San Joaquin River Flow and Water Quality Modeling: Graphical Users Interface and Data Atlas Update for 2004

Introduction

This report describes progress during year 1 of the Modeling (Task 6) portion of the Upstream SJR Monitoring and Investigations project (Upstream Project), funded by CBDA. One element of the modeling task was updating the SJR water quality data atlas with 2004 data. The DSM2 model was not extended to include the tributaries as planned because of difficulty in obtaining the geometry data; this should be accomplished in early 2006. A users interface was developed to more easily specify inputs and parameter values for the SJR river model and the DWSC water quality model, as well as make comparative simulations and graphically view the results.

The data atlas summarizes and integrates the available data for the San Joaquin River between the Stevinson gage (at Highway 165 Bridge) and the Stockton Deep Water Ship Channel (DWSC). The gathering and processing of the data faithfully collected along the San Joaquin River by several government agencies remains a tedious and sometimes frustrating task. Integrating the available data into a graphical format allows the SJR flow and water quality conditions to be visually described and understood. The Upstream Project modeling work is funded by CBDA to support the SJR Dissolved Oxygen TMDL effort, although many others who are interested in the recent San Joaquin River water quality conditions may benefit from this summary of measured flow and water quality parameters.

The DSM2-SJR model was originally developed and calibrated for flow and EC by DWR staff. Some additional testing and calibration of the DSM2-SJR model was accomplished by HydroQual and by Jones & Stokes, under a previous CBDA contract. DWR has revised the geometry data for the model, to match travel time measurements previously collected by USGS. DWR has also recently produced an initial flow and EC calibration for 1990-1999. The effort to extend the DSM2-SJR model up the three eastern tributaries (i.e., Stanislaus, Tuolumne, and Merced Rivers) and to include Salt and Mud Sloughs was undertaken by LBNL. However, the extension of the SJR hydraulic geometry data and simulations with the extended model has been delayed by difficulties in obtaining the stream channel geometry data.

Based on their review of the DSM2-SJR water quality modeling features, the modeling team is suggesting that the project switch from the DSM2-SJR model to the watershed and river water quality model, called WARMF. The WARMF (Watershed Analysis Risk Management Framework) model allows the adjoining watersheds and irrigated lands to be included in the modeling framework. The river model within WARMF includes several important variables that are not presently in the DSM2-SJR model, including suspended solids, variable light extinction as a function of suspended solids, and the adsorption of nutrients and metals onto the particulates. The WARMF model also includes basic minerals and pH calculations, which will be important for tracking algal photosynthesis.

SJR Modeling (Task 6) Objectives

The overall Task 6 objectives from the Upstream Project work plan are summarized below. This first year modeling report includes progress on several of these modeling objectives. Only some of these objectives were accomplished during the first year.

1) A new extended version of the DSM2-SJR model (DSM2-SJR-extended) will be developed by DWR as part of a separate contract with CBDA. The new extended model that will include the tributaries and Salt and Mud Sloughs will be used for this project. [This work was subsequently declined by DWR due to staff constraints and transferred to LBNL. However, LBNL staff were unable to accomplish this objective because of difficulty in obtaining the necessary cross-sectional data; they expect to finish this work in early 2006].

2) Watershed runoff and groundwater hydrologic features of the SJRIODAY model will be incorporated into the new DSM2-SJR model by Systech and DWR. Estimates of runoff and groundwater salinity inputs from SJRIODAY will be incorporated to enhance the capability for short-term forecasting of water quality variables. The daily rainfall-runoff and groundwater flow routines in the current SJRIODAY model will be included in the new DSM2-SJR flow and water quality input formulations to allow surface-water accretions and runoff quality to be calculated from forecasts of basin precipitation. Groundwater accretion estimates will be developed by LBNL and used in the SJR model to allow schedules of east-side reservoir releases to be used in flow, salinity, and other water quality variable forecasting.

3) The existing SJRIODAY graphical user interface will be expanded by Systech to include the necessary water quality inputs and forecast variables for the SJR model upstream of the Delta (to Mossdale). The water quality parameters that can be adjusted and compared in the user interface (flow and EC only in SJRIO) will be expanded to include temperature, turbidity, TSS, VSS, nutrients, chlorophyll-a (live algae pigment) and phaeophyton (dead algae pigment), pH, BOD, and DO. This list of model variables matches the tributary input and main-river monitoring variables.

4) Historical data for inflows and diversions will be compiled by LBNL and Jones & Stokes. The extended model will be tested with the compiled flow data to determine its ability to match the historical data of observed flow and salinity at downstream stations. Systech and DWR will calibrate the new DSM2-SJR model for flow, EC, temperature, turbidity, TSS, VSS, nutrients, chlorophyll-a, phaeophytin, pH, BOD, and DO using data already collected by various agencies and monitoring projects from 2000 to 2004 (5 years). The data for DSM2-SJR model inputs and calibration comparisons will be compiled in annual and comparison spreadsheets (i.e., "data atlas" files) with daily measurements for interactive graphical displays. [Because of staff limitations, DWR has agreed to provide limited consultation for the calibration effort].

5) Systech and Jones & Stokes will incorporate the water quality algorithms found to be important and applicable in the previous DO model of the DWSC (i.e., City of Stockton water quality model developed by Systech) into the new version of the DSM2-SJR water quality model. These include light attenuation by total suspended solid, pH, phaeophytin (i.e., dead algae), nutrient and algal dynamics, re-aeration and tracking of fluxes for various oxygen consuming processes. Jones & Stokes will evaluate alternative approaches for estimating SJR algal concentration and loading. A complete set of model sensitivity studies for the major adjustment parameters will be performed. The sensitive model parameters will indicate specific measurements that should be included in the continuing adaptive monitoring programs. The calibrated model will be used to evaluate various alternatives to reduce algae biomass at Mossdale. These alternatives may include the control of nutrient releases from wetlands and initial algae biomass from agricultural drainage. It may also include flow management to increase the net river flow into DWSC during critical months.

6) The graphical user interface and model tool will be used to perform bi-weekly forecasts with weekly updates of water quality conditions at Mossdale. The forecasted results will be posted on a website for stakeholders. Forecasting results will be used to adaptively improve the predictive accuracy of the new DSM2-SJR flow and water quality model. A web site will be developed for public review and distribution of model calibration and forecasting results. The DSM2-SJR model and the adopted DWSC model (i.e., Stockton water quality, DSM2-Delta, HydroQual, or UC Davis 3-D model) will be used to begin interpretation of results and advanced forecasting of river conditions at Mossdale as well as low-DO conditions in the DWSC.

Initial Development of the DSM2 San Joaquin River Model

The initial version of the DSM2-SJR model was prepared by DWR staff in 2000 and 2001 (DWR 2000, DWR 2001) to extend the upstream SJR boundary of the DSM2 Delta model from Vernalis to Stevinson, to allow simulation of SJR water quality management alternatives, including re-circulation of DMC releases to the SJR. The initial geometry input for the 92 stream segments was developed. The simulated stage-discharge relationships appeared to match measured stage at the SJR flow stations (Newman, Crows Landing, Patterson, and Vernalis). A flow and EC calibration was performed for the 1997-1999 period. The agricultural diversions, return flows, and groundwater accretions were estimated following the SJRIO assumptions. Nevertheless, a substantial amount of missing water (and salt) was identified for these three years. A constant additional inflow of 200 cfs was simulated at Patterson, along with an additional 150 cfs at Vernalis. The salinity was assumed to be twice the Orestimba Creek EC. The need for this additional water and salt suggested that the measured tributary inflows, together with the estimated diversions and return flows from SJRIO are not sufficient to match the measured flows and salinity at Patterson and Vernalis. DWR was not able to proceed with the identification and estimation of the actual sources of the missing water (or overestimated diversions).

In 2004 DWR staff prepared some monthly equations for estimating salinity (EC) for the major tributaries of the SJR so that the model could be linked to a longer period of CALSIM and DSM2 Delta modeling (DWR 2004). These estimates were based on the review of available monthly average EC data from these tributaries. These estimates of flows and EC were blended with the SJRIO estimates of diversions, return flows, and groundwater accretions to provide an initial simulation of a longer period, from 1990 through 1999. These DWR efforts can be reviewed at the DWR Delta modeling website:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/dsm2sjrextension.cfm

SJRIO Inflow and Groundwater Inputs

The SJRIO (daily) model has been used by RWQCB, LBNL and DWR staff to estimate the daily water and salt budgets for the SJR downstream of Stevinson gage at Highway 165. These inflow estimates were to be incorporated into the DSM2-SJR model inputs, to allow agricultural diversions from the river, and irrigation drainage and groundwater accretions to the river to be simulated. However, the SJRIO modeling effort was discontinued after a 5-year period, so the “time-adjusted” estimates of drainage and groundwater inflows and riparian diversions along the SJR cannot be obtained directly from updated inputs to the SJRIO model. No final report has been prepared summarizing this work. The procedures for estimating these monthly SJR inflows and diversions have been generally followed in the DSM2-SJR input files developed by DWR. Because these monthly estimates are the most likely source for the missing water, these estimates should be evaluated and adjusted to eliminate the need to add 350 cfs to the simulated flows at Vernalis. This estimation of a revised water and salt budget is recommended as an important modeling objective for 2006.

DSM2-SJR QUAL Initial Testing by HydroQual

Under a previous CBDA contract, HydroQual performed initial simulations with the QUAL module of the DSM2-SJR model to test model performance for flow, temperature, nutrients, algae biomass (chlorophyll) and DO for 2000 and 2001 (HydroQual 2005). This report is included in the bonus files that are on the 2004 Data Atlas CD. A brief summary of HydroQual's initial findings is given here.

Jones and Stokes (working under the HydroQual contract in 2004) reviewed the simulated river hydraulic conditions and determined that the average river volume was about 50% too large at flows of 1,000 cfs to 2,500 cfs. DWR subsequently determined that several of the cross sections were too wide, and adjusted the geometry data to provide a good match of the river volume estimated from USGS dye study travel times (DWR 2005). The HydroQual report includes as an appendix the Jones and Stokes evaluation of river geometry as a function of flow for each model segment. This independent geometry evaluation was necessary because the DSM2 model has no tabular or statistical or graphical output features. The model results must be requested in a model run control file, imported from the resulting DSS files into Excel, and then summarized and evaluated and graphed in the spreadsheet file. The DSM2 model does not provide an output of the simulated geometry (surface area, conveyance area, average depth, volume). Because the water quality processes depend on these geometrical properties, this makes the evaluation of model results more difficult. A great deal of effort is needed to specify the desired model output parameters, process the basic model results to provide a summary of the results, and produce a useful analysis. Jones and Stokes developed Excel files for developing hourly, daily and monthly inputs (to create DSS input files) and displaying daily and hourly results (reading DSS output files) from the DSM2-SJR model. A graphical users interface (GUI) for the DSM2 model would be really great!

Flow, EC, and Temperature

Jones and Stokes also simulated the flow, EC, and temperature for the 2000-2003 (4-year) period, based on measured daily flow, salinity (EC), and temperature input data gathered and integrated into the SJR Data Atlas (for 1984-2003 data). The DWR estimates of monthly diversions, agricultural return flows and groundwater accretions were used. This extended the calibration period prepared by DWR. The need for additional water upstream of Patterson and Vernalis was confirmed for this modeling period; the seasonal pattern of "missing" water and salt provided some clues as to the nature of the water. Figures were produced for each year indicating the daily pattern of missing water and salt at Patterson and Vernalis. These figures suggested that the missing water and salt fluctuated somewhat during the year (DWR had previously suggested an average "add-water" of 200 cfs at Patterson and 150 cfs at Vernalis) with an average EC of between 1,000 and 2,000 uS/cm.

The identification and estimation of these unmeasured sources of water and salt might be considered a major result from the SJR flow and salt modeling. Either the SJRIO monthly estimates of diversions are generally too high, or the estimates of return flows and groundwater accretions along the SJR are too low. A combination of direct measurements of some of the diversions and drainage flows, along with modeling investigations will be required to resolve this discrepancy. However, adding the missing water and salt to the SJR model inputs should not be considered a satisfactory model calibration. The model was helpful in identifying the pattern and magnitude of the missing flow and salt; but the actual sources of this missing flow and salt must be identified and added to the model before a satisfactory calibration can be achieved. Any ideas?

The temperature simulations by DSM2 appeared to be too responsive to meteorology and depth. The diurnal variations simulated at Patterson and Mossdale were much higher than measured. HydroQual found additional problems with upstream segments during low flow periods, when both temperature and reaeration equations produced model instability. They solved these problems by changing the model code to limit reaeration at shallow depth and not simulate heat exchange processes. A heat-balance was retained, so that downstream temperatures were the volume average of the upstream inflows. This however, produced downstream temperatures that did not follow the measured warming and cooling patterns and did not have any diurnal variation. Two versions of the DSM2-SJR QUAL model now exist: the DWR version cannot simulated DO because of the reaeration code error and instability at shallow depths, and the HydroQual version does not simulate temperature accurately. Heads I win, tails you loose.

The extension of the SJR model to include the tributaries and Salt and Mud Sloughs has been described by DWR in their future plans and was an objective of the first year modeling effort. LBNL agreed to pursue this objective after DWR was unable to allocate staff for this effort. LBNL found that geometry data for Mud and Salt Sloughs were not available. LBNL successfully partnered with Professor Tom Harmon at UC Merced and developed a kayak-mounted sonar system that has been tested and is capable of obtaining continuous bathymetry information for depths of over 3 ft. A preliminary survey along one reach of the Merced River has been completed. In September 2005 LBNL performed a 2-day bathymetry and cross-section survey of Salt Slough. Preliminary data has been obtained for Mud Slough geometry. The extended model geometry, once completed by LBNL will be used to build an extended DSM2 model, or could be used in the WARMF river model, as described at the end of this progress report.

Nutrients, Light and Algae

HydroQual estimated the daily nutrients and algae inputs and performed an initial calibration for nutrients and algae for 2000 and 2001. Some sensitivity runs were also compared and described. They adjusted the constant light extinction coefficient to be specified for each by river segment, but not to vary with time, because DSM2-SJR does not include suspended sediment as a model variable. Some of their findings from simulation of these two years are summarized here.

The focus of the HydroQual calibration was nutrients and algae. The model simulates algae biomass carbon (i.e., about 40% of total biomass) concentration (algae-C), but the field measurements of algae biomass were chlorophyll-a, active pigment representing live algae (ug/l), and phaeophytin, inactive pigment representing dead algae (ug/l). A constant conversion of 50 between chlorophyll-a (ug/l) and algae-C (ug/l) was assumed (i.e. chlorophyll-a is 2 % algae-C). The model does not consider dead algae. The model simulates ammonia-N, nitrate-N, and organic-N. The model also simulates PO_4-P and organic-P. Organic-P was estimated as total P minus PO_4-P, although most of the total P is likely absorbed onto particles, and not actually decaying to PO_4-P.

Algae cells use PO_4-P and ammonia-N or nitrate-N during photosynthesis for growth of new algae. In the model, decaying algae are the only internal source of organic-N and organic-P. The organic-N and organic-P decay to produce ammonia-N and PO_4-P. The SJR nutrient concentrations are dominated by high nitrate and PO_4-P, so these are the most important for potential control of algae growth. Daily input concentrations were estimated for nutrients and algae-C by interpolating monthly averages of available measurements from UC Davis or USGS for 2000-2001.

SJR BOD concentrations were generally estimated to be less than 20 mg/l (as ultimate 30-day values) and surface re-aeration is strong enough to maintain nearly saturated DO conditions. The BOD is dominated by the algae concentrations, and provides another measure of algae biomass. Another measurement variable not included in DSM2-SJR is volatile suspended solids (VSS). This is the concentration of organic particulates, measured by difference between the TSS (i.e., filtered material) and TSS after burning (oxidizing) the organic materials. This may provide another easily measured estimate of algal biomass (i.e., VSS should be about 2.5 times algae-C).

HydroQual found that the nutrient inputs matched the downstream nutrient concentrations at Patterson and Vernalis reasonably well. PO_4-P concentrations were relatively constant at 0.1-0.2 mg/l above the Merced River, with nitrate-N concentrations that declined from about 5 mg/l in the spring to about 2 mg/l in the fall. Nutrients became more uniform at Patterson, with PO_4-P concentrations of about 0.2 mg/l and nitrate-N concentrations of about 2-4 mg/l. At Vernalis, the simulated PO_4-P concentrations were about 0.1 mg/l and the nitrate-N concentrations were about 2 mg/l. The downstream reduction in nutrients can be largely explained by the dilution from the Merced, Tuolumne, and Stanislaus rivers. These SJR nutrient concentrations are all generally considered surplus nutrient concentrations for algal growth.

Sensitivity results were used to determine what was the dominant control on algae growth. Eliminating all nutrients and algae except the SJR upstream at Stevinson (not a likely scenario) reduced algae biomass by about 75% at Patterson, but only by about 50% at Vernalis. The reduced initial algae biomass was growing as the river flowed downstream and recovering to about 50% of the Vernalis average chlorophyll concentration of 30 ug/l. Reducing the algae growth to zero eliminated only about 50% of the average algae at Patterson and Vernalis. So about half of the simulated algae at Vernalis was the direct result of inputs and about 50% grew within the river channel.

HydroQual did not investigate the sensitivity of light conditions on algae growth in the SJR. The seasonal effects of temperature and solar radiation on algae cannot be easily distinguished in the model. The summer maximum simulated chlorophyll concentration was about 50-75 ug/l for both 2000 and 2001 at Patterson and Vernalis. Similar values were simulated along the entire river from Crows Landing (downstream of the Merced River) to Mossdale. The two years algae simulations appear to be very similar, and the simulated algae biomass patterns generally matched the measured chlorophyll values. Substantial algal biomass was confined to the months of June-September, although the seasonal light and temperature variations appear to be more gradual. The combination apparently limited growth in May and October.

A simple mass-balance for the maximum measured chlorophyll-a of about 100 ug/l indicates that the corresponding algae-C would be about 5 mg/l (i.e., 50 [C/chl-a ratio] x 100 ug/l) and that the maximum nitrate-N uptake would be 0.88 mg/l (i.e., 0.176 [N/C ratio] x 2) and the maximum PO4-P uptake would be about 0.12 mg/l (i.e., 0.024 [P/C ratio] x 2). About half of the measured nutrients at Vernalis would be needed to grow the maximum chlorophyll measured during the summer.

Both HydroQual and DWR were required to develop their own approach to showing the DSM2-SJR results, because there is no standard method for viewing the model results (no GUI). Both chose to display the 10 year (DWR) or 2-year HydroQual) results on a single graph. While this allows the full range of conditions for the entire simulation to be seen, it is difficult to focus on the differences between model results and measurements. Because it is the differences between the model results and the field data that provide the keys to learning new things from the model, a convenient way to view several years of data compared with model results, but also to focus in on a single year for investigating discrepancies, is needed. The SJR Data Atlas is one approach for displaying field data from several years, and the GUI that was developed for DSM2-SJR is another approach that can directly compare field data with a series of model predictions for the entire simulation or a selected period.

SJR Flow and Water Quality Data Atlas

This historical SJR flow and water quality data atlas (SJR Data Atlas) efforts directly supports the modeling development for the SJR, because these historical data are used to estimate the boundary (i.e., inflow) conditions and because the measured patterns of salinity, nutrient concentrations, and algae biomass are the basic water quality conditions that the SJR water quality model will attempt to simulate for existing and future modified conditions. The initial SJR water Quality data atlas (Jones & Stokes, 2005) was prepared for 1984-2003 data as part of a previous SJR modeling project, funded by CALFED (CBDA), and conducted by HydroQual and Jones & Stokes. The San Joaquin River Upstream Monitoring and Investigations project (Upstream Project) will supplement and extend these historical data collection efforts. The update of the atlas to include 2004 data is described and illustrated in the following sections. The 2004 update of the data atlas does not include any of the extended data collection efforts of the Upstream Project, which began in March of 2005.

Purpose of the SJR Data Atlas

Many types of data are available for the SJR and DWSC from a variety of government agencies that routinely measure river flow, temperature, salinity, and other water quality parameters with monitoring devices and samples for laboratory analysis. Different agencies have collected data during various time periods, at different stations and with different parameters. These data are stored in several different public and private databases, operated by several different agencies. This makes it difficult for stakeholders, agencies, or interested persons to access the full range of available data. Each type of data must be individually located, downloaded, processed, compiled, and compared. These data retrieval tasks make the compilation, analysis and modeling of the SJR and DWSC water quality a time-consuming and tedious exercise.

The SJR Data Atlas was created to give stakeholders, agencies, and other interested persons a rapid and consistent method to access available data on the SJR and DWSC flow and water quality conditions for the 20+ year period of 1984 to 2004. The SJR Data Atlas includes flow and water quality data from the SJR Stevinson gage (Highway 165 Bridge, also referred to as Lander Avenue), downstream to the DWSC portion of the SJR. Tributary flow and water quality data are included for the Merced, Tuolumne, and Stanislaus Rivers, as well as Salt Slough and Mud Slough. Some basic tidal stage, salinity, temperature, and other water quality data from the Delta are included for reference.

The SJR Data Atlas uses a spreadsheet format (Excel) to allow daily flow and water quality data to be graphed and evaluated. SJR flow and water quality patterns for a wide variety of runoff conditions (i.e. seasonal flows) can be viewed in a series of annual graphs. This allows periods with water quality conditions of interest (e.g. low DO episodes) to be selected for more intensive analysis or for modeling evaluation. Additional graphs or summary tables can be added to the spreadsheet files by individual users. Selected data can easily be transferred from the annual atlas files to modeling input files or other data analysis tools.

The SJR Data Atlas was designed for daily data. Grab samples collected monthly, for example, show up in the Data Atlas on the day they were collected. The daily column of data, if samples were collected monthly, will have just 12 values. Monitoring data from a temperature probe or DO probe may record hourly or 15-minute interval data. These measurements are summarized in the Data Atlas as daily minimum, average, and maximum values in three separate columns of 365 values. The database sources and station ID names or numbers are given in the top of each column of data in the annual data atlas files. Additional “meta-data” that may describe the collection agency and sampling program objectives and general sampling and laboratory methods are sometimes available from the original database. No specific “meta-data” information is included in the Data Atlas.

Each calendar year of data is contained in a “master” annual spreadsheet. These sheets have all the data from that year but contain no graphs. A number of different multi-year spreadsheets provide graphs for basic comparisons of selected variables for different years. These special multi-year spreadsheets have been created for (1) SJR meteorology, (2) SJR flow, salinity (EC), and temperature, (3) Dissolved oxygen (DO) in the DWSC data, (4) City of Stockton Regional Wastewater Control Facility (RWCF) effluent data, (5) City of Stockton river stations water quality data, and (6) SJR algae, particulates and nutrient data.

The availability of the selected types of data for each year, as well as the seasonal patterns of various water quality parameters can be reviewed rapidly by selecting the year of interest and viewing the annual graphs. Some of these graphs for 2004 conditions will be shown in this report to introduce the SJR Data Atlas capabilities and illustrate the 2004 conditions.

Retrieval and Display of Data

The identification of available data for the SJR and DWSC requires searching and finding bits and pieces. This process is greatly facilitated by the web-based search and database retrieval services provided by several agencies. Nevertheless, it is a slow-going and tedious process. The SJR Data Atlas is only possible because of the dedicated and persistent efforts of the agency field crews and monitoring instrumentation maintenance crews and supporting laboratory technicians and computer staff. These are the people who go to these stations and collect water samples, or prepare and process chemical measurements, or install and maintain the flow and water quality measurement equipment. The goal of the SJR Data Atlas is to produce useful information from the wealth of data that have been collected over the years by these hard-working field and laboratory crews.

Some important data sources that should be included in the SJR Data Atlas may still be missing. Several new sources of data have been identified during the 2004 Data Atlas update process. One of the “best finds” was the update of the USGS daily EC and temperature records, which were available through 1996 on the Hydrodata CDs, but are not available on a public website. These daily EC (min, mean, max) and temperature data (min, max) appear in the .pdf versions of the USGS Water Resources Data for California reports (paper copies are no longer published) on the USGS website, but can only be obtained electronically by requesting them from USGS (but you have to know they are available). These data for the USGS SJR and tributary stations have now been obtained from USGS data management staff and added to the Data Atlas files.

Another “best find” was the DWR SJR at Maze flow and EC data. This DWR data was “hidden” because annual data reports are no longer published and the data are not available from a pubic website. The EC record was discontinued in 1993 because of equipment failure; DWR is considering reinstalling a multi-parameter probe (EC, temperature, DO, pH) at the Maze station and linking the hourly data to CDEC. This station identifies the SJR water quality immediately upstream of the Stanislaus River and should be useful for estimating the Stanislaus flows needed to meet the salinity objectives at Vernalis.

Multi-Year Comparison Files and Graphs

Each multi-year comparison file is designed to provide a graphical analysis tool for exploring selected flow and water quality parameters along the SJR. Each multi-year comparison file contains a “graph” sheet in which the year can be selected (e.g. typed into a yellow box at the top of the graph sheet, and when “enter” is pressed (or F9 to recalculate) the graphs will automatically update with the new data from the selected year. The primary purpose of the Data Atlas graphs is to provide annual “pictures” of the available data as “time-series” from several stations along the SJR to provide an initial comparative analysis tool. A brief description of each comparison file along with some examples of the graphs are presented in the following sections.

Meteorology

This comparison file contains several graphs of the daily meteorology for the CIMIS stations at Lodi, Modesto, and Kesterson. These stations were chosen to represent the meteorology along the SJR from North to South. The four parameters of daily air temperature (dry bulb) and dew point temperature (humidity), solar radiation and windspeed are the basic parameters required for water temperature and algal photosynthesis modeling. Hourly windspeed data from the R&RI station (collected by

DWR but not available on website) at the DWSC has been updated for recent years (2000-2004).

Flow EC & Temperature

This comparison file contains all the available SJR and tributaries daily flow, EC, and temperature data. The downstream station at Vernalis is generally used as the representative SJR flow and EC (salt load) station. The other flow and EC stations allow the sources of the water and salt load to be described and understood. There are many graphs provided in this comparison file. Several of the graphs for 2004 are shown in this report.

The flow and EC comparison file contains some simple analyses of the raw data. For example, estimated flows upstream of the major tributary rivers must be calculated by difference, because it is not directly measured. Calculations of salt load for several tributaries and mainstem SJR stations are included. The EC value (uS/cm) is assumed to be 1.5 times the TDS (mg/l) and the daily salt load (lbs/day) is 5.4 times the TDS (mg/l) times the flow (cfs). Graphs showing the "dilution" relationship between higher flows and lower EC values and the corresponding daily salt loads are given. The combination of flow and EC data provides an important analysis tool for checking the water and salt mass balances along the SJR.

Figure 1 shows the measured flows at Vernalis, Patterson, Crows Landing, and Newman, and the estimated Vernalis flow based on Patterson plus Tuolumne plus Stanislaus inflows for 2004. The Vernalis flow is not matched during periods of missing tributary inflows (i.e., Tuolumne in April and May), and considerable missing (i.e., unknown) inflows are identified throughout the year, except during the June-August period of 2004. The flow management during VAMP (April 15-May 15) and in October for the benefit of Chinook salmon migration was a major feature of the 2004 SJR flows. Vernalis flows were between 1,000 cfs and 1,500 cfs for most of the summer months (i.e., June to mid-October). A DMC re-circulation experiment in late August released 250 cfs into the Newman wasteway that enters the SJR just upstream of the Merced River. The increase in downstream flows can be seen in the daily flow and EC measurements.

Figure 2 shows the San Joaquin tributary flows, including Salt and Mud Sloughs for 2004. Tuolumne flows were highest during the winter rainfall period, the Stanislaus flows were highest from May through August, and the Merced flows were highest during VAMP and the October pulse-flow period. Each of the tributary rivers have a managed flow of about 250 cfs during the Chinook salmon migration, spawning, and incubation period of October through March. The purpose of the late-June peak flows released from the Stanislaus River was apparently for salinity control (See Figure 9).

Figure 3 shows the San Joaquin River flow at Vernalis and EC measurements at Vernalis, Mossdale, Brandt Bridge, and Rough & Ready Island for 2004. The salinity is strongly diluted at all stations during the VAMP and the October pulse-flow periods. The R&RI EC values suggest a slower response to the flow variations, and almost no dilution during the June pulse flow. The variations in the EC measured at Vernalis, Mossdale, and Brandt Bridge is apparently a combination of measurement errors and agricultural drainage. The Brandt Bridge EC is not likely to actually be lower than the Vernalis EC and the Mossdale EC.

Figure 4 shows the San Joaquin River flow and EC measurements at Vernalis, with calculated daily salt loads (tons/day) for 2004. The Stanislaus dilution flows at Ripon are shown in light blue. The dilution of the salt load with higher dilution flow is evident in the June pulse flow from the Stanislaus. The daily salt load is relatively stable from day to day, with a minimum of about 1,000 tons/day during the summer irrigation season. This might be the period of maximum drainage from the high selenium tile drainage area, but it is not the period of highest SJR salt load.

Figure 5 shows the San Joaquin River flow and EC measurements at Vernalis and Brandt Bridge, with EC objective and monthly average EC at Vernalis for 2004. The EC objective is a 30-day moving average, slightly different but similar to the monthly average. The Brandt Bridge EC is expected to be slightly higher than Vernalis because of agricultural drainage to the SJR. The Brandt Bridge stage and EC data were recently (2005) added to CDEC, but data are missing for October-December of 2004.

Figure 6 shows the Stanislaus flow and EC at Ripon with calculated daily salt loads for 2004. The Stanislaus River provides very low salinity water for dilution of the San Joaquin River salinity. Nevertheless, the salinity-flow relationship indicates that there are a range of salt loads entering the river that are lowest following the rainfall season in the spring, and increases through the summer and fall. The EC at a flow of 250 cfs can be as low as 100 uS/cm, but can be as high as 150 uS/cm. If a single salinity-flow relationship cannot be determined for the Stanislaus River, we certainly cannot expect the entire San Joaquin River system to be accurately described with a single salinity-flow relationship.

Figure 7 shows the Stanislaus River flows and irrigation diversions for 2004. The Stanislaus River flow is relatively uniform from the Goodwin dam release below the irrigation diversions (1,500 cfs maximum in summer) past Orange Blossom to Ripon. Not much of the irrigation water returns to the Stanislaus River, because the Ripon flows are about the same as the Goodwin flows.

Figure 8 shows the San Joaquin River measured flow, estimated flow, estimated EC, and estimated EC load at Maze, upstream of the Stanislaus River for 2004. The estimates are obtained by subtracting the Ripon flow and EC load from the Vernalis flow and EC load. The measured flow is lower than the estimated flow.

The DWR flow data are not available on CDEC or any public website. DWR measured EC through 1993 when the instrument was lost (they may replace the unit next year, in 2006). USGS measured EC here from 1986-1989 only. This is a key station that could be used to confirm the Vernalis flow and EC measurements and provide estimates of the needed dilution flows from the Stanislaus to meet the Vernalis EC objective.

Figure 9 shows the San Joaquin River estimated flow, EC, and EC load at Maze, upstream of the Stanislaus River for 2004. The needed Stanislaus releases to meet the Vernalis EC objective are shown as the green line. The actual Stanislaus flow follows the required dilution flow in June, July and August. The relatively high pulse flow of 1,000 cfs in late June may have been made for EC control, because the EC at Vernalis was greater than 700 uS/cm in early June (See Figure 6). However, this was much more than actually needed for salinity control, because the EC load was decreasing in June. EC measurements at Maze would be helpful for more efficient salinity management operations.

Figure 10 shows the Tuolumne River flow and EC at Modesto with calculated daily salt loads for 2004. The Tuolumne River provides low salinity water (EC of 150-200 uS/cm) that dilutes the San Joaquin River salinity. There are some irrigation return flows or other sources of water between La Grange Dam and Modesto. The releases from La Grange Dam were about 125 cfs during the summer and 200 cfs from October to December, while the flow at Modesto was 250 cfs during the summer and fall of 2004. Some of the VAMP flow pulse was supplied from the Tuolumne River in April 15- May 15 and in late October.

Figure 11 shows the San Joaquin River flow and EC with calculated salt loads at Patterson for 2004. The EC was relatively constant between 1,000 and 1500 uS/cm, except during the VAMP pulses. The flow was about 500 cfs all year long, except for the VAMP pulse flows. The only period of rainfall-runoff appears to be the late February storm, when the flow was higher and the EC was lower. Because the EC load increased during the runoff period, a single EC-flow dilution relationship cannot provide an accurate estimate of the EC at Patterson. Reclamation’s re-circulation experiment in late August, that released 250 cfs from the DMC into the Newman wasteway, increased flow (by 200 cfs) and diluted the EC (by 250 uS/cm) at Patterson in late August (Aug 20-Aug 31).

Figure 12 shows the Merced River flow and EC with calculated salt loads at Stevinson for 2004. The flow was high during the April 15-May 15 and October VAMP flows. Minimum flows during summer period were just 100 cfs. Flows in the fall and winter were about 200 cfs for Chinook salmon spawning and rearing. There was not much change in flow between Cressy (mile 27.6) and Stevinson (mile 4.8). The EC was about 150 uS/cm during the winter period and increased to about 300 uS/cm in the summer. The EC data is from the USGS River Road station.

Figure 13 shows the Mud Slough flow and EC with calculated salt load near Gustine (downstream of San Luis Drain discharge) for 2004. The contribution of salinity from the San Luis Drain, with a summer flow of about 50 cfs and EC of 4,000 uS/cm is compared. The salt load of about 250 tons/day from the San Luis

Drain is about 20% of the Vernalis salt load, although the flow of 50 cfs is only 5% of the Vernalis flow (See Figure 4) during the summer months.

Figure 14 shows the San Joaquin River flow and EC with calculated salt load at Freemont Ford (upstream of Mud Slough) for 2004. The flow was relatively constant at 200 cfs through the year, except for the runoff period in late February. The majority of the flow at Freemont Ford comes from Salt Slough, with an EC of about 1,000 uS/cm during the summer. The summer salt load of 250 tons/day at Freemont Ford is similar to the salt load from the San Luis Drain. The water from upstream of Salt Slough in the winter runoff period apparently had an EC that was greater than the Salt Slough EC.

Figure 15 shows the San Joaquin River temperatures for 2004. The upstream temperatures fluctuate more in response to meteorology, but the summer maximum temperatures of about 80 F are similar throughout the river. Temperature fluctuations are least in the DWSC measured at the Rough & Ready Island station. Temperatures of more than 70 F are thought to limit adult Chinook salmon migration, so SJR migration probably began in October of 2004.

Figure 16 shows the Stanislaus and Tuolumne River temperatures for 2004. The upstream temperatures remained cool throughout the year because they are released from the upstream reservoirs. The release temperatures were about 55 F in September and began cooling to 50 F by the end of November. The downstream temperatures approached the Vernalis temperatures throughout the year in response to meteorology (i.e., equilibrium temperatures).

Stockton River Water Quality

This comparison file contains the water quality measurements that have been made by the City of Stockton for its NPDES wastewater discharge permit. The river sampling locations (R1 to R8) used by the City of Stockton are shown in Figure 16. This comparison file contains most of the parameters, including DO, temperature and nutrients. The frequency of these required river surveys was daily in the early years (1984-1992) and is now generally weekly under the current NPDES permit during the summer and fall (April-November).

Figure 17 shows the temperatures and turbidity measured by the City of Stockton in the SJR and DWSC for 2004. Temperatures are fairly uniform while turbidity is reduced from settling at downstream stations in the DWSC.

Figure 18 shows the nitrate-N, TKN and ammonia-N concentrations measured by the City of Stockton in the SJR and DWSC for 2004. Nitrate concentrations increase through the summer. Ammonia concentrations were very high (4 mg/l) in the winter period of low flows. The City of Stockton is currently building a nitrification facility and is expected to discharge predominantly nitrate-N, with less than 2 mg/l ammonia-N beginning in 2006.

Stockton RWCF Effluent

This comparison file includes the daily discharge and water quality measurements of final effluent from the Stockton Regional Wastewater Control Facility (RWCF). Graphs with CBOD, TSS, and ammonia-N, as well as the RWCF daily flows and loads for these parameters, are given in the file.

Figure 19 shows the Stockton RWCF discharge and temperatures for 2004. Discharge is shut off on some weekends. Average effluent temperatures are somewhat warmer than Mossdale temperatures.

Figure 20 shows the Stockton RWCF CBOD and CBOD load (lbs/day) for 2004. The CBOD concentrations are usually less than 10 mg/l and the load is usually less than 2,500 lbs/day.

Figure 21 shows the Stockton RWCF ammonia-N and Ammonia-N load (lbs/day) for 2004. The ammonia-N concentrations are about 25 mg/l in the winter, but remained above 10 mg/l through the summer of 2004. The NBOD equivalent load will be about 5 times the ammonia-N load because about 5 mg/l of DO are required to oxidize 1 mg/l of ammonia-N. A nitrification facility is being constructed to reduce the ammonia-N concentrations to 2 mg/l.

DWSC DO

This comparison file contains the daily minimum, average, and maximum daily DO data from the SJR at Mossdale and Rough & Ready Island stations, and some comparative data from the City of Stockton. The saturated DO concentration is shown for comparison, calculated from the daily temperature.

Figure 22 shows the Mossdale and Rough & Ready Island minimum and maximum DO data for 2004. The upstream river DO concentrations are usually near the saturated DO value, and are often super-saturated from algae photosynthesis in the summer. The Rough & Ready Island DO is generally below saturation in the summer because of the high BOD from river algae and the relatively low flows. The DO is sometimes below saturation in the winter during low flows, because the high ammonia loads from the Stockton RWCF (high NBOD) can reduce the DWSC DO concentrations.

Figure 23 shows the Rough & Ready Island minimum DO as a function of Stockton flow for 2004. The DO tends to be lowest when the flow is less than 500 cfs. The relationship is somewhat improved by considering the DO deficit from saturation, which is lower at higher temperatures in the summer. The DO deficit is generally about 6 mg/l when Stockton flows are less than 500 cfs, and the DO deficit is reduced with higher flows.

Figure 24 shows the comparison of the Rough & Ready DO and the City of Stockton River station DO measurements from R3 to R6 for 2004. The City measurements are collected in the morning and are similar to the minimum DO at the Rough & Ready station. This is a good example of how data from two independent sources confirms the measured data pattern. However, the January and February City of Stockton measurements indicated that DO was near saturation, while the R&RI DO monitoring data suggest that DO was less than 8 mg/l in January and less than 6 mg/l in February. The differences in January and February cannot be resolved without additional information.

Figure 25 shows the measured daily average flows at the USGS tidal flow station at Stockton and estimated flows for 2004. The estimated flows are based on a relationship developed from the previous years with measured data (1996-2004). The SJR flow at Stockton can be generally estimated as 50% of the SJR at Vernalis flow minus 5% of the combined CVP and SWP pumping. The measured Stockton flows were greater than the estimates during periods when the head of Old River barrier weir was in place (i.e., April 15-May 15, and October), and during the summer when the south Delta agricultural barriers were in place (June-September). The USGS measurements are very important because the estimates are not reliable when barriers are installed.

Figure 26 shows the calculated daily DO deficit "loads" in the DWSC with measured and estimated flows for 2004. The deficit load is calculated from the DO target (DO objective + 0.5 mg/l) and the measured minimum daily DO concentrations as:

Deficit Load (lb/day) = 5.4 * (DO target – Minimum DO) * Flow (cfs).

The existing aeration device near channel point was designed to deliver about 2,000 lb/day into the DWSC. The oxygenation device that is being constructed at the western end of Rough & Ready Island by DWR is designed to deliver 10,000 lb/day into the DWSC. The DO deficit loads in September and October of 2004 were somewhat greater than the 10,000 lb/day capacity of the oxygenation device.

Nutrients Particulates and Algae

This comparison file contains the UC Davis (UCD) data that was collected by Professor Randy Dahlgren for nutrients, particulates, and algae pigments (e.g., chlorophyll and phaeophytin) along the SJR and tributaries. The UCD data was collected for water years 2000 to 2004, with half of water year 2005. The SJR Upstream Project is continuing these data collection efforts. Historical nutrients, particulates, and chlorophyll data collected by USGS are available for a few stations in previous years. DWR has collected nutrients, particultes and algae data monthly or bi-weekly in the SJR at Mossdale and Vernalis, and at Buckley Cove in the DWSC.

Figure 27 shows the algae concentrations in the SJR at Mossdale and Vernalis for 2004. The SJR flow at Vernalis is shown for reference. The peak total algae pigment concentration (chlorophyll plus phaeophytin) was about 175 ug/l in June at Mossdale. The algae biomass at Mossdale apparently declined to 150 ug/l in June, to 125 ug/l in August, and to just 50 ug/l in September. The seasonal pattern of high algae pigment in the SJR is generally limited to the months of June-September. The reasons for the reduction in algae pigment during the summer of 2004 are unknown. The river flow was relatively steady (i.e., 1,000 cfs to 1,500 cfs) during this four-month period. The Mossdale algae pigment concentrations appear to be about 25 ug/l higher than the Vernalis concentrations, suggesting that algal growth continues in this portion of the SJR.

Figure 28 shows the algae concentrations in the SJR at Maze and Patterson for 2004. The SJR estimated and measured flows are shown for reference. The peak total algae pigment (chlorophyll plus phaeophytin) was about 150-200 ug/l at these two stations in June, with declining concentrations in July, August, and September. The algae loads (biomass of organic material per day) at these stations are less because of the lower SJR flows upstream of the Stanislaus and Tuolumne rivers.

Figure 29 shows the algae concentrations in Mud Slough and in the San Luis Drain that discharges into Mud Slough for 2004. The San Luis Drain flow and Mud Slough flow are shown for reference. The summer flow is dominated by the San Luis Drain flow of about 50 cfs (i.e., Grasslands selenium bypass project). The peak total algae pigment in Mud Slough was about 175-225 ug/l, and the peak in the San Luis Drain was also about 175-225 ug/l. This Mud Slough algae is considered to be a potential “seed source" for the algae in the SJR. These are the highest pigment values measured during the 5-year UCD study by Professor Dahlgren.

Figure 30 shows the algae concentrations in Salt Slough and along the SJR from Patterson to Mossdale for 2004. The peak total algae pigment in Salt Slough was only about 50 ug/l in 2004. This is higher than the eastside tributary rivers, which have peak pigment concentrations of only about 10-20 ug/l, but much lower than the Mud Slough or SJR pigment concentrations. A very interesting feature of the SJR algae pigment data is that the seasonal concentrations of about 100-200 ug/l are relatively constant from Mud Slough all the way to Mossdale, suggesting light limitation as the dominant factor controlling algae biomass and pigment concentrations. Although the SJR algae concentrations are diluted by the Merced, Tuolumne, and Stanislaus river inflows, with relatively low algae concentrations, the algae is apparently able to grow downstream and reach similar concentration along the SJR to Mossdale.

Figure 31 shows the TSS and VSS and turbidity data from Mossdale and Vernalis for 2004. The TSS and turbidity values appear to have a seasonal pattern with the highest concentrations of particulates in the summer. Peak turbidity was about 25 NTU at Mossdale, but turbidity was 40 NTU at Vernalis in August and September. TSS values were very similar to turbidity in 2004 at both stations. VSS values were a maximum of 5-10 mg/l at both stations. Some of the VSS particulates are algae, which contribute to the self-shading that may be limiting the maximum algae concentrations in the SJR.

Figure 32 shows the TSS and VSS and turbidity data from Patterson and Mud Slough for 2004. The TSS and turbidity values appear to have a seasonal pattern with the highest concentrations of particulates in the summer. Peak turbidity was about 50 NTU inn July and August at Patterson, and was 30-40 NTU in Mud Slough during the summer. TSS concentrations were similar to the turbidity values.

Figure 33 shows the nitrogen and phosphorus concentrations at Mossdale and Maze (upstream of the Stanislaus) for 2004. The nitrogen (nitrate) concentrations during the summer were about 2 mg/l at Mossdale and about 3 mg/l at Maze, which are relatively high nutrient concentrations. The phosphate (PO_4-P) concentrations (most readily available for algae uptake) were also relatively high, about 100 to 200 ug/l. The suspended clay minerals can adsorb some total phosphorus, which may not be bio-available for algae growth, so the PO_4 concentrations are normally tracked in algae modeling studies.

Figure 34 shows the nutrients in the SJR at Patterson (upstream of the Tuolumne River) and in Mud Slough. The nitrate and PO_4 concentrations are about twice as high at Patterson as at Maze and Mossdale. The nitrate concentrations in Mud Slough are exceptionally high, whereas the phosphate concentrations are relatively low (consistent with a ground water source). The low phosphate may be limiting algae growth in the San Luis Drain and Mud Slough during the summer. However, the highest algae concentrations were measured in the San Luis Drain and in Mud Slough.

These Data Atlas graphs indicate the measured patterns of nutrients, particulates, and algae pigments in the SJR. Understanding the relationships between flows, particulates, nutrients, and algae biomass is one of the major purposes for developing a water quality and algae growth model for the SJR. Determining the response in SJR algae biomass that might be achieved with some combination of managed flows, particulates, and nutrients is one of the major applications for the SJR algae model.

Graphical Users Interface for DSM2-SJR

The SJRIO (daily) model that was used by DWR and LBNL had a graphical users interface (GUI) developed by Systech Engineering (Systech) to allow model users to review and edit (change) the inputs, model assumptions, and view selected results. A model interface allows many more people to review modeling inputs and outputs, and make comparative simulations and review changes between model runs. A similar interface has been developed by Systech to allow the DSM2-SJR inputs and results to be reviewed and changed and compared. This effort was completed during the first year of Task 6 modeling efforts. A brief report on the GUI features is given here.

The San Joaquin River Model Interface (Version 1.0) has been created by Systech. The modeling interface includes the DSM2-SJR model and the City of Stockton water quality model of the DWSC. The modeling interface can be used to make simulations using a modified batch file that runs the DSM2-SJR model, converts some of the downstream results, and then runs the DWSC water quality model to simulate DO and other parameters in the Stockton DWSC. Results from the river model and the DWSC model are available for review and comparison with previous runs and field data.

The batch file runs DSM2-SJR for the upstream San Joaquin River to Mossdale. The hydrology and water quality outputs for DSM2-SJR downstream segment at Mossdale are then extracted from the simulation results. The electrical conductivity from the DSM2-SJR river model output is converted to TDS by multiplying by 0.6 and is then inserted into the DWSC model boundary file. Temperature, BOD, dissolved oxygen, ammonia, nitrate, phosphate, and algae daily values are copied directly from the DSM2-SJR output file to the DWSC model boundary file. The flow predicted by DSM2-SJR at Mossdale cannot be used as input to the DWSC model because the flow split at the head of Old River junction is not simulated in the DSM2-SJR model. The DWSC water quality model uses the measured daily flow at Garwood Bridge (i.e., Stockton) for its upstream boundary condition. The remainder of the SJR flow (and load) is assumed diverted into Old River.

The SJR Model Interface can also be used to run the Watershed Analysis Risk Management Framework (WARMF) watershed and river models for the lower San Joaquin River. WARMF is a water quality decision support tool developed by Systech for previous TMDL projects and recently released by the USEPA as a recommended TMDL analysis tool. WARMF is available in the public domain from the EPA TMDL modeling toolbox.

WARMF includes a river model to simulate fate and transport of pollutants linked to a watershed model which calculates non-point source loads to the river channels. The WARMF river model has been set up using the same stream segmentation, cross-sections, and reaction rates as the DSM2-SJR model (HydroQual Version). It uses the same measured upstream boundary conditions at Bear Creek, Salt Slough, and Mud Slough as used by DSM2-SJR. The extent of the WARMF river model is larger, however. It includes the east side tributaries upstream to Tulloch, Don Pedro, and McClure reservoirs and it includes some other west side tributaries besides Salt Slough and Mud Slough. WARMF also simulates the land catchments throughout the watershed area that it simulates. The tributary geometry in WARMF is preliminary to demonstrate its capabilities for the SJR watershed and river modeling. It does not currently include the smaller sources and sinks of water and it has not been calibrated.

Figure 35 shows the map used to interface with the DSM2-SJR, WARMF, and the DWSC models that are included as part of the “users interface”. Model output for DSM2-SJR (or the WARMF river model), and the DWSC models can be viewed by double-clicking on river segments on the map. The dividing line between the river models and the DWSC model is at the junction (i.e., head) of Old River and San Joaquin River (i.e., Mossdale). Upstream of this point, output is displayed for DSM2-SJR or WARMF-River, whichever has been simulated. Downstream of this point, output is displayed for the DWSC model. Output is presented in graphical format for all parameters simulated by the respective models, as long as output is “turned-on” for the constituent selected. Output can include hourly results or the daily mean, minimum, and maximum values, as well as comparisons with observed data.

The output can also be exported to text files for further statistical analyses or graphical evaluations in excel. Each DSM2-SJR channel corresponds to a WARMF river model segment and is represented by a single river segment on the map. When the user double-clicks on a river segment upstream of the Old River, simulation results appear for that specific segment. Within the DWSC model domain, the output display is the same as for the DSM2-SJR or the WARMF river models.

Figure 36 shows the results from DSM2-SJR segment 1 (Mossdale) for the user-selected study period of WY 1998 to WY 2005. All eight years are run for the WARMF river model; the HydroQual version of the DSM2-SJR model includes inputs for only WY 2000 and WY 2001. The graph compares the results from the HydroQual version of DSM2-SJR model (in blue) and the initial WARMF-River results (in green). Observed data are shown with black circles.

Figure 37 shows the results from Mossdale for nitrate during the study period of WY 1998-2005. The HydroQual results for 2000-2001 appear higher than measured, but the WARMF river model results appear lower than measured nitrate. The time sequence compared in a graph can be adjusted by running a shorter model period or selecting a period from the results.

Figure 38 shows the measured and simulated DO concentrations at Mossdale for 2000-2001. The large diurnal variations in DO during the summer correspond to the highest chlorophyll a concentrations and indicate the simulated algae growth effects on DO. The WARMF river model appears to simulate the super-saturated DO concentrations in the summer, while the DSM2-SJR model did not match these super-saturated DO concentrations as well. Both models can probably be calibrated to better match these measured variations.

Figure 39 shows the results from segment Mossdale for algae pigment (chlorophyll a) during the study period of WY 1998-2005. The HydroQual results for 2000-2001 appear to match the measured values reasonably well. The WARMF river model results appear similar for these two years and show highest simulated values in the summers of 2002, 2003, and 2004. Higher flows in 1999 and 2005 resulted in lower measured chlorophyll a values. The WARMF river model has not yet been calibrated because it is not yet adopted as the San Joaquin River water quality model. The WARMF river model does include variable light conditions to be simulated, and includes periphyton (i.e., attached algae) as well as three different suspended algal types (i.e., greens, diatoms, and blue-greens).

Figure 40 shows the simulated and measured EC at Mossdale. Some of the simulated values above 1,000 uS/cm are suspect, because there is a water quality objective of 1,000 uS/cm upstream at Vernalis. It is likely that some of the inputs used in WARMF river model need correction. This can be done using the GUI to compare estimated and measured values at each input location.

More sophisticated graphs can be created in Excel once the results from the SJR-SJR or WARMF river model and the DWSC model are exported from the GUI. The ability to explore a wide range of inputs and flow conditions within the standardized GUI for the SJR models, and the ability to directly evaluate the simulated changes in DWSC DO conditions that might result from changes in river conditions at Mossdale that are simulated by either river model makes the GUI an extremely useful tool for San Joaquin River water quality evaluations.

Possible Use of the WARMF-River Model

The initial calibration results with the HydroQual version of DSM2-SJR have not been entirely encouraging. Although the DSM2-SJR model uses public-domain software, the ability to make model equation and logic (i.e., “model code”) changes and then compile the model as an executable module requires expertise that DWR was planning to provide, but DWR has not been able to provide enough staff time. The Fortran and C++ compiles have a moderate cost of about $1,500. Several limitations were identified by HydroQual and Jones & Stokes during their initial DSM2-SJR water quality calibration of nutrients and algae.

In order for the Upstream San Joaquin River Monitoring and Investigations Proect to be successful, the DSM2-SJR model must be upgraded to simulate the observed algal biomass patterns, including periphyton (attached algae), phaeophytin (dead algae), and grazing. Periphyton may be a major component of the algae biomas in the tributary streams and may contribute suspended algae (phytoplankton) to the main river. Phaeophytin pigment represents dead algae that is decaying and no longer growing. Short-term monitoring of algae fluorescence indicates that the algae growth during the day and grazing at night are much more rapid than previously considered. The DSM2 model must also be upgraded to simulate detritus (VSS), which is an oxygen consuming organic matter, and total suspended sediment (or turbidity), which influences the light availability for algal growth and the transport of adsorbed nutrients.

DSM2-SJR Limitations

For the DSM2-SJR model to simulate stream flow accurately, it is necessary to provide a method to calculate the shallow ground water accretion along the river. DSM2-SJR does not calculate the shallow ground water accretion. The model estimates (inputs) that are based on historical records, as used in the SJRIODAY model, have not yielded consistent estimates and must be adjusted for each new period of stream flow. DWR calibration of DSM2-SJR indicates that an average of 350 cfs is still missing from the SJR water budget.

The field measurements from the upstream SJR and the modeling investigations of these data should be interactive, so that new data is rapidly input to the models to determine and investigate any discrepancies between model predictions and observations. For this to happen effectively, the model interface (i.e., inputs and display) must be user friendly. DSM2-SJR is a Fortran “batch” (i.e., DOS-based) model that has not been written or adapted to be user friendly. There is no users guide or basic documentation for the river model. The DSM2-Delta model is well used by agency staff and consultants, but it is not user-friendly and requires separate development of input and output file and graphics.

For the SJR water quality model to become a forecasting tool for real-time adaptive water quality management, it is necessary to link the upstream San Joaquin River model and the DWSC model together. With this linkage, the loads of organic materials simulated by the upstream San Joaquin River model will automatically feed into the downstream DWSC model for simulating DO and other water quality conditions.

As the Upstream Project proceeded, it was recognized that DSM2-SJR required several modifications. Jones and Stokes found that DSM2-SJR could not simulate observed flows due to the unreliable estimates of diversions, returns, and groundwater accretions discussed earlier. HydroQual found that the model could not simulate river temperatures in shallow segments. They had to turn off the heat exchange at the water surface and simulate temperature as a conservative substance. HydroQual also found the need to adjust the formulation for the re-aeration coefficient for shallow water. The measured diurnal DO variation, with super-saturated DO at Mossdale, was not accurately simulated in the initial calibration; additional calibration will certainly be required.

The task of upgrading DSM2-SJR model was originally assigned to DWR. Due to personnel shortages, DWR has not been able to accept full responsibility for this task. Expansion of the DSM2-SJR model to the east side tributaries was subsequently re-assigned to LBNL. They have encountered considerable difficulties obtaining channel geometry data for the east side tributaries; geometry inputs could not be made above 200 feet elevation, and initial flow simulations for the tributaries were difficult to obtain. Because LBNL staff are not directly familiar with the DSM2-SJR model code, necessary changes have been made by DWR.

WARMF Capabilities

For the real time adaptive management of San Joaquin River dissolved oxygen, Systech. has developed a graphical user interface (GUI) for the DSM2-SJR model, as described in the previous section. The graphical user interface was adapted from a GIS based watershed model called WARMF (Watershed Analysis Risk Management Framework). WARMF was developed to simulate surface hydrology, surface runoff and stream flow, shallow groundwater storage and accretion, non-point source loads, and mineral, nutrients, algae, and contaminants water quality parameters for a river basin. It has a very user friendly GUI to help users calculate and explore management strategies and satisfy TMDL requirements for the combinations of point source discharges and non-point source loads of pollutants to meet the water quality criteria in the basin.

The GUI links the upstream SJR and the downstream DWSC. The existing DWSC water quality model might be replaced in the future by the 3-D model that is being developed by HydroQual, or by the 3-D water quality model being developed by UC Davis, Stanford, and the USGS.

The data module of WARMF contains an extensive database for developing the inputs and calibrating the models to match observed data. The data module of WARMF can be used to facilitate the transfer of new data from the field investigators to the modeling team. The field investigators will be furnishing measured stream flows and water quality data observed at various stations in spreadsheet format. This data will be used to update the SJR Data Atlas files. It is a simple matter of cutting and pasting the columns of data into the data module of WARMF. The modeling team can then run the model for a selected period, compare the model predictions to the observed data, and show the results to the field investigators for discussion. The rapid exchange of information between the modelers and field investigators was a cornerstone of the Upstream Project, which advocates the adaptive management of the SJR water quality.

In addition, there are other WARMF capabilities that can be put to good use for the San Joaquin study. Being a watershed model, WARMF can simulate the soil and shallow groundwater budget, with the resulting runoff and groundwater accretion to the river, as a function of rainfall and irrigation water applied to the lands within each sub-basin. WARMF already simulates many water quality parameters, including minerals, temperature, pH, dissolved oxygen, CBOD, NBOD, VSS, TSS, algae, periphyton, and nutrients (nitrogen, phosphorus). These are important parameters that are being measured in the field program.

WARMF simulates the concentrations of major cations and anions (minerals), which constitute TDS. EC is not included in WARMF, but can be added. WARMF already simulates pathogens (i.e. coliform) and pesticides. Therefore, it is possible to use WARMF to perform evaluations for TDS, pesticides, and other pollutants of concern. WARMF has recently been enhanced to simulate mercury and its bioaccumulation in fish. Those algorithms can possibly be expanded to simulate selenium and its bioaccumulation. Because of the difficulties to meet the water quality criteria of TDS and selenium, farmers are recycling some agriculture drainage and using it to irrigate other lands. WARMF can be used to evaluate the water quality consequence of such practices and determine its sustainability.

Another important consideration is that WARMF has recently been released by USEPA for free distribution as a public domain model. The USEPA has performed an internal review and testing, which WARMF has passed. The model has been peer reviewed following EPA guidelines for use in evaluating TMDL limits and load allocations.

Recommendation to Adopt WARMF-SJR

At the end of the first year of the Task 4 modeling efforts, several recommended changes are suggested for consideration by the management team and CDBA.

Based on the above discussions, implementing WARMF as the overall modeling framework for the upstream study is the best way to achieve the modeling goals (Task 6) of the Upstream San Joaquin River monitoring and investigations project. The GUI developed for DSM2-SJR can be used for the WARMF San Joaquin River application (WARMF-SJR). The existing map-based interface will be used as the interface for WARMF-SJR. The data used to drive the DSM2 model can be directly used for WARMF-SJR. The meteorology, managed flows (reservoir releases and irrigation diversions), point sources, river cross-sections, and coefficients used for DSM2 will be used by WARMF-SJR. Topographic data and watershed boundaries have already been imported, which can be used to route the groundwater lateral and overland flow of catchments (urban and agriculture lands) to the river sections.

All investigators, sponsoring agencies, stakeholders, the Regional Water Quality Control Board and other interested parties can obtain a copy of the software and the database so that they can use WARMF-SJR. Because of the user-friendly features of the model, everybody can learn how to run the model. This will empower the stakeholders to understand how the San Joaquin River works, and how to formulate and evaluate the alternatives to solve water quality problems of San Joaquin River. WARMF includes a photograph library that allows users to point and click on available photographs of the SJR river and tributary features. This allows users to get a direct visual orientation of the riparian and upland features of the watershed within the GUI.

Develop Integrated WARMF-SJR Model

The technical work needed to switch from using DSM2-SJR to using WARMF-SJR as the modeling framework will include several tasks. Following is a brief description of these tasks, which can be accomplished during the second year of the project.

The first step is to adapt WARMF to the Upper San Joaquin River by taking advantage of recently developed GUI for DSM2-SJR model. The domain of the DSM2-SJR model will be expanded to include the Merced River downstream of Lake McClure, the Tuolumne River downstream of Don Pedro Reservoir, and the Stanislaus River downstream of Tulloch Lake. The WARMF-SJR will include the San Joaquin River downstream of Mossdale, extending through the Stockton DWSC to Light 18 near McDonald Tract. All existing data from the Data Atlas will be imported to WARMF-SJR for the selected study period of 2000-2004, five years with the most comprehensive water quality data, including algae, nutrients, and particulates collected by Dr. Randy Dahlgren at UC Davis. New field data will also be imported to WARMF-SJR for subsequent years (i.e., 2005-2007) as the upstream investigations proceed.

Calibrate WARMF-SJR

The next step will be the flow and salinity (EC, as well as minerals) calibration. A comparison of predicted and observed flows at various stations can be used to determine where there is unaccounted flow. The unaccounted flow may be caused by the local surface runoff and groundwater accretion to the river sections from the adjacent agricultural land. WARMF can simulate both surface runoff and groundwater accretion to the river sections, based on diversions, groundwater pumping and irrigation data. Available data from various irrigation districts about their diversions, groundwater pumping and the amount and timing of irrigation will be obtained. This data will be used to identify where tile drainage is used and if there is special management of the agricultural return flows. With the information, the model coefficients can be adjusted to improve the simulation of groundwater and tile drainage flows.

WARMF-SJR will then be calibrated for temperature, dissolved oxygen, pH, nutrients, algae, periphyton, VSS, TSS (particulates), and other constituents for the upper section of the San Joaquin River. The discrepancies between model results and observed data will be identified. Analysis will be made to identify the most likely causes of the discrepancies. Adjustments will be made to improve the match between the simulated and observed water quality parameters for 2000-2004. During coordination meetings of field measurements and modeling investigators, recent data and recent modeling results will be exchanged and discussed. Any major differences between field data and model results will be evaluated and resolved. Reasons for the discrepancies will be discussed and potential data gaps will be identified. Model changes and comparative simulations (i.e. sensitivity) to investigate observed differences or changes will be recommended.

Evaluate Water Quality Management Actions

The routine use of the WARMF-SJR to investigate various management actions is the ultimate goal of the modeling (Task 6 of the Upstream Project). The usefulness of WARMF-SJR for the evaluation of the probable success of water quality management actions within the SJR watershed will be demonstrated. The WARMF-SJR computer model and GUI will be valuable tools to evaluate the DO-TMDL management actions. It will simulate all sources of organic matter and identify where the sources originate within the sub-watersheds of the upper San Joaquin River. The WARMF-SJR models can become a central part of the real time adaptive management of dissolved oxygen in DWSC. The tool can be used to forecast the initiation of low DO problems ahead of time. The tool can be used to evaluate various management options (reducing point source discharge of BOD and ammonia, increasing flow by closing the operable barrier at the Old River, and/or turning on the oxygenation system at DWSC). The WARMF-SJR computer model and GUI can become one of the strongest workhorses for the SJRDO TMDL implementation and adaptive management efforts.

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DWR (2005) Presentation by Jim Wilde at DSM2 Users Meeting on February 16, 2005. Available from DWR Delta modeling website.

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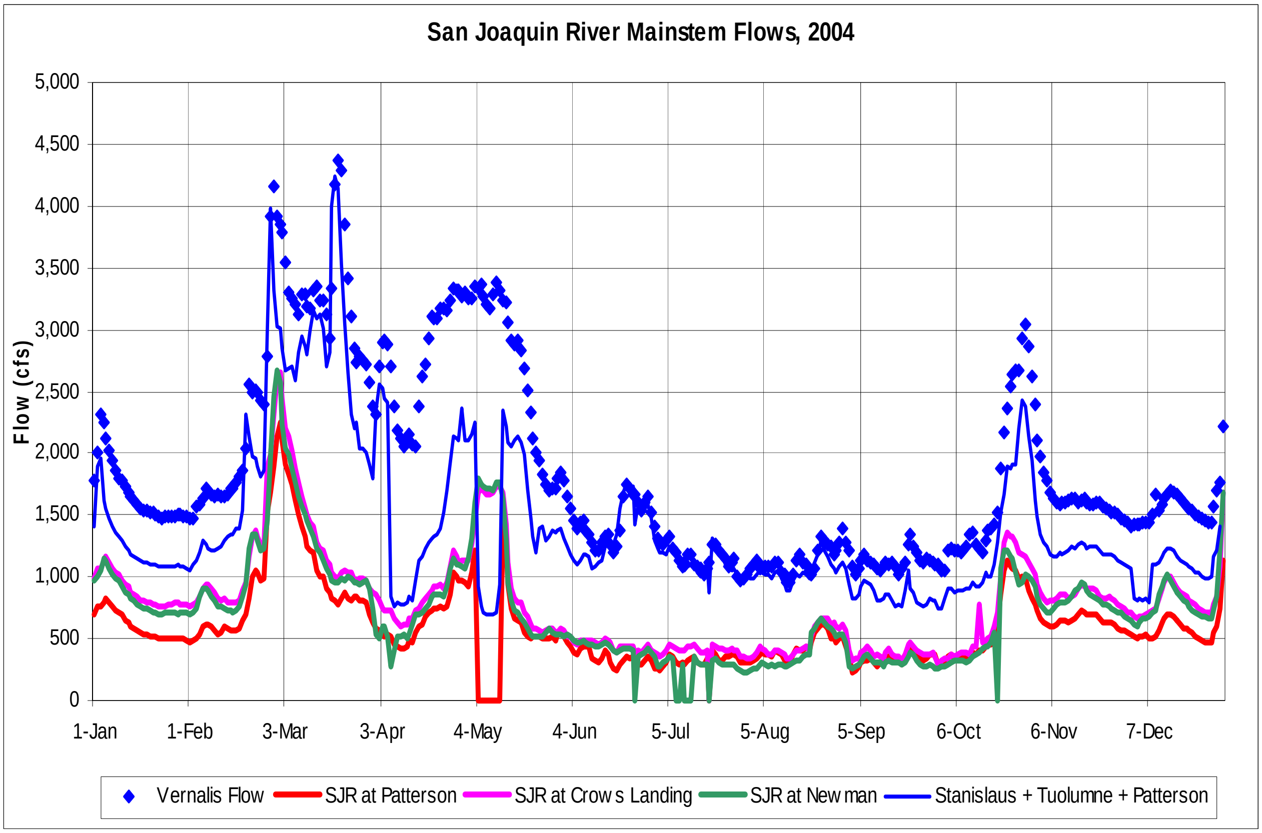


Figure 1. Measured flows at Vernalis, Patterson, Crows Landing, and Newman, and estimated Vernalis flow based on Patterson plus Tuolumne plus Stanislaus inflows for 2004. The flow management during VAMP (April 15-May 15) and in October for the benefit of Chinook salmon migration was a major feature of the 2004 flows. A recirculation experiment in late August released 250 cfs from the DMC into the Newman wasteway which enters the SJR upstream of the Merced River.

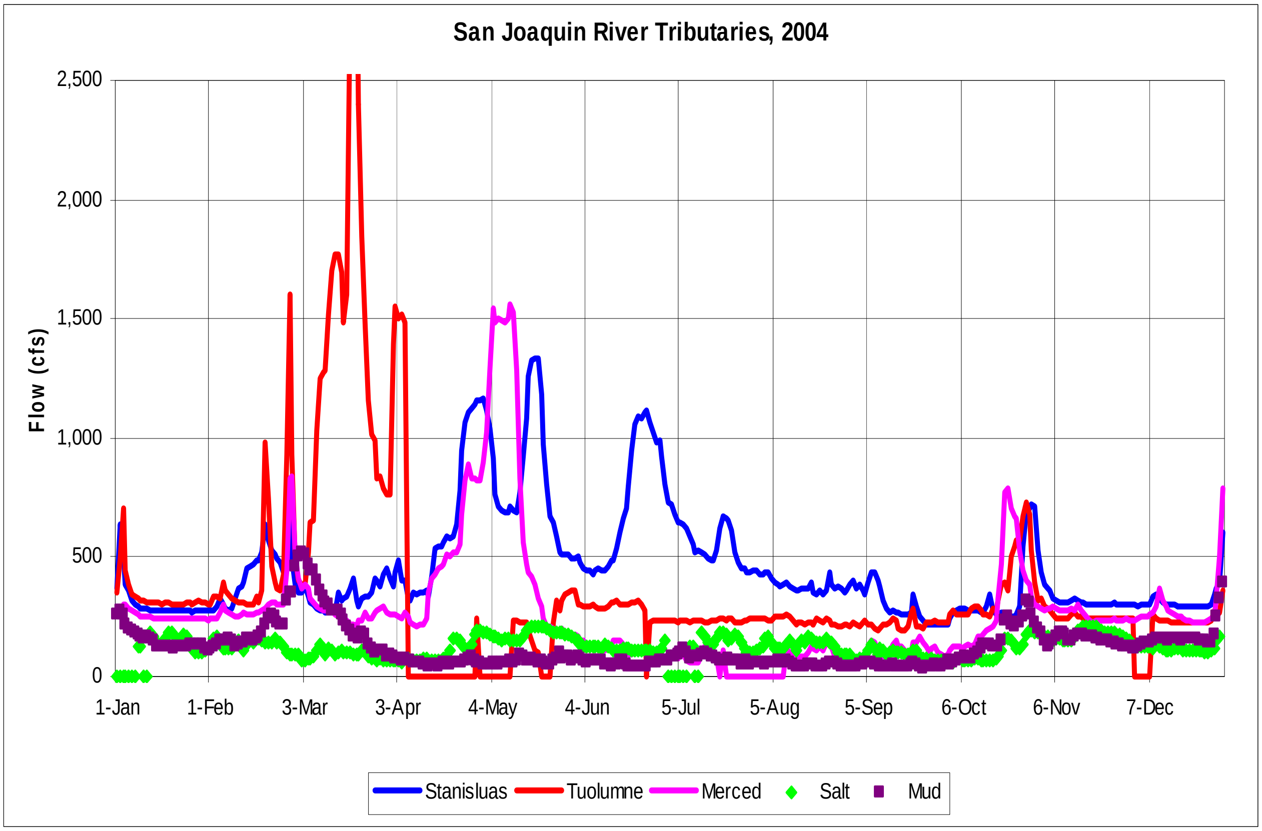


Figure 2. San Joaquin tributary flows, including Salt and Mud Sloughs for 2004. Tuolumne flows were highest during the winter rainfall period, the Stanislaus flows were highest from May through August, and the Merced flows were highest during VAMP and the October pulse-flow period. Each of the tributary rivers have a managed flow of about 250 cfs during the Chinook salmon migration, spawning, and incubation period of October through March.

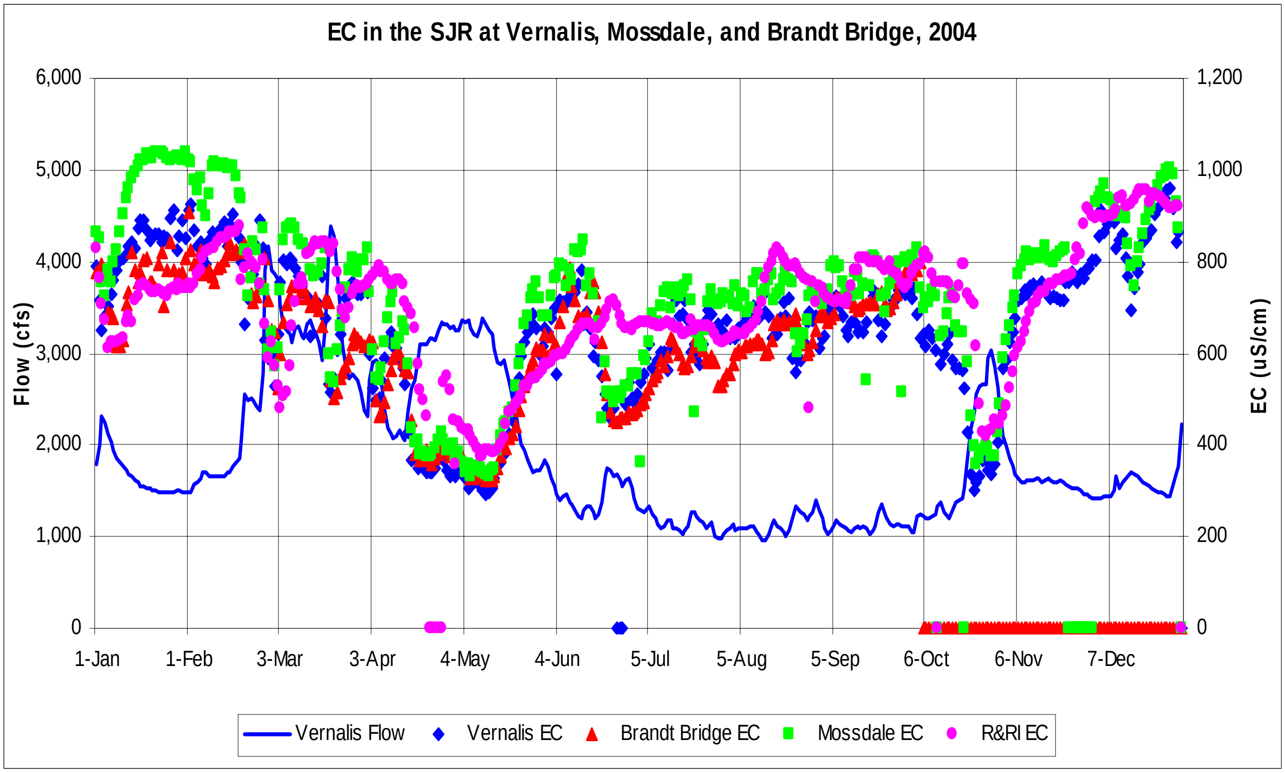


Figure 3. San Joaquin River flow at Vernalis and EC measurements at Vernalis, Mossdale, Brandt Bridge, and Rough & Ready Island for 2004. The salinity is strongly diluted at all stations during the VAMP and the October pulse-flow periods. The R&RI EC values suggest a slower response to the flow variations, and almost no dilution during the June pulse flow. The variations in the EC measured at Vernalis, Mossdale, and Brandt Bridge is a combination of measurements error and agricultural drainage.

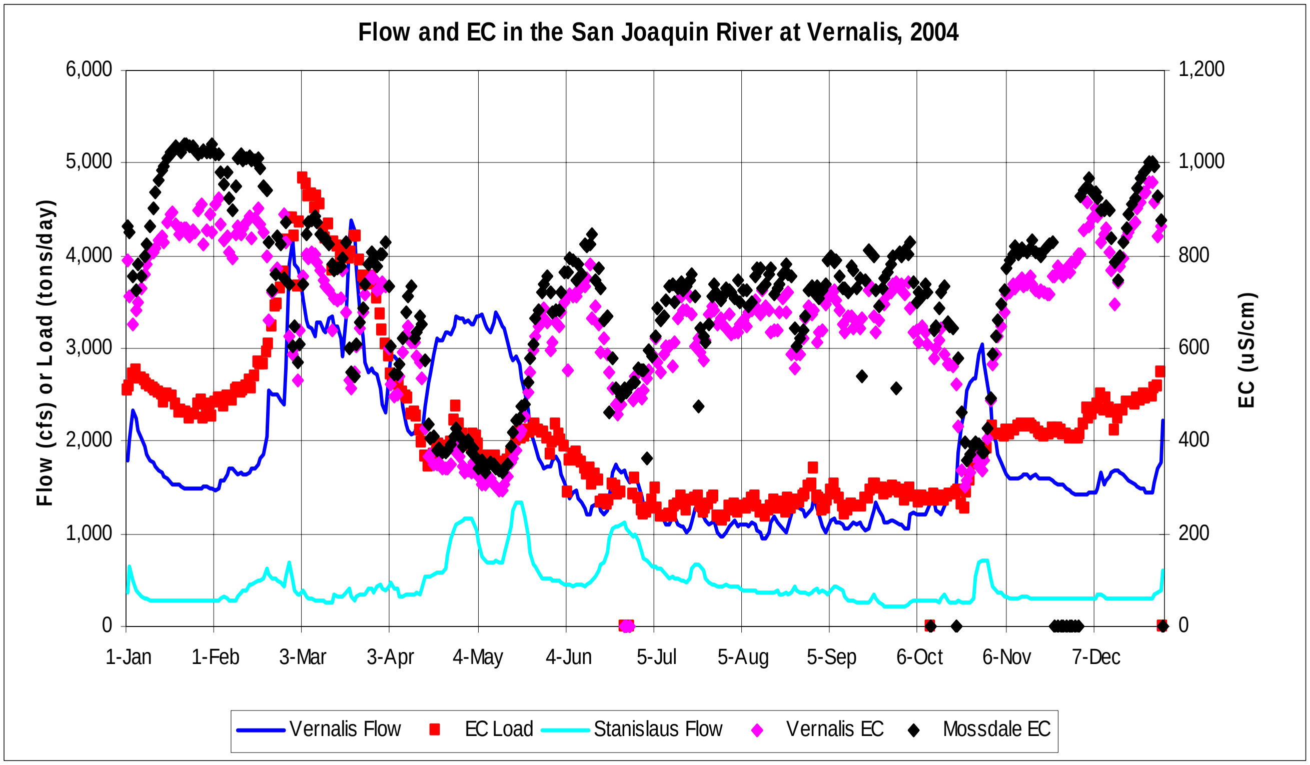


Figure 4. San Joaquin River flow and EC measurements at Vernalis, with calculated daily salt loads (tons/day) for 2004. The Stanislaus dilution flows at Ripon are shown in light blue. The dilution of the salt load with higher dilution flow is evident in the June pulse flow from the Stanislaus. The daily salt load is relatively stable from day to day, with a minimum of about 1,000 tons/day during the summer irrigation season. This might be the period of maximum drainage from the high selenium tile drainage area, but it is not the period of highest SJR salt load.

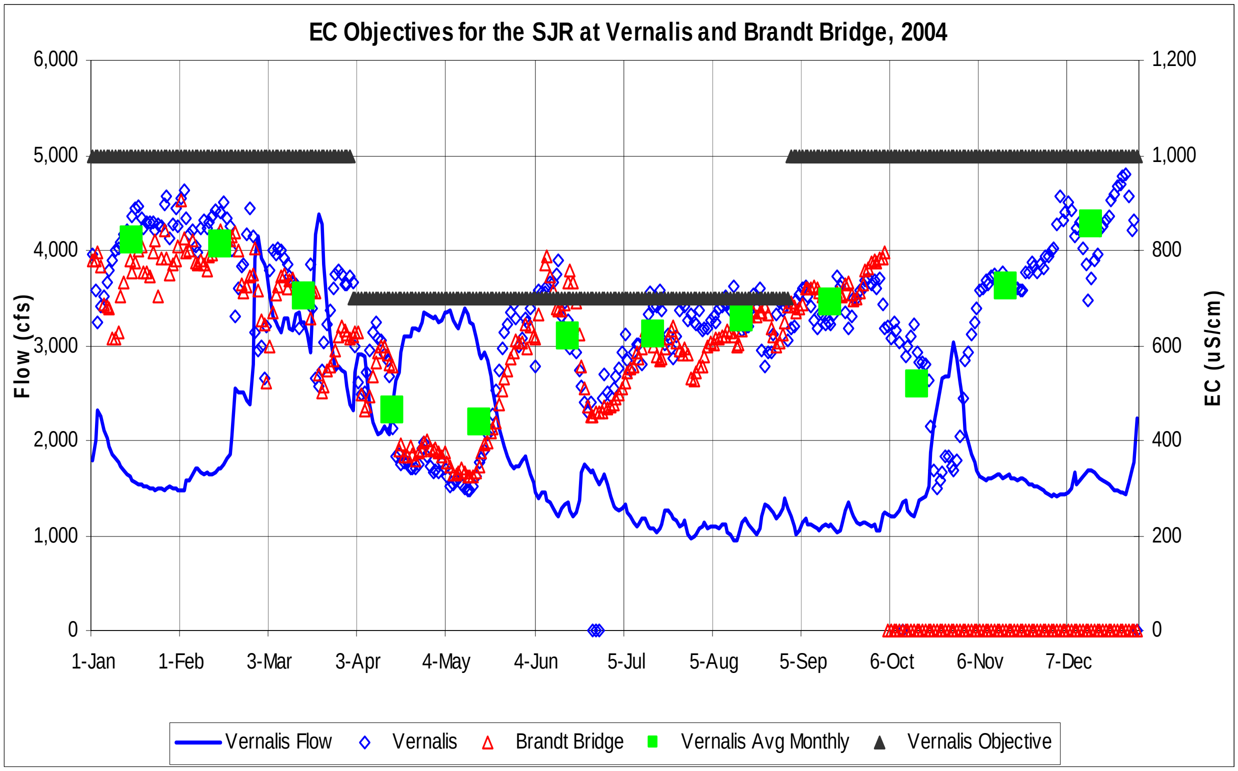
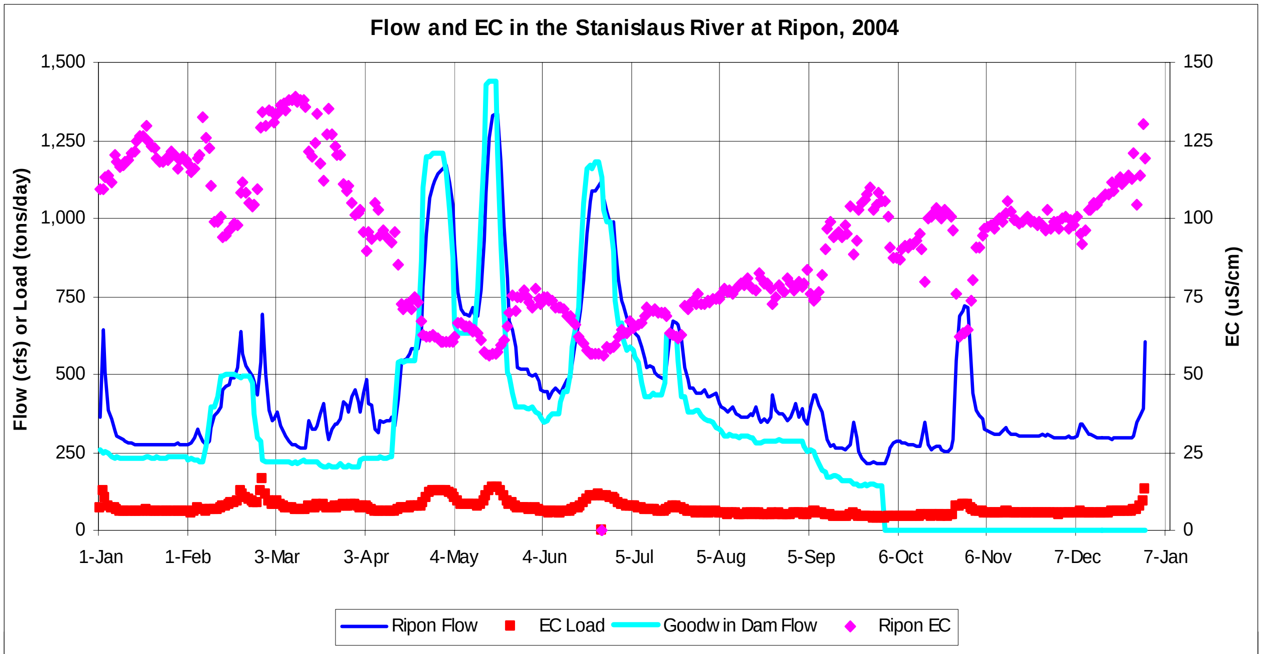


Figure 5. San Joaquin River flow and EC measurements at Vernalis and Brandt Bridge, with EC objective and monthly average EC at Vernalis for 2004. The EC objective is a 30-day moving average, slightly different but similar to the monthly average. The Brandt Bridge EC is expected to be slightly higher than Vernalis because of agricultural drainage to the SJR. Brandt Bridge stage and EC data was recently (2005) added to CDEC. Data are missing for October-December 2004.



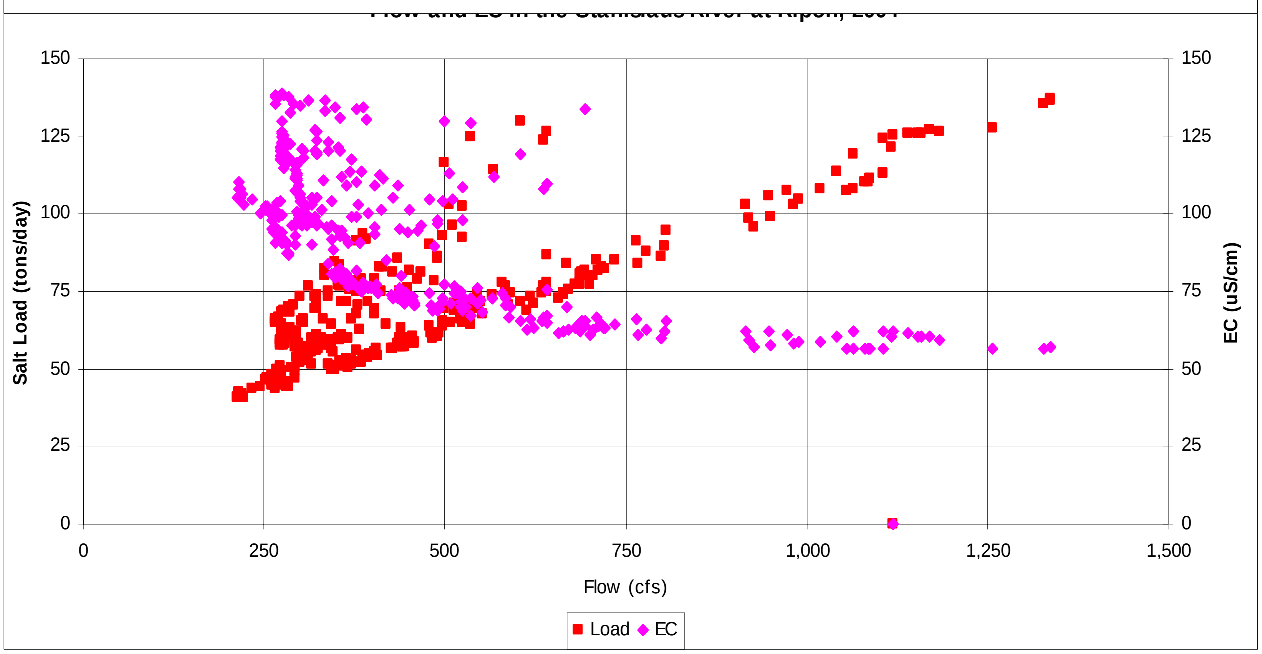


Figure 6. Stanislaus flow and EC at Ripon with calculated salt loads for 2004. The Stanislaus River provides very low salinity water for dilution of the San Joaquin River salinity. Nevertheless, the salinity-flow relationship indicates that there is a range of salt loads entering the river that is lowest following the rainfall season in the spring, and increases through the summer and fall. The EC at a flow of 250 cfs can be as low as 100 uS/cm, but can be as high as 150 uS/cm.

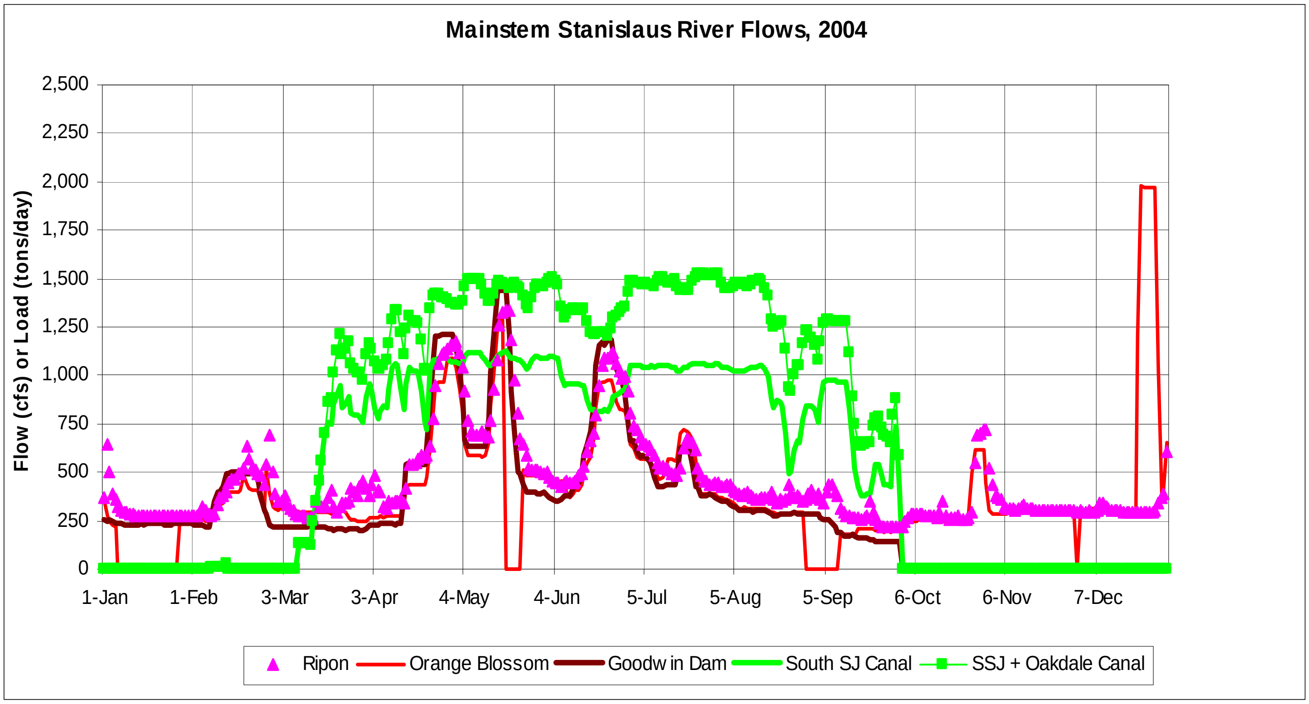


Figure 7. Stanislaus River flows and irrigation diversions for 2004. The Stanislaus River flow is relatively uniform from the Goodwin dam release below the irrigation diversions (1,500 cfs maximum in summer) past Orange Blossom to Ripon. Not much of the irrigation water returns to the Stanislaus river because the Ripon flow is similar to the Goodwin flow.

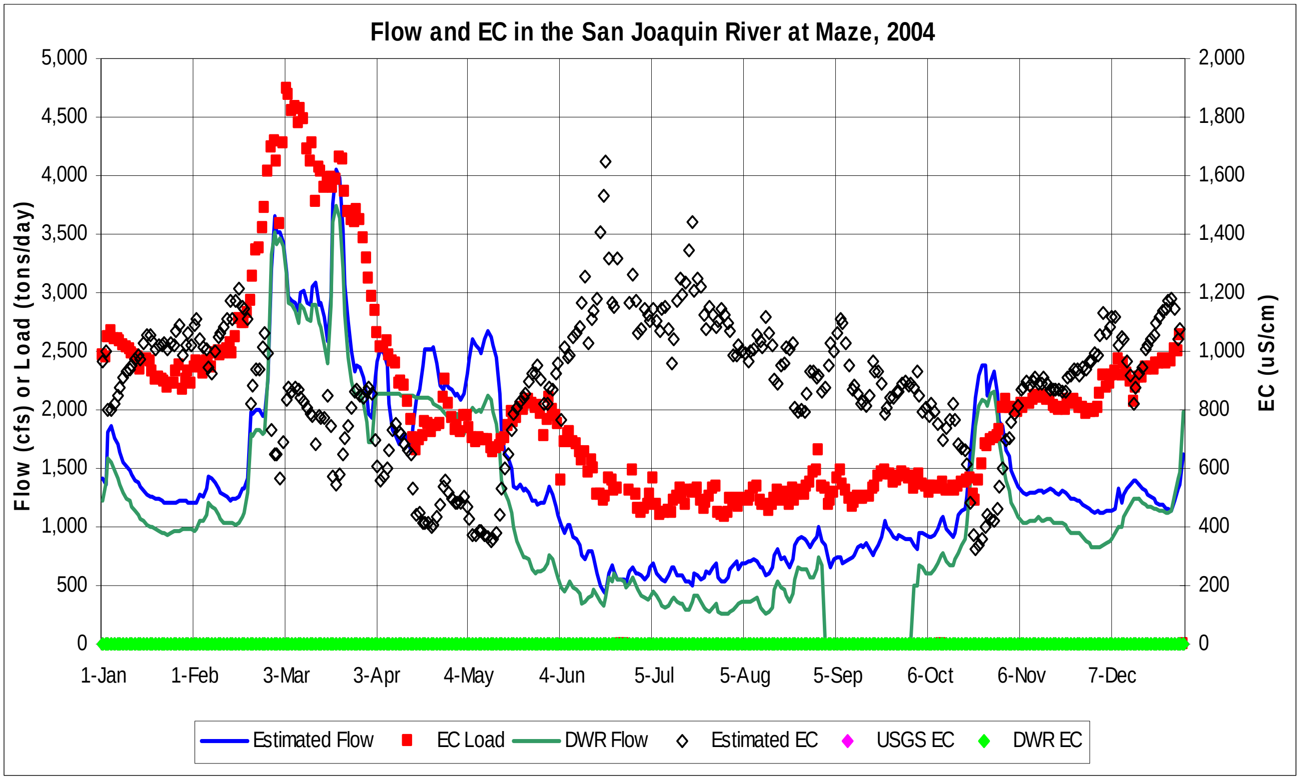


Figure 8. San Joaquin River measured DWR flow, estimated flow, estimated EC, and estimated EC load at Maze, upstream of the Stanislaus River for 2004. The measured DWR flow is lower than the estimated flow. The flow and EC estimates are obtained by subtracting the Ripon flow and EC load from the Vernalis flow and EC load.

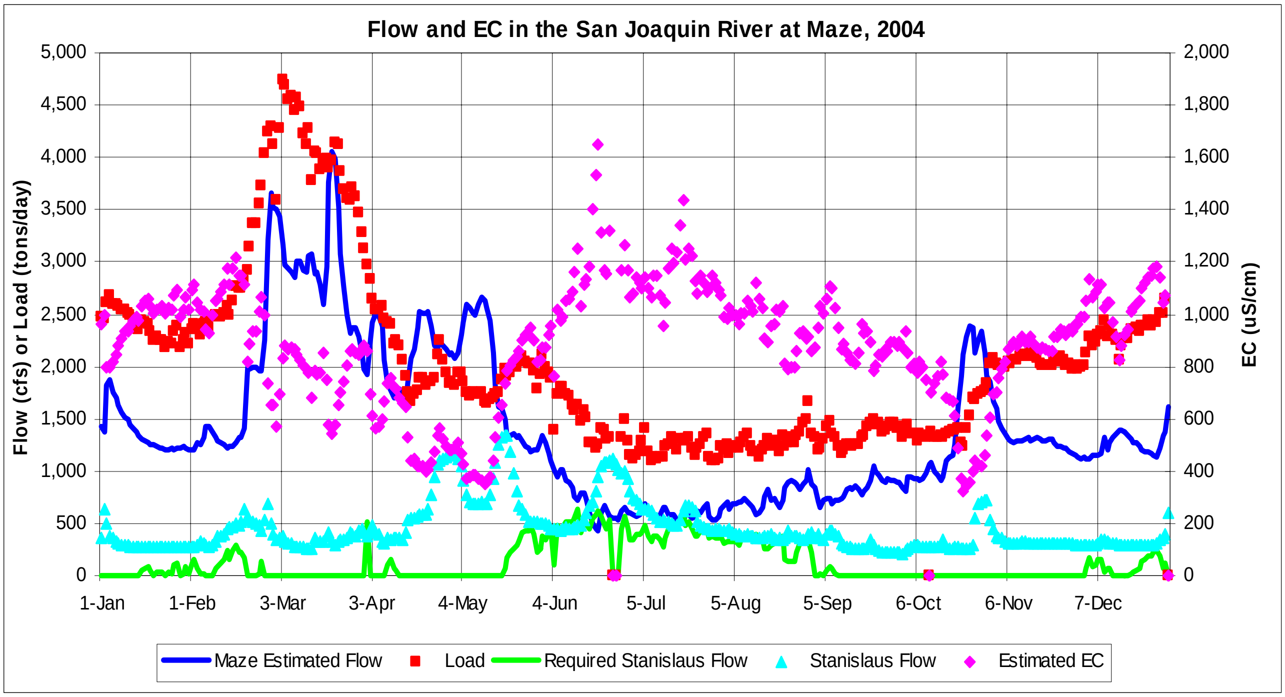


Figure 9. San Joaquin River estimated flow, EC, and EC load at Maze, upstream of the Stanislaus River for 2004. The needed New Melones Reservoir release flow to meet the Vernalis EC objective is shown as the green line. The actual Stanislaus flow follows the required dilution flow in June, July and August. The relatively high pulse flow of 1,000 cfs in late June may have been made for EC control, because the EC at Vernalis was greater than 700 uS/cm in early June (See Figure 6). However, this was much more than needed for salinity control, because the EC load was decreasing in June. Actual measurements at Maze would be helpful for more efficient salinity management operations.

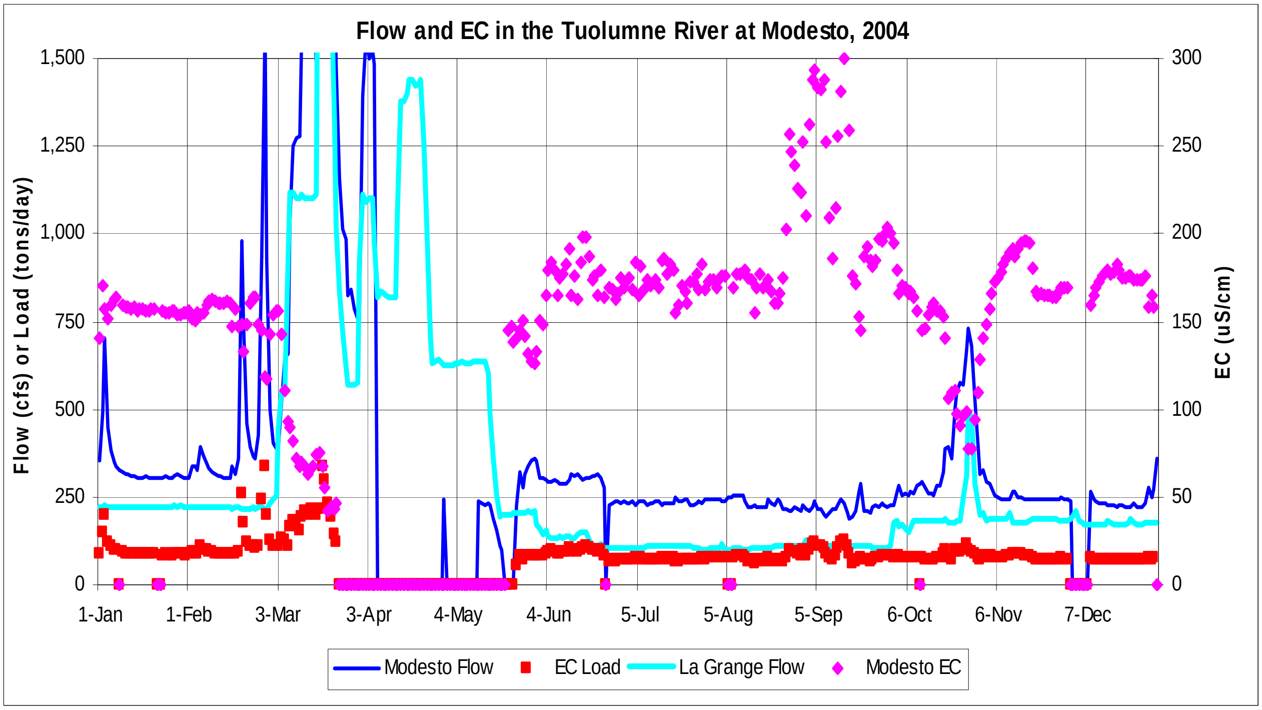
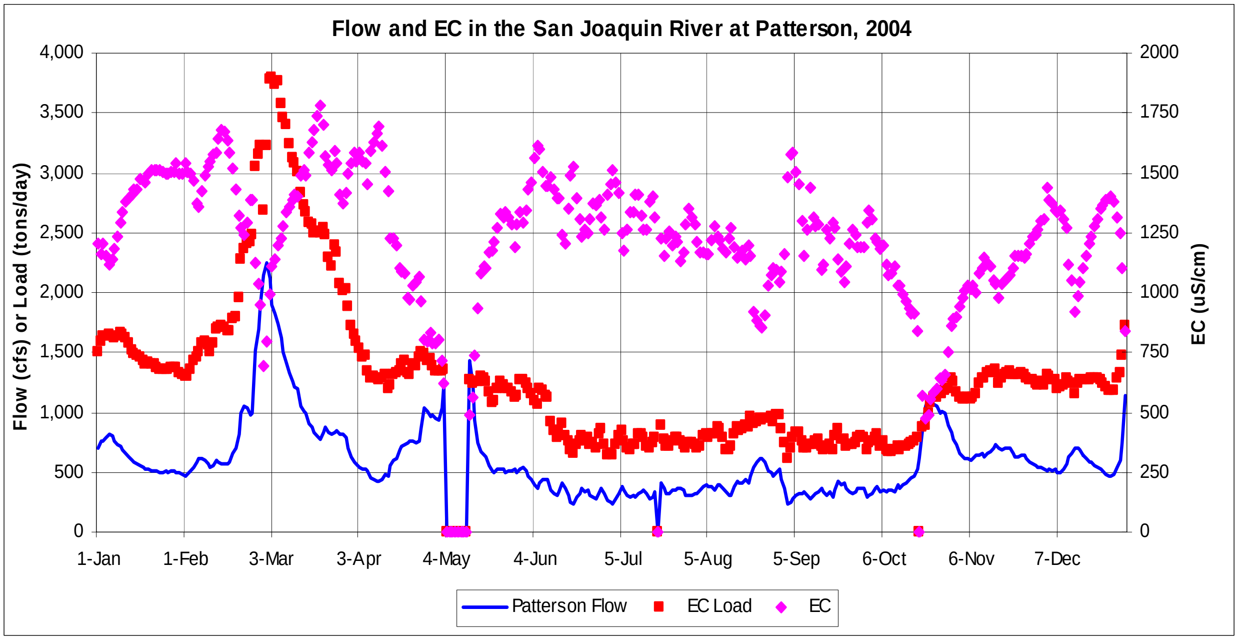


Figure 10. Tuolumne River flow and EC at Modesto with calculated daily salt loads for 2004. The Tuolumne River provides low salinity water (EC of 150-200 uS/cm) that dilutes the San Joaquin River salinity. There are some irrigation return flows or other sources of water between La Grange Dam and Modesto. The releases from La Grange Dam were about 125 cfs during the summer and 200 cfs from October to December, while the flow at Modesto was 250 cfs during the summer and fall of 2004. Some of the VAMP flow pulse was supplied from the Tuolumne River in April 15- May 15 and in late October.



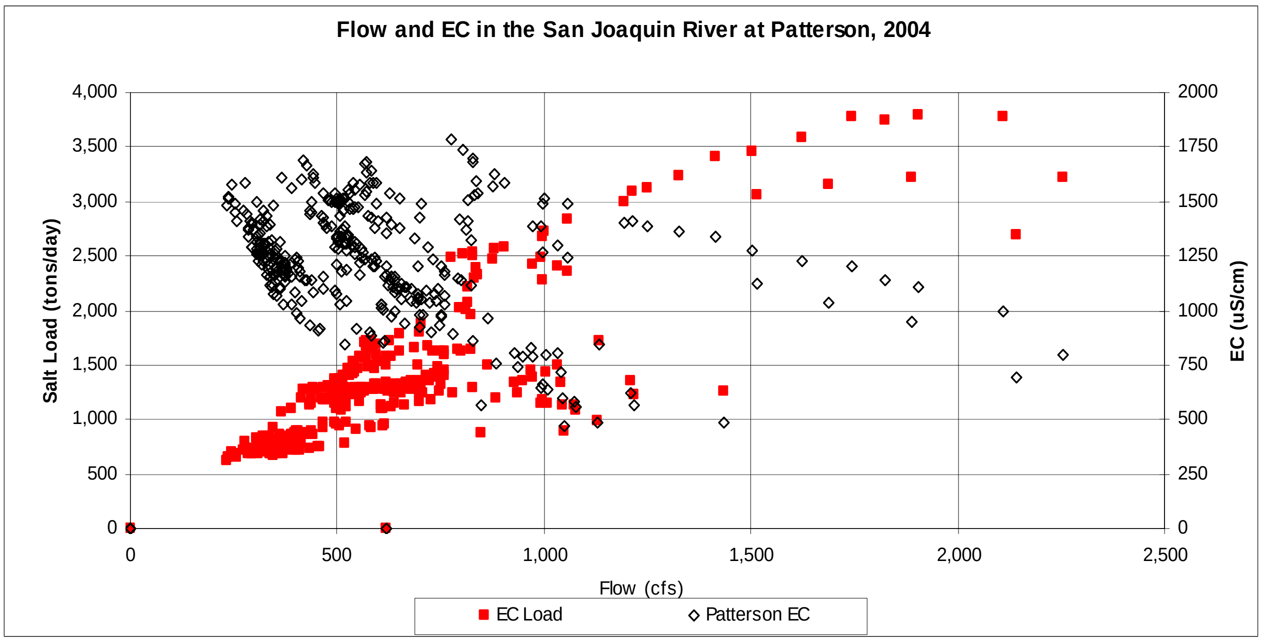
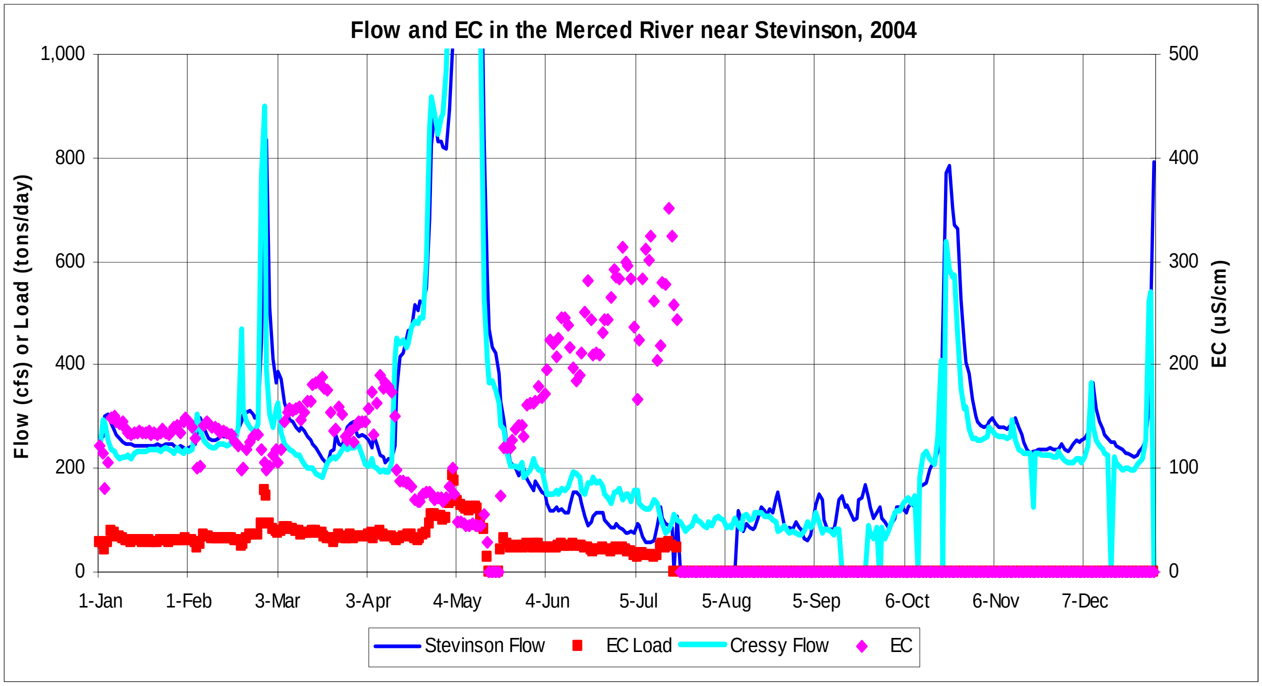


Figure 11. San Joaquin River flow and EC and calculated salt load at Patterson for 2004. The EC was relatively constant between 1,000 and 1500 uS/cm, except during the VAMP pulses. The flow was about 500 cfs all year long, except for the VAMP pulse flows. The only period of rainfall-runoff appears to be the late February storm, when the flow was higher and the EC was lower. The EC load increased during the runoff period. The recirculation experiment in late August that released 250 cfs from the DMC into the Newman wasteway increased flow (by 200 cfs) and diluted the EC (by 250 uS/cm) at Patterson in late August (Aug 20-Aug 31).



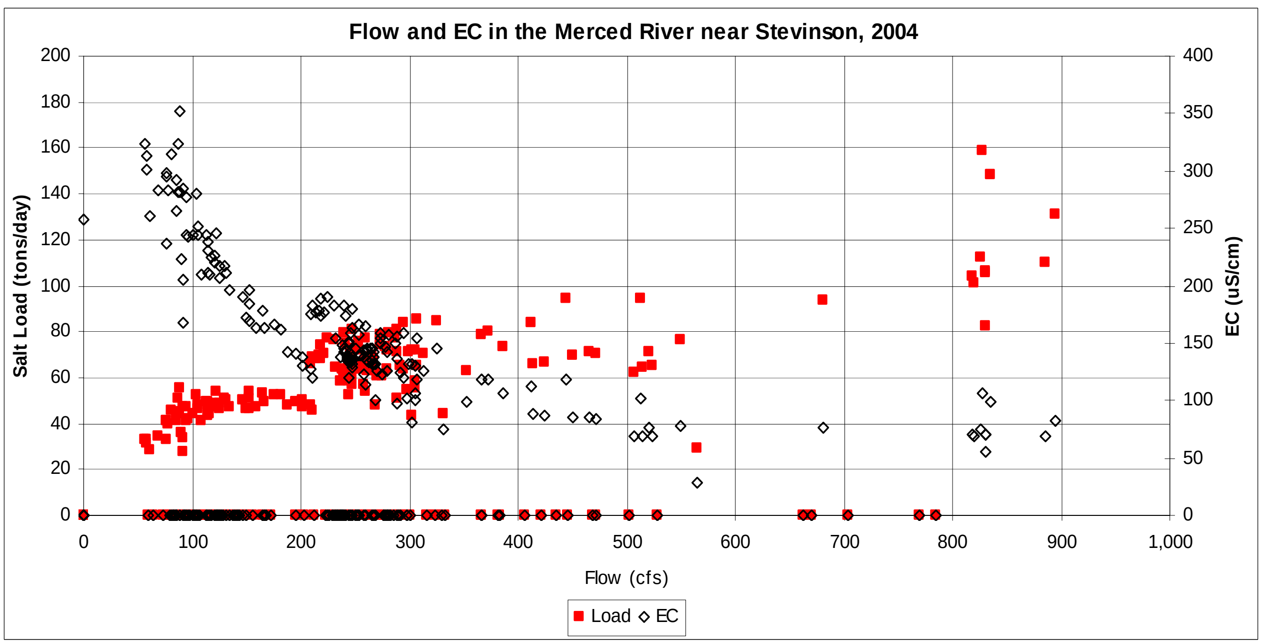
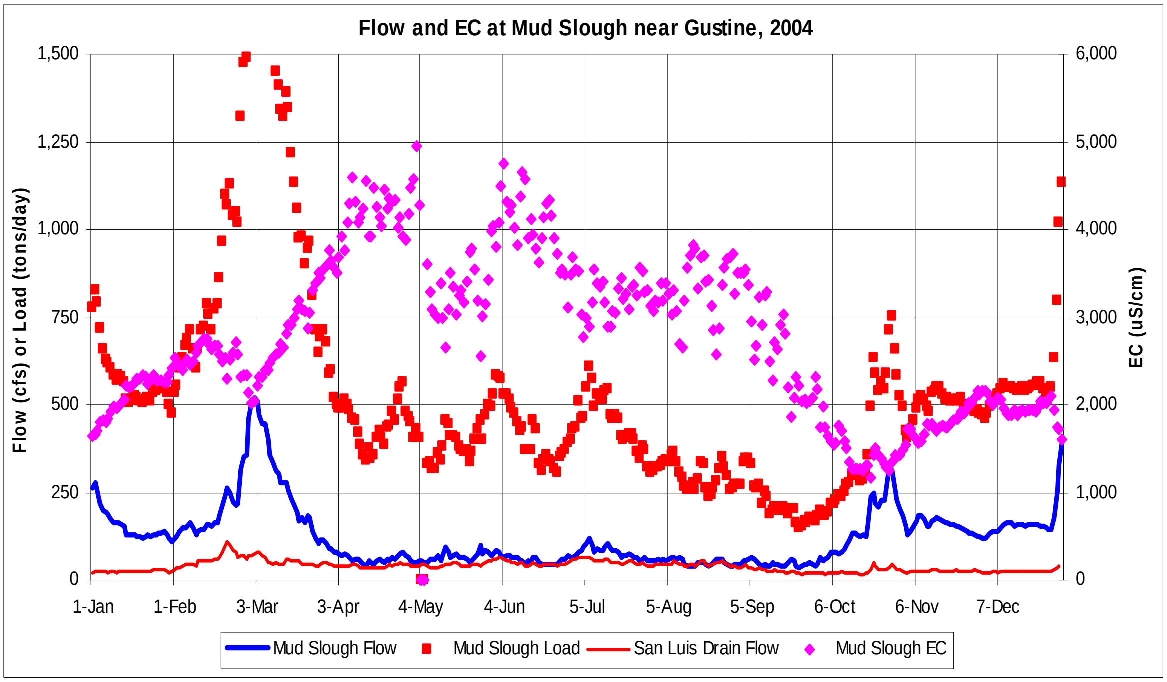


Figure 12. Merced River flow and EC and calculated salt loads at Stevinson for 2004. The flow was high during the April 15-May 15 and October VAMP flows. Minimum flows during summer period are just 100 cfs. Flows in the fall and winter are about 200 cfs for Chinook salmon spawning and rearing. There was not much change in flow between Cressy (mile 27.6) and Stevinson (mile 4.8). The EC was about 150 uS/cm during the winter period and increased to 300 uS/cm in the summer. The EC data is from the USGS River Road station.



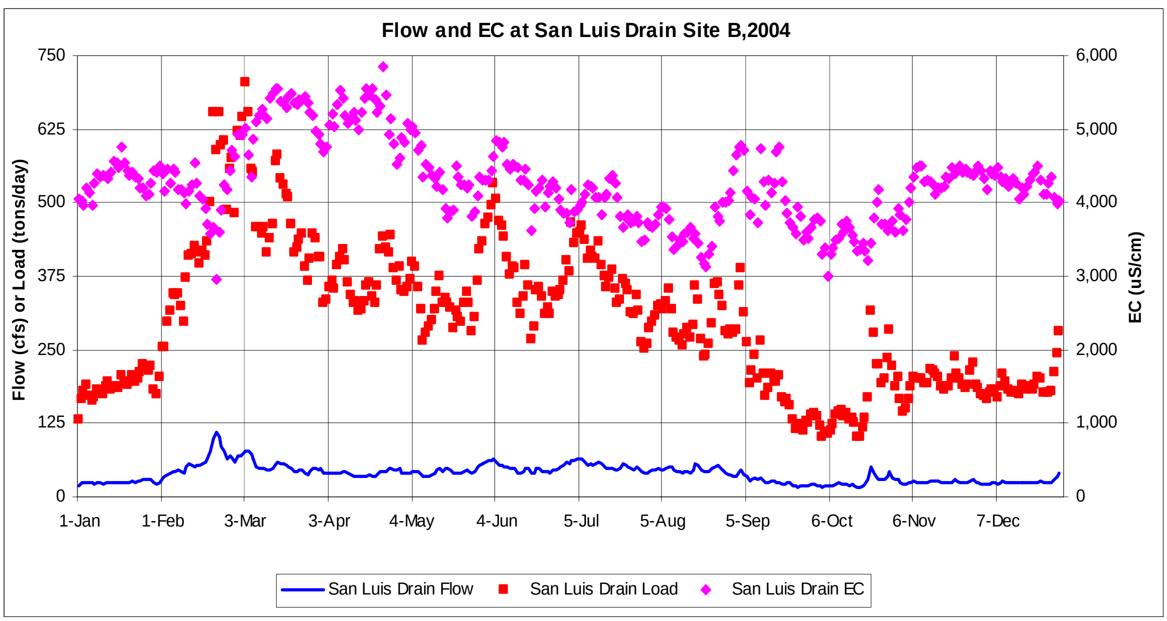
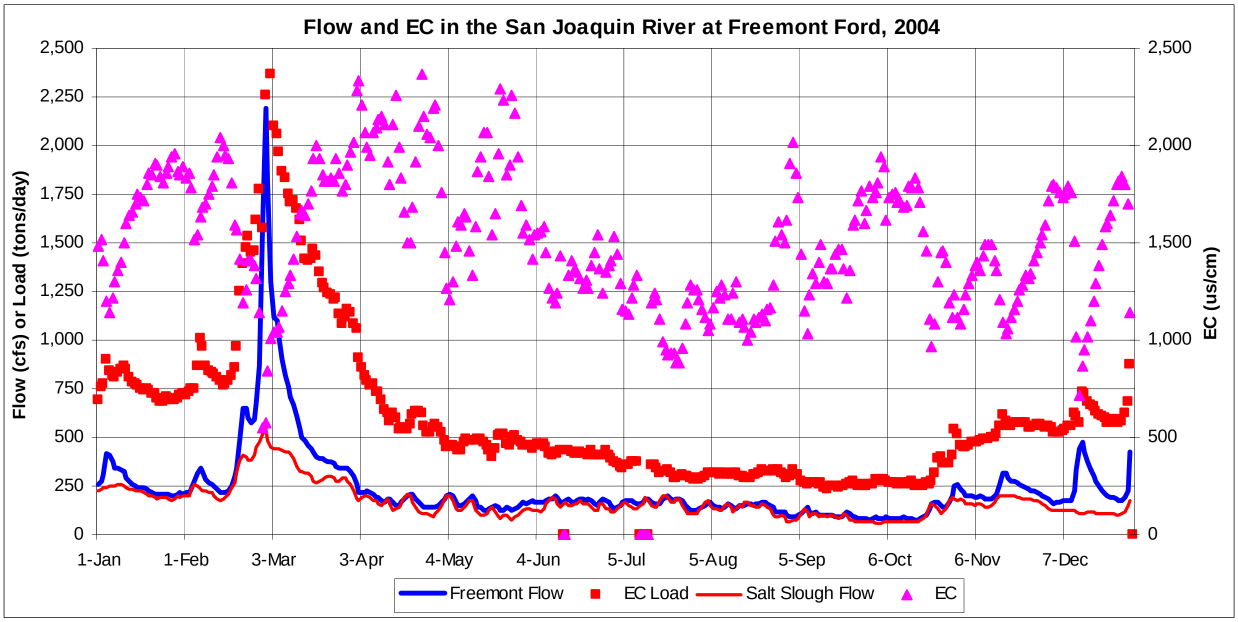


Figure 13. Mud Slough flow and EC and calculated salt loads near Gustine (downstream of San Luis Drain discharge) for 2004. The contribution of salinity from the San Luis Drain, with a summer flow of about 50 cfs and EC of 4,000 uS/cm is compared. The salt load of about 250 tons/day from the San Luis Drain is about 20% of the Vernalis salt load, although the flow of 50 cfs is only 5% of the Vernalis flow during the summer months.



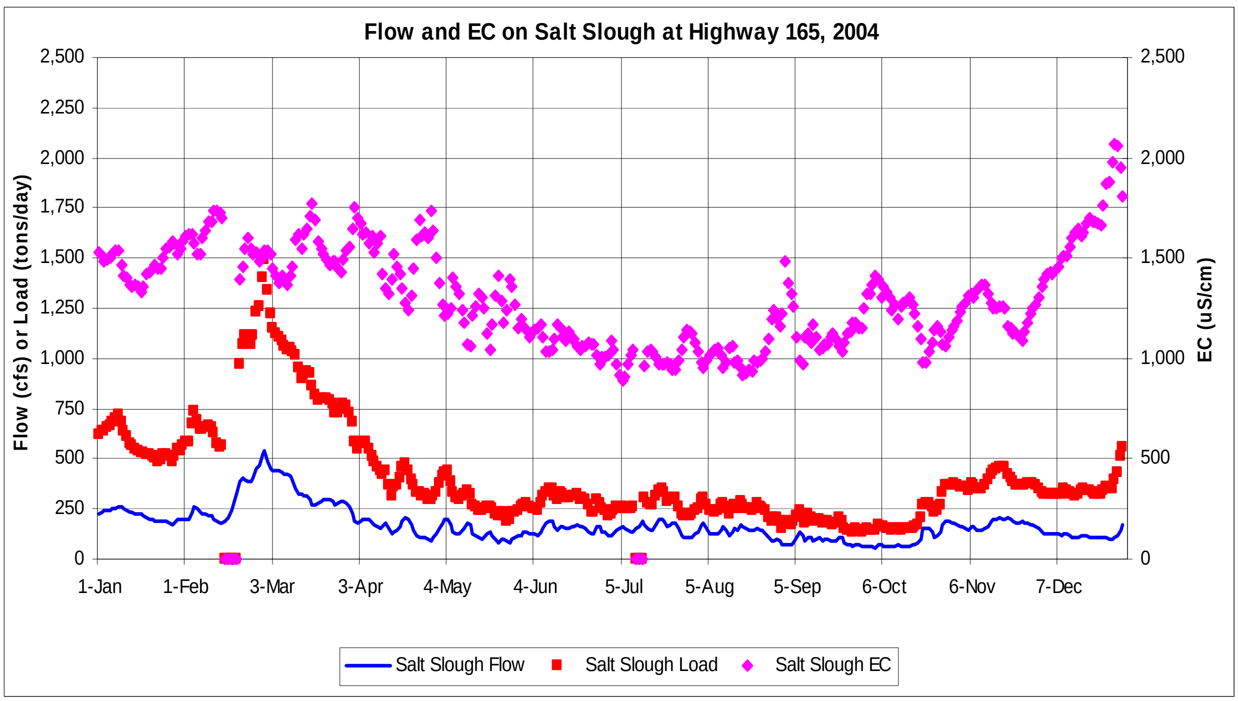
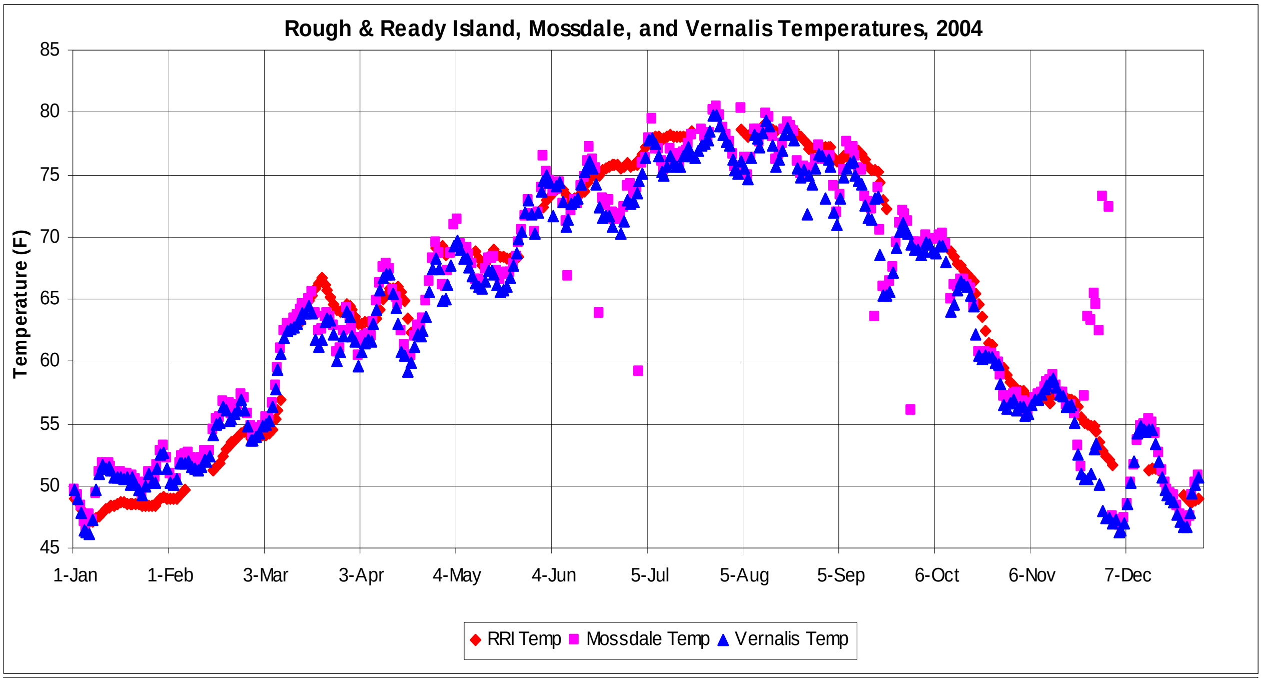


Figure 14. San Joaquin River flow and EC and calculated salt load at Freemont Ford (upstream of Mud Slough) for 2004. The flow was relatively constant at 200 cfs through the year, except for the runoff in late February. The majority of the flow at Freemont Ford comes from Salt Slough, with an EC of about 1,000 uS/cm during the summer. The summer salt load of 250 tons/day at Freemont Ford is similar to the salt load from the San Luis Drain.



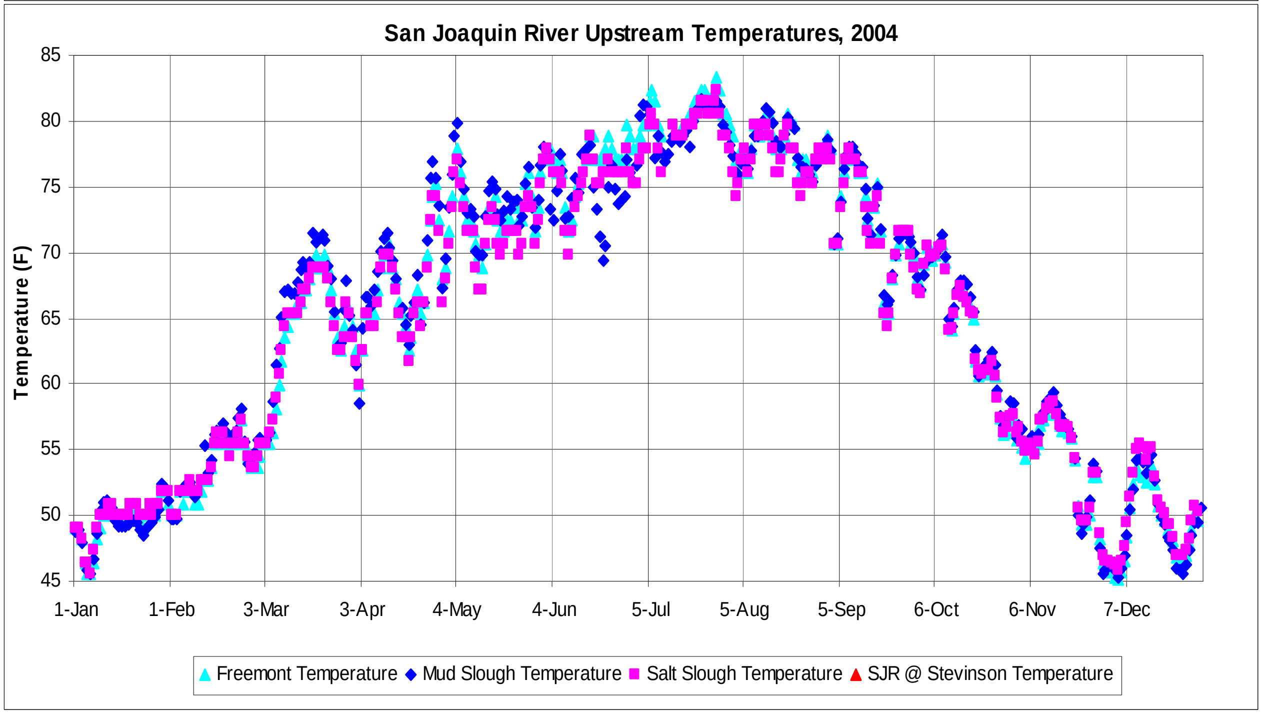
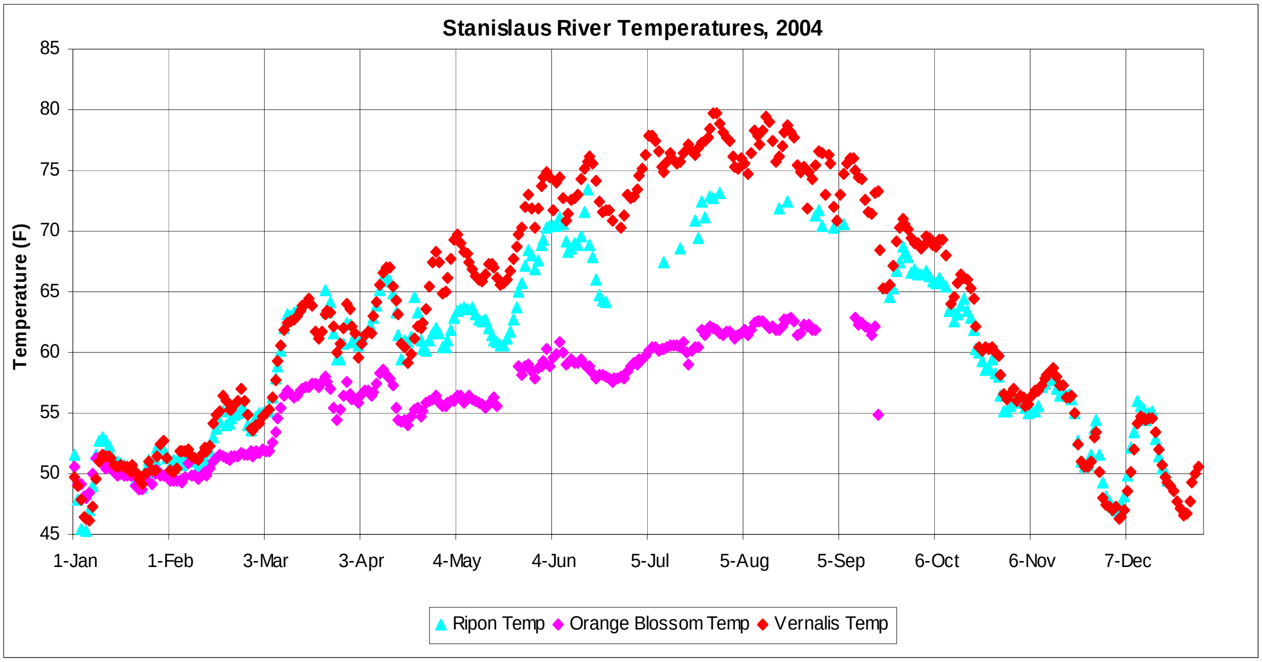


Figure 15. San Joaquin River temperatures for 2004. The upstream temperatures fluctuate more in response to meteorology, but the summer maximum temperatures of about 80 F are similar throughout the river. Temperature fluctuations are least in the DWSC measured at the Rough & Ready Island station. Temperatures of more than 70 F are generally thought to limit adult Chinook salmon migration, so migration probably began in October of 2004.



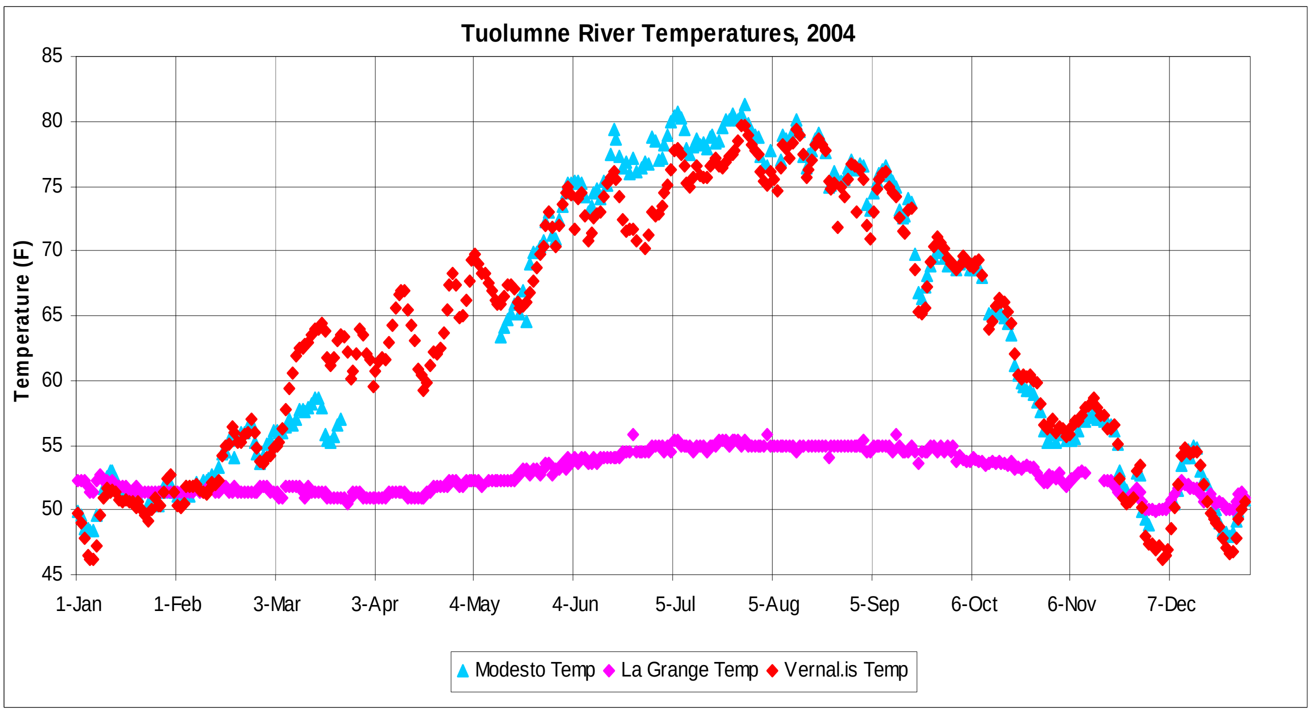
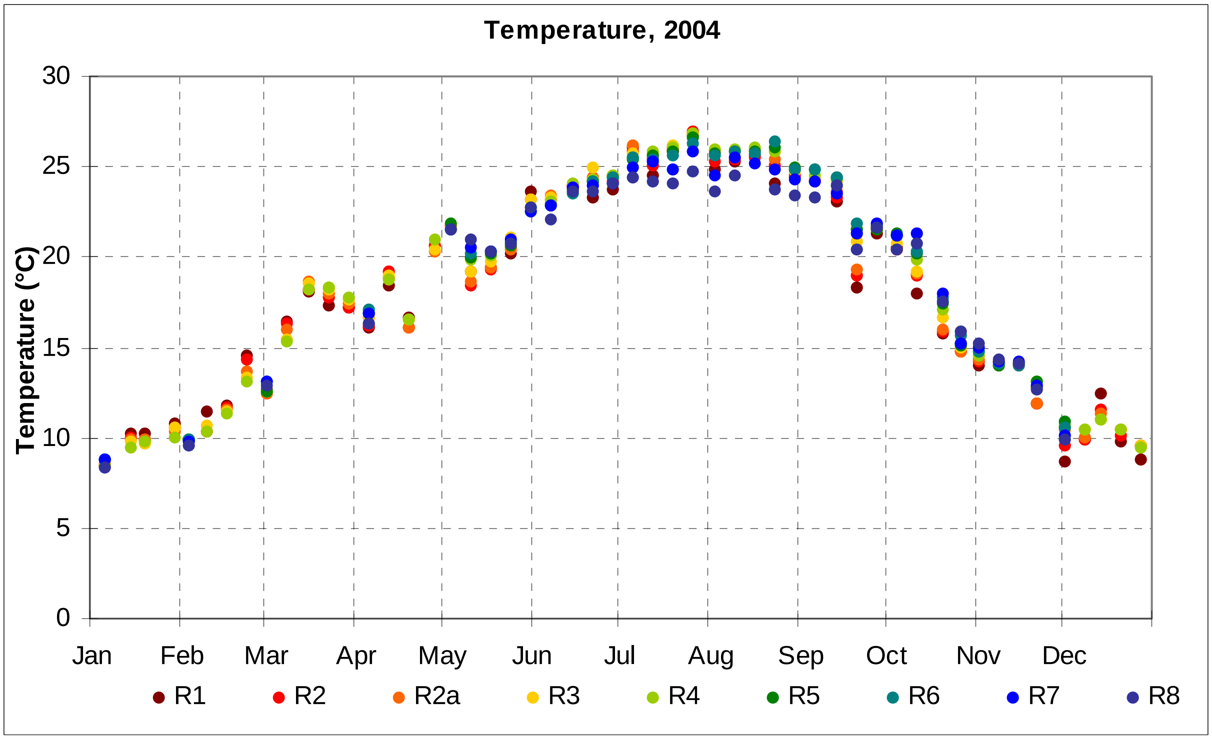


Figure 16. Stanislaus and Tuolumne River temperatures for 2004. The upstream temperatures remain cool throughout the year because they are released from the upstream reservoirs. The Tuolumne release temperatures are about 55 F in September and cool to 50 F by the end of November. The downstream temperatures are approaching the Vernalis temperatures in response to meteorology (i.e., equilibrium temperatures).



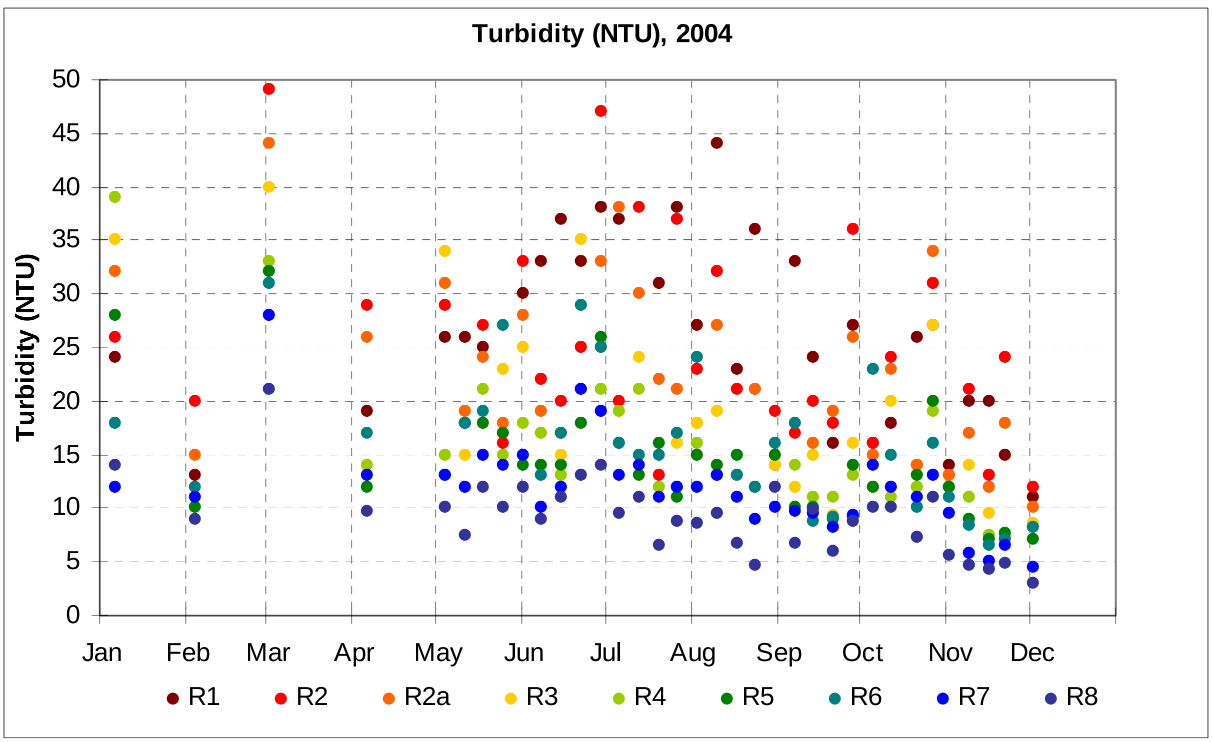


Figure 17. Temperatures and turbidity measured by the City of Stockton in the SJR and DWSC for 2004. Temperatures are fairly uniform while turbidity is reduced in the DWSC from settling.

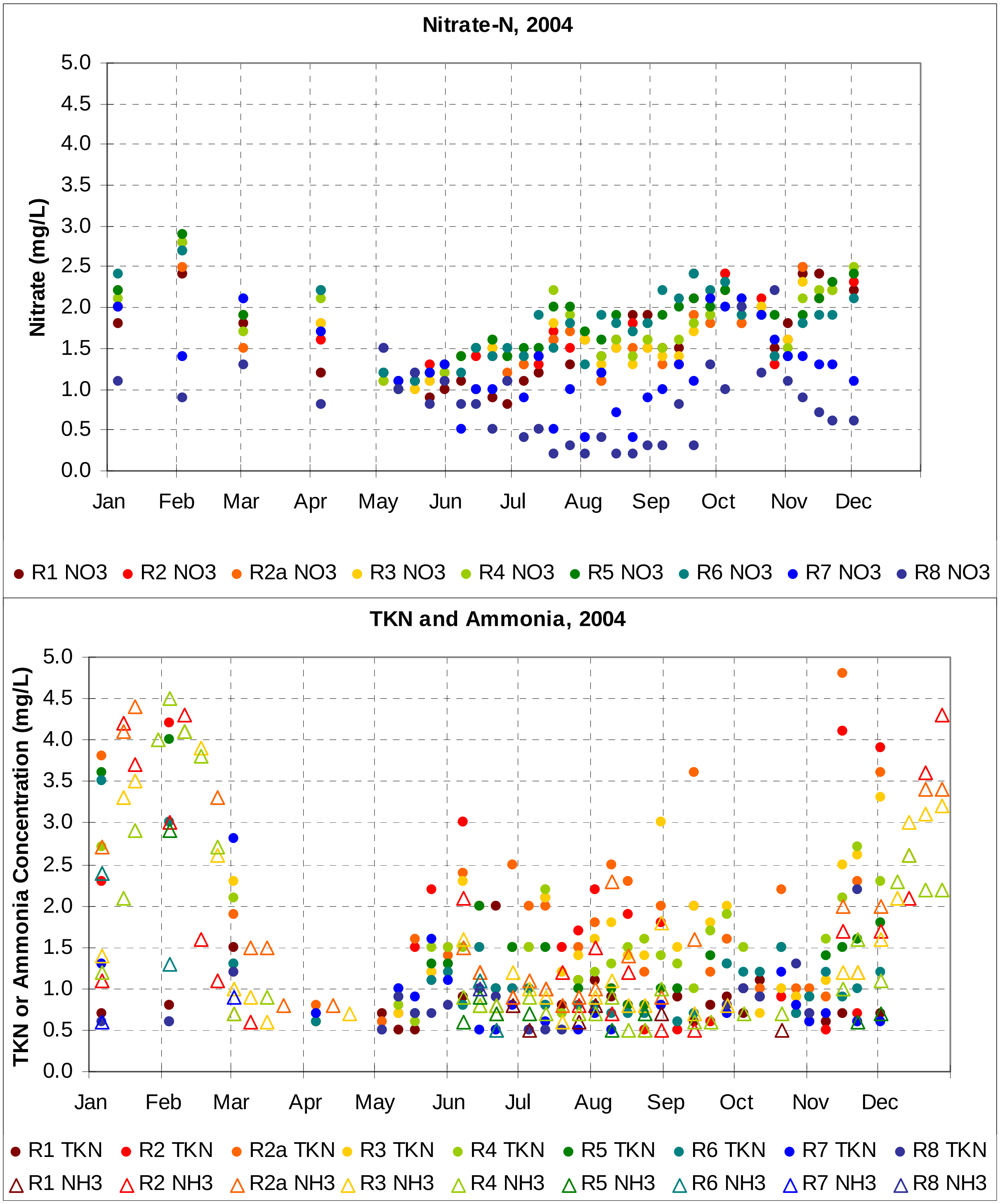
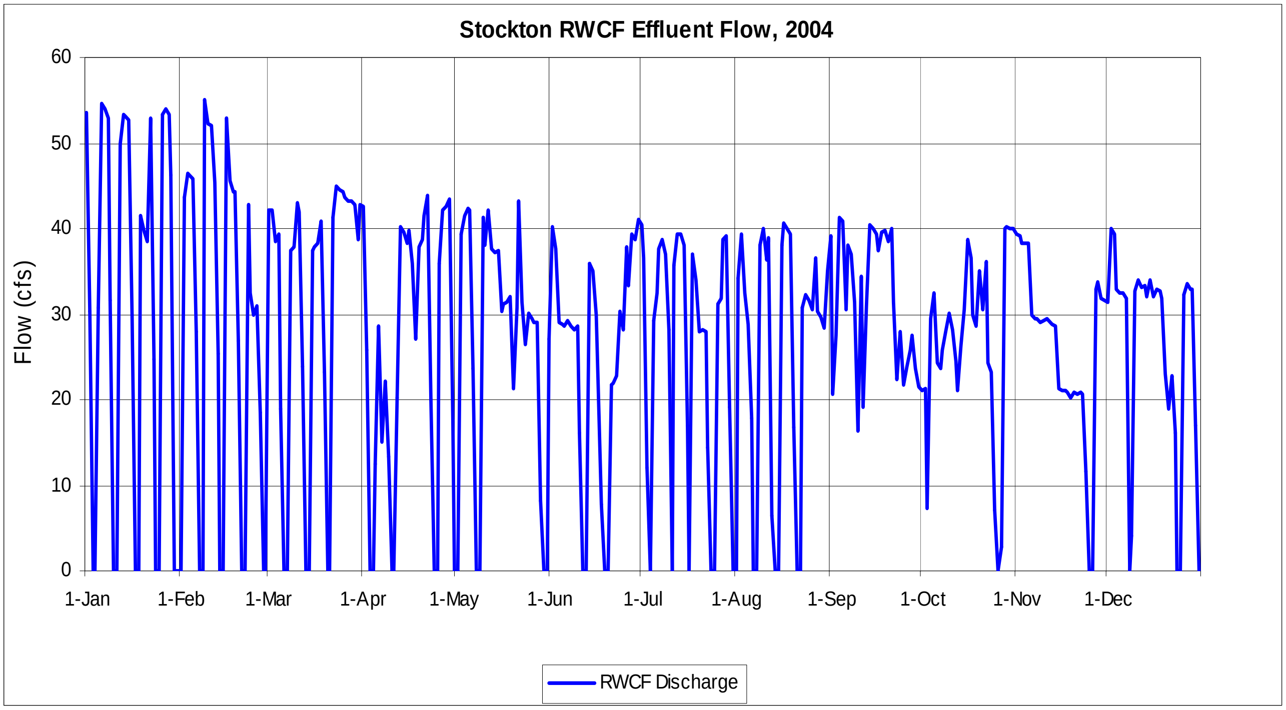


Figure 18. Nitrate, TKN and ammonia nitrogen concentrations measured by the City of Stockton in the SJR and DWSC for 2004. Nitrate concentrations increase through the summer. Ammonia concentrations were very high (4 mg/l) in the winter period of low flows.



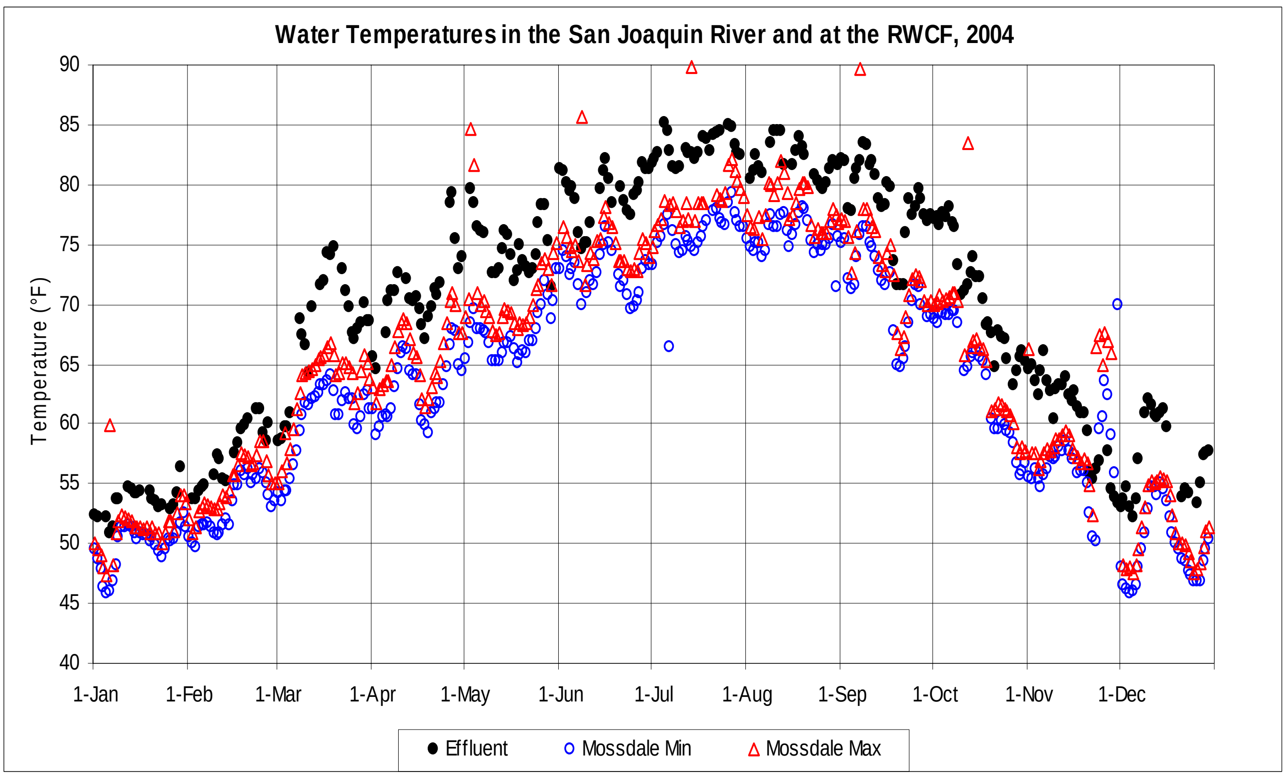
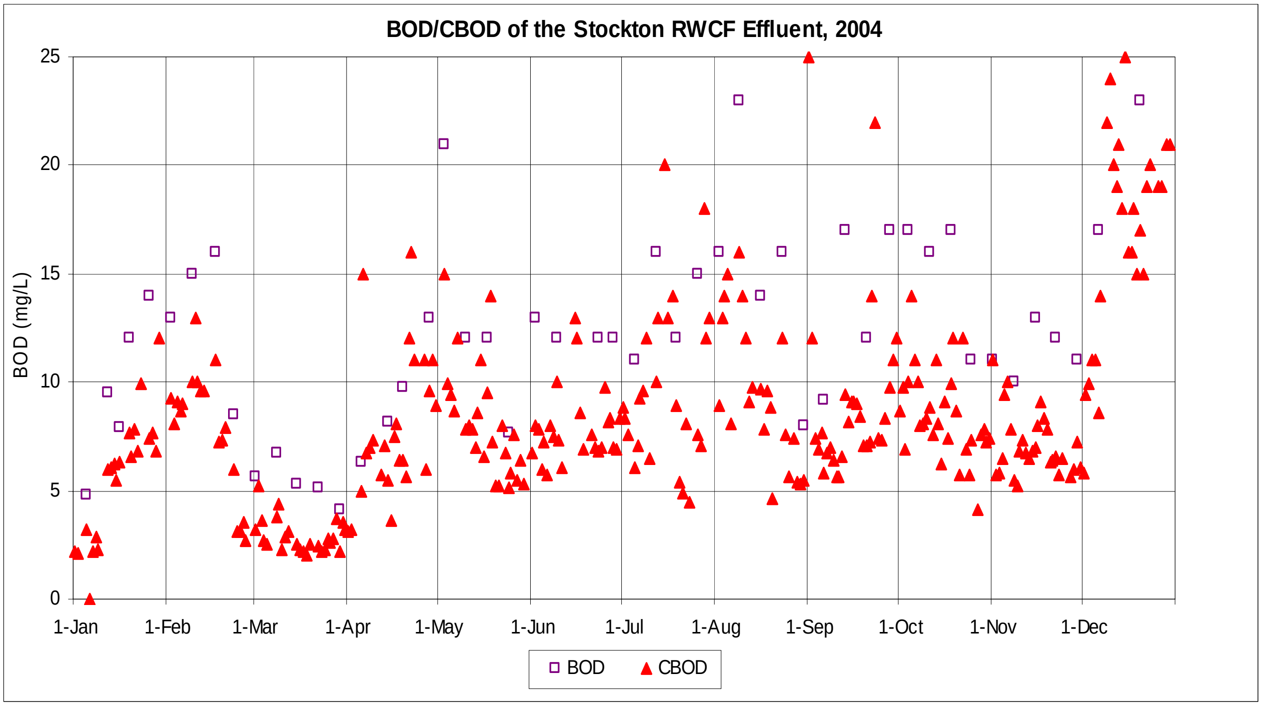


Figure 19. Stockton Regional Wastewater Control Facility Discharge and temperatures for 2004. Discharge is shut off on most weekends. Average effluent temperatures are warmer than Mossdale temperatures.



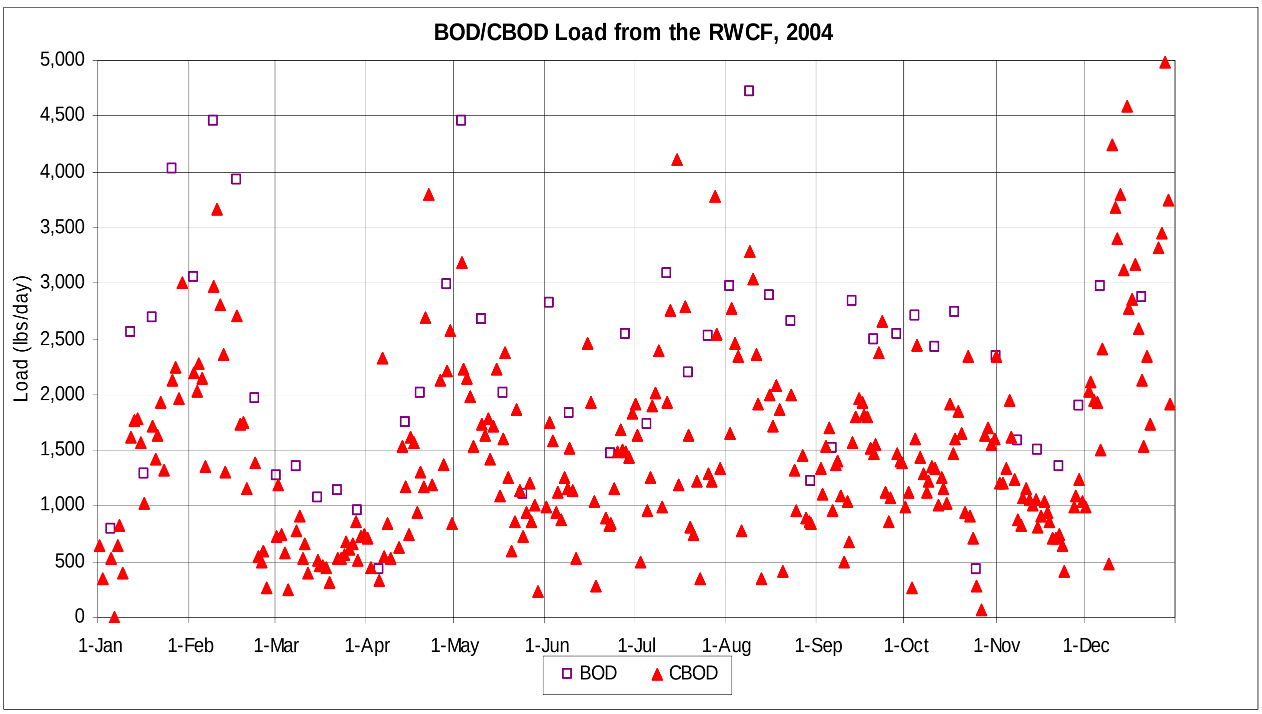
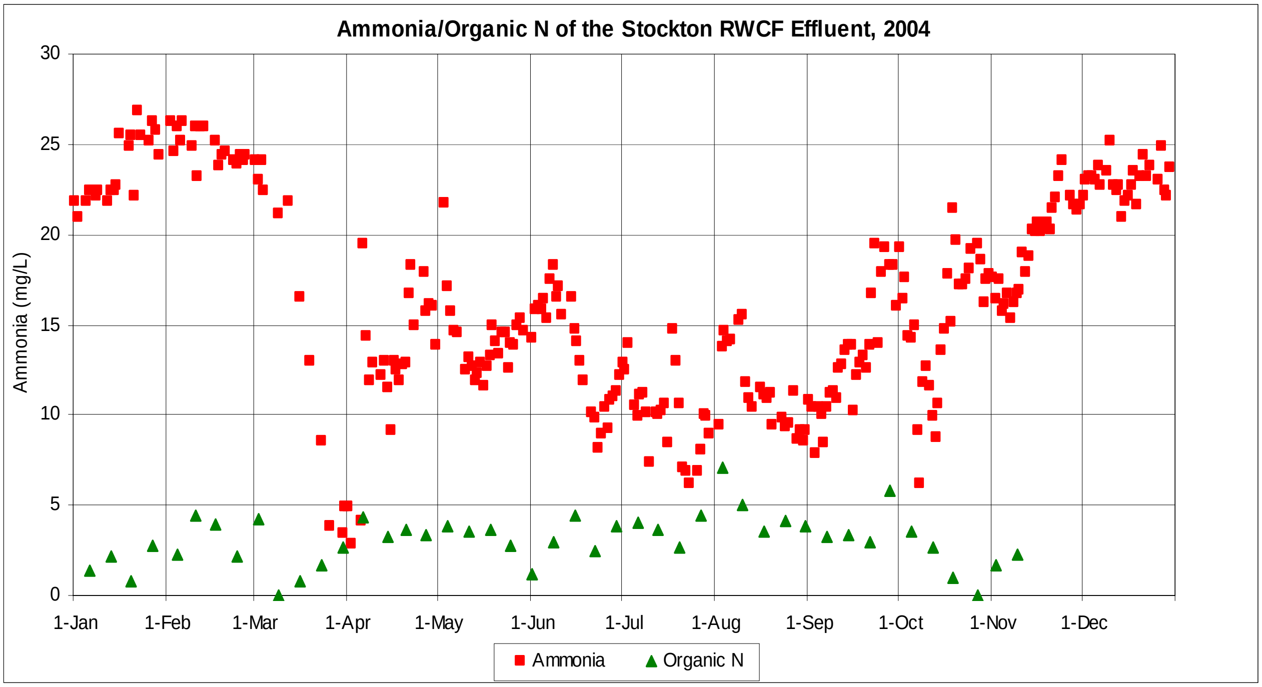


Figure 20. Stockton RWCF BOD and BOD load (lbs/day) for 2004. The CBOD concentrations are usually less than 10 mg/l and the load is usually less than 2,500 lbs/day.



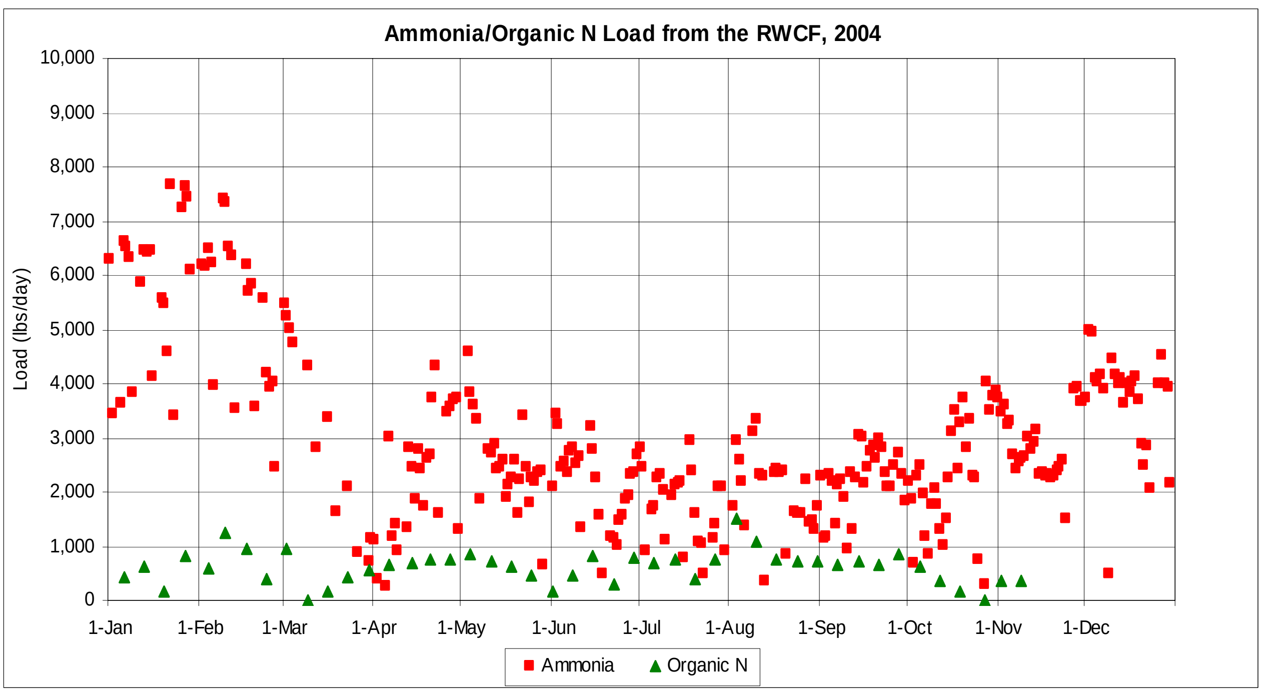


Figure 21. Stockton RWCF Ammonia-N and Ammonia-N load (lbs/day) for 2004. The Ammonia-N concentrations are about 25 mg/l in the winter, but remained above 10 mg/l through the summer. The BOD equivalent load will be about 5 times the ammonia-N load because 5 mg/l of DO are required to oxidize each mg/l of ammonia-N. A nitrification facility is being constructed to reduce the ammonia-N concentrations to 2 mg/l.

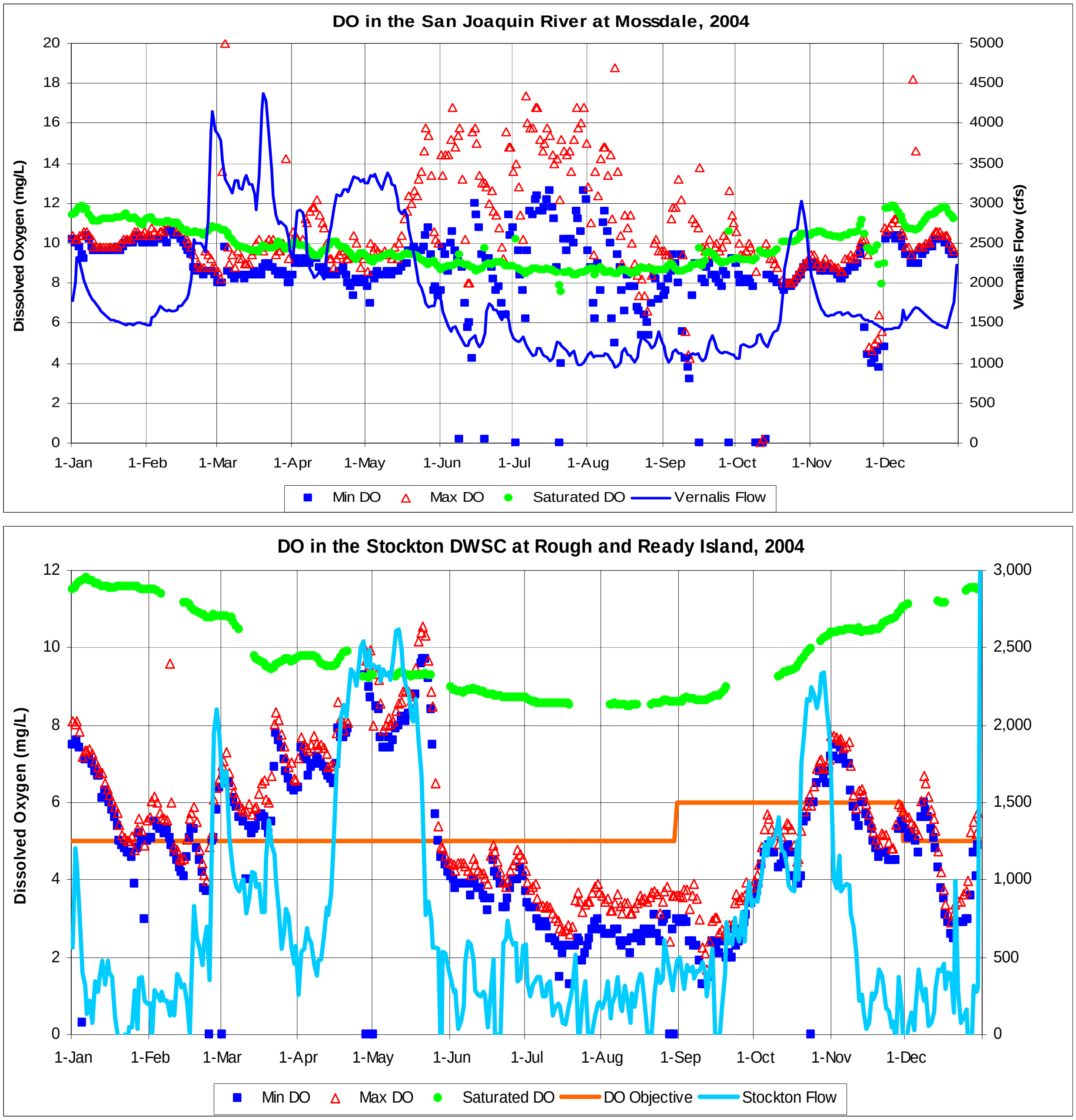
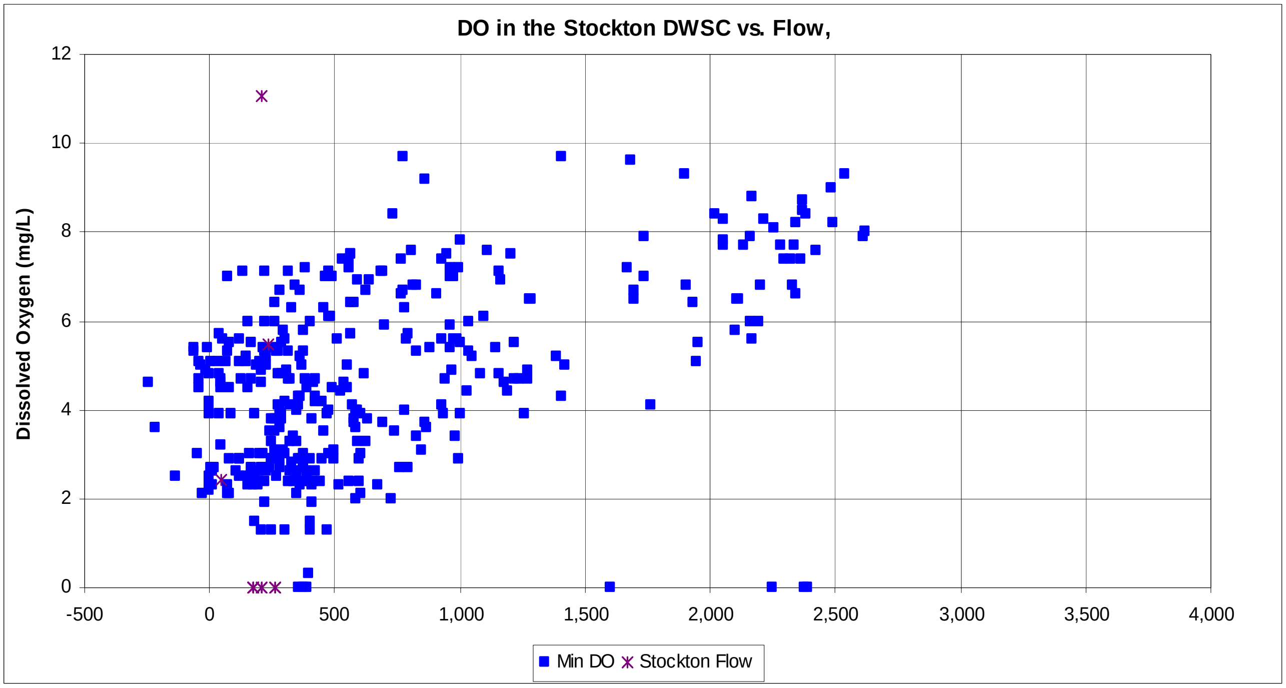


Figure 22. Mossdale and Rough & Ready Island minimum and maximum DO data for 2004. The upstream river concentrations are usually near the saturated value, and are super-saturated from algae photosynthesis in the summer. The Rough & Ready Island DO is generally below saturation in the summer and sometimes in the winter during low flows with high ammonia loads from the Stockton RWCF.



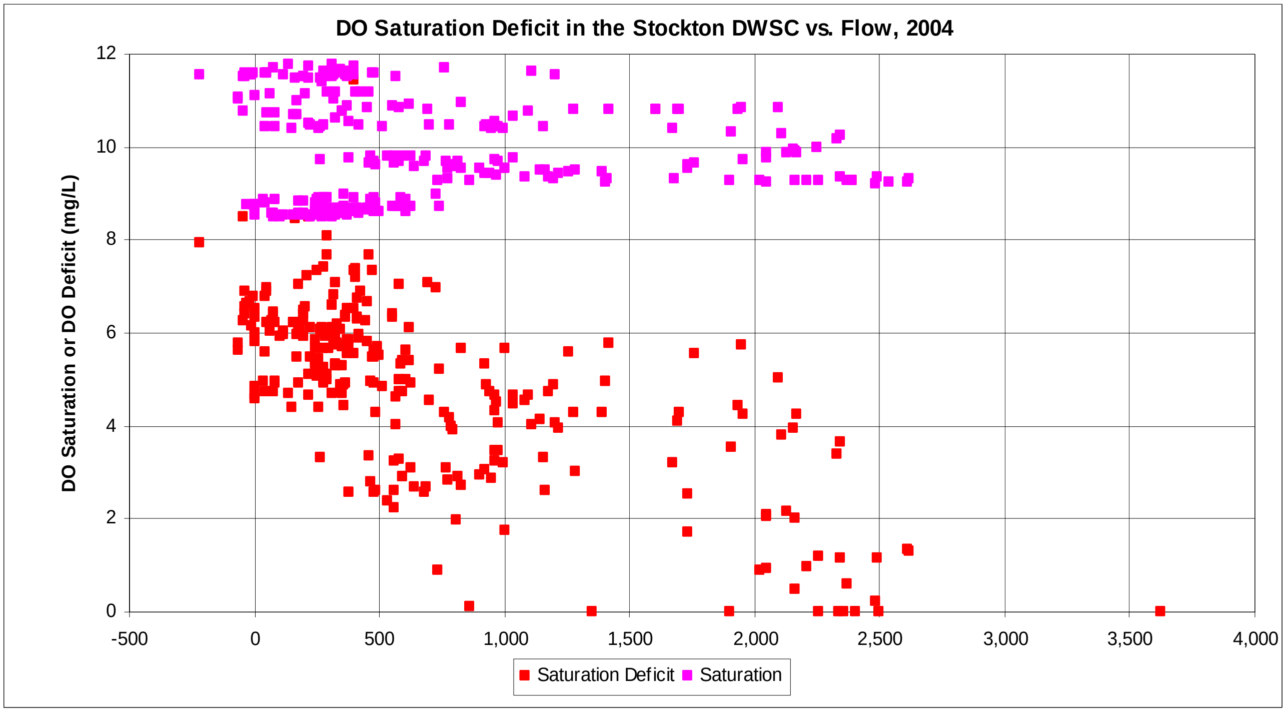


Figure 23. Rough & Ready Island minimum DO as a function of Stockton flow for 2004. The DO tends to be lowest when the fllow is less than 500 cfs. The relationship is somewhat improved by considering the DO deficit from saturation, which is lower at higher temperatures in the summer. The DO deficit is about 6 mg/l when flows are less than 500 cfs.

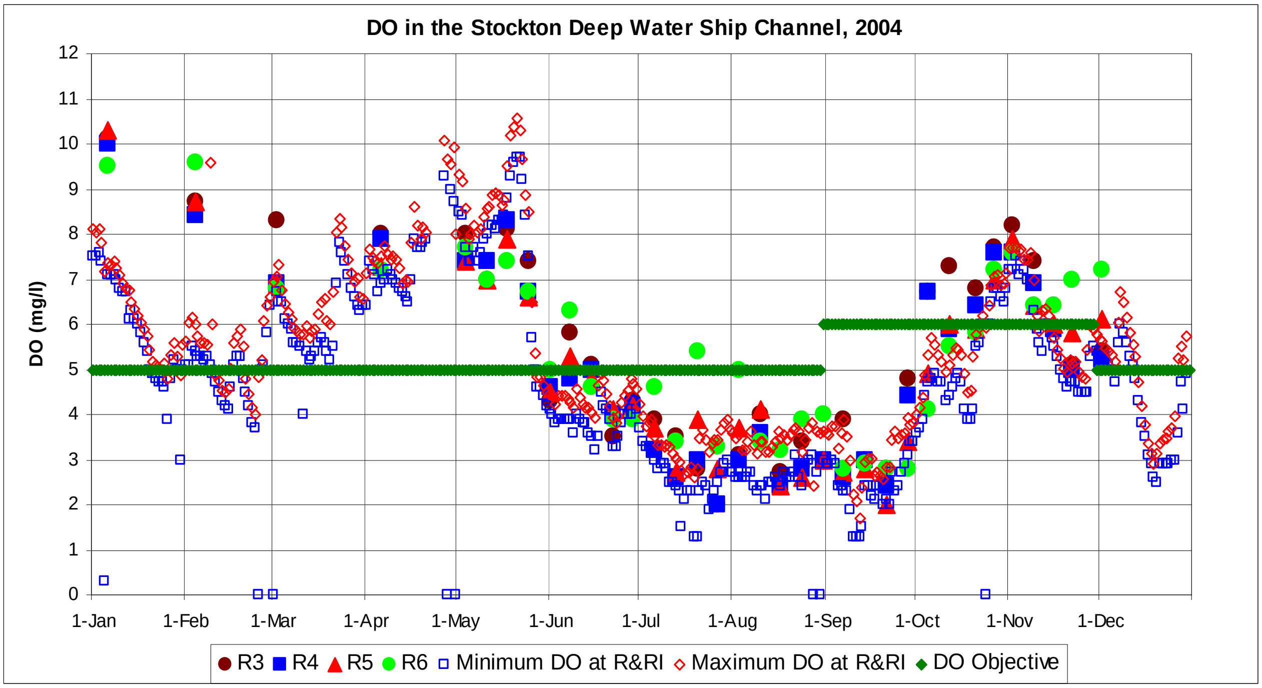


Figure 24. Comparison of the Rough & Ready DO and the City of Stockton River station DO measurements from R3 to R6 for 2000. The City measurements are collected in the morning and are similar to the minimum DO at the Rough & Ready station. This is an example of using data from two independent sources to confirm the measured data pattern.

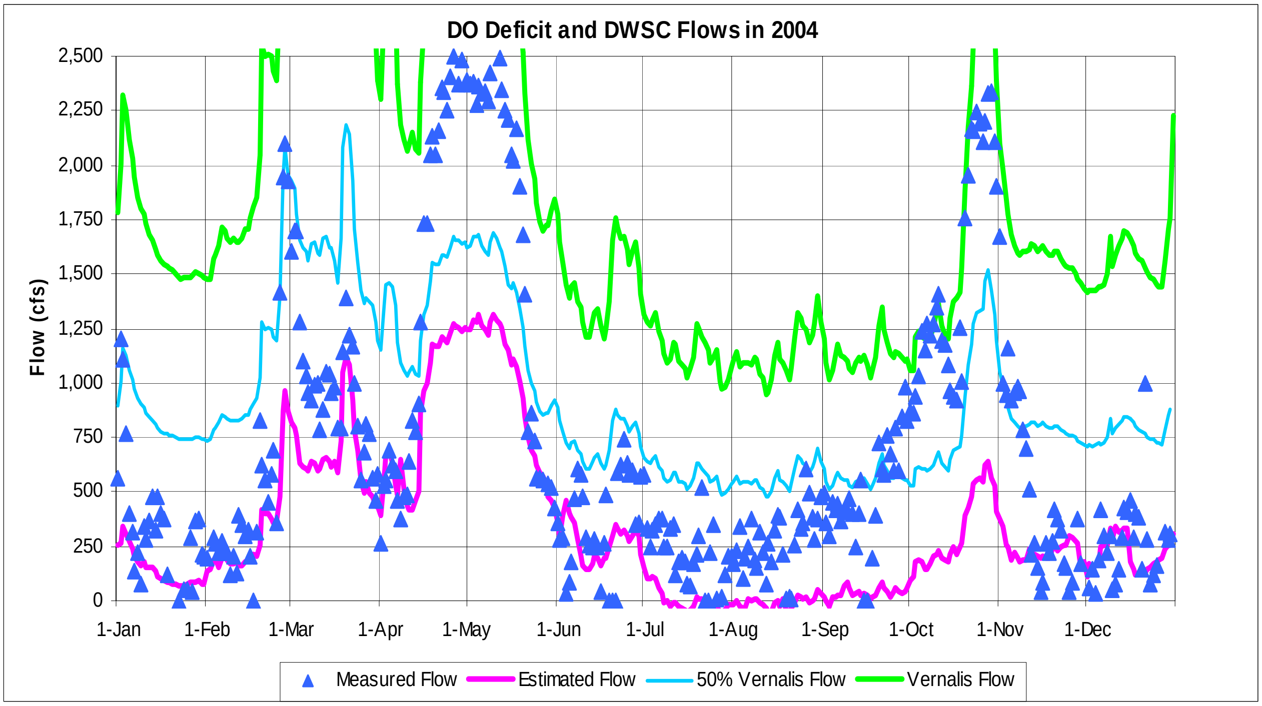


Figure 25. Measured flows at the USGS tidal flow station at Stockton and estimated flows for 2004. The estimated flow is based on a relationship developed from the years with measured data (1996-2004). The SJR flow at Stockton can be estimated as 50% of Vernalis flow minus 5% of the combined CVP and SWP pumping. The measured Stockton flow is greater than the estimate during periods when the head of Old River barrier weir was in place (i.e., April 15-May 15, and October), and during the summer when the south Delta agricultural barriers were in place (June-September).

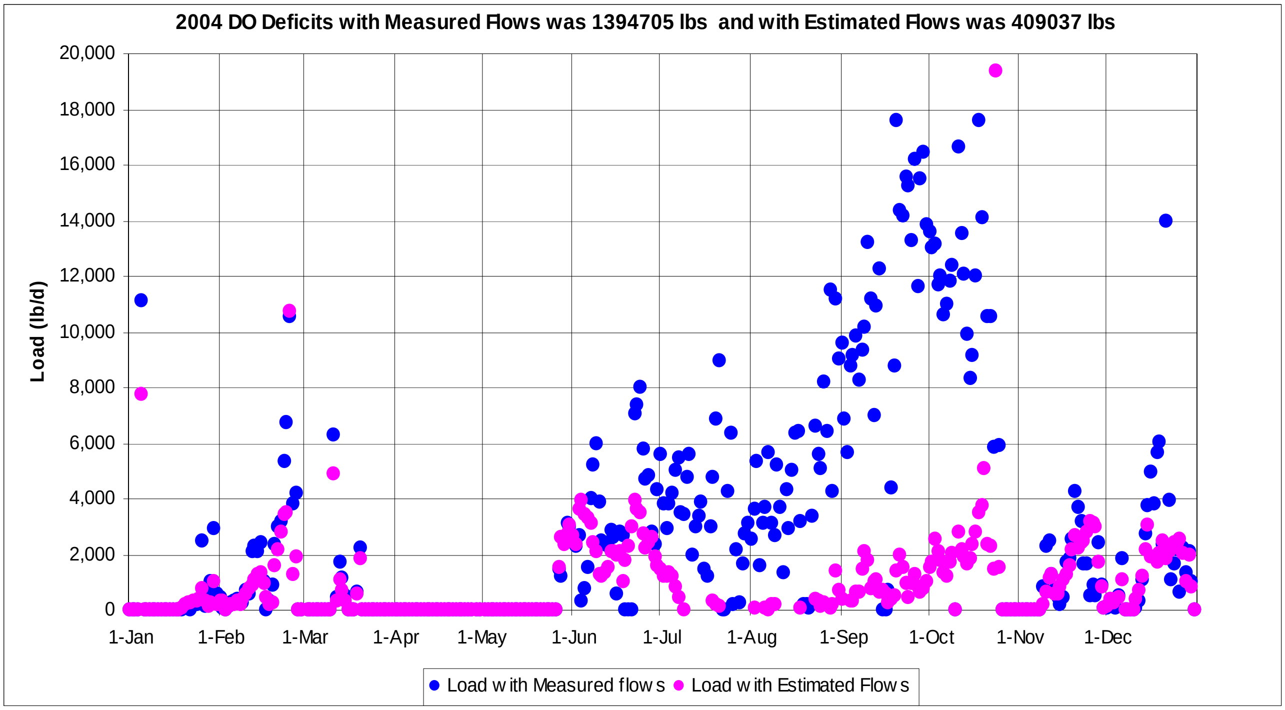
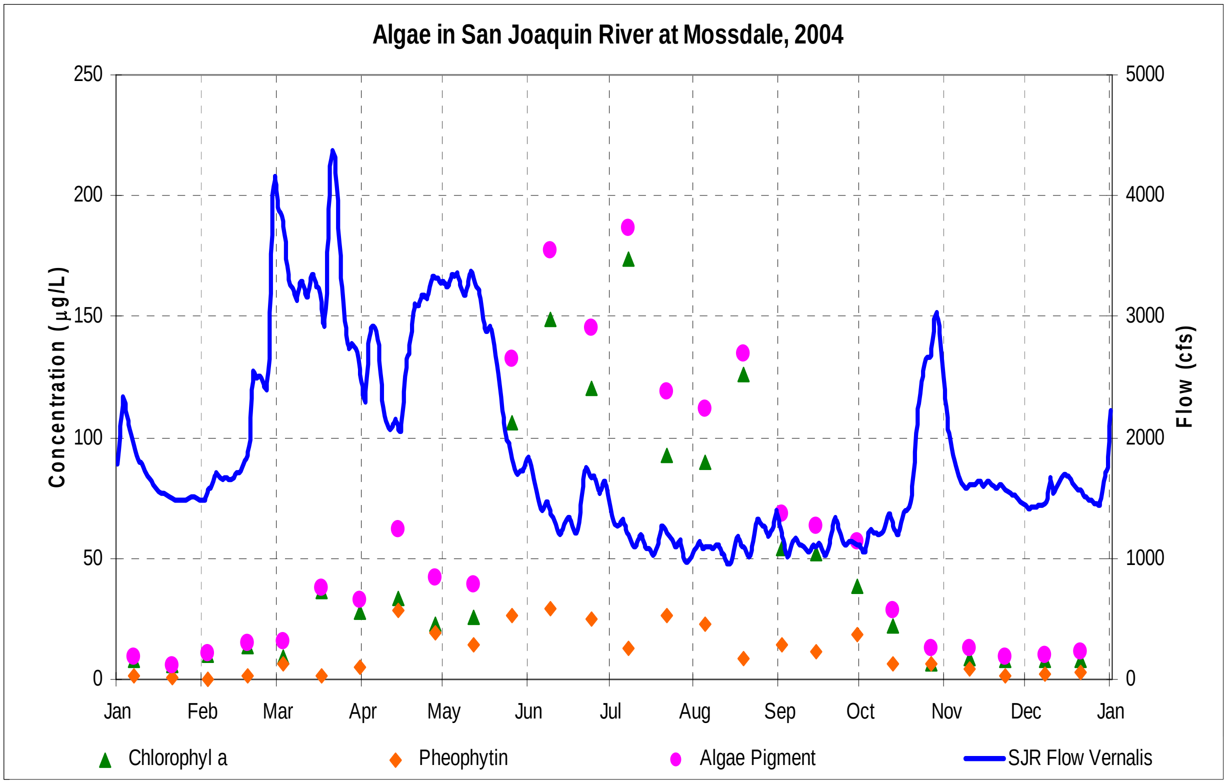


Figure 26. Calculated daily DO deficit "load" in the DWSC with measured and estimated flows for 2004. The deficit load is calculated from the DO target (DO objective + 0.5 mg/l) and the measured minimum daily DO concentrations as Deficit Load (lb/day) = 5.4 * (DO target – Minimum DO) * Flow (cfs). The oxygenation device that is being constructed at the wester end of Rough & Ready Island by DWR is designed to deliver 10,000 lb/day into the DWSC.



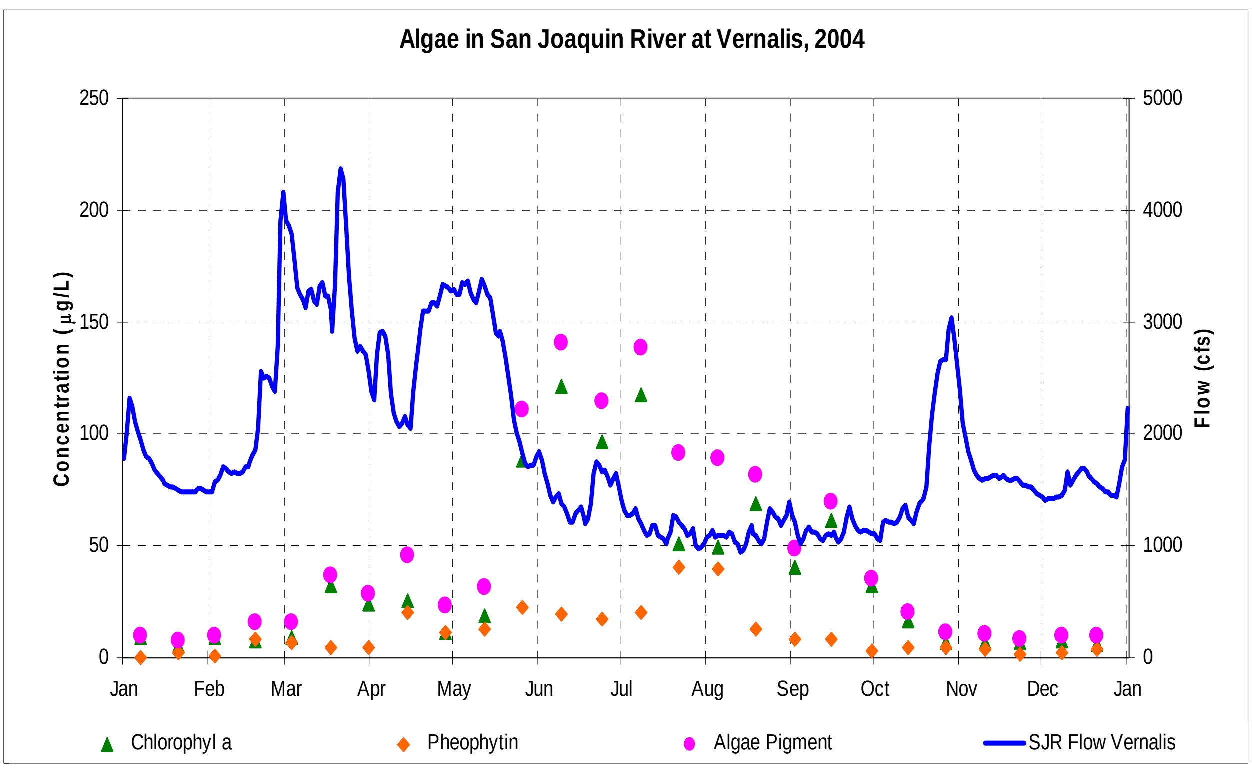
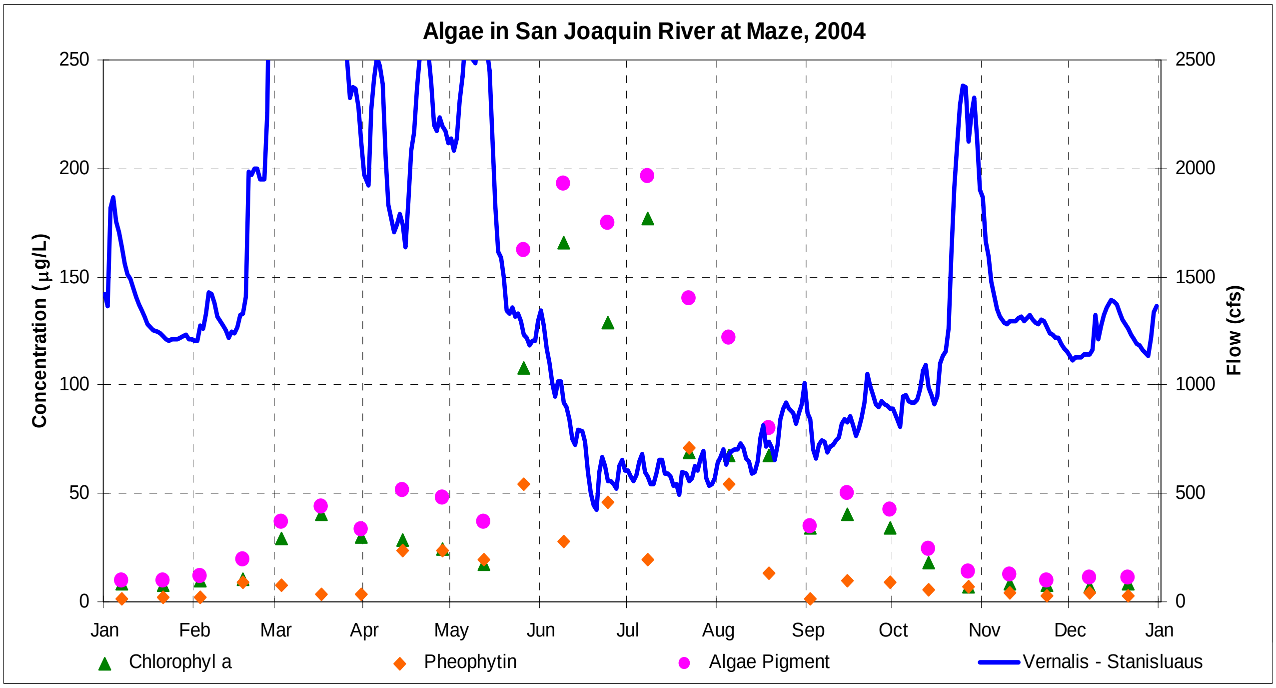


Figure 27. Algae pigment concentrations at Vernalis and Mossdale for 2004.



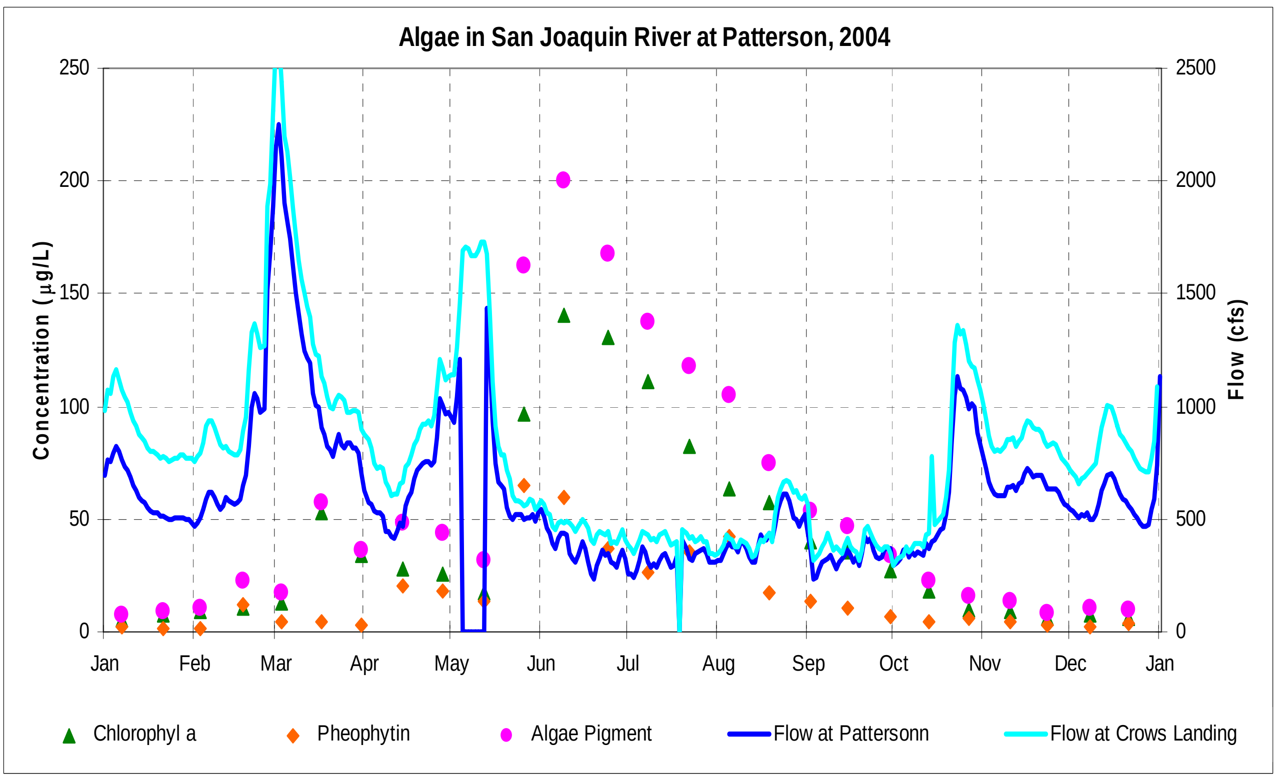
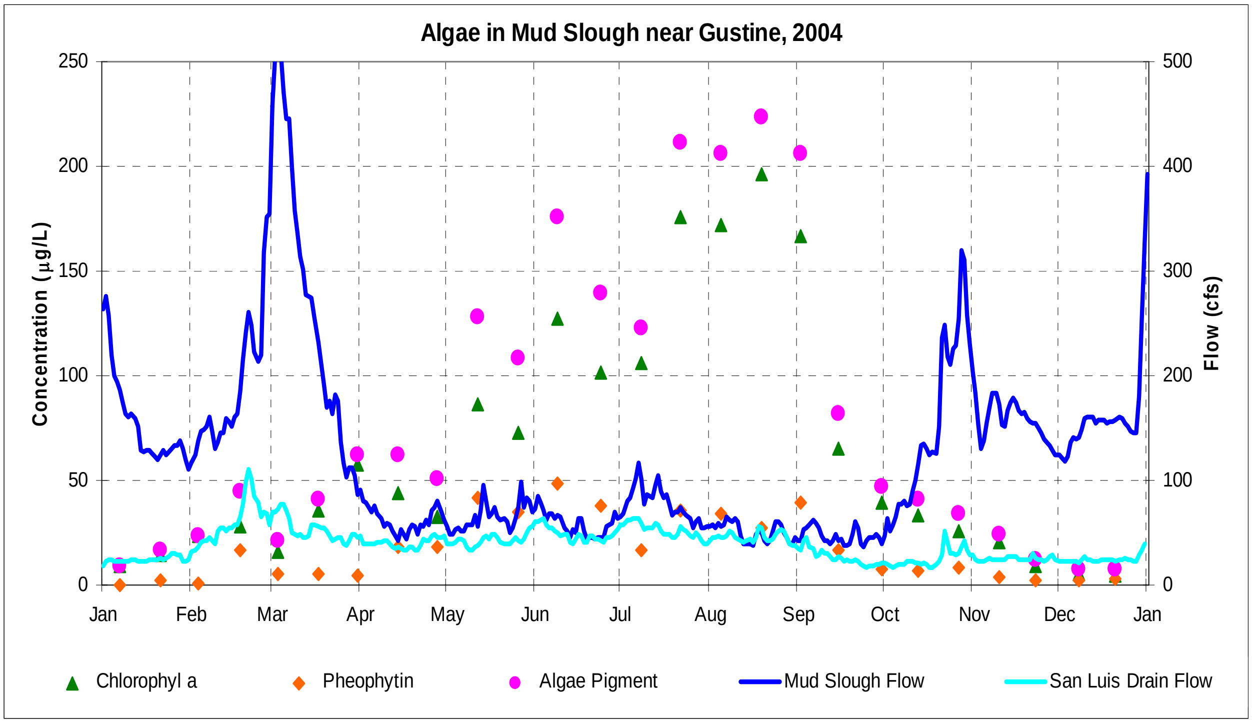


Figure 28. Algae pigment concentrations at Maze and Patterson for 2004. Flow estimates at Maze and flow measurements at Patterson and Crows Landing.



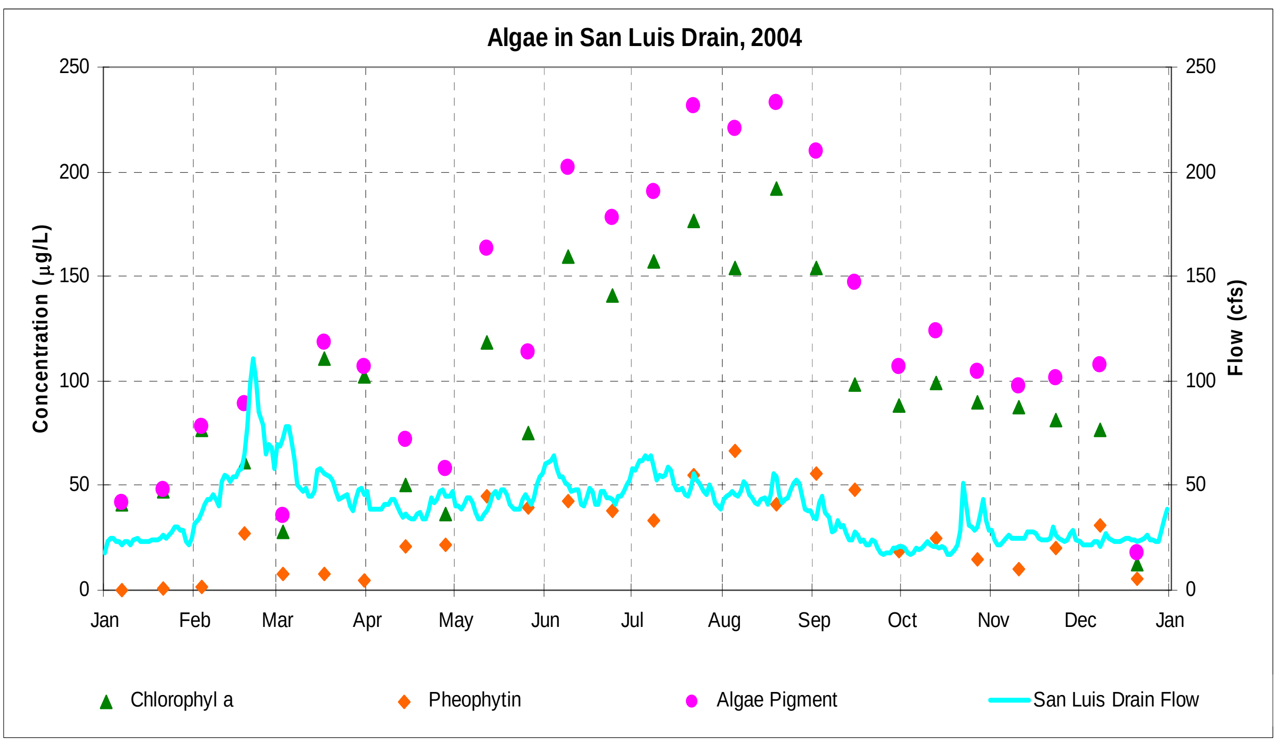
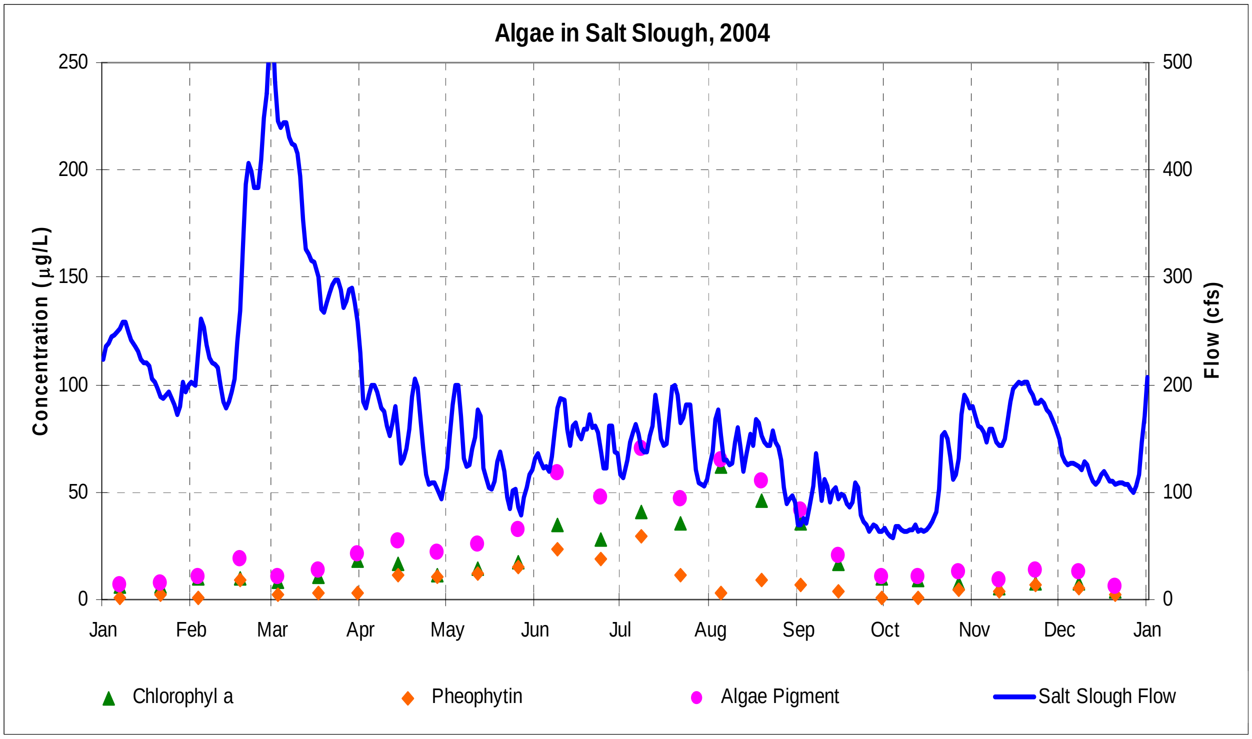


Figure 29. Algae pigment concentrations in Mud Slough and San Luis Drain for 2004. Mud Slough flow is predominantly San Luis Drain flow during the summer period.



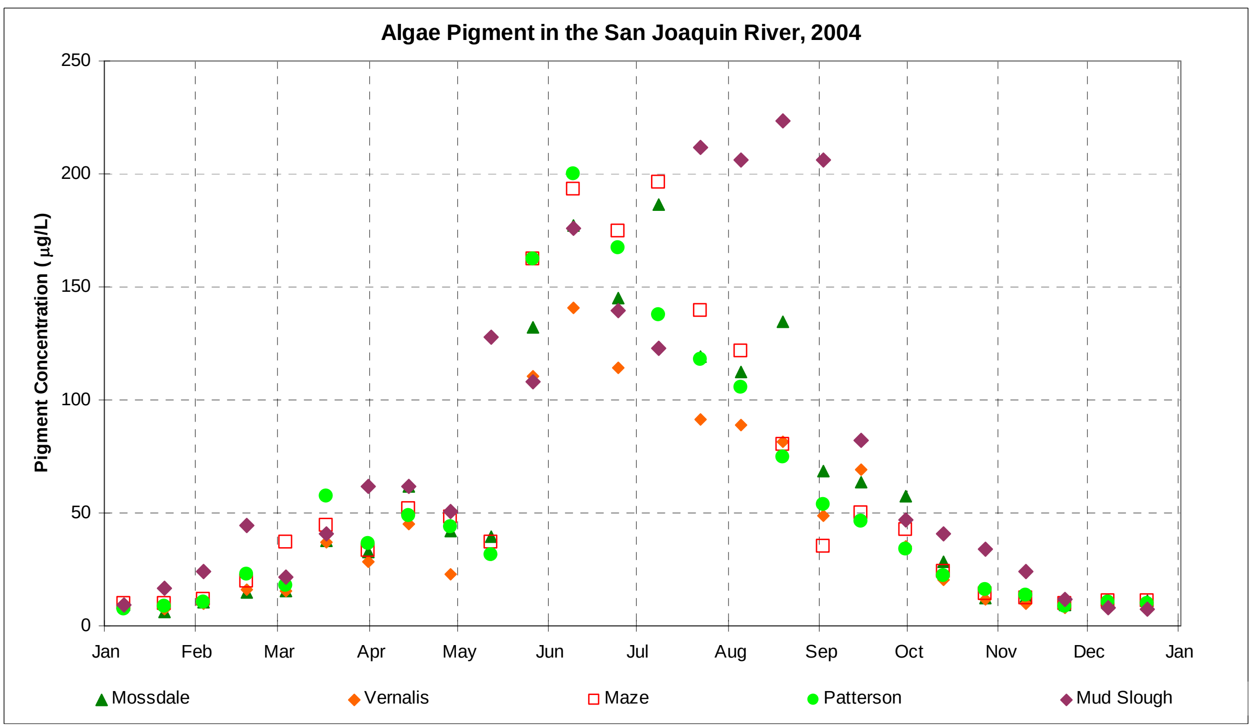
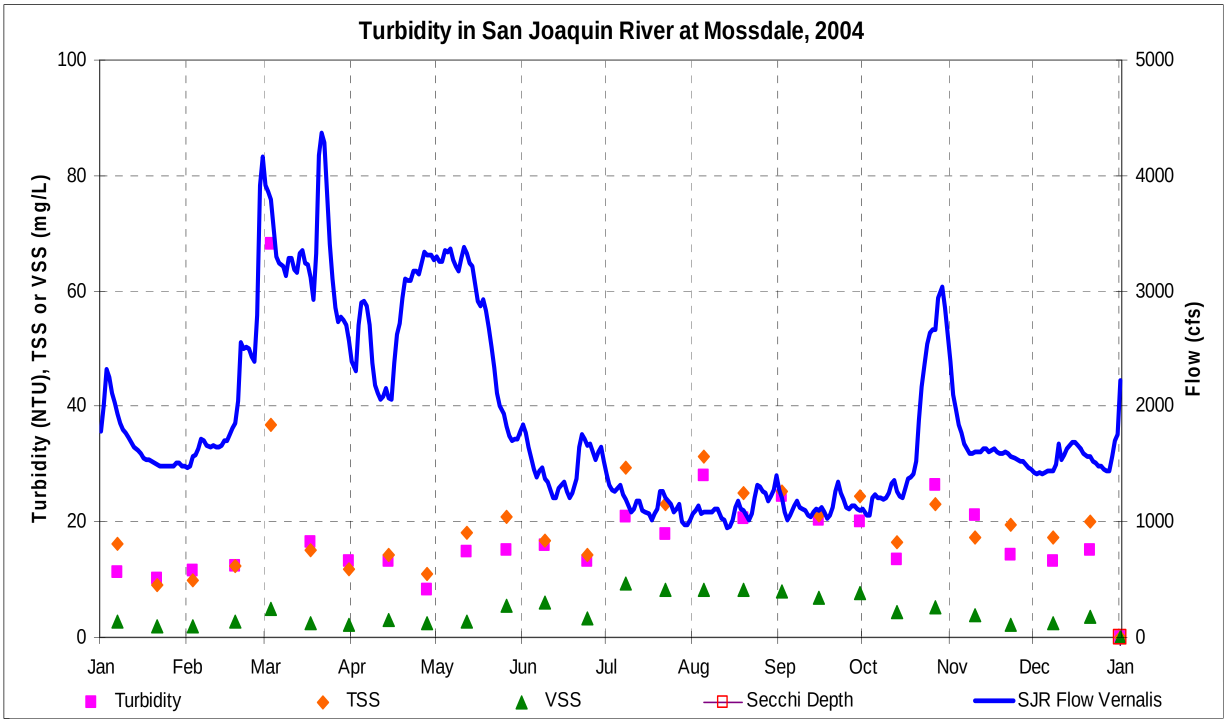


Figure 30. Algae pigment concentrations in Salt Slough and along the SJR for 2004. Algae in Salt Slough is much lower than Mud Slough with peak algae pigments of only 50 ug/l. Algae pigments are similar at Patterson, Maze, Vernalis, and Mossdale.



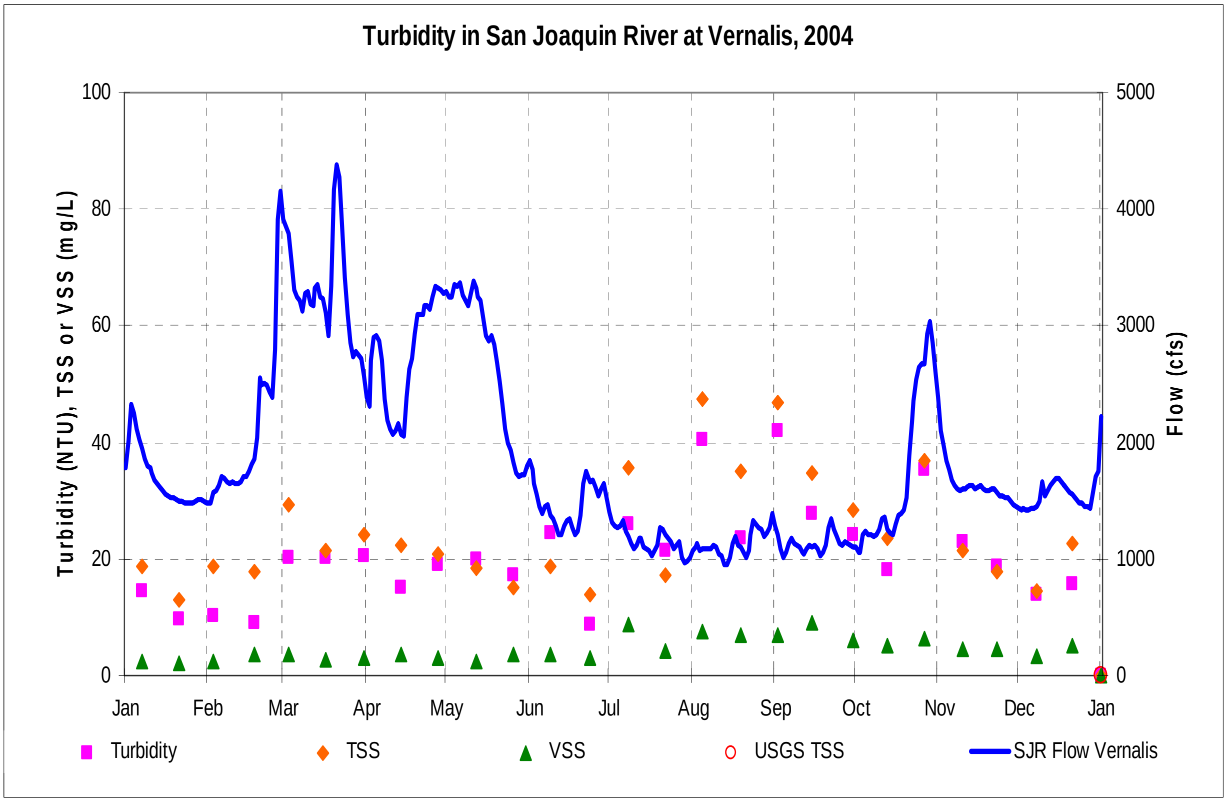
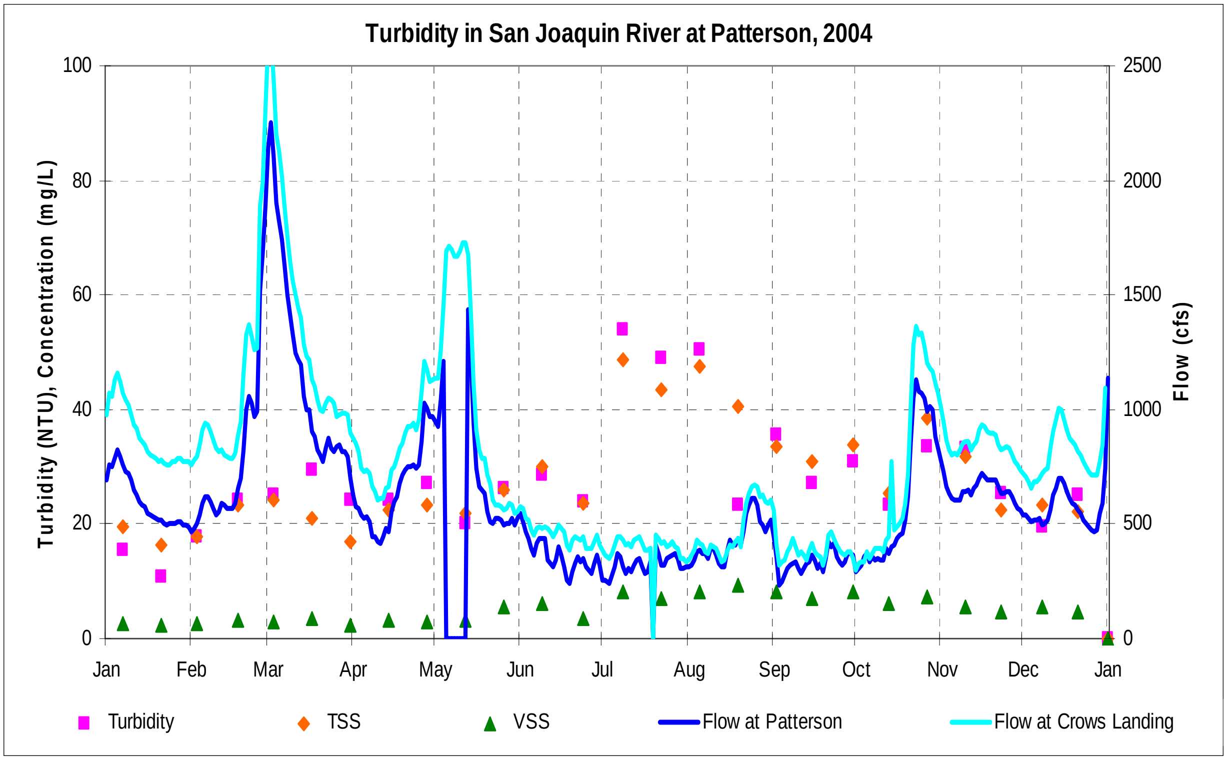


Figure 31. Turbidity and particulates (TSS and VSS) in the SJR at Mossdale and Vernalis for 2004.



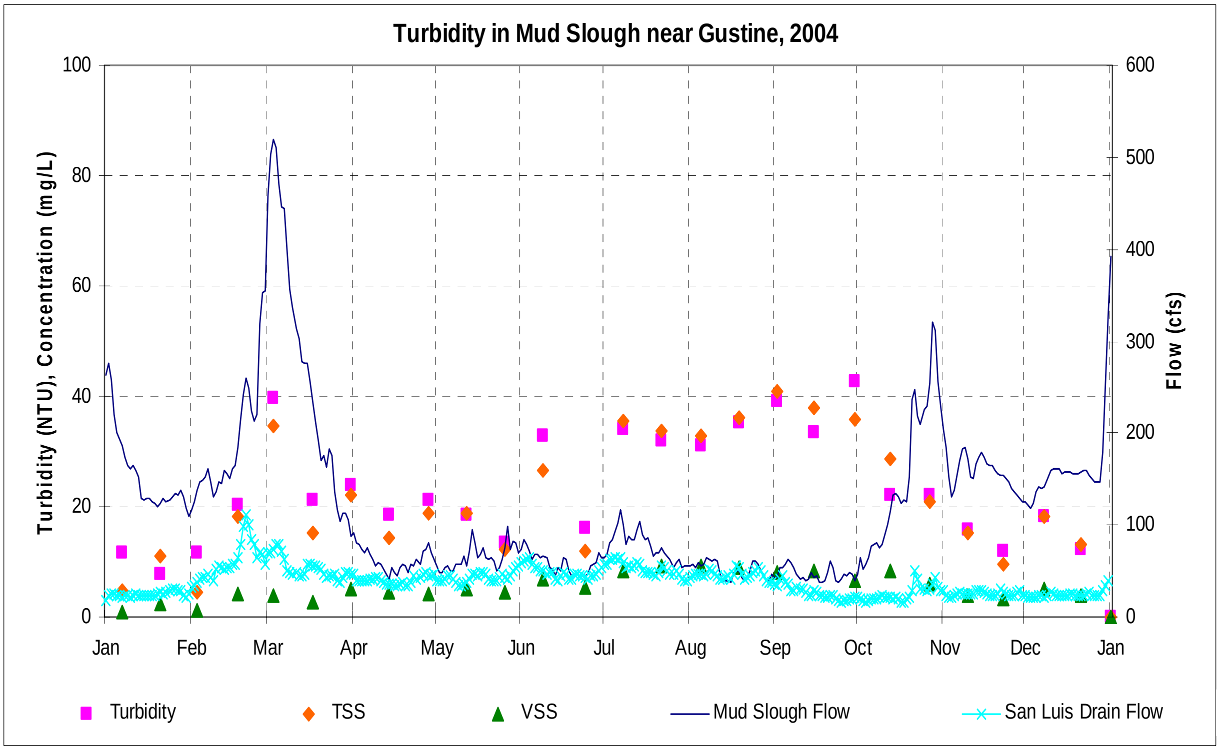


Figure 32. Turbidity and particulates (TSS and VSS) at Patterson and in Mud Slough for 2004.

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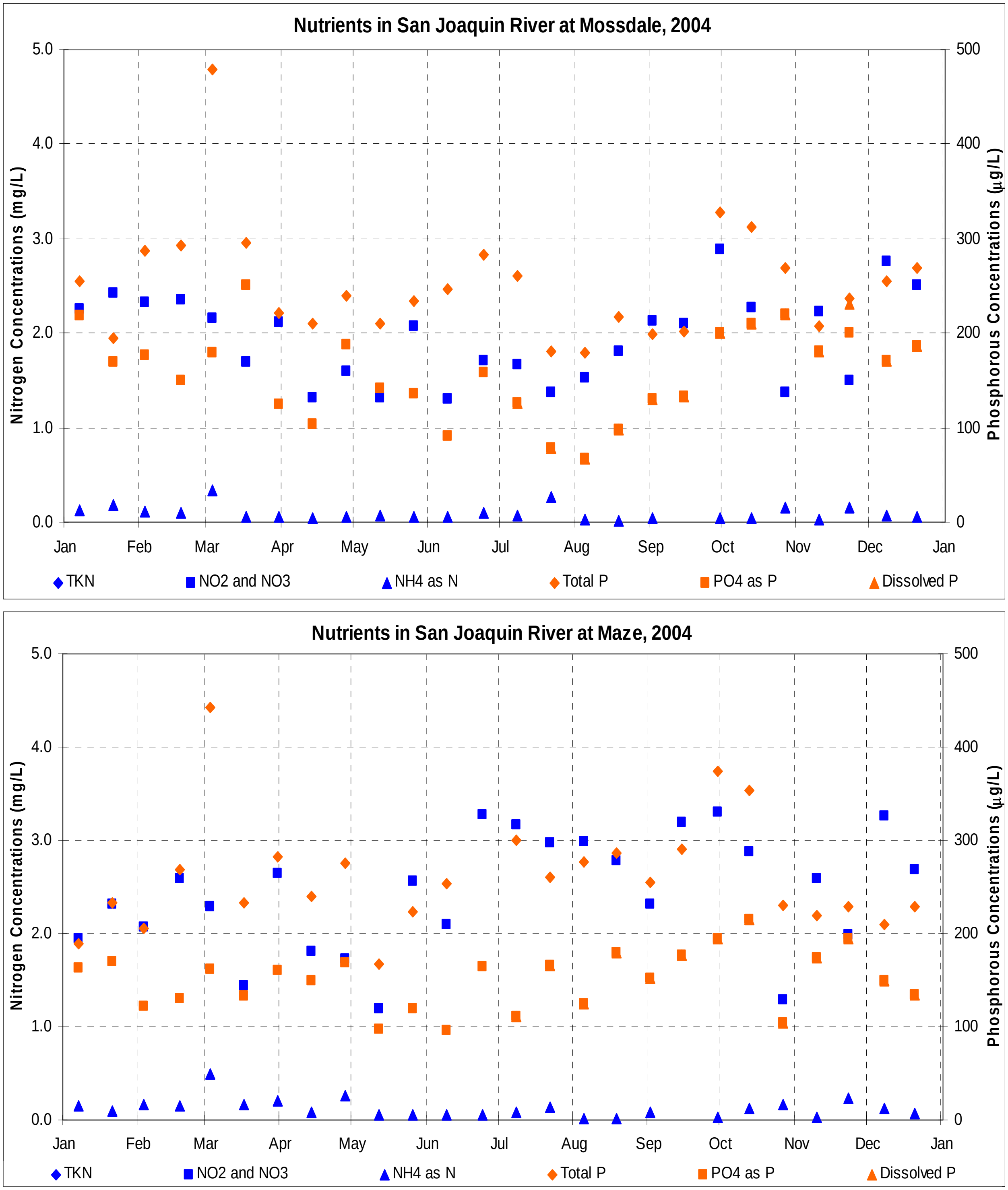
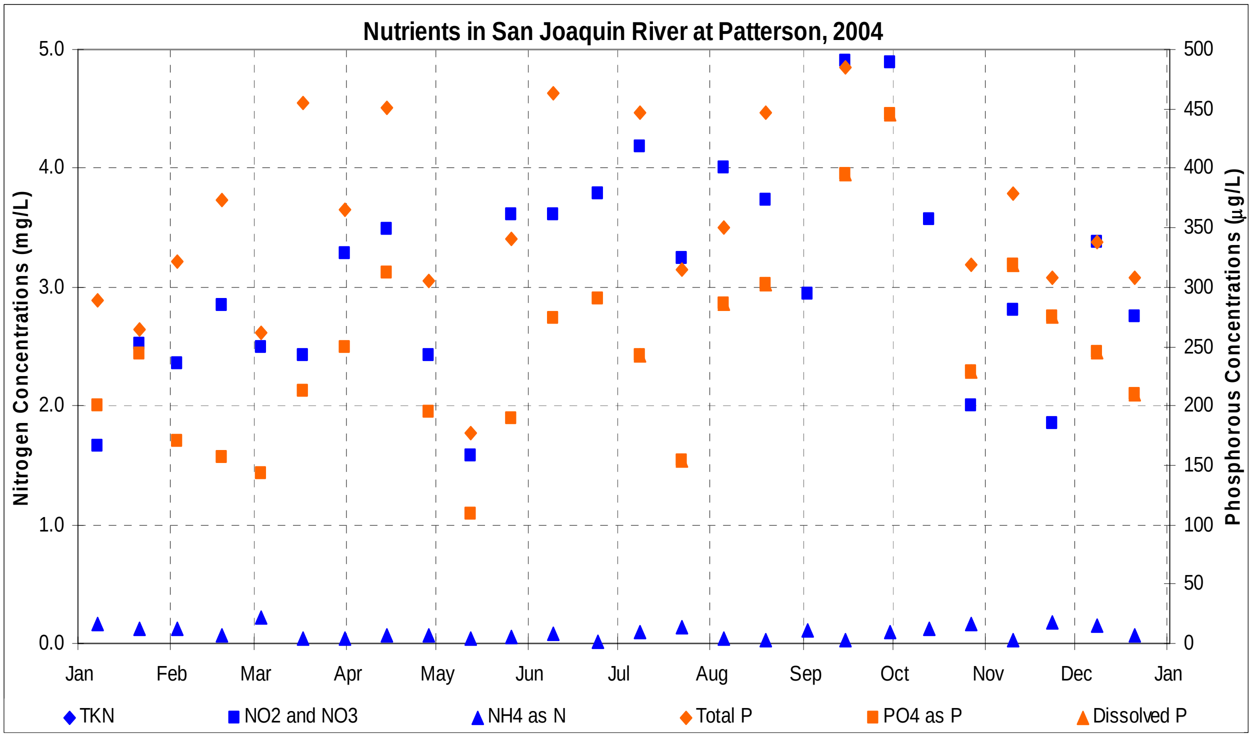


Figure 33. Nutrients (nitrogen and phosphorus) in the SJR at Mossdale and Maze for 2004.



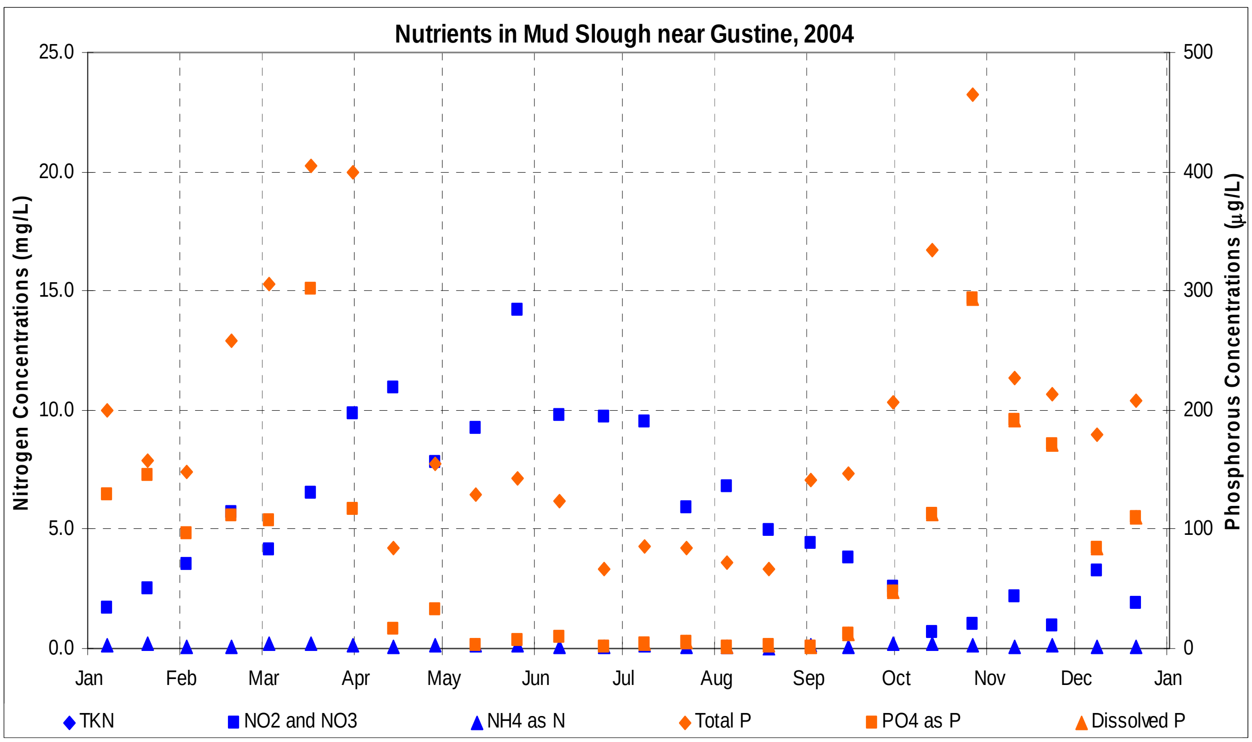


Figure 34. Nutrients (nitrogen and phosphorus) in the SJR at Patterson and in Mud Slough for 2004. The nitrate in the San Luis Drain is very high, while the phosphorus in the San Luis Drain is very low (i.e., tile drainage source).

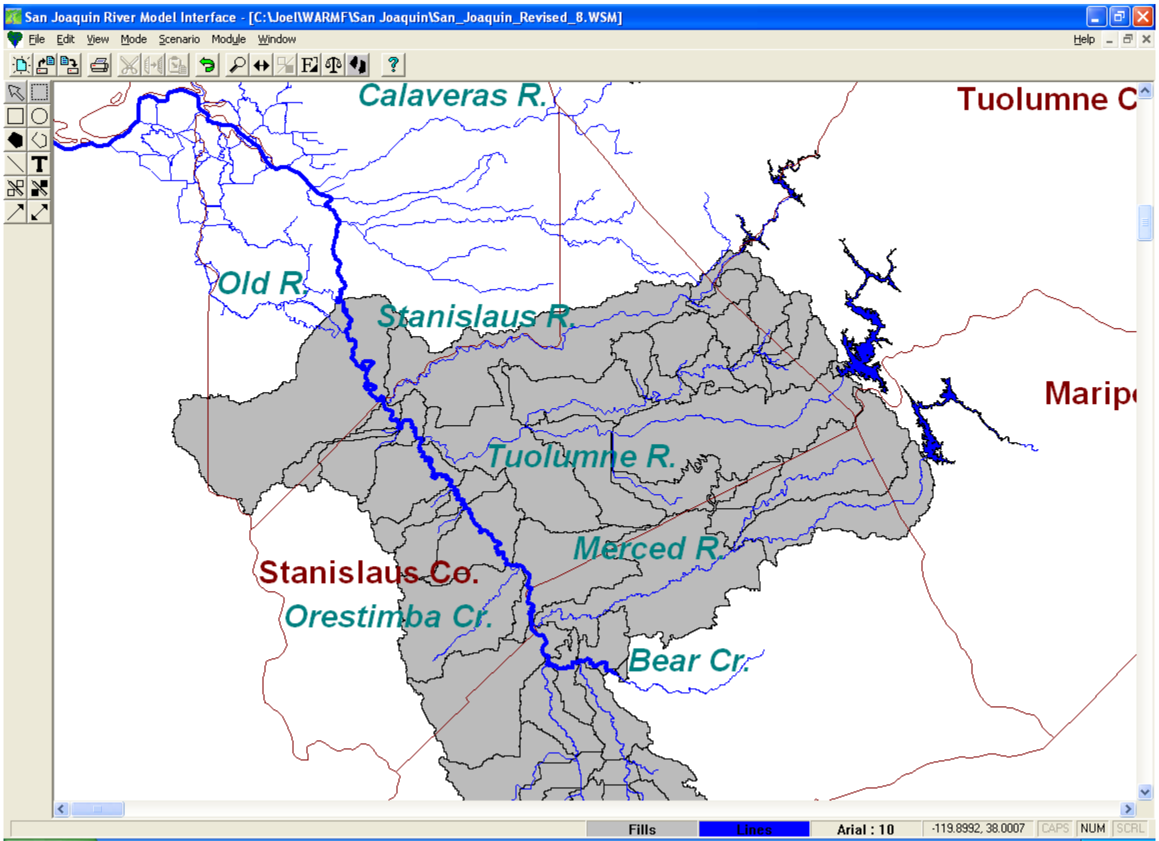


Figure 35: San Joaquin River Map with associated catchment (watershed) areas

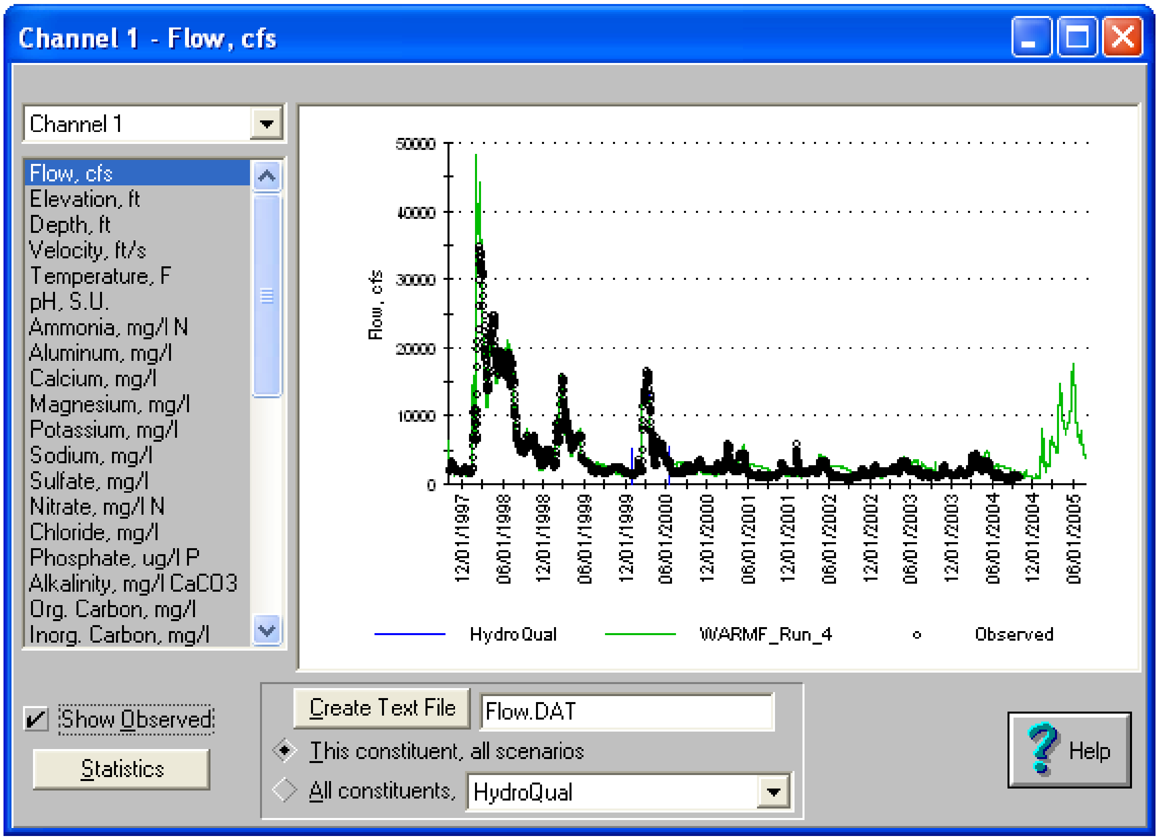


Figure 36: Flow, San Joaquin River at Vernalis

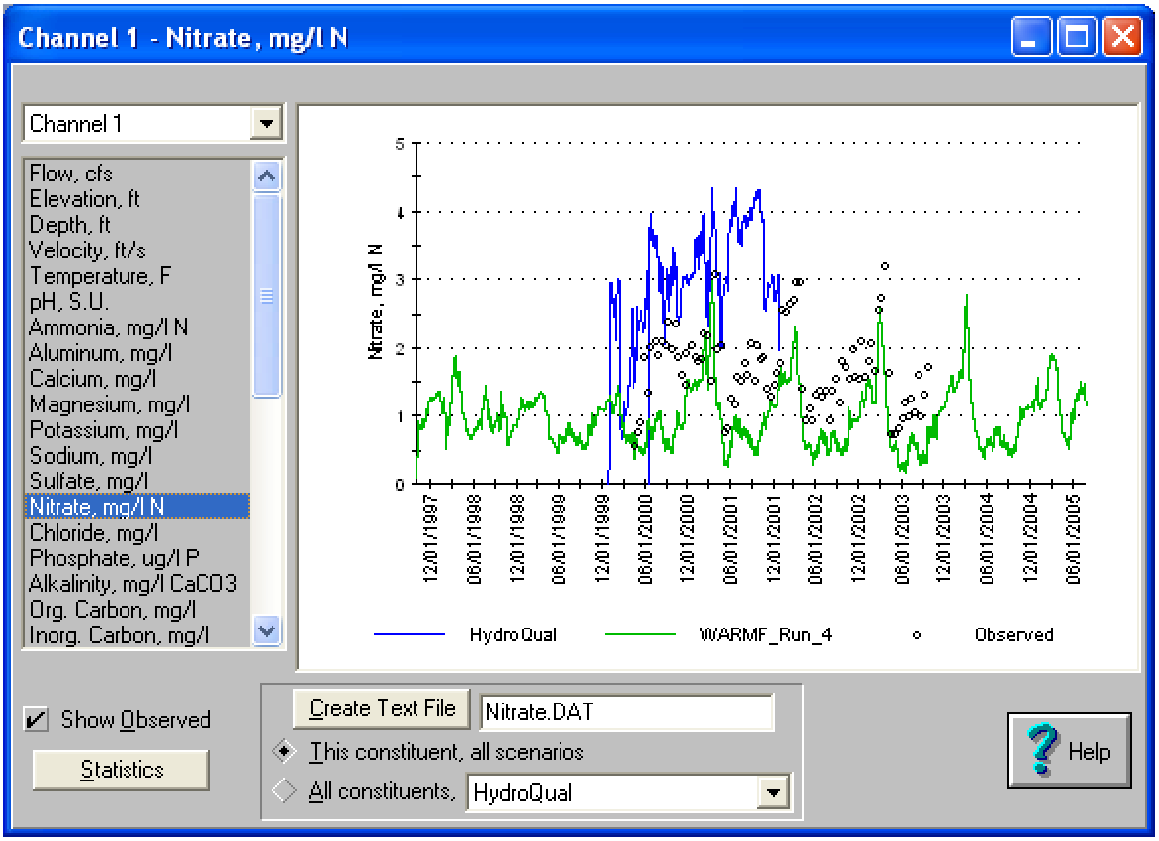


Figure 37: Nitrate, San Joaquin River at Mossdale

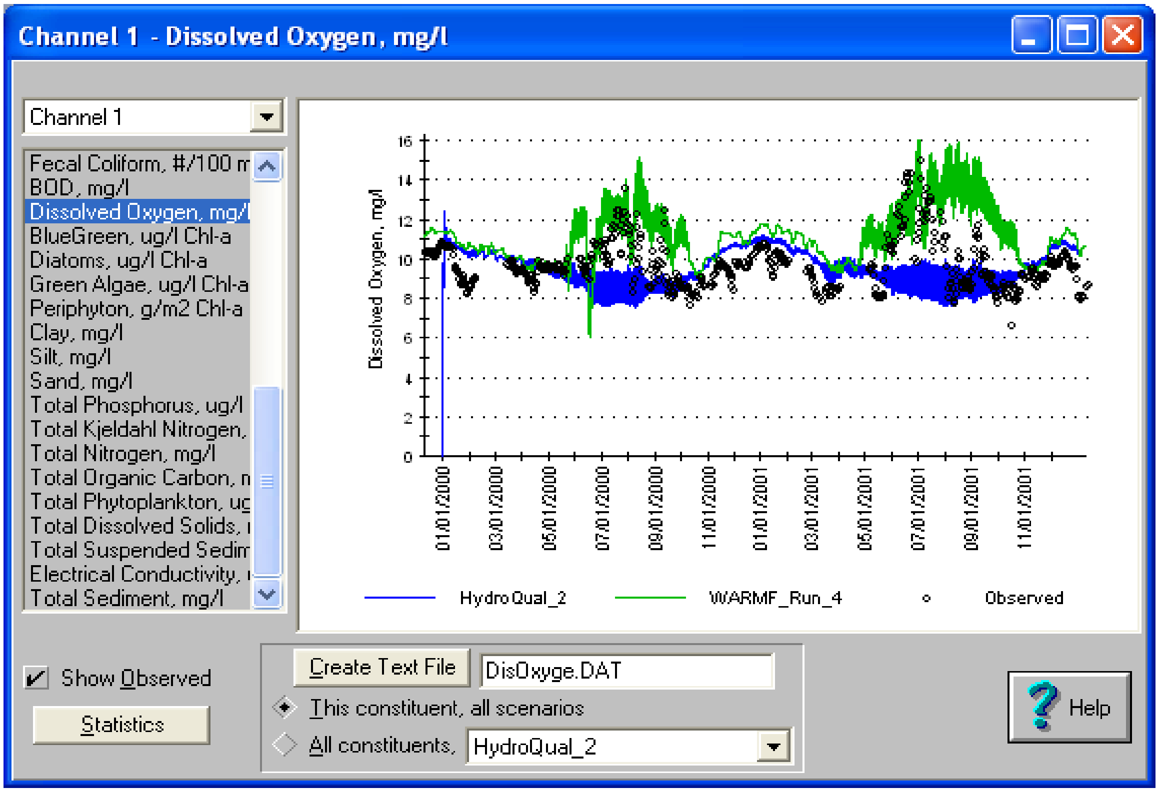


Figure 38: Dissolved Oxygen, San Joaquin River at Mossdale

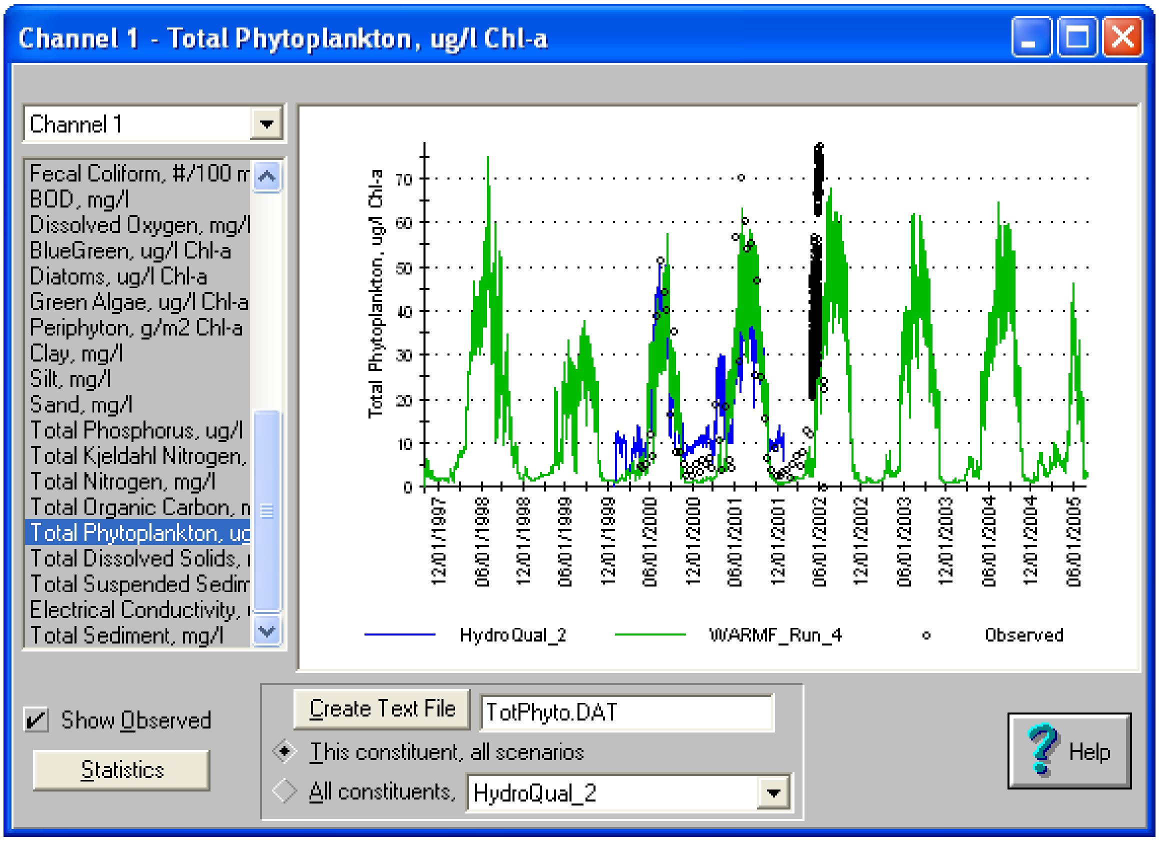


Figure 39: Total Phytoplankton, San Joaquin River at Mossdale

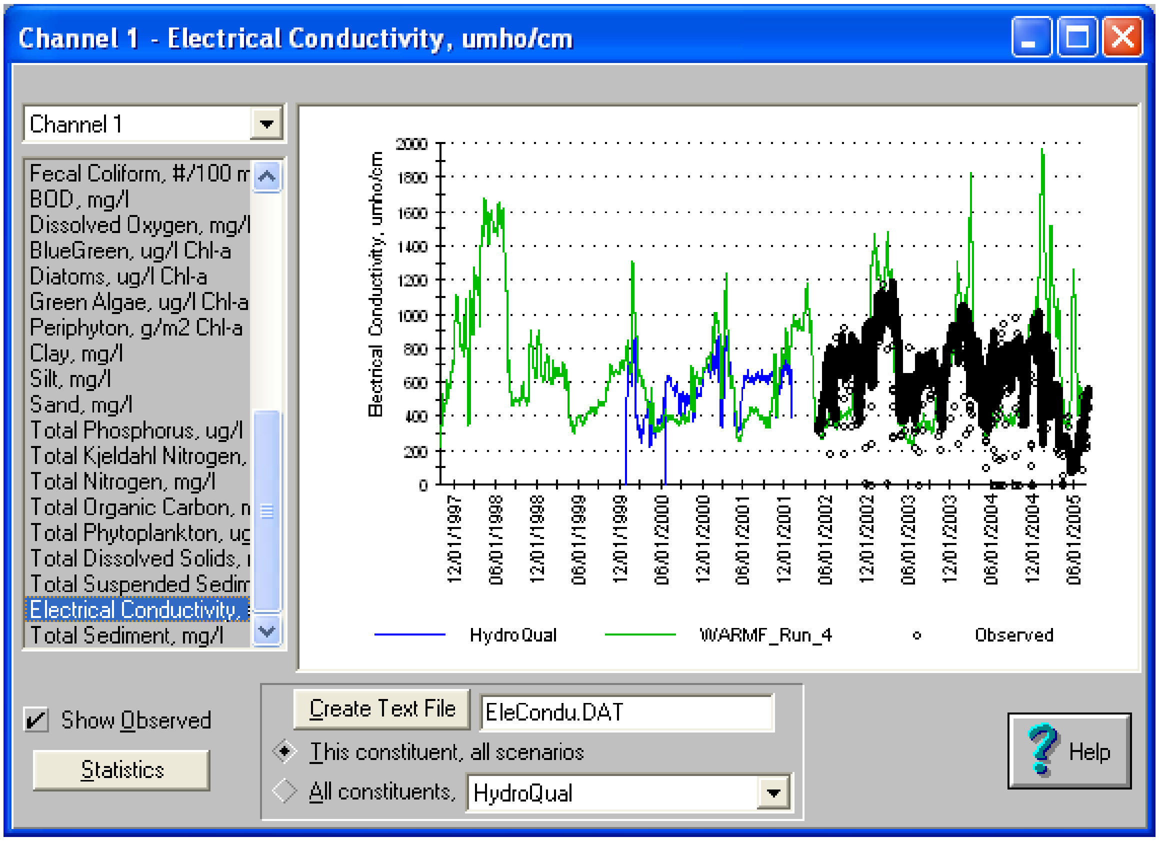


Figure 40: Electrical Conductivity, San Joaquin River at Mossdale