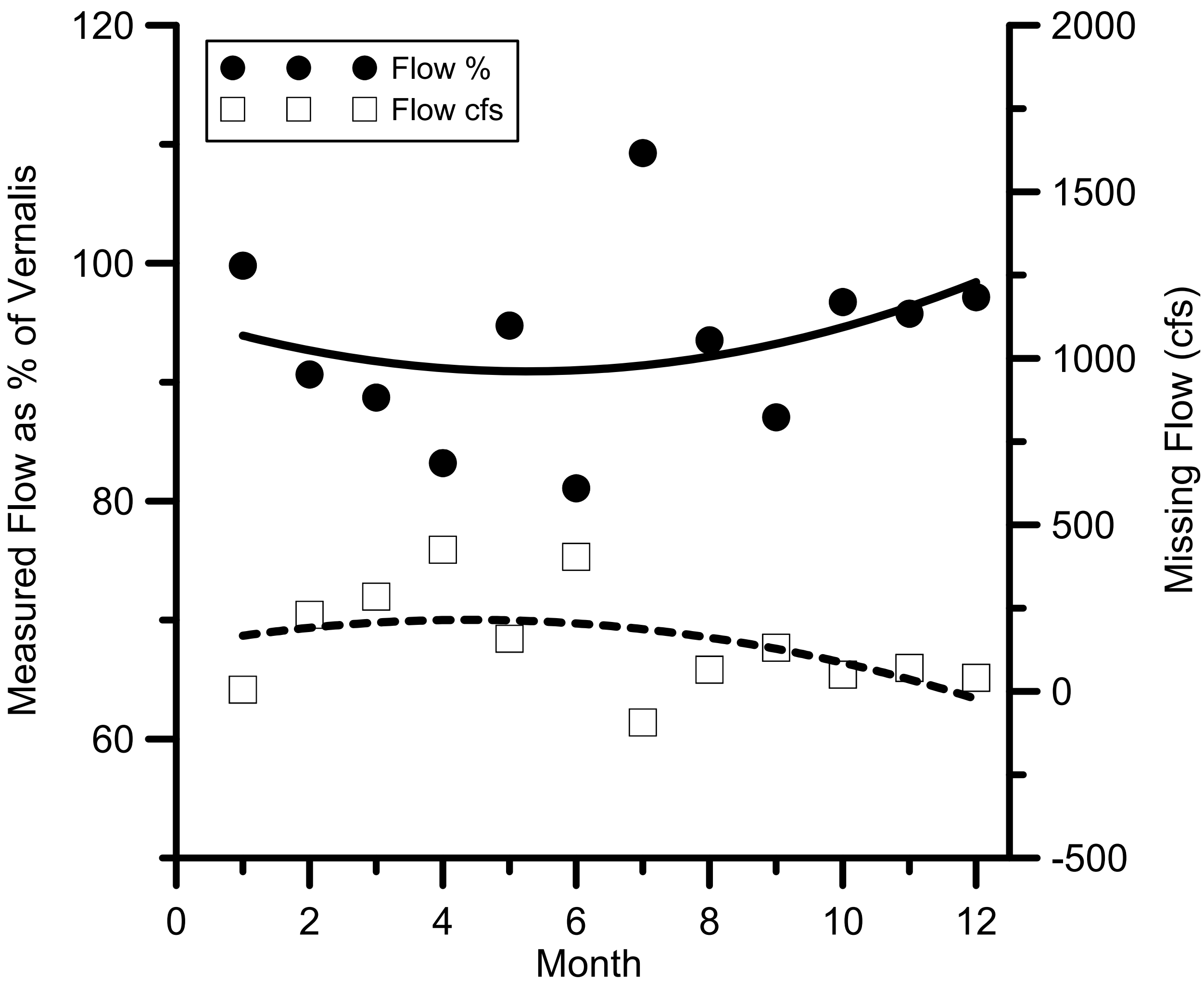


Figure 6. Loads of phytoplankton entering the San Joaquin River represent only a fraction of the phytoplankton loads observed at Vernalis because phytoplankton grow in the river (calculated loads for 2007 shown). Phytoplankton (algae), like most constituents of concern to the dissolved oxygen TMDL, are not conserved substances and models must be used to fully understand the relationship between input to the river from drainages and outcomes, such as low dissolved conditions, in the river.

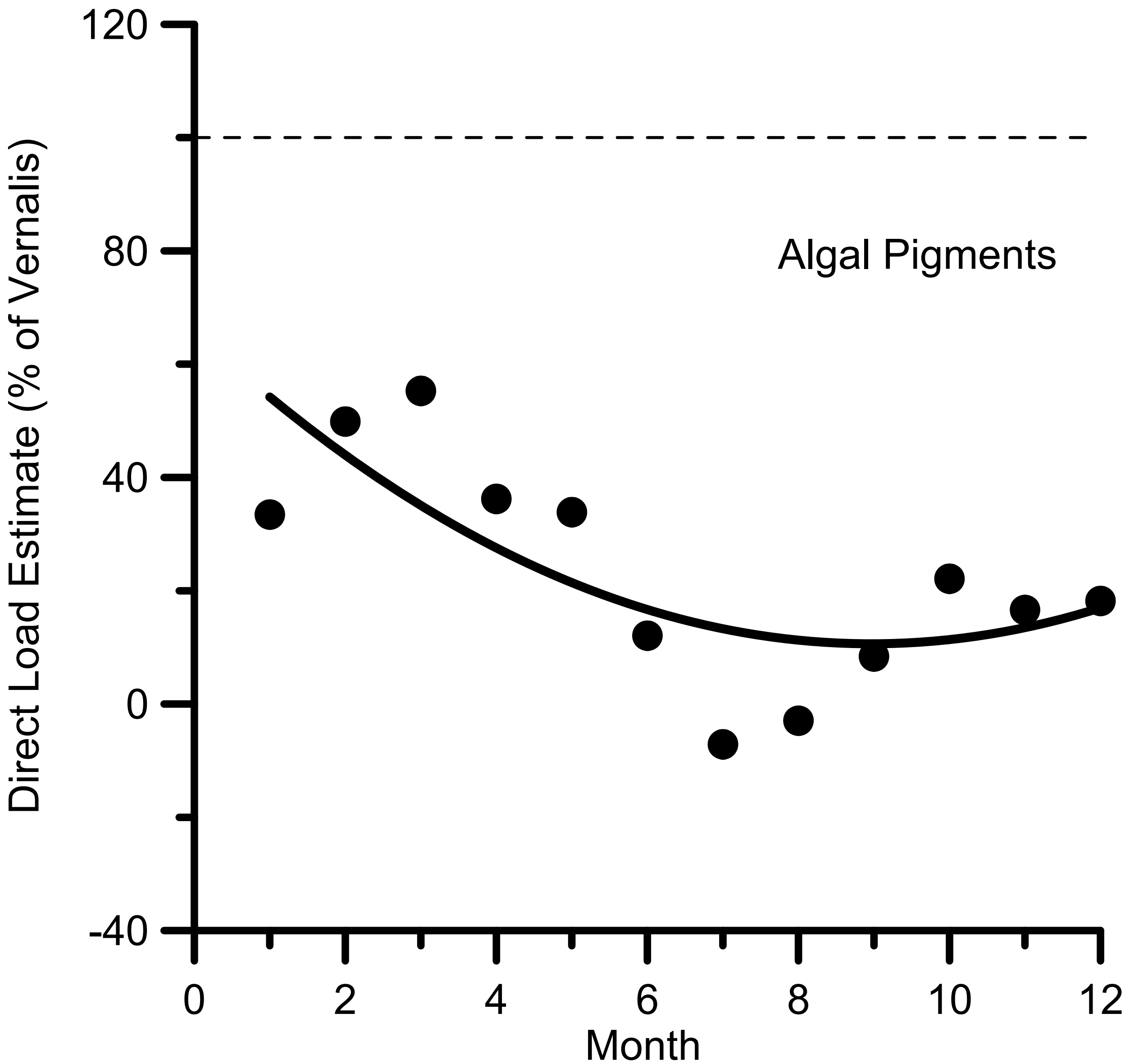


Figure 7. Growth of phytoplankton in the San Joaquin River. Select data for 2005 illustrate seasonal trends and patterns in algal growth in the Mainstem reach between Crows Landing (residence time = 0) and Mossdale (final point). Loads are calculated from mean daily flows and results of grab samples taken on individual days in the months shown. Seasonal changes in growth rates are due to many factors, including the decline in available light after the summer solstice.

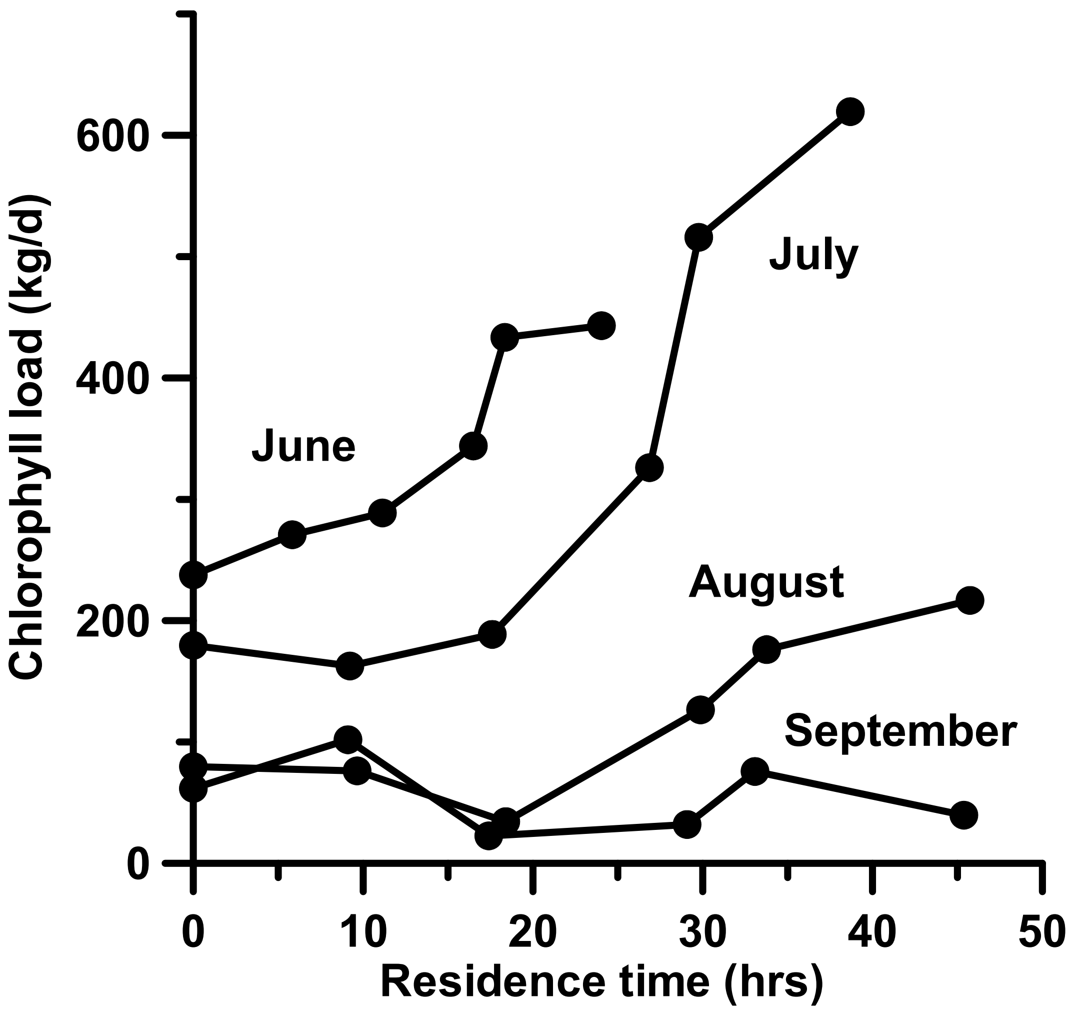


Figure 8. Mean annual loads of chlorophyll entering the San Joaquin River in the Mainstem and Southern study areas of the Upstream DO TMDL Project. Chlorophyll is an indicator of phytoplankton. Determining the sources of phytoplankton loads to the San Joaquin River was a major objective of the project. The Jenks natural break methods was use to set scale.

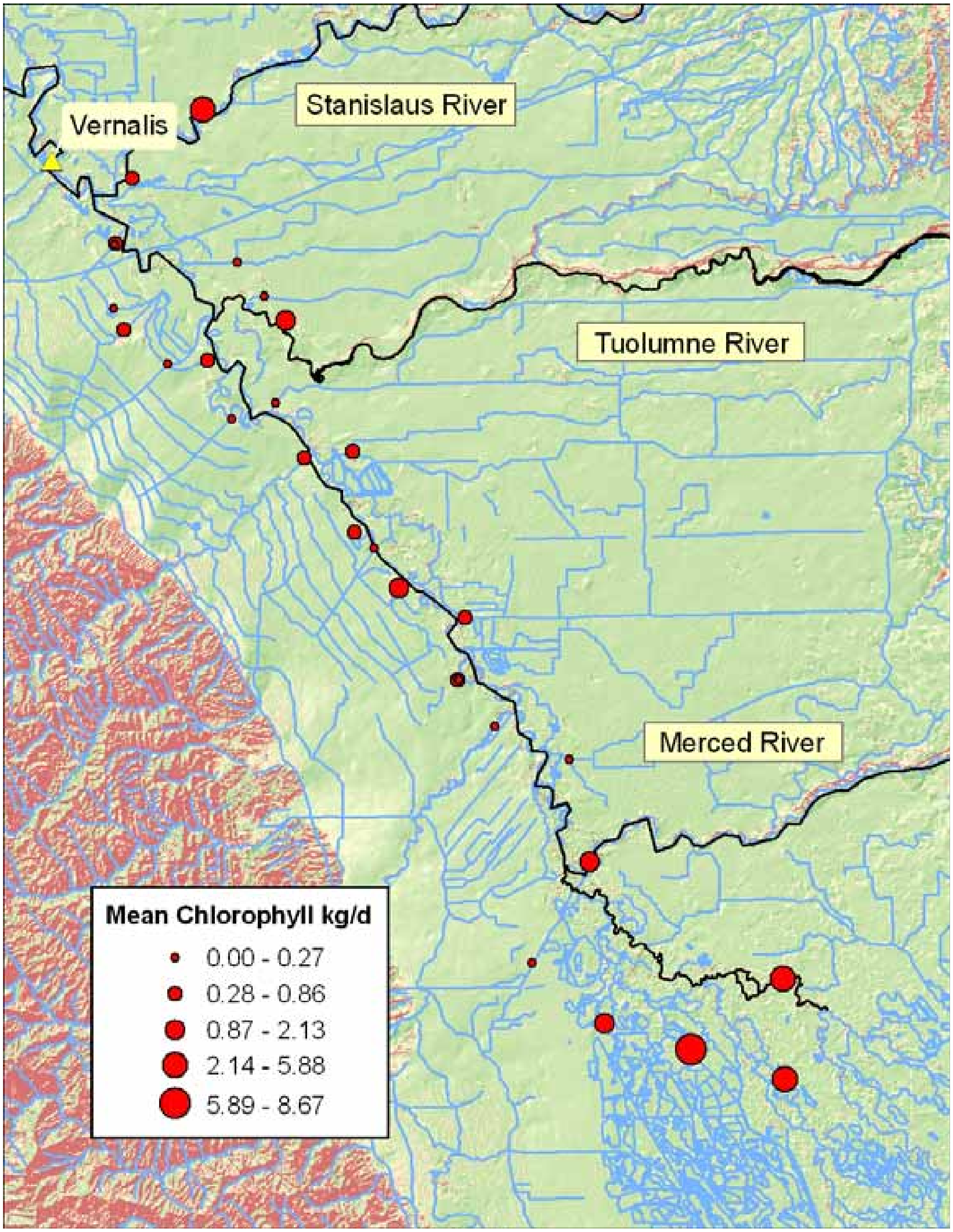


Figure 9. Loss of phytoplankton in the San Joaquin River estuary between Mossdale Landing (set as mile 0) and Channel Point. Mean and standard deviation of measured algal pigment (chlorophyll and pheophytin) concentrations are shown for on studies conducted in the summers of 2005, 2006, and 2007.

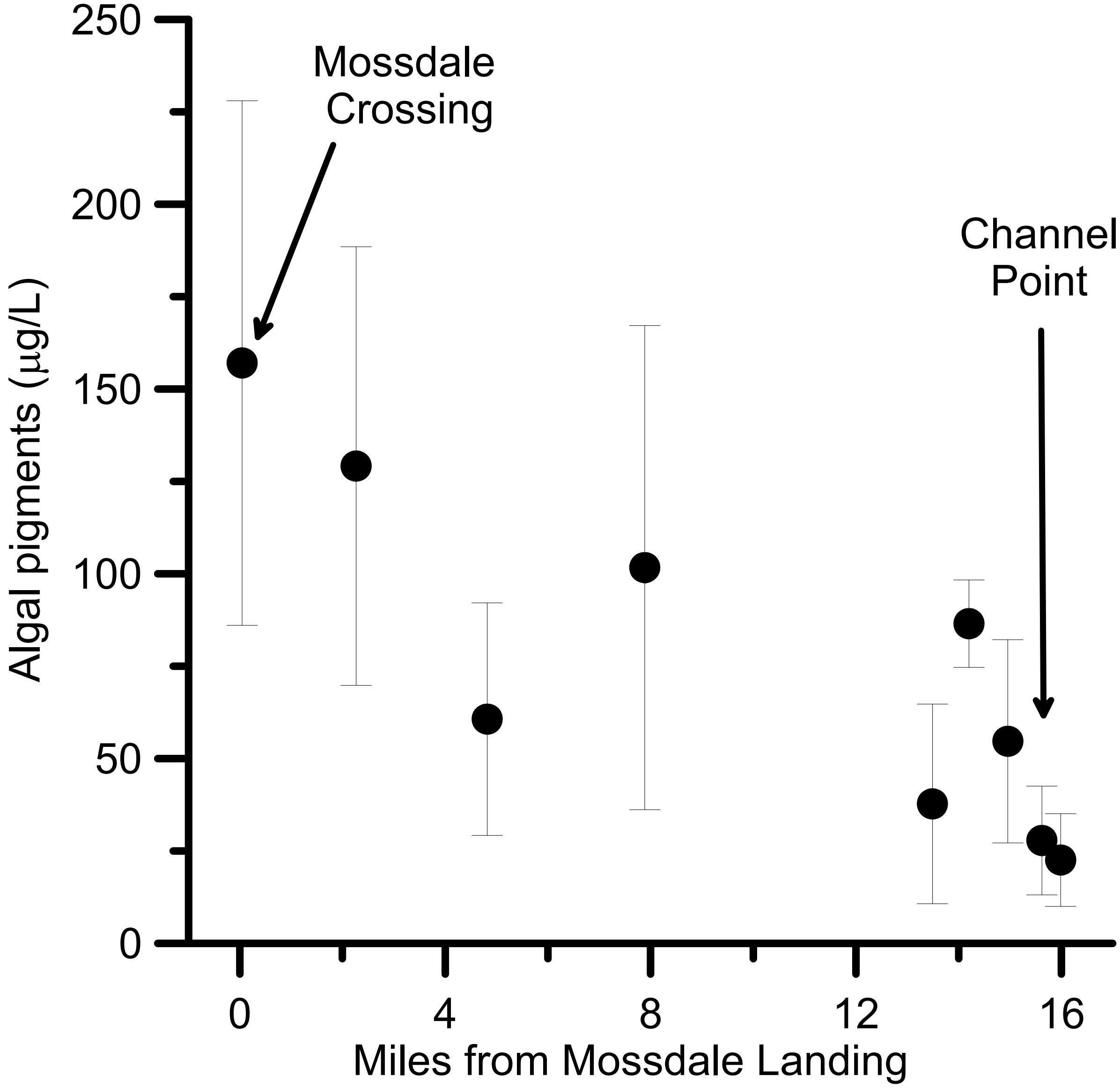


Figure 10. Nitrate and phosphate mass balance in the San Joaquin River. Nitrate and soluble phosphate are reactive substances and there is a loss of these compounds in the river. Data from 2007 shown as an example, but similar patterns can be seen for other years. Models must be used to fully understand the relationship between inputs to the river from drainages and outcomes, such as low dissolved conditions, in the river.

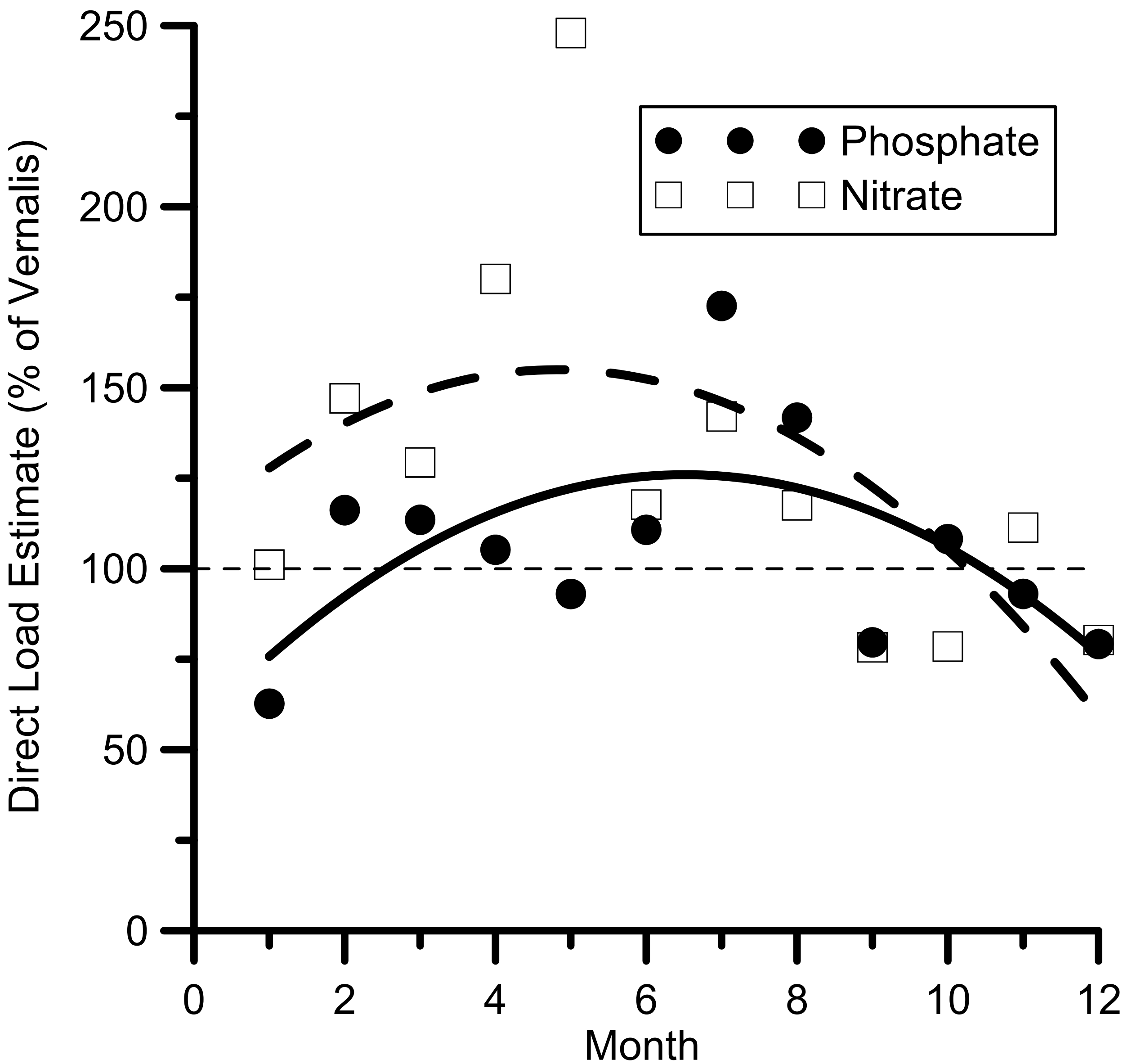


Figure 11. Mean annual loads of soluble reactive phosphate (as P) entering the San Joaquin River in the Mainstem and Southern study areas of the Upstream DO TMDL Project. Determining the sources of nutrient loads to the San Joaquin River was a major objective of the project. The Jenks natural break methods was use to set scale.

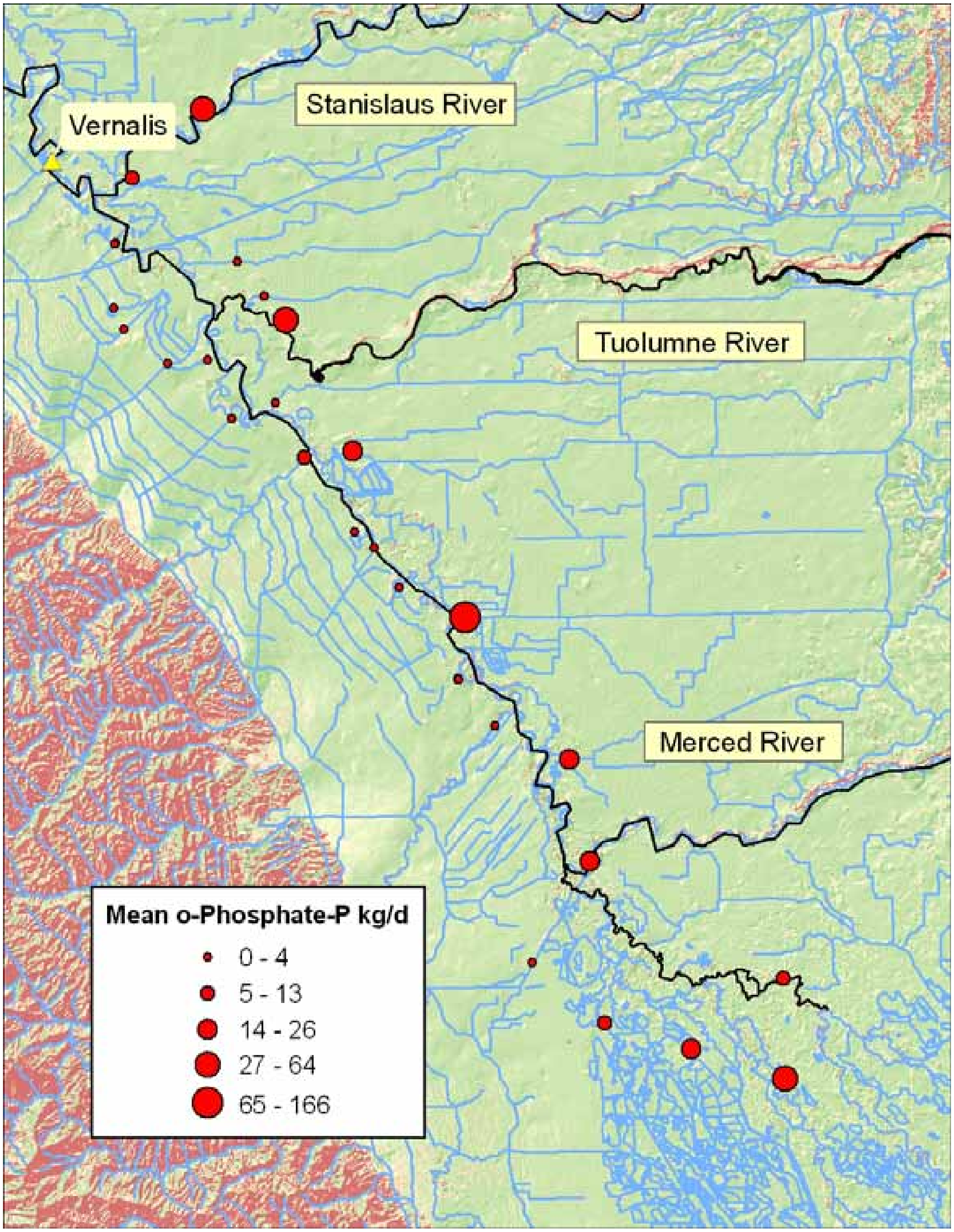


Figure 12. Predicted effect of two management strategies using the SJR-WARMF model. The model predicts that phytoplankton concentration at Vernalis would be reduced more by a reduction in phytoplankton loads from the Southern reach than from a reduction of total nitrogen and phosphorous loads throughout the Mainstem and Southern reaches. The use of a 2001 time period was for illustrative purposes only, to show the types of hypotheses that can be tested with the model, and has no other significance.

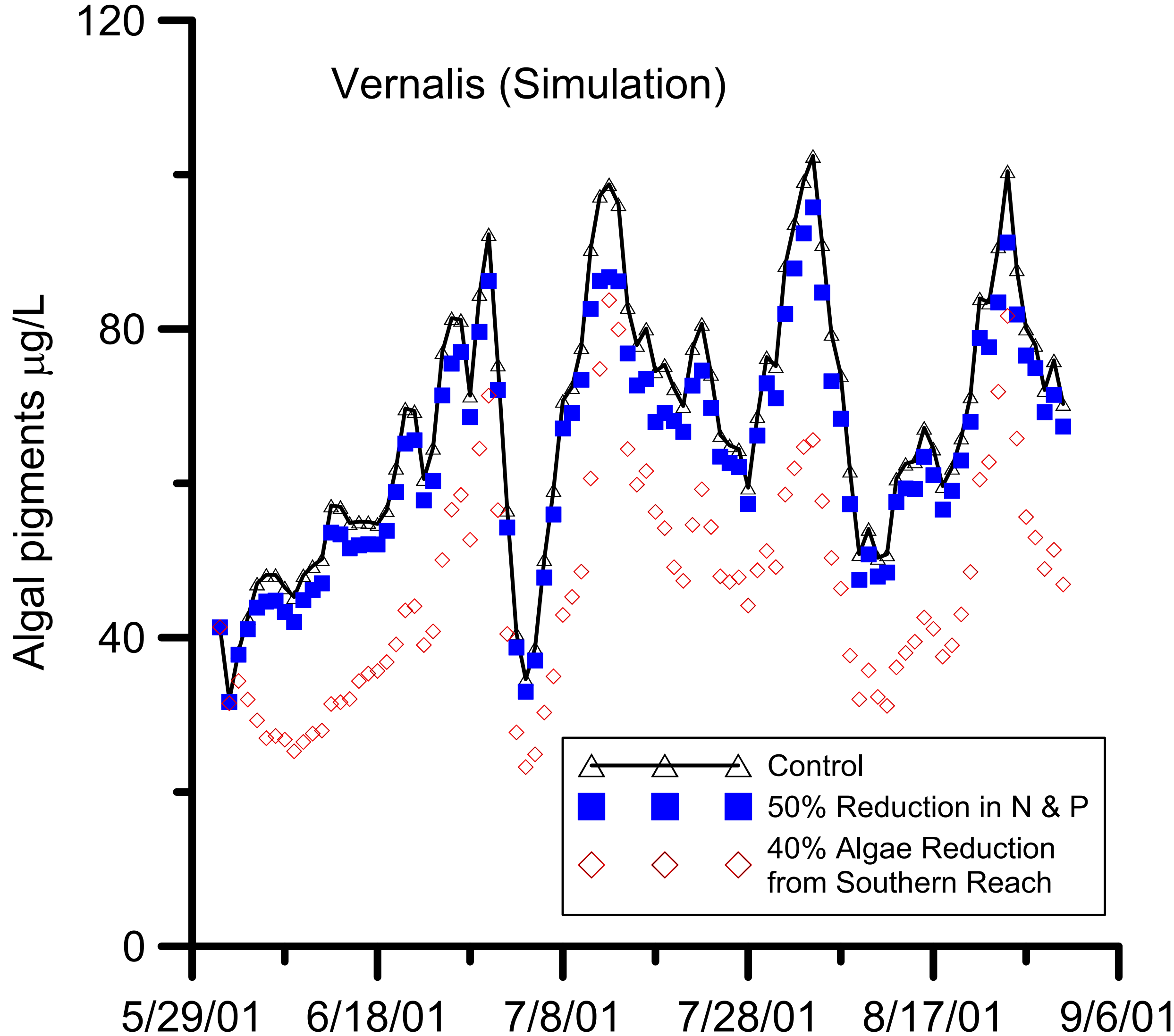


Figure 13. Flow patterns differ in drainages dominated by agricultural activities or wetlands. Average flows by month for all 15 minute data from 2005 and 2006 are shown for DO-34 Ingram Creek (agricultural drainage) and DO-62 Mallard Slough (wetland drainage). Note that 2005 and 2006 were both wet years, but winter flows in the agricultural drain remained low.

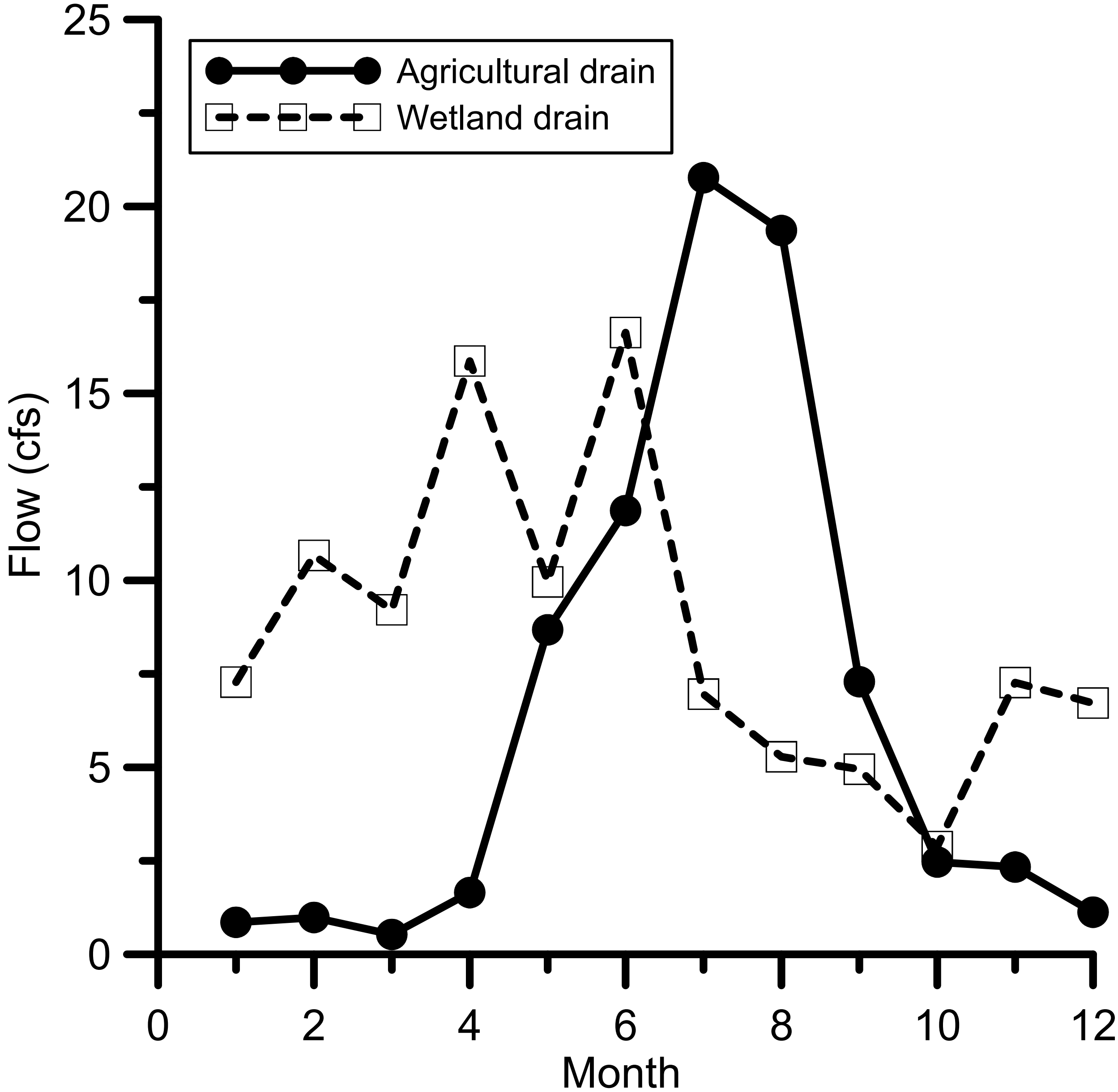
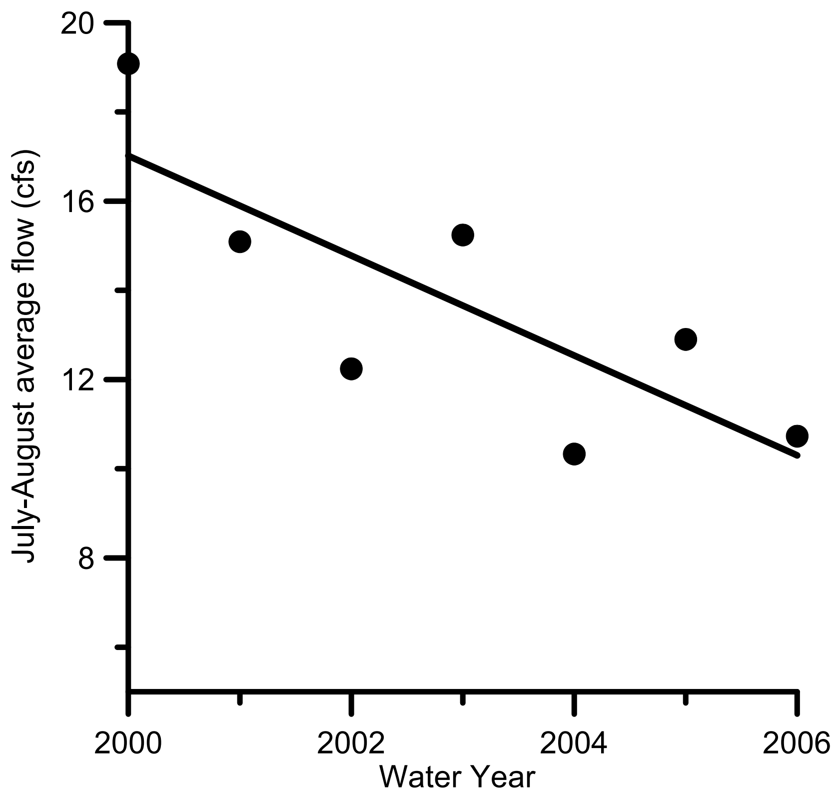
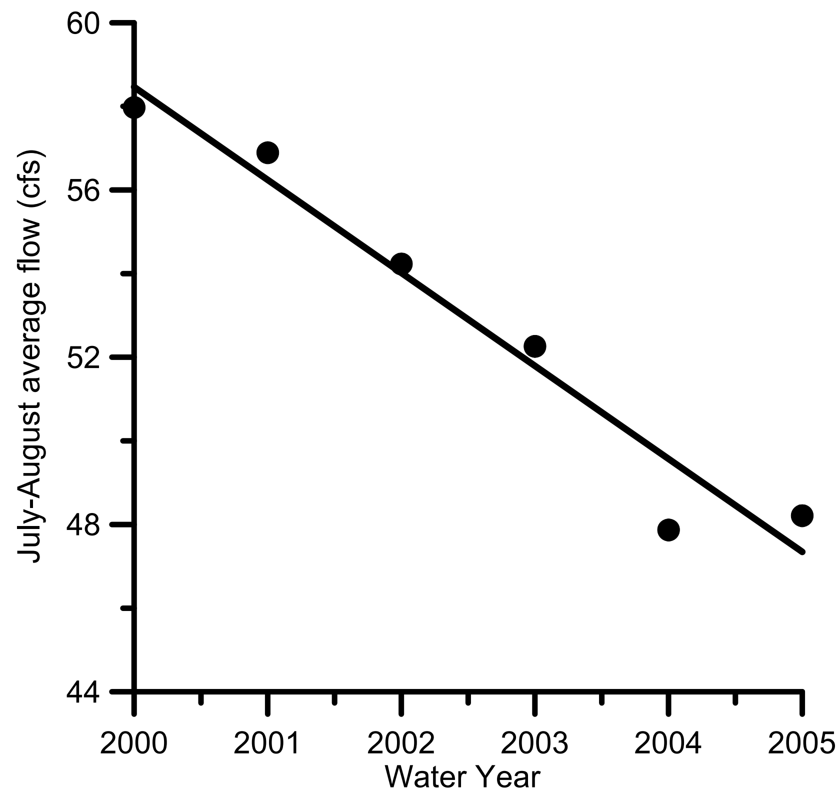


Figure 14. Temporal trends in return flows from agricultural drains show a year to year decline. Declines can be related to changing agricultural practices and the implementation of water conservation best management practices. The implication of these trends for the management of the DO TMDL and the overall heath of the SJR ecosystem is not yet understood.



a. DO-21 Orestimba creek



b. San Luis Drain

Figure 15. Seasonal and daily trends in chlorophyll-a observed in the San Joaquin River at Patterson. Daily fluctuations in chlorophyll can exceed 50% of mean values and vary in response to daylight. The SJR-WARMF model is calibrated to model seasonal and daily trends in chlorophyll and phytoplankton concentration. Chlorophyll fluorescence (RFU) has a linear relationship to chlorophyll (chlorophyll ≈ RFU x 9).

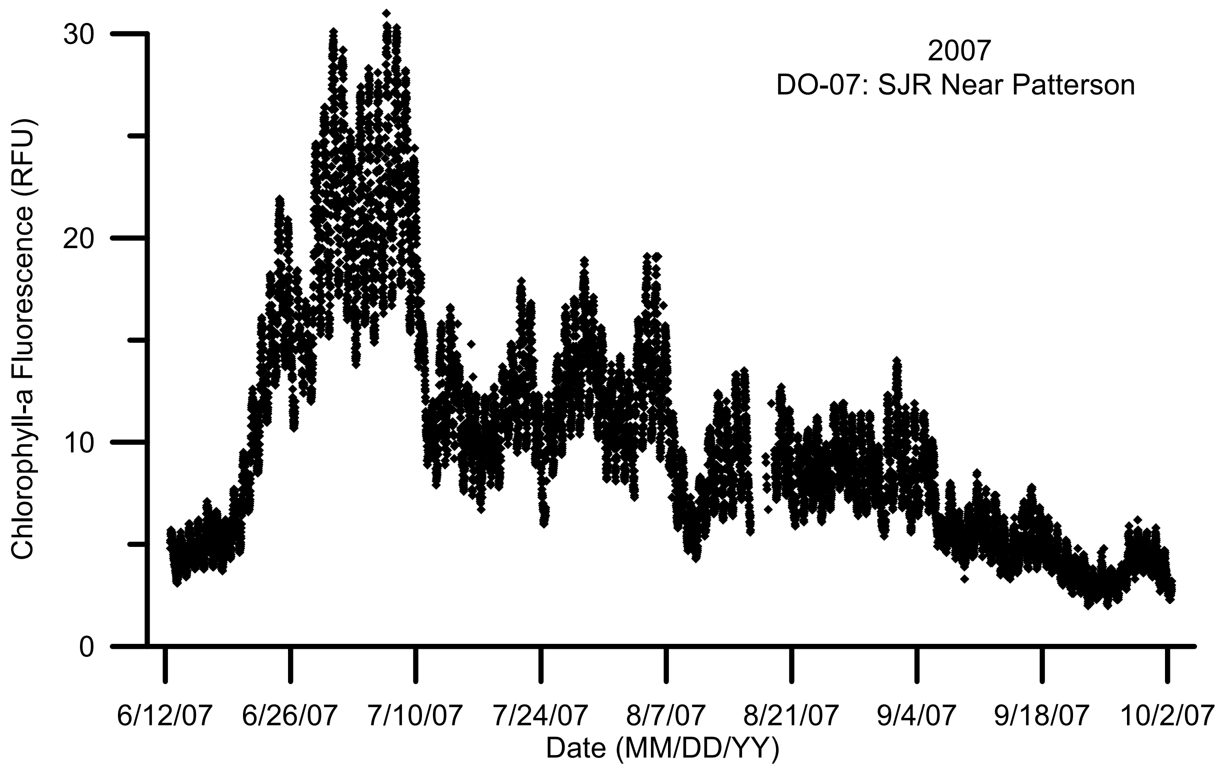


Table 1. The Upstream DO TMDL project was organized into administrative, data collection, scientific, and modeling activities. Specific Tasks were defined in the Recipient Agreement scope of work in order to meet overall project objectives. Task Final Reports, containing complete documentation of efforts and results for each data collection and scientific task, are available on the University of the Pacific Ecological Engineering Research Program (EERP) website (www.eerp-pacific.org).

Task	Task Name	Major accomplishments and activities
1	**Project Administration**	Monthly reports and invoices were filed. Activities between participating organizations were coordinated.
2	**Environmental Compliance**	Compliance documents were filed and landowner permissions were negotiated.
3	**QAPP**	A SWAMP compliant QAPP was prepared and approved by SWAMP reviewers.
4	**Monitoring Study**	Water quality and flow data were collected throughout the DO TMDL Project study area. Flow stations installed in Task 5 were maintained and calibrated. A full understanding of the surface water flows and water quality in the Southern and Mainstem areas has been developed. Scientific and engineering analyses were conducted to investigate temporal and spatial trends in flow and water quality. Data were organized and distributed to project participants and stakeholders. Outreach meeting were held to inform stakeholders of project activities and demonstrate how DO TMDL Project results could be used to plan management actions in response to the DO TMDL requirements. Data and analysis were provided in support of Task 6.
5	**Upgrade of Monitoring Stations**	New flow monitoring stations were installed throughout the study area. Improvements to existing stations in the Mainstem and Southern reaches of the SJR were made in cooperation with existing station owners (various water districts and the DWR).

Task	Task Name	Major accomplishments and activities
6	**Modeling Study**	A model to describe the Southern and Mainstem reaches of the DO TMDL Project study area (the SJR-WARMF model) was developed and calibrated. The model was reviewed by stakeholders using an independent expert. The model was used to evaluate TMDL management scenarios. In the first two years of the project, Task 6 activities were contractually limited to the riverine portion of the SJR to avoid duplication of effort with other CALFED funded Delta modeling efforts. In the final year of the project, limited development of the model for the Tidal Estuary portion of the DO TMDL study area (Link-Node model) was authorized and executed.
7	**BOD Isotope Study**	Surface water samples collected as part of Task 4 were analyzed for $\delta^{13}C$, $\delta^{15}N$, and C:N ratio of particulate organic matter (POM); $\delta^{18}O$ and $\delta^{2}H$ of water; and $\delta^{15}N$ and $\delta^{18}O$ of nitrate (NO_3). Subsets of the samples were also analyzed for $\delta^{13}C$ of dissolved organic carbon (DOC); $\delta^{18}O$ of phosphate; and $\delta^{34}S$ and $\delta^{18}O$ of sulfate (SO_4). Isotope analysis was used to identify seasonal trends in the sources and composition of the POM and spatial and temporal patterns in water and nutrient sources to the SJR.
8	**Linking Study**	The fate of planktonic algae in the Tidal Estuary was investigated using a combination of continuous monitoring, grab sampling, and Lagrangian studies (where a parcel of water is followed as it flows back and forth on the tidal cycle). Significant net phytoplankton losses can occur in the Tidal Estuary study area between Vernalis and Channel Point on the SJR. Major determining factors controlling net changes in phytoplankton concentration are light availability and the intensity of zooplankton grazing. Settling during slack tide periods and dispersion associated with tidal flows are much less important factors.

Task	Task Name	Major accomplishments and activities
9	**Grazing Study**	Measurements of zooplankton and phytoplankton were made for samples collected as part of Task 8. Plankton were identified and categorized. Zooplankton abundance and biovolume were measured and used to calculate grazing impacts. It was determined that bivalves were not abundant in the study reach and were not a significant factor in phytoplankton losses in the Tidal Estuary area. Data collected in Task 9 were used in Task 8 to estimate the impact of grazing on phytoplankton losses in the Tidal estuary study area.
10	**Installation of New Station in Tidal Estuary**	Studies were conducted to determine the extent of the upstream excursion of the plume from the Stockton waste water treatment plant due to tidal forces. Water quality monitoring equipment was installed at the Brandt DWR station, which was determined to be above the tidal excursion under most flow conditions.
11	**Local Access Databases**	Project data were entered by DWR into the Interagency Ecological Program public database. Data were entered into the SWAMP data system in a compliant format. A local database was created.
12	**Final Report**	In addition to Task Final Reports, a Project Final Report summarizing major accomplishments and findings of the Upstream SJR DO TMDL Project was written. (This report is the Project Final Report).
13	**Project Closure**	Final project documentation and invoicing completed. (Pending).

End Table 1

Table 2: Seasonal algal load as chlorophyll a (chl-a) from primary tributaries to the San Joaquin River above Vernalis. Load in kg/d are calculated using 2007 flow data and compiled monthly average chl-a measurements for 2005 to 2007. Loadings of chl-a in the San Joaquin River at Vernalis and Crows Landing are provided for reference. Diversions, which remove water and water quality constituents from the river, are sinks and are calculated as negative loads. Missing values have no data, zero values represent periods of no flow.

	DO No.	Chl-a kg/d Jan.	Chl-a kg/d Feb.	Chl-a kg/d Mar.	Chl-a kg/d Apr.	Chl-a kg/d May	Chl-a kg/d Jun.	Chl-a kg/d Jul.	Chl-a kg/d Aug.	Chl-a kg/d Sep.	Chl-a kg/d Oct.	Chl-a kg/d Nov.	Chl-a kg/d Dec.
SJR at Lander Avenue	**10**	2.29	8.49	6.29	5.84	4.23	4.76	7.75	4.80	1.99	1.25	0.62	0.73
Stanislaus River	**12**	6.69	7.38	14.59	5.97	10.52	4.89	2.62	3.06	2.25	2.59	1.60	1.53
Tuolumne River	**14**	3.01	4.61	6.53	3.49	1.87	1.26	1.47	1.58	0.97	1.35	1.58	0.96
Merced River	**16**	2.17	0.98	0.63	4.19	4.29	3.19	0.78	0.65	1.19	1.95	2.23	2.24
Mud Slough near Gustine	**18**	7.54	9.84	14.89	16.22	11.59	7.90	5.23	3.13	3.36	10.41	6.71	7.25
Salt Slough at Lander Avenue	**19**	5.81	11.64	10.41	7.07	6.24	6.97	10.03	5.42	3.37	3.29	2.86	3.12
Los Banos Creek	**20**	1.29	2.53	7.44	2.17	1.76	1.34	3.51	1.65	1.19	0.00	0.00	0.00
Orestimba Creek	**21**	3.21	1.39	0.06	0.13	0.12	0.14	0.36	0.21	0.08	0.28	0.26	0.19
Modesto ID Lateral 4	**22**	0.00	0.00	0.20	0.54	0.13	0.12	0.04	0.03	0.08	0.07	0.00	
Modesto ID Lateral 5	**23**	0.00	0.00	0.31	0.99	0.31	0.21	0.17	0.17	0.22	0.08	0.00	
Miller Lake	**25**	0.00	0.00	0.52	1.46	0.62	0.62	0.70	0.39	0.71	0.53	0.42	0.00
Turlock ID Lateral 2	**27**	0.00	0.00	0.06	0.52	0.03	0.02	0.00	0.05	0.06	0.04	0.00	
Turlock ID Westport Drain	**28**	0.00	0.39	0.48	2.83	0.40	0.23	0.21	0.17	0.25	0.37	0.18	
Harding Drain	**29**	0.41	1.66	0.47	1.19	0.54	0.47	0.59	0.53	1.16	0.31	0.22	0.21
Turlock ID Lateral 6 & 7	**30**	0.33	0.14	0.10	0.20	0.19	0.20	0.16	0.25	0.11	0.47	0.27	
Grayson Drain	**32**	0.14	0.16	0.10	0.40	1.87	0.58	1.68	1.37	1.34	0.00	0.04	0.02
Hospital Creek	**33**	0.04	0.04	0.06	0.29	0.23	0.54	0.77	0.53	0.29	0.01	0.00	0.00
Ingram Creek	**34**	0.10	0.01	0.09	0.59	1.20	1.62	2.51	1.67	0.18	0.02	0.01	0.04
Westley Wasteway	**35**	0.04	0.08	0.03	0.18	0.12	0.15	0.38	0.17	0.18	0.05	0.03	0.01
Del Puerto Creek	**36**	0.21	0.12	0.28	1.27	1.05	0.78	0.83	1.13	2.25	0.85	0.14	0.04
Marshall Road Drain	**38**	0.10	0.49	0.11	0.20	0.59	0.64	0.34	0.10	0.05	0.04	0.02	0.01
Salado Creek	**39**	0.14	0.16	0.10	0.40	1.37	1.16	0.87	0.81	0.40	0.14	0.04	0.02
Patterson ID Diversion	**40**	0.00	0.00	-5.97	-8.01	-7.81	-11.95	-26.05	-14.70	-6.57	-1.18	0.00	0.00
W. Stanislaus ID Diversion	**41**	-0.58	-0.50	-2.45	-14.93	-10.00	-14.62	-20.58	-10.16	-5.55	-1.79	-0.65	-0.20
El Solyo WD Diversion	**43**	-0.04	-0.12	-0.43	-1.60	-1.71	-2.91	-7.41	-9.55	-2.76	-0.12	-0.07	0.00
Ramona Drain	**57**	0.00	0.00	0.00	3.09	2.79	1.87	2.54	0.68	0.53	0.45	0.03	1.99
Moran Drain	**64**	0.02	0.00	0.03	0.15	0.05	0.11	0.41	0.35	0.10	0.01	0.00	0.00
Spanish Grant Drain	**65**	0.22	0.06	0.14	0.55	0.60	0.92	1.06	1.14	0.35	0.12	0.00	0.00
Maze Boulevard Drain	**66**	0.14	0.16	0.10	0.40	0.54	0.58	1.46	0.73	0.39	0.12	0.04	0.02
Newman Wasteway	**67**	0.14	0.16	0.10	0.40	0.13	0.27	0.45	0.73	0.21	0.39	0.04	0.02
SJR at Vernalis	**5**	43.59	83.86	63.14	138.63	124.46	201.95	147.72	114.92	73.75	51.65	25.44	19.25
SJR at Crows Landing	**8**	31.74	50.63	55.18	101.21	70.79	58.72	66.55	40.00	24.77	24.28	22.41	21.03

Table 3: Seasonal nitrate-N (NO_3-N) load from primary tributaries to the San Joaquin River above Vernalis. Load in kg/d are calculated using 2007 flow data and compiled monthly average nitrate-N measurements for 2005 to 2007. Loadings of nitrate-N in the San Joaquin River at Vernalis and Crows Landing are provided for reference. Diversions are calculated as negative loads. Missing values have no data, zero values represent periods of no flow.

	DO No.	NO_3-N kg/d Jan.	NO_3-N kg/d Feb.	NO_3-N kg/d Mar.	NO_3-N kg/d Apr.	NO_3-N kg/d May	NO_3-N kg/d Jun.	NO_3-N kg/d Jul.	NO_3-N kg/d Aug.	NO_3-N kg/d Sep.	NO_3-N kg/d Oct.	NO_3-N kg/d Nov.	NO_3-N kg/d Dec.
SJR at Lander Avenue	**10**	48	701	405	55	12	83	223	177	21	21	6	4
Stanislaus River	**12**	541	385	822	334	297	349	251	215	191	264	257	262
Tuolumne River	**14**	993	996	351	499	652	466	879	871	862	836	939	990
Merced River	**16**	978	703	124	730	4,196	841	957	860	758	1,816	3,168	2,212
Mud Slough near Gustine	**18**	2,075	2,020	1,845	1,223	1,101	443	341	387	189	243	538	685
Salt Slough at Lander Avenue	**19**	438	1,600	1,380	480	493	827	752	340	71	94	152	144
Los Banos Creek	**20**	36	28	99	30	32	10	36	42	19	0	0	0
Orestimba Creek	**21**	55	13	15	24	41	46	161	72	26	30	36	51
Modesto ID Lateral 4	**22**	0	0	212	298	16	26	85	9	117	75	0	
Modesto ID Lateral 5	**23**	0		29	525	1	66	24	22	35	45	0	
Miller Lake	**25**	0	0	4	121	41	66	33	41	76	65	11	0
Turlock ID Lateral 2	**27**	1	11	67	291	33	69	1	78	80	42	0	
Turlock ID Westport Drain	**28**	0	1,862	1,116	1,645	898	738	744	647	612	425	790	
Harding Drain	**29**	495	1,445	817	873	796	852	1,018	905	887	761	1,099	885
Turlock ID Lateral 6 & 7	**30**	244	668	254	955	396	326	422	539	189	715	1,041	
Grayson Drain	**32**	14	21	35	62	51		44	451	67	56	9	5
Hospital Creek	**33**	4	5	20	44	9	20	13	26	9	0	0	0
Ingram Creek	**34**	10	28	72	158	53	76	204	246	31	12	21	11
Westley Wasteway	**35**	4	10	10	28	7		6	8	11	20	8	2
Del Puerto Creek	**36**	80	32	5	93	84	138	289	331	486	343	24	7
Marshall Road Drain	**38**	10	66	37	31	56	37	61	25	6	2	5	3
Salado Creek	**39**	14	21	35	62	114	42	157	20	85		9	5
Patterson ID Diversion	**40**	0	0	-495	-294	-318	-467	-948	-951	-704	-183	0	0
W. Stanislaus ID Diversion	**41**	-68	-43	-203	-548	-407	-571	-749	-658	-596	-280	-146	-45
El Solyo WD Diversion	**43**	-6	-11	-40	-62	-75	-75	-230	-440	-203	-19	-20	0
Ramona Drain	**57**	0	0	0	101	35	36	54	39	43	12	10	1
Moran Drain	**64**	2	0	12	23	48	37	21	73	2	0	0	0
Spanish Grant Drain	**65**	23	8	47	85	220	199	135	237	73	36	0	0
Maze Boulevard Drain	**66**	14	21	35	62			32	153	19	8	9	5
Newman Wasteway	**67**	14	21	35	62	85	42	102	153	38	52	9	5
SJR at Vernalis	**5**	5,952	7,217	5,521	4,439	3,616	4,012	3,603	4,184	4,468	6,996	7,163	6,513
SJR at Crows Landing	**8**	3,296	4,598	3,482	4,035	3,491	2,795	2,696	2,891	2,932	2,870	3,508	4,051

Table 4: Seasonal ortho-phosphate-P (PO_4-P) load from primary tributaries to the San Joaquin River above Vernalis. Load in kg/d are calculated using 2007 flow data and compiled monthly average ortho-phosphate-P measurements for 2005 to 2007. Loadings of ortho-phosphate-P in the San Joaquin River at Vernalis and Crows Landing are provided for reference. Diversions are calculated as negative loads. Missing values have no data, zero values represent periods of no flow.

	DO No.	PO_4-P kg/d Jan.	PO_4-P kg/d Feb.	PO_4-P kg/d Mar.	PO_4-P kg/d Apr.	PO_4-P kg/d May	PO_4-P kg/d Jun.	PO_4-P kg/d Jul.	PO_4-P kg/d Aug.	PO_4-P kg/d Sep.	PO_4-P kg/d Oct.	PO_4-P kg/d Nov.	PO_4-P kg/d Dec.
SJR at Lander Avenue	**10**	5.0	29.0	34.6	4.7	3.6	4.1	4.7	5.0	3.8	4.0	1.5	1.2
Stanislaus River	**12**	64.4	21.9	181.9	136.8	75.5	58.3	42.6	37.0	32.6	47.3	17.3	8.5
Tuolumne River	**14**	20.1	7.8	35.4	85.9	37.6	29.3	61.5	61.4	47.8	29.8	14.3	8.8
Merced River	**16**	11.8	5.2	5.1	38.8	104.7	29.3	12.8	8.5	9.8	16.7	26.6	11.1
Mud Slough near Gustine	**18**	42.7	64.1	75.6	3.3	5.2	0.6	1.0	0.3	2.3	63.3	66.1	45.0
Salt Slough at Lander Avenue	**19**	30.6	95.7	100.6	62.6	101.8	63.9	57.3	35.8	21.0	32.2	24.6	18.1
Los Banos Creek	**20**	12.9	11.1	53.8	22.7	15.5	6.7	10.1	16.4	8.9	0.0	0.0	0.0
Orestimba Creek	**21**	1.9	0.3	0.3	0.8	1.5	1.9	2.6	1.8	1.3	3.1	1.9	1.2
Modesto ID Lateral 4	**22**	0.0	0.0	6.5	10.7	0.5	0.4	1.7	0.8	2.5	2.3	0.0	
Modesto ID Lateral 5	**23**	0.0	0.0	2.6	21.9	1.2	1.1	1.6	3.1	4.1	2.3	0.0	
Miller Lake	**25**	0.0	0.0	16.7	6.5	3.5	5.6	12.5	6.4	4.7	9.5	3.7	0.0
Turlock ID Lateral 2	**27**	0.1	0.2	2.1	10.5	0.2	0.2	1.7	1.5	1.7	1.3	0.0	
Turlock ID Westport Drain	**28**	0.0	29.4	30.6	50.9	14.9	9.3	13.7	10.0	9.8	12.5	19.2	
Harding Drain	**29**	129.2	264.6	109.8	134.8	164.8	201.9	192.0	167.3	104.5	130.5	248.0	205.8
Turlock ID Lateral 6 & 7	**30**	13.5	10.6	5.6	23.2	14.2	13.9	14.2	22.9	5.7	23.8	33.5	
Grayson Drain	**32**	1.8	0.2	0.5	2.4	2.6	3.3	5.0	5.2	3.8	2.8	0.3	0.1
Hospital Creek	**33**	0.4	0.1	0.3	1.7	4.1	3.4	1.7	6.0	1.0	0.0	0.0	0.0
Ingram Creek	**34**	3.0	0.1	0.4	3.1	4.2	4.9	5.8	6.2	1.0	0.3	1.2	0.3
Westley Wasteway	**35**	0.6	0.1	0.1	1.1	0.9	0.8	0.7	0.9	0.8	0.3	0.3	0.1
Del Puerto Creek	**36**	2.5	1.0	1.1	8.0	6.5	7.1	10.5	16.8	33.1	25.0	0.3	0.4
Marshall Road Drain	**38**	1.3	0.7	0.5	1.2	3.8	1.8	1.8	1.9	0.6	0.4	0.2	0.1
Salado Creek	**39**	1.8	0.2	0.5	2.4	0.8	2.4	4.0	5.1	5.6	2.8	0.3	0.1
Patterson ID Diversion	**40**	0.0	0.0	-39.8	-31.4	-35.7	-42.6	-75.6	-71.3	-52.0	-12.2	0.0	0.0
W. Stanislaus ID Diversion	**41**	-5.9	-2.9	-16.3	-58.6	-45.8	-52.1	-59.8	-49.3	-43.9	-18.6	-14.2	-3.9
El Solyo WD Diversion	**43**	-0.5	-0.7	-3.8	-6.6	-8.9	-7.2	-10.1	-20.9	-9.9	-0.9	-1.3	0.0
Ramona Drain	**57**	0.0	0.0	0.0	5.5	1.7	4.8	1.6	1.1	1.9	0.3	0.5	0.3
Moran Drain	**64**	0.2	0.0	0.2	0.9	0.5	1.0	1.8	2.4	0.2	0.0	0.0	0.0
Spanish Grant Drain	**65**	2.8	0.1	0.6	3.3	5.8	5.2	5.3	7.6	2.3	0.6	0.0	0.0
Maze Boulevard Drain	**66**	1.8	0.2	0.5	2.4	2.9	3.3	3.1	4.9	1.5	0.7	0.3	0.1
Newman Wasteway	**67**	1.8	0.2	0.5	2.4	2.9	2.5	3.6	4.9	3.2	1.6	0.3	0.1
SJR at Vernalis	**5**	548.1	464.1	534.1	524.6	527.7	329.7	190.9	211.6	263.3	353.0	478.0	375.6
SJR at Crows Landing	**8**	95.7	181.3	220.9	139.1	170.8	127.5	82.7	86.2	86.2	124.1	193.2	139.3

Table 5: Seasonal biochemical oxygen demand (BOD) load from primary tributaries to the San Joaquin River above Vernalis. Load in kg/d are calculated using 2007 flow data and compiled monthly average BOD measurements for 2005 to 2007. Loadings of BOD in the San Joaquin River at Vernalis and Crows Landing are provided for reference. Missing values have no data, zero values represent periods of no flow.

	DO No.	BOD kg/d Jan.	BOD kg/d Feb.	BOD kg/d Mar.	BOD kg/d Apr.	BOD kg/d May	BOD kg/d Jun.	BOD kg/d Jul.	BOD kg/d Aug.	BOD kg/d Sep.	BOD kg/d Oct.	BOD kg/d Nov.	BOD kg/d Dec.
SJR at Lander Avenue	**10**	415	1,672	1,783	876	470	515	814	568	281	172	100	126
Stanislaus River	**12**	1,683	1,667	2,760	3,613	3,055	2,036	1,356	1,100	1,068	1,204	606	574
Tuolumne River	**14**	1,332	838	1,630	3,731	2,369	671	754	876	620	820	397	411
Merced River	**16**	945	665	226	1,677	1,685	1,426	861	987	594	1,450	2,076	1,099
Mud Slough near Gustine	**18**	1,507	1,705	2,329	1,690	1,254	776	735	620	743	3,293	1,862	1,233
Salt Slough at Lander Avenue	**19**	1,252	1,947	1,643	1,289	1,370	1,421	1,417	971	709	909	686	735
Los Banos Creek	**20**	366	440	1,134	487	455	287	589	598	436	0	0	0
Orestimba Creek	**21**	217	75	14	16	32	27	76	49	21	44	70	81
Modesto ID Lateral 4	**22**	0	0	79		43	40	26	36	39	27	0	0
Modesto ID Lateral 5	**23**	0	0	129	311	78	88	72	83	110	65	0	0
Miller Lake	**25**	0	0	142	280	171	176	226	123	156	143	102	0
Turlock ID Lateral 2	**27**	0	1	25		35	24	22	22	27	15	0	0
Turlock ID Westport Drain	**28**	0	110	168	1,221	168	112	151	108	106	112	66	0
Harding Drain	**29**	248	403	256	484	382	447	804	562	499	326	185	150
Turlock ID Lateral 6 & 7	**30**	86	39	24	168	114	128	93	83	24	104	25	0
Grayson Drain	**32**	17	12	22	61	196	107	251	234	274	54	9	5
Hospital Creek	**33**	4	3	13	43	133	180	142	115	50	1	0	0
Ingram Creek	**34**	11	2	10	85	136	251	397	448	53	6	14	7
Westley Wasteway	**35**	5	6	6	28	33	27	92	39	56	14	8	2
Del Puerto Creek	**36**	63	25	86	207	280	206	225	633	937	519	24	10
Marshall Road Drain	**38**	12	38	24	31	110	170	152	26	39	10	5	3
Salado Creek	**39**	17	12	22	61	97	281	160	1,012	117	54	9	5
Patterson ID Diversion	**40**	0	0	-797	-840	-984	-1,334	-2,601	-2,036	-984	-211	0	0
W. Stanislaus ID Diversion	**41**	-93	-54	-327	-1,566	-1,261	-1,632	-2,055	-1,408	-832	-321	-165	-46
El Solyo WD Diversion	**43**	-8	-17	-79	-203	-234	-321	-592	-1,085	-285	-17	-15	0
Ramona Drain	**57**	0	0	0	418	466	383	327	158	209	91	13	111
Moran Drain	**64**	2	0	8	22	11	55	189	112	35	1	0	0
Spanish Grant Drain	**65**	27	5	30	83	250	319	437	362	135	18	0	0
Maze Boulevard Drain	**66**	17	12	22	61	97	107	154	234	159	26	9	5
Newman Wasteway	**67**	17	12	22	61	55	77	290	234	56	61	9	5
SJR at Vernalis	**5**	9,640	12,253	16,830	17,349	15,937	19,597	12,824	12,605	15,421	8,173	5,003	4,638
SJR at Crows Landing	**8**	4,504	6,930	6,531	10,587	8,999	6,614	6,584	4,617	3,135	3,910	4,707	3,638

Table 6. List of physical, chemical, and biological measurements made at monitoring locations included in the Upstream SJR DO TMDL Project. See Figure 3 and the Task 4 and 7 Final Reports for details. Additional measurements of phytoplankton and zooplankton were made as part of Task 9 on selected samples.

Measurement	Measurement
Absorbance at 254 nm	Lipids, Algal
Chlorophyll (chlorophylls/ pheophytin)	Lipids, Bacteria
Alkalinity	Lipids, Diatom
Biochemical Oxygen Demand, Carbonaceous	Lipids, Dinoflagelate
Biochemical Oxygen Demand, Nitrogenous	Lipids, Green Algae
Biochemical Oxygen Demand, Total	Lipids, Terrestrial
Carbon, Dissolved Organic	Lipids, Total
Carbon, Total Inorganic	Longitude
Carbon, Total Organic	Nitrogen, Ammonia
Chlorophyll a	Nitrogen, Nitrate
Chlorophyll b	Nitrogen, Organic
Chlorophyll c	Nitrogen, Total
Day length	Oxidation Reduction Potential
Flow, Volume-time	Oxygen, Percent Saturation
Flow, Velocity	Oxygen, Dissolved
Fluorescence, Algal	pH
Ions, Br	Pheophytin a
Ions, Ca	Phosphate, Soluble Reactive
Ions, Cl	Phosphorous, Total
Ions, K	Precipitation
Ions, Mg	Protein, Particulate
Ions, Na	Protein, Soluble
Ions, Si	Protein, Total
Ions, SO4	Silica, Dissolved
Iron, Total	Solar Radiation, Langleys/day
C:N Ratio of POM	Solar Radiation, PAR
Isotopes, δ^{13}C-DOC	Solids, Mineral Suspended
Isotopes, δ^{13}C-POM	Solids, Total Dissolved
Isotopes, δ^{15}N-NO3	Solids, Total Suspended
Isotopes, δ^{15}N-POM	Solids, Volatile Suspended
Isotopes, δ^{18}O-NO3	Specific Conductance
Isotopes, δ^{18}O-SO4	Stage
Isotopes, δ^{18}O-water	Temperature, Air
Isotopes, δ^{34}S-SO4	Temperature, Water
Isotopes, δ^{2}H-water	Turbidity, NTU
Latitude	

Table 7. Comparison of predicted values and actual values for flow using the SJR-WARMF model. The model provides an accurate estimation of flow at key river locations. Accurate estimation of flow is necessary for the development of mass balance calculations for water quality constituents.

Gaging Station	Relative Error	Absolute Error
Stevinson	+1%	18%
Fremont Ford (data begins 10/2001)	+2%	18%
Newman	-6%	11%
Crows Landing	0%	11%
Patterson	+15%	27%
Maze Road (data begins 1/2005)	-2%	11%
Vernalis	-1%	13%

Table 8. Comparison of predicted values and actual values for sodium using the SJR-WARMF model. The model provides an accurate estimation of sodium at key river locations. The SJR-WARMF model provides an accurate estimate of most ions and other conserved substances in the Mainstem and Southern reaches of the Upstream SJR DO TMDL Project study area.

Monitoring Station	Relative Error	Absolute Error
Stevinson	-1%	3%
Crows Landing	+9%	17%
Patterson	-15%	19%
Maze Road	-11%	16%
Vernalis	-11%	19%
Mossdale	-2%	13%

Table 9. Comparison of predicted values and actual values for phytoplankton using the SJR-WARMF Model. The riverine SJR-WARMF model provides a good estimation of phytoplankton at key river locations above the tidal estuary (Stevinson, Crows Landing, Patterson, Maze, and Vernalis), where phytoplankton chlorophyll concentrations exhibit a daily cycle that can be greater than 50%. The development of the estuary portion of the model was not included in the Upstream DO TMDL Project scope of work.

Monitoring Station	Relative Error	Absolute Error
Stevinson	-3%	9%
Crows Landing	-12%	41%
Patterson	-27%	46%
Maze Boulevard	-14%	49%
Vernalis	+8%	57%

Table 10. Mass balance on phytoplankton using the SJR-WARMF model. Sources and sinks of phytoplankton, including the amount produced by growth and lost by mortality and physical processes are estimated by the model. Loads represent model calculated average loads of chlorophyll-a for five years (2000 to 2005). The model indicates that the majority of phytoplankton observed at Mossdale grew within the San Joaquin River.

Sources and Sinks	Phytoplankton Load (kg/day Chl-a)
Stanislaus River	3.6
Tuolumne River	5.0
Merced River	1.8
San Joaquin River (from upstream of Lander Ave.)	11.3
Salt Slough	7.7
Mud Slough	9.5
Los Banos Creek	1.4
Orestimba Creek	0.5
Del Puerto Creek	0.5
Hospital & Ingram Creeks	0.9
Agricultural Spills / Drains + Modesto WQCF	2.3
Groundwater Accretion and Surface Runoff	0.0
Growth in the San Joaquin River	420.5
Mortality, Respiration, and Settling to River Bed	-186.0
Diversions	-77.6
TOTAL (at Mossdale)	**201.4**

Table 11. Comparison of predicted values and actual values for phytoplankton loads using the Link-Node Model. Model errors are higher at the Tidal Estuary locations (Mossdale, Garwood and Buckley Cove) than for riverine locations (Table 9). The full development of the estuary portion of the model was not included in the Upstream DO TMDL Project scope of work, but a preliminary calibration was completed.

Monitoring Station	Relative Error	Absolute Error
Mossdale	+41%	65%
Garwood Bridge	-1%	75%
Buckley Cove / City of Stockton R6	-41%	85%

Appendix A:
Calculation of Relative and Absolute Error as Used in the Task 12 Report

Relative error E_r is a measure of model bias. It is the average deviation between simulated values (x_s) and observed data (x_o) as shown in equation 1. n is the number of observed data points for which a comparison can be made.

$$E_r = \frac{\sum_n (x_s - x_o)}{n} \tag{1}$$

Since the errors from the model in one instance predicting a value higher than observed and at another time predicting a value lower than observed cancel each other out, the relative error does not indicate how well the model's simulated results match individual data points. Rather, the relative error is used to evaluate systemic error producing consistently higher or lower values than observed data.

In the form shown in equation 1, E_r is expressed in the same units as x_s and x_o such as ^oF or mg/l. The value of E_r alone may not be informative, however. An error of 0.5 mg/l would be poor for a constituent for which concentration is typically less than 1 mg/l, but such an error would be excellent for a constituent averaging 20 mg/l. For this reason, E_r can be expressed as a percent by dividing the original error by the average of observed values as shown in equation 2.

$$E_r(\%) = \frac{E_r}{\overline{x_o}} \tag{2}$$

Absolute error E_a is a measure of model precision. It is the average of the absolute values of the deviations between simulated values (x_s) and observed data (x_o) as shown in equation 3.

$$E_a = \frac{\sum_n | x_s - x_o |}{n} \tag{3}$$

Since the errors of individual data points do not cancel each other out, E_a measures the model's error with respect to individual data points. E_a does not, however, address the possibility that the model error is one of timing rather than magnitude. As with E_r, the magnitude may or may not be informative as to the predictive power of the model, so E_a can be expressed as a percent as well as shown in equation 4.

$$E_a(\%) = \frac{E_a}{\overline{x_o}} \tag{4}$$

Table A1-1 shows an example time series demonstrating how E_r and E_a are calculated. Note in Table A1-1 that on the 4th day there is no measured value, so the simulated value on that day is not used in calculation of error. The number of data points is 9. The relative error is -0.3 cfs, or -4.0%. The absolute error is 1.9 cfs or 28.7%. Note also that the simulation predicts the peak flow on day 6 instead of day 5 as seen in the observed data. The error in timing of the peak flow is evident in the absolute error on day 5, but the relative error average is not affected because the model under-prediction on day 5 is counterbalanced by corresponding over-predictions on days 6-9.

Table A1-1: Example Time Series with Calculation of E_r and E_a

Day	Simulated Flow x_s	Measured Flow x_o	x_s-x_o	$\|x_s$-$x_o\|$
1	5.0 cfs	4.5 cfs	+0.5 cfs	0.5 cfs
2	4.6 cfs	5.0 cfs	-0.4 cfs	0.4 cfs
3	3.9 cfs	4.5 cfs	-0.6 cfs	0.6 cfs
4	3.8 cfs	(not measured)		
5	3.8 cfs	12.5 cfs	-8.7 cfs	8.7 cfs
6	13.2 cfs	10.0 cfs	+3.2 cfs	3.2 cfs
7	8.5 cfs	6.5 cfs	+2.0 cfs	2.0 cfs
8	7.5 cfs	6.0 cfs	+1.5 cfs	1.5 cfs
9	6.2 cfs	6.0 cfs	+0.2 cfs	0.2 cfs
10	4.9 cfs	5.0 cfs	-0.1 cfs	0.1 cfs
Average	**6.4** cfs	**6.7** cfs	**E_r=-0.3 cfs**	**E_a=1.9 cfs**
% of Observed	**96%**	**100%**	**E_r(%)=-4.0%**	**E_a(%)=28.7%**