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POSSIBLE SJR DO TMDL IMPLEMENTATION PROCEDURES

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Acronyms

af	acre-feet
BOD	biological oxygen demand
CBDA	California Bay-Delta Authority
cfs	cubic feet per second
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
DO	Dissolved Oxygen
DWR	Department of Water Resources
DWSC	Deep Water Ship Channel
EC	electrical conductivity
ENOD	excess net oxygen demand
LC	loading capacity
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
RWCF	Regional Wastewater Control Facility
SJR	San Joaquin River
SWP	State Water Project
TMDL	Total Maximum Daily Load
TWG	Technical Work Group
UOP	University of the Pacific
USACE	United States Army Corps of Engineers
VAMP	Vernalis Adaptive Management Program
VSS	volatile suspended solids
WDR	Waste Discharge Requirements

Appendix A
Possible SJR DO TMDL Implementation Procedures

Introduction

This appendix supplements the *Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report* prepared by ICF International. It provides information about a possible scenario of how the Demonstration Aeration Facility (Aeration Facility) could be operated in the future as part of the San Joaquin River (SJR) Dissolved Oxygen (DO) Total Maximum Daily Load (TMDL) implementation program.

In its Final Staff Report for the SJR DO TMDL Basin Plan Amendments, the Central Valley Regional Water Quality Control Board (CVRWQCB) generally discussed the need for procedures that could allocate responsibility for low-DO concentrations observed in the SJR's Deep Water Ship Channel (DWSC). However, neither the CVRWQCB nor the SJR DO TMDL Technical Work Group (TWG) developed specific procedures for determining how much responsibility for measured DO objective deficits should be assigned to the three general causes of low DO—DWSC geometry, reduced flows, and biochemical oxygen demand (BOD) loads—or to individual BOD load sources. The development and approval of such accounting procedures by CVRWQCB and stakeholders will be necessary for the future operation of the Aeration Facility (as part of the TMDL implementation program), which could be used to reduce periods of low-DO concentrations in the DWSC. Such accounting procedures could ultimately be used to formally apportion responsibility for DO objective deficits in the DWSC, guide Aeration Facility operation, and allocate costs associated with Aeration Facility operation.

This appendix is divided into two main sections, each of which describes an important SJR DO TMDL implementation program topic related to the accounting procedures briefly described above.

1. **Review of the Final Staff Report for the SJR DO TMDL Basin Plan Amendments**. This section identifies the regulatory framework for the SJR DO TMDL implementation program by excerpting and discussing key portions of the CVRWQCB's 2005 Basin Plan Amendments and Final Staff Report (Central Valley Regional Water Quality Control Board 2005). This review identifies the TMDL accounting and reporting procedures that must be developed (and approved by stakeholders and CVRWQCB staff) for the future SJR DO TMDL implementation program.
2. **Suggested SJR DO TMDL Implementation Accounting Procedures**. This section identifies possible SJR DO TMDL accounting procedures that could be used for estimating the effects of SJR and DWSC flows, upstream river algae concentrations, and Stockton Regional Wastewater Control Facility (RWCF) effluent concentrations on the combined inflow BOD to the DWSC and the resulting DO concentrations in the DWSC. These daily accounting procedures may provide a reliable framework for understanding the causative factors of low DO in the DWSC and assigning proportional responsibilities to stakeholders for Aeration Facility operation (or other

implementation measures) to meet the DO objective. If approved by RWQCB staff and stakeholders, these proposed accounting procedures could also provide a reporting framework to demonstrate compliance with the SJR DO TMDL implementation program.

Figure 1a shows how the regulatory framework (described in the first section) was the basis for the development of the accounting procedures (described in the second section). The basic conceptual model for the SJR DO TMDL implementation program is shown in the upper left portion of the diagram. Periods of low DO in the DWSC are generally considered to be the result of three factors: DWSC geometry, low flows, and high BOD loads from upstream river algae or treated wastewater effluent. The basic implementation measures are shown in the upper right portion of the diagram; these were identified in the Final Staff Report as wastewater BOD load reductions, operation of the City of Stockton RWCF nitrification facility, operation of the Aeration Facility, increased SJR flows, and reduced river algae BOD loads. The bottom of the diagram shows the TMDL accounting procedures that could be used to estimate the relative contributions of the factors causing low-DO concentrations in the DWSC, and evaluate the benefits (increased DO) from various implementation measures, including the operation of the Aeration Facility.

Should these suggested TMDL implementation accounting procedures be approved by the CVRWQCB and stakeholders, next steps will include development of a monitoring strategy and development of an operations strategy for the Aeration Facility. Recommendations for these two strategies conclude this appendix.

Review of the SJR DO TMDL Implementation Program

This first section of the appendix reviews the SJR DO TMDL implementation program, and identifies the regulatory basis for the TMDL accounting procedures. The framework proposed by CVRWQCB staff for the SJR DO TMDL implementation program was based on the concept of excess net oxygen demand (ENOD), which was defined in the 2005 Basin Plan Amendments and Final Staff Report as the excess oxygen demand measured at the location of minimum DO concentration in the DWSC. The basic idea was that load allocations (i.e., reductions) for oxygen demanding substances (BOD loads), necessary augmentation of SJR or DWSC flow, and required compensation for the effects of DWSC geometry (increased depth and travel time) on DO concentrations may only be needed when the minimum DO measured in the DWSC was below the DO objective (i.e., 5 mg/l from December–August and 6 mg/l in September–November).

These TMDL calculations of ENOD and the effects of flows, geometry, and BOD loads on DWSC DO were generally described in the Final Staff Report sections “Excess Net Oxygen Demand and Total Maximum Daily Load” (Section 4.4), “Waste Load and Load Allocations” (Section 4.5), and “Program of Implementation” (Section 4.6) (Central Valley Regional Water Quality Control Board 2005). The major concepts introduced in these sections of the Final Staff Report are reviewed and discussed below to provide the regulatory basis for developing possible TMDL accounting procedures. Some excerpts (inset) from the Final Staff Report (Central Valley Regional Water Quality Control Board 2005) are provided here with some review comments to introduce the purpose and need for the suggested SJR DO TMDL accounting procedures.

From 4.4 Excess Net Oxygen Demand and Total Maximum Daily Load

> “When dissolved oxygen concentrations in the DWSC are below Basin Plan objectives, the assimilative capacity of the water column for net oxygen demand has been exceeded. For the purpose of this TMDL, net oxygen demand is defined as the net rate by which all chemical, biological, and physical mechanisms in the water column either add or remove dissolved oxygen (pounds of oxygen demand per day). When the rate of oxygen removed from the water column is greater than the rate by which it is added, there is a decrease in the dissolved oxygen concentration. The net rate of oxygen demand over and above the loading or assimilative capacity, at the point of lowest DO concentration in the DWSC, is referred to as the ENOD.”
>
> “This TMDL and associated control program allocates responsibility for reduction of ENOD such that the Basin Plan DO objectives are attained in the DWSC. This TMDL assigns 100% of the responsibility for reducing ENOD to those parties collectively responsible for each of the three contributing factors: 1) sources of oxygen demanding substances; 2) DWSC geometry; and 3) reduced DWSC flow.” (Page 35 of Final Staff Report)

This paragraph introduces the basic concept that the parties (i.e., stakeholders) are collectively responsible for reducing the ENOD (i.e., DO deficit) and that the TMDL will be implemented with an adaptive control program that requires some changes or management actions to reduce or eliminate the ENOD to meet the DWSC DO objective at all times.

From 4.4.1 Loading Capacity

"DO concentrations in the DWSC are affected by the relative rate of chemical and physical mechanisms that remove oxygen from the water column (oxygen demand) versus those that add oxygen (re-aeration). At any particular point in the river, when the rate of all oxygen demanding mechanisms are greater than the rate of all the re-aeration mechanisms, DO concentrations decrease (and visa versa). Net oxygen demand will be expressed as pounds of oxygen per day."

"The loading capacity (LC) of the DWSC is the amount of net oxygen demand that can be present at any point in the DWSC such that Basin Plan DO objectives are not violated. This does not include consideration of a margin of safety or other factors that reduce loading capacity. In equation form LC is given by:

$LC = \{DO_{sat} - DO_{obj}\} \times Q_{DWSC} \times 5.4$ (Eq 4-1)

"where DO_{sat} is the saturation DO concentration, which is itself a function of water temperature, in milligrams per liter; DO_{obj} is the applicable Basin Plan DO objective in milligrams per liter; Q_{DWSC} is the net daily flow rate through the DWSC4 in cubic feet per second; and 5.4 is a unit conversion factor that provides LC, in terms of pounds of oxygen per day. It can be seen from the above equation that LC is a function of flow through the DWSC and temperature (to the extent that temperature affects DO_{sat})." (Page 36 of Final Staff Report)

The ideas that there is a natural oxygen balance and that some oxygen demanding load (i.e., BOD) can be assimilated by the natural reaeration of the river or DWSC (without violating the DO objective) are introduced in this section. Equation 4-1 provides an estimate of the amount of DO that is missing from the DWSC at the point of minimum DO concentration, which is caused by the balance between the daily BOD decay and the daily reaeration. Because the natural reaeration within the DWSC increases as DO concentration decreases, estimates of the inflowing oxygen demands (i.e., BOD) and the rate of BOD decay are needed to calculate the maximum daily assimilative capacity (pounds of BOD) for the DWSC. The maximum loading capacity for the DWSC would occur when the measured DO concentration was reduced to the DO objective. An oxygen balance (i.e., sources and sinks) calculation for the DWSC is needed to estimate the maximum BOD load capacity of the DWSC. Possible calculations of the DWSC DO-BOD balance are introduced later in this appendix.

From 4.4.2 Excess Net Oxygen Demand

"In equation form, the general concept of ENOD is represented by the following:

$ENOD = \{DO_{obj} – DO_{meas}\} \times Q_{DWSC} \times 5.4$ (Eq 4-2)

where DO_{obj} is the applicable Basin Plan DO objective in milligrams per liter; DO_{meas} is the measured DO concentration, in milligrams per liter; Q_{DWSC} is the net daily flow rate through the DWSC in cubic feet per second; and 5.4 is a unit conversion factor that provides ENOD in terms of pounds of oxygen per day." (Page 38 of Final Staff Report)

The basic idea introduced with the ENOD calculation is that SJR DO TMDL implementation measures will only be required when the minimum DO in the DWSC is below the DO objective. The ENOD calculation is an approximate estimate of the amount of oxygen that would need to be added each day (from the Aeration Facility) to increase the minimum DWSC DO to the DO objective. The daily excess net oxygen demand is not equivalent to the BOD load reduction (lb/day) that may eliminate the DO impairment. The minimum DO in the DWSC is the result of the cumulative decay of BOD (about 10% per day), balanced with the cumulative surface reaeration that increases with the DO saturation deficit. The results from the DWSC DO Model, as described in Appendix A of the 2008 Operations Report (ICF International 2010b), indicate that a reduction of about 4 mg/l of BOD will increase the minimum DO in the DWSC by about 1 mg/l.

From 4.4.4 Total Maximum Daily Load

> "When excess net oxygen demand exists, it is the combined effect of all load and non-load related contributing factors present at that time. Although they do not represent a discharge of an oxygen-demanding substance or precursor, the effect of the DWSC geometry and reduced flow through the DWSC magnifies the impact of waste loads and loads of oxygen demanding substances by reducing the loading capacity and hence increasing excess net oxygen demand." (Page 39 of Final Staff Report)

This paragraph introduces the general idea that oxygen-demanding loads (i.e., BOD) and other factors (e.g., flows and geometry) will be included in the TMDL control (implementation) program. But the methods for relating flow and geometry to the measured ENOD were not presented. Possible procedures for accounting for the effects of these flow and geometry factors on DWSC DO concentrations are introduced and described later in this appendix.

From 4.5.1 Apportioning Excess Net Oxygen Demand

> "The two contributing factors of DWSC geometry and reduced flows through the DWSC are not loads of a substance for which mass or concentration limits can be assigned. Instead, these factors reduce the oxygen demand loading capacity of the DWSC available to assimilate loads of oxygen demanding substances, thereby increasing excess net oxygen demand. To eliminate the DO impairment, a combination of source controls to reduce the oxygen demand from upstream loads, combined with measures to restore the loading capacity impacted by the two non-load related factors, must be implemented such that excess net oxygen demand is eliminated."
>
> "Those parties collectively responsible for each contributing factor will need to coordinate with those responsible for the other factors to implement control measures that eliminate excess net oxygen demand (plus the margin of safety). This TMDL does not specify the relative responsibility among these three factors. Entities responsible for each of the three main contributing factors will need to determine among themselves the relative responsibility that will be assumed by each contributing factor."
>
> "Credit for source controls or alternate measures implemented after 12 July 2004 will count towards satisfying the excess net oxygen demand either apportioned to the associated contributing factor or allocated to specific sources of oxygen demanding substances and their precursors. This will require the ability to establish a baseline to quantify the amount of impairment reduction achieved by the various source controls and/or alternate measures to ensure equitable participation from all responsible entities." (Pages 40-41 of Final Staff Report)

These paragraphs emphasize the shared responsibility among stakeholders to implement control measures that will eliminate the ENOD, and that the allocation of responsibility should be determined by the stakeholders themselves. The possibility of credits for reducing ENOD through source controls or alternative measures (e.g., aeration facilities) is introduced. The need to establish a baseline for tracking and accounting for multiple control measures is also introduced. Suggested accounting procedures for determining responsibility for ENOD and credits for source controls and other measures are described in this appendix. The suggested accounting procedures would use the historical conditions as the baseline, and would include methods for adjusting the observed flows, BOD loads, and aeration operations to estimate the effects of each factor on the observed DWSC DO conditions.

From 4.5.2 Waste Load and Load Allocations to Point and Non-Point Sources

> "A number of studies have generated data to evaluate the impact of City of Stockton RWCF effluent, loads of algae, and other sources on the DO impairment in the DWSC. Based on the relative contribution of BOD_u loads calculated from historical data discussed above, 30 percent of the responsibility for excess net oxygen demand apportioned to loads of oxygen demanding substances is allocated as a waste load, WLA_{RWCF}, to the RWCF. Based on best professional judgment, 10 percent of the responsibility for reducing excess net oxygen demand is allocated as a reserve [unassigned] to address unknown sources and impacts, and known or new sources that have an insignificant impact. This includes unknown impacts from waste load allocations to existing NPDES permitted discharges other than the Stockton RWCF. The remaining 60 percent of ENOD is allocated as a load allocation, LA_{NPS}, to non-point sources of algae and/or precursors in the watershed."
>
> "The complexities of determining the relative contributions to oxygen demand in the DWSC are numerous. Most important is an understanding of the mechanisms by which the various carbonaceous and nitrogenous compounds are oxidized in the DWSC and how these mechanisms are affected by variables such as flow, temperature, and environmental factors. More data and analysis are needed to understand the dynamics of these different mechanisms. Modeling is also needed to evaluate the net effect of these mechanisms on DO concentrations. The specific data needs and the studies that must be performed to provide this data are discussed in Section 4.6."
>
> "The allocations between the various point and non-point sources may be modified in a revision to this TMDL based on the findings of future studies regarding the relative impact of these sources on oxygen demand in the DWSC." (Pages 41-42 of Final Staff Report)

These paragraphs describe the initial allocations of responsibility for reducing the BOD loads that contribute to any observed ENOD conditions (DO deficit). The possibility that additional information about the load and non-load factors would be useful and that the TMDL load allocation might be revised based on new information is introduced. Possible procedures for estimating the relative contributions to the DWSC DO concentrations and the corresponding responsibility for operating the Aeration Facility to reduce or eliminate the low DO conditions are developed and described later in this appendix.

From 4.6.1 Phased Implementation Approach

> "Although there is adequate scientific understanding to support a general allocation of responsibility for excess net oxygen demand described in Section 4.5, there is inadequate understanding at this time to support more detailed waste load or load allocations to specific sources of oxygen demanding substances and their precursors. Various agricultural drainage and irrigation districts are currently in the process of establishing a contract for the bulk of the field studies with the California Bay-Delta Authority (CBDA). The [CBDA sponsored] modeling studies in the DWSC are recently underway. This program of implementation also describes the actions being taken by various agencies responsible for DWSC geometry and reduced flow through the DWSC to study and then implement measures to reduce their associated impacts on excess net oxygen demand conditions in the DWSC."
>
> <u>Source Control and Implementation Studies</u>
>
> "As the sources of oxygen demanding substances and their linkages to the DO impairment are better understood, those sources linked to the DO impairment will be required to implement measures to reduce or eliminate their contribution to the impairment. Some of these proposed measures may directly control the source, and others may provide alternate means of reducing the impact to less than that apportioned in the TMDL."
>
> <u>Study of Alternative Implementation Measures for Non-Load Related Factors</u>
>
> "The aeration feasibility and demonstration project is a two-phased project that starts with a small-scale feasibility study of different aeration technologies that may be effective in the DWSC. This first phase will also include the design of a monitoring network to measure the impact of aeration on DO concentrations in the DWSC. Once the preferred technologies are identified by the feasibility study, the next phase of the project will be the construction and operation of a large-scale demonstration project using the aeration technologies determined most effective in the DWSC. The purpose of this large-scale project is twofold. First, the purpose is to collect performance and cost data for consideration in development of the final phase of the program of implementation. The second purpose is to begin improving DO conditions prior to development and implementation of the final phase."
>
> "As currently planned by the California Bay-Delta Authority, construction of the aeration demonstration project will be financed by Proposition 13 funds. A group of various agencies in the watershed are currently negotiating an assurance agreement to provide the resources needed to operate, maintain, and monitor the performance of the aerators after construction." (Pages 44-47 of Final Staff Report)

These paragraphs provide the most direct connection between the Aeration Facility studies and the SJR DO TMDL implementation (control) program. However, the methods for determining responsibility for the ENOD conditions or assigning credits for the Aeration Facility operations were not specified. The various funded studies of the DWSC and DWSC upstream river water quality were anticipated to provide additional information that would be used to finalize the TMDL control program. How much of the ENOD conditions could be reduced or eliminated by the Aeration Facility was not known. Likewise, the effects of the RWCF nitrification facility on DWSC DO concentrations could not be accurately anticipated without further studies. The possible TMDL accounting procedures described in this appendix could be used to estimate the effects of these control measures on the DWSC DO conditions (i.e., TMDL credits).

From 4.6.2 Actions Addressing Point Sources

> "As described in Section 4.5, the City of Stockton RWCF will receive a waste load allocation equivalent to 30 percent of the excess net oxygen demand apportioned to loads of oxygen demanding substances. The magnitude of this 30 percent allocation is variable depending upon the excess net oxygen demand conditions in the DWSC. This allocation is for excess net oxygen demand, at the point of lowest DO concentration in the DWSC, expressed in units of pounds of oxygen per day."
>
> "This waste load allocation of oxygen demand in the DWSC, however, must be converted and expressed in terms of effluent concentration or mass load limits for constituents in the RWCF discharge. This will require understanding the linkage between a given quantity of a oxygen-demanding constituent in the RWCF and the corresponding impact on DO concentration in the DWSC. Further field and modeling studies are required to understand the specific mechanisms in the DWSC that convert RWCF constituents into oxygen demand and how they are impacted by numerous environmental variables. Of particular interest is how reduced flow through the DWSC influences the amount of oxygen demand that is exerted from the City of Stockton ammonia loads in the DWSC." (Page 48 of Final Staff Report)

This paragraph describes the need to understand how flow may reduce (i.e., dilute) the effects from RWCF ammonia oxidation and BOD decay on the DWSC minimum DO concentrations. This section implies that the planned RWCF nitrification facility may have a major effect on the ENOD conditions. Because operation of the nitrification facility began in 2007, and testing and evaluation of the Aeration Facility began in 2008, the effects from these two major TMDL control measures should be separately and accurately evaluated.

From 4.6.3 Actions Addressing Non-Point Sources

> "As described in Section 4.5, sixty percent of the responsibility for ENOD is apportioned to nonpoint sources of algae and its precursors. Consistent with the Conditional Waivers for Discharges from Irrigated Lands (Resolution No. R5-2003-0105), and for the purpose of this control program, non-point source discharges are discharges from irrigated lands. Irrigated lands are lands where water is applied for producing crops and, for the purpose of this control program, includes, but is not limited to, land planted to row, field, and tree crops, as well as commercial nurseries, nursery stock production, managed wetlands and rice production."
>
> "Many mechanisms are known or are suspected of influencing the growth, transport, and decay of algae in the DWSC. Of particular interest are the growth dynamics of algae as it is conveyed downstream through the watershed. Better understanding of these dynamics is needed to determine how specific sources of algae, and specific sources of nutrients that contribute to algal growth, are linked to DO concentrations in the DWSC." (Page 51 of Final Staff Report)

This paragraph indicates that results of the (planned) upstream river water quality studies would be used to determine the effects of agricultural drainage on upstream algae growth and subsequent BOD loads entering the DWSC. The results from the upstream studies conducted from 2005 to 2007 are now available and have been incorporated into the accounting procedures for upstream river algae concentrations that are described in this appendix.

From 4.6.4 Actions Addressing Deep Water Ship Channel Geometry

> “The DWSC geometry reduces the efficiency of mechanisms that supply oxygen to the water column, like natural surface re-aeration and algal photosynthesis. At the same time, the DWSC geometry magnifies the impact of oxygen demanding substances (e.g., ammonia) that reduce DO concentrations in the water column. The net effect is that the DWSC reduces the loading capacity, and hence worsens excess net oxygen demand conditions in the DWSC for a given load of oxygen demanding substances.”
>
> “The USACOE is the primary entity responsible for the existing and any future deepening in the DWSC. The Port of Stockton is the entity responsible for any future berth deepening at its facilities along the DWSC.”
>
> “Because DWSC geometry does not discharge any substances, however, no waste load or load allocations can be assigned to entities responsible for the DWSC geometry. Instead, the CVRWQCB will rely upon its authority under Section 401 of the CWA to require that the cumulative effects on excess net oxygen demand conditions caused by future changes in DWSC geometry are adequately mitigated.”
>
> “The USACOE has already attempted to provide some level of mitigation for past DWSC geometry alterations. Between 1984 and 1987, the DWSC was deepened from 30 feet below MLLW to 35 feet below MLLW. As part of their National Environmental Policy Act (NEPA) documentation for that project, the USACOE performed modeling that estimated the deepening could reduce loading (assimilative) capacity by as much as 2,500 pounds of oxygen per day (USACOE 1990). To mitigate this impact, the USACOE constructed and now operates [with the Port of Stockton] a jet aeration system in the DWSC near where the San Joaquin River enters the DWSC at Channel Point.” (Page 52 of Final Staff Report)

These paragraphs introduce the concept of allowing mechanical aeration facilities to compensate for the existing and future effects of the DWSC geometry on the low DO observed at the Rough and Ready Island (RRI) monitoring station. The effects of aeration facilities are included in the proposed TMDL accounting procedures.

From 4.6.5 Actions Addressing Reduced Flow through the Deep Water Ship Channel

> “The impact of reduced flow on excess net oxygen demand conditions in the DWSC has been well documented under current DWSC geometry and variable loading conditions. As flow into the DWSC at a given DO concentration is reduced, less oxygen demand can be exerted before DO concentrations drop below the Basin Plan objectives. It has also been hypothesized that increased DWSC residence times increases how much of the oxygen demand from upstream loads of oxygen demanding substances is exerted in the DWSC. Although relationships between reduced flow through the DWSC and the DO impairment are fairly well understood, further field analysis and modeling studies are required to better understand the specific oxidation

> mechanisms, and how they are affected by flow, both within the DWSC and upstream." (Page 53 of Final Staff Report)

This paragraph mentions but does not provide specific details about the impacts of reduced flow on DO concentrations in the DWSC. The suggested TMDL accounting procedures include the effects of river flow on the upstream algae loading and the effects of the DWSC flow on dilution of the RWCF discharges and residence time in the DWSC. The proposed accounting procedures would enable an accurate evaluation of the effects of increased flow on the minimum DO concentrations in the DWSC.

From 4.6.6 Consideration of Alternative Implementation Measures

> "Alternate implementation measures may be needed as a substitute for direct control of certain causative factors if on-going studies show that certain causative factors cannot be successfully mitigated by direct controls. It may also be necessary to rely on short-term alternate implementation measures as longer-term control measures take more time to implement and become effective. The CVRWQCB will need to consider if alternate implementation measures that are proposed by those responsible for certain contributing factors are acceptable. In order to be acceptable, any alternative implementation measures proposed for consideration by the CVRWQCB must adequately address the impact on the DO impairment and must not degrade water quality in any other way. If alternate implementation measures are selected to address certain impacts, load allocations in a revision to this TMDL will need to be converted and expressed in terms of these alternate implementation measures or their impact on excess net oxygen demand conditions in the DWSC."
>
> "After a better understanding of the sources and linkages is obtained by the additional studies described in Section 4.6.1, the CVRWQCB may also consider allowing a portion of waste load and load allocation to be met through a load-trading program. The details of such a program would need to be developed as part of a revision to this TMDL that establishes more detailed waste load and load allocations." (Page 55-56 of Final Staff Report)

This paragraph introduces the concept of using alternative control measures (e.g., Aeration Facility) to reduce or eliminate low DO conditions in the DWSC. It mentions the possibility that upstream dischargers of BOD loads might purchase shares in the Aeration Facility operation to reduce or eliminate the low DO conditions in the DWSC. The technical guidelines for identifying the daily responsibilities for low DO conditions and estimating credits that might be assigned to the Aeration Facility, the nitrification facility, or to increased flows are not provided. Possible accounting procedures for estimating responsibilities for low DO conditions and determining credits for the nitrification facility or flow management actions are described in this appendix.

Suggested SJR DO TMDL Implementation Accounting Procedures

This second section of the appendix introduces the calculations that could be used to estimate the daily contributions from the various factors causing low DO concentrations in the DWSC. Based on the description of the SJR DO TMDL implementation program in the Final Staff Report, a possible accounting procedure has been developed for review by the CVRWQCB staff and stakeholders that could provide a method for tracking the implementation of the SJR DO TMDL control measures. This possible accounting procedure is based on daily estimates of the major factors causing periods of low DO within the DWSC, including the effects of geometry on reaeration and algae growth, the effects of tidal flow on transport and mixing, and the effects of flow on upstream river algae loads, the dilution of the Stockton RWCF effluent, and the travel time within the DWSC (to Turner Cut). The results from more detailed modeling of the SJR water quality (e.g., algae) conditions, the tidal dilution and transport of the RWCF effluent, and the DWSC stratification and tidal mixing are included in the proposed accounting procedures. The accounting procedures are formulated in a spreadsheet that allows measured data from a specified calendar year to be selected for the TMDL accounting and evaluation of contributing factors and BOD loads. Graphics of river flows, travel times, algae concentrations, effluent concentrations, and the resulting DWSC DO concentrations are presented within this spreadsheet. Changes in historical conditions (e.g., higher flows, reduced BOD) can be specified in the accounting tool to determine the effects of flows, river algae, RWCF effluent concentrations, and the Aeration Facility on the resulting minimum DO concentrations in the DWSC.

A series of simplified relationships between the SJR flow and water quality conditions, the DWSC inflow, and the RWCF discharge concentrations and the resulting DO profile in the DWSC are calculated. Because the basic elements of the most important relationships between SJR and DWSC flow and water quality parameters (e.g., algae, BOD, DO, ammonia, temperature) are included, it can be considered a quantitative-descriptive model for the SJR DO TMDL. Because various implementation measures are included in the calculations, the incremental effects of each factor can be identified by running several comparative calculations with the daily accounting tool. The daily accounting calculations can be used to track the effects of daily changes in river conditions and BOD loads, as well as the improvements (i.e., credits) from control measures (e.g., nitrification, aeration) on the DWSC DO concentrations.

Organization of Accounting Procedures

Figure 1b shows a flowchart depicting the framework for the TMDL daily accounting tool. There are three major accounting segments: the upstream SJR tributaries, the tidal transport from Mossdale past the head of Old River (diversion) to the Stockton RWCF discharge and into the DWSC, and the tidal downstream movement and longitudinal DO profile in the DWSC.

The first segment of the accounting tool includes the upstream SJR tributaries and calculates the corresponding river algae concentration (biomass or BOD) at Mossdale. This segment calculates the river conditions at Mossdale, based on upstream flows and other conditions. The measured flow (at Vernalis), temperature, turbidity, DO concentration, and estimated algae concentration (biomass or

BOD) are the variables that will be used for estimating downstream effects on DWSC DO concentrations. Salt (electrical conductivity [EC]) concentrations can be used to help calibrate the flow (water budget). The SJR selenium TMDL implementation measures that will reduce the future San Luis Drain discharge of salt and algae biomass into Mud Slough are included in this upstream segment. Stanislaus River releases from New Melones Reservoir to provide higher flows necessary to meet the salinity objective are included in the upstream segment. Chlorophyll fluorescence and diurnal DO fluctuations at the Mossdale water quality monitoring station are used to estimate the river concentrations of algae biomass.

The second segment of the daily accounting tool is the downstream tidal movement and associated changes in river conditions between Mossdale and the DWSC (e.g., settling of turbidity, algae growth, zooplankton grazing, reaeration and BOD decay). This segment includes the diversion of water from the SJR into Old River and the effects of Central Valley Project (CVP) and State Water Project (SWP) export pumping and the south Delta temporary barriers (i.e., weirs) on this diversion flow, as well as the effects of the head of Old River barrier (or gate) as an implementation measure to increase the downstream flow in the DWSC. This segment also includes the tidal dilution of the Stockton RWCF discharge. The nitrification facility that was added by the City of Stockton to its tertiary treatment facility in 2007 is a major implementation measure that is located within this segment of the TMDL accounting tool.

The third segment of the daily accounting tool is the longitudinal DO profile conditions in the DWSC. Because the tidal movement in the DWSC is about 2 miles between high tide (6 feet) and low tide (2 feet), the DO profile conditions in the DWSC between the SJR inflow at channel point (Mile 39.5) and Turner Cut (Mile 32.5) are estimated for both low-tide and high-tide conditions. The effects of the DWSC geometry on temperature stratification, algae growth and settling, and reaeration are included in the calculations for the DWSC. These effects can be adjusted with user-specified parameters. The major implementation measures that are included in the DWSC segment of the accounting tool are the Port of Stockton / United States Army Corps of Engineers (USACE) aeration facilities (Dock 13) and the Aeration Facility (Dock 20).

The development of this simplified TMDL accounting tool was only possible because of the many water quality measurements that are routinely obtained by DWR, USGS, and other agencies, as well as the research and modeling efforts funded by CALFED within the DWSC and upstream in the SRJ above Vernalis. This daily flow and water quality accounting tool is an extension of the SJR water quality Data Atlas effort that was part of the DWSC Modeling and Upstream Studies, funded by CALFED and DFG-ERP. These previous measurements and modeling efforts are summarized and simplified in the daily accounting calculations.

Because there is variability in the observed conditions, there will always be a range of possible effects from upstream conditions and implementation measures on the observed or expected DO conditions in the DWSC. The range of possible changes in the DWSC DO concentrations in response to upstream conditions or implementation measures can be explored by changing some of the uncertain parameters in the daily accounting tool. The effects of this uncertainty can be identified by comparing the measured DO profiles within the DWSC to the accounting tool calculations for various upstream conditions. The accounting tool provides a unified procedure for considering all of the changing river conditions and potential implementation measures. The daily accounting tool can be used to identify likely responsibilities for observed low DO conditions in the DWSC (i.e., ENOD) and to estimate TMDL credits for implementation measures through time. Several example calculations for recent years (2001–2010) are shown to demonstrate the capabilities and limitations of the daily accounting tool.

Segment 1—Estimating River Algae Concentrations at Mossdale

The first segment of the daily accounting tool uses water quality measurements at Vernalis or Mossdale to estimate the river algae pigment and algae biomass concentrations at Mossdale. The daily calculations of upstream river conditions were derived from results of the UC Davis nutrients and algae studies, the DFG-ERP Upstream Studies for the SJR DO TMDL, and results from the TMDL watershed model (SJR-WARMF) that was developed as part of these upstream studies (Systech 2008). The goal is to estimate the seasonal pattern of algae biomass, which is assumed to depend on the seasonal light and temperature patterns as well as the SJR flow (i.e., travel time for algae growth).

The major implementation measures in this segment are the reductions in the San Luis Drain discharge (flow, salinity, nutrients, and algae biomass) to Mud Slough that are the result of the SJR-selenium TMDL, and the possible additional releases from New Melones Reservoir to reduce salinity to meet the Vernalis EC objective. Both of these measures will change the river flows and may change the Mossdale algae concentrations.

Available Data

DWR maintains a continuous water quality monitoring station at Mossdale. This station has recorded hourly (or 15-minute) measurements of temperature, EC, pH, and DO and has more recently begun measuring turbidity and algal fluorescence. This provides an extensive historical database for evaluating the SJR water quality as it enters the tidal zone (SJR estuary). DWR also collected water samples on a monthly basis at Mossdale until about 1997 to measure nutrients and algae pigment (chlorophyll and phaeophytin). DWR continues to collect monthly water quality samples at Vernalis, which can be used to compare with the Mossdale monitoring records of DO, pH, and algal fluorescence. UC Davis collected semi-monthly (two per month) water quality and algae samples at Vernalis and Mossdale from 2000 to 2005 as part of a regional nutrients and algal productivity study. Some 10-day BOD measurements were collected in 2004 to coordinate with the TMDL studies at Mossdale, Vernalis, and Maze (SJR upstream of the Stanislaus).

Bi-weekly water quality samples were collected in the summers of 2000 and 2001 at Vernalis and Mossdale (and other upstream stations) for special studies (funded by CALFED) for the SJR- DO TMDL investigations (Kratzer et al 2004). Measurements of chlorophyll, nutrients, 5-day and 10-day biochemical oxygen demand (BOD5 and BOD10) were made during the summer of 2001 by DWR as part of the DWSC studies for the SJR DO TMDL (Lehman 2004). This assortment of nutrients, volatile suspended solids (VSS), algal pigment (chlorophyll and phaeophytin), and BOD, together with the monitoring of algal fluorescence, DO, and pH were used to develop relationships for estimating the daily algae biomass at Mossdale.

Algae Biomass (BOD) Calculation Methods

Measurements of water quality at Mossdale provide the most direct method for estimating the algae biomass and BOD concentration in the SJR as it flows into the tidal river zone between Mossdale and the DWSC. Relationships between monitoring records of DO, pH, and algal pigment fluorescence will be used to estimate the daily algae biomass and resulting BOD at Mossdale. The calculation method will use the 15-minute measurements of DO, pH, and algal fluorescence at Mossdale to estimate the daily algae biomass and total BOD concentration in the river. This method is briefly described below.

The seasonal pattern Mossdale daily DO range (maximum DO – minimum DO) has been found to correlate fairly well with the seasonal pattern of Mossdale algal fluorescence and the UCD extracted algal pigment (chlorophyll a plus phaeophytin). The approximate match indicates that each 1 mg/l of daily DO range is equivalent to about 25 µg/lµg/l of extracted pigment (or algal pigment fluorescence). Although high DO concentrations will decrease from surface reaeration, the relationship between the daily DO range and algae biomass appears to be linear. The available Mossdale DO and algal fluorescence data for 2000–2010 are shown here to demonstrate the method and show the seasonal correlation between these two monitoring variables and the more limited extracted chlorophyll data.

A similar match between the seasonal pH pattern and the daily DO range has consistently matched the algal fluorescence and extracted pigment concentrations. The diurnal DO range is produced by the photosynthesis of the river algae that releases about the same amount of oxygen as the increased algal biomass. The maximum observed daily DO range is about 5 mg/l in low-flow summers. A similar reduction in the dissolved CO_2 in the water is required during photosynthesis. But because the alkalinity of the river moderates the carbonate equilibrium, the ph increases as the CO_2 is taken up for algae biomass. The daily DO range appears to be linear with algal biomass or chlorophyll, while the pH increases above 7.5 (no algae), indicating a doubling of the algae concentration for each 0.5 increment of pH value above 7.5. Although the low CO_2 concentrations (high pH) will increase from reaeration with the atmosphere, the historical data indicates that the maximum pH can be used to estimate the algae biomass at Mossdale. The approximate correlation that was found to match the historical pH, daily DO range and algal fluorescence (pigment) data at Mossdale is given in Table A-1.

Table A-1. Approximate Relationship between Mossdale pH and Mossdale Algae Pigment Concentration (µg/l)

Mossdale Maximum Daily pH	Approximate Daily DO Range (mg/l)	Approximate Algae Pigment Concentration (µg/l)
7.5	0	0
8.0	1	25
8.5	2	50
9.0	4	100
9.5	8	200

Review of Measured Algae Pigment and Daily DO Range at Mossdale

The calculation methods for estimating SJR algae biomass and BOD are demonstrated in this section by showing the available measurements of daily DO range, daily pH, and algae pigment concentrations (µg/l) for 2000–2010. The seasonal patterns, the effect of low SJR flows, and the general correspondence between these alternative measures of algae biomass are demonstrated with the following annual graphs of Mossdale water quality data.

Figure 2a shows the daily minimum and maximum DO at Mossdale for 2000, with the saturated DO concentration shown for comparison (left scale of 0–20 mg/l). The daily minimum DO is usually equal to the saturated DO, but the daily maximum DO is often higher than saturated DO during the summer months of June–September because of algal photosynthesis. The daily DO range (maximum DO –minimum DO) is shown at the bottom of the graph. The daily SJR flows at Vernalis are shown to indicate the period of time when flows are relatively low, which corresponds to periods when there would be several days for algae growth upstream of Vernalis (right scale of 0–5,000 cfs). The effects of algae photosynthesis on the daily DO range at Mossdale appears to be greatest when the Vernalis flows are less than about 3,000 cfs during the spring and summer months. The maximum daily DO range was about 4 mg/l in July and August when the Vernalis flows were about 2,000 cfs.

Figure 2b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment (chlorophyll and phaeophytin) concentrations for 2000. The fluorescence measurements generally must be adjusted with a calibration factor to match the extracted algae pigment concentrations. The daily DO range is shown for comparison with the algal fluorescence and the extracted algal pigment concentration data. The graph scales were set to demonstrate that each 1 mg/l of daily DO range corresponds to about 25 µg/l of algal pigment (or calibrated fluorescence). The empirical estimate of algae pigment based on the maximum pH at Mossdale (Table A-1) is also shown. The maximum pH of about 9.0 measured in July and August would correspond to an estimated algae pigment concentration of about 100 µg/l. The highest algae pigment concentrations of about 50–75 µg/l in July correspond to the highest measured fluorescence, highest daily DO ranges, and highest pH values. The seasonal pattern was similar for each of these estimates of algae biomass, with increasing concentration in late June (as flows decreased to less than 3,000 cfs), highest concentrations in July, and declining concentrations in August and September.

Figure 3a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2001. The SJR flows were considerably lower than in 2000, with flows of about 1,500 cfs from mid-June through mid-October. The daily DO range was a maximum of 6 mg/l in mid-June and was about 4 mg/l in July, but was only about 2 mg/l in August and September. Figure 3b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2001. The highest extracted algae pigment concentrations were about 75 µg/l in June and July. The daily DO range and the estimate of algae pigment based on daily pH values are also shown. The maximum estimates of algae pigment were about 100–125 µg/l in June and July, with declining concentrations in August and September. The seasonal pattern was similar for each of these estimates of algae biomass , with increasing concentration in late May (as flows decreased to less than 3,000 cfs), highest concentrations in June and July, with declining concentrations in August and September.

Figure 4a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2002. The SJR flows were similar to 2001 flows, with flows of less than 1,500 cfs from early-June through mid-October. Minimum flows of about 1,000 cfs were measured in August and early September. The daily DO range was about 5 mg/l in June; about 4 mg/l in July, August, and early September; and about 2 mg/l in October. Figure 4b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2002. The highest extracted algae pigment concentrations were about 150 µg/l in July and August. This was twice the maximum algae pigment measured in 2000 or 2001. The measured fluorescence values fluctuated between 75 µg/l and 150 µg/l in the months of June–September 2002. The daily DO range and the estimate of algae pigment based on daily pH values for 2002 matched the measured fluorescence pattern. The maximum estimates of algae pigment were about 75–125 µg/l in June–September, with declining concentrations in October. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l for the entire June–September period.

Figure 5a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2003, with the SJR flows at Vernalis shown for reference. The SJR flows were about 2,000 cfs in June and about 1,500 cfs in July, August, and September. The daily DO range was about 4 mg/l in June to early August, and was a maximum of about 5 mg/l in mid-August, with decreasing values in September and October. Figure 5b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2003. The fluorescence device was changed in April 2003 from a Turner Model 10 to a Turner SCUFA unit, with a different calibration factor. The highest extracted algae pigment concentrations were about 100–125 µg/l in June–August, with one very high measurement of 225 µg/l in mid-August. The fluorescence also peaked at 200–250 µg/l in mid-August 2003, with corresponding high measurements of pH and daily DO ranges at Mossdale. The estimates of algae pigment based on the daily DO range and daily pH values matched the measured fluorescence pattern for 2003. The maximum estimates of algae pigment were about 50–100 µg/l in June–August, with the peak of 125 µg/l in mid-August and declining concentrations in September. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l for the entire June–September period.

Figure 6a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2004, with the SJR flows at Vernalis shown for reference. The SJR flows were similar to 2001 flows, with flows of less than 1,500 cfs from early-June through mid-October. Minimum flows of about 1,000 cfs were measured in July, August, and September 2004. The daily DO range was about 6 mg/l in early June, was about 4 mg/l from mid-June to mid-August, and was 2–4 mg/l from mid-August through September. Figure 6b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2004. The highest extracted algae pigment concentrations were about 125–175 µg/l in June and early July. The measured fluorescence values fluctuated between 75 µg/l and 150 µg/l in June and July and were less than 75 µg/l in August (data is missing for September). The estimates of algae pigment based on daily DO range and daily pH values for 2004 matched the measured fluorescence pattern. The maximum estimates of algae pigment were about 75–125 µg/l in June and July, but were decreasing in August and were about 50 µg/l in September. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l from late May through September.

Figure 7a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2005, with the SJR flows at Vernalis shown for reference. The SJR flows were very high until mid-July of 2005. The SJR flows were about 2,500 cfs in August, September, and October of 2005. Because of the high flows, the daily DO range was greater than 2 mg/l only from mid-July to mid-September of 2005. Figure 7b shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2005. The highest extracted algae pigment concentrations were only about 50 µg/l in July and August. The measured fluorescence values fluctuated between 25 µg/l and 50 µg/l in July and August. The estimates of algae pigment based on daily DO range and daily pH (missing pH in July) matched the measured fluorescence pattern for 2005. The maximum estimates of algae pigment were about 50–75 µg/l in July and August. The seasonal pattern was similar for each of these estimates of algae biomass, with algae pigment concentrations greater than 50 µg/l only in July and August 2005.

Figure 8a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2006, with the SJR flows at Vernalis shown for reference. The SJR flows were very high the entire year. The SJR flows were less than 4,000 cfs only in August and September. Because of the high flows, the daily DO range was a maximum of 2 mg/l only in late July. Figure 8b [data not yet available] shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment (chlorophyll and phaeophytin) concentrations for 2006. The high flows prevented any substantial algae biomass concentrations at Mossdale in 2006.

Figure 9a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2007, with the SJR flows at Vernalis shown for reference. The SJR flows were less than 3,000 cfs for the entire year. The SJR flows were less than 1,500 cfs from mid-June to mid October. The SJR flows were about 1,000 cfs in July, August, and September 2007. The daily DO range was greater than 2 mg/l from June through mid-September, with maximum values of 4–6 mg/l from mid-June to mid-August. Figure 9b [data not yet available] shows the daily minimum and maximum algal fluorescence at Mossdale, along with extracted algae pigment concentrations for 2007. The maximum algae pigment concentrations were likely about 100 µg/l, based on the daily DO range values in July and August.

Figure 10a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale with the SJR flows at Vernalis shown for reference for 2008. The SJR flows averaged about 2,500 cfs in January–April, with a Vernalis Adaptive Management Program (VAMP) pulse flow of 3,000 cfs from April 20–May 20, and then were less than 1,000 cfs from mid-June through September. The daily DO range was between 4 mg/l and 6 mg/l in June, July, and August (September DO data is missing), corresponding to the low flow period in 2008. Figure 10b shows the daily minimum and maximum algal fluorescence at Mossdale for 2008, along with extracted algae pigment concentrations from Vernalis (DWR data). The highest monthly algae pigment concentration was more than 250 µg/l in early June. The July pigment concentration was about 100 µg/l, and the August, September, and October pigment concentrations were about 50 µg/l. The measured fluorescence values were highest in early June, with values of 100–150 µg/l in June, 75–100 µg/l in July, and about 50 µg/l in August. The estimates of algae pigment based on daily DO range and daily pH (September DO and pH data is missing) were about 100–150 µg/l in June and July and about 75–

125 μg/l in August. These estimates from DO and pH measurements were higher than the pigment concentrations and fluorescence values in July and August.

Figure 11a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2009, with the SJR flows at Vernalis shown for reference. The SJR flows were very low all year, with flows of about 1,000 cfs in June and just 500 cfs from mid-July to mid-September. The daily DO range showed an unusual high value of 4 mg/l in mid-March to mid-April when the SJR flow was just 1,000 cfs. The daily DO range was 2 mg/l during the mid-April to mid-May when the flows were about 2,500 cfs. The daily DO range in the summer months was 4–6 mg/l in June, greater than 6 mg/l in July (DO data missing in August), and was 2–4 mg/l in September. Figure 11b shows the daily minimum and maximum algal fluorescence at Mossdale for 2009, along with extracted algae pigment concentrations from Vernalis (DWR data). The algae pigment concentration in mid-March was about 75 μg/l. The highest monthly algae pigment concentration (missing in June) was about 125 μg/l in July, but was only 50 μg/l in August, and less than 25 μg/l in September. The estimates of algae biomass from the DO and pH data in June and July were 100–200 μg/l, somewhat higher than the fluorescence and algae pigment concentrations. The 2009 algae pigment and fluorescence values were lower than in several previous years, although the 2009 flows were the lowest observed in recent years.

Figure 12a shows the daily minimum, maximum, and saturated DO (and daily DO range) at Mossdale for 2010, with the SJR flows at Vernalis shown for reference. The SJR flows were higher than 3,000 cfs from April through June and decreased to about 1,500 cfs from mid-July to mid-September. The daily DO range was about 2 mg/l at the end of March, was 4–6 mg/l from mid-July to mid-August, and declined to about 2 mg/l in September. Figure 12b shows the daily minimum and maximum algal fluorescence at Mossdale for 2010, along with extracted algae pigment concentrations from Vernalis (DWR data). The highest monthly algae pigment concentration was just 75 μg/l in early August. The measured fluorescence values were highest in mid-July, with values of 100–150 μg/l, with values of 75-125 μg/l in August, and 25–75 μg/l in September. The estimates of algae pigment based on daily DO range and daily pH were about 100–150 μg/l in the second half of July, decreased to about 50–75 μg/l in August, and were less than 50 μg/l in September. These estimates from DO and pH measurements were similar to the fluorescence values in July, August, and September of 2010.

These data from 2000–2010 clearly demonstrate the seasonal pattern of maximum algae pigment in the summer months of June–September and the effects of low SJR flow (less than 3,000 cfs) on the measured algae pigment and the corresponding daily DO range and maximum pH values. The last step in the segment 1 calculations is to estimate the BOD concentrations corresponding to the algae biomass (pigment) patterns.

Calculating the Algal Biomass and BOD

Assuming the pigment content (mass pigment/biomass) of algae is about 1.25%, there would be about 12.5 μg/l of pigment (chlorophyll plus phaeophytin) for each 1 mg/l of algae biomass. Because each 1 mg/l of daily DO range (maximum – minimum) was shown with the 2000–2010 Mossdale data to be equivalent to about 25 μg/l of algal pigment, each 1 mg/l of daily DO range would also be equivalent to about 2 mg/l of algae biomass and about 3 mg/l of ultimate (long-term) BOD. Because the maximum daily DO range was about 5 mg/l (in 2001, 2002, 2003, and 2004 with summer flows of about 1,000 cfs to 1,500 cfs), the peak estimated river algae pigment concentration was about 125 µg/l, and the estimated peak algae biomass (VSS) was about 10 mg/l with an ultimate BOD estimate of about 15 mg/l. Because some higher algal fluorescence and algal pigment concentrations of 150-200 µg/l were measured (in 2002, 2003, and 2004) but the maximum daily DO range did not exceed 5-6 mg/l, the daily DO range may provide a minimum estimate of algae pigment concentration (and biomass). The daily maximum pH measurements were about 9.0 in most years and were 9.5 for a few periods in low-flow years; these values confirm the maximum algae pigment concentrations during the summer months were about 100 µg/l in most years (pH value of 9.0) with a few peak pigment concentrations of 200 µg/l (pH value of 9.5) in some low-flow years.

DWR conducted an algal assay and BOD study in the DWSC during the summer of 2001 (Lehman 2004). Some of the basic relationships identified in this study indicate that algal dynamics in the SJR and DWSC are similar to those observed in other rivers. Lehman used field measurements, algal growth assays (C-14 uptake and DO changes), and laboratory BOD measurements to determine the chemical content and growth of algae in the SJR and DWSC. Organic carbon and organic nitrogen measurements suggested the carbon content of about 50% and a nitrogen content of about 10%, with a phosphorus content of about 1%. Of particular interest was the amount of oxygen produced per chlorophyll that was measured during photosynthesis. These measurements suggest that a 1 mg/l DO range would match the daily photosynthetic DO production from about 25 µg/l of algal pigment with full sunlight.

The City of Stockton collected algal pigment and VSS (biomass) and BOD5 measurements at Mossdale and Vernalis in the summer of 2001 (Jones & Stokes 2002). Comparing the maximum values measured in June and July when the SJR flow at Vernalis was less than 1,500 cfs provides a general indication of the ratio between these algal biomass variables. The maximum VSS (biomass plus detritus) was about 12–15 mg/l. The maximum algal pigment was 100–125 µg/l. The maximum measured 5-day BOD values were about 6 mg/l. Assuming a 10% BOD decay rate, the 5-day BOD would be about 40% of the ultimate BOD, the 10-day BOD would be about 9 mg/l (60% of the ultimate BOD), and the ultimate BOD would be about 15 mg/l (2.5 times the 5-day BOD). These values are similar to the assumed relationships used here for the Mossdale algae accounting calculations. An algal pigment concentration of 125 µg/l would correspond to an estimated VSS (biomass) concentration of about 10 mg/l, and the ultimate BOD concentration would be about 15 mg/l. UC Davis collected BOD10 values during 2004 in cooperation with the RWQCB TMDL studies. The maximum summer algal pigment concentrations were 150 µg/l, and the maximum BOD10 values were about 12 mg/l, corresponding to an ultimate BOD of about 20 mg/l. Considering the uncertainty in the BOD and the chlorophyll measurements, these values are similar to the assumed relationships used here for the accounting procedures.

The peak algae pigment concentrations were not consistently measured through the summer low-flow period and were not observed when the summer flow at Vernalis was greater than about 1,500 cfs. Travel time in the river channel upstream of Vernalis and other factors such as temperature and turbidity (light) may play some role in producing the maximum algae biomass at Mossdale. Based on river geometry data in the DSM2-SJR model developed by DWR, the variation in the travel time in the 65-mile reach of the SJR between Mud Slough (Mile 121) and Mossdale (Mile 56) would be about 4 days at a flow of 500 cfs, 3.5 days at 750 cfs, 3.1 days at 1000 cfs, 2.5 days at 2,000 cfs, and 2 days at 3,000 cfs. The Tuolumne and Stanislaus River inflows increase the river flow and reduce the travel time from Vernalis (Mile 72) to Mossdale (Mile 56). An upstream SJR flow of more than 1,000 cfs would reduce the travel time to less than 3 days and would limit the algae biomass concentration at Mossdale to less than the maximum observed algae pigment of 150–200 µg/l (corresponding to 12–16 mg/l of VSS and 18–24 mg/l of BOD). Only low-flow periods during the summer months will result in maximum algal biomass and corresponding BOD concentrations at Mossdale.

Because the algae biomass at Mossdale is difficult to estimate from seasonal factors (i.e., temperature and light) and SJR flow alone, the measured daily DO range at Mossdale is suggested as the preferred TMDL accounting method to estimate the daily algae biomass and corresponding BOD at Mossdale. Because this is a very important estimate of the upstream effects on the DWSC DO conditions, these daily algae concentration estimates should be confirmed with the daily pH and algal fluorescence monitoring. These monitoring estimates should also be confirmed during the summer months of June through September with weekly (or daily) measurements of BOD10, VSS, and extracted algal pigment (perhaps sampled by the City of Stockton). Calculations of how much of the river algae biomass at Mossdale will be transported downstream to the DWSC will be described in the second segment of the TMDL accounting procedures.

Segment 2—Estimating DWSC Flow and Inflow BOD Concentrations

The effects from the City of Stockton RWCF effluent concentrations on the DWSC inflow concentration of BOD is the most accurately measured factor that may contribute to low DO conditions in the DWSC. The National Pollutant Discharge Elimination System (NPDES) permit and Waste Discharge Requirements (WDR) for the Stockton RWCF have for many years mandated a full set of effluent concentration measurements as well as river station water quality sampling. These river sampling data and effluent measurements can be used to estimate the inflow BOD concentration increments contributed by the RWCF discharge to the DWSC. The DWSC flow will dilute the RWCF effluent concentrations before entering the DWSC. The goal of the second segment of the TMDL accounting procedures is to convert the RWCF effluent measurements and the DWSC flow into an equivalent daily BOD concentration entering the DWSC. The estimated Mossdale algae concentration and the DWSC flow are used to estimate the inflow BOD from upstream Mossdale algae in the second segment of the TMDL accounting procedures. The BOD contribution from the RWCF can be compared to the effects from the SJR algae BOD concentrations at Mossdale to identify the relative contributions of these two major sources of BOD into the DWSC. The effects of the combined BOD inflow concentration on the DO concentration profiles in the DWSC can be determined with a DO-BOD balance calculation for the DWSC. The response of the DWSC DO profile and the minimum DO to the inflow BOD is calculated in the third segment of the TMDL daily accounting tool.

The two major implementation measures that are included in the second segment of the TMDL accounting procedures are the barrier (or gate) at the head of Old River and the RWCF nitrification facility. As required by the CVRWQCB in the 2003 WDR Permit, the City of Stockton constructed a nitrification facility in 2006 that removes almost all of the ammonia from RWCF effluent. The ammonia-N is converted to nitrate-N using a nitrifying bio-tower, so the ammonia concentration from the oxidation ponds is (after nitrification) discharged to the river as nitrate (with no remaining oxygen demand). This removal of ammonia-N concentration (now measured as the effluent nitrate-

N concentration) represents a TMDL credit (i.e., BOD reduction) for the City of Stockton. The effects of the nitrification on the historical BOD from the RWCF discharge can be calculated in the second segment of the TMDL accounting tool. The effects of the head of Old River barrier (or gate) on the DWSC flow can also be calculated in the second segment of the accounting tool. The daily flow without the barrier/gate will be less than 50% of the Vernalis flow, while the daily flow with the barrier/gate would be about equal to the Vernalis flow. This increased flow would provide a greater dilution of the RWCF effluent and reduce the inflow BOD to the DWSC.

Estimating DWSC Flow

Not all of the SJR flow measured at Vernalis will enter the DWSC because about half of the flow will be diverted into Old River, about 3 miles downstream of Mossdale. There are several tidal flow measurement stations downstream of Old River (i.e., SJR at Lathrop, SJR at Garwood Bridge, and in the DWSC at RRI). However, the net daily flow is sometimes difficult to estimate from these tidal flow measurements. In most cases the USGS Garwood tidal flows and the DWR Lathrop tidal flows provide a reliable net flow estimate, but the net flow is more uncertain when it is less than about 500 cfs.

An estimate of the DWSC net flow can be made from the Vernalis flow and the SWP and CVP export pumping in the South Delta near Tracy. This provides a good estimate of the river flow that transports algae biomass downstream from Mossdale and dilutes RWCF discharge before it enters the DWSC. The general flow split at the head of Old River is about 50% each way (i.e., into Old River and downstream to Stockton). However, CVP and SWP export pumping increases the Old River diversion and reduces the DWSC flow. The DWSC flow can be estimated as:

DWSC Flow (cfs) = 50% of Vernalis Flow (cfs) – 5% of CVP and SWP Pumping (cfs)

This equation indicates that DWSC flow will be very low whenever the CVP and SWP export pumping is more than 10 times the Vernalis flow. This can happen during the summer low-flow period if the Vernalis flow is less than 1,500 cfs. The temporary barriers that DWR installs in Old River near the DMC intake, Grant Line Canal, and Middle River can reduce the effect of pumping on the DWSC flow. The DWSC flows are increased to the Vernalis flow minus about 500 cfs of leakage when the rock barrier at the head of Old River is installed during the VAMP period (April–May) to protect downstream migration of juvenile Chinook salmon or during the fall (September–October) to improve the SJR attraction flow for adult Chinook salmon upstream migration. A permanent gate would likely have a bypass flow of about 500 cfs for dilution of the Tracy treated wastewater effluent. The RWCF discharge (of about 40 cfs) should be added to the estimated or measured SJR flow at Garwood or Lathrop. The DWSC flow is important for estimating the fraction of the Mossdale River algae biomass that will reach the DWSC and for estimating the dilution of the RWCF effluent.

Estimating River Algae Biomass Reduction between Mossdale and the DWSC

The next calculation in the second segment of the accounting procedures is an estimate of the reduction in the Mossdale algae biomass before it enters the DWSC. This reduction in algae biomass is caused by settling, decay of the algae, and zooplankton grazing of the algae in this tidal reach of the SJR, between Mossdale and the DWSC. Algae may continue to grow in this reach, but because the river depth increases, the average light level is reduced and the measured algae concentrations generally decline between Mossdale and the DWSC. The loss of the algae biomass is estimated as a function of travel time, with an assumed daily loss rate that can be specified in the TMDL accounting calculations. The daily loss rate is generally about 10–20% per day for this tidal reach of the SJR.

The travel time is calculated from the channel volume between Mossdale and the DWSC (estimated to be about 3,500 acre-feet (af) at low tide, and about 5,000 af at high tide). The channel surface area is about 500 acres between Mossdale and the DWSC, with an average depth of about 7 feet at low tide and 10 feet at high tide. Using the low-tide volume estimate, the travel time for water between Mossdale and the DWSC is calculated as:

Travel Time (days) = 0.5 x 3,500 (af)/ River Flow (cfs)

Because 1 cfs of flow for a day is equivalent to about 2 af, a flow of 1,000 cfs would have a travel time of about 1.75 days. A flow of 500 cfs would have a travel time of about 3.5 days. A flow of 250 cfs would have a travel time of about 7 days. These travel time estimates were generally confirmed with several dye studies conducted by Dr. Gary Litton from the University of the Pacific (UOP) in 2008 between Old River and the DWSC (ICF International 2010a).

If the net algae loss rate (i.e., growth minus settling and grazing) was assumed to be 10% per day, the algae biomass would be reduced by about 15% for a flow of 1,000 cfs, by about 30% for a flow of 500 cfs, and by about 50% for a flow of 250 cfs. These loss rates are difficult to estimate from VSS, algae pigment, or BOD5 measurements because of the strong tidal mixing along the river reach that mixes the RWCF effluent and river water over several miles each day. The City of Stockton's river sampling at three upstream stations (R1 at Brandt Bridge, R2 at Garwood Bridge, and R2a at Navy Bridge)and in the DWSC at R3 (NA 48) can be used to provide a rough estimate for the algae loss rate during the summer low flow period.

Figures 13a and 13b shows the City of Stockton VSS and algae pigment concentration measurements at R1 (Brandt Bridge) and at R2 (Garwood Bridge) and R2a (Navy Bridge) for 2008. Brandt Bridge is at Mile 48, about 8 miles upstream from Navy Bridge at Mile 40. Mossdale is about 8 miles further upstream, so only about half of the travel time and VSS reduction is measured between these stations. During the summer months of 2008 the Vernalis flow was about 1,000 cfs and the algae pigment concentrations were reduced to about 25% of the R1 concentrations at stations R2 and R2a. Figure 13c and 13d show that the VSS and algal pigment concentrations were reduced to about 50% of the R1 concentrations at R2 and R2a. The DWSC flow would have been less than 500 cfs, and the measured net tidal flows were less than 250 cfs most of the summer. If the DWSC flow was 250 cfs, the travel time would have been about 7 days, and a 10% daily decay rate would reduce the Mossdale VSS or algae biomass concentrations to about 50% by the time it entered the DWSC. A daily decay rate of 20% would reduce the Mossdale VSS or algae concentrations to about 20% by the time it entered the DWSC. This loss rate between Mossdale and the DWS is uncertain, but the effects of various assumed loss rates can be compared with the TMDL accounting procedures tool.

For the TMDL accounting procedures, a lower daily loss rate (of 5%) may result in the maximum responsibility for DWSC DO conditions from the upstream river algae BOD contributions. For example, a Vernalis flow of 1,000 cfs would result in an algae pigment concentration of about 150 μg/l and would correspond to a river algae biomass of 12 mg/l and a BOD concentration of about 18 mg/l at Mossdale. This relatively low river flow of 1,000 cfs would allow the maximum algae biomass to grow at Mossdale, but a low daily loss rate would allow the maximum fraction of the Mossdale BOD concentration to enter the DWSC. For example, if the DWSC flow was 500 cfs (no export pumping), the algae loss from Mossdale to the DWSC would be about 15% (3 days travel time) and the BOD entering the DWSC would be about 15 mg/l. With 5,000 cfs of export pumping, the DWSC flow would be reduced to about 250 cfs, and about 75% (5 days travel time) of the river algae would enter the DWSC. A higher loss rate would cause less of the river algae BOD to enter the DWSC and would result in a lower contribution (i.e., lower responsibility) from upstream algae sources.

Estimating the DWSC Inflow DO Concentration

The river flow and the river algae (BOD) can be used to estimate the inflow DO concentration, which is needed for calculating the DWSC DO profile. The BOD decay that is estimated for this SJR reach can also be used to calculate the DO concentration at the DWSC. The calculation uses the Mossdale BOD concentration and the specified BOD loss rate and reaeration rate to determine how much of a DO deficit (below DO saturation) would remain at the downstream end entering the DWSC. The calculation is based on the simple idea that the daily BOD decay will be balanced by the daily reaeration, which is dependent on the DO deficit. The accounting procedures tool calculates the remaining river algae BOD at the DWSC inflow, and then estimates the inflow DO:

Inflow BOD (mg/l) = Mossdale BOD x (1–BOD decay rate) ^ Travel Time (days)

The BOD decay rate is measured to be about 0.1 per day at 20°C. The actual decay rate might be higher if zooplankton grazing consumes the algae at faster than the standard decay rate. The BOD decay rate may be less in cooler water temperatures, or if there are new BOD materials forming from algae growth. The range of likely BOD decay rates is about 5% to 15% per day. As the river BOD decays it will consume oxygen and lower the DO in the river. But surface reaeration will raise the DO whenever it is less than DO saturation. The daily source of DO from reaeration is usually calculated as a function of the DO deficit from saturation:

Daily Reaeration (mg/l) = (Saturated DO – River DO) x Reaeration Rate (per day)

The DO monitoring in the DWSC to measure the effectiveness of the Aeration Facility has found that the DWSC reaeration rate is about 20% per day, as described in Appendix A of the 2008 Operations Report (ICF International 2010b). The reaeration rate in the SJR between Mossdale and DWSC should be higher because the water depth is less and the water velocity is higher. The DO and BOD of the river will be in equilibrium. The daily BOD decay (i.e., River BOD x BOD decay rate) will balance the daily reaeration source. Rearranging the terms for the daily DO consumed and the daily DO reaeration source provides an estimate of the inflow DO to the DWSC:

Inflow DO (mg/l) = Saturated DO – Inflow BOD (mg/l) x BOD Decay Rate / Reaeration Rate

The diluted RWCF BOD concentration (described next) will contribute to the river BOD and reduce the inflow DO just upstream of the DWSC. The accounting calculations assume that the inflow DO will be in equilibrium with the combined inflow BOD from the RWCF effluent and the river algae transported downstream from Mossdale.

For example, if the BOD decay rate was specified as 10% per day and the reaeration rate was specified as 40% per day (2 times the DWSC value), the equilibrium DO deficit would be about 25%

of the inflow BOD concentration (i.e., 0.1/0.4 = 25%). If the river algae and RWCF combined BOD was about 8 mg/l, the DO deficit would be about 2 mg/l, and the inflow DO would be about 6 mg/l (in summer months when the saturated DO was 8 mg/l). The VSS and DO concentrations measured at the City of Stockton river sampling stations R1, R2, and R2a can be used to estimate the BOD decay and the reaeration rate, by matching the decay of VSS and the DO deficits for the recent years of data (2000–2010).

Stockton RWCF Effluent Measurements

The NPDES permit and WDR issued by the CVRWQCB for the Stockton RWCF have effluent and river sampling requirements. To comply with these limits, measurements are made daily or weekly; these provide an accurate description of RWCF effluent quality as well as the volume of effluent discharged each day. Because the City of Stockton has made many changes to its wastewater treatment facilities, and because the inflow BOD from Stockton canneries has decreased, the most recent effluent quality data (dating to 2007) are most representative of future estimates of the City of Stockton BOD loads and possible TMDL nitrification credits.

The City of Stockton submits the effluent measurements in monthly self-monitoring reports to the CVRWQCB, and these measurements were included in the Data Atlas files that were originally produced for the DWSC modeling and upstream river water quality studies, funded by CALFED and CBDA (last updated in 2007). These daily data files have been updated to September 2010. Graphics from these Data Atlas files will be shown here to demonstrate the calculation of DWSC inflow BOD concentrations from the Stockton RWCF discharge, as diluted by the DWSC flow.

The basic water quality measurements of the Stockton RWCF effluent include the following.

- Effluent daily flow (mgd)
- BOD5 (mg/l)
- 5-day carbonaceous BOD (CBOD5) (mg/l)
- Total suspended solids (TSS) (mg/l)
- VSS (mg/l)
- Hardness (mg/l)
- Alkalinity (mg/l).
- Ammonia-nitrogen (NH3-N) (mg/l).
- Nitrate-nitrogen (NO3-N) (mg/l).
- Nitrite-nitrogen (NO2-N) (mg/l).
- Total Kheldahl nitrogen (TKN) (mg/l).
- Organic-nitrogen (organic-N) (mg/l).
- Total dissolved solids (TDS) (mg/l).
- EC (uS/cm).
- Temperature (°F).

- DO (mg/l).

Effluent flow (mgd) is converted to cubic feet per second (cfs) to be compared to the river flow (i.e., dilution factor). Because the City of Stockton operates large oxidation ponds (with storage capacity), the tertiary treatment facility (and effluent) was often shut down on the weekends to reduce operating expenses. A 5-day moving average discharge is used to estimate the daily effluent contribution (inflow) to the DWSC. This 5-day moving average also accounts for the tidal mixing of the effluent over several days in the river before entering the DWSC.

Measurements of BOD5 and CBOD5 are used to estimate the ultimate (total) BOD concentration (and load) from the RWCF. The BOD5 and CBOD5 measurements are traditionally made at 20°C (68°F). The carbonaceous BOD (CBOD) measurement is made after adding a biocide to inhibit the nitrifying bacteria from growing. This eliminates the contribution of ammonia in the CBOD5 measurement. Comparison of CBOD5 and BOD5 provides an estimate of the nitrogenous BOD NBOD5, although this difference has usually been relatively small and suggests that not much of the ammonia was nitrifying in the 5-day BOD measurements. CBOD5 has been the primary measurement of CBOD in recent years; ammonia-N has been used to estimate the ultimate NBOD.

The particulate material in the effluent is measured by filtering and drying water samples. This provides a measure of the particulates or TSS in the effluent. The organic fraction is determined by combustion of the filtered TSS materials to determine the VSS. Comparison of these measurements (both were made in some years) indicates that the VSS concentration is generally greater than 80% of the TSS concentration. TSS has been the primary effluent particulate measurement in recent years. Both TSS and VSS measurements are usually made for the river samples.

Estimating Stockton RWCF BOD Contribution and Possible Nitrification Credit

The Stockton RWCF BOD concentration and nitrification credit calculations are relatively simple. The Stockton RWCF effluent discharge and effluent BOD concentration are used to estimate the total inflow BOD entering the DWSC. The inflow BOD concentration from the RWCF effluent depends on the DWSC flow. Because the DWC flow is variable and uncertain, a representative river flow of 200 cfs was used for demonstrating the daily accounting procedures. The inflow CBOD and the inflow NBOD are separately estimated to account for the large effects of RWCF ammonia (prior to 2007) and to allow the RWCF nitrification credits to be estimated (since 2006).

The first step in the Stockton RWCF accounting procedures is to convert the daily effluent concentration measurements into daily ultimate BOD concentration estimates. The CBOD5 and the BOD5 measurements are multiplied by a factor of 2.5, because the assumed BOD decay rate (at 20°C) is 0.1 per day, so that about 40% of the ultimate BOD would decay and consume oxygen in the first 5 days (i.e., 0.9^5 = 0.4). The TSS measurements are assumed to be organic (VSS) and are multiplied by 1.5, because each 1 mg/l of organic matter is assumed to consume about 1.5 mg/l of oxygen during decay. The ammonia-N concentration is multiplied by a factor of 5 because about 5 mg/l of DO are required to oxidize (nitrify) 1 mg/l of ammonia-N to 1 mg/l of nitrate-N. The total effluent BOD would be the combination of the CBOD5 or TSS estimate of ultimate CBOD plus the ammonia-N estimate of ultimate NBOD. The estimated effluent total BOD concentration will then be diluted by the DWSC flow prior to entering the DWSC. The estimate of the NBOD concentration (from effluent ammonia) entering the DWSC is:

Inflow NBOD = RWCF Discharge (cfs) x 5 x NH_3-N (mg/l) / [River flow (cfs) + Discharge (cfs)]

The estimate of the DWSC inflow CBOD from CBOD5 or from TSS measurements can be similarly calculated as:

> Inflow CBOD (from CBOD5) = Discharge (cfs) x 2.5 x CBOD5 (mg/l) / [River Flow (cfs) + Discharge (cfs)]
>
> Inflow CBOD (from TSS) = Discharge (cfs) x 1.5 x TSS (mg/l) / [River Flow (cfs) + Discharge (cfs)]

The daily river flow at the RWCF discharge location and entering the DWSC is seasonally variable and somewhat uncertain. Therefore, the effects of the RWCF effluent ammonia-N and CBOD5 or TSS on the daily DWSC inflow CBOD and NBOD are shown for an average discharge of 50 cfs with a representative river flow of 200 cfs. A river flow of 200 cfs would reduce (i.e., dilute) the DWSC inflow BOD concentration to about 20% of the RWCF effluent BOD concentration (i.e., 50 / [50+200] = 0.2). The actual daily DWSC inflow BOD concentration would be less than this calculated inflow BOD when the river flow was higher than 200 cfs, and would be greater than this calculated inflow BOD when the river flow was lower than 200 cfs. A river flow of 450 cfs would reduce the DWSC inflow BOD to half the calculated value (10% effluent BOD) for the representative flow of 200 cfs. A river flow of 75 cfs would increase the DWSC inflow BOD to twice the calculated value (40% of effluent BOD) for the representative flow of 200 cfs.

RWCF BOD Contributions for 2000–2010

The RWCF discharge and effluent concentration measurements for 2000–2010 are shown here to demonstrate the suggested TMDL accounting procedures for the RWCF effluent. The reduction in the RWCF effluent ammonia-N concentrations since 2007 demonstrates the effects of the RWCF nitrification facility on reducing the BOD inflow to the DWSC. This reduction is the basis for the suggested RWCF nitrification credit calculations.

Figure 14a shows the Stockton RWCF daily and 5-day moving average discharge for 2000. The RWCF effluent discharge was highest in the winter (rainfall) period and averaged about 50 cfs most of the year. The monthly average effluent flows are given as magenta colored squares. The 5-day moving average effluent flow can be used to account for the week-end shut-downs and the tidal mixing in the river, but even the 5-day moving average discharge is somewhat variable. Therefore a representative effluent discharge of 50 cfs will be used in the example accounting procedure calcualtions. The 2001–2010 RWCF daily discharges were similar to the 2000 values, and graphs for these years will not be shown (the data is available in the accounting tool).

Figure 14b shows the daily BOD5, CBOD5, and TSS concentrations of the RWCF effluent for 2000. The 5-day CBOD measurements were generally less than 5 mg/l with some values of 10 mg/l in the winter period. These CBOD values are relatively low compared to the permitted monthly average CBOD concentration of 10 mg/l. The 5-day BOD concentrations were usually not much higher than the CBOD values, but increased to 15–20 mg/l in a few periods during the winter period. Apparently not much of the ammonia was being oxidized in the 5-day BOD tests. The TSS concentrations were generally a little higher than the 5-day BOD and ranged from about 5 mg/l to 25 mg/l. The 2001–2006 BOD5, CBOD5, and TSS concentrations of the RWCF effluent were generally similar to the 2001. The BOD5, CBOD5, and TSS concentrations of the RWCF effluent since 2007 have been much lower than the 2000 data because of improvements in the tertiary treatment (i.e., constructed wetlands and additional filters). Graphs for these years will not be shown (the data is available in the accounting tool).

Figure 14c shows the RWCF effluent concentrations of ammonia-N, nitrate-N, organic-N and total N for 2000. The nitrate-N was less than 1 mg/l except in the spring (April-June) when it increased to a maximum of about 10 mg/l. The organic-N was about 5 mg/l all of the year. The ammonia-N concentration was about 25 mg/l in January and again in November and December. The ammonia-N concentration generally declined in the spring and summer (from oxidation pond uptake for algae growth) and was a minimum of less than 5 mg/l in May–August.

Figure 14d shows the calculated BOD entering the DWSC with an assumed discharge of 50 cfs and representative river flow of 200 cfs for 2000. The RWCF effluent CBOD5 and TSS concentrations result in a CBOD estimate of about 3–5 mg/l entering the DWSC. These are moderate BOD concentrations that may be oxidized in the DWSC and balanced by surface reaeration without causing low DO. The calculated CBOD concentration entering the DWSC would be 50% of the RWCF effluent CBOD5, because the ultimate CBOD will be 2.5 times the CBOD5, but the assumed river flow of 200 cfs would reduce the CBOD concentration to 20% (i.e., 2.5 x 0.2 = 0.5). The CBOD concentration entering the DWSC based on the TSS concentration would be about 30% of the RWCF effluent TSS concentration, because the effluent CBOD would be 1.5 times the TSS, and the assumed river flow of 200 cfs would reduce the effluent CBOD concentration to 20% (i.e., 1.5 x 0.2 = 0.3). The CBOD inflow estimate based on TSS was similar but often higher than the estimate based on the CBOD5. Because the RWCF effluent ammonia-N concentration will require about 5 mg/l of oxygen for each 1 mg/l of ammonia-N, the NBOD entering the DWSC would be equal to the ammonia-N for the assumed river flow of 200 cfs (i.e., 5 x 0.2 = 1).

Figure 15a shows the measured RWCF effluent nitrogen concentrations for 2001. The ammonia-N concentration was about 25 mg/l in January and February, but was more variable, between 5 mg/l and 20 mg/l, in the remainder of the year. The nitrate-N concentration was low in the winter, increased to 10–15 mg/l in April and May, and was low through the summer but increased to 5 mg/l in December. This occasional oxidation of the ammonia-N to nitrate-N in the oxidation ponds reduced the NBOD concentrations. The organic-N concentration was relatively uniform at about 3–5 mg/l through the year. The total-N concentration was 30 mg/l in January and February, declined to about 15 mg/l from May through September, and increased to about 20–25 mg/l in October–December. Figure 15b shows the calculated DWSC inflow CBOD and NBOD concentrations for a representative river flow of 200 cfs for 2001. The calculated CBOD concentration entering the DWSC was generally less than 5 mg/l throughout the year. The NBOD concentration dominated the estimated inflow BOD entering the DWSC from the RWCF effluent. The calculated NBOD entering the DWSC was greater than 10 mg/l in July and August and may have contributed to low DO in the DWSC if the river flow was less than 200 cfs.

Figure 16a shows the 2002 ammonia-N concentration was less than 10 mg/l in early January and increased to 25 mg/l in early March. The ammonia-N concentration was reduced to less than 5 mg/l from early April through July 2002. The increase in NBOD during August and September may have coincided with low DO in the DWSC. Figure 16b shows the calculated DWSC inflow CBOD and NBOD concentrations for an assumed RWCF discharge of 50 cfs with a representative river flow of 200 cfs for 2002.

Figure 17a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2003. The 2003 ammonia-N concentration was 25 mg/l from January through May, was less than 10 mg/l from June through October, and then increased to 20 mg/l by the end of the year. Figure 17b shows the calculated DWSC inflow CBOD and NBOD concentrations for an assumed RWCF discharge of 50 cfs with a representative river flow of 200 cfs for 2003.

Figure 18a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2004. The ammonia-N concentration was about 12 mg/l in January and February and December. The ammonia-N decreased to between 10 and 20 mg/l from March through November. This was somewhat higher ammonia-N concentration during the summer than in most previous years. Figure 18b shows the calculated CBOD and NBOD inflow concentrations for 2004 with an assumed discharge of 50 cfs and representative river flow of 200 cfs was 10-15 mg/l during most of the low flow summer period of June through September. This relatively high NBOD during the summer months may have contributed to low DO conditions in the DWSC during 2004.

Figure 19a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2005. The ammonia-N concentration was 20-25 mg/l from January through April, and was less than 10 mg/l only in June. The ammonia-N increased to 20 mg/l in September and was 25 mg/l at the end of the year. Figure 19b shows the calculated CBOD and NBOD inflow concentrations for 2005 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated NBOD concentrations entering the DWSC were higher than 10 mg/l from August through October, and may have contributed to low DO conditions in the DWSC during 2005.

Figure 20a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2006. The ammonia-N concentration was 20–25 mg/l from January through April, and was 10–15 mg/l in June, July, and August. The ammonia-N decreased to less than 10 mg/l in September and October, and was 10–15 mg/l in November and December. The nitrate-N concentrations increased from about 5mg/l in September to about 15 mg/l in December, as the nitrification facility began operation. Figure 20b shows the calculated CBOD and NBOD inflow concentrations for 2006 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The nitrification facility was first operated in the late summer of 2006 and the ammonia-N concentrations were reduced and the nitrate-N concentrations were increased. As the RWCF ammonia-N was converted to nitrate-N in the bio-towers, the calculated inflow BOD to the DWSC was reduced to between 5 and 15 mg/l in the fall months. The nitrification credit can be estimated from the effluent nitrate-N concentration, assuming that the nitrate-N concentration was usually less than 1 mg/l without the nitrification bio-towers. The calculated inflow BOD credit (from reduced ammonia-N) was about 5–15 mg/l during these first months of operation of the nitrification facility.

Figure 21a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2007. The ammonia-N concentrations were somewhat variable from January through June, but were consistently less than 3 mg/l for the remainder of the year. This was a dramatic reduction in ammonia-N compared to previous years. The nitrate-N concentrations were 20–25 mg/l in January and February, decreased in the spring to less than 5 mg/l in June and July, and then increased to 20 mg/l by the end of the year. Figure 21b shows the calculated CBOD and NBOD inflow concentrations for 2007 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The 2007 calculated NBOD concentration were somewhat variable during the winter (first winter of nitrifying bio-tower operation). The nitrification credits (i.e., reduction in ammonia-N) can be estimated from the measured nitrate-N concentration, since nitrate concentrations were generally less than 1 mg/l in previous years without nitrification. The nitrification credit is not 25 mg/l throughout the year because the oxidation ponds usually reduced the ammonia-N concentrations in the spring and summer period.

The effluent nitrate-N concentration is recommended as the best estimate of the nitrification credit. This nitrification credit can also be expressed as the NBOD concentration that would have entered the DWSC if the nitrification facility were not operating. For 2007, this nitrification BOD reduction credit was 15–25 mg/l in January and February, decreased to a minimum of 5 mg/l in June and July, and then increased to about 15–20 mg/l in November and December. Because the ammonia-N concentration was already reduced in the oxidation ponds during the summer months, the nitrification credits were also lowest (5–10 mg/l) during the summer months. Nevertheless, this was a major reduction in the BOD entering the DWSC and likely improved the DO conditions in the DWSC compared to what they would have been without the nitrification facility.

Figure 22a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2008. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 22b shows the calculated CBOD and NBOD inflow concentrations for 2008 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated CBOD concentrations entering the DWSC were less than 2 mg/l. The nitrification credit for the reduction in the NBOD concentration (shown at nitrate inflow concentrations) would depend on the DWSC flow.

Figure 23a shows Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2009. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 23b shows the calculated CBOD and NBOD inflow concentrations for 2009 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The ammonia-N concentrations were consistently less than 1 mg/l during 2009. The calculated nitrification credits for the reduction in the NBOD concentration entering the DWSC for the representative flow of 200 cfs were about 25 mg/l in January and February, were reduced to about 15 mg/l in April and May, were a minimum of about 5–10 mg/l in June and July, and were increased to 25 mg/l in September and October, and were 15-25 mg/l in November and December. This was a substantial reduction in the NBOD concentrations entering the DWSC most of the year. The actual nitrification credit would depend on the DWSC flow.

Figure 24a shows the Stockton RWCF effluent concentrations of ammonia-N and nitrate-N for 2010. The ammonia-N concentrations were generally less than 1 mg/l. The nitrate-N concentrations were 15–20 mg/l from January through May, decreased in the spring to about 10 mg/l in July, and then increased to 20 mg/l from October through December. Figure 24b shows the calculated CBOD and NBOD inflow concentrations for 2010 with an assumed discharge of 50 cfs and representative river flow of 200 cfs. The calculated nitrification credits in 2010 with the representative flow of 200 cfs were about 25 mg/l in January and were reduced to a minimum of about 10–15 mg/l in the summer period. The nitrate-N concentrations will presumably increase to about 25 mg/l at the end of the year, as observed in previous years.

Because the effects of algal growth in the oxidation ponds on the effluent ammonia and nitrate concentrations are variable form year to year, the measured RWCF effluent nitrate-N is the suggested TMDL accounting method for estimating the nitrification credits provided by the nitrification bio-towers. The benefits that will be achieved in the DWSC (i.e., increased minimum DO concentration) from the nitrification facility reduction in effluent ammonia concentrations will be calculated below in the third segment of the suggested TMDL accounting procedures.

Effects of Flow on the Combined (River Algae and RWCF) BOD Concentration

The SJR flow at Vernalis will govern the maximum concentration of algae at Mossdale, as previously described in the first segment of the suggested TMDL accounting procedures. The SJR flow downstream of the head of Old River will control the fraction of the river algae that will be transported to the DWSC and will also control the dilution of the Stockton RWCF effluent. There is a tradeoff between the benefits of flow from diluting the RWCF effluent and the impacts of flow from transporting more of the upstream river algae into the DWSC. The head of Old River barrier or gate could be used to control the flow and provide the best flow for the TMDL implementation program.

The proposed TMDL accounting procedures will properly calculate both of these effects (algae transport and RWCF dilution) from the DWSC flow. The effects of south Delta export pumping, that reduces the DWSC flow could be compensated with the head of Old River barrier (or gate). Estimating the flow that may provide the best overall TMDL benefit can be investigated with the TMDL accounting tool, for a range of RWCF effluent BOD and river algae BOD concentrations. If the Mossdale algae BOD concentration was high and the RWCF effluent BOD was relatively low, a lower DWSC flow might provide the greatest TMDL benefit. For most conditions, a minimum flow of about 200 cfs, to provide a dilution to about 20% of the RWCF effluent BOD concentration, may result in DO concentrations in the DWSC that would meet the DO objective.

The downstream DO profile and the minimum DO in the DWSC will be estimated in the third segment of the TMDL accounting procedures. The calculations of the minimum DO in the DWSC will match the measured DO at the RRI station only if the upstream river algae BOD, the transport to the DWSC, the dilution of the RWCF effluent and the combined inflow BOD and inflow DO concentrations are accurately estimated. Annual graphs of the TMDL daily accounting tool calculations of the DWSC DO concentrations in comparison with the daily minimum RRI data and the City of Stockton DO measurements will be used to show the ability of the accounting tool to estimate the DWSC DO and demonstrate the effects of TMDL implementation measures (i.e., upstream algae, DWSC flow, RWCF nitrification, Aeration Facility).

Segment 3—Estimating the Minimum DO in the DWSC

The third segment of the daily TMDL accounting procedures calculates the downstream DO-BOD balance in the DWSC, based on the inflow BOD, the inflow DO, the assumed DWSC reaeration rate, and the assumed BOD decay rate. The DO-BOD balance is based on the DWSC DO Model described in Appendix A of the 2008 Operations Report (ICF International 2010b). The Aeration Facility is proposed as a major TMDL implementation measure that can be included in the calculations of the third segment of the accounting procedures.

DO and BOD Balance in the DWSC

The downstream DO profile in the DWSC is controlled by the balance between the BOD decay (loss of DO) and the surface reaeration (source of DO). The Aeration Facility can add DO to the natural DWSC DO profile as tidal flows move back and forth past the diffuser, but the downstream reaeration will be reduced by this added DO (because the downstream DO deficit from saturation will be reduced). Many longitudinal DO profiles have been measured by the DWR *San Carlos* boat surveys and by the UOP boat surveys. The DWSC DO Model was developed to match the measured *San Carlos* DO profiles by specifying the DWSC flow, inflow DO, inflow BOD, and reaeration rate. The DWSC reaeration rate has been estimated to be about 20% per day.

The TMDL accounting procedures include a simplified DO balance that calculates the downstream BOD concentration, using the inflow BOD and inflow DO estimated in Segment 2 of the TMDL accounting tool and the specified BOD decay (assumed to be 10% per day). Therefore, both the reaeration rate (20% per day) and the BOD decay rate (10% per day) have been previously estimated for the DWSC and are assumed to be constant for all future conditions in the DWSC. The TMDL accounting tool calculates the daily DO and BOD balance for 5 days in the DWSC. Because the DO and BOD are assumed to be in equilibrium as the water moves downstream in the DWSC, the daily remaining BOD and DO deficit from saturation are determined by the initial DO and BOD. The inflow DO concentrations are assumed to be in equilibrium with BOD decay and reaeration for the river between Mossdale and the DWSC (Segment 2). The BOD decay rate was assumed to be 10% (same as in the DWSC), but the river reaeration rate was assumed to be 50% per day (higher than in the DWSC). The assumed DO saturation was 8 mg/l, corresponding to summer temperatures of about 20°C.

Table A-2 gives the daily BOD concentrations, DO concentrations, and the DO deficits (from DO saturation) calculated for 10 days in the DWSC with assumed inflow BOD concentrations of 5 mg/l, 10 mg/l, and 15 mg/l. The calculations indicate that the inflow DO for an assumed inflow BOD of 5 mg/l would be about 7.07 mg/l (DO deficit of 0.9 mg/l), and the minimum DO in the DWSC after 5 days would be about 6.38 mg/l. The inflow DO for an assumed inflow BOD of 10 mg/l would be about 6.15 mg/l (DO deficit of 1.9 mg/l), and the minimum DO in the DWSC after 5 days would be about 4.77 mg/l. The inflow DO for an assumed inflow BOD of 15 mg/l would be about 5.22 mg/l (DO deficit of 2.8 mg/l), and the minimum DO in the DWSC after 5 days would be about 3.15 mg/l. These are approximate values, assuming no other sources of BOD in the DWSC. With the BOD decay rate of 10% per day, about 40% of the BOD would be decayed after 5 days (60% remaining) and about 65% of the BOD would be decayed after 10 days (35% remaining). The inflow BOD of 5 mg/l would correspond to a BOD5 measurement of 2 mg/l. The inflow BOD of 10 mg/l would correspond to a BOD5 measurement of 4 mg/l. The inflow BOD of 15 mg/l would correspond to a BOD5 measurement of 6 mg/l. With the assumed BOD decay of 10% per day and the assumed reaeration rate of 20% per day, the minimum DO will always be calculated after 5 days. Therefore, a 5-day calculation of the DO-BOD balance will give the minimum DO expected in the DWSC.

The downstream position in the DWSC after 5 days (when the minimum DO is expected) depends on the net flow in the DWSC. This is a simple function of the geometry of the DWSC. Because there is about 2,000 af in each mile at low tide, the downstream movement would be about 1 mile per day for a flow of 1,000 cfs. Because the RRI station is 1.5 miles downstream from the SJR inflow at Channel Point (Dock 13), the SJR inflow would reach the RRI station in about 1.5 days with a flow of 1,000 cfs. If the flow was 500 cfs, the downstream movement would be 0.5 miles per day, and the SJR inflow would reach the RRI station after about 3 days. If the flow was 250 cfs, the downstream movement would be about 0.25 miles per day, and the SJR inflow would reach the RRI station after about 6 days.

Table A-2 indicates that the RRI station would measure the minimum DO in the DWSC for travel times of between 3 and 6 days, corresponding to flows of between about 250 cfs and 500 cfs. The minimum DO (after 5 days) would likely be measured upstream of RRI for lower flows and would likely be measured downstream of RRI for higher flows. Because of the tidal movement of water in the DWSC (of more than a mile each day), the RRI station will likely measure the minimum DO in the DWSC for a range of relatively low flows, when the inflow BOD would be relatively high and the minimum DO concentrations in the DWSC could be lower than the DO objective.

Table A-2. Calculated DWSC BOD and DO Concentrations for Inflow BOD of 5 mg/l 10 mg/ and 15 mg/l

Day	BOD (mg/l)	DO (mg/l)	DO Deficit (mg/l)
A. Inflow BOD of 5 mg/l			
0	5.0	7.07	0.9
1	4.5	6.76	1.2
2	4.1	6.56	1.4
3	3.6	6.44	1.6
4	3.3	6.39	1.6
5	3.0	6.38	1.6
6	2.7	6.41	1.6
7	2.4	6.46	1.5
8	2.2	6.53	1.5
9	1.9	6.61	1.4
10	1.7	6.69	1.3
B. Inflow BOD of 10 mg/l			
0	10.0	6.15	1.9
1	9.0	5.52	2.5
2	8.1	5.11	2.9
3	7.3	4.88	3.1
4	6.6	4.78	3.2
5	5.9	4.77	3.2
6	5.3	4.82	3.2
7	4.8	4.93	3.1
8	4.3	5.06	2.9
9	3.9	5.22	2.8
10	3.5	5.39	2.6
C. Inflow BOD of 15 mg/l			
0	15.0	5.22	2.8
1	13.5	4.28	3.7
2	12.2	3.67	4.3
3	10.9	3.32	4.7
4	9.8	3.16	4.8
5	8.9	3.15	4.9
6	8.0	3.23	4.8
7	7.2	3.39	4.6
8	6.5	3.59	4.4
9	5.8	3.83	4.2
10	5.2	4.08	3.9

Demonstration of DWSC Minimum DO Calculations

The accurate calculation of the minimum DO in the DWSC is the ultimate goal of the daily TMDL accounting tool. As described in the previous section, the DWSC minimum DO will occur after a travel time of about 5 days. A DO monitoring probe at the Navy Bridge (City R2a station) or Garwood Bridge (City R2 station and USGS tidal flow station) would be a good location for measuring the river inflow DO to the DWSC. Weekly measurements are collected at stations R1, R2, and R2a by the City of Stockton. These river data along with the RRI daily minimum DO concentrations will be used to confirm the daily estimates from the TMDL accounting procedures for recent years (2000–2010). Once the accuracy of the daily TMDL accounting tool is confirmed to the satisfaction of the CVRWQCB staff and stakeholders, it could be used to evaluate responsibility for periods of low DO and determine the benefits (i.e., increased DWSC DO concentrations) for nitrification and other BOD reduction measures, as well as to identify the benefits from increased flows.

Demonstration of Accounting Calculations for 2000

Figure 25a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2000. The measured flows are generally used in the TMDL accounting calculations, but the estimated flows (based on export pumping and periods when the head of Old River barrier is installed) are shown to confirm the measured patterns. DWSC flows of less than 500 cfs were measured in January, early July, and December 2000. These were the periods with lowest dilution of RWCF effluent.

Figure 25b shows the calculated inflow BOD concentrations for 2000. The BOD from upstream river algae (estimated from the daily DO range at Mossdale) that was calculated to enter the DWSC (estimated from the travel time and algae decay rate of 5% per day) is shown (green triangles). The maximum algae BOD during 2000 was about 10 mg/l from mid-July to mid-August, corresponding to the lowest SJR flows of about 2,000 cfs. The calculated RWCF BOD contributions (purple boxes) depend primarily on the ammonia-N concentrations and the river flow. The ammonia-N concentrations were lowest during the summer months (previously shown). Because the DWSC flows were relatively high most of the year, the RWCF BOD contributions were greatest in the winter and fall months with flows of less than 500 cfs. The maximum BOD calculated for the RWCF were 15–25 mg/l in January and in December.

Figure 25c shows the estimated inflow DO to the DWSC for 2000. The inflow DO was calculated from the saturated DO and the estimated BOD (green and red lines at the bottom of the graph, using the right scale) for the assumed BOD decay rate of 10% per day and the assumed river aeration rate of 50% per day. The minimum inflow DO estimated in 2000 was about 6 mg/l in July and August. The weekly DO measurements at station R2 (City of Stockton) indicate the minimum inflow DO concentrations were about 7 mg/l in 2000.

Figure 25d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2000. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 1 mg/l in early January, because of the very high inflow BOD estimated during the low flow period. Although the minimum daily RRI DO concentration were 5–6 mg/l (DO saturation deficit of 6 mg/l), the accounting tool is apparently overestimating the effects of the high

BOD on the inflow DO and on the DWSC DO. Perhaps the assumed BOD decay rate of 10% per day should be reduced during the cool winter months. The daily DO estimates follow closely the measured DO concentration patterns for most of the year. The minimum estimated DO concentrations of about 4 mg/l in July and August were very close to the measured DO concentrations during this period. The estimated DO decline in December (caused by RWCF ammonia-N and low flows) was very close to the measured RRI DO concentrations. Considering the many uncertainties in the TMDL accounting methods, this first year of comparison provided a remarkable match of the estimated daily DO concentrations with the measured DO patterns in the DWSC.

Demonstration of Accounting Calculations for 2001

Figure 26a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2001. The estimated flows were used for 2001 because the Garwood measured flows were missing during the summer months. DWSC flows of less than 500 cfs were measured in January and February, early April, from mid-June to early October (head of Old River barrier installed), and in December 2001. These were the periods with lowest dilution of the RWCF effluent.

Figure 26b shows the calculated inflow BOD concentrations for 2001. The maximum estimated river algae BOD concentrations (green triangles) were about 10 mg/l in June and July, with about 5 mg/l estimated for July and August of 2001. The SJR flows at Vernalis were about 1,500 cfs during these four summer months. The calculated RWCF BOD contributions (purple boxes) depend primarily on the ammonia-N concentrations and the river flow. The ammonia-N concentrations were lowest during April–June and were about 10 mg/l in July-September (previously shown). The calculated RWCF BOD contributions were about 5–10 mg/l in January, February, July, and September, with the highest BOD of 10–15 mg/l calculated in August. The highest calculated combined inflow BOD concentrations were about 15–20 mg/l in July and August. This was the period with the lowest expected inflow DO and DWSC DO concentrations.

Figure 26c shows the estimated inflow DO to the DWSC for 2001. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2001 was about 5 mg/l in July and August. The weekly DO measurements at station R2 (City of Stockton) generally confirm these estimated inflow DO concentrations for 2001.

Figure 26d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2001. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 7–9 mg/l in January–April and matched the measured DO concentrations reasonably well. The estimated daily DO declined in late May and June as the river algae BOD increased, and the estimated DO of about 4 mg/l in June was similar to the DO measurements. The estimated DO was a minimum of 2–3 mg/l in July and early August, and then increased to about 5 mg/l in September and 8 mg/l in November as the estimated BOD was reduced. The estimated DO in December was about 9 mg/l, but the measured DO was only about 7 mg/l, suggesting that the estimated inflow BOD was not high enough. This was caused by using the estimated flows of about 500 cfs in December, while the measured flows were about 250 cfs. This difference indicates the importance of the DWSC flow estimates during relatively low flow periods for accurately estimating the dilution of the ammonia-N concentrations in the RWCF effluent. Considering the many uncertainties in the TMDL accounting methods, this second year of comparison provided a remarkable match of the estimated daily DO concentrations with the measured DO patterns in the DWSC.

Demonstration of Accounting Calculations for 2002

Figure 27a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2002. The measured Garwood flows (5-day moving average) were used for 2002. DWSC flows of less than 500 cfs were measured in mid-January through mid-April, from June through August, and in early December 2002. These were the periods with lowest dilution of the RWCF effluent.

Figure 27b shows the calculated inflow BOD concentrations for 2002. The maximum estimated river algae BOD concentrations were about 10 mg/l from mid-June to mid-September of 2002. The SJR flows at Vernalis were less than 1,500 cfs during these summer months. The calculated RWCF BOD contributions were greater than 10 mg/l in February and March, were about 5 mg/l from mid-August to mid-November, and were 10–25 mg/l in late November and early December (because of very low flows).

Figure 27c shows the estimated inflow DO to the DWSC for 2002. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2002 was about 5–6 mg/l in June through September. The weekly DO measurements at station R2 (City of Stockton) and at R2a (new station at Burns Cut) suggest that the actual inflow DO was about 4–5 mg/l during these summer months. This suggests that the river algae BOD might have been higher than estimated in 2002.

Figure 27d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2002. The daily minimum DO measured at the RRI station and the weekly DO measurements at stations R4, R5, and R6 are shown for comparison. The minimum estimated DO concentrations were about 8–9 mg/l in January, whereas the measured DO was only 5–6 mg/l. The estimated DO concentrations in February–March were 4–7 mg/l, matching the measured DO very well. The higher estimated inflow and DWSC DO concentrations in April–May (because of the increased SJR flows and installation of the head of Old River barrier) matched the measured DO concentrations reasonably well. The estimated daily DO declined in late May and June as the river algae BOD increased, and the estimated DO of about 4 mg/l at the end of June was similar to the DO measurements. The estimated DO was 5 mg/l in July and early August, while the measured DO was 3–4 mg/l. The minimum estimated DO was about 3 mg/l from mid-August to mid-September, increased to 5 mg/l at the end of September, and was 7–8 mg/l at the end of October. The measured DO confirmed these DO estimates in September and October. The very low estimated DO at the end of November and early December (caused by low flows) was lower than the measured DO of about 3–4 mg/l. Nevertheless, the daily estimated minimum DWSC DO concentrations for 2002 were similar to the measured DO concentrations during almost all periods of the year.

Demonstration of Accounting Calculations for 2003

Figure 28a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2003. The measured Garwood flows (5-day moving average) were used for 2003. DWSC flows of less than 500 cfs were measured in January through mid-April, early June, July-mid-September, and mid-November through December 2003. These were the periods with lowest dilution of the RWCF effluent.

Figure 28b shows the calculated inflow BOD concentrations for 2003. The maximum estimated river algae BOD concentrations were about 10 mg/l from late May to early September. The SJR flows at Vernalis were about 1,500 cfs during these summer months. The calculated RWCF BOD contributions were about 10 mg/l in January, about 20–25 in early February (low flows), and about 10 mg/l in March. The calculated RWCF BOD was less than 5 mg/l during the VAMP flow period, but increased in late May (low flows) to about 10–20 mg/l, and increased again in mid-November and December to about 15–20 mg/l (low flows).

Figure 28c shows the estimated inflow DO to the DWSC for 2003. The inflow DO was calculated from the saturated DO and the estimated inflow BOD with the assumed BOD decay and reaeration rates. The minimum inflow DO estimated in 2003 was about 6 mg/l in February, about 4–5 mg/l in late May, and about 6 mg/l in mid-June through August. The weekly DO measurements at station R2 (City of Stockton) and at R2a (new station at Burns Cut) suggest that the lowest inflow DO was about 4–5 mg/l during July, and about 6–7 mg/l during most of the June–September period.

Figure 28d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2003. The minimum estimated DO concentrations were about 3 mg/l in early February and 5–6 mg/l in mid-February through March, whereas the measured DO was less than 2 mg/l in February and increased from 2 mg/l to 6 mg/l in March. The estimated DO concentrations decreased in late May to 2–3 mg/l, whereas the measured DO was 3–4 mg/l in early June. The estimated DO of 4–5 mg/l matched the measured DO in June–August, and both the estimated and measured DO increased to about 6 mg/l at the end of September, and were both about 8 mg/l at the end of October. The estimated DO was 5–6 mg/l at the end of November and early December, but decreased to 2–3 mg/l at the end of December. The measured DO at RRI was 6–7 mg/l in mid-November through December. The accounting procedures may be overestimating the decay of BOD in the winter months (should add temperature correction to the BOD decay rate). Nevertheless, the daily estimated minimum DWSC DO concentrations for 2003 were similar to the measured DO concentrations during most periods of the year.

Demonstration of Accounting Calculations for 2004

Figure 29a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2004. The measured Garwood flows (5-day moving average) were used for 2004. DWSC flows of less than 500 cfs were measured in January and February, June–September, and mid-November through December 2004. These were the periods with lowest dilution of RWCF effluent.

Figure 29b shows the calculated inflow BOD concentrations for 2004. The maximum estimated river algae BOD concentrations were about 10 mg/l from late May to late July. The SJR flows at Vernalis were about 1,500 cfs in June and just 1,000 cfs in July, August, and September. The calculated RWCF

BOD contributions were very high (10–25 mg/l) in January and February, about 10–15 in early June and early August, and very high (10–25 mg/l) again in mid-November through December because of low flows. The calculated RWCF BOD was less than 5 mg/l during the VAMP flow period and in October when DWSC flows were greater than 1,000 cfs. The combined BOD was greater than 15 mg/l during June, July, and August, as well as in the low flow periods of January–February and November–December.

Figure 29c shows the estimated inflow DO to the DWSC for 2004. The minimum inflow DO estimated in 2004 was less than 6 mg/l in late January and late November. The R2 and R2a measurements suggest that the inflow DO was not quite this low in these cooler months. The estimated inflow DO was 4–5 mg/l in the summer months, and the R2 and R2a measurements were even lower (3–4 mg/l) in July and August. The river DO can be substantially reduced by high BOD concentrations during summer (warm) low flow periods.

Figure 29d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2004. The minimum estimated DO concentrations were less than 1 mg/l in late January, about 3–4 mg/l in early February and 6–8 mg/l in March through May. The measured DO was 4–5 mg/l in late January and February, and was 7–8 mg/l in March–May. The estimated DO decreased in late May to a minimum of 1–3 mg/l in early June. The measured DO showed a decrease from about 7 mg/l to 3–4 mg/l in June. The estimated DO matched the measured DO quite well in July and August, with a minimum of about 2–3 mg/l from mid-July to mid-August. The estimated DO increased to 4–5 mg/l in September, while the measured DO remained at 2–3 mg/l. The river algae or the RWCF effluent BOD was apparently higher than calculated in September. The estimated DO increased in October from 5 to 8 mg/l, while the measured DO increased from 4 to 7 mg/l. The estimated DO was greatly reduced to less than 2 mg/l at the end of November and averaged about 3–4 mg/l in December. The measured DO was reduced to about 5 mg/l at the end of November and was very low (3–5 mg/l) in December. The calculations apparently should reduce the BOD decay rate in the winter months. Adjustments in these initial estimates of the river algae and RWCF BOD effects (to better match the measured DO) may provide a more accurate historical baseline for evaluating the effects of more flow and reduced ammonia on the DWSC DO concentrations.

Demonstration of Accounting Calculations for 2005

Figure 30a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2005. The measured Garwood flows (5-day moving average) were used for 2005. The SJR flows in 2005 were very high throughout the year, with a minimum flow of about 2,000 cfs in early September and mid-November. DWSC flows were about 1,000 cfs in August and were less than 500 cfs from mid-November to mid-December. Because of these high flows, the BOD concentrations are not expected to be high enough to cause low DO conditions in the DWSC.

Figure 30b shows the calculated inflow BOD concentrations for 2005. The maximum estimated river algae BOD concentrations were about 5–10 mg/l from mid-July to mid-September. The calculated RWCF BOD contributions were less than 5 mg/l until the low flow period of mid-November to mid-December. The combined BOD was about 10 mg/l during July and August, and was greater than 20 mg/l in the November–December low flow period. Figure 30c shows the estimated inflow DO to the DWSC for 2005. The minimum inflow DO estimated in 2005 was 6–7 mg/l in mid-July to mid-

September. The estimated inflow DO was 3–5 mg/l in the November-December period, while the measured DO at R2 and R2a was 6–8 mg/l.

Figure 30d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2005. The minimum estimated DO concentrations were 8–10 mg/l in the months of January–June because of the high flows and low BOD concentrations. The measured DO concentrations in January and February were lower (6–8 mg/l), suggesting that the inflow BOD was not accurately estimated. The estimated DO concentrations decreased in July from about 7 mg/l to a minimum of 4 mg/l and were 4–5 mg/l in August and early September, matching the measured DO relatively well. The estimated DO increased in September and October to about 8 mg/l. The measured DO was about 1 mg/l less than the estimated DO during this period. The estimated DO was much lower that the measured DO of 5–6 mg/l in December, again suggesting that a temperature modifier may be helpful for the winter months. A reduction in the DWSC DO was observed in December of 2005 (caused by high ammonia and low flow), but it was not as strong as estimated with the TMDL accounting calculations.

Demonstration of Accounting Calculations for 2006

Figure 31a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2006. The measured Garwood flows (5-day moving average) were used for 2006. The SJR flows in 2006 were very high throughout the year, higher than 2005, with a minimum flow of about 2,000 cfs in early December. DWSC flows were higher than 2,500 cfs until mid-July, and were a minimum of about 1,500 cfs from mid-July through August. Because of these high flows, the BOD concentrations are not expected to be high enough to cause low DO conditions in the DWSC.

Figure 31b shows the calculated inflow BOD concentrations for 2006. The maximum estimated river algae BOD concentrations were about 5–10 mg/l in late July and early September. The calculated RWCF BOD contributions were less than 5 mg/l until the low flow period of early December. The combined BOD was about 10 mg/l during late July, early September, and early December. Figure 31c shows the estimated inflow DO to the DWSC for 2006. The minimum inflow DO estimated in 2006 was about 7 mg/l in July. The estimated DO was within 1 mg/l of the saturated DO for most of the year. The measured DO generally confirmed the high inflow DO concentrations during this year with low BOD concentrations.

Figure 31d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2006. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in late July, corresponding to the period of highest estimated algae. The estimated DO increased from about 6 mg/l at the beginning of September to about 9 mg/l at the end of October. The measured DO concentrations were about 1 mg/l less than the estimated DO during this period. The estimated DO was reduced to about 7–8 mg/l in early December because of the low flow. The measured DO was similar (8–9 mg/l) in November and early December. The reduced BOD concentrations were accurately estimated and resulted in higher DO concentrations in the DWSC during both 2005 and 2006 with higher SJR and DWSC flows. Nevertheless, the Aeration Facility might have been operated for some periods in these high flow years. For example, measured DO concentrations were less than 5 mg/l in July and August and less than 6 mg/l in September 2005. Measured DO concentrations were slightly less than 5 mg/l in late July 2006.

Demonstration of Accounting Calculations for 2007

Figure 32a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2007. The measured Garwood flows (5-day moving average) were used for 2007. The SJR flows in 2007 were very low again, similar to flows in 2001–2004. The minimum SJR flows were about 1,000 cfs in July–September. The DWSC flows were less than 500 cfs in early April and from June through September, and again in mid-November through December. The DWSC flows were apparently about 0 cfs in July and August 2007, but a minimum flow of 160 cfs was specified to provide a minimum calculated dilution of the RWCF effluent (DWSC inflow was about 20% effluent).

Figure 32b shows the calculated inflow BOD concentrations for 2007. The estimated river algae BOD concentrations were about 10 mg/l in June. Higher algae concentrations were expected in July–September, corresponding to the low SJR flows of about 1,000 cfs. But the daily DO range at Mossdale did not indicate much algae photosynthesis during these low flow months. The calculated RWCF BOD contributions were less than 3 mg/l throughout the entire year, because the nitrification facility was operating, and the constructed wetlands and additional filters also reduced the CBOD concentrations.

A special study was performed by UOP scientists to determine the effects of the fall pulse flow and the head of Old River installation on downstream algae and BOD entering the DWSC and the DO profile in the DWSC. Boat surveys with sampling and water quality monitoring were conducted from Mossdale to Turner Cut weekly from September 19 through November 15, 2007 (ICF International 2010a). Patterns of algae biomass and BOD were generally decreasing slightly from Mossdale to the DWSC, during this fall periods with flows ranging from less than 250 cfs to 1,500 cfs. The patterns of algae growth, degradation, and zooplankton grazing that were measured with these boat surveys in this transition between Mossdale and the DWSC can only be approximated in the TMDL accounting procedures.

Figure 32c shows the estimated inflow DO to the DWSC for 2007. The minimum inflow DO estimated in 2007 was about 6 mg/l in mid-June corresponding to the highest algae BOD. But the measured DO from R2 and R2a stations indicated much lower inflow DO of about 5 mg/l in July and 6 mg/l in August. The measured DO concentrations suggest that the estimated algae BOD for July and August should have been much higher.

Figure 32d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2007. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in mid-June, corresponding to the highest algae BOD for 2007, and increased to 6–7 for July–September. However, the measured DO in late June was 3 mg/l, was 4–5 mg/l in July and August, and about 5–6 mg/l in September. The estimated DO was about 2 mg/l higher than the measured DO in these three months, indicating that the actual algae BOD should have been higher. Although the estimated RWCF BOD concentrations were much lower with the reduction of ammonia-N concentrations in 2007, the measured DO concentrations were less than 5 mg/l for June–August and less than 6 mg/l in September. Therefore, the Aeration Facility might have been operated for some periods in 2007. Because the DWSC flows were generally less than 250 cfs, one pump and U-tube operations might have been sufficient (4,000 lb/day) to increase the measured DO to the DO objective.

Demonstration of Accounting Calculations for 2008

Figure 33a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2008. The measured Garwood flows (5-day moving average) were used for 2008. The SJR flows in 2008 were about 2,000 cfs in the winter months and were reduced to about 1,000 cfs from mid-June through September. The DWSC flows were less than 500 cfs in parts of January and February, June–September, and for most of November and December 2008. A minimum flow of 160 cfs was again specified.

Figure 33b shows the calculated inflow BOD concentrations for 2008. The estimated river algae BOD concentrations were about 10 mg/l in June, July, and August (as was expected for similar low flows in 2007). The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility was operating, and because the constructed wetlands and additional filters also reduced the CBOD concentrations.

Figure 33c shows the estimated inflow DO to the DWSC for 2008. The minimum inflow DO estimated in 2008 was about 7 mg/l in June–August corresponding to the highest algae BOD. But the measured DO from R2 and R2a stations indicated lower inflow DO of about 5–6 mg/l in July and 6 mg/l in August. The measured DO concentrations suggest that the estimated algae BOD for June–August should have been somewhat higher.

Figure 33d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2008. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation for most of the year. The minimum estimated DO was about 5 mg/l in June–August, corresponding to the highest algae BOD for 2008, and increased from 6 to 8 mg/l in September. The measured DO in June was about 5–6 mg/l and was increased slightly in July and August. July and August were the first months of operational testing (about half-time) of the Aeration Facility, and the Aeration Facility operations increased the RRI DO data by 1–2 mg/l. The measured DO in early September was about 5 mg/l, and then increased to about 7 mg/l with the Aeration Facility operated for 10 days at the end of the month. The effects of the Aeration Facility are not yet included in the TMDL accounting calculations, so the estimated DO does not reflect periods of testing in 2008. The measured DO in June was generally just below 5 mg/l, so one pump operations may have been sufficient to meet the DO objective. Some Aeration Facility operations may also have been needed in July–September 2008 to meet the DO objectives. The Aeration Facility can generally increase the RRI DO by 1–2 mg/l.

Demonstration of Accounting Calculations for 2009

Figure 34a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2009. The measured Garwood flows (5-day moving average) were used for 2009, except for July and August when a minimum flow of 160 cfs was specified (measured flows were less than 0 cfs–reversed). The SJR flows in 2009 were extremely low, with only about 1,000 cfs in the winter months, a small peak flow of 2,500 cfs during the VAMP period, and a minimum of only 500 cfs at Vernalis in July and August. The DWSC flows were less than 500 cfs for most of the year, and apparently reversed in July and August.

Figure 34b shows the calculated inflow BOD concentrations for 2009. The estimated river algae BOD concentrations were greater than 5 mg/l in the low flow period of March and April, and were between 5 and 10 mg/l from June through September, with a peak of 15 mg/l in mid-July. The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility was operating, and the constructed wetlands and additional filters also reduced the CBOD concentrations. River algae was the only substantial source of BOD entering the DWSC during 2009.

Figure 34c shows the estimated inflow DO to the DWSC for 2009. The minimum estimated DO was about 6 mg/l in mid-July corresponding to the highest algae biomass estimate. The measured DO at R2 and R2a was about 5 mg/l from mid-May through July, and was about 6 mg/l in August. These measured DO concentrations suggest that the river algae biomass was higher than estimated from the daily range of DO at Mossdale. A more reliable estimate of the river algae BOD may be required for more accurate estimates of the inflow BOD and corresponding inflow DO to the DWSC.

Figure 34d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2009. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation in the winter and decreased to about 7 mg/l during the March–April period with increased river algae. The measured DO during this period was higher (8–9 mg/l), suggesting the increased river algae BOD did not actually reach the DWSC. The estimated DO decreased in May and was 5–6 mg/l in June. The minimum estimated DO was about 5 mg/l in July, but decreased to 3 mg/l during the peak algae biomass estimate. The estimated DO was 5–6 mg/l in August and September, and increased to about 1 mg/l below DO saturation in October-December. The measured DO was 5–6 mg/l from June to mid-September, and increased to 7 mg/l at the end of September. The measured DO was about 2 mg/l below DO saturation in October–December, with a peak DO of 9 mg/l measured during the late October pulse flow period. The estimated DO was generally within 1 mg/l of the measured DO for most of the year. Adjustments in the river algae BOD estimates would likely improve the estimated DWSC minimum DO concentrations.

The Aeration Facility was operated for testing in 2 weeks of September and 1 week of October 2009. Although the measured DO was about 5 mg/l for the summer months, one pump operations of the Aeration Facility might have been used to increase the DO to about 6 mg/l in June–September. As observed in most years, September temperatures are often high enough that saturated DO is still about 8 mg/l, and the measured DO concentrations are often between 5 mg/l and 6 mg/l. The Aeration Facility may have been needed to increase the September DO concentrations to 6 mg/l.

Demonstration of Accounting Calculations for 2010

Figure 35a shows the measured daily flows at Garwood and the estimated daily DWSC flows for 2010. The measured Garwood flows (5-day moving average) were used for 2010 (through September). The SJR flows at Vernalis in 2010 were moderate, with winter flows of about 2,500 cfs, spring flows of about 5,000 cfs, and minimum flows of less than 1,500 cfs from mid-July to mid-September. The DWSC flows were less than 500 cfs for a short period in early February and from mid-July to mid-September.

Figure 35b shows the calculated inflow BOD concentrations for 2010. The estimated river algae BOD concentrations were greater than 5 mg/l in the low flow period of late March, were greater than 10 mg/l in mid-July, but declined to about 5 mg/l in August and September. The calculated RWCF BOD contributions were less than 2 mg/l throughout the entire year, because the nitrification facility reduced the ammonia-N concentration to about 1 mg/l. The combined BOD was less than 5 mg./l for the entire year except for July and August.

Figure 35c shows the estimated inflow DO to the DWSC for 2010 (through August). The minimum estimated DO was only about 1 mg/l less than saturated DO except for the late March and July periods with higher river algae BOD estimates. The measured DO was also generally just 1–2 mg/l below DO saturation, until late July and early August when the measured DO at R2 and R2a was 4–5 mg/l. These low DO concentrations suggest that the estimated river algae BOD concentrations must have been higher than was estimated from the daily DO range at Mossdale. A more reliable estimate of the river algae BOD may be required for more accurate estimates of the inflow BOD and corresponding inflow DO to the DWSC.

Figure 35d shows the daily estimated minimum DO in the DWSC, based on the inflow DO and inflow BOD for 2010. The minimum estimated DO concentrations were about 2 mg/l below the DO saturation in the winter but decreased to about 7 mg/l during the late March period with increased river algae. The measured DO during February and early March was lower than the estimated DO, suggesting higher BOD concentrations than were estimated. The estimated DO decreased to 6 mg/l in late June, was a minimum of about 4 mg/l in mid-July, and increased from 5 to 6 mg/l in August. The measured DO was a minimum of 5 mg/l in late July, and was 5–6 mg/l in August. The estimated DO in the summer of 2010 was relatively high because of higher SJR flows in June (higher than 3,000 cfs) and relatively low algae biomass estimated in July and August. The estimated DO was generally within 1 mg/l of the measured DO for most of the year. Adjustments in the river algae BOD estimates would likely improve the estimated DWSC minimum DO concentrations.

The Aeration Facility was operated for testing for 10 days in August and 7 days in September of 2010. Although the measured DO was less than 5 mg/l on in late July, one pump operations of the Aeration Facility might have been used to increase the DO to about 6 mg/l from mid-July to mid-September. The summer DO concentrations in the DWSC during the past 4 years (2007–2010) have been only slightly less than 5 mg/l (DO objective) in June–August, and slightly less than 6 mg/l (DO objective) in September. This appears to be the direct result of the City of Stockton RWCF nitrification facility, which has reduced the effluent ammonia-N concentrations to about 1 mg/l. The minimum DO in the DWSC is now primarily controlled by the upstream river algae BOD, which is only high enough to cause low DO conditions in the summer months. Additional measurements of the river algae concentrations at Mossdale would allow more accurate estimates of the DWSC inflow BOD and the resulting minimum DO concentrations, and could be used to forecast periods when the Aeration Facility could be operated to increase the DWSC DO concentrations.

Conclusions and Recommendations

This appendix has reviewed portions of the SJR DO TMDL implementation program and described possible TMDL accounting procedures that could be used to track SJR and DWSC flows and water quality conditions that are directly related to the measured DWSC DO concentrations. This appendix is included in the *Stockton Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Project Final Report* (ICF International 2010c) as a contribution toward the future SJR DO TMDL implementation plan to help meet the DO objective, using all available information about the SJR and DWSC water quality conditions and biochemical processes and influences. These suggested TMDL accounting procedures could be used as a framework for continued research to better understand some of the remaining uncertainties, and as a tool for integrating and interpreting water quality monitoring data from the SJR stations in DWSC stations. These accounting procedures incorporate the findings from the previous DWSC and upstream studies that were funded by CALFED and ERP grants.

The first section of this appendix reviewed the SJR DO TMDL implementation plan described in the 2005 Basin Plan Amendments, which discussed the need for quantitative daily accounting of the various effects on DO in the DWSC and for identification of proportional responsibilities for future low DO concentrations. Because the accuracy of the suggested TMDL accounting calculations has been demonstrated by matching the estimated minimum DO patterns with the measured DO concentrations for 2000–2010, these calculations can be used with confidence to estimate the effects of DWSC geometry, SJR and DWSC flows, and BOD concentrations from upstream algae and from the City of Stockton RWCF effluent.

The second section of this appendix described the framework and specific calculations for possible SJR DO TMDL accounting procedures that might be used for estimating the effects of SJR and DWSC flows, upstream river algae concentrations, and Stockton RWCF effluent concentrations on the combined inflow BOD to the DWSC and the resulting DO concentrations in the DWSC. The accounting procedures are described as three segments: Segment 1 provides an estimate of upstream river algae at Mossdale from several water quality monitoring records, Segment 2 provides an estimate of DWSC flows that control the fraction of river algae transported to the DWSC and the dilution of the Stockton RWCF effluent concentrations, and Segment 3 calculates the minimum DO in the DWSC as a function of inflow BOD (from river algae and RWCF effluent) that controls the inflow DO and the downstream DO-BOD balance in the DWSC.

These daily accounting procedures were demonstrated with a series of comparative graphs showing the estimated DO compared to the measured DO in the DWSC for 2000–2010. Because these years included a wide range of SJR flows and water quality conditions, the ability of the accounting procedures to accurately estimate the DWSC DO concentrations for each of these different years was generally confirmed. These TMDL accounting calculations could be used as a tool for understanding the causative factors for low DO in the DWSC and assigning proportional responsibilities for operating the Aeration Facility (or other implementation measures) that could increase the DWSC DO concentrations to meet the DO objective. If approved by RWQCB staff and stakeholders, this suggested accounting procedure could also provide a reporting framework to demonstrate compliance with the SJR DO TMDL implementation program.

The further development and approval of these proposed daily accounting procedures by the CVRWQCB and stakeholders will be necessary prior to their use as part of the SJR DO TMDL implementation program. The future operation of the Aeration Facility as part of the TMDL implementation plan to meet the DO objective is dependent on the adoption of a mechanism to regulate and fund its operation. The Aeration Facility is a promising method for reducing or eliminating periods of low DO concentrations (below the DO objective) in the DWSC, thus reducing or eliminating the need for upstream BOD load reductions or SJR flow management. Two major recommendations follow from the development and comparison of the daily accounting procedures for the historical 2000–2010 SJR and DWSC flows and water quality conditions.

- **Monitoring Strategy**. A future SJR DO TMDL monitoring strategy should be developed based on the existing measurements and previous special studies of the DWSC and the upstream river hydrology and water quality processes. A TMDL monitoring strategy would likely include water quality monitoring in the DWSC and at several upstream SJR stations. The future SJR DO TMDL monitoring strategy should be developed and approved by the CVRWQCB staff and stakeholders; accordingly, it is not discussed in this appendix. However, the proposed accounting procedures described herein may provide a useful template for specifying the most important monitoring locations and water quality variables that could be included in a future monitoring and reporting framework.
- **Operations Strategy**. A future operations strategy for the Aeration Facility should be developed by stakeholders to guide the effective and efficient operations as part of the SJR DO TMDL implementation plan. The accounting procedures described in this appendix demonstrate that the upstream SJR flow and water quality (algae) conditions as well as the DWSC flow and dilution of the RWCF are each important in determining the minimum DO in the DWSC, and may provide reliable forecasting of low-DO conditions. The Aeration Facility operations strategy could be developed by stakeholders based on a review of the DWSC DO conditions during recent years (2000–2010) and the evaluation of expected changes in DWSC DO from increased flows or reduced BOD concentrations. The monitoring strategy together with the operations strategy should identify periods when the Aeration Facility could be effectively used to increase the DO concentrations in the DWSC and reduce any future DO objective deficits. The operations strategy might include coordinated DWSC operations that would satisfy the existing aeration requirements for the Port of Stockton (for dredging permit) and the USACE (for channel deepening effects) as well as the SJR DO TMDL implementation requirements. The future operation of the Aeration Facility by a “stakeholder alliance” as part of the SJR DO TMDL implementation plan would require an agreement between the CVRWQCB and stakeholders for monitoring, daily accounting of flows and water quality, and funding allocation procedures.

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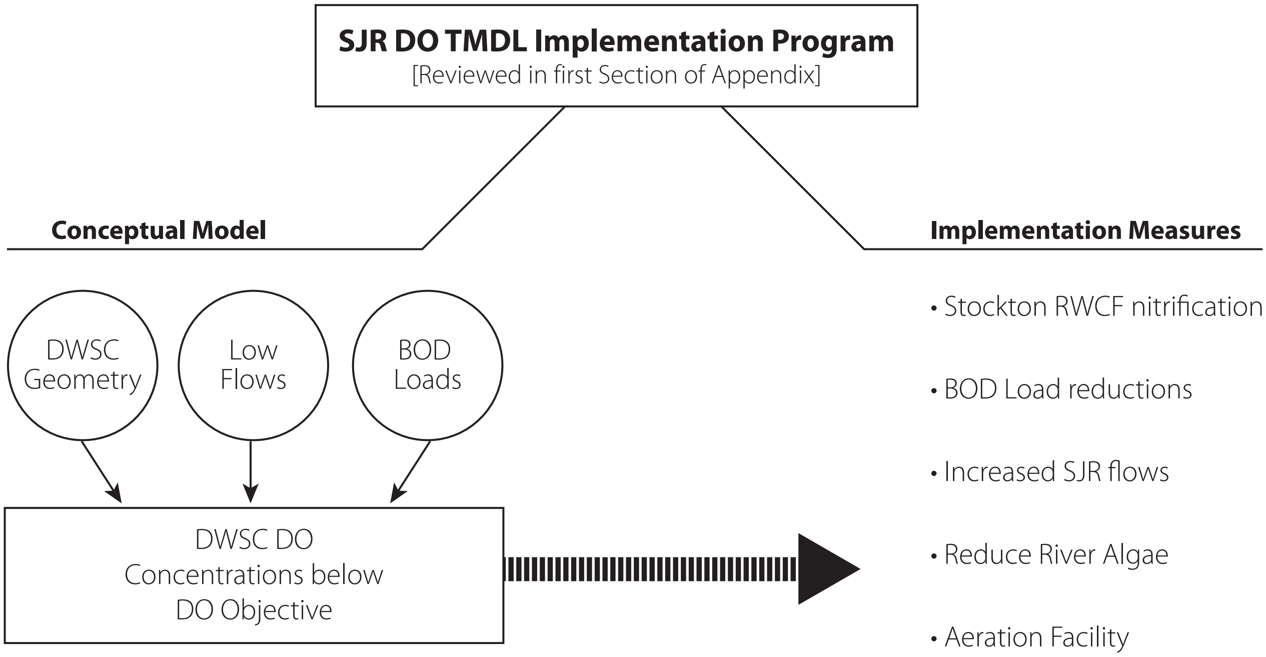

TMDL Accounting Procedures

[Reviewed in second Section of Appendix]

+ Needed to provide quantitative tracking of factors causing low DWSC DO

+ Needed to identify benefits of implementation measures

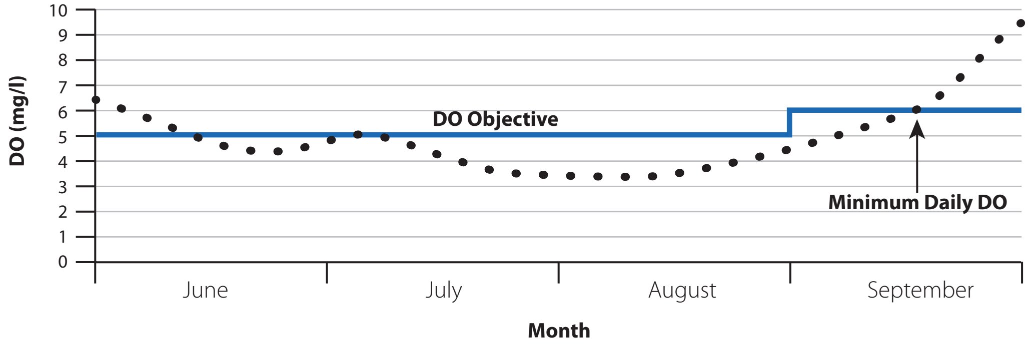

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Figure 1a
Diagram of the SJR DO TMDL Implementation Program

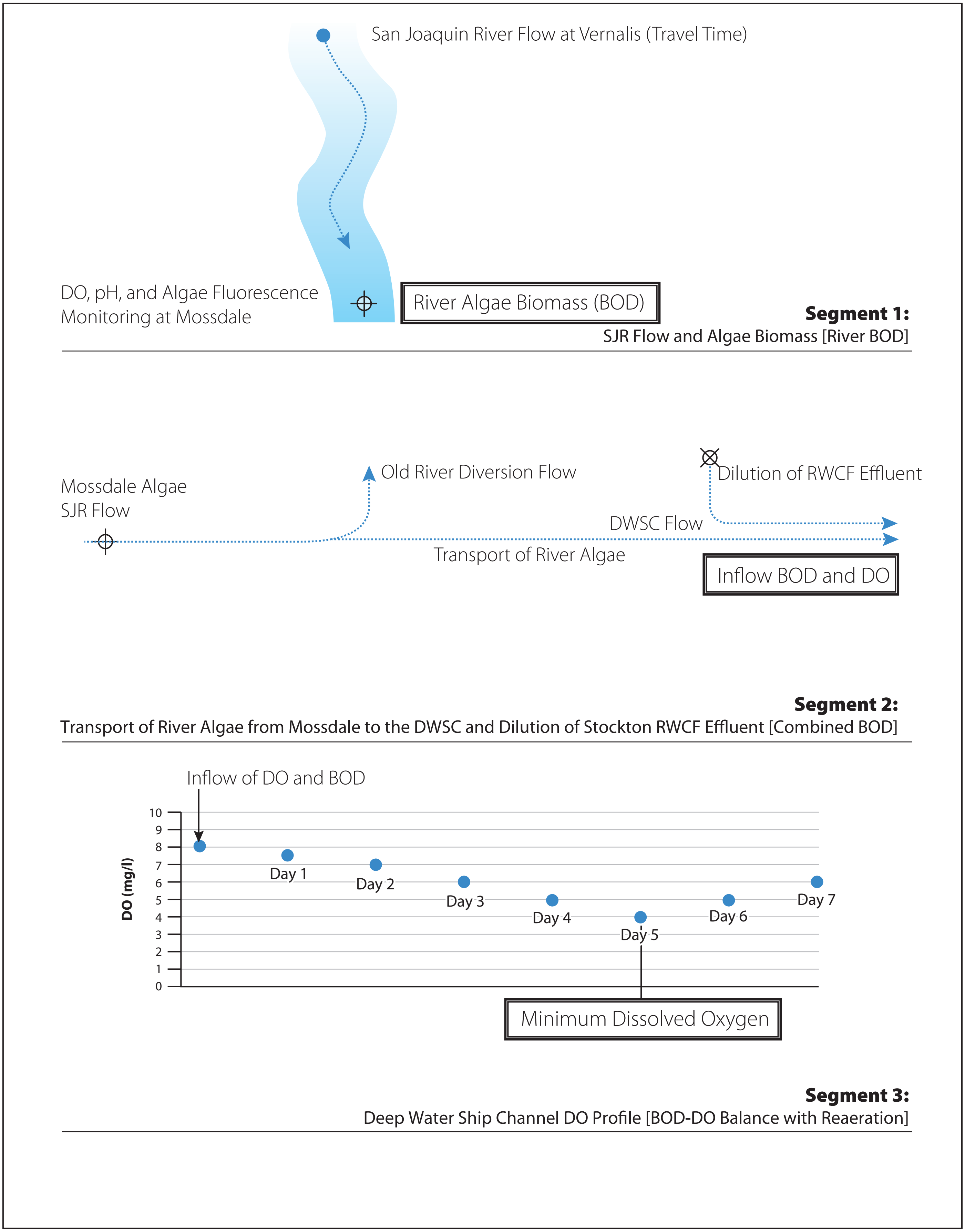

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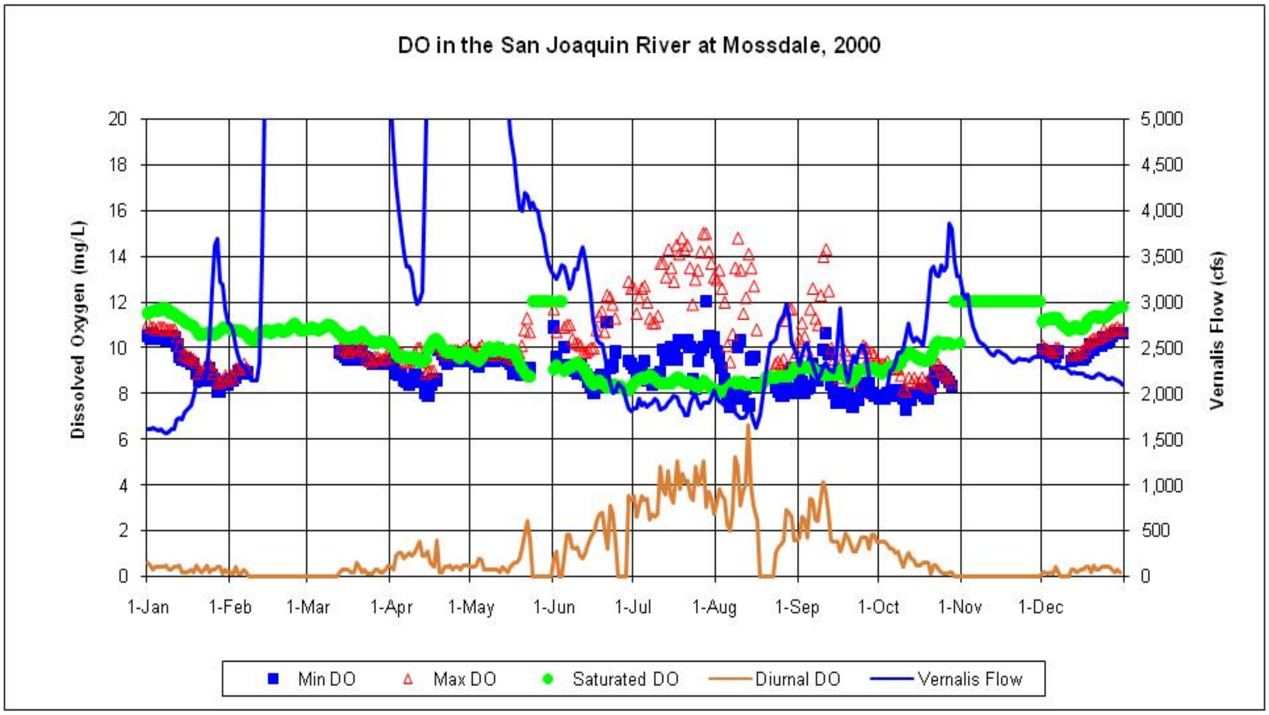
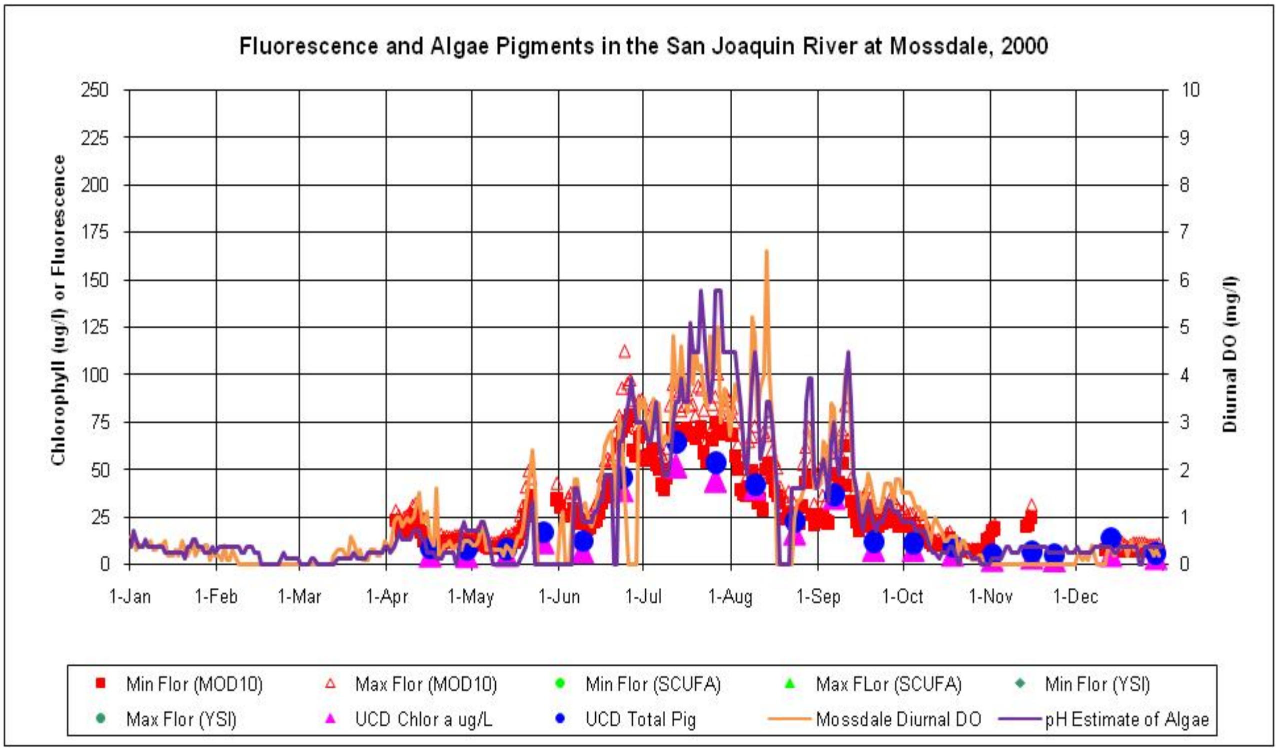
Figure 1b
Framework for the SJR DO TMDL Accounting Procedures

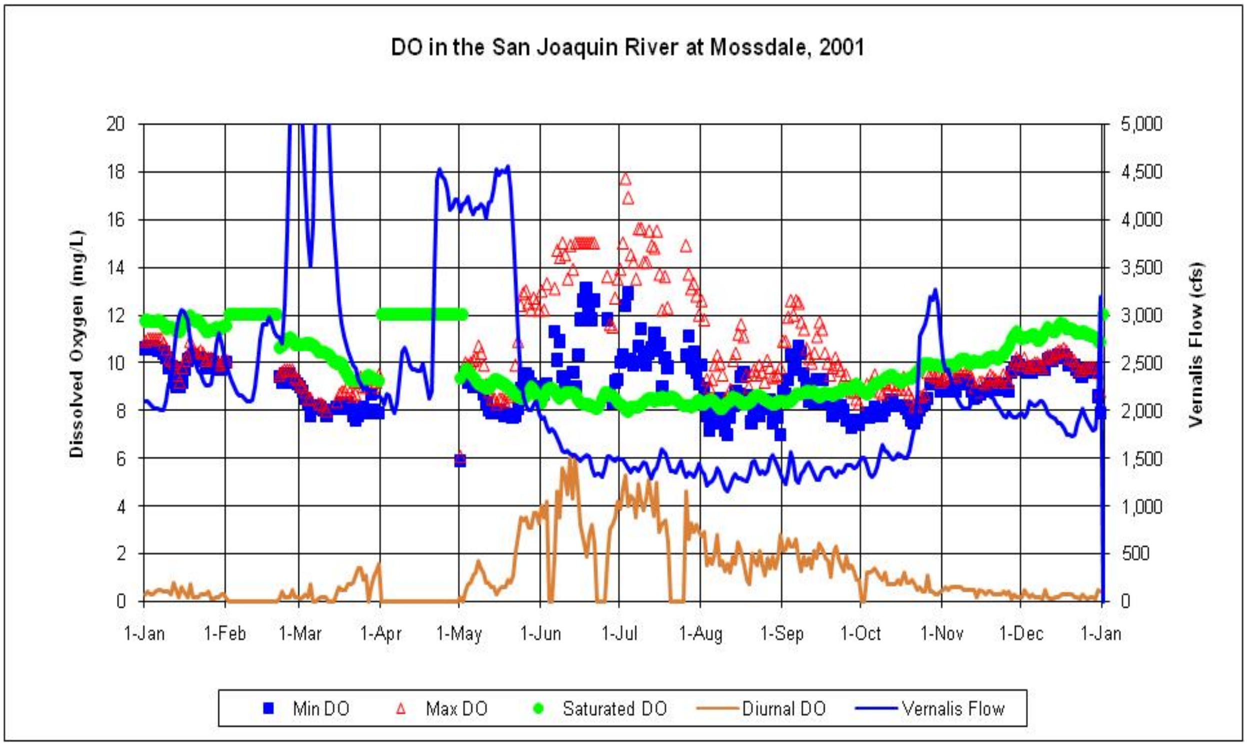


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2000.

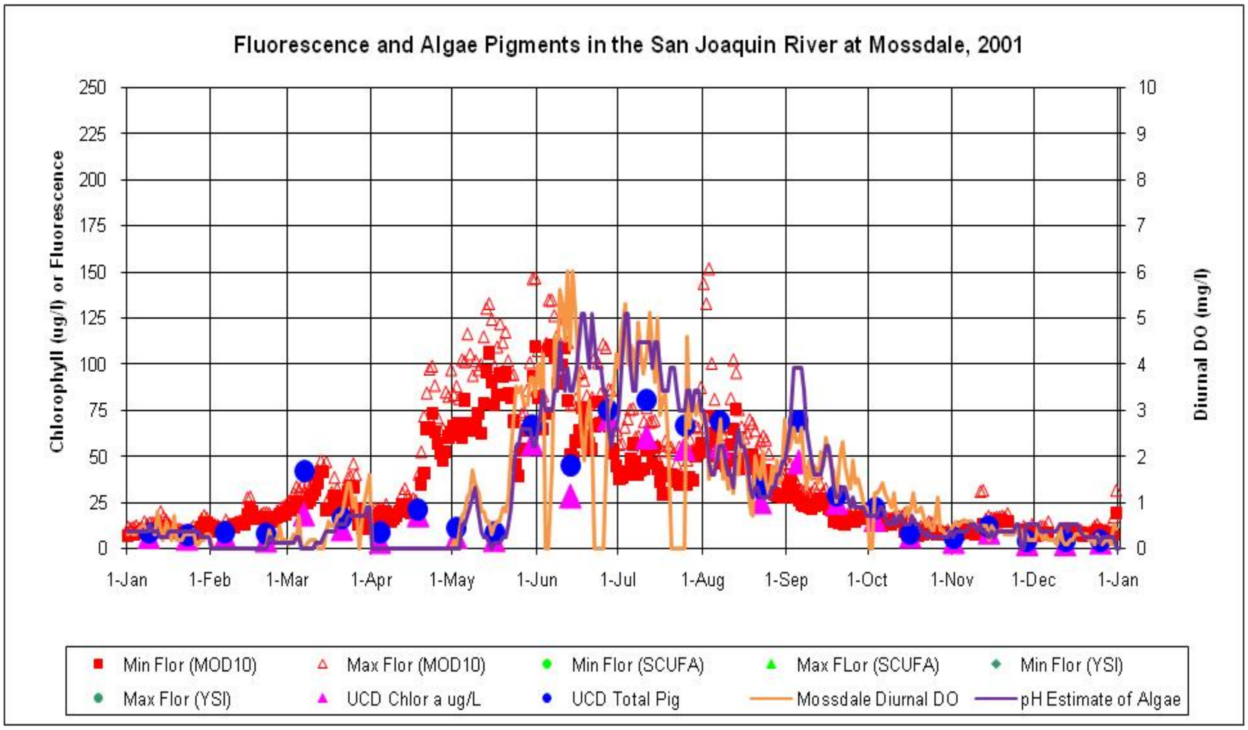


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2000. (Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 2

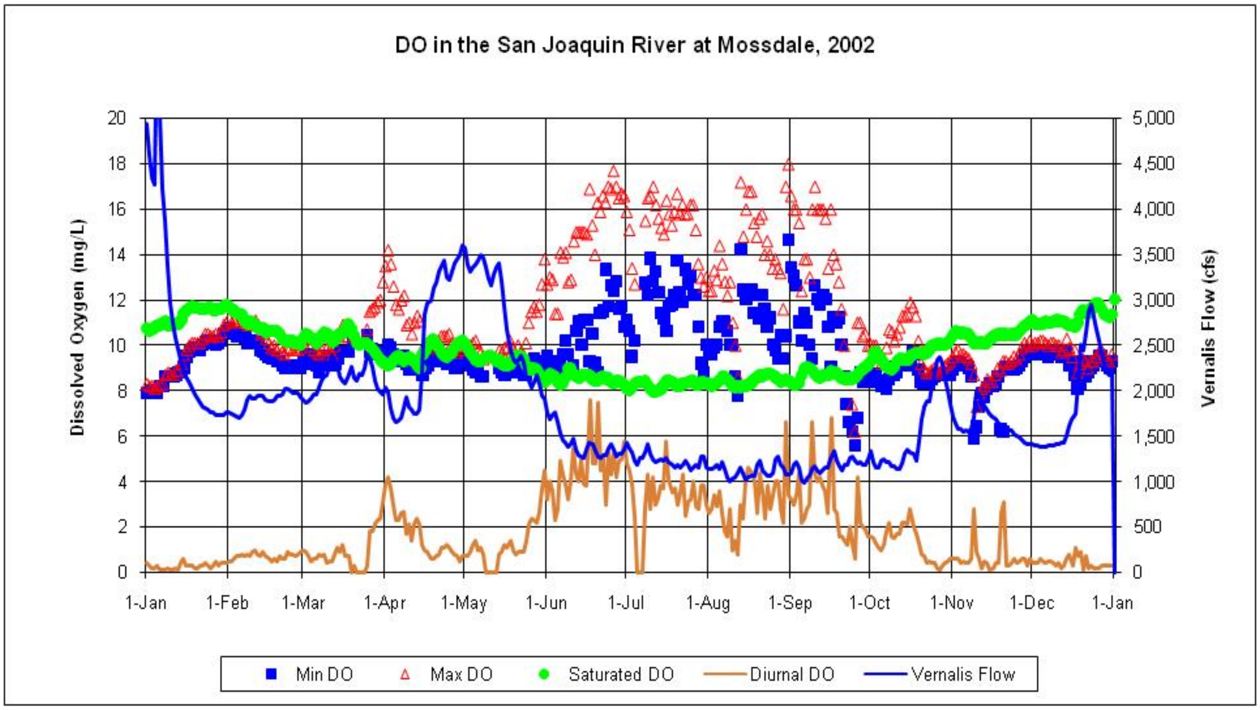


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2001.

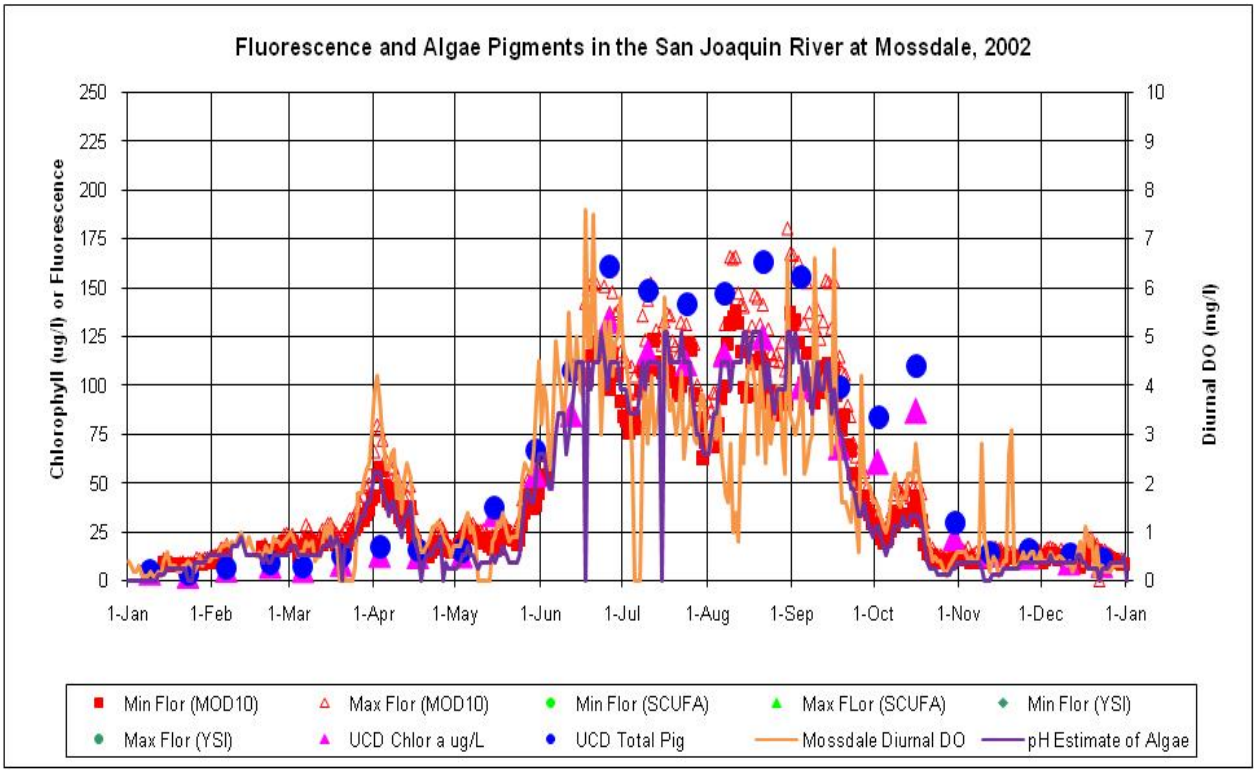


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2001. (Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 3

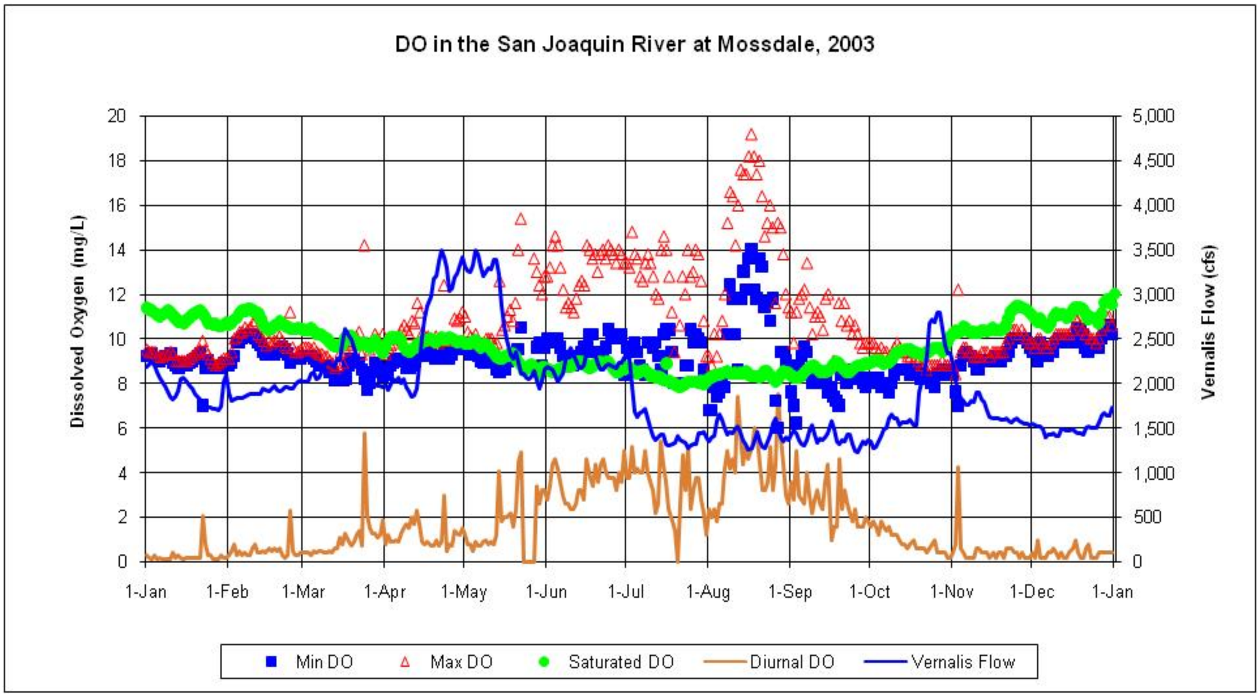


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2002.

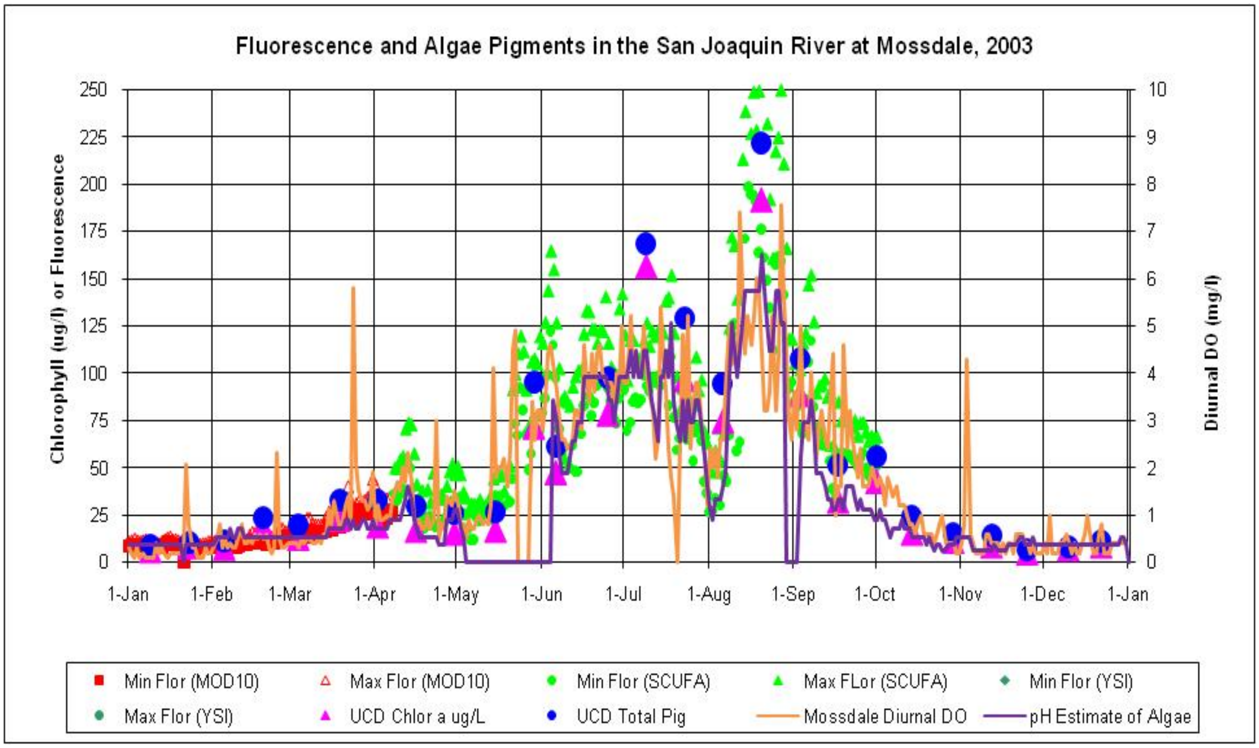


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2002. (note: Turner Model 10 fluorescence multiplied by 0.5 to match UCD pigment).

Figure 4

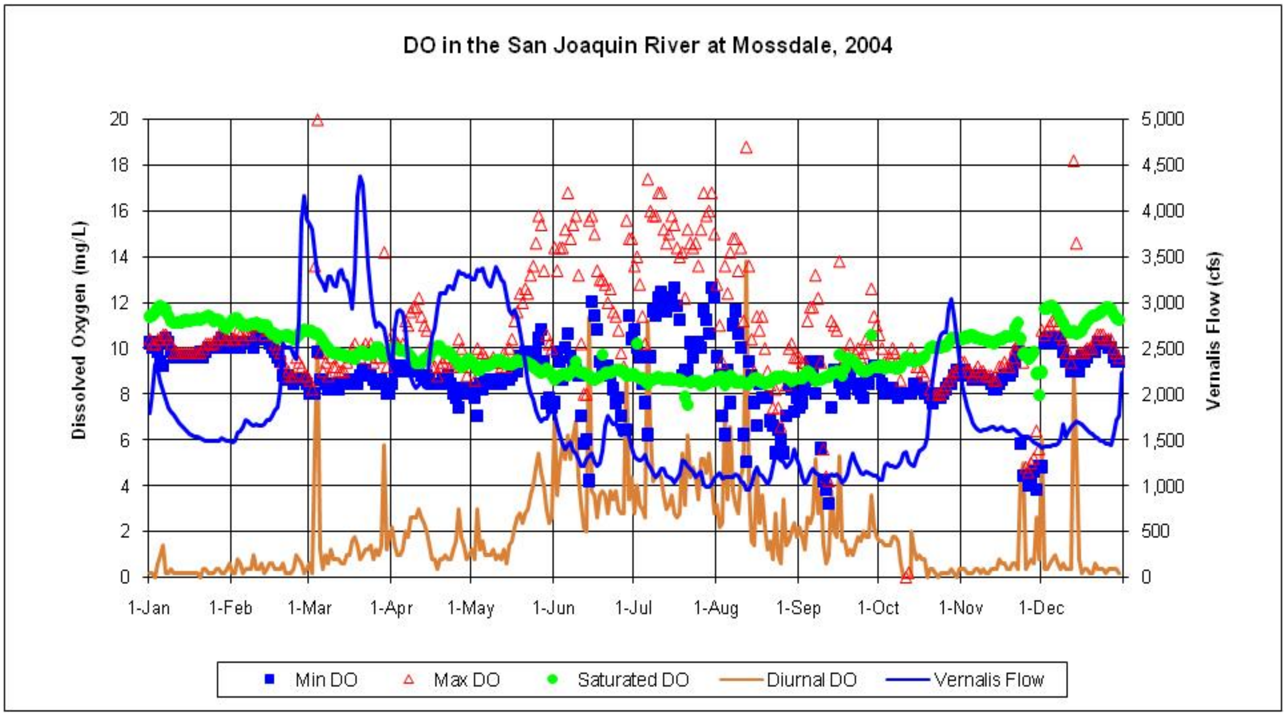


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2003.

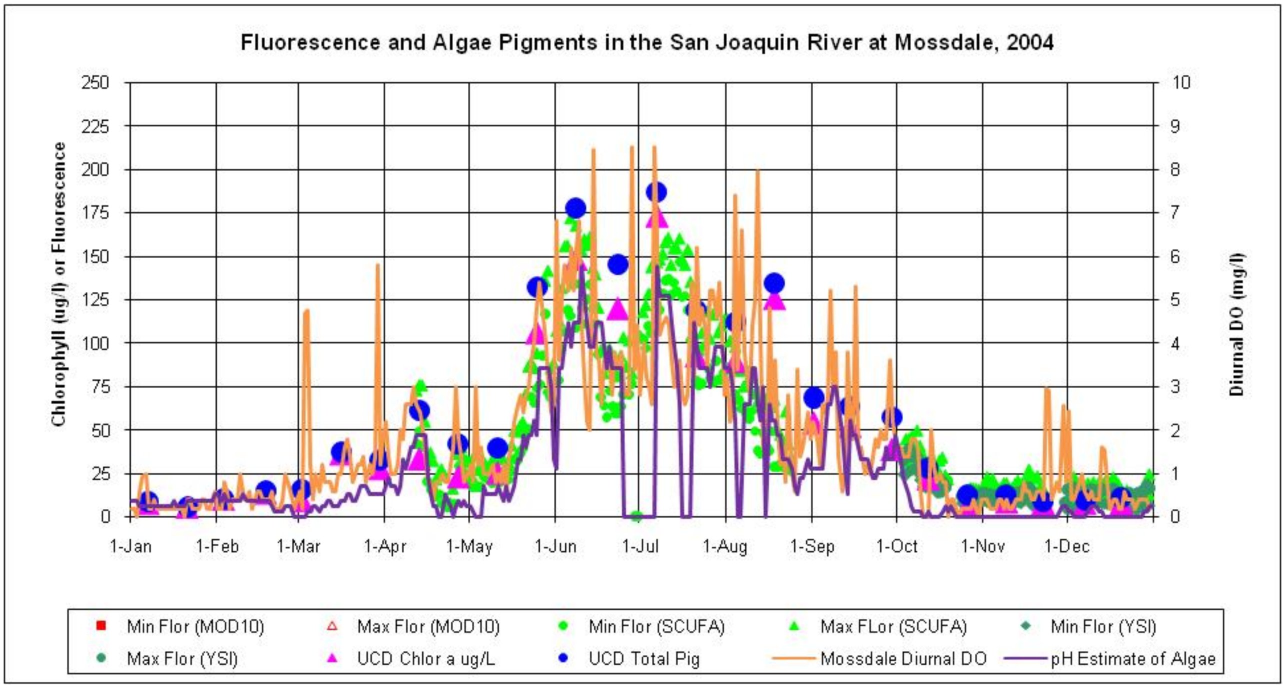


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2003. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment).

Figure 5

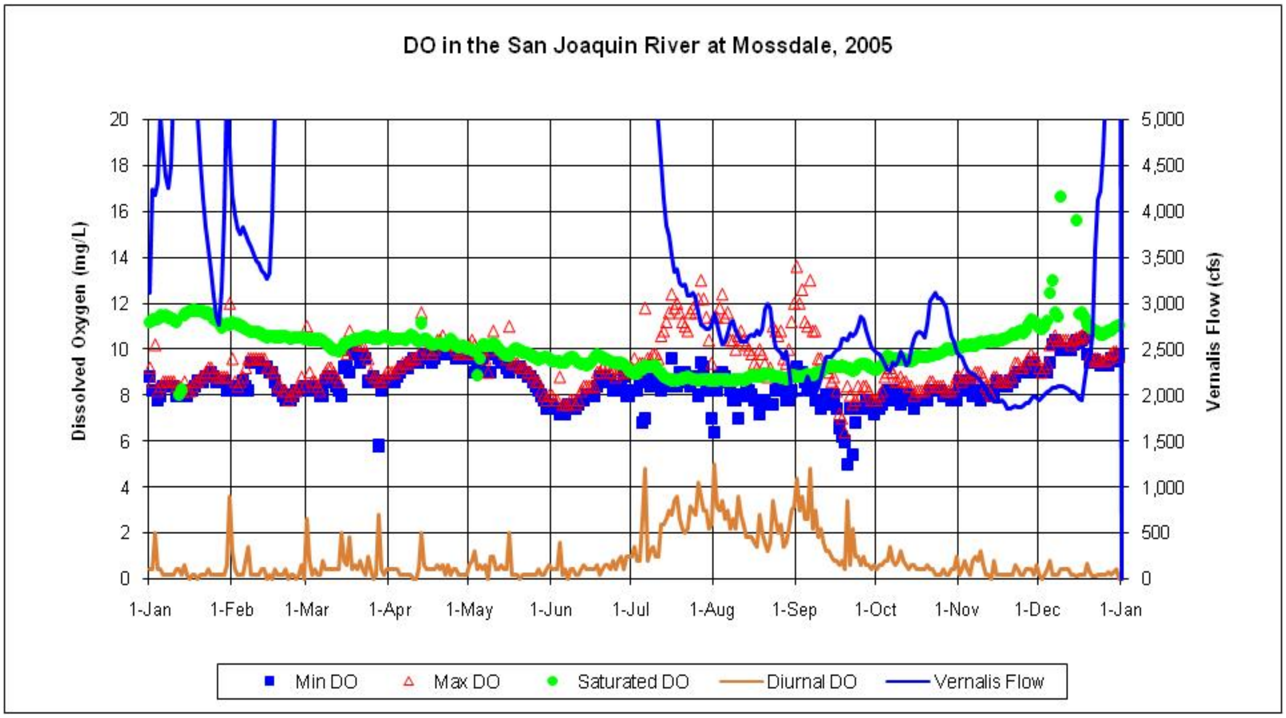


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2004.

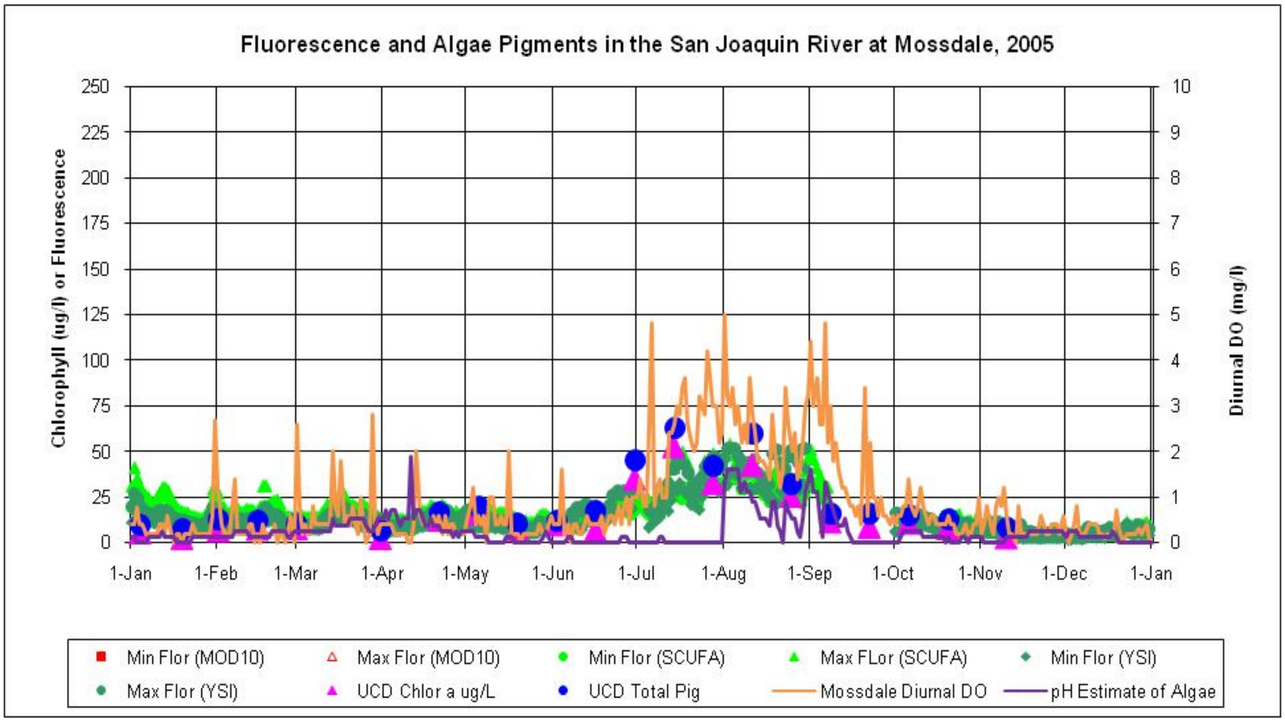


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2004. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment. YSI fluorescence (began in October) multiplied by 1.5 to match UCD pigment).

Figure 6

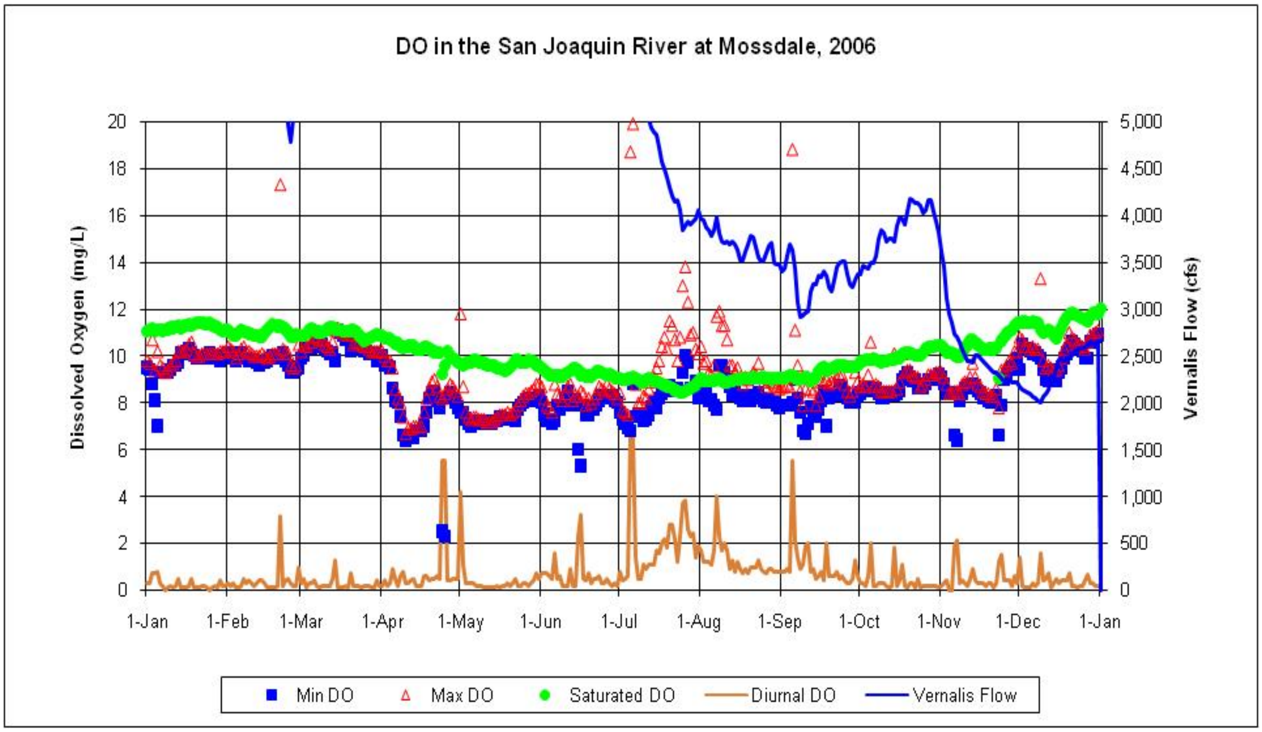


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2005.

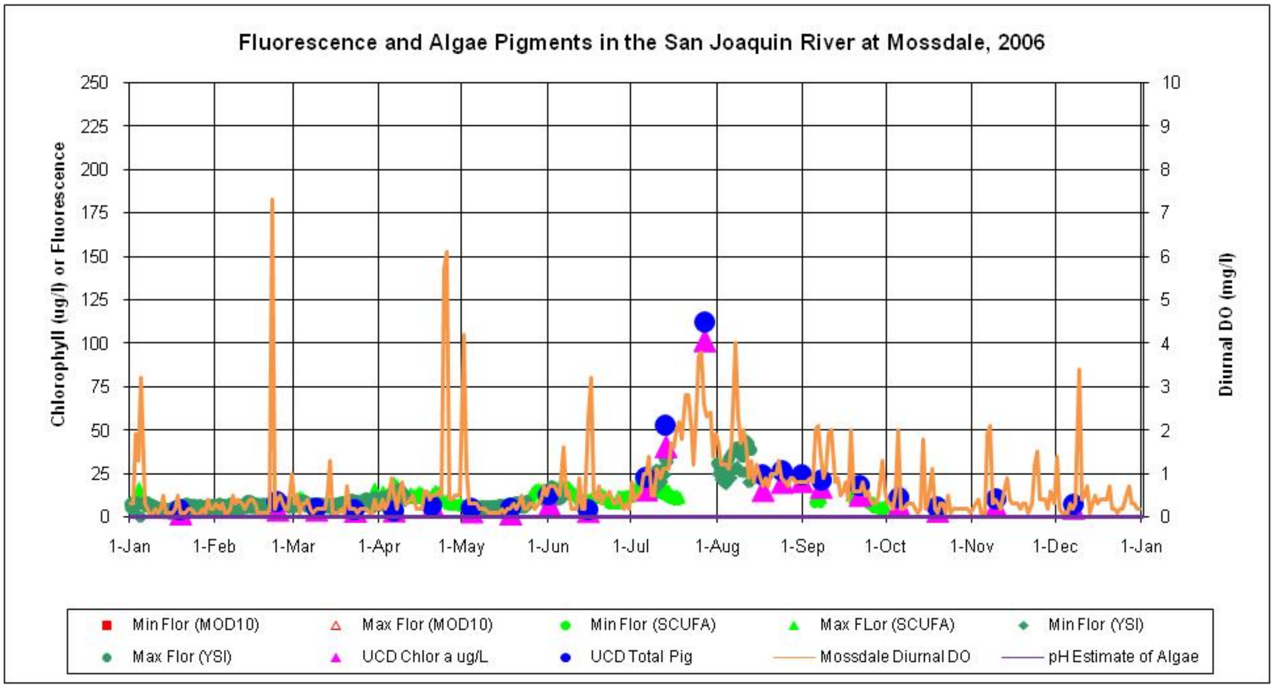


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (UC D and UOP) Concentrations at Mossdale for 2005. (note: Turner SCUFA fluorescence multiplied by 2.5 to match UCD pigment [ends in September]. YSI fluorescence multiplied by 1.5 to match UCD pigment).

Figure 7

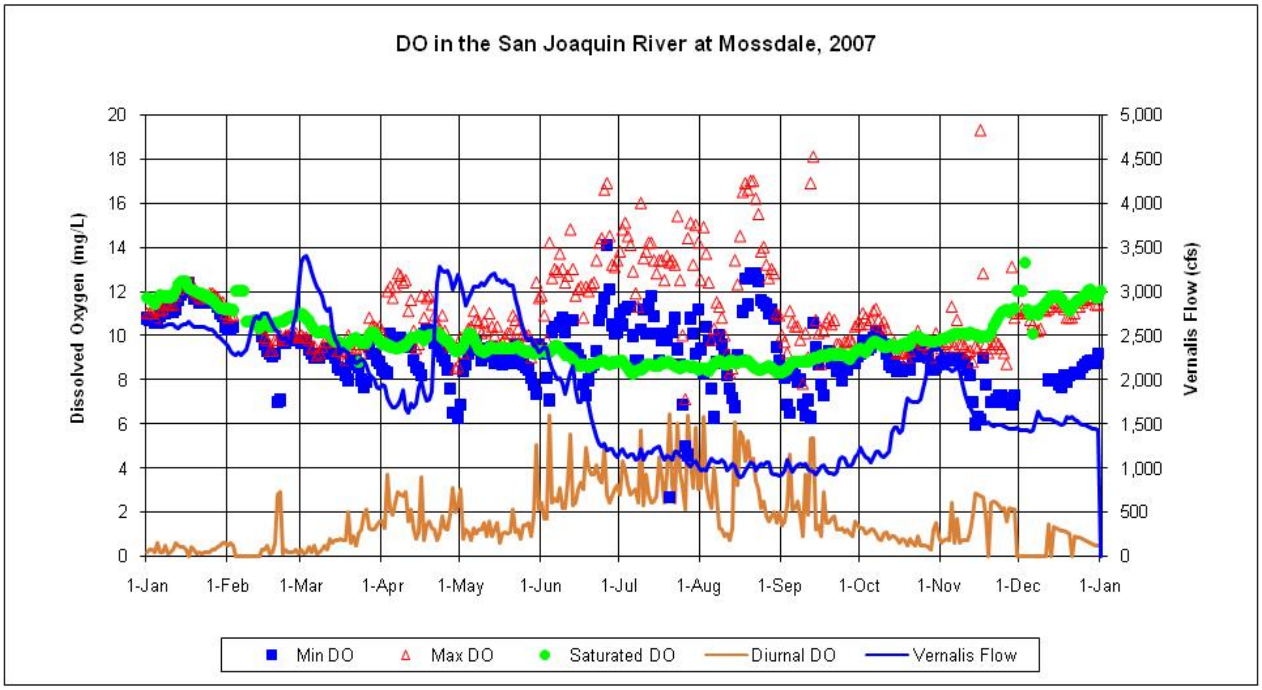


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2006.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH (not shown), Measured Fluorescence (not shown), and Extracted Algae Pigment (UOP) Concentrations at Mossdale for 2006. (note: YSI fluorescence multiplied by 1.5 to match UCD pigment).

Figure 8



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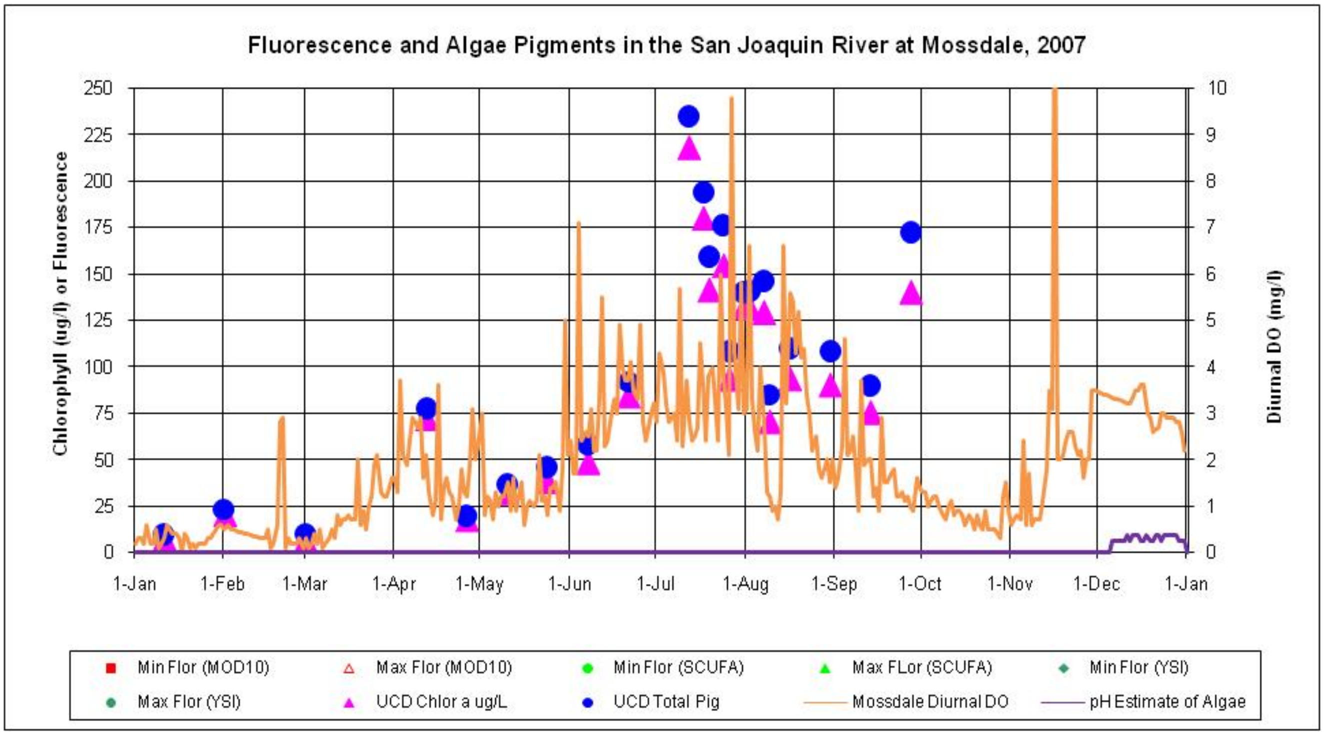
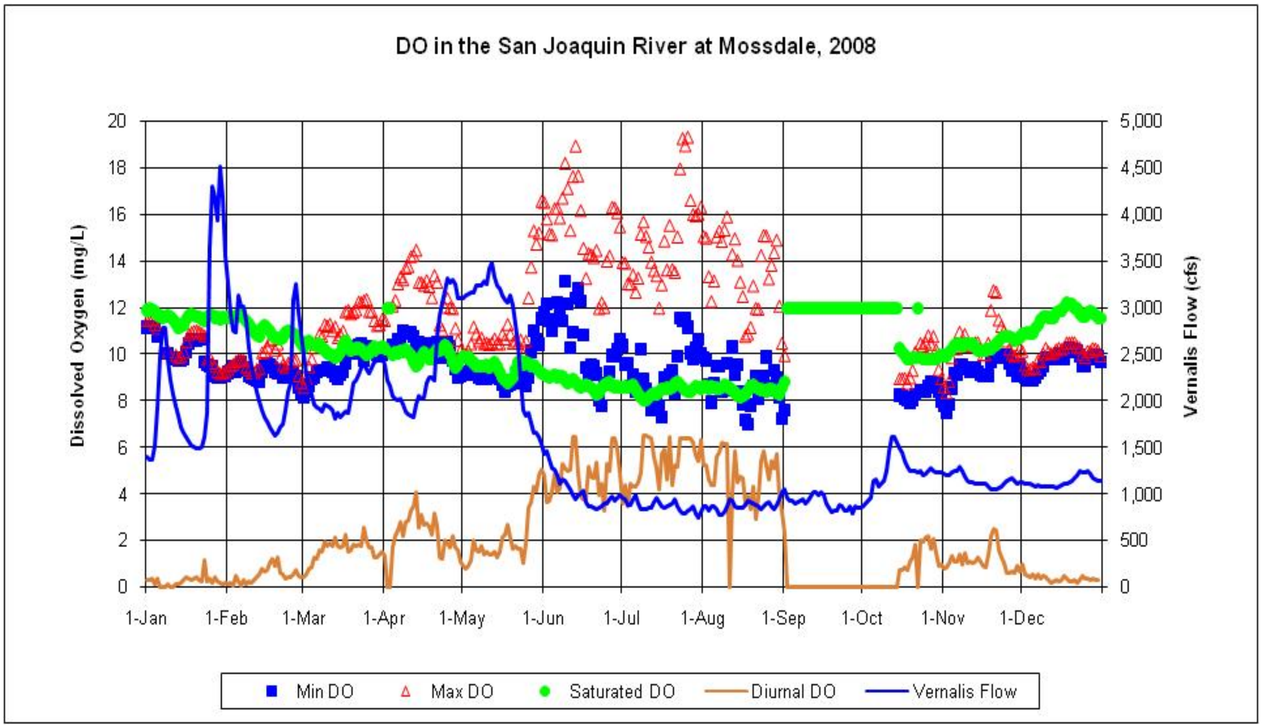
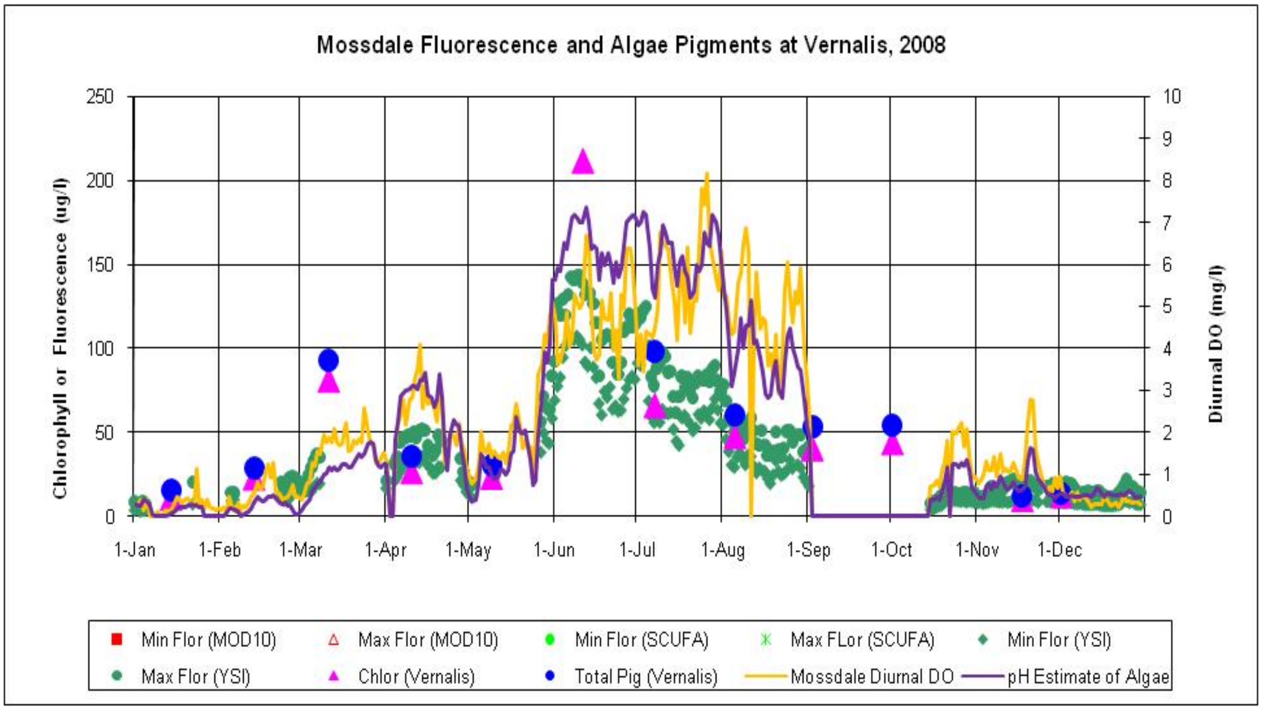


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH(not shown), Measured Fluorescence (not shown), and Extracted Algae Pigment (UC Davis) Concentrations at Mossdale for 2007.

Figure 9

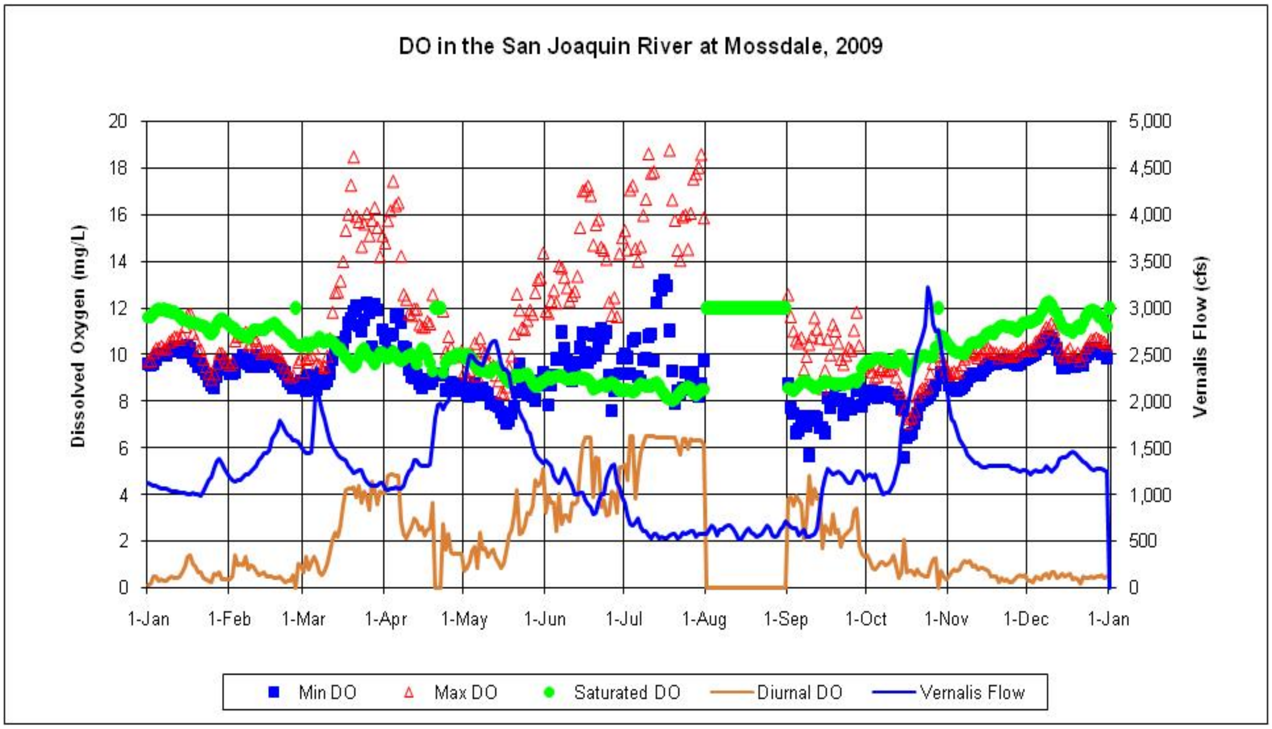


a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2008.

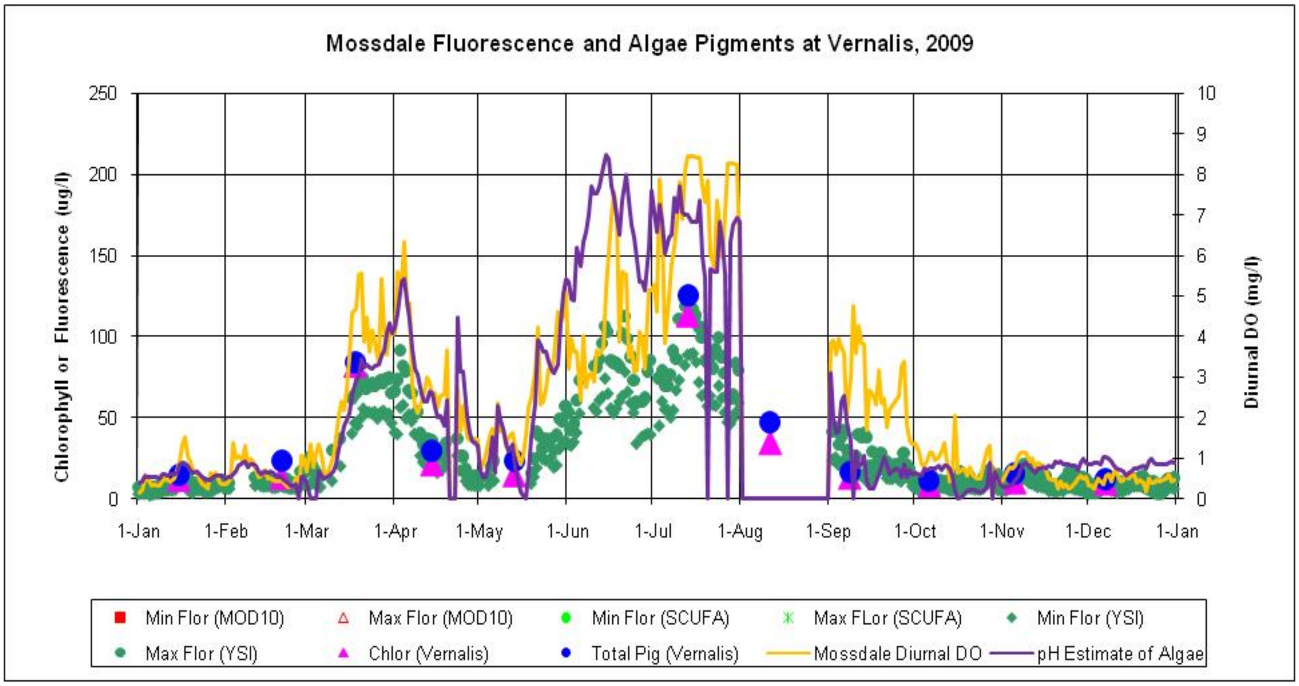


b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2008. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

Figure 10



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2009.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2009. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

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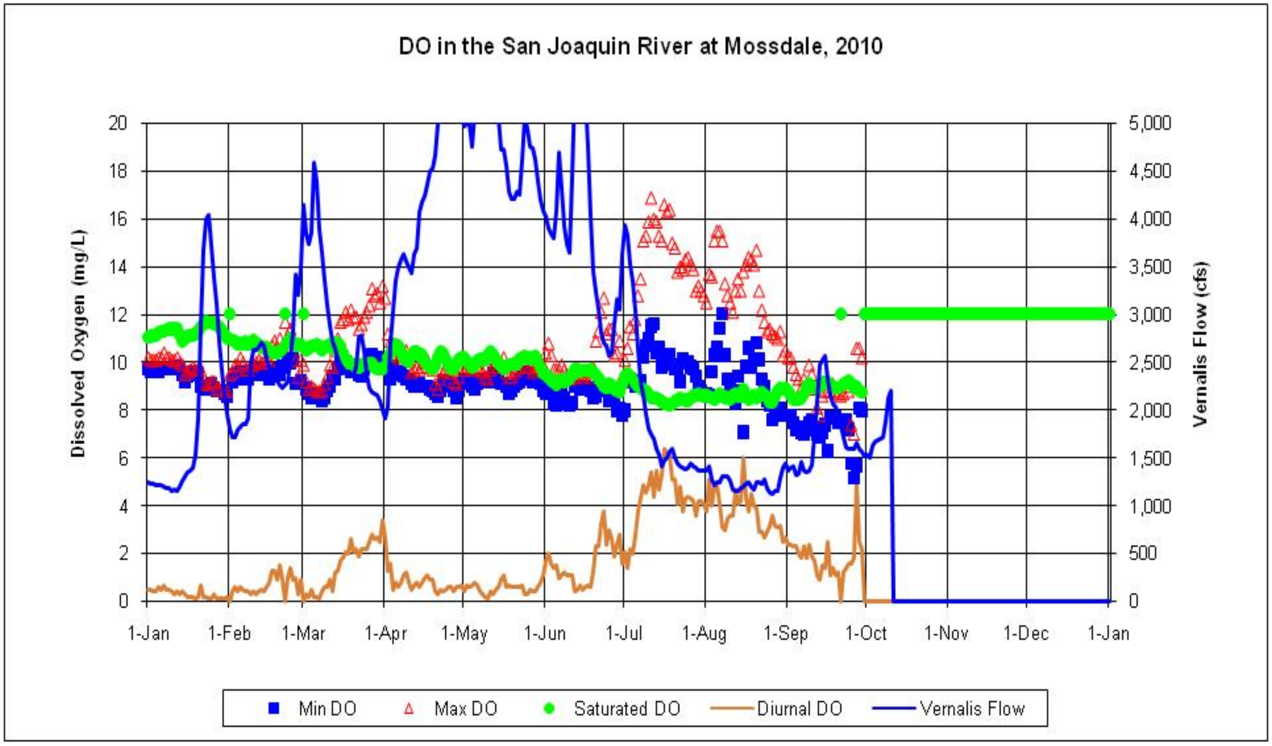
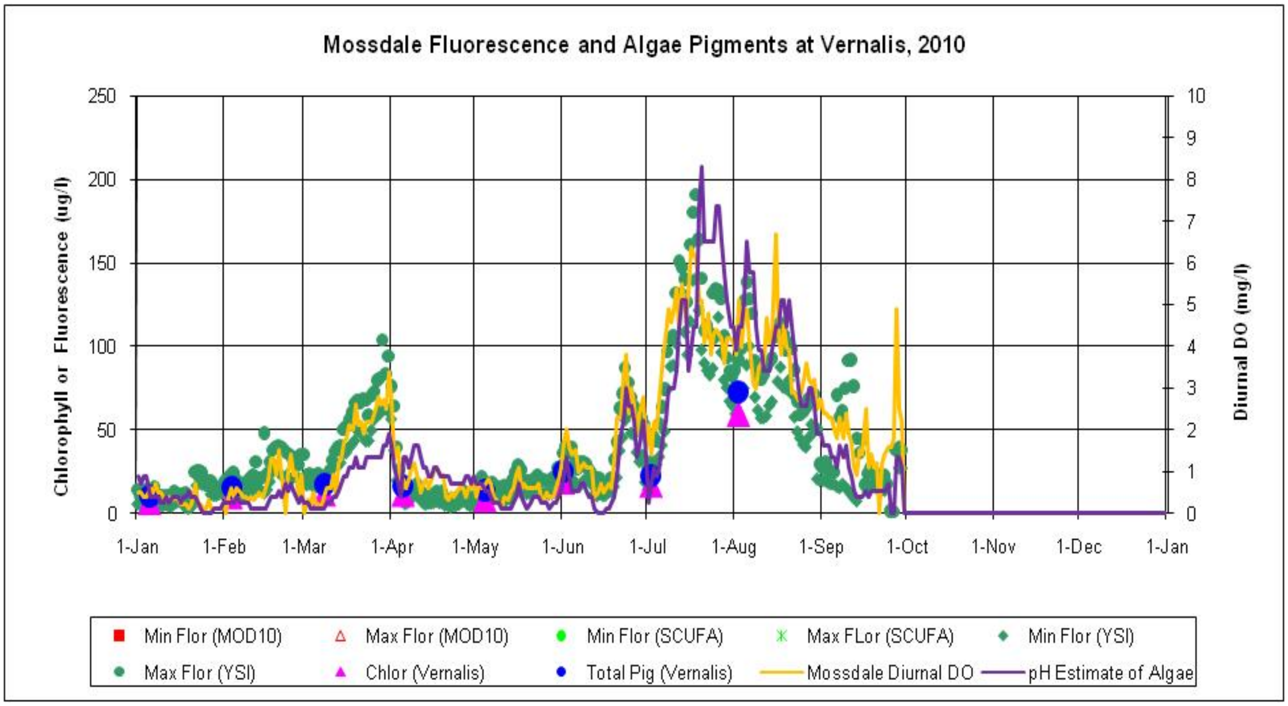
Figure 11



a) Daily Minimum, Maximum, and Saturated DO Concentrations at Mossdale, with the SJR Flow at Vernalis Shown as Reference for 2010.



b) Comparison of the Daily DO Range, Estimated Algae Pigment from Maximum pH, Measured Fluorescence, and Extracted Algae Pigment (DWR) Concentrations at Mossdale for 2010. (note: YSI fluorescence multiplied by 1.5 to match DWR algae pigment).

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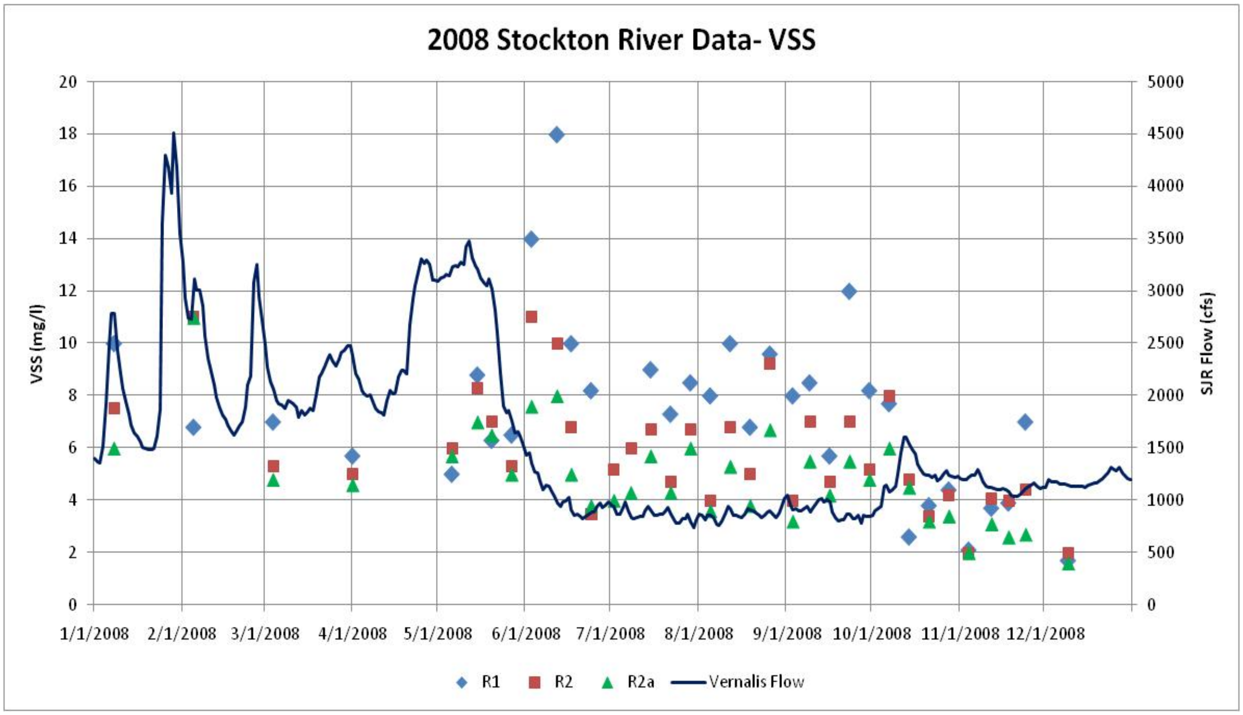
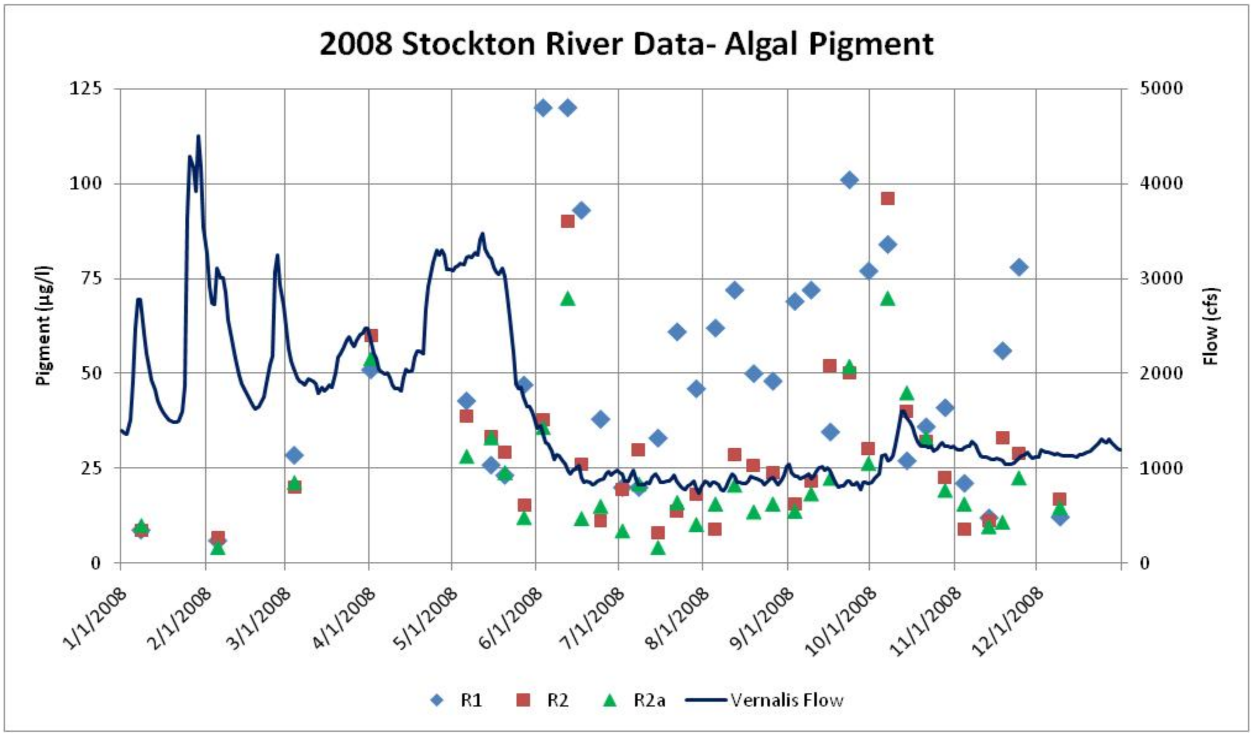
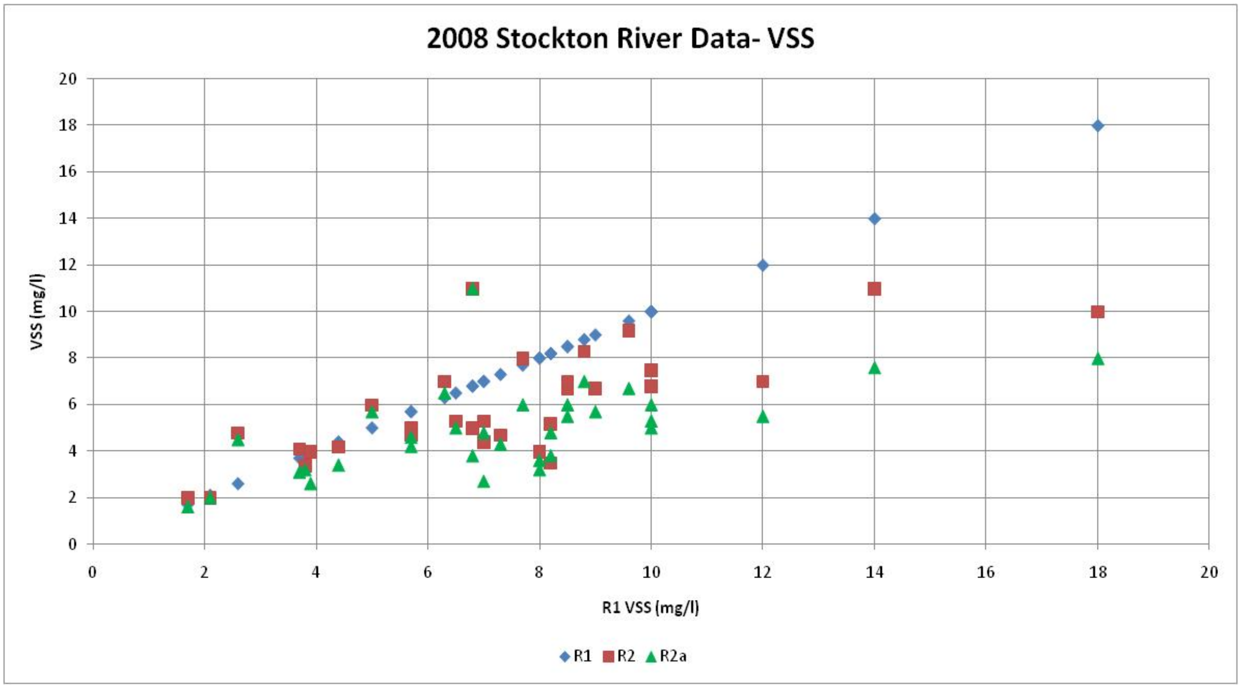
Figure 12



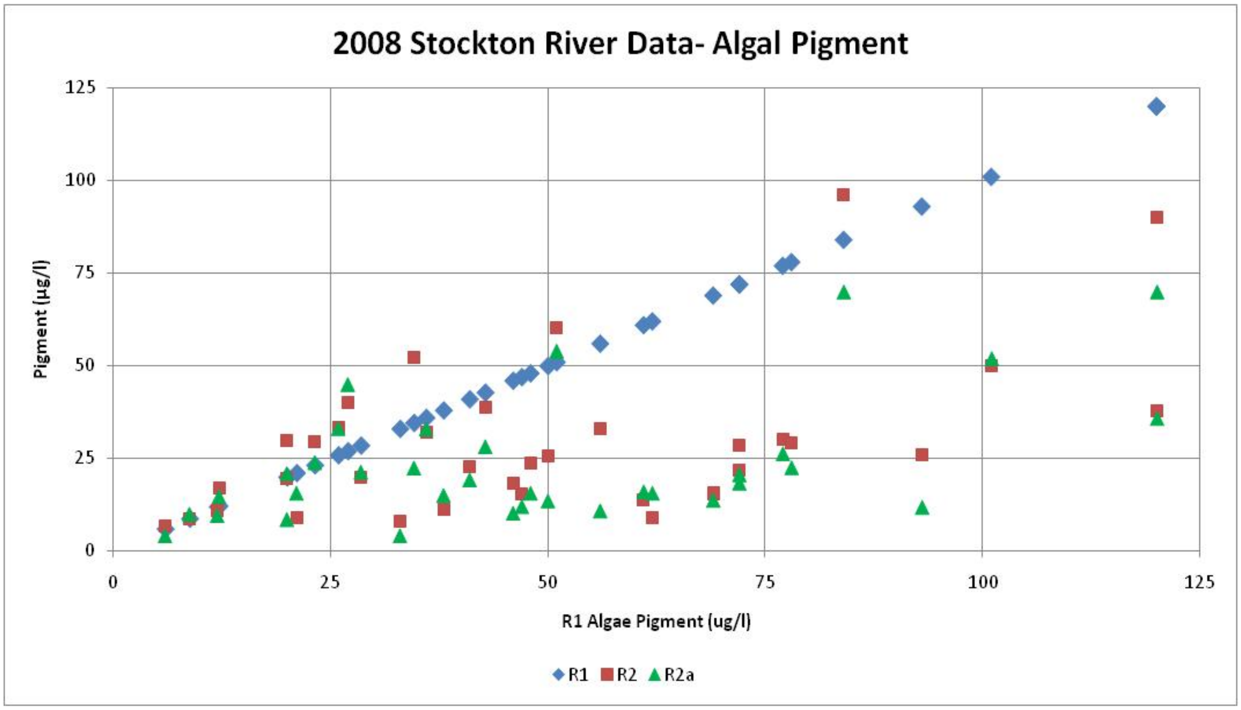
a) City of Stockton River Station Measurements of VSS at R1, R2, and R2a for 2008.



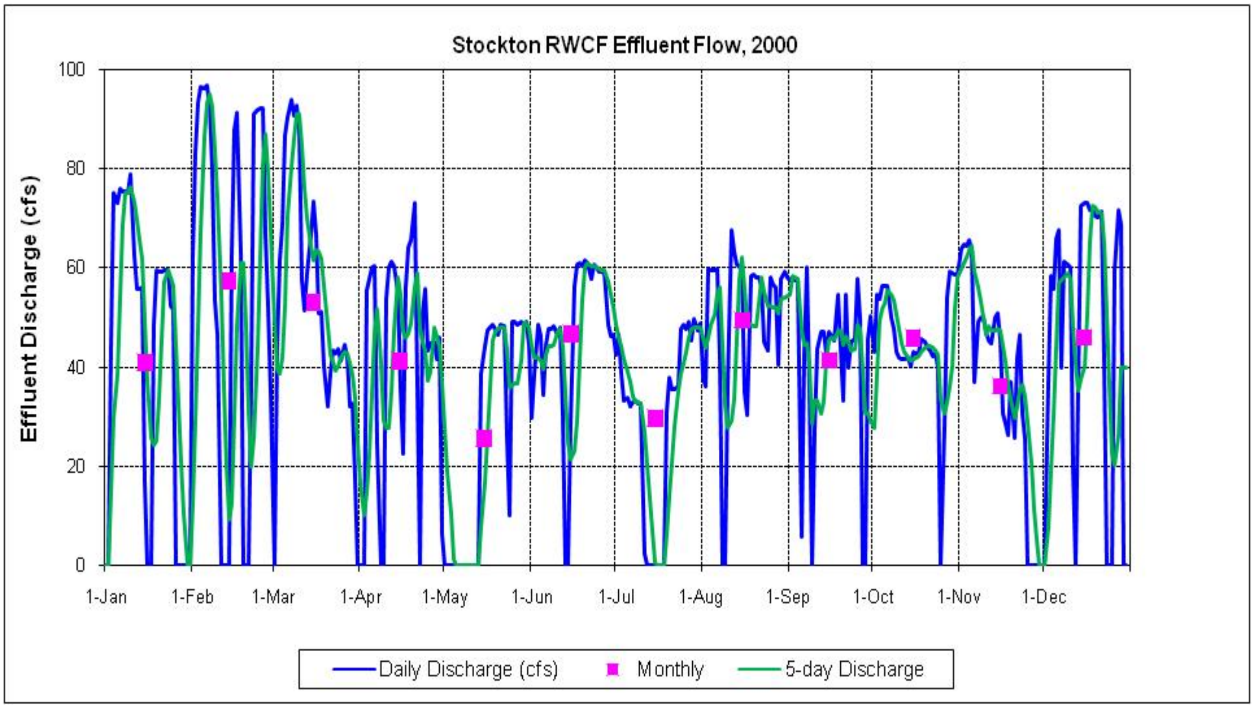
b) City of Stockton River Station Measurements of Algae Pigment (chlorophyll and phaeophytin)at R1, R2, and R2a for 2008. The San Joaquin River flow at Vernalis is shown for comparison.



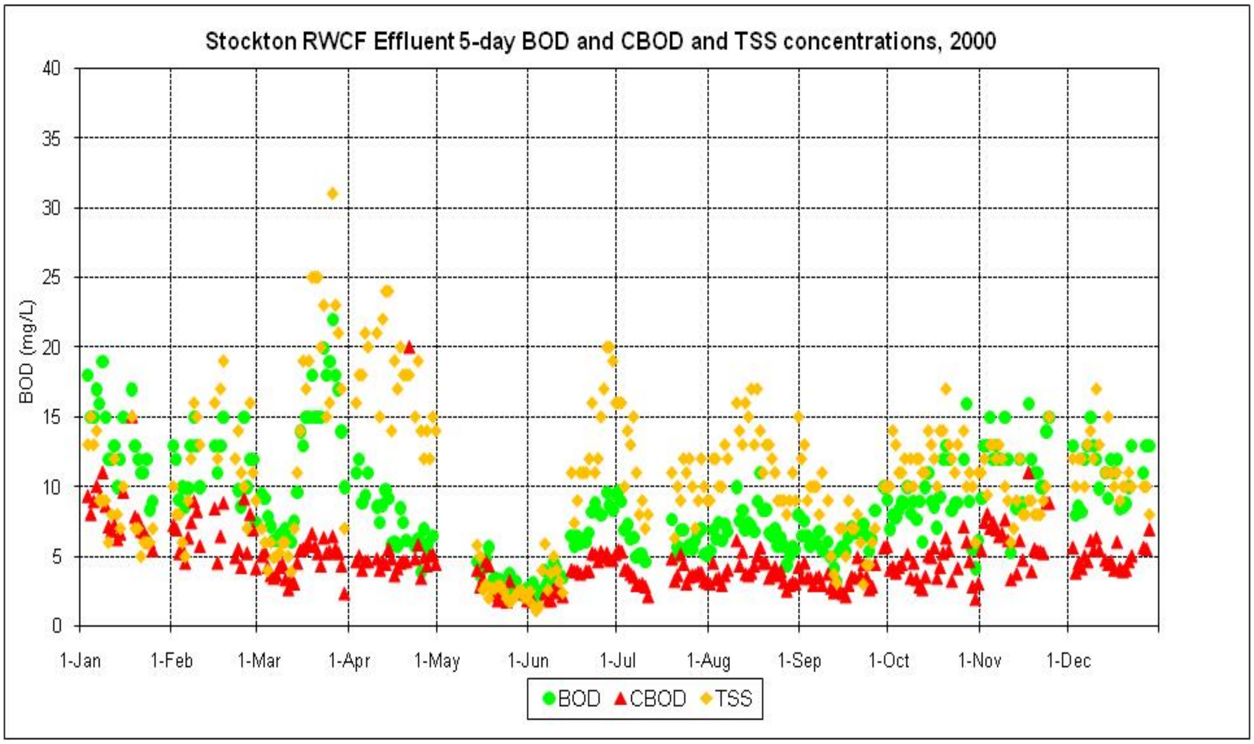
c) City of Stockton River Station Reduction of VSS from R1 to R2 and R2a for 2008.



d) City of Stockton River Station Reduction of Algae Pigment from R1 to R2 and R2a for 2008.

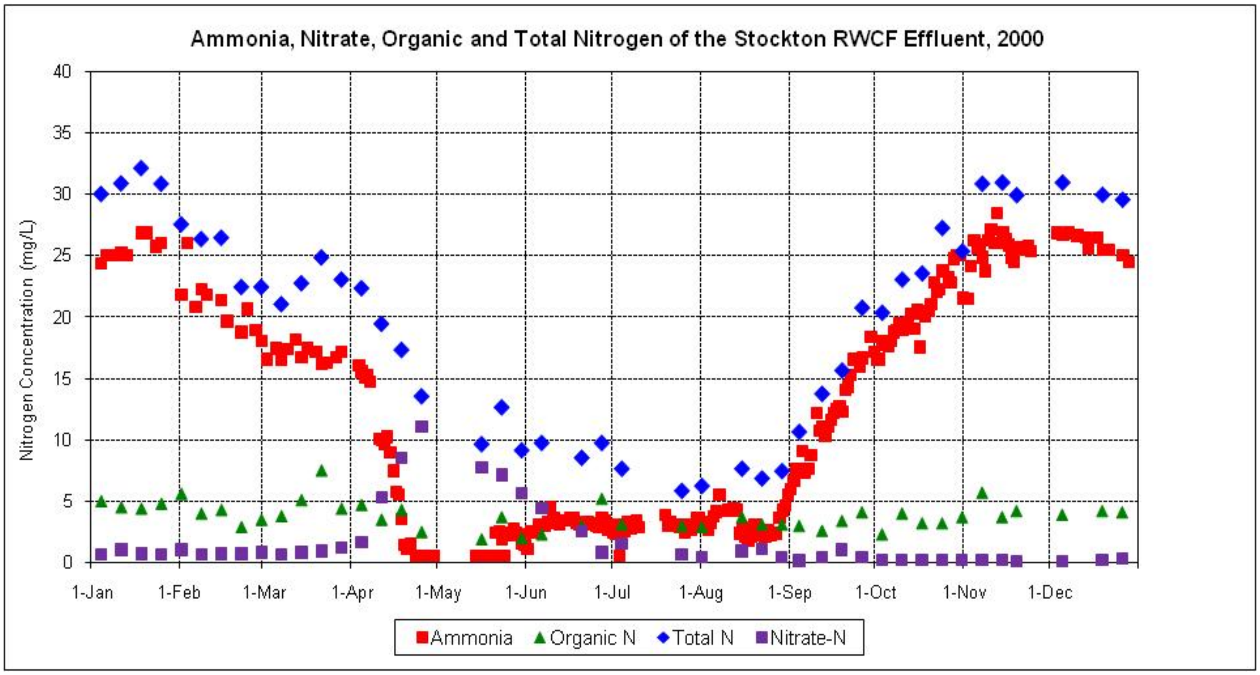


a) Stockton RWCF effluent daily discharge, 5-day moving average discharge and monthly average discharge (cfs) for 2000.

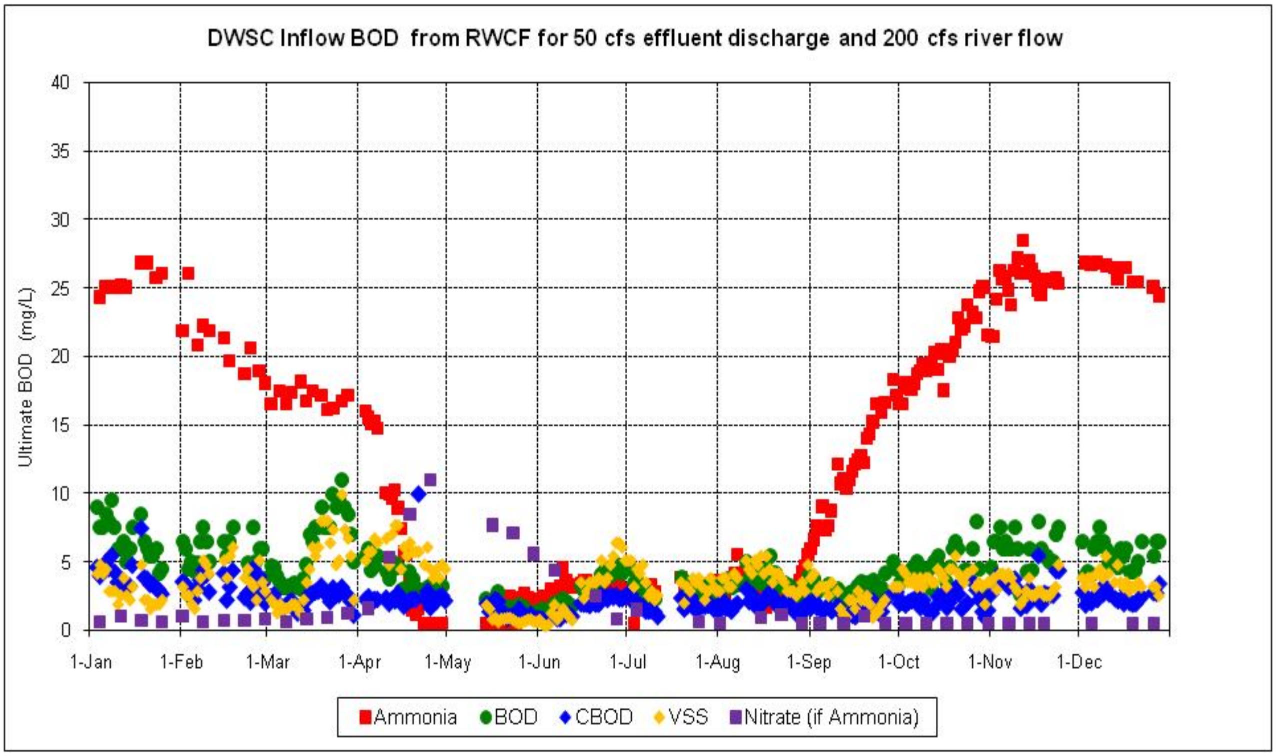


b) Daily measurements of 5-day BOD, 5-day CBOD and TSS concentrations (mg/l) for 2000.

Figure 14

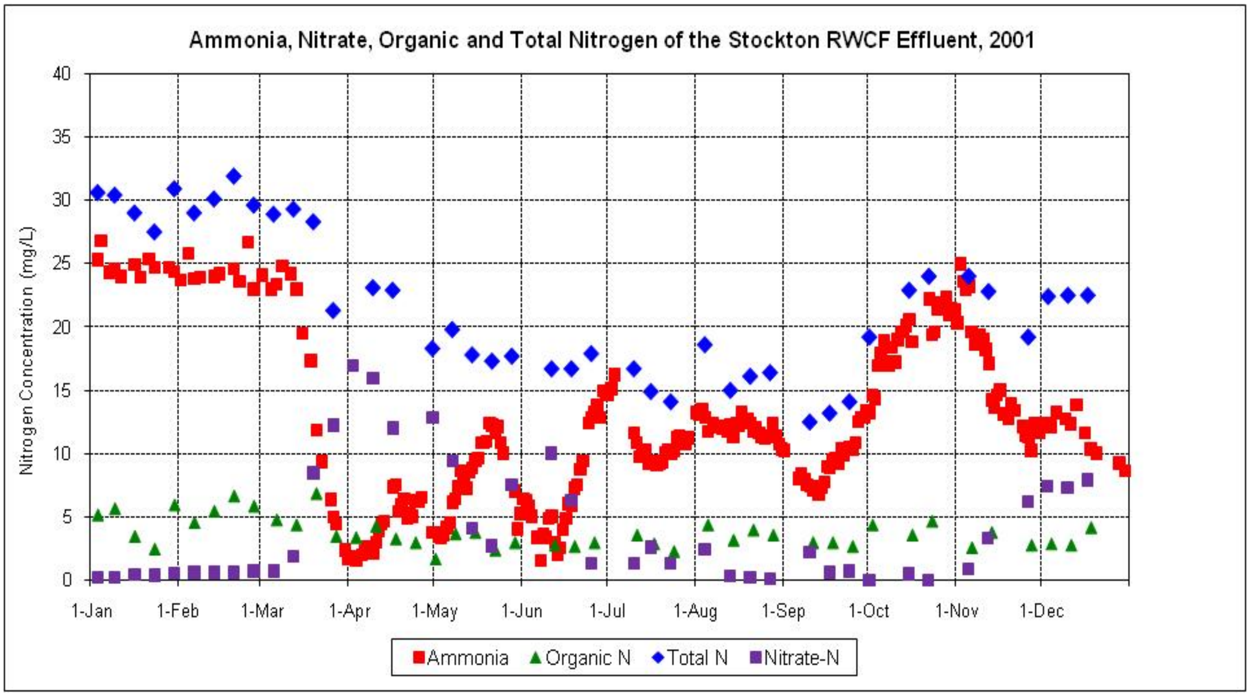


c) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2000.

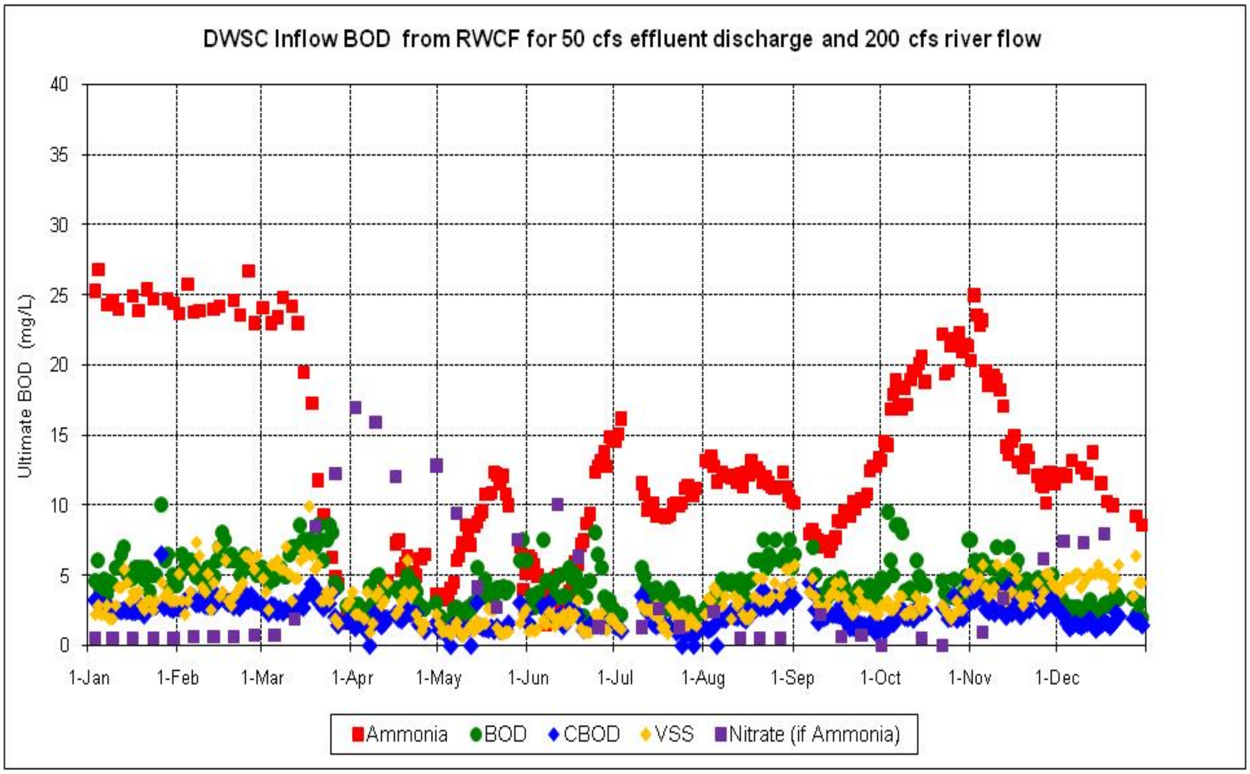


d) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2000.

Figure 14
Continued

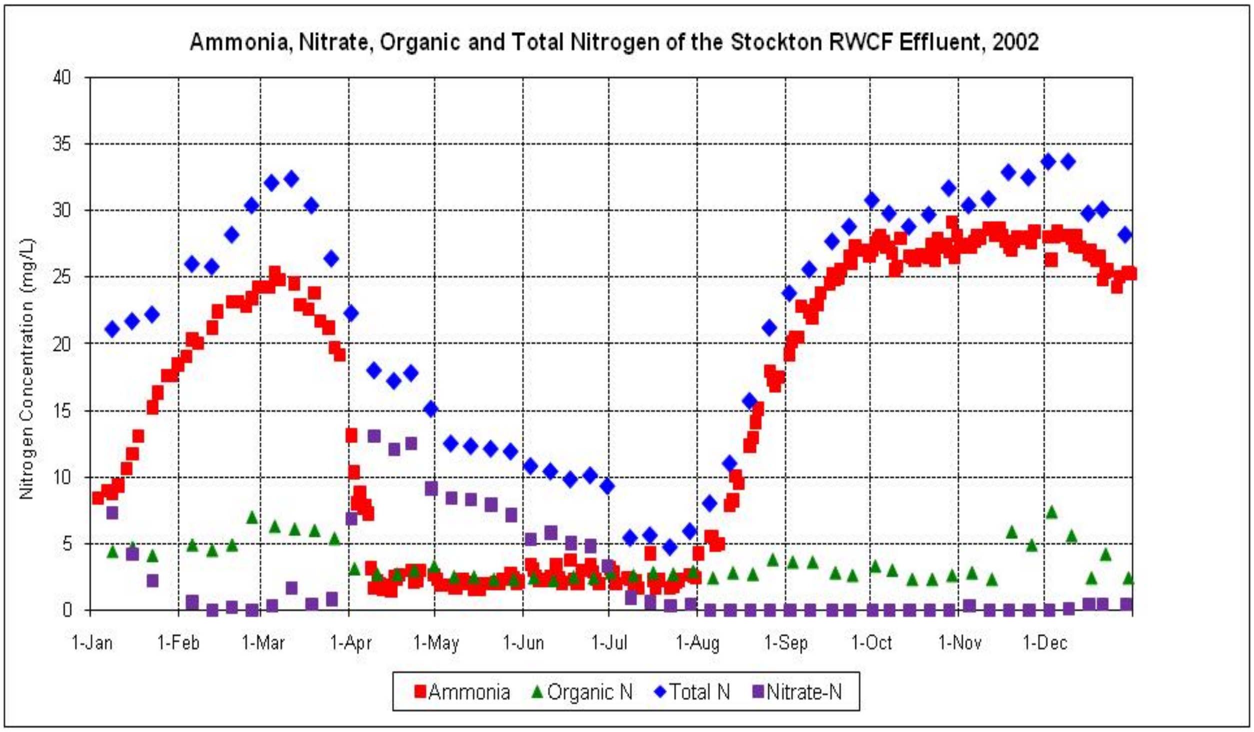


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2001.

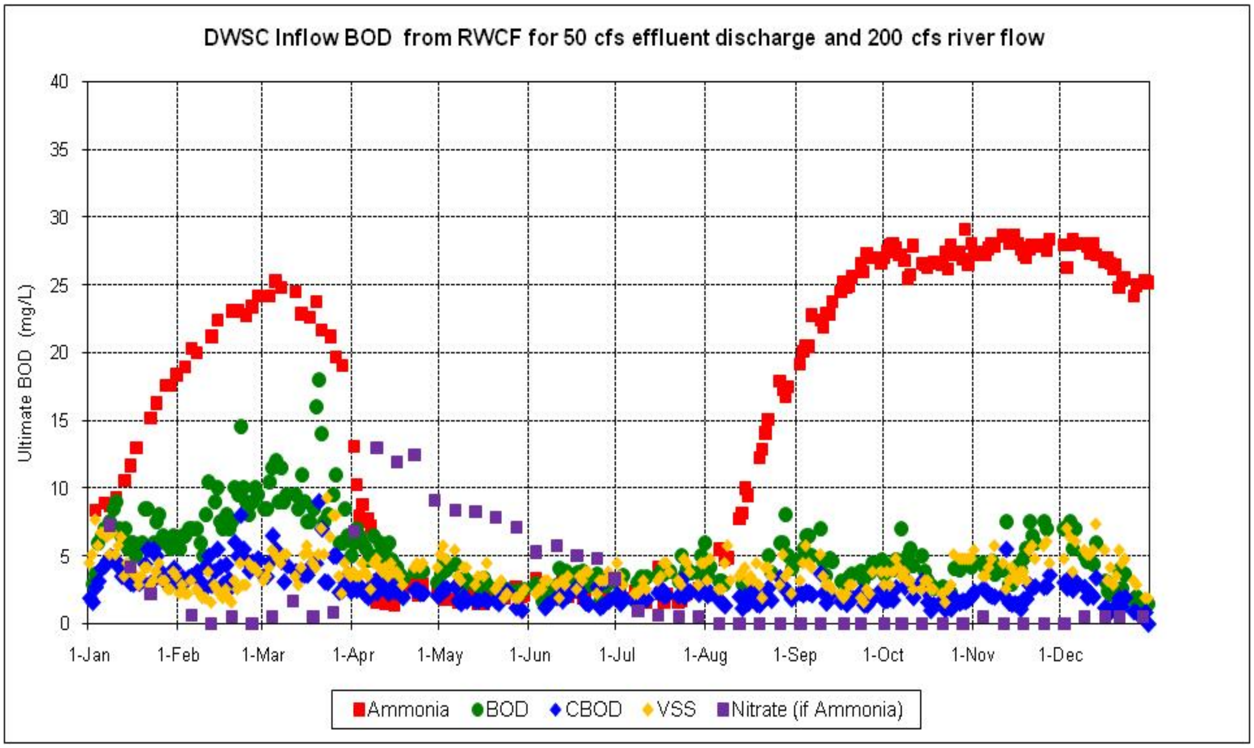


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2001.

Figure 15



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2002.



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2002.

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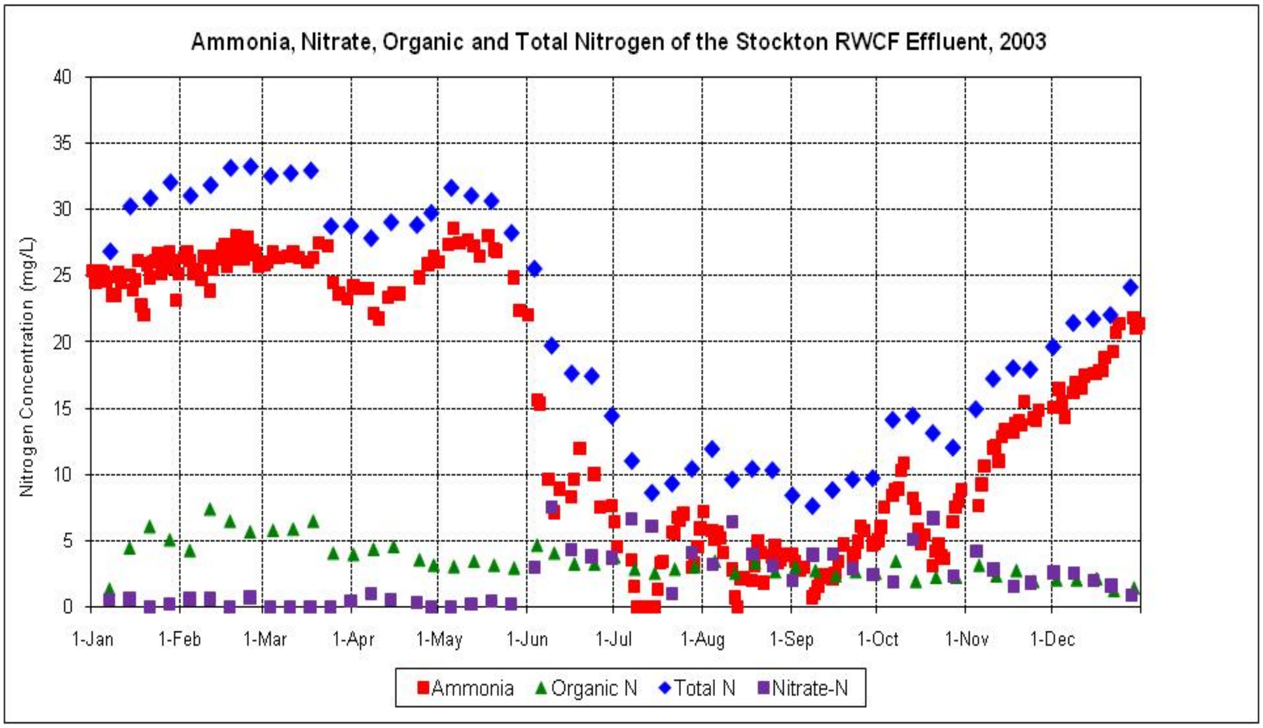
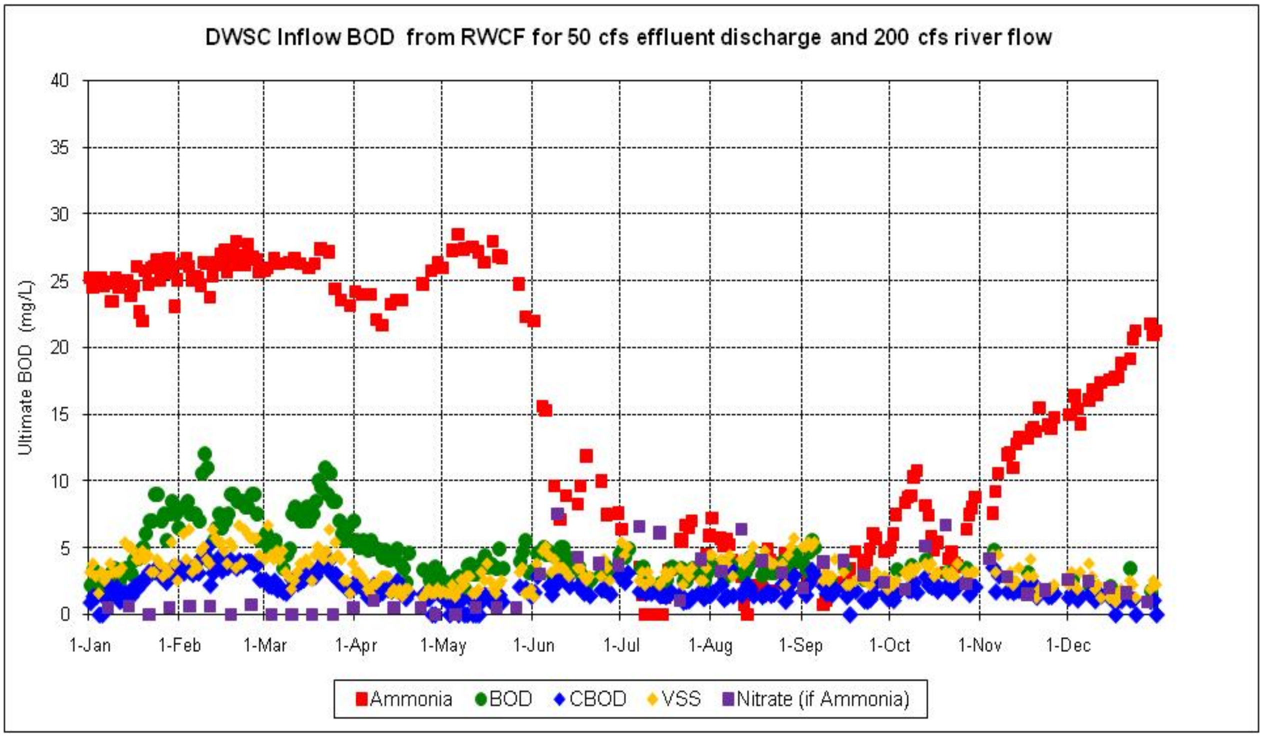
Figure 16

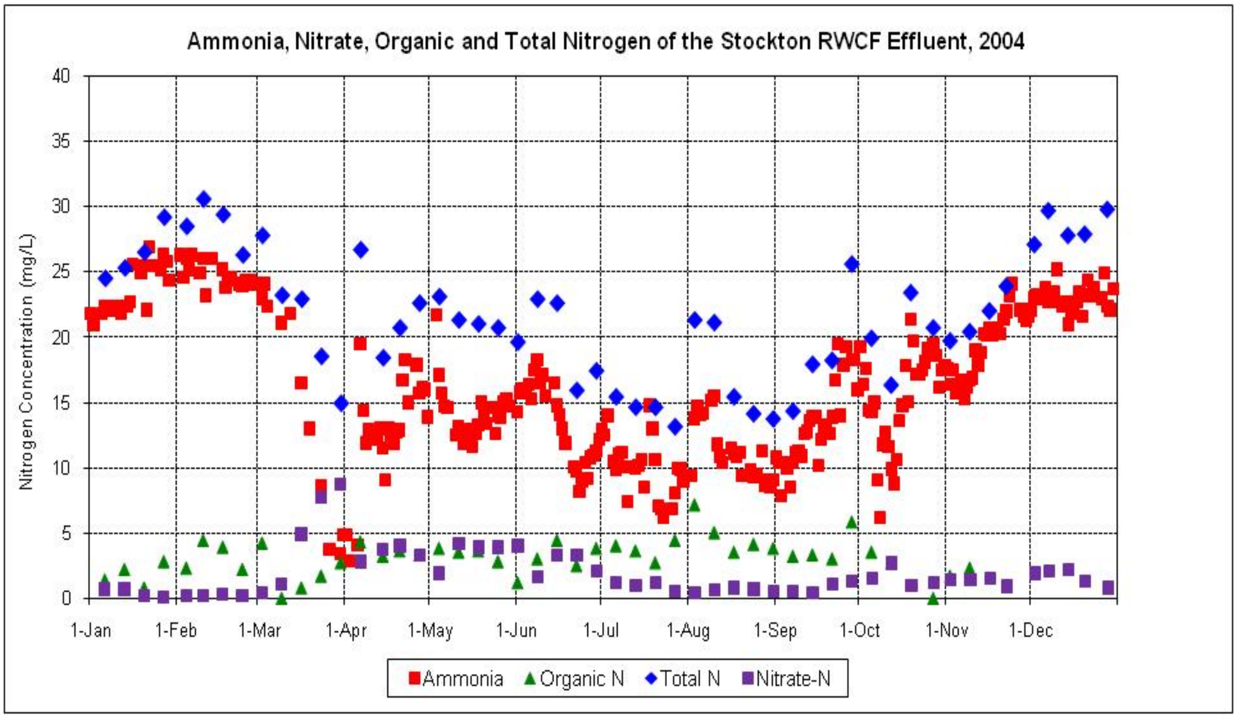


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2003.

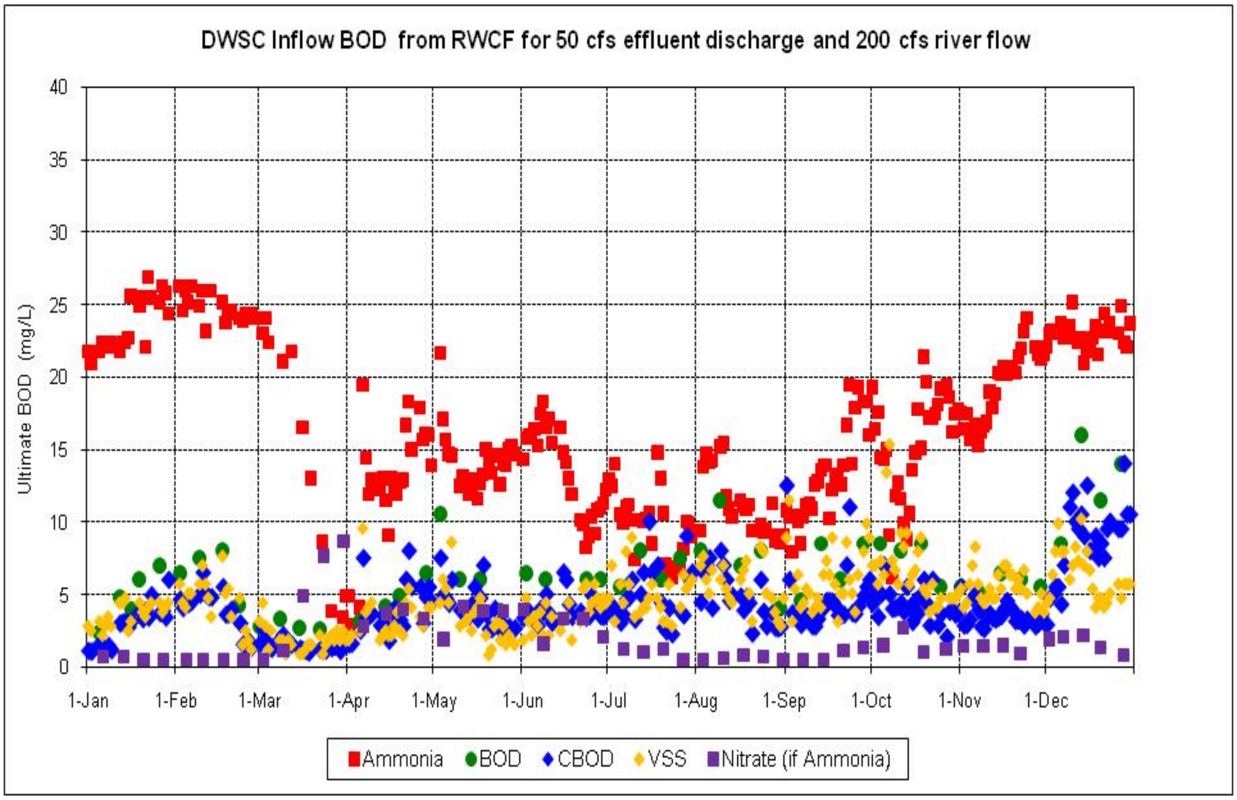


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2003.

Figure 17

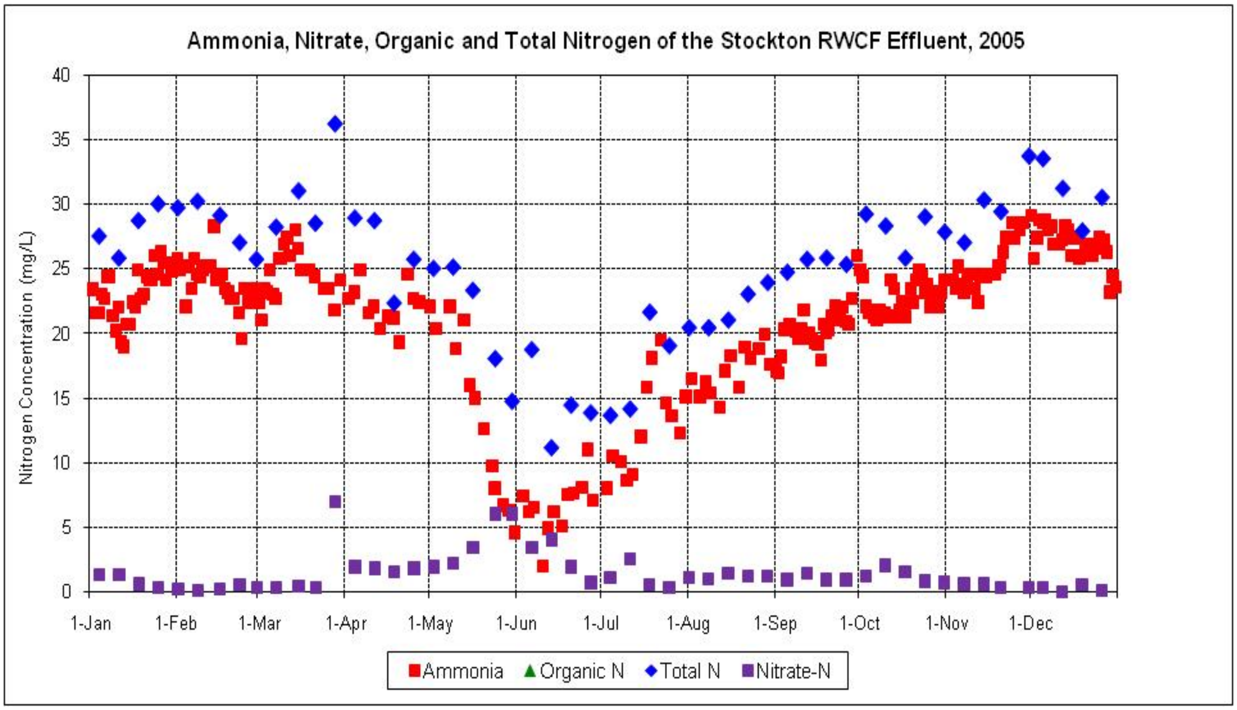


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2004.

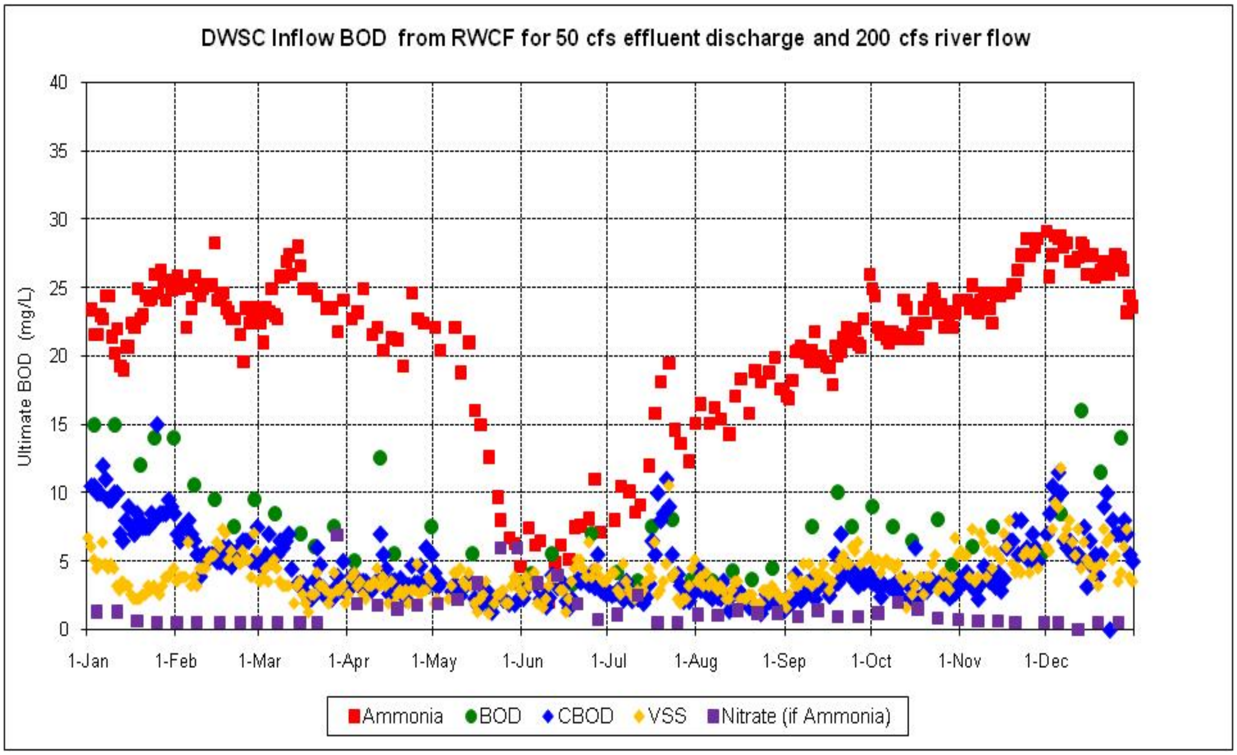


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2004.

Figure 18

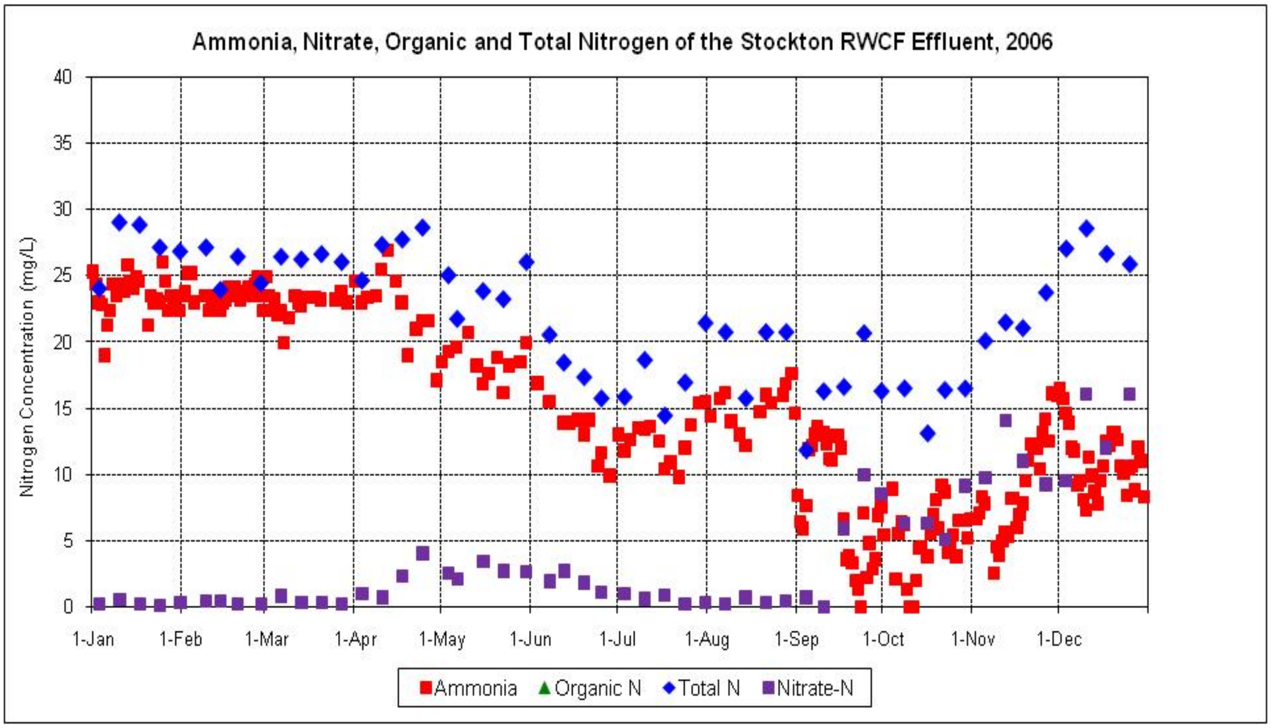


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2005.

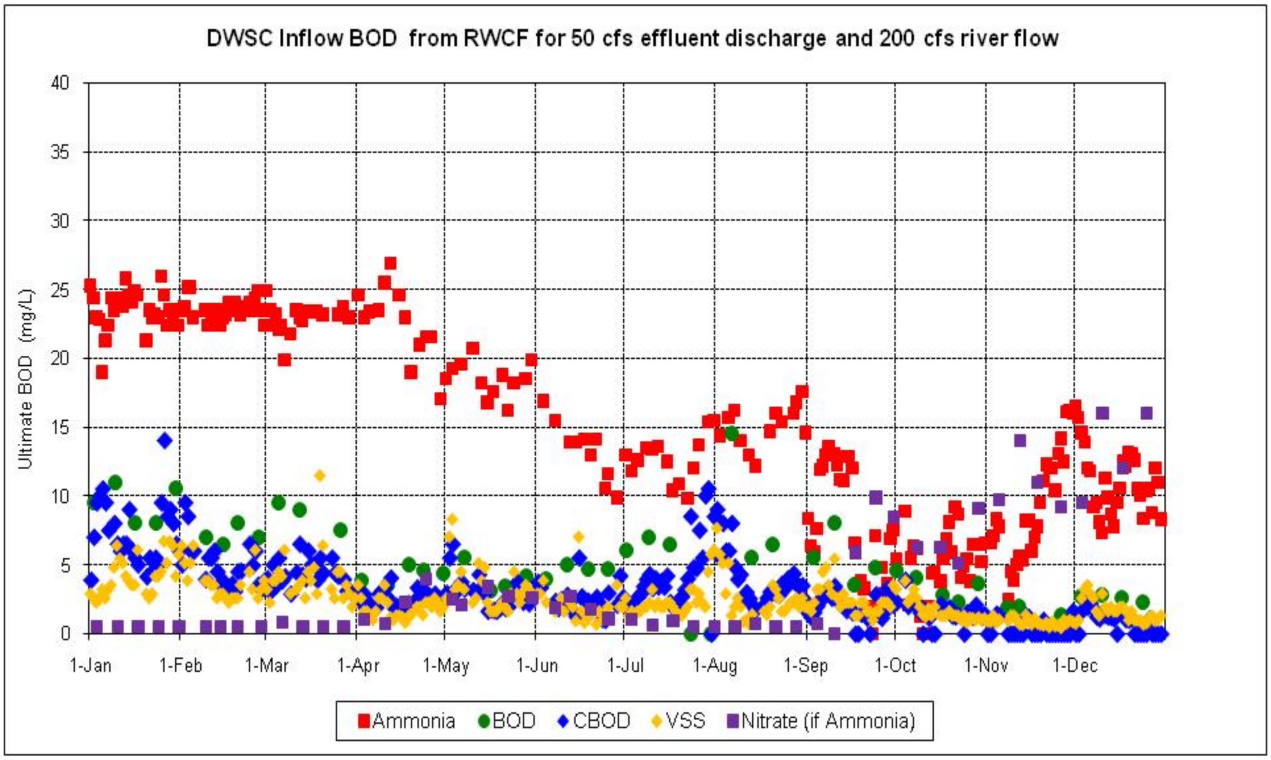


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2005.

Figure 19



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2006.



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2006.

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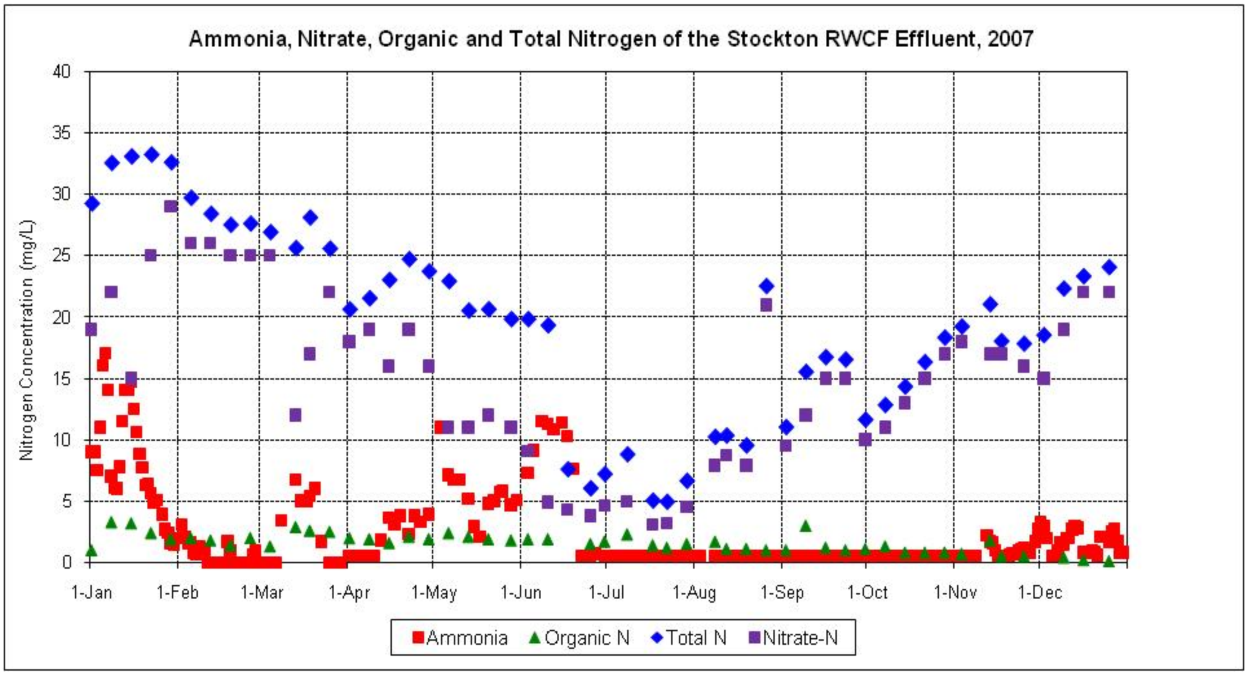
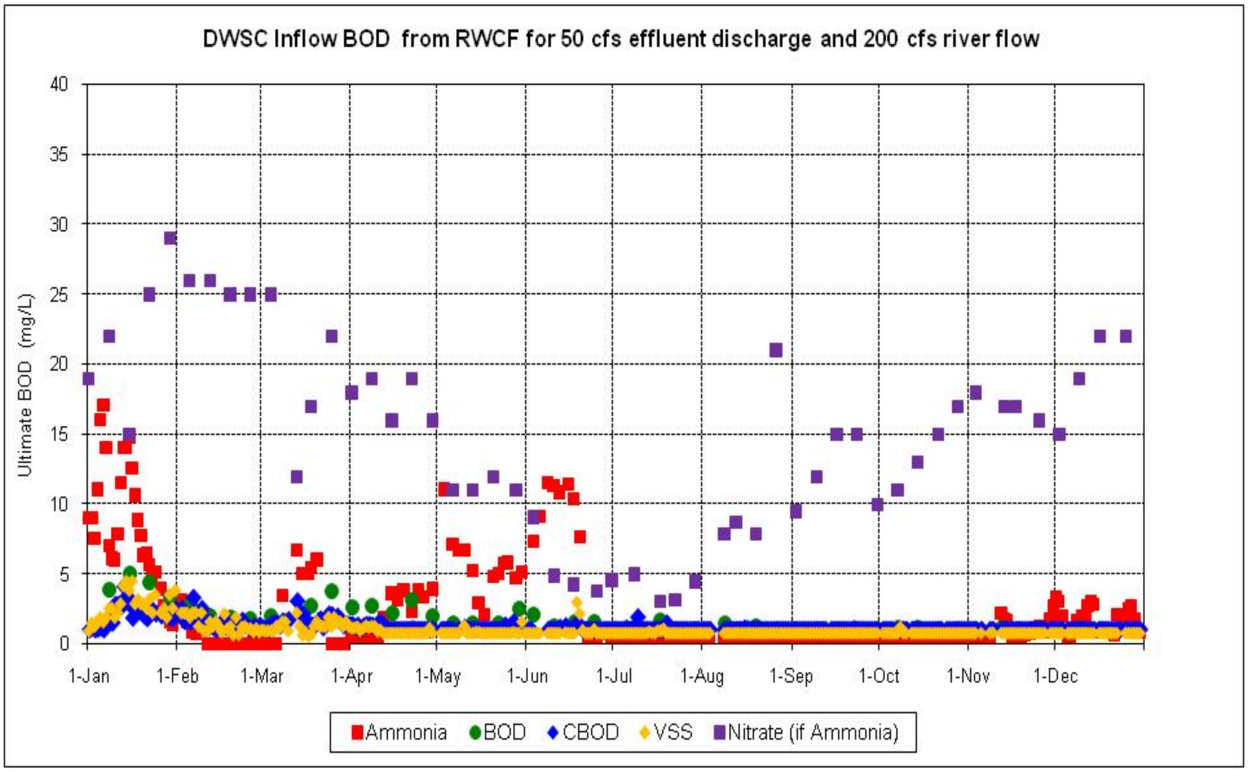
Figure 20

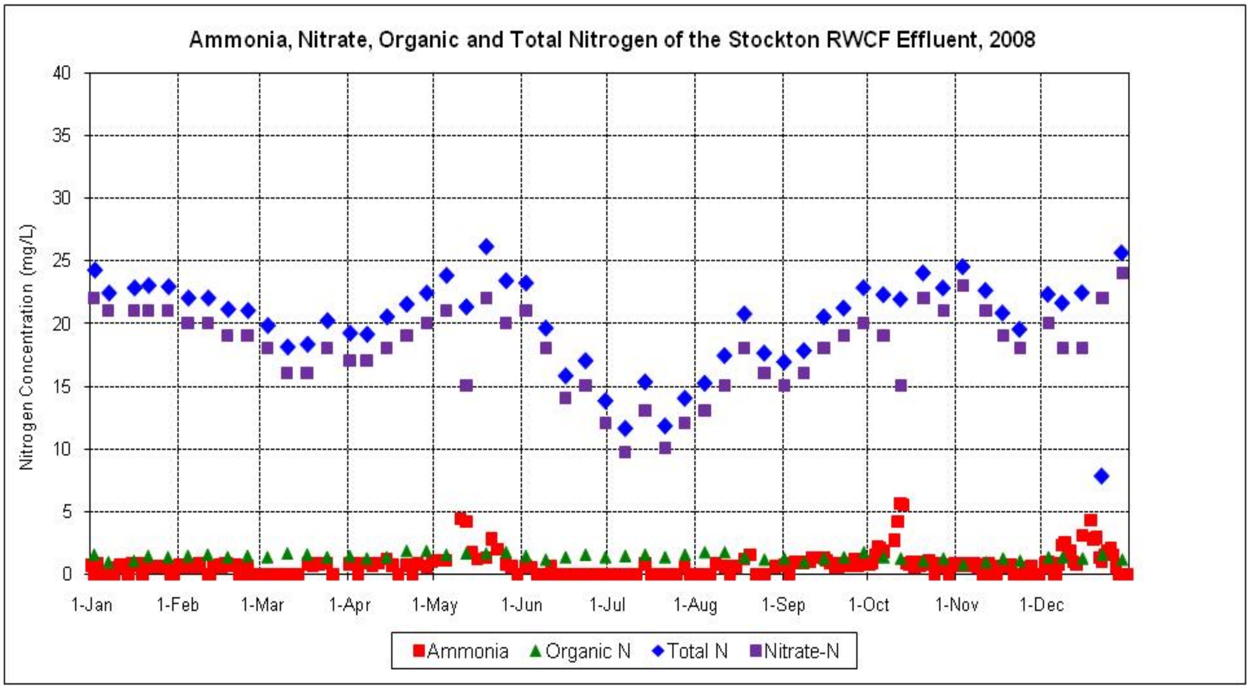


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2007.

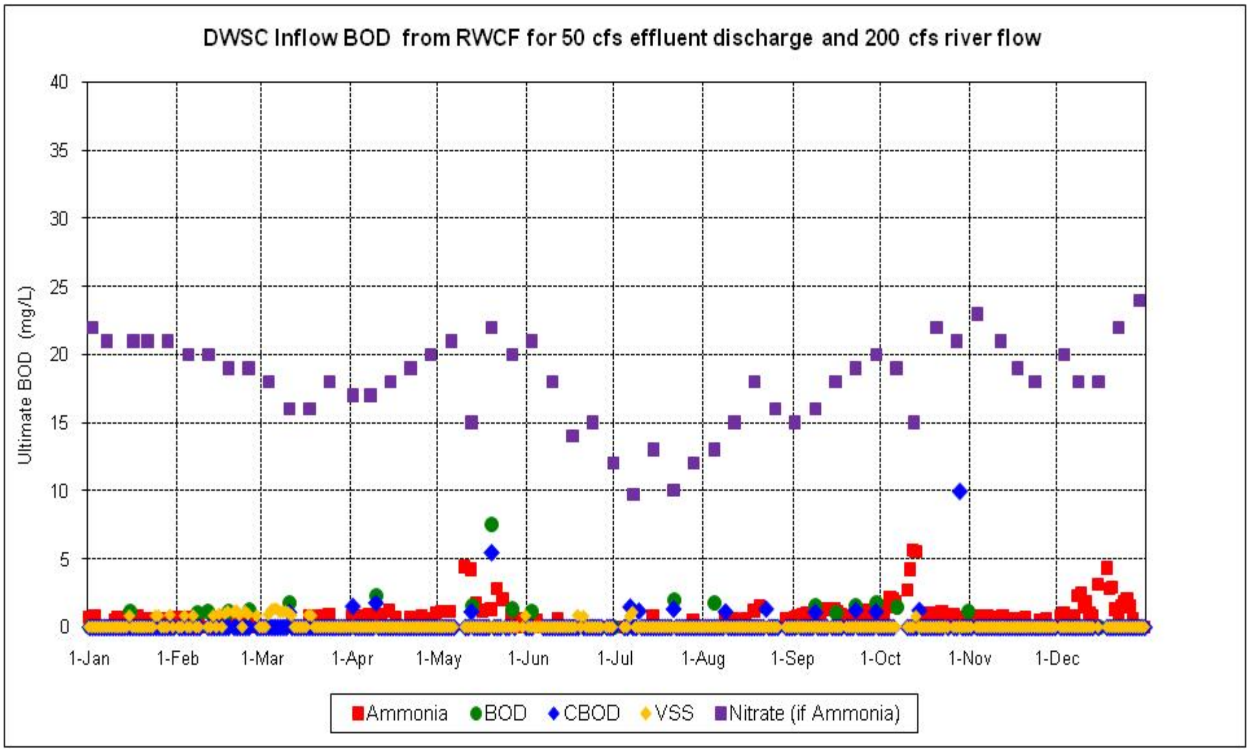


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2007.

Figure 21



a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2008 [Most ammonia-N was <0.5 mg/l].



b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2008.

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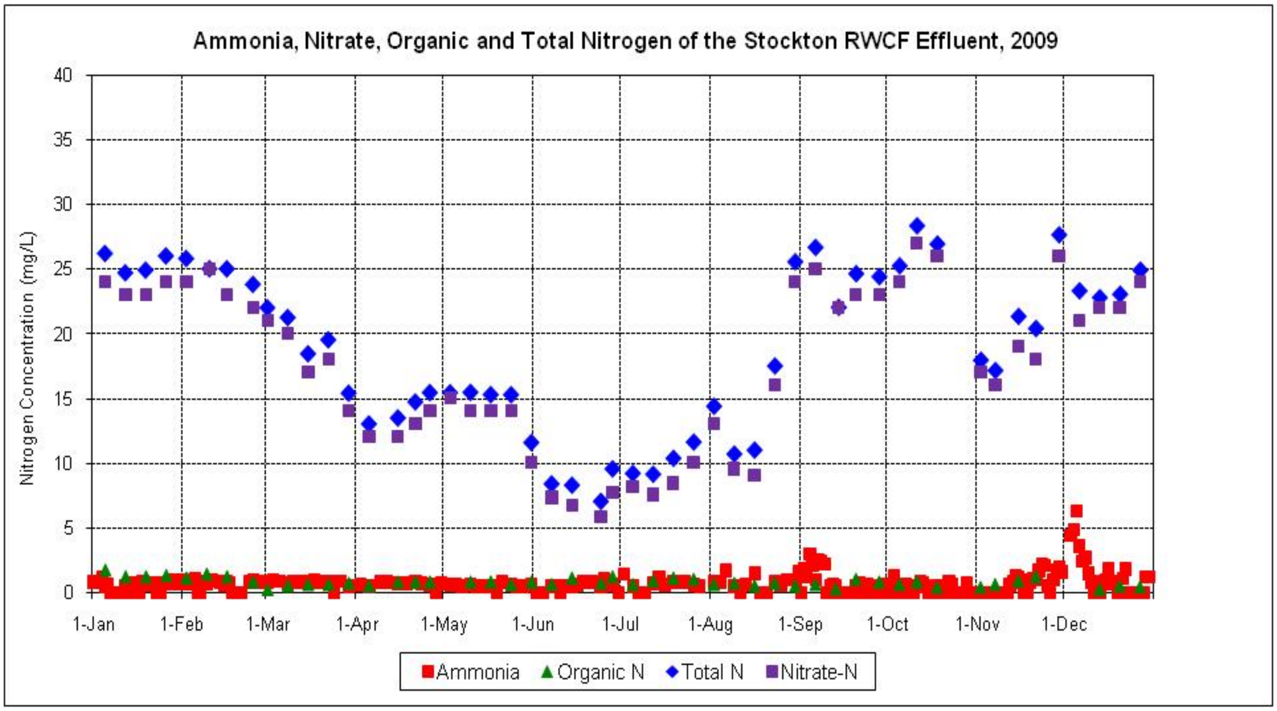
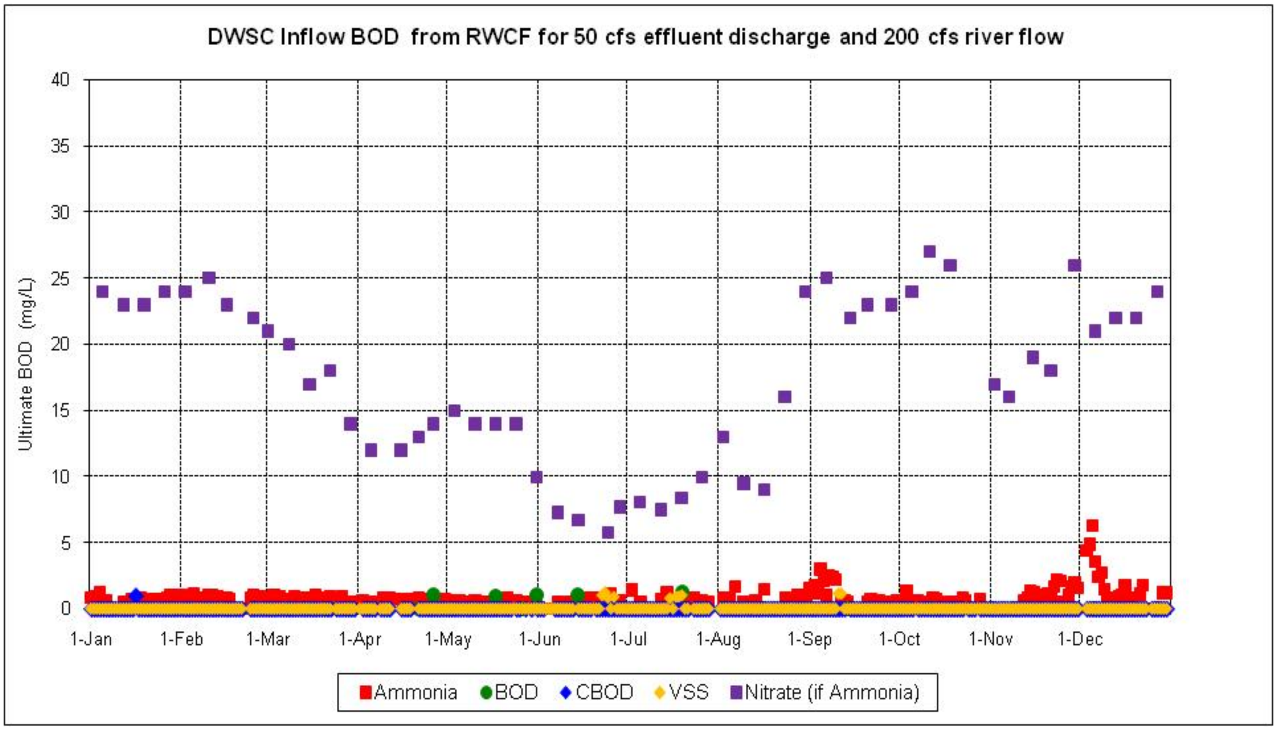
Figure 22

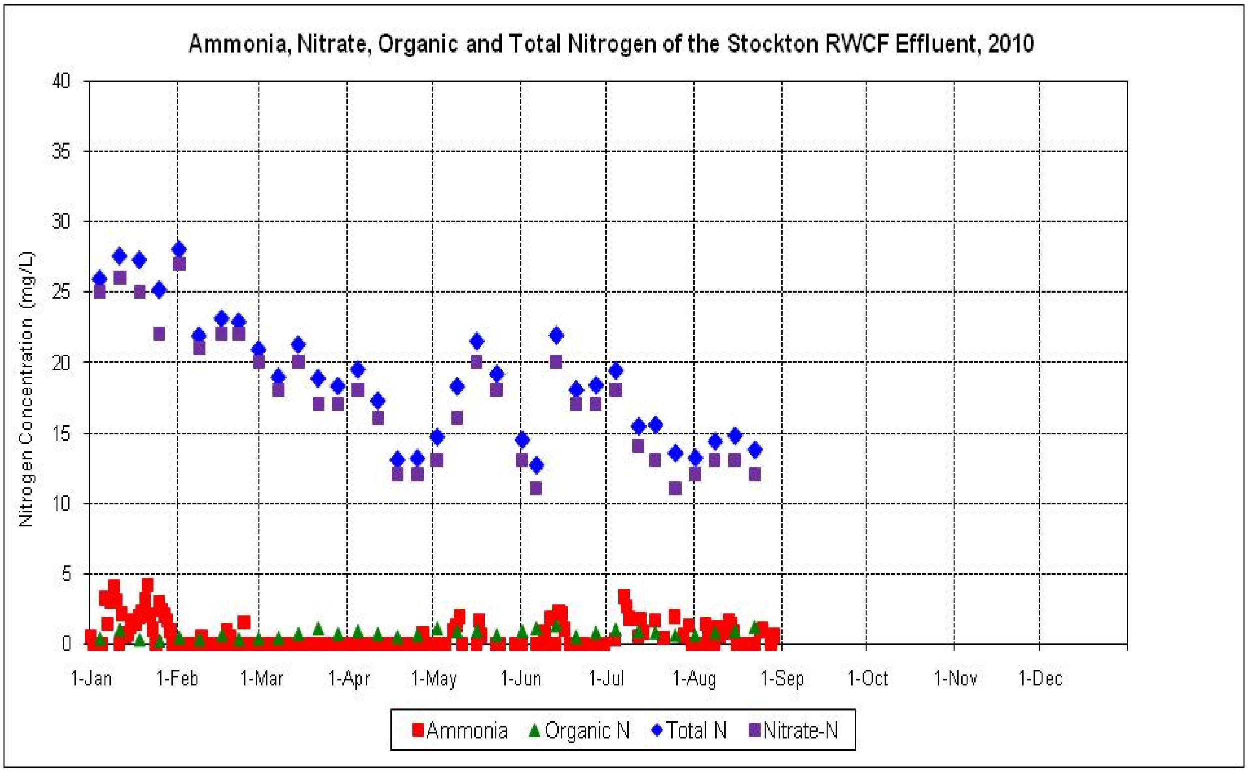


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2009 [Most ammonia-N was <0.5 mg/l].

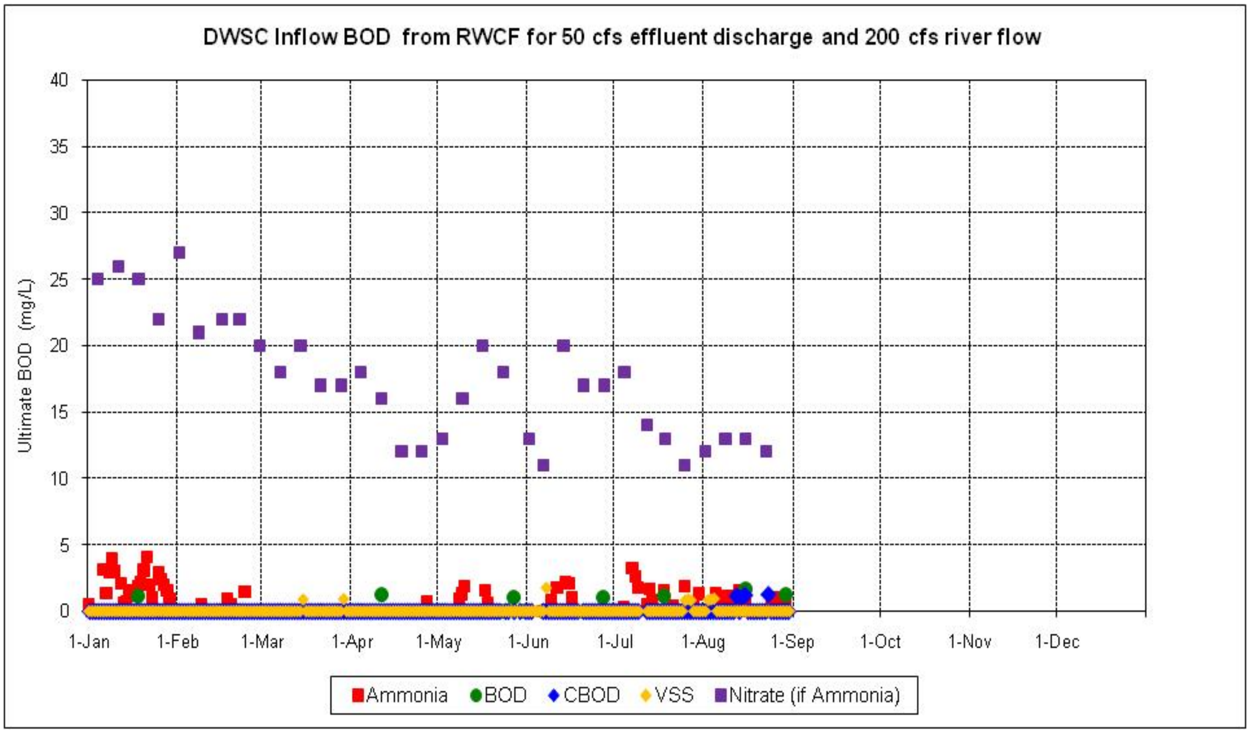


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2009.

Figure 23

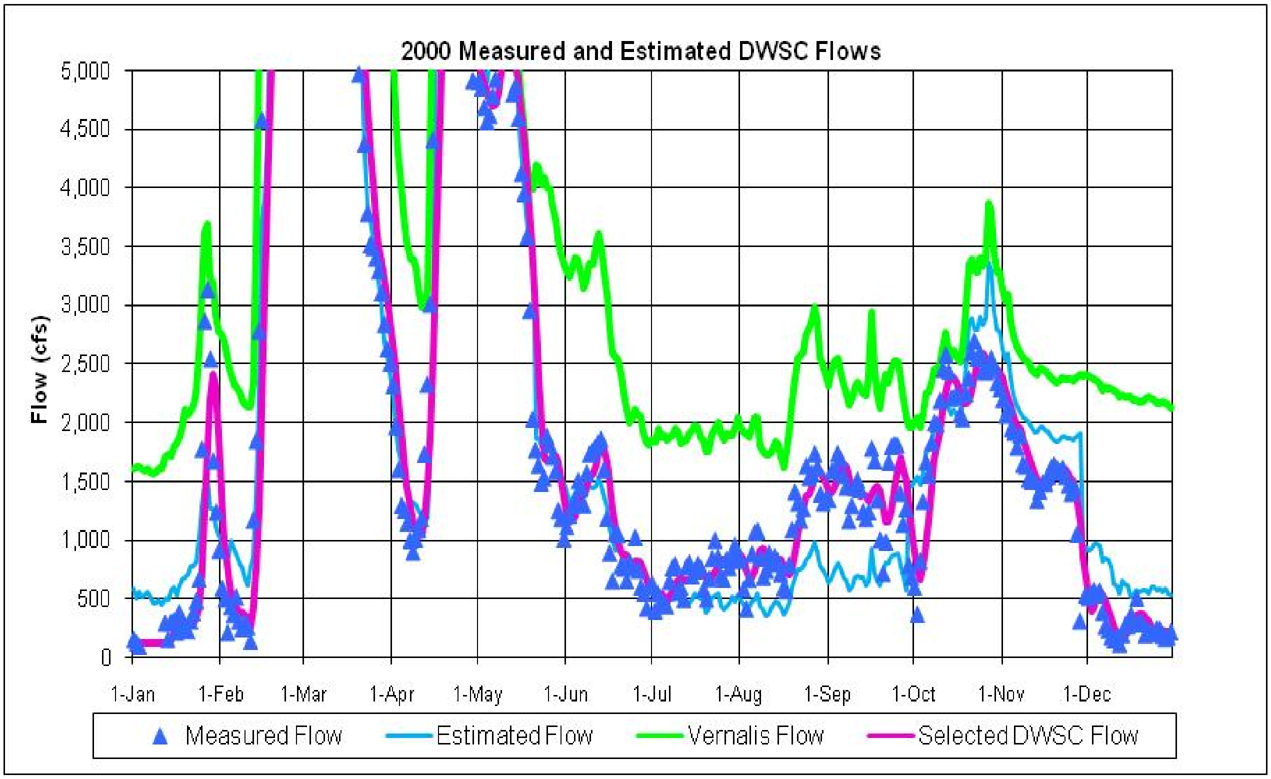


a) Stockton RWCF effluent nitrogen concentrations (mg/l) for 2010 [Most ammonia-N was <0.5 mg/l].

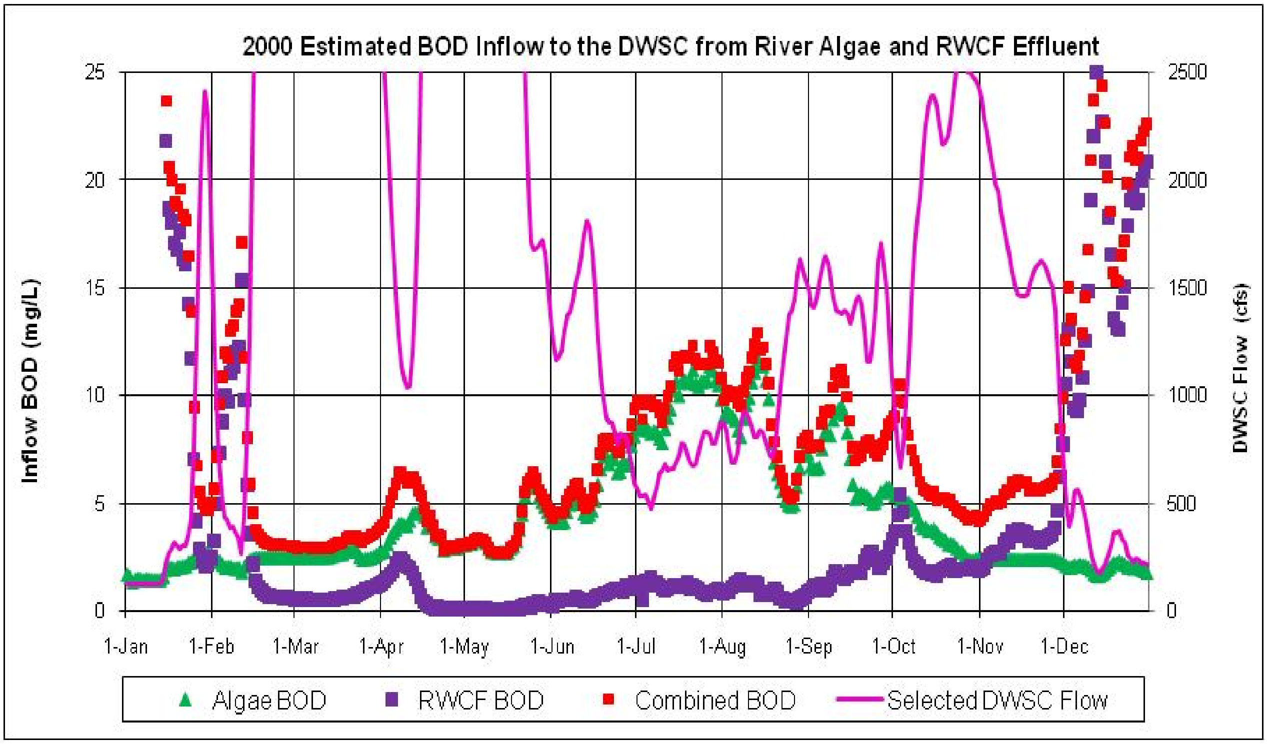


b) Calculated DWSC inflow CBOD and NBOD concentrations from the RWCF with assumed effluent discharge of 50 cfs and river flow of 200 cfs (dilution factor of 5) for 2010.

Figure 24



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2000.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2000.

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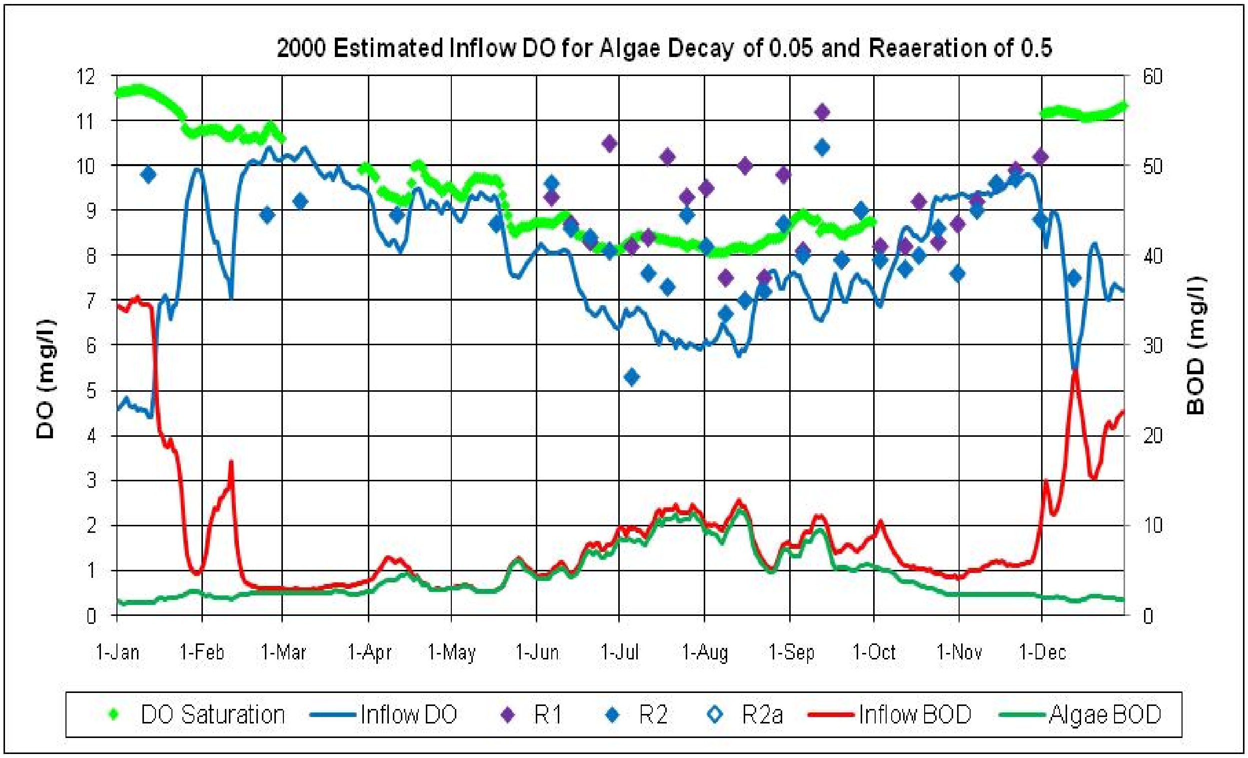
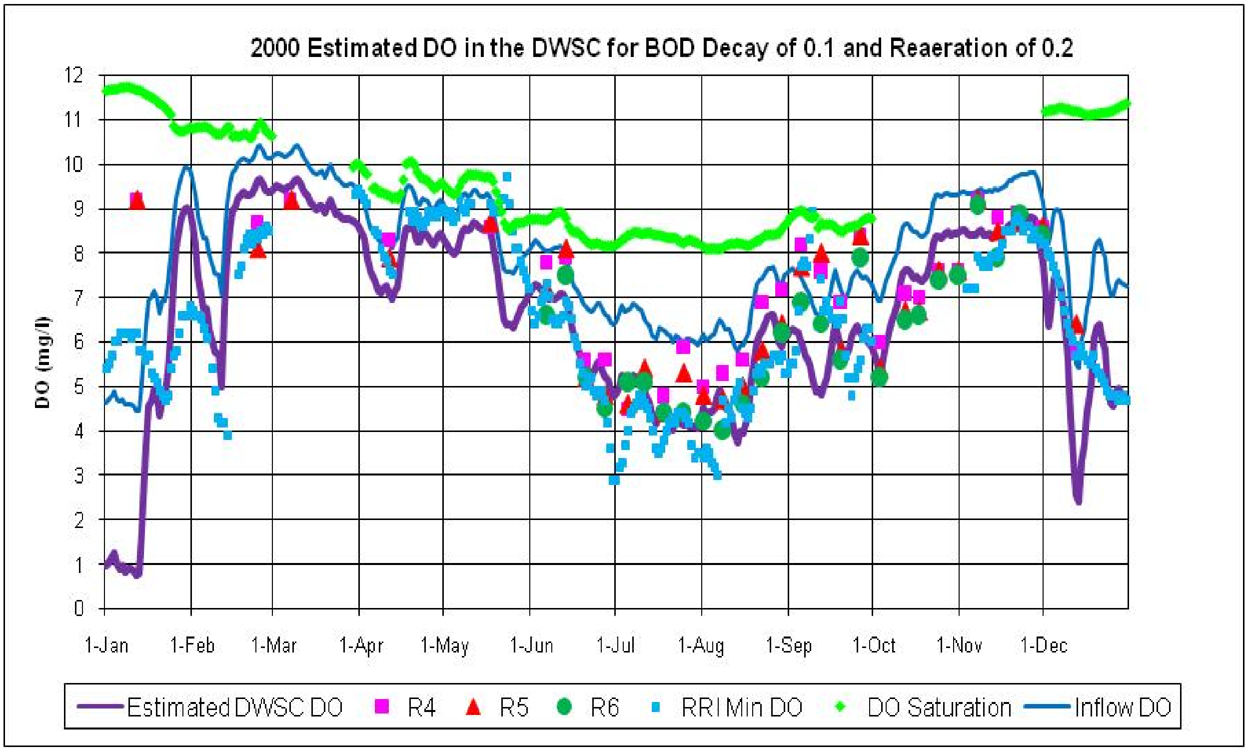
Figure 25



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2000.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2000.

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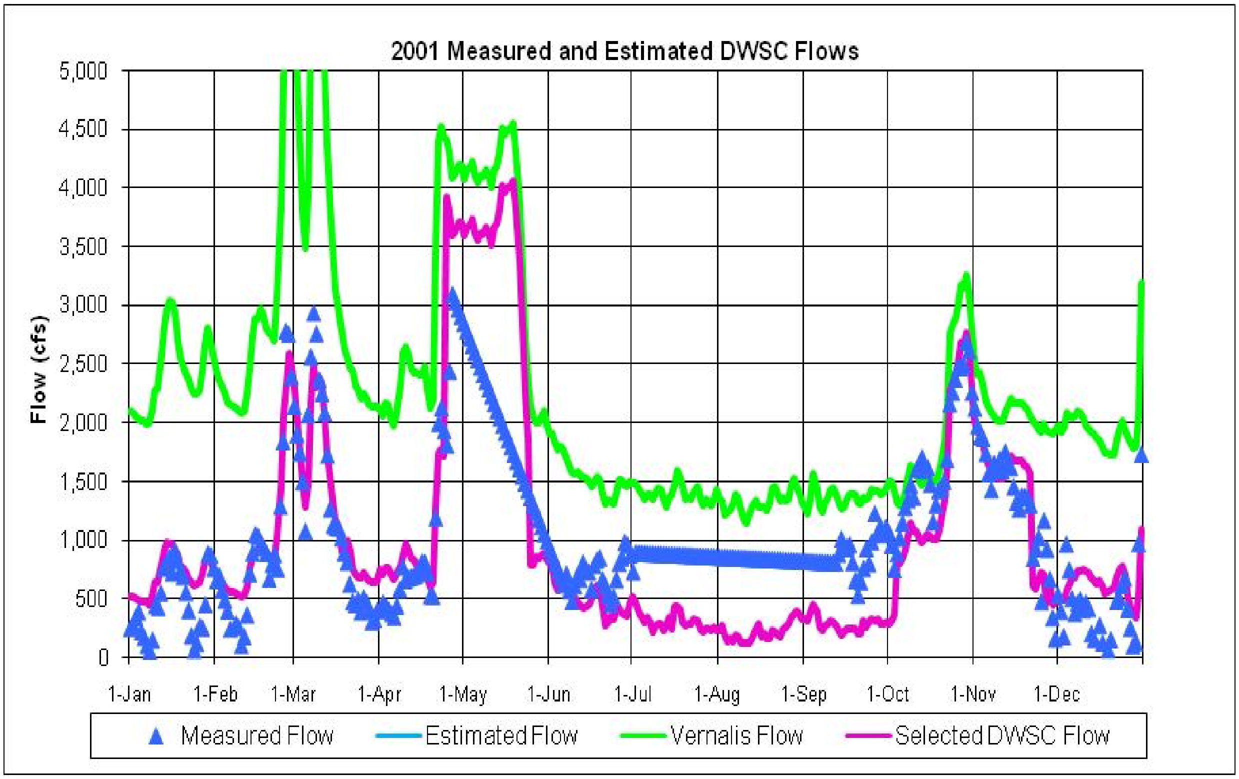
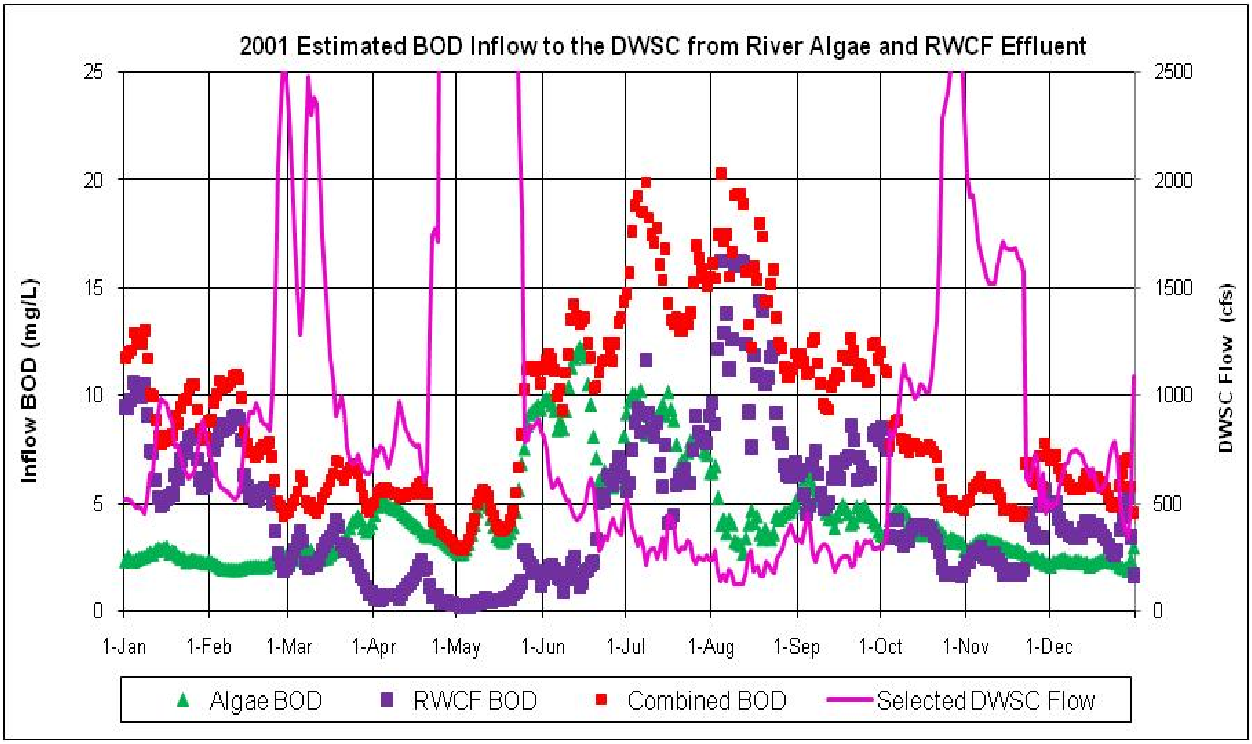
Figure 25
Continued



a) Daily Measured and Estimated (Selected) DWSC Flow with SJR Flows at Vernalis for 2001.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2001.

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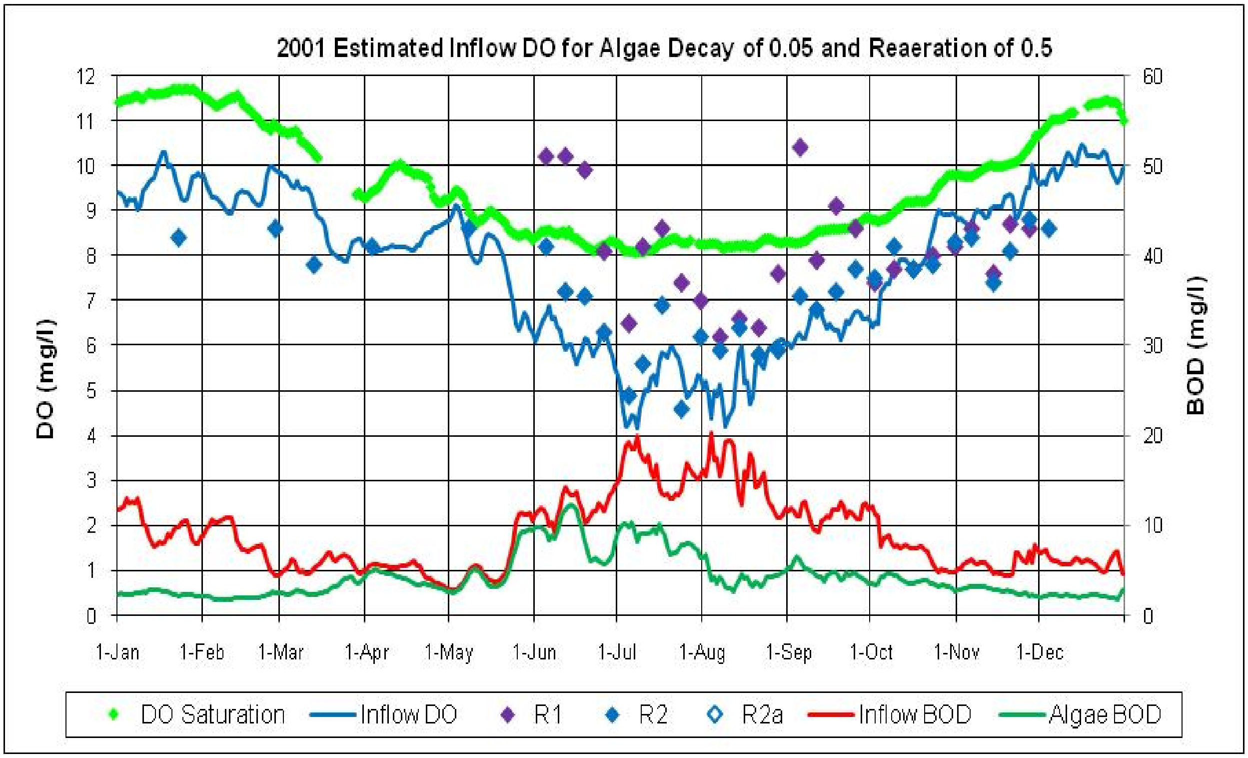
Figure 26



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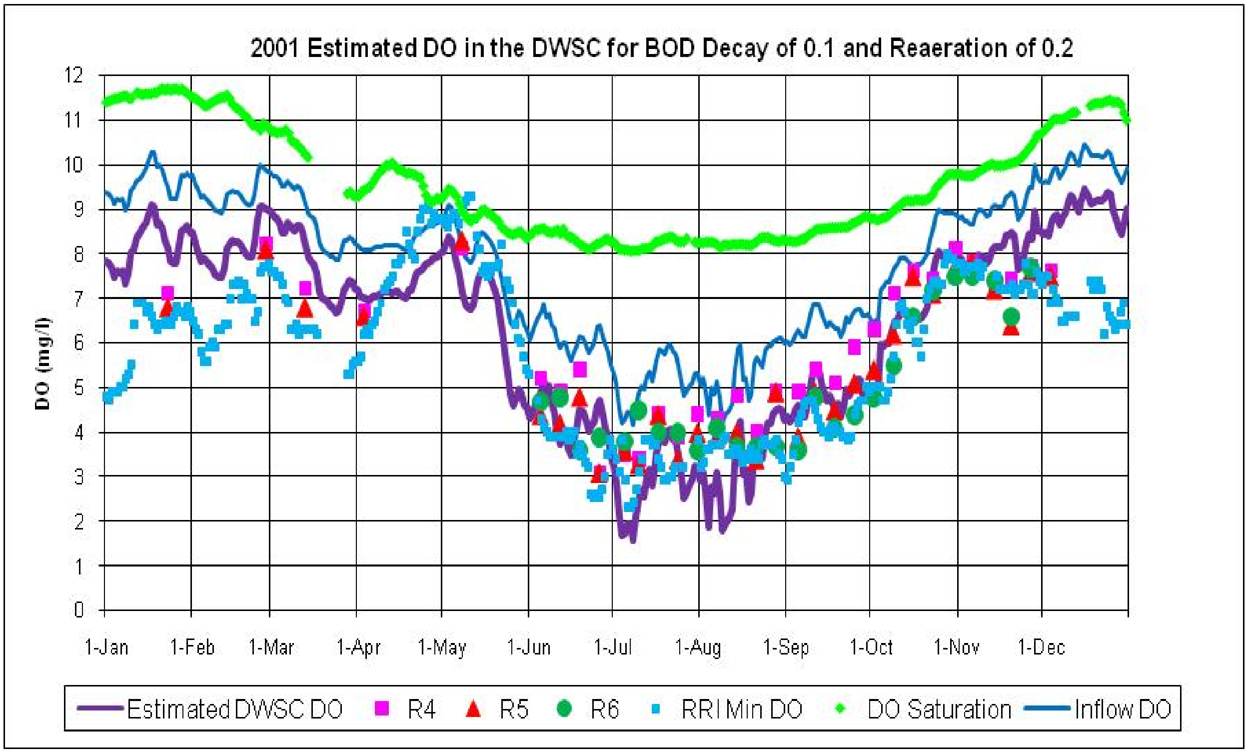
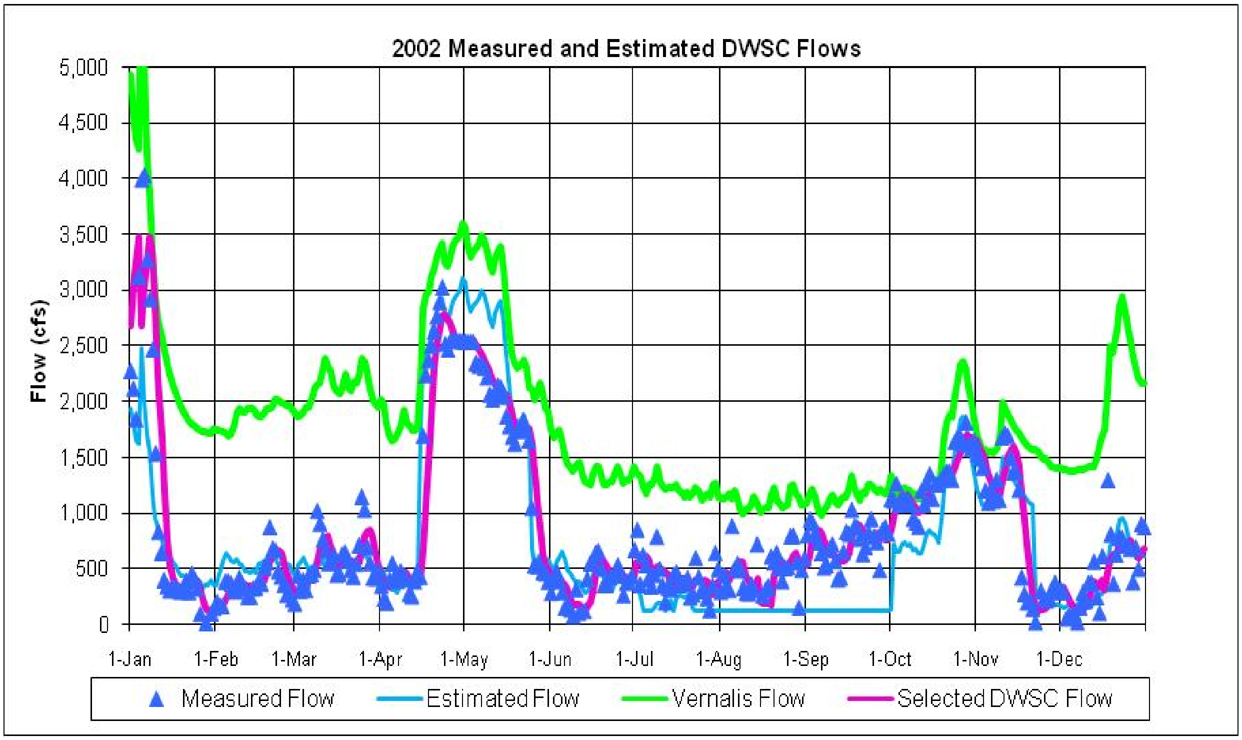
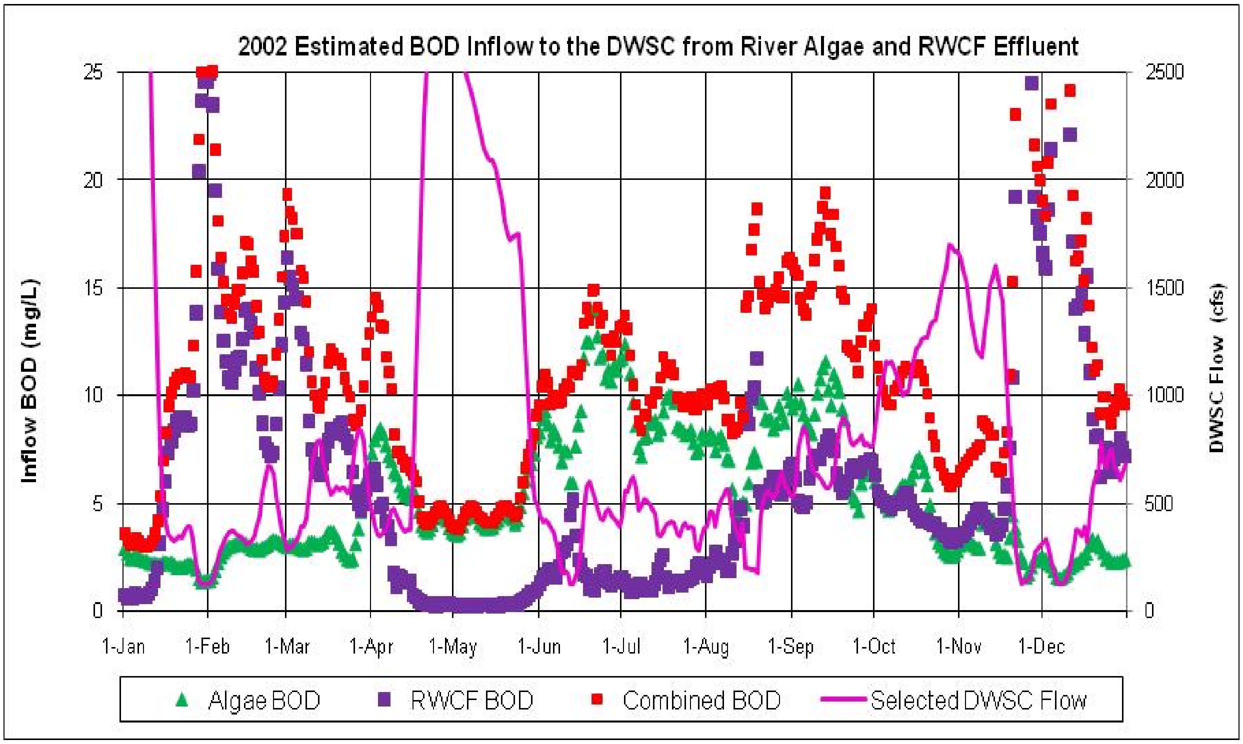


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2001.

Figure 26
Continued



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2002.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2002.

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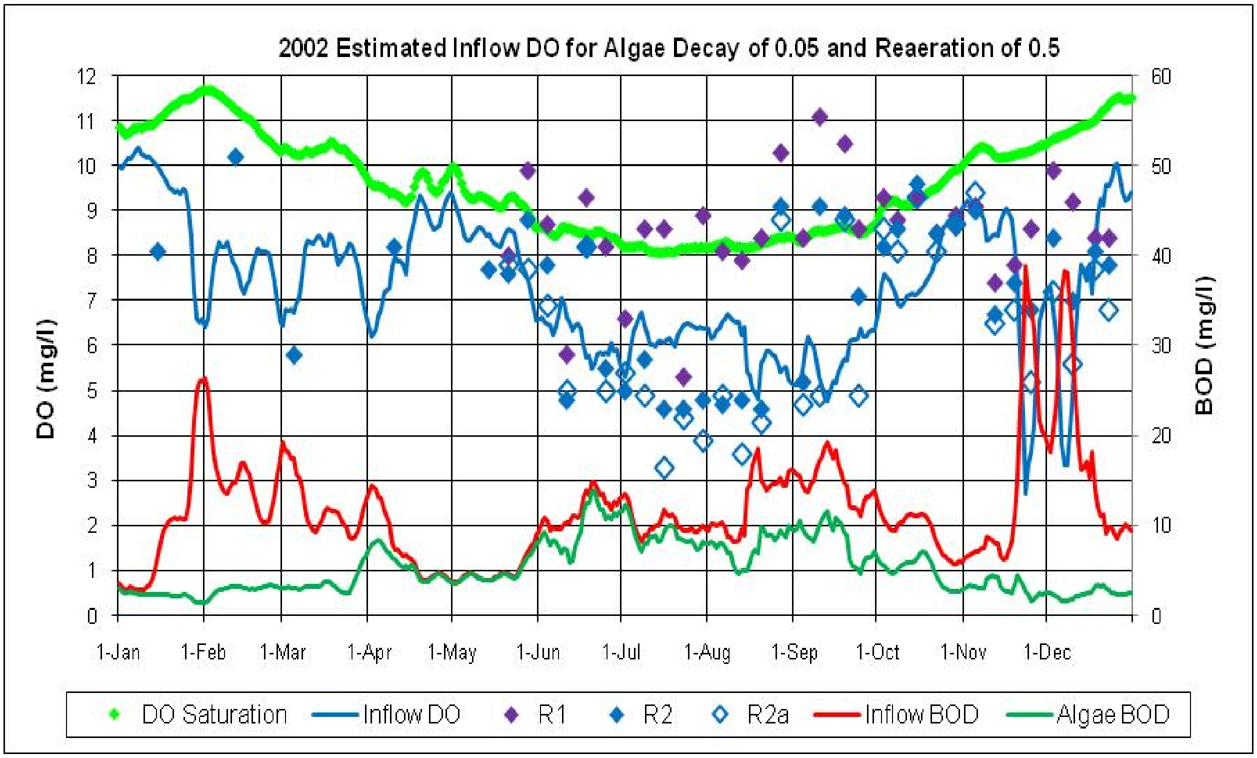
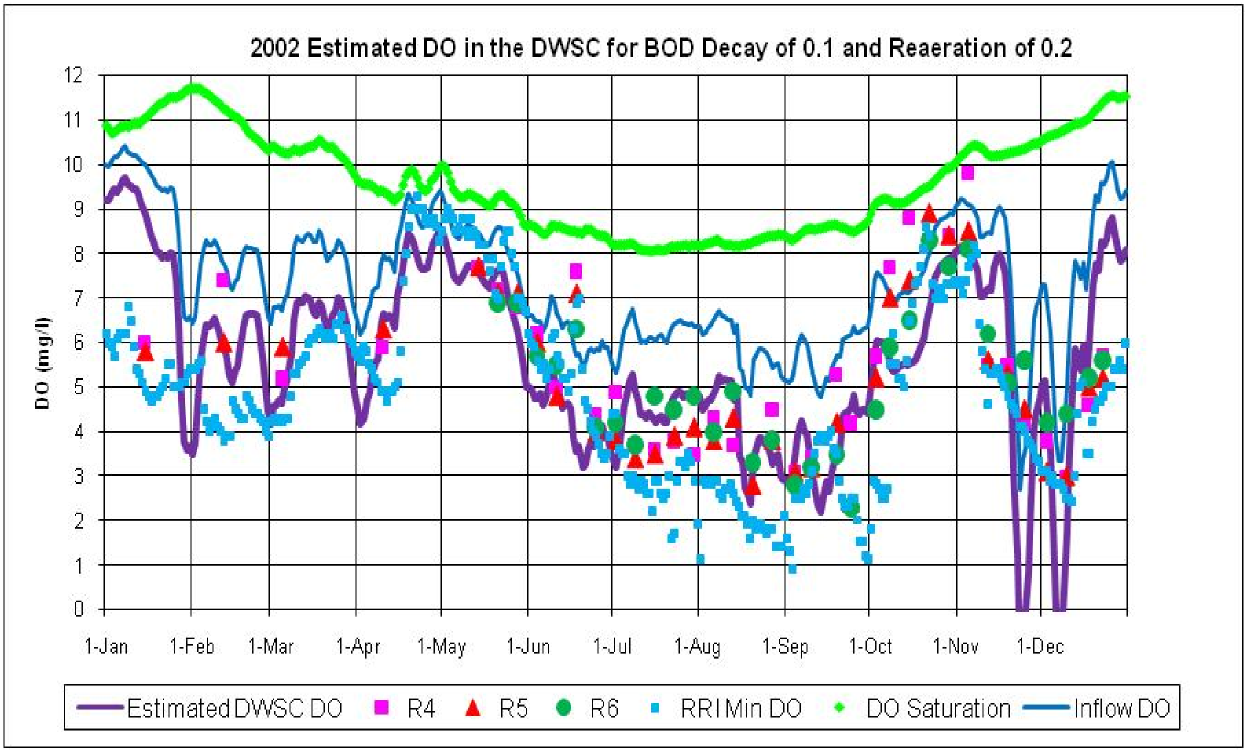
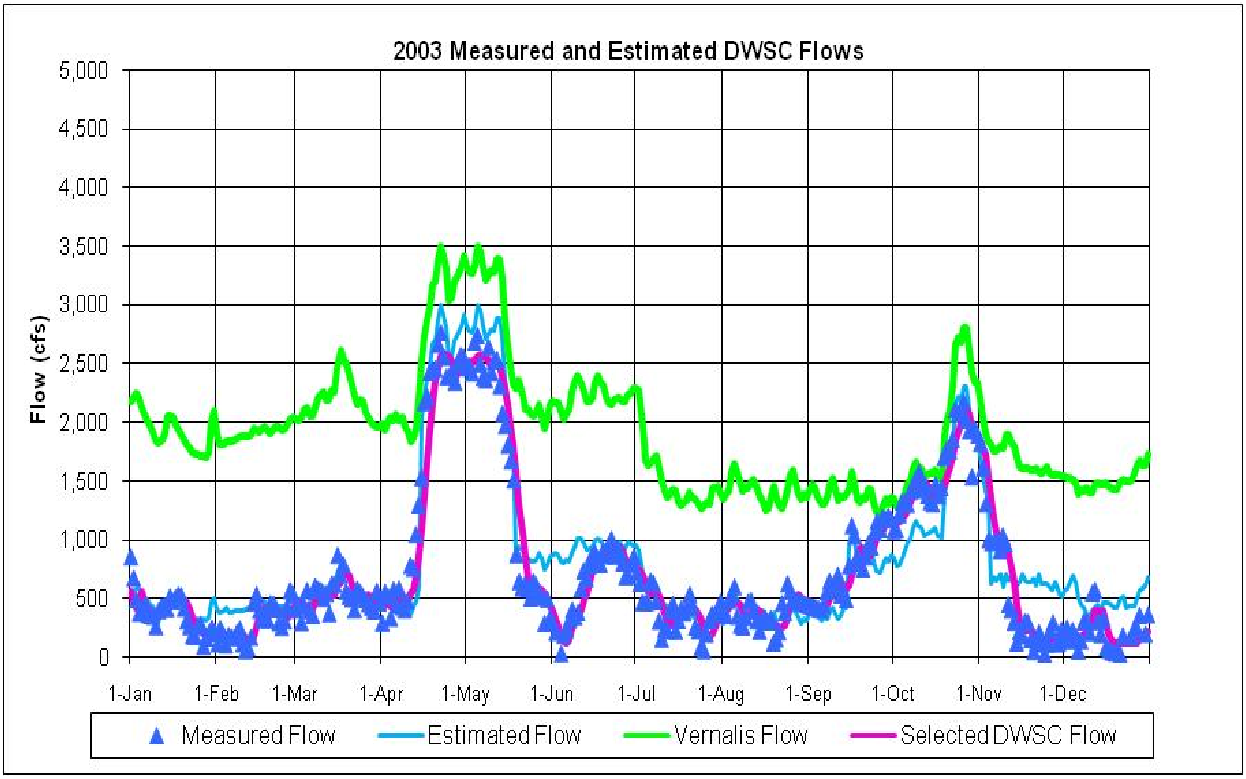
Figure 27



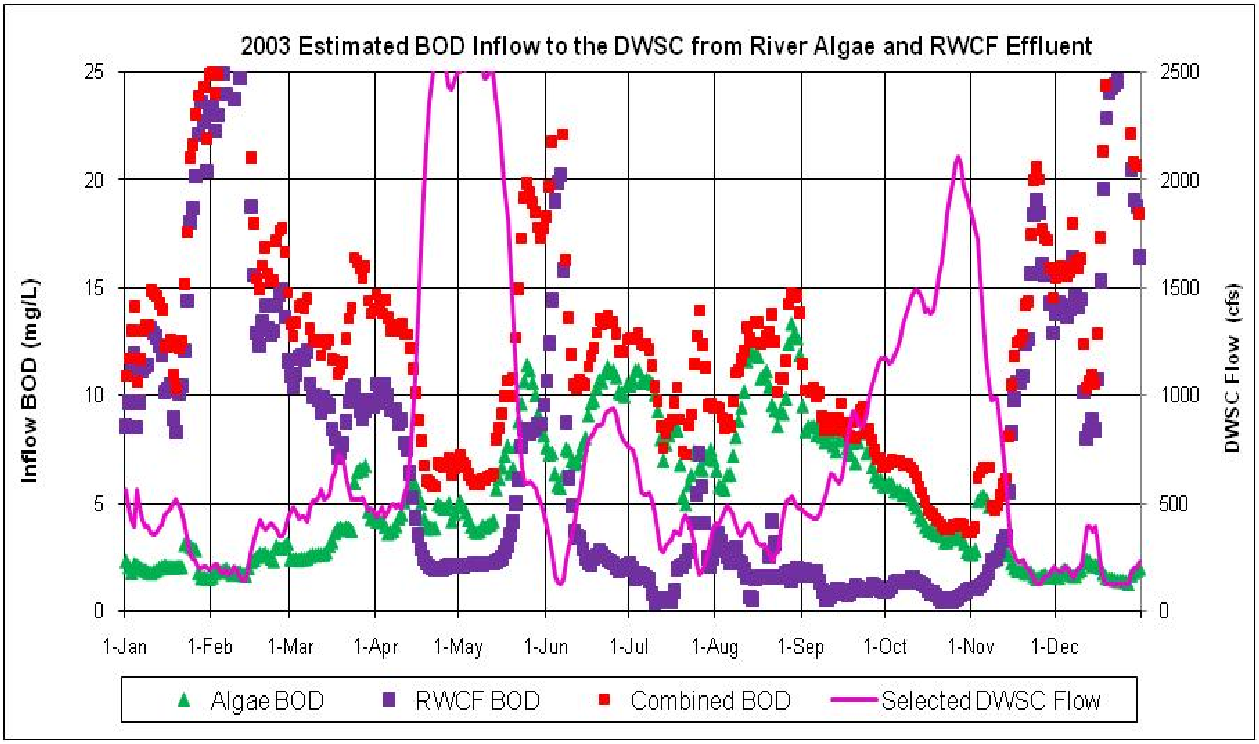
c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2002.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2002.



a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2003.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2003.

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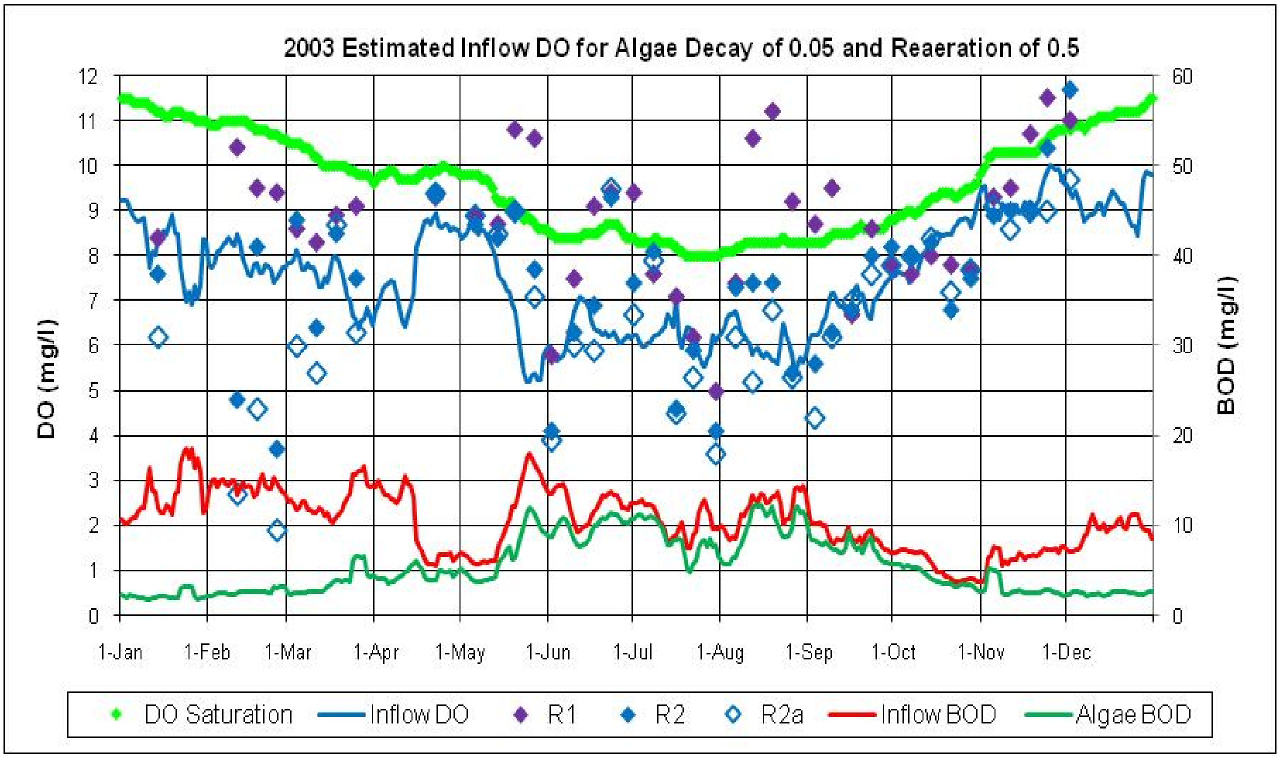
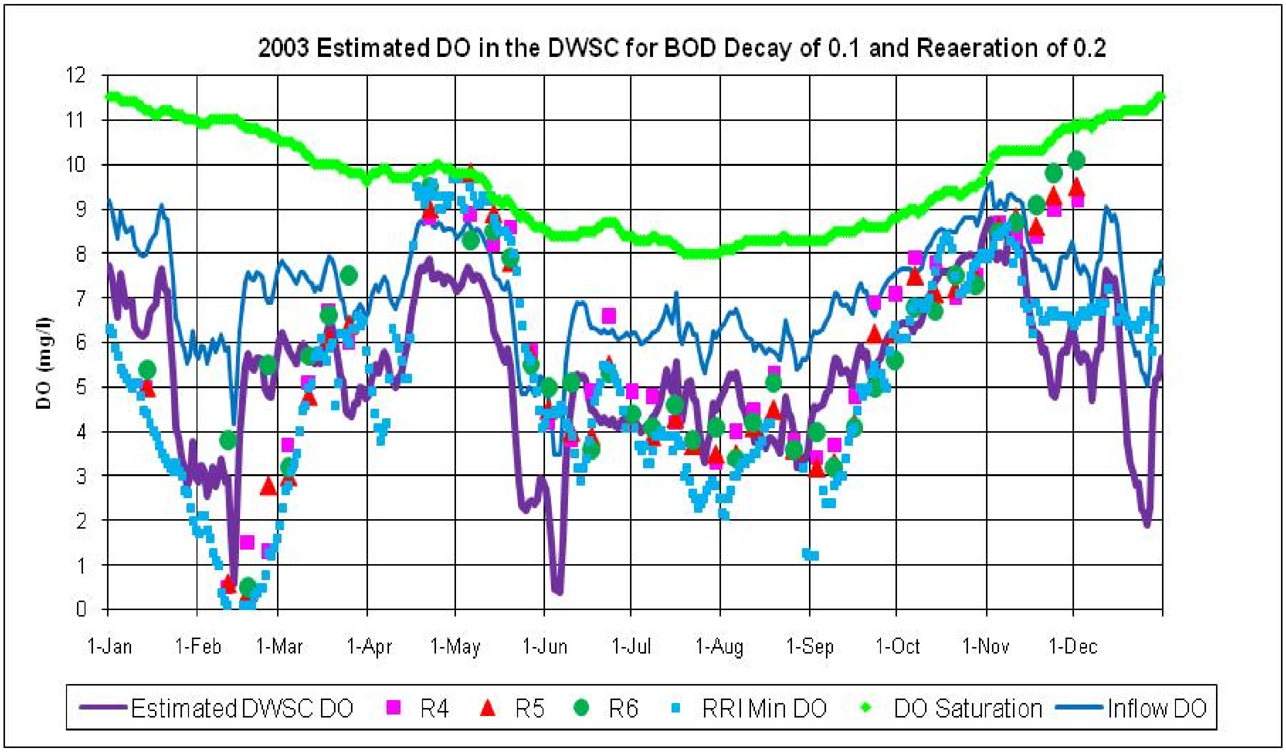
Figure 28

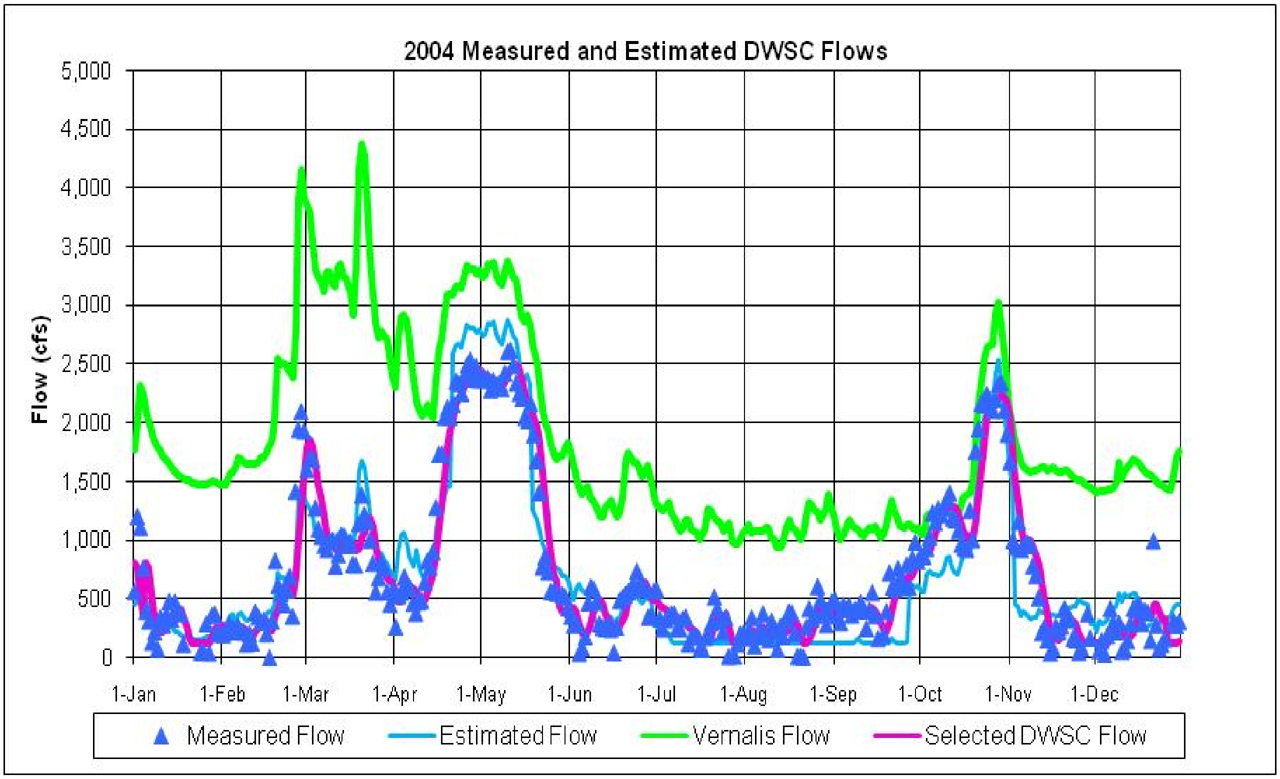


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2003.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2003.

Figure 28
Continued



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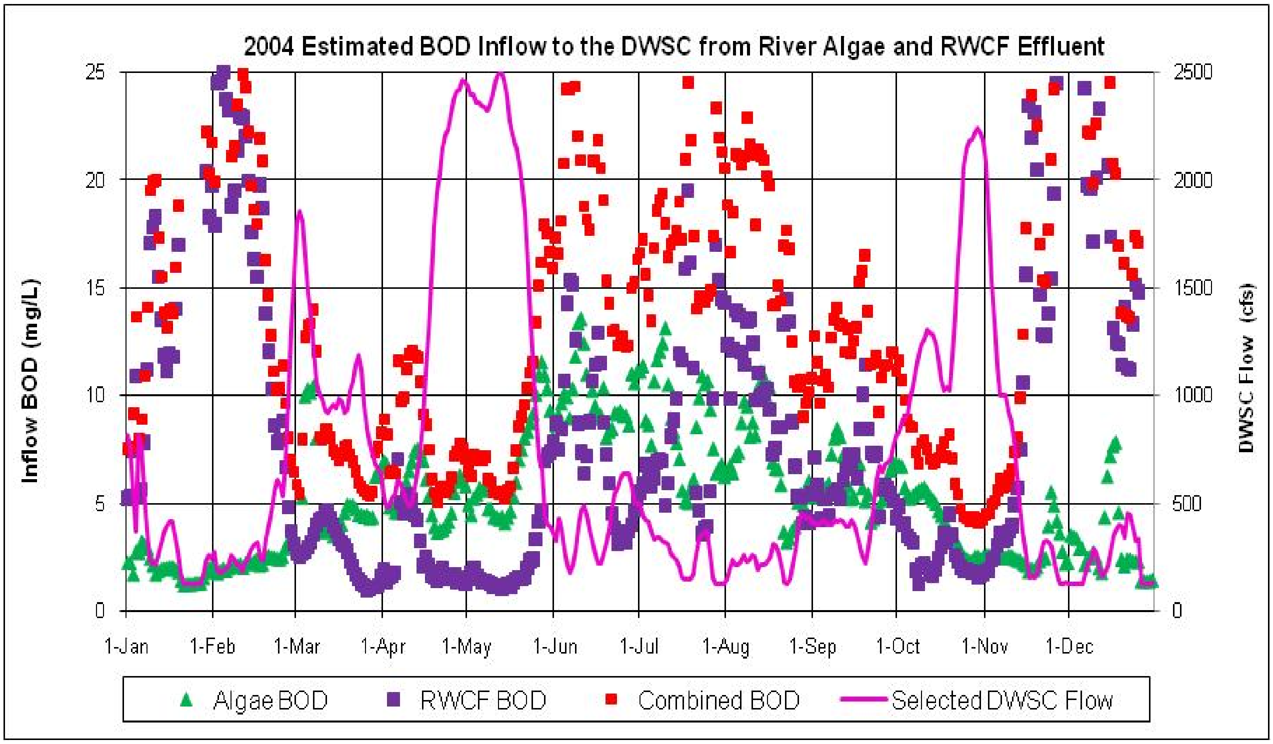
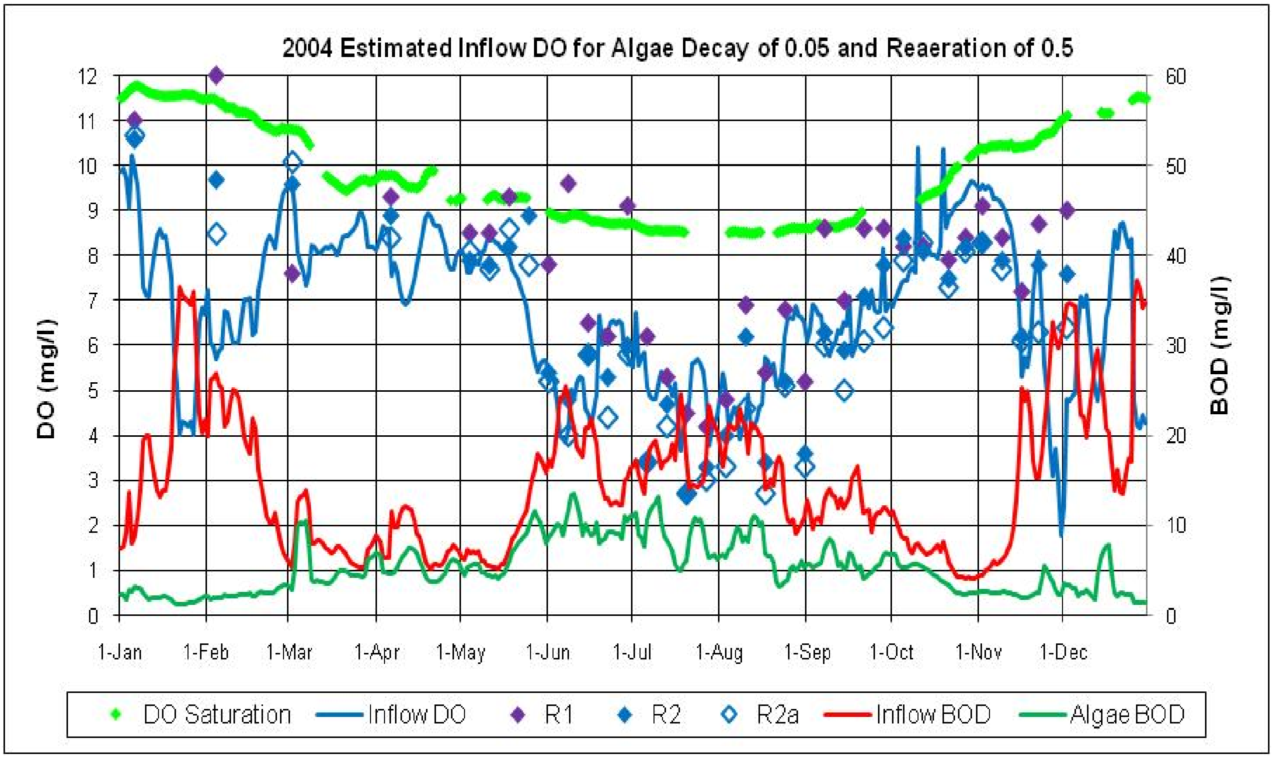


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2004.

Figure 29



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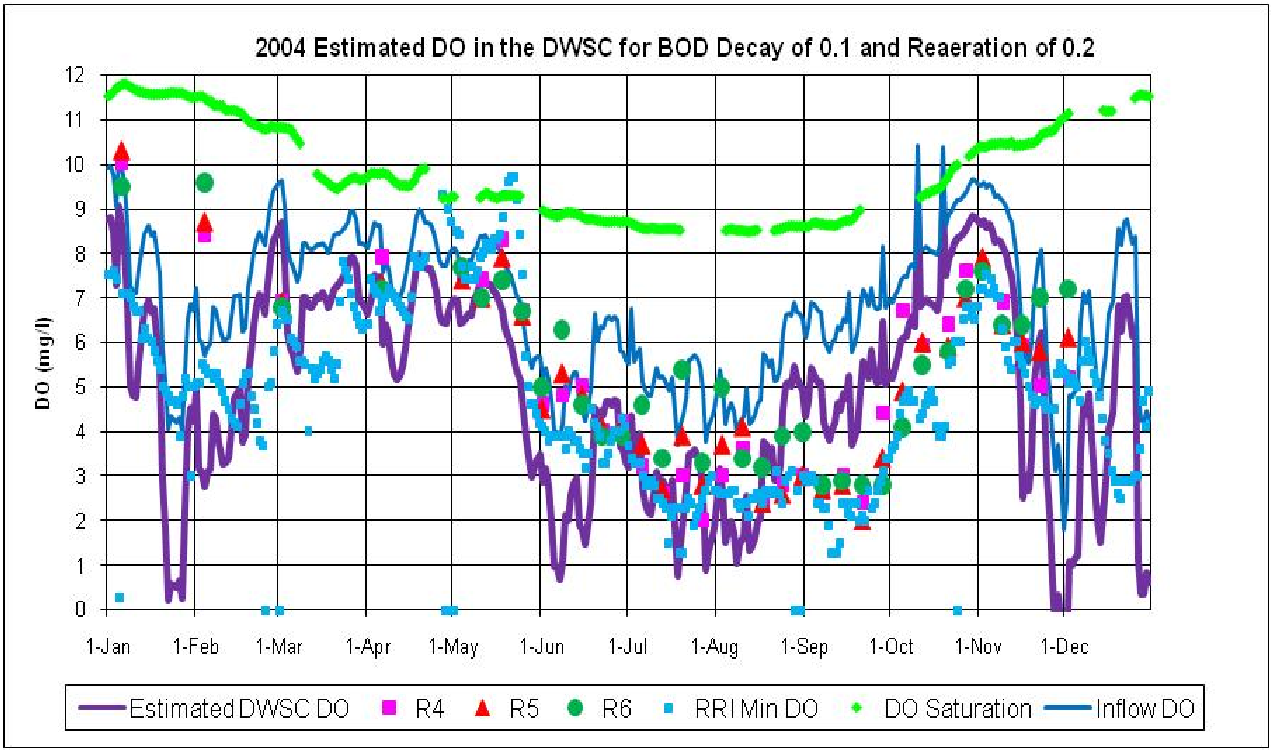
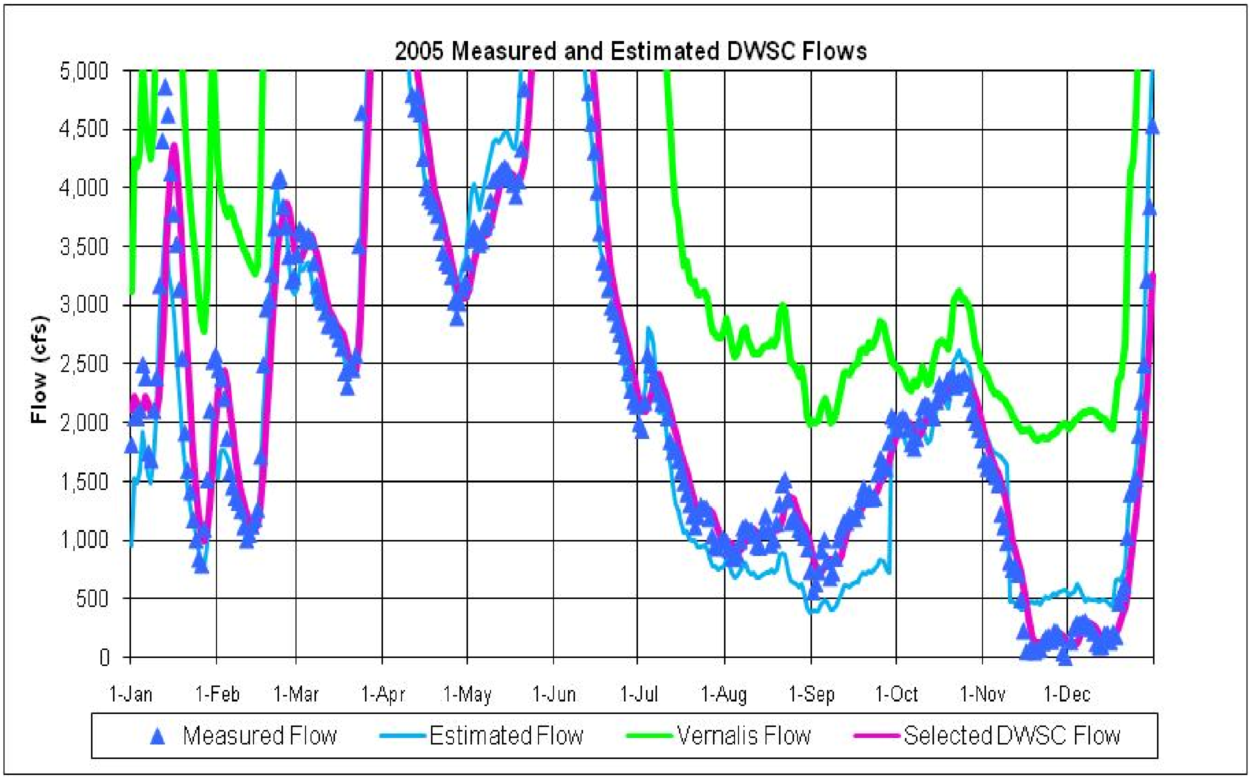


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2004.

Figure 29
Continued



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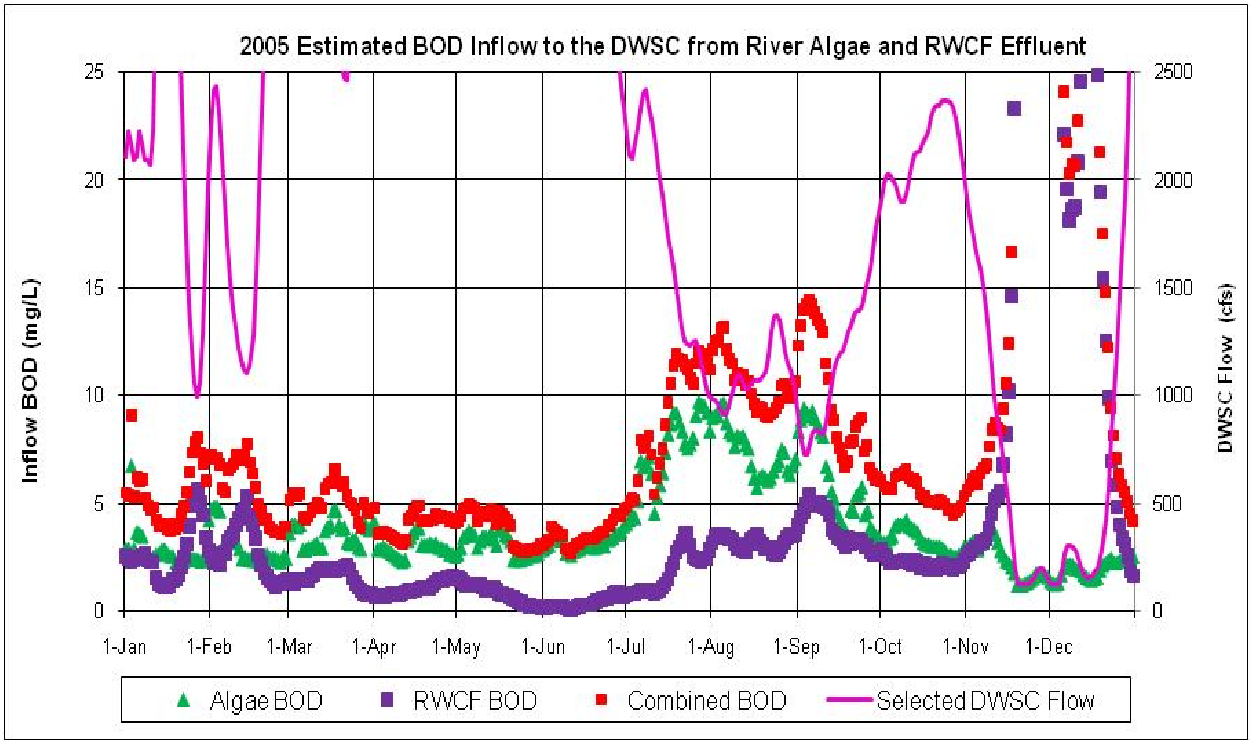
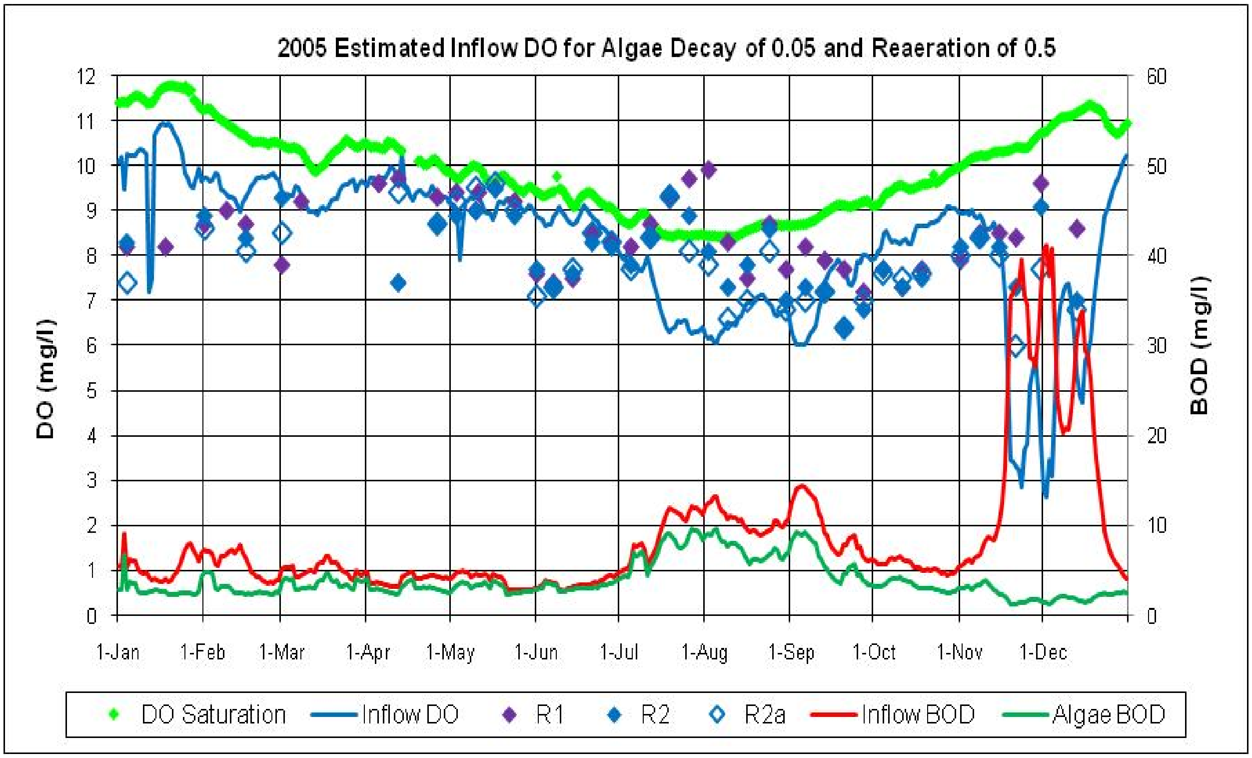
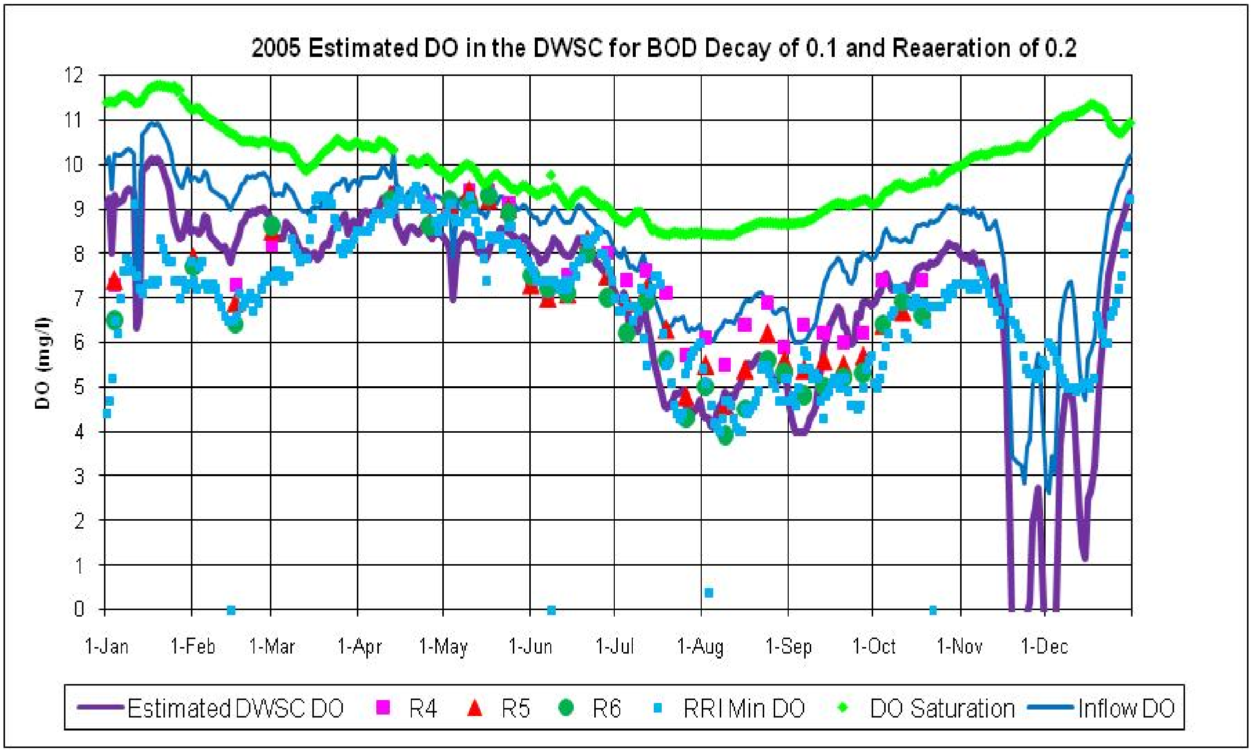


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2005.

Figure 30

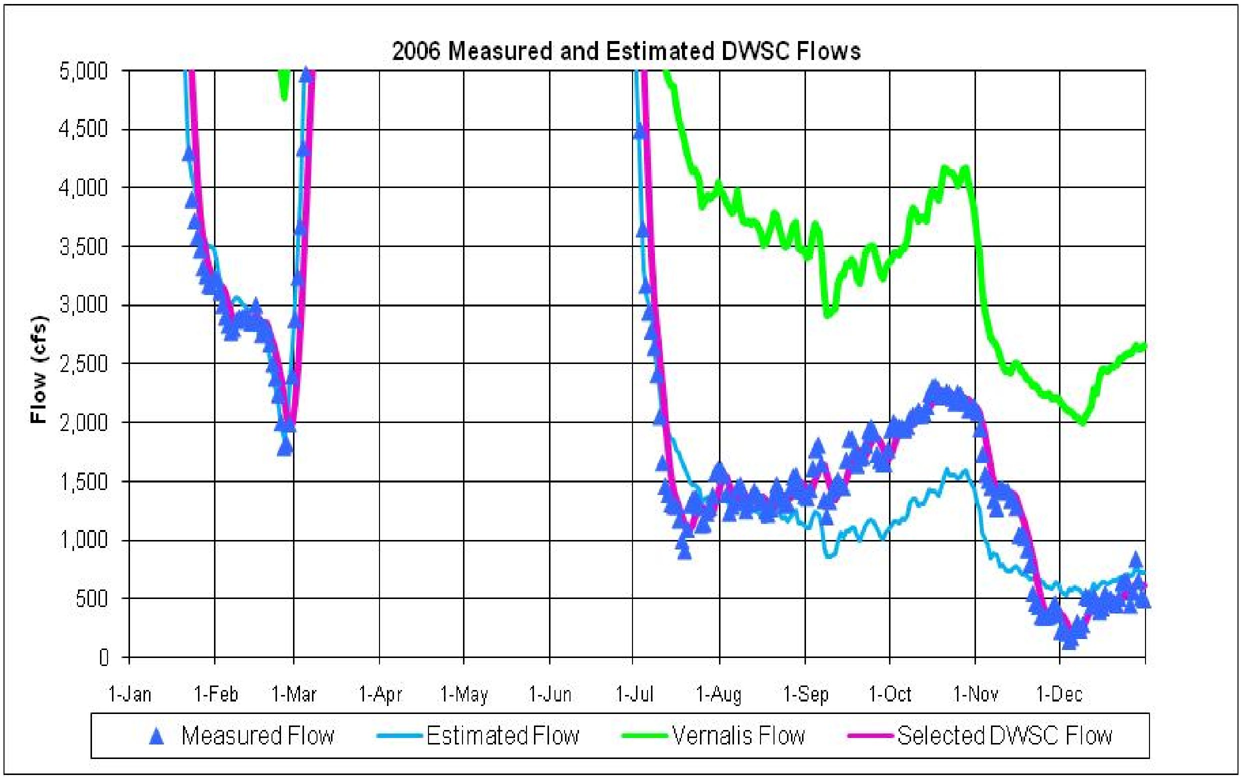


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2005.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2005.

Figure 30
Continued



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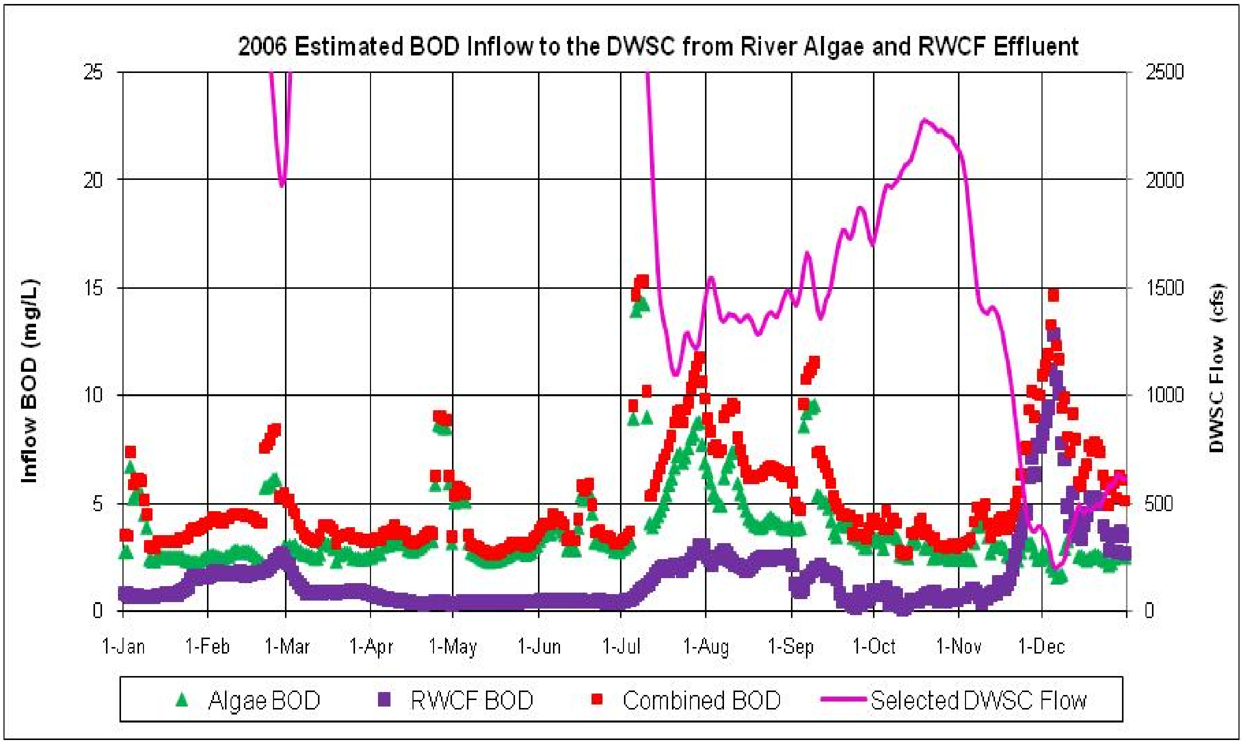

b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2006.

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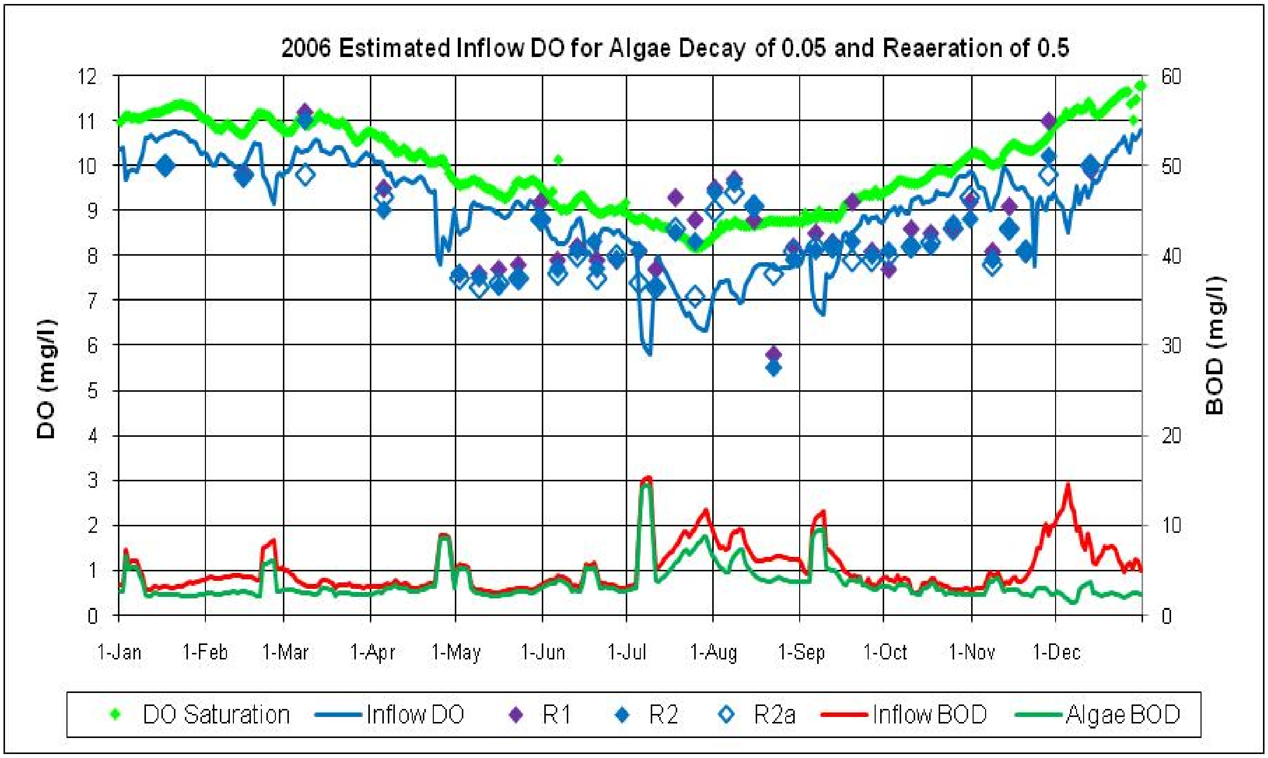
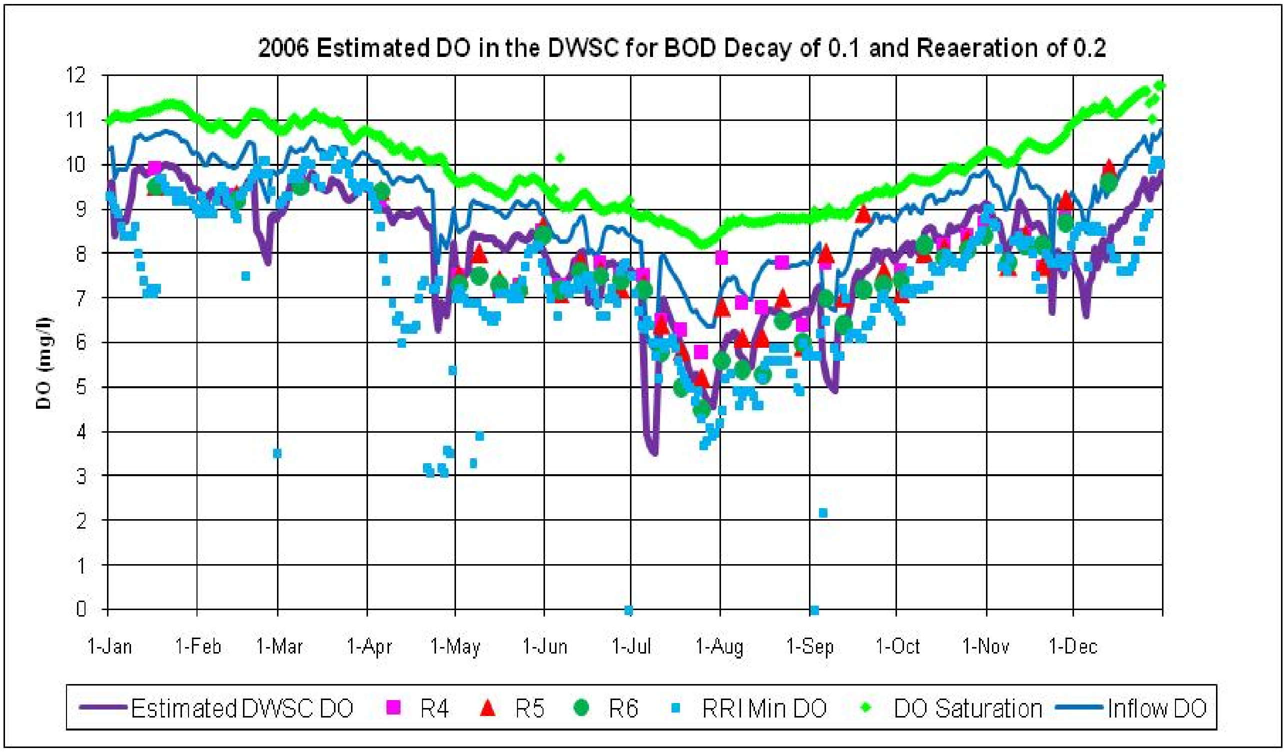
Figure 31



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2006.



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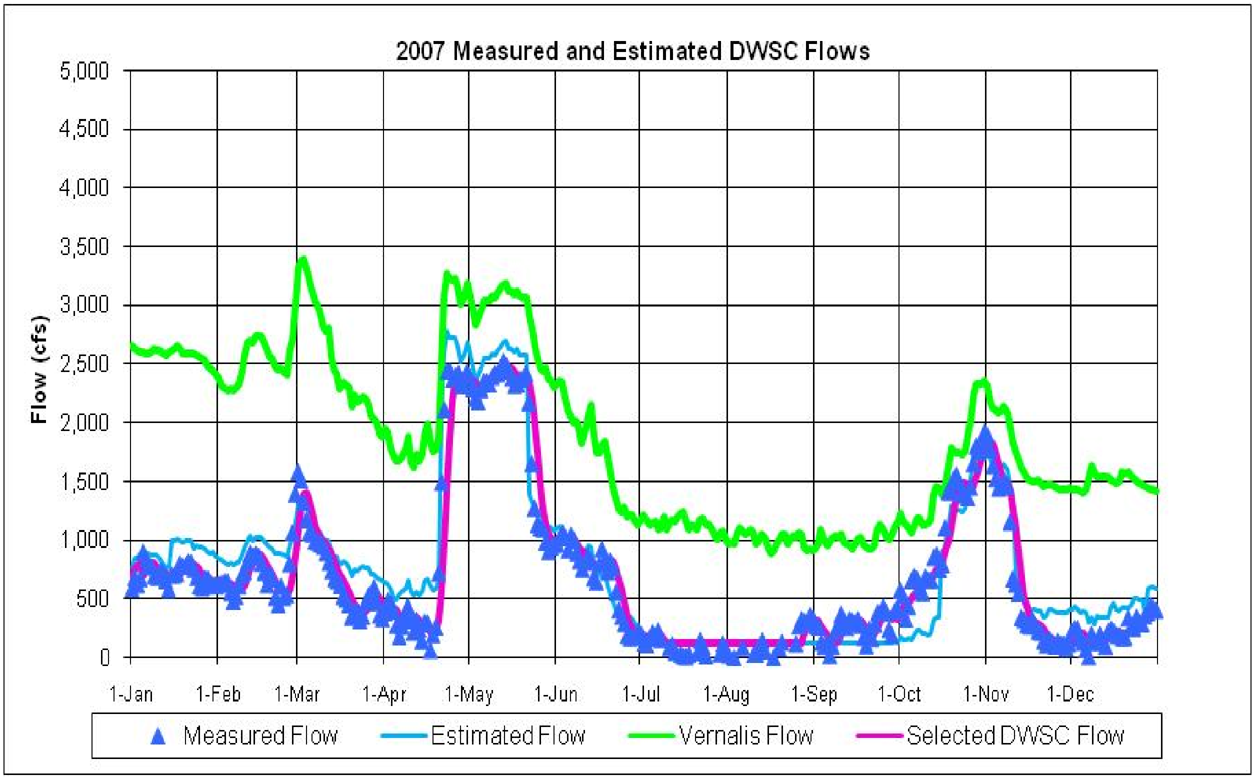

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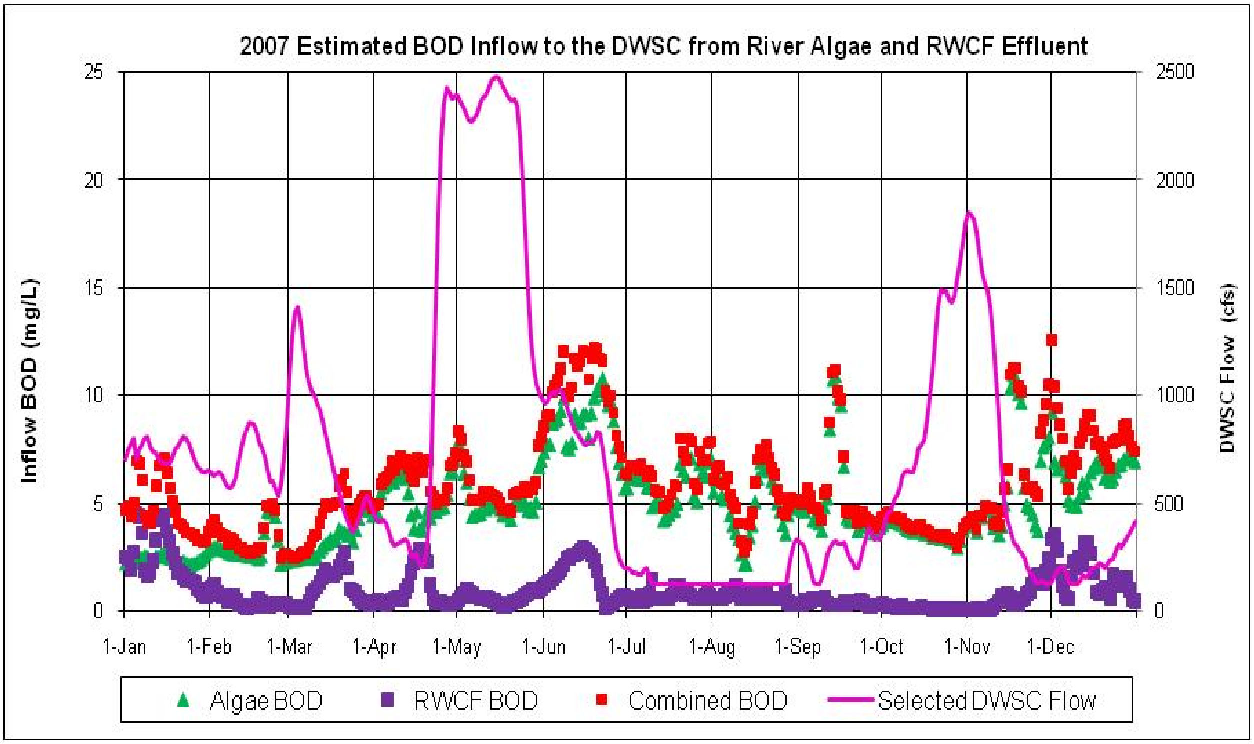
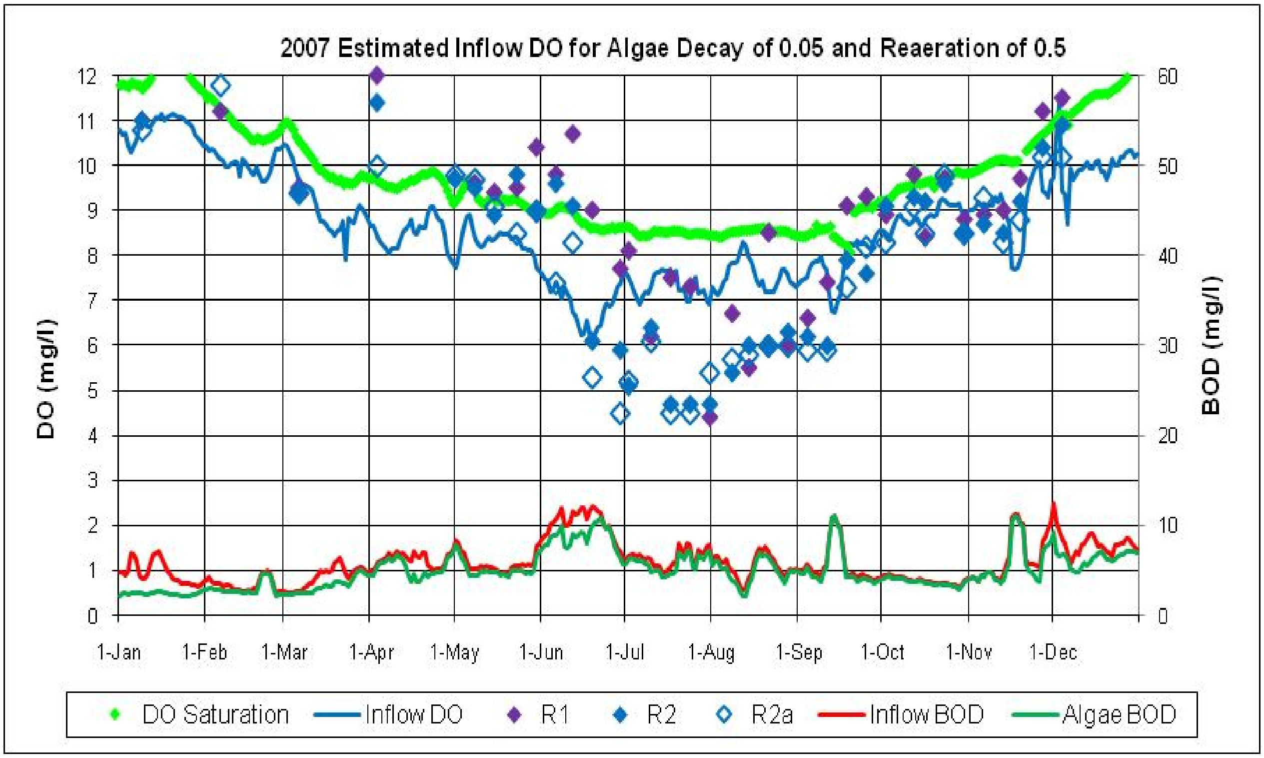
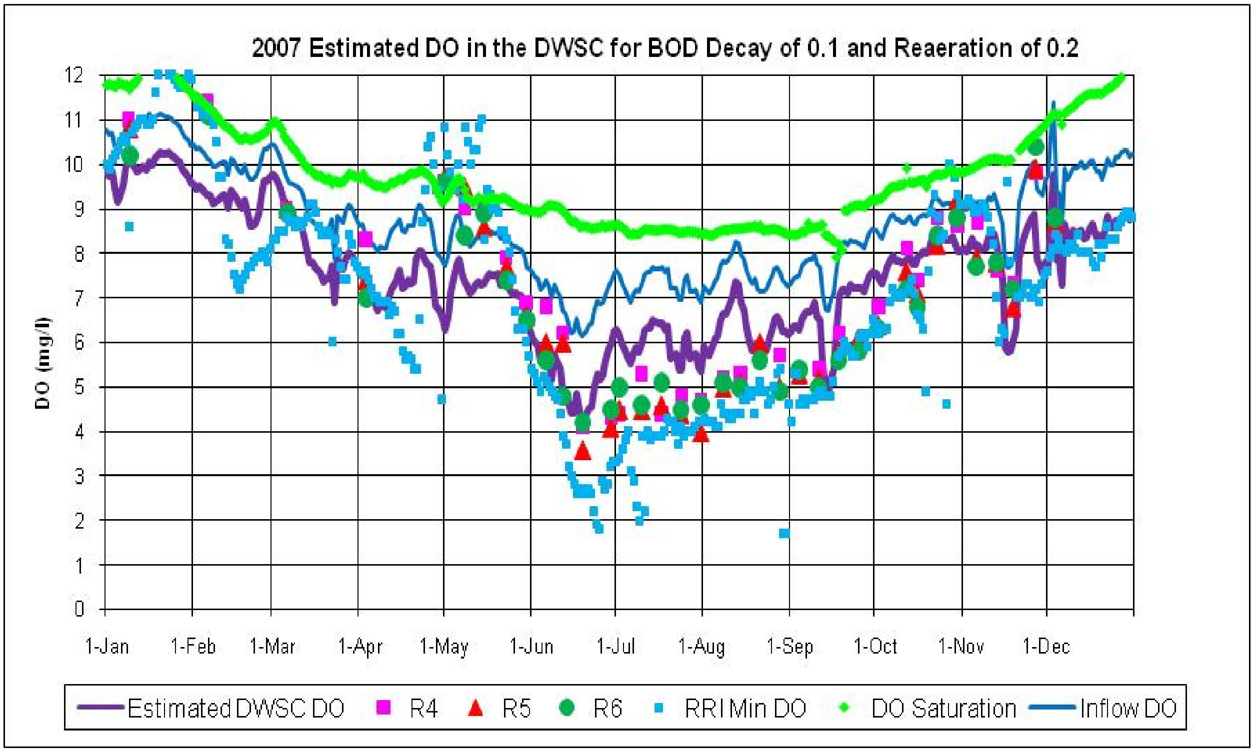


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2007.

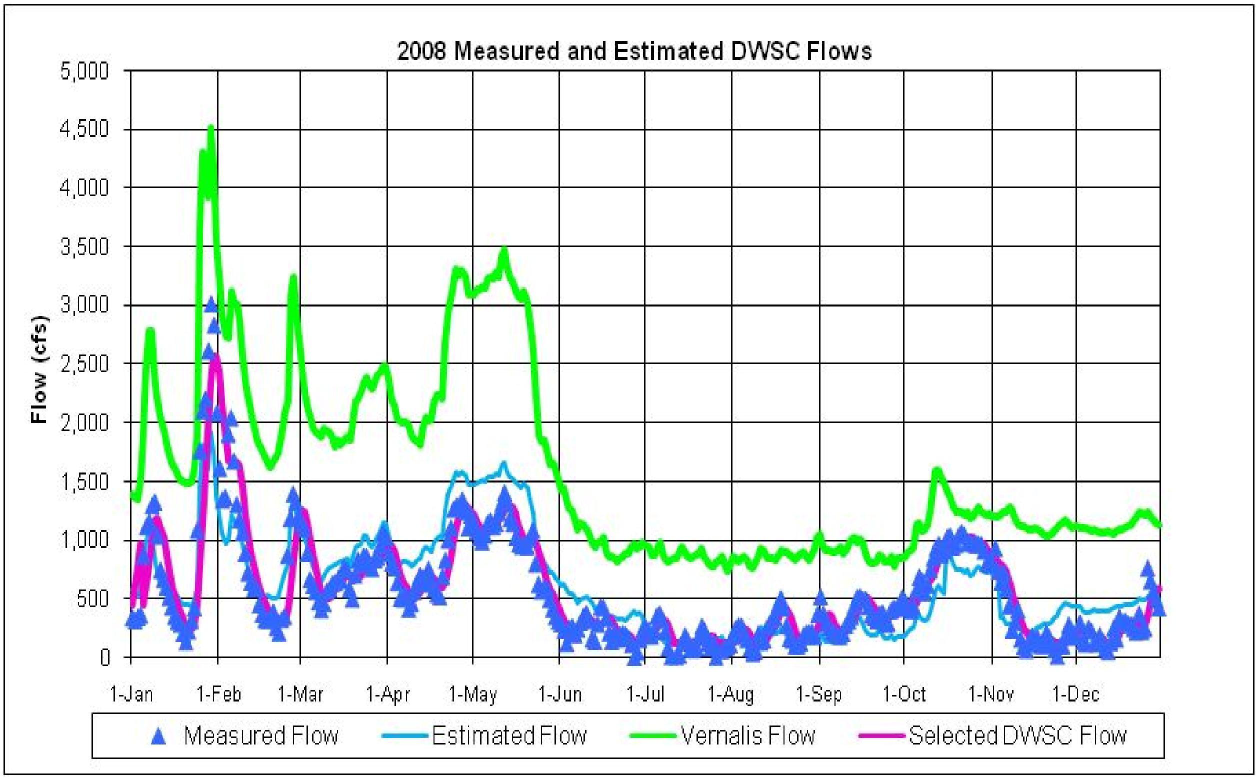


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2007.

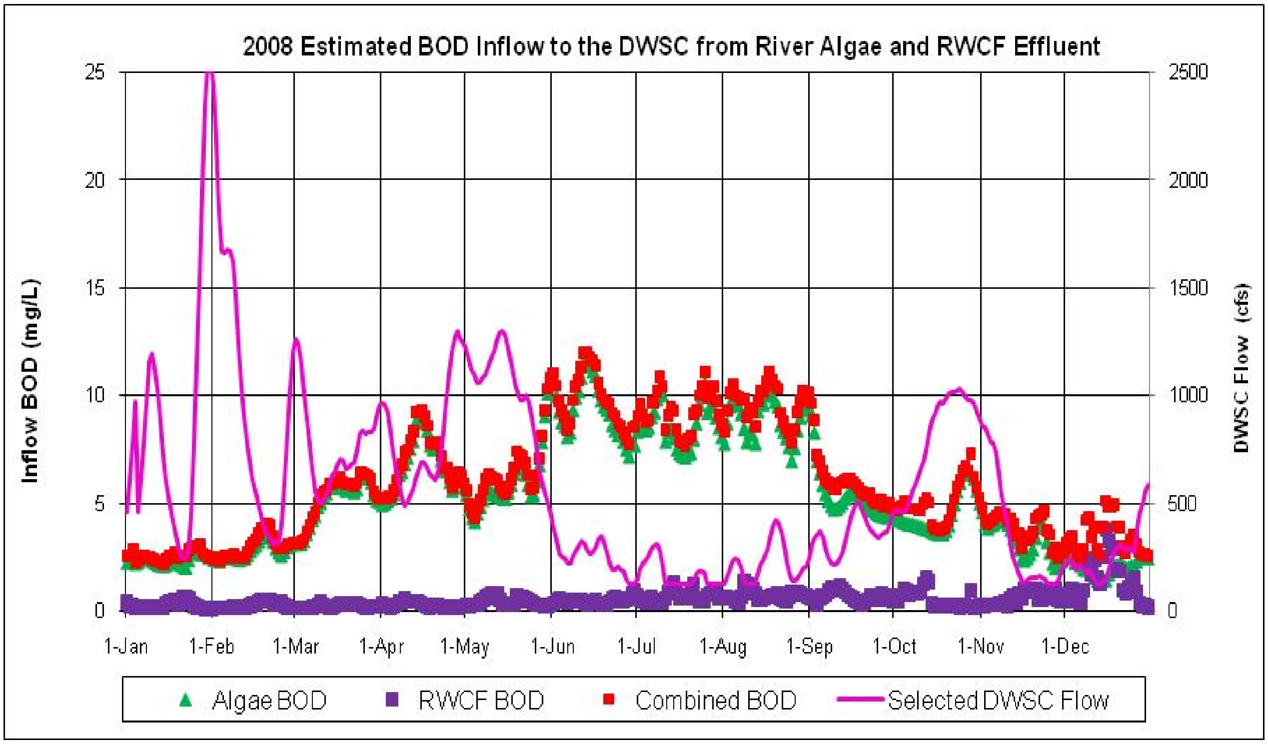


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2007.

Figure 32
Continued

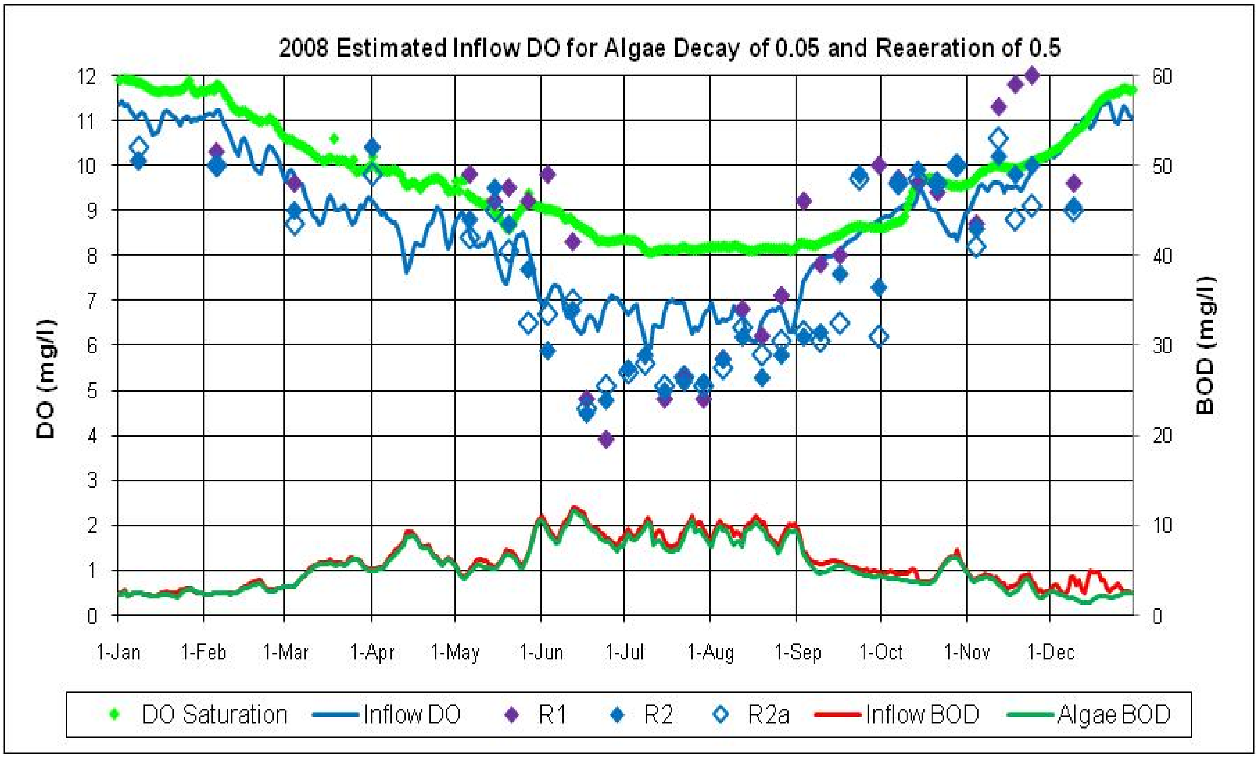


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2008.

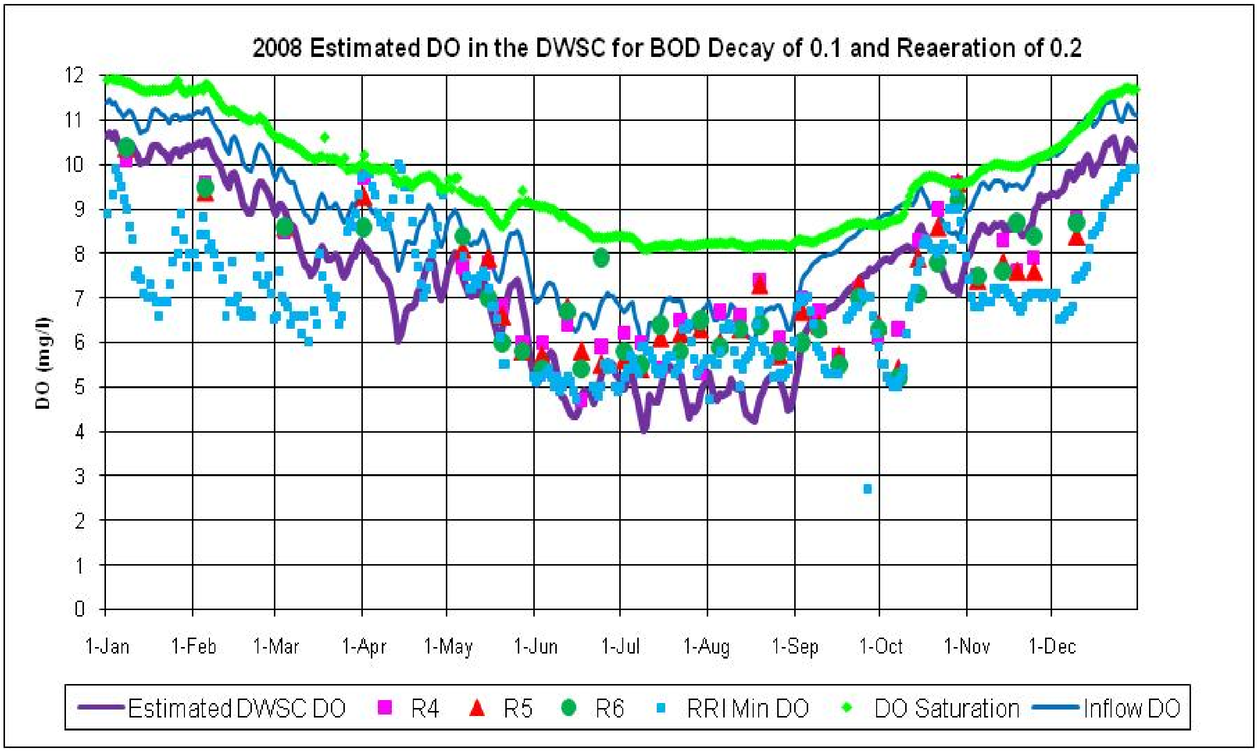


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2008.

Figure 33

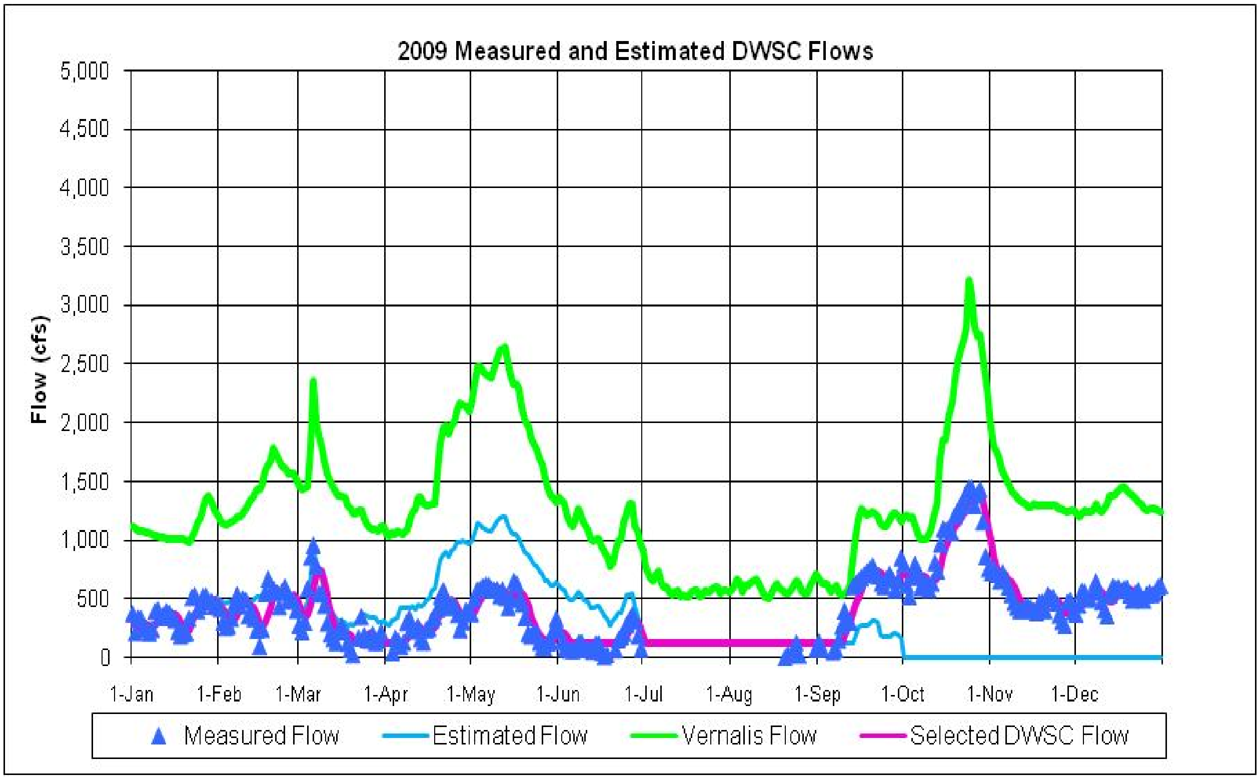


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2008.

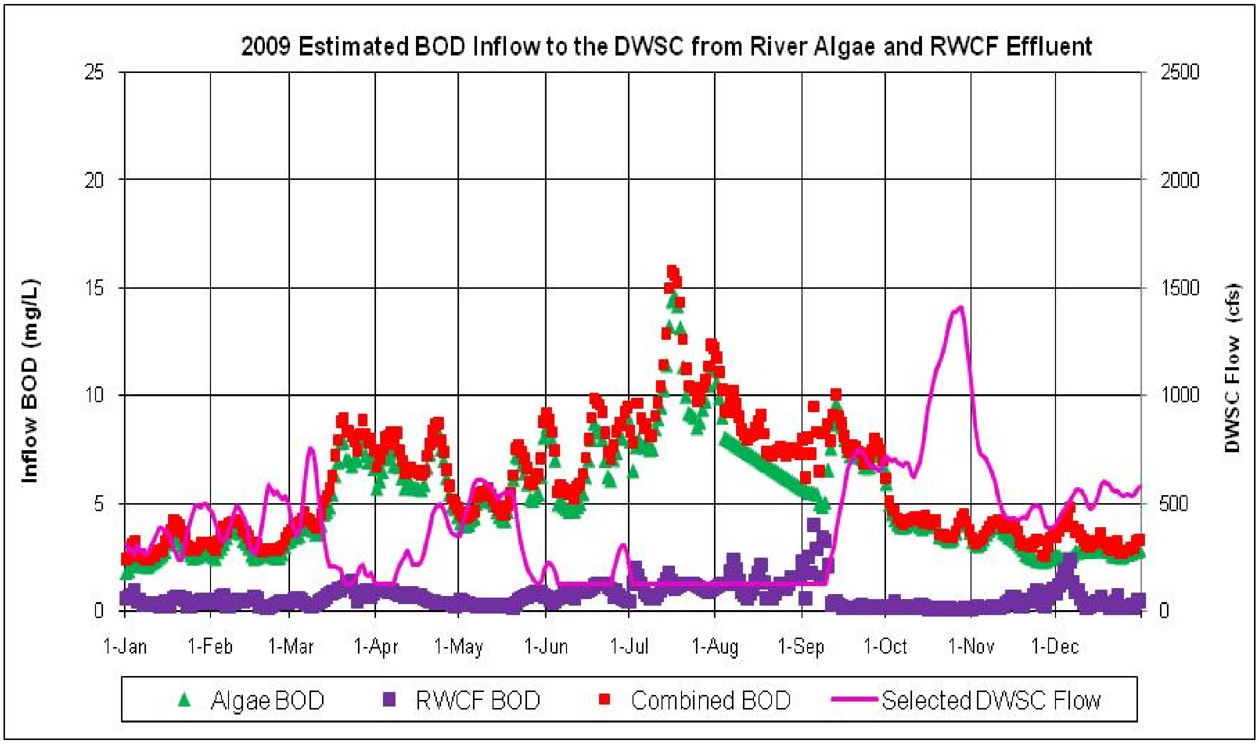


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2008.

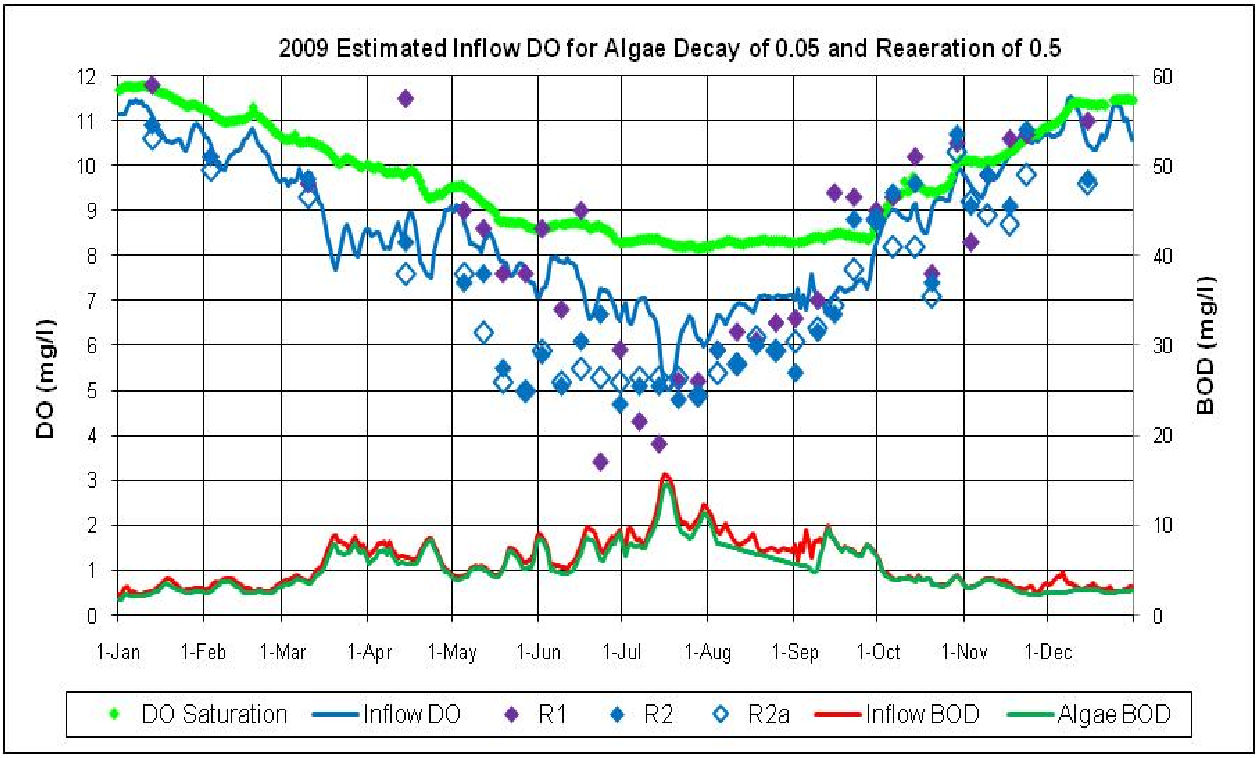
Figure 33
Continued



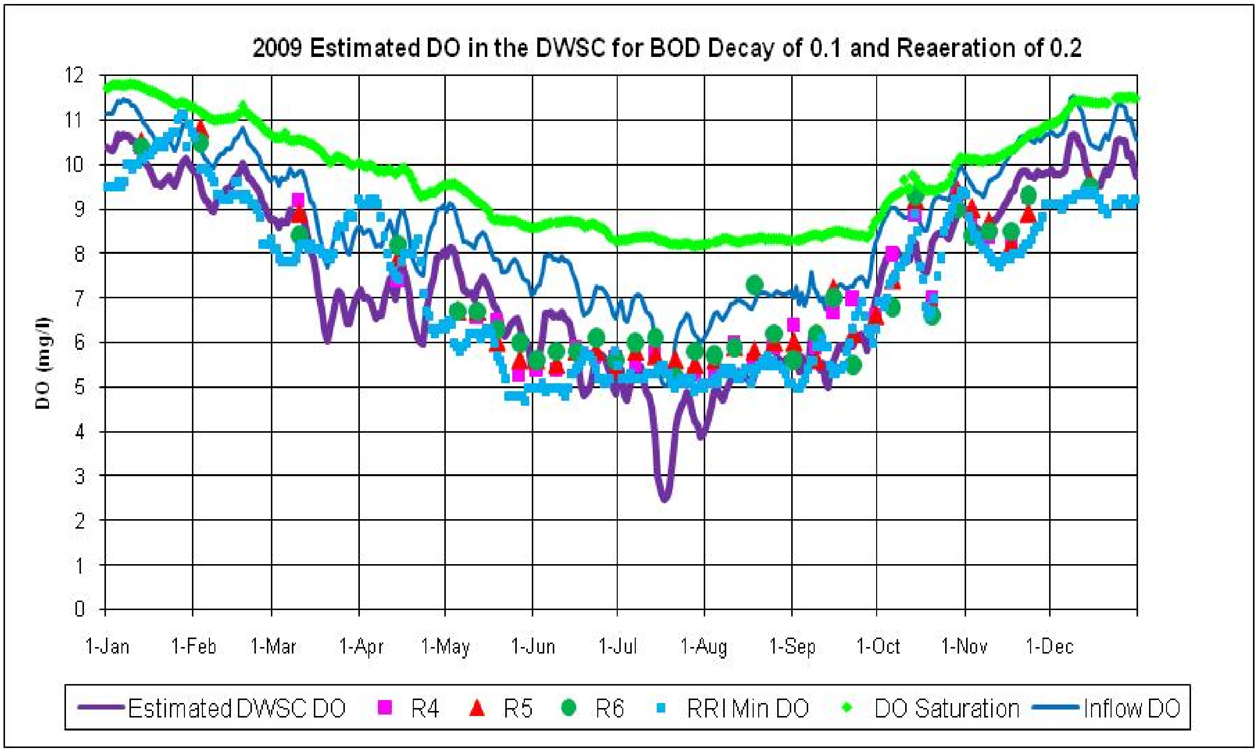
a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2009.



b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2009.

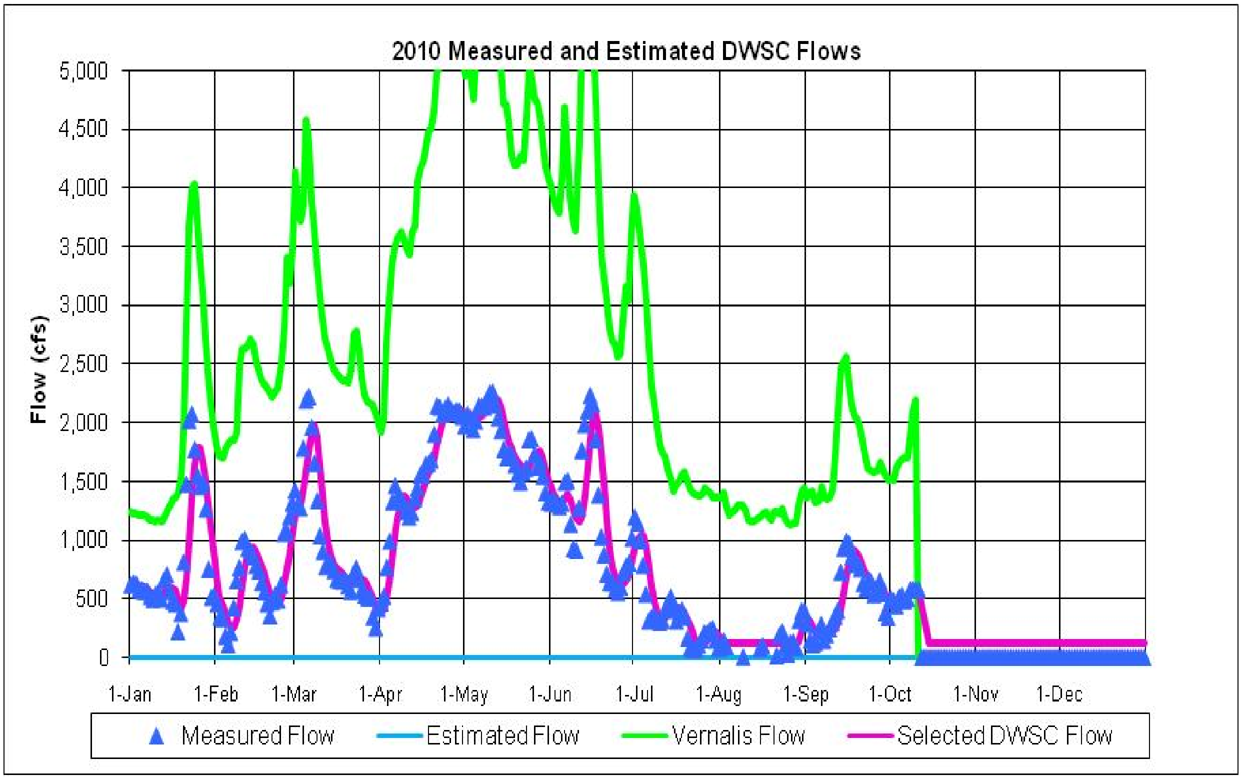


c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2009.

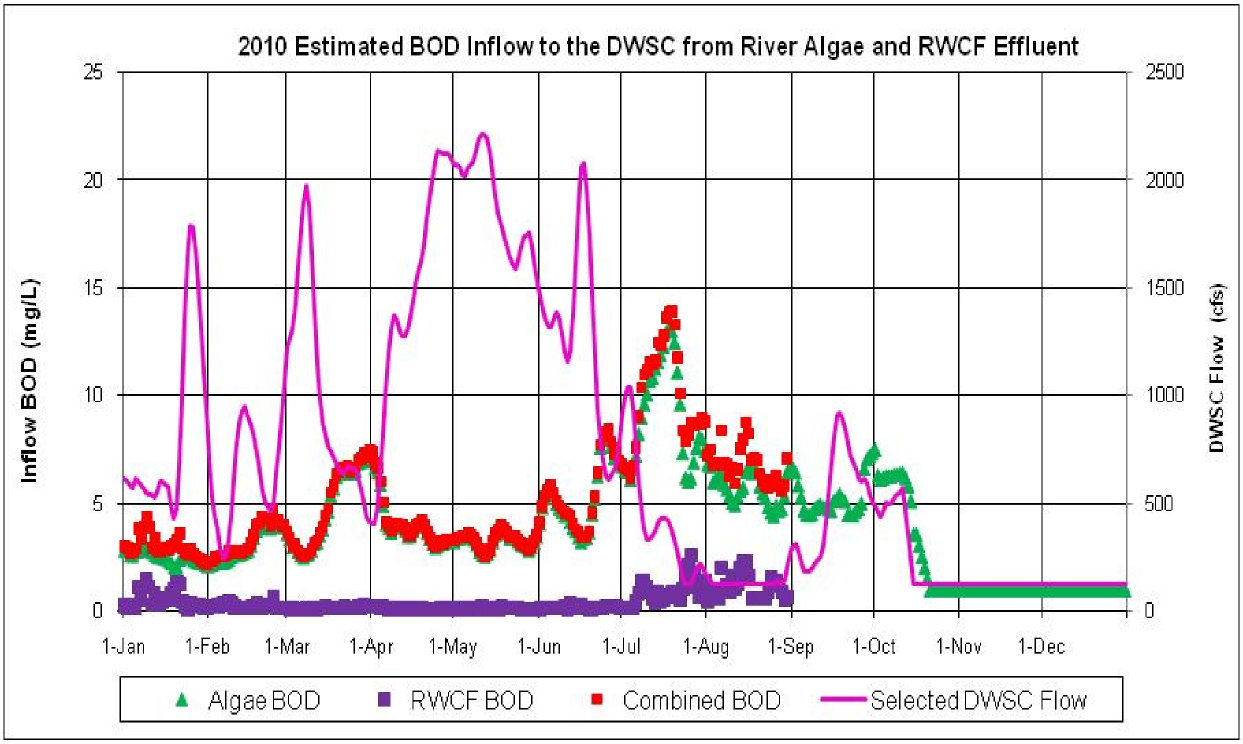


d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2009.

Figure 34
Continued

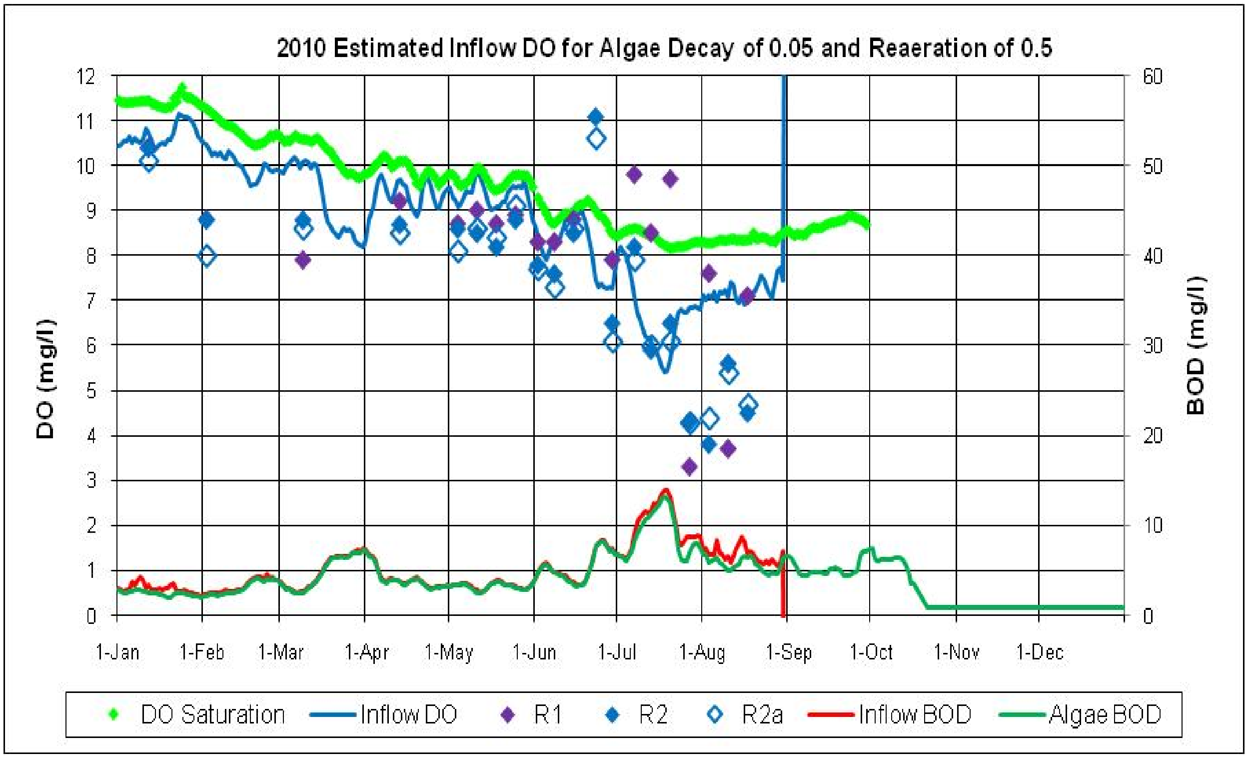


a) Daily Measured (Selected) and Estimated DWSC Flow with SJR Flows at Vernalis for 2010.

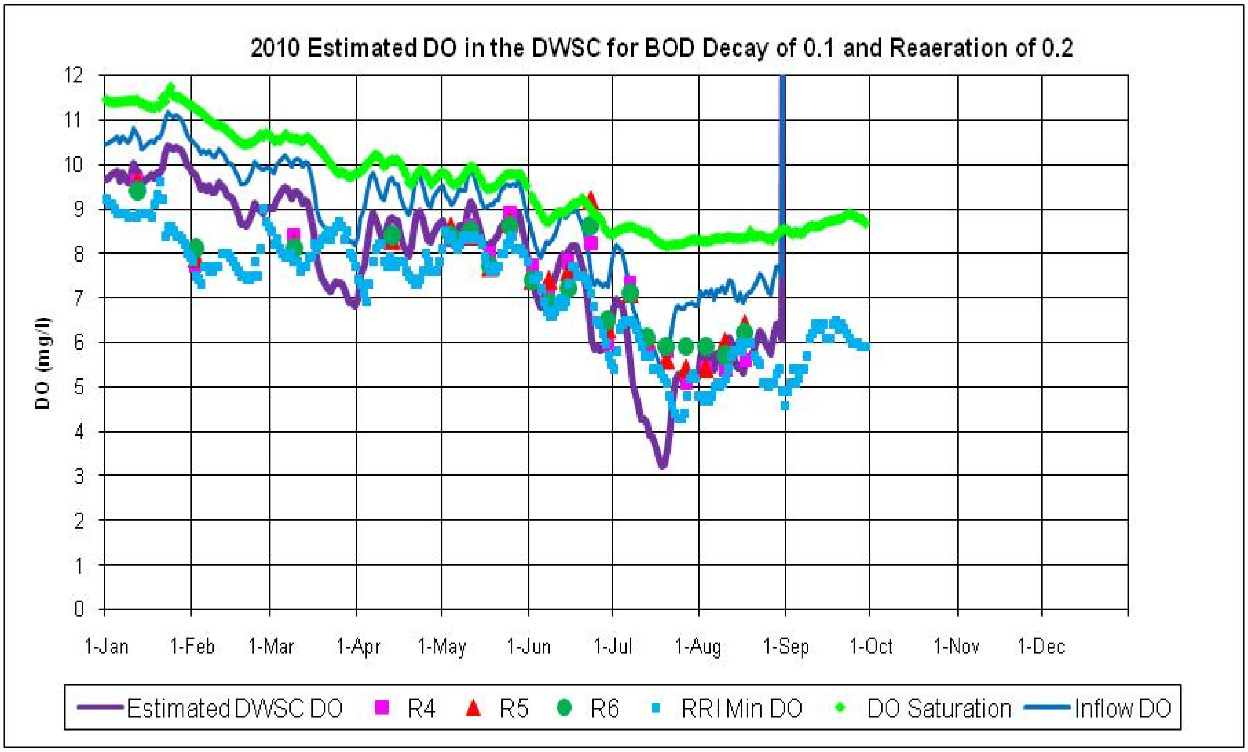


b) Daily Estimated Upstream River Algae BOD and Stockton RWCF BOD Entering the DWSC for 2010.

Figure 35



c) Daily Estimated Inflow DO Compared to Measured DO at Stations R1, R2, and R2a for 2010.



d) Daily Estimated Minimum DO in the DWSC Compared to Minimum DO at RRI and Measured DO at R4, R5, and R6 for 2010.

Figure 35
Continued