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Earth Sciences Division

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[1]REAL-TIME WATER QUALITY MODELING AND MANAGEMENT IN THE SAN JOAQUIN RIVER

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ABSTRACT

The San Joaquin River (SJR) is one of the most regulated flowing waterbodies in the nation. Current regulations include minimum seasonal flows for salmon migration and water quality objectives for salinity, selenium, boron, sediment, temperature, and most recently dissolved oxygen. Modeling tools have been developed in the past decade to quantify contaminant sources and to help improve coordination of high quality east-side Basin reservoir releases and degraded west-side Basin agricultural and wetland drainage flows. Other projects in the watershed have allowed enhancements to be made in modeling capability. The Grassland Bypass Project, initiated in 1996 has significantly reduced salt, selenium and boron loading from west-side agricultural sources through innovative drainage management, reuse and water conservation measures . The Vernalis Adaptive Management Program (VAMP) has shown that SJR flow and tributary releases can be manipulated and controlled for short periods of time in a highly deterministic manner. CALFED has supported a real-time water quality management project in Grasslands Basin wetlands that is investigating the flexibility of wetland management practices to control discharges of salt and oxygen-demanding biological constituents without negatively impacting wetland habitat values. In the Panoche-Silver Creek watershed rainfall gauges and real-time flow and water quality monitoring have been installed to provide early warning and initial estimates of flood flows during large storm events. An initiative, to resolve dissolved oxygen deficit problems in the Stockton Deep Water Ship Channel (DWSC), has created an opportunity to expand the current flow and salinity forecasting effort to consider factors affecting biochemical oxygen demand. This paper reviews progress made in the past decade towards development of a real-time management of water quality system for the SJR and considers the work ahead to develop a comprehensive decision support system.

BACKGROUND

The San Joaquin River Basin (SJRB) is bounded by the crest of the Sierra Nevada on the east, the Coast Range on the west and the Kings River on the south. The drainage area is about 32,000 square miles, the size of Maine. It provides about 16 percent of the State's water supply and has ten major tributaries: Cosumnes, Mokulumne, Calaveras, Stanislaus, Tuolomne, Merced, Chowchilla, Fresno, San

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Joaquin, and Kings Rivers. The average annual runoff from the mainstem is 1.7 million acre-feet. The SJR Basin reservoirs store snowmelt later used for hydropower generation and water supply. Of the 57 major reservoirs in the basin, four can store up to 1,000,000 acre-feet or more each, another 12 can each store up to 100,000 acre-feet. Reservoir releases provide storage for flood flows, satisfy agricultural irrigation water demands, support a river rafting industry and provide pulse flows to aid migrating Chinook salmon. Adult Chinook salmon return to the tributaries to spawn, beginning in October, and the resulting salmon smolts leave the tributaries and pass through the Delta,to the Pacific Ocean , during the spring.

More than 95 percent of the water in the SJR is captured each year by Friant Dam and diverted south down the Friant-Kern Canal and north in the Madera Canal to farms and cities on the east-side of the San Joaquin Valley. Saltier water from the Delta is brought back into the Valley in the Delta-Mendota Canal and California Aqueduct to farmlands and managed wetlands on the west-side of the SJRB. This water has an average salinity of 350 ppm. A portion of this applied water returns to the river as surface or subsurface drainage increasing the river's salt load. The largest component of the salt load in the lower SJR is derived from west-side agricultural sources (50%) and wetland sources (10%). These west-side sources, particularly subsurface agricultural drainage and wetland drainage often cause SJR water quality objectives to be exceeded. Agricultural drainage discharges are highest during the irrigation season (March – October) with peak flows generated during the pre-irrigation season (March – May). Impounded water in seasonal wetlands are released according schedules that optimize conditions for waterfowl habitat.

It has been customary in the past for decisions affecting reservoir releases, agricultural drainage discharges and wetland releases to be made independently without regard to impacts to other water users and to water quality conditions in the SJR. Exceptions to this rule are commonly court-imposed remedies to tort litigation. For example the US Bureau of Reclamation has a legal obligation to meet Vernalis water quality objectives through releases from New Melones Reservoir on the Stanislaus River resulting from a court settlement reached between the agency and the South Delta Water Agency.

Water quality objectives (Table 1) for the SJR have been developed by the State Water Resources Control Board (SWRCB) for selenium and boron at Crows Landing (immediately downstream from the confluence with the Merced River), for salinity at Vernalis (below the confluence with the Stanislaus River) and for dissolved oxygen in the Deep Water Ship Channel (DWSC) which is used by the Port of Stockton to allow access to ocean-going cargo vessels. The assimilative capacity for each of these contaminants is defined as the contaminant load (in pounds or tons per year) that the river can still accept before exceeding the contaminant objective for compliance. Positive assimilative capacity means more of the contaminant can be discharged into the river without exceeding objectives. Negative assimilative capacity quantifies the load of the contaminant that must be removed to meet objectives. The impetus for real-time water quality management in the SJR Basin is to decrease the frequency with which water quality standards are exceeded along the main stem of the River.

Table 1 : San Joaquin River Water Quality Objectives

Water Quality Constituent	Compliance Monitoring Station	Seasonal Water Quality Objective Irrigation Season (April to September)	Seasonal Water Quality Objective Non-Irrig Season (October to March)
Salinity (EC)	Vernalis	700 mS/cm	1,000 mS/cm
Boron	Crows Landing	1 mg/l	1 mg/l
Selenium	Crows Landing	5 ug/l	5 ug/l
Dissolved oxygen	Channel Point – Deep Water Ship Channel	5 mg/l	5 mg/l

Real-Time Water Quality Management

Real-time water quality management on the SJR for a particular constituent can be defined as a collaborative process by which the assimilative capacity of the SJR for that constituent is shared among stakeholder dischargers in a manner that avoids violation of SWRCB water quality objectives. It comprises four major activities: data collection, data processing/modeling, analysis, and information dissemination. Raw data must be quickly assembled and checked for accuracy prior to data analysis. To be effective as a management tool, these activities must be executed in near real time. The data processing/modeling and analysis steps should consider the end users and facilitate dissemination of information results to stakeholders to assist coordination of water management activities in the Basin.

Typically, river stakeholders manage water according to a set of rules that dictate when water is stored, used, or discharged. These stakeholders normally operate independently, making decisions on water use that are based on the quantity and or quality of water supplies available to them and their own individual needs. For example, reservoir operators manage reservoirs based on criteria and rule curves that address flood control, water delivery scheduling, power generation, and recreation demands. Each criterion is further controlled by a combination of long term or seasonal specifications such as seasonal maximum storage allowances, as well as short-term specifications such as rainfall or reservoir inflow.

Real time water quality management in the SJR Basin relies on coordinated and cooperative actions that encourage manipulation of the scheduling of east-side reservoir releases and west-side agricultural and wetland return flows to meet improve compliance with numeric water quality objectives. Successful implementation assumes that stakeholders can be informed of one another's actions and that they have the flexibility and resolve to adjust their operational schedule to minimize conflicts. With better information on upstream conditions, downstream users can adjust their timing of use to avoid diverting irrigation water with high salt or high boron concentrations. Reservoir releases can be timed to improve flows for fish migration and agricultural uses. Releases of saline water may be matched to the assimilative capacity of the SJR to help reduce the frequency of exceedence of salinity water quality objectives at Vernalis. Finally, releases of saline water from wetlands and drainage systems can been scheduled to coincide with the need for outflows sought by fisheries managers.

Chronology of SJR Real-Time Water Quality Management Initiatives

The concept of Real-Time Water Quality Management in the San Joaquin Basin was first proposed by Alex Hildebrand in 1988 as a means of disposing of excess salts. Hildebrand's concept was a series of groundwater wells adjacent to the SJR that would evacuate a portion of the groundwater salt reservoir during wet years, when there was excess assimilative capacity. The use of SJR assimilative capacity was further advanced by the development of the San Joaquin River Input-Output (SJRIO) model (Kratzer, 1987). This model was used by the San Joaquin Valley Drainage Program to compare management actions to reduce west-side salt and selenium mass loads to comply with SWRCB river water quality objectives. The formation of the Water Quality Subcommittee of the San Joaquin River Management Program (SJRMP-WQS) in 1989 led to the first funded research projects, specifically geared to establishing a network of real-time SJR water quality monitoring stations and developing procedures to forecast short term changes in SJR assimilative capacity. In the past 5 years the implementation of a number of resource management initiatives have greatly enhanced the prospects for realization of this concept.

VERNALIS ADAPTIVE MANAGEMENT PROGRAM

The Vernalis Adapative Management Project (VAMP) is a 14 year-long experiment to improve scientific understanding of the relationship between flow and fish resources in the SJR. Fishery biologists developed a program of study to gather data on the impact of flows, Delta project export rates and delta diversions on the populations of salmon smolts in the lower SJR. The VAMP was developed as an alternative that provides an equivalent level of protection to the SJR flow objectives contained in the SWRCB's 1995 Bay-Delta Water Quality Control Plan. The VAMP agreement also identifies and quantifies the sources and volumes of water required to implement the VAMP study that are managed by the San Joaquin River Group Authority, whose members are willing sellers of water supply. The primary uses of the VAMP water supply are to (a) provide a pulse flow for a 31-day period at Vernalis between April 15 and May 15 each year; and (b) to manage Delta export pumping and other diversion flows identified by the

CVPIA water acquisition plan, during this period, to facilitate migration and attraction of anadromous fish. The VAMP is described as an adaptive management study that anticipates that the flow requirement changes annually in response to hydrologic and biologic conditions. The VAMP Agreement provides for up to 137,500 acre-feet of water annually.

The implications for real-time management of water quality are significant and positive during the April 15 to May 15 VAMP period, when east side reservoir releases become highly deterministic improving forecasting skill of SJR flows. It follows that by increasing the accuracy of the flow forecast the accuracy of salt assimilative capacity forecasts in the SJR also improves significantly.

GRASSLANDS BYPASS PROJECT

The Grasslands Bypass Project (GBP) was conceived in the late 1980's as a means of removing selenium contaminated agricultural drainage water from wetland channels within the Grassland Water District. The source of this drainage water are farms in the 97,000 acre Grassland Drainage Area (GDA). The GBP uses a portion of the federal San Luis Drain to convey this drainage water directly to Mud Slough (north), a tributary of the SJR. This has significantly reduced the selenium contamination in more than 93 miles of wetland supply channels. Use of the Drain by GDA farmers is contingent on compliance with strict monthly and annual selenium load targets and the formation of a regional drainage management authority. The monthly and annual load targets were established through a lengthy negotiated process between the water districts, state and federal resource agencies, the US Environmental Protection Agency, Environmental Defense, and activist organizations.

Selenium load objectives are based on average pre-project monthly selenium loads from the GDA. Annual load objectives were initially set at the 9-year mean of 6600 lbs per year - these targets and monthly load targets were to be reduced by 5% per year in the last 3 years of the 5 year project. The project has been re-authorized for another 8 years until the end of 2009. In 2005, the selenium load targets are reduced incrementally to the Total Maximum Monthly Load (TMML) limits, recently set by the California Regional Water Quality Control Board – Central Valley Region (CRWQCB). The 2005 TMML selenium load objectives will vary according to water year type (critical, dry/below normal, above normal, wet) which will offer some relief during wet years when assimilative capacity in the SJR is high (Figure 1). However the allowable selenium loads in a typical TMML approach are less than 70% of those allowable under an equivalent real-time water quality management system which takes advantage of about 80% of the SJR assimilative capacity for selenium. The project has been successful in meeting selenium load limits in normal water years as is shown in Figure 1. Selenium loads to the SJR have dropped steadily since September 1996.

In order to meet selenium load targets innovations have been made at the farm and water district level. Continuous flowmeters have been installed at main discharge points from the GDA. Telemetry systems were installed to allow real-time monitoring of individual water district's contribution to overall drainage flow and to project selenium mass load.. With this knowledge water districts have developed customized selenium load targets for each tile sump based on correlations between tile drain flow and selenium load. This has been accomplished at a fraction of the cost of daily selenium monitoring and has proved an efficient system for encouraging compliance from local farmers enabling the GDA to meet monthly selenium load targets.

The GDA water districts also enacted a moratorium on tailwater discharges into District owned canals. The Districts assisted farmers to design and construct tailwater return systems that allowed the blending of tailwater and surface water canal deliveries. Panoche Water District invested in a district-scale recirculation system that collects and conveys accumulated tailwater to the inlet diversion points along the California Aqueduct. The District closely monitors the salinity of the blended water to ensure that during periods of reuse that no farmers receives

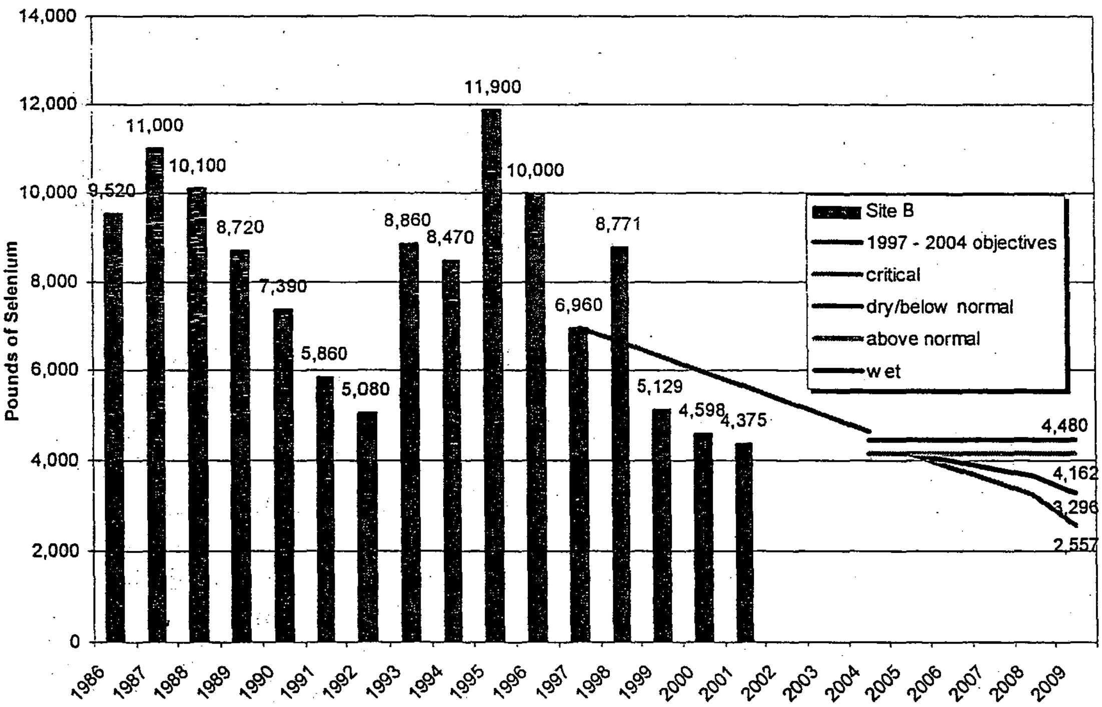

Figure 1. Selenium mass loading and the impact of the Grassland Bypass Project

canal deliveries with salt concentrations exceeding 600 ppm between the dates of June 30 – September 30. Drainage sump stage control sensors were raised so that they were activated only when water tables were within 5 feet of the ground surface. Color coded floating risers were installed in monitoring wells – to provide a visual indicator of water table depth. From the roadside. To control gravity drains that discharge directly to open ditches the main drainage lines were severed and weir control structures installed to help to store more drainage water beneath each field prior to discharge to the District's collector system.

Drainage management policies have been amended to allow the GDA water districts to cycle their sump pumps to help meet monthly selenium load objectives. Knowledge of the sumps that produce the highest selenium concentrations and loads allows the water districts some latitude in meeting load targets. This policy helped to produce greater than 40% reductions in selenium load during the first five years of the project (Figure 1).

The impacts of real-time drainage management are best illustrated using a simple dilution volume analysis which uses releases from New Melones Reservoir as a surrogate for river salt assimilative capacity for years before and during the GBP. Figure 2 illustrates how the various drainage selenium load management practices have altered the shape of the annual salt load hydrograph from the basin. Not only are the reductions in salt load also significant from the GBP water districts since 1996 but the policy appears also to have changed the shape of the salt load discharge hydrograph, damping the peak salt loads during pre-irrigation season – shifting some of this salt load export into the following months.

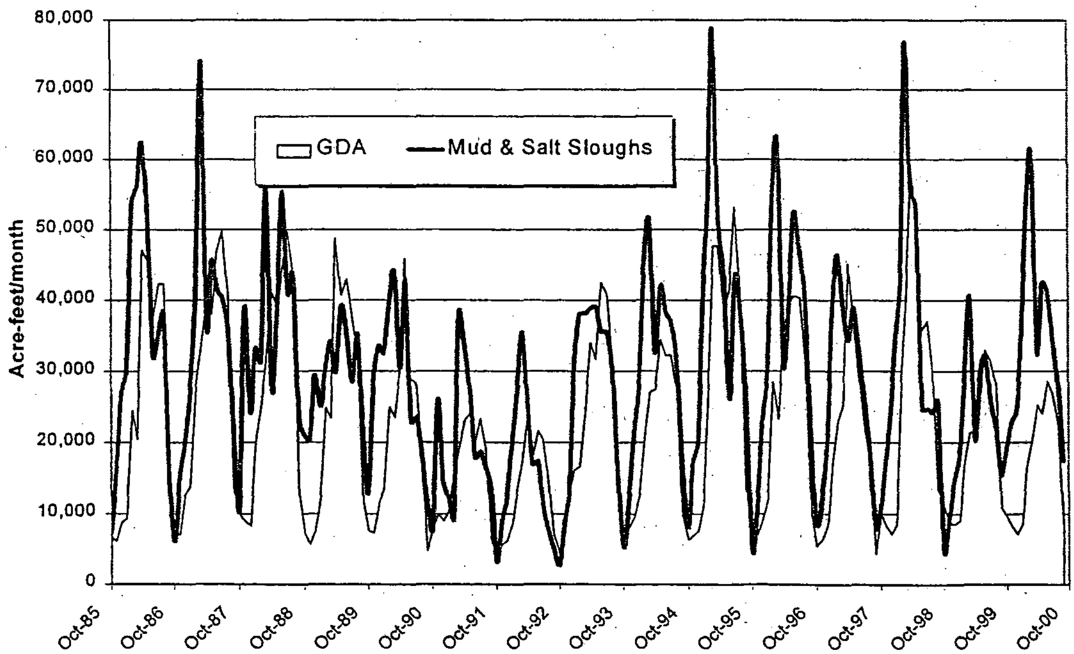

Figure 2. Monthly volume of water required to dilute drainage return flows from the Grassland Drainage basin to meet Vernalis standards (1988-2001)

The important lesson from the GBP is that given clear, unambiguous effluent load targets, water districts can manipulate the timing of their drainage exports. What is less certain is how to make the transition from a TMML drainage management approach to a more dynamic real-time system, which is better tuned to real-time and forecast river assimilative capacity.

WETLAND REAL-TIME WATER QUALITY MANAGEMENT

Private wetlands and state and federal refuges have not been exempted from the CRWQCB salinity control plan for the San Joaquin Basin. The Grassland Water District (GWD) has initiated a project aimed at quantifying salinity mass loading from the private duck clubs and cattle ranches that comprise the 51,500 acre northern half of the District. Management of salts from wetlands is more complicated than from agricultural land because of the larger number of system constraints, including diversity goals, poorly understood relationships between soil salinity and moist soil plant propagation, and the lack of a decision support system to assist with the selection of best management practices. A GIS-based salinity accounting model has been developed to simulate the dynamics of salinity concentrations in seasonal and permanent wetlands within the Northern GWD and to provide a decision support tool for real-time wetland salinity management.

Five new flow and salinity outflow monitoring sites and one inflow monitoring site have been installed in the Northern GWD. A parallel experimental monitoring system has been installed at the Salinas Duck Club, one of the most intensively managed and progressive duck clubs in the watershed. The Salinas Club experiment is providing information on salt mass loading during drawdown from shallow, deep, early season and late season wetland managements units that have been separately monitored. The long-term impacts of these management regimes on habitat quality is being assessed for each of these management regimes. These small-scale and large-scale monitoring systems will likely form the backbone of any future wetland real-time water quality management system.

PANOCHE-SILVER CREEK WATERSHED FORECAST SYSTEM

The 380 square mile Panoche-Silver Creek watershed is the largest west-side tributary to the SJR and the primary source of selenium to the SRJB. Measures to limit these contaminant loads including early-warning systems of significant runoff events can help to reduce the impact on SJR water quality. Recently installed monitoring stations and agency simulation models of precipitation, snowmelt and runoff for the east-side watersheds allow for advance forecasts of east-side tributary streamflow. The same capability is not yet available for the west-side. West -side ephemeral streams can deliver flows up to 10 % of the total flow into the SJR, carrying significant sediment, salt, and selenium loads. Implementing predictive modeling and measurement applications on the west-side will expand the San Joaquin water quality monitoring network.

A CALFED-sponsored project, administered by the watershed-based, Coordinated Resource Management Program, is adding to the existing real-time water quality management network by providing rainfall, flow and water quality monitoring stations within the watershed on three of the major tributaries to Panoche/Silver Creek. A GIS-based rainfall-runoff and streamflow model will be developed using data collected during significant storm events. The goal is to be able to forecast times of potential high runoff concentrations, maintain an expanded operational flow and water quality monitoring network, and provide advisories via the SJRMP-WQS web site and listserver.

SJR REAL-TIME WATER QUALITY MANAGEMENT

Real time forecasts of SJR assimilative capacity for salt are currently made using an existing monthly model, the San Joaquin River Input-Output (SJRIO) model (Kratzer et al., 1987), which has been adapted to calculate flows and water quality in the SJR on a daily basis (SJRIODAY model). The original SJRIO model provides a base case condition, monthly data files from which are overwritten with real-time data collected from a network of real-time flow and water quality monitoring stations in the San Joaquin Basin. Figure 3 shows the locations of these gauging stations.

The monthly SJRIO model performs a mass balance accounting of discharge, TDS, boron, and selenium for a 60-mile reach of the lower SJR, between Lander Avenue in the south to Vernalis. Lander Avenue was chosen as the upstream boundary of the model because the SJR is often dry upstream of the confluence with Bear Creek in all but wet years. The SJR near Vernalis was chosen as the downstream boundary because it is a water quality compliance monitoring station, it is upstream of Delta tidal effects and has a long-term historical data record. Water is supplied to agricultural water districts from three sources: diversions from the SJR, groundwater pumping, and pumpage from the Federal project located in the Delta. For its base case the model uses the average of each of four water year types - critically dry, dry, normal, and wet. SJR inflows, diversions and water quality are calculated for every tenth of a mile along the 60-mile reach of the River. Estimates for diversions from seventy-five diversion pumps on the SJR and the east side tributaries were based on water rights records available at the SRWRCB. Model inputs for which there are no available real time data were estimated using similar-year mean monthly hydrology. Annual drainage flows from west-side tile drains, which contribute over 50% of the annual SJR salt load, were estimated by multiplying tile drainage factors ranging from 0.65 to 0.85 acre-feet per acre per year by the tile drained acreage (Kratzer et al. 1987). Gauged surface agricultural return flow data were available for water districts on the east-side of the SJR. Average monthly TDS, boron, and selenium concentrations were determined based on a survey of available data for sumps and drains carried out by the CRWQCB.

DECISION SUPPORT SYSTEM

The decision to build a functional decision support system (DSS) to aid real-time water quality management in the SJR was made in 1995 by the SJRMP-WQS. System requirements were to retrieve pertinent data from field-based sensors, allow quality assurance checks to be performed on the downloaded data, fill data gaps, display data graphically, then transform the data into information useful to operational decisions. A useful feature of the DSS developed by Systech Engineering Inc. was the the Windows™ - based, graphical user interface (GUI) which was simple to use and served the needs of modelers and stakeholder's alike (Quinn et al., 1997). The purpose of the GUI was to assist stakeholders who make operational decisions on drainage discharges, recycling and temporary storage with respect to SJR assimilative capacity. The system facilitates the inspection of real time and forecast data, and features routines to expedite the collection of model input data and disseminate water quality forecasts (Figure 3).

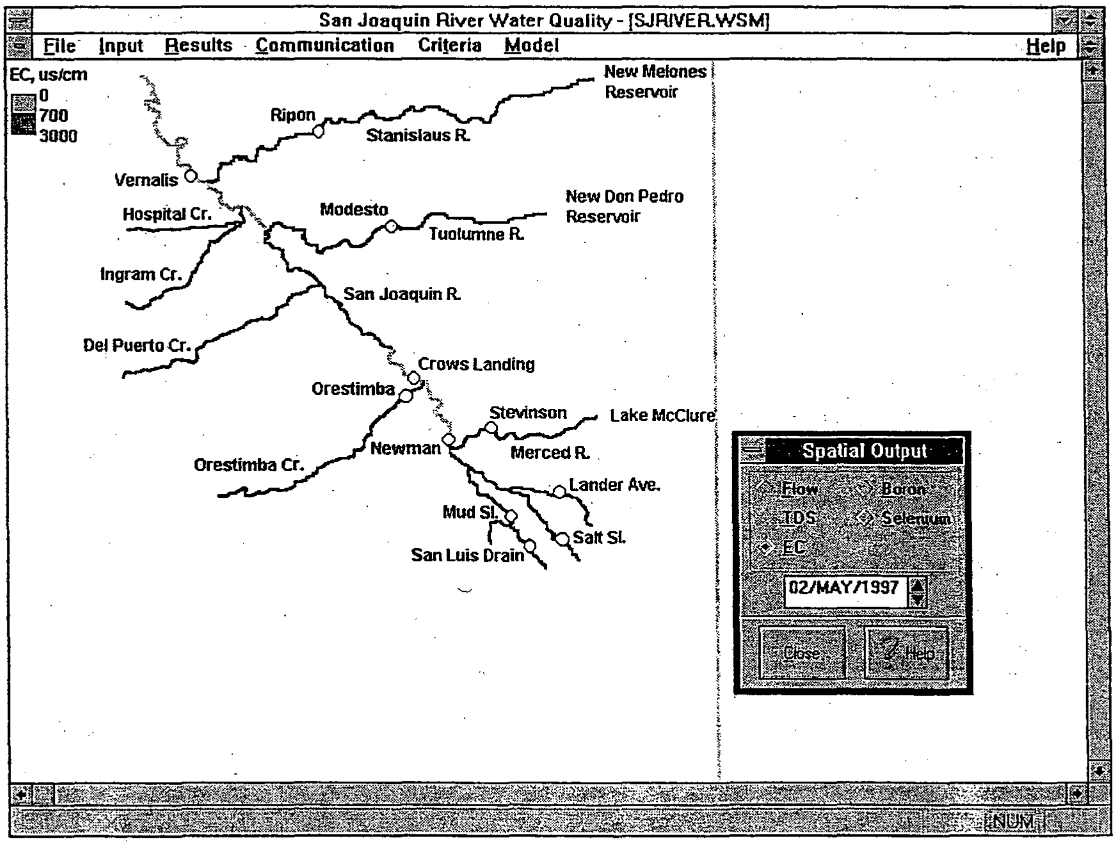

Figure 3. GUI visualization of monitoring sites on the San Joaquin River and the major tributaries and current SJR water quality conditions

Reservoir operators can enter daily schedules of diversions and discharges and upload these schedules every two weeks to the person making the flow and water quality forecasts. Likewise, this person can also use the GUI to download operational schedules from agencies where timely data is routinely posted to a public ftp site. The criteria menu may be selected to specify the color code used to display the spatial variations of water quality. Results from model runs can be viewed as a time series or by spatial location. When time series is chosen, a dialog box appears for the selection of flow and water quality parameters (TDS, boron, or selenium). The color representation of water quality is usually set according to the water quality objective.

In theory the GUI allows water managers to coordinate their operational decisions on a weekly basis by providing a spreadsheet-type entry of operational schedules consisting of the past week's operation and two weeks projected operation. Water district managers who decide to change their drainage or diversion operational schedules as a result of the model run output would be able to contact SJRMP-WQS members by telephone or email. The model run input data would be revised and SJRMP-WQS staff would rerun the model again, posting the revised run results on an FTP or project web site.

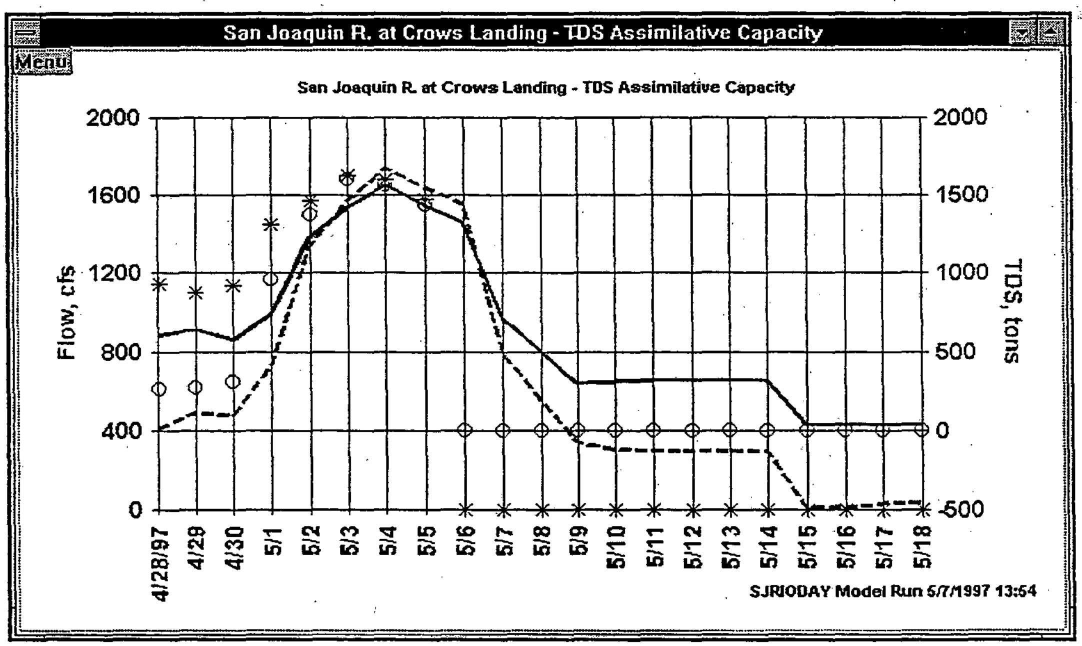

Figure 4. Assimilative capacity at Vernalis for the SJRIODAY run beginning 5/5/97

In early 1999 the SJRMP-WQS abandoned the GUI approach in favor of the world wide web. The GUI approach required that co-operators install the GUI on their home machines and update their input data files from a dedicated computer housed at DWR, Fresno. Forecasts using "push" technology, whereby an e-mail was distributed to stakeholders containing a url link to the forecast web site, was considered more effective than "pull" technology whereby the co-operator has to initiate the request for information. The web site also allows the distribution of associated data and supplemental information that would be difficult to communicate with the GUI-based approach.

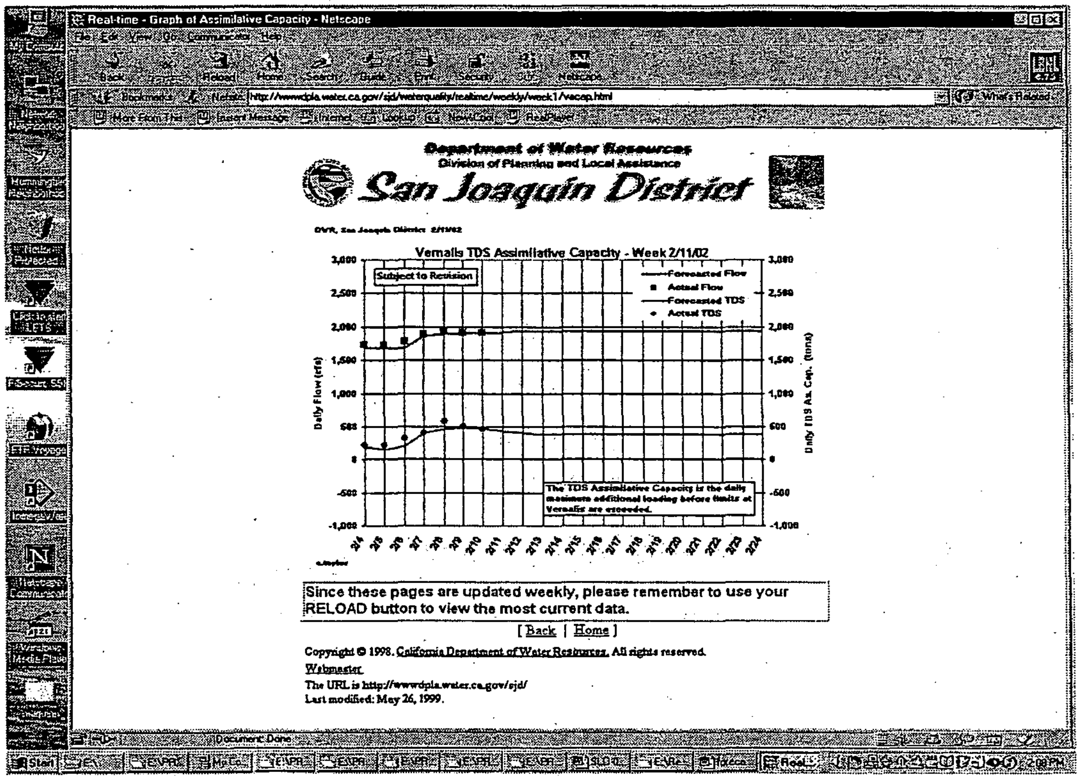

Figure 5. Weekly forecast of San Joaquin River assimilative capacity.

Forecasts continue to be made on a weekly basis by the SJRMP-WQS project team which comprise individuals from the DWR, CRWCB, Berkeley National Laboratory, UC Berkeley and the US Bureau of Reclamation. Active users of the system are the planners for the SJR VAMP and the San Joaquin River Dissolved Oxygen TMDL project.

DISSOLVED OXYGEN MANAGEMENT TMDL

Dissolved oxygen levels in the Deep Water Ship Channel operated by the Port of Stockton regularly fall below EPA water quality standards during the late summer and fall each year. The problem is created by a transition in hydraulic residence time as river water passes from the shallow well-oxygenated SJR to the deep, wide ship channel, a transition which promotes settling of suspended material including algae and encourages occasional channel stratification. When dissolved oxygen falls below 5 ppm the DWSC may create an effective barrier to fall run salmon migration – jeopardizing the viability of the fishery as well as CALFED investments in upper watershed fish habitat restoration. The problem is especially acute during dry and critically dry years when hydraulic residence times within the Ship Channel increase with diminished inflow from the lower SJR. Intensive monitoring of a number of water quality indicators has taken place since 1999 to attempt to develop a dissolved oxygen TMDL for the DWSC and improve compliance with EPA standards.

Management solutions to address this problem involve (1) recognition of the relative contribution to the problem by agricultural, wetland and municipal sources; (2) coordinated continuous monitoring of the factors contributing to low dissolved oxygen in the DWSC; and (3) development of a decision support and management tool that allows forecasting of future dissolved oxygen conditions in the SDWSC that will assist real-time management of techniques to address the problem when it develops. A goal of real-time forecasting of dissolved oxygen in the SJR will be to improve coordination of activities among those entities that directly benefit from and depend on the resources of the SJR system leading to an overall improvement in SJR water quality. There are many implementation options that could provide additional benefit if integrated into a real time management system. These include: operations of South Delta barriers, low head recirculation pumping at the Head of Old River, aeration in the DWSC, release timing of effluent discharge from wastewater treatment plants, release timing of flows from duck clubs, wetlands and wildlife refugees, release timing of flows from urban stormwater holding ponds, and release timing and flow levels from east side tributaries for fall pulse salmon attraction flows.

An improved hydrodynamic and water quality model of the lower SJR and Delta system is under development based on DWR's existing DSM-2 model. The model will be used as an aid to decision making - to compare aeration, source control and other management options and to simulate waste load allocation policies as part of a long-term management solution to the oxygen deficit problem. A calibrated DSM-2 model of the upper SJR was recently completed (DWR, 2001) which uses the same input database as SJRIODAY but which is capable of running with 15 minute data – allowing more realistic simulation of the hydraulics and water quality dynamics of the River system.

The model will play a role in the integration of the various real-time water quality management projects, described in this paper, within the SJRB.

CONCLUSIONS

The purpose of real-time forecasting of dissolved oxygen and salinity in the SJR is to improve coordination of activities among those entities that directly benefit from and depend on the resources of the SJRB leading to an overall improvement in River water quality. The major components of any real-time management system for the SJR require monitoring, modeling, information dissemination and resource management. Improvements in data automation, the cost effectiveness of data acquisition and dissemination, and coordination of modeling activities have been accomplished in the past 5 years with the formation of the inter-agency SJRMP Water Quality Subcommittee and the awards of grant funding to develop the present system. The most challenging next step will be to develop the institutional framework and water management policy to move the concept of real-time water quality management from theory to practice. This may eventually require the formation of an institution or appointment of a "water quality czar" to maintain and manage a network of flow and water quality monitoring stations and the development of a integrated decision support system to set target flows and contaminant loading schedules for all entities discharging to the SJR.

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