CONCEPT PAPER FOR REAL-TIME TEMPERATURE AND WATER QUALITY MANAGEMENT FOR SAN JOAQUIN RIVER RIPARIAN HABITAT RESTORATION

Prepared for :

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Mid Pacific Region

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1.0 Concept of real-time water quality management

The San Joaquin River is a major tributary of the Sacramento-San Joaquin Delta (Delta) that drains approximately 8.7-million acres in California's Central Valley. Land and water uses in the SJR watershed have resulted in significant impacts to water quality, fish and wildlife habitat, flood protection, and recreation. Salinity concentrations in the SJR frequently exceed established water quality objectives during the irrigation season (Apr.-Sep.) Consequently, the State Water Resources Control Board has designated the Lower SJR as an impaired river. Chinook salmon historically migrated up all of the San Joaquin River tributaries to spawn – the construction of Friant Dam and the diversion of water from the upper watershed to the Madera and Friant-Kern Canals has eliminated the fishery in a 120 mile reach of the River between Friant Dam and Lander Avenue. Temperatures in the San Joaquin River during the summer months and during major migration periods often exceed desirable temperatures for fish growth, reproduction and disease containment.

The concept of real-time management, currently advocated for reducing the frequency of violation of salinity objectives in the lower San Joaquin River, involves timing releases of saline discharges to coincide with periods when there is assimilative capacity in the river. Previous modeling efforts indicate that improved management and coordination of tributary releases and agricultural and wetland drainage could improve water quality in the SJR and reduce the quantity of fresh water releases required to meet salinity water quality objectives in the SJR at the Airport Way Bridge Near Vernalis. The same concept of real-time management can be applied to other constituents as well as pH, temperature and dissolved oxygen. Real-time monitoring and management of temperature in the SJR would involve the collection of temperature and flow data at a series of monitoring stations, temperature modeling and forecasting to anticipate future problems with temperature in the River and finally the decision to take actions such as the release of cold water from deep in the reservoir to lower ambient river temperatures downstream of the dam.

Prior to the inception of the current real-time water quality monitoring program in the lower San Joaquin River, discharge, diversion, and water quality data was being collected by multiple agencies at different frequencies and during different time frames. No single entity had a long-term coordinating interest in compiling, analyzing, and disseminating real-time SJR flow and water quality data for holistic water quality management purposes. The current real-time water quality management program was established to: (1) collect real time flow and water quality data; (2) use the data collected to model and forecast short-term water quality conditions in the SJR, and (3) disseminate information on current and forecasted future SJR assimilative capacity for salt loads to facilitate water management decisions.

2.0 CALFED Real-time Water Quality Management Project

In order to understand the application of real-time concepts to temperature management in the upper San Joaquin River it is instructive to understand the development and practice of the current San Joaquin River real-time water quality management program.

2.1 Watershed Setting

The SJR watershed is bounded by the Sierra Nevada Mountains on the east, the Coast Ranges on the west, the Delta to the north, and the Tulare Lake Basin to the south (Figure 1). From its source in the Sierra Nevada Mountains, the San Joaquin River flows southwesterly until it reaches Friant Dam. Below Friant Dam, the SJR flows westerly to the center of the San Joaquin Valley near Mendota, where it turns northwesterly to eventually join the Sacramento River in the Delta. The main stem of the entire SJR is about 300 miles long and drains approximately 13,500 square miles. The mean annual discharge of the LSJR at the Airport Way Bridge near Vernalis gaging station was approximately 3.7-million acre-feet (MAF) from water-years 1977 through 1997.

The major tributaries to the San Joaquin River upstream of the Airport Way Bridge near Vernalis (the boundary of the Sacramento-San Joaquin Delta) are on the east side of the San Joaquin Valley, with drainage basins in the Sierra Nevada Mountains. These major east side tributaries are the Stanislaus, Tuolumne, and Merced Rivers. Several smaller, ephemeral streams flow into the SJR from the west side of the valley. These streams include Hospital, Ingram, Del Puerto, Orestimba, Panoche, and Los Banos Creeks. All have drainage basins in the Coast Range, flow intermittently, and contribute sparsely to water supplies. Mud Slough (north) and Salt Slough also drain the Grassland Watershed on the west side of San Joaquin Valley. During the irrigation season, surface and subsurface agricultural return flows contribute greatly to these creeks and sloughs.

The hydrology of the San Joaquin River is complex and highly managed through the operation of dams, diversions, and supply conveyances. Water development has fragmented the watershed and greatly altered the natural hydrograph of the river. Runoff from the Sierra Nevada and foothills is regulated and stored in a series of reservoirs on the east side of the SJR. Most of the natural flow in the upper SJR is impounded behind Friant Dam (Millerton Lake) and diverted south to out-of-basin agricultural users. Consequently, over 20 miles of river channel upstream from Mendota Pool is dry in most years. The Delta-Mendota Canal (DMC) was built, in large part, to replace SJR river water that is diverted at Friant. The DMC conveys water from the Tracy Pumping Plant in the South Delta to the Mendota Pool. The imported DMC water from the Delta has a higher salt content than the upper SJR water it replaces. Water users receive deliveries directly from the DMC and from the Mendota Pool. Altogether, DMC water is currently being delivered to about 36 agricultural, municipal, and wetland water users in the LSJR basin.

Water is released from the Mendota Pool and diverted into a number of irrigation canals located upstream of Sack Dam. As a result of these diversions the SJR downstream of Sack Dam and upstream of Bear Creek frequently has little or no flow except during flood flows. During non-flood flow periods, water contained in this reach of the SJR is composed of groundwater accretions and agricultural return flows. The river channel has aggraded over time with sand deposited from intermittent flood flows. The SJR downstream of Bear Creek once again becomes a permanent stream that flows all year. The flow in the reach of the SJR downstream of Bear Creek and upstream of the Merced River confluence, however, is dominated by agricultural and wetland return flows and by groundwater accretions. Downstream, the Merced, Tuolumne, and Stanislaus Rivers add substantial flow in the LSJR. The study area for the real-time water quality management program is limited to the SJR downstream of Lander Avenue.

This reach overlaps to a small extent the reach of interest to the San Joaquin River Riparian Habitat Restoration Program (SJRRP) which stretches from Friant Dam to the confluence with the Merced River (McBain and Trush, 2002). Incorporating a water quality and temperature monitoring network, supported by the SJRRP, into the existing San Joaquin River monitoring network will be discussed later in this report.

2.2 Chronology of SJRMP-WQS Project

In 1990, the California legislature authorized the establishment of the San Joaquin River Management Program to identify the problems facing the river system and to prepare a plan that would identify solutions to improve, restore and enhance currently degraded conditions. As part of this program, a water quality subcommittee was formed to identify the river's major water quality problems and to work towards the implementation of solutions. Members of the SJRMP Water Quality Subcommittee include representatives of the California Department of Water Resources, Lawrence Berkeley National Laboratory, United States Bureau of Reclamation and California Regional Water Quality Control Board, Central Valley Region. The SJRMP-WQS identified real-time management as a key implementation strategy for improving water quality conditions in the SJR system.

In September 1994, the USBR issued a Challenge Grant to the SJRMP-WQS, via DWR, to demonstrate improved river water quality management through the use of telemetered water quality and flow monitoring stations (USBR Agreement No. 4-FG-20-12010). A final report entitled "*San Joaquin River Real-time Water Quality Management Demonstration Project*" documents the achievements and results of that project. This demonstration project was completed in June of 1997.

In 1997, the San Joaquin River Real-time Water Quality Management Demonstration Project was continued and expanded with CALFED funding. The updated San Joaquin River Real-time Water Quality Management program was funded from the CALFED Bay-Delta Program's 1997 Category III, Request for Proposals for Ecosystem Restoration Projects (ERP). The original term of the agreement was January 1, 1999 through December 31, 2000 but was extended through an amendment B81467/97-C08 (Amendment 1) that was approved March 13, 2001. This amendment extended the contract one year to December 31, 2001. This agreement was subsequently extended to June 30, 2002 through a no cost amendment (Amendment 2). The real-time water quality management program, however, was denied funding in the 2002 round of ERP funding resulting in completion of the program in July 2002. Alternate funding sources are now being sought to continue and expand the program.

2.3 Monitoring network

The current real-time water quality monitoring network for the SJRMP real-time water quality monitoring project is shown in Figure 2. The stations are currently maintained by the Department of Water Resources (DWR), the US Geological Survey for the US Bureau of Reclamation and Lawrence Berkeley National Laboratory. The stations in the network were chosen based on their importance as flow monitoring sites and their relative importance in measuring contaminant loads such as selenium, boron and salinity. Crows Landing and Vernalis on the San Joaquin River are compliance monitoring sites as in Site B on the San Luis Drain. Regular maintenance and frequent sensor calibration at these monitoring sites helps to ensure data quality and minimize the need for estimation.

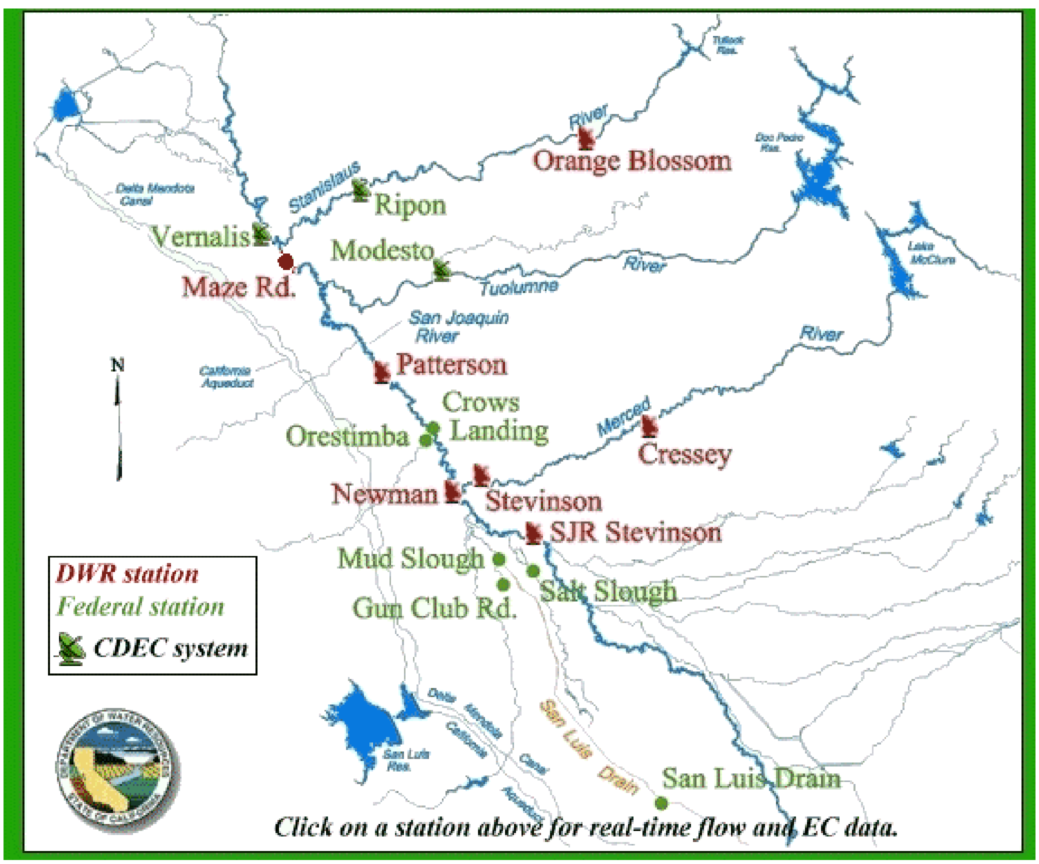


Figure 1. Real-time water quality monitoring network in the lower San Joaquin River.

2.4 Project achievements

Since beginning operation in April 1999 to the programs conclusion in June 2002, real-time flow and water quality data has been continuously collected and the SJRIODAY model has been operated to provide flow and water quality forecasts on a weekly basis to water resource managers in the basin. This information can be found on DWR's San Joaquin District website at the following address:

(http://wwwdpla.water.ca.gov/sjd/sjrmp/index.html) .

The Real-time Water Quality Management Program data has demonstrated that the San Joaquin River experiences prolonged periods of poor water quality and that opportunities exist to significantly improve water quality in the San Joaquin River through real-time management of agricultural and wetland discharges. The current Real-time Water Quality Monitoring Program successfully established the monitoring, communications, and modeling systems needed to provide water managers with much of the information necessary to allow them to coordinate reservoir releases and drainage discharges on real-time basis.

3.0 Related real-time water quality management activities

The real-time TMDL concept advanced by the SJRMP-WQS requires a high degree of collaboration and coordination of water management activities in the San Joaquin Basin. This can probably only be accomplished through the creation of a entity that has broad powers to make decisions affecting the scheduling of short term west-side return flows and releases from the east-side reservoirs along the major tributaries. Until this is accomplished the SJRMP-WQS can serve a role as catalyst, stitching together those features of related activities that could be contained in a more comprehensive program. The following is a synopsis of related real-time and quasi-real-time activities in the Basin (Quinn and Eacock, 2002). Aspects of these projects that add capability to the current CALFED-sponsored San Joaquin River Real-Time Water Quality Management program are identified. The importance of these current projects to the SJRRP should not be overlooked since dilution water provided to the SJR below the Merced confluence as a result of Friant temperature releases for fish, could provide significant benefits to each of these projects. The promise of future funding for SJRRP activities may be enhanced by a synergy between a real-time water quality management program in the SJR above the Merced confluence and the current real-time water quality monitoring and management projects.

3.1 Vernalis Adaptive Management Program

The Vernalis Adaptive Management Project is a 14 year-long experiment to improve scientific understanding of the relationship between flow and fish resources in the SJR. Fishery biologists from state and federal agencies and other stakeholders developed a program of study to gather data on the impact of flows, Delta project export rates and delta diversions on the salmon smolts in the lower SJR. The VAMP was developed as an alternative that provides an equivalent level of protection to the San Joaquin River 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. 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 flow. It follows that by increasing the accuracy of the flow forecast the accuracy of assimilative capacity forecasts for salt in the SJR also improve significantly. The SJRMP-WQS has worked closely with

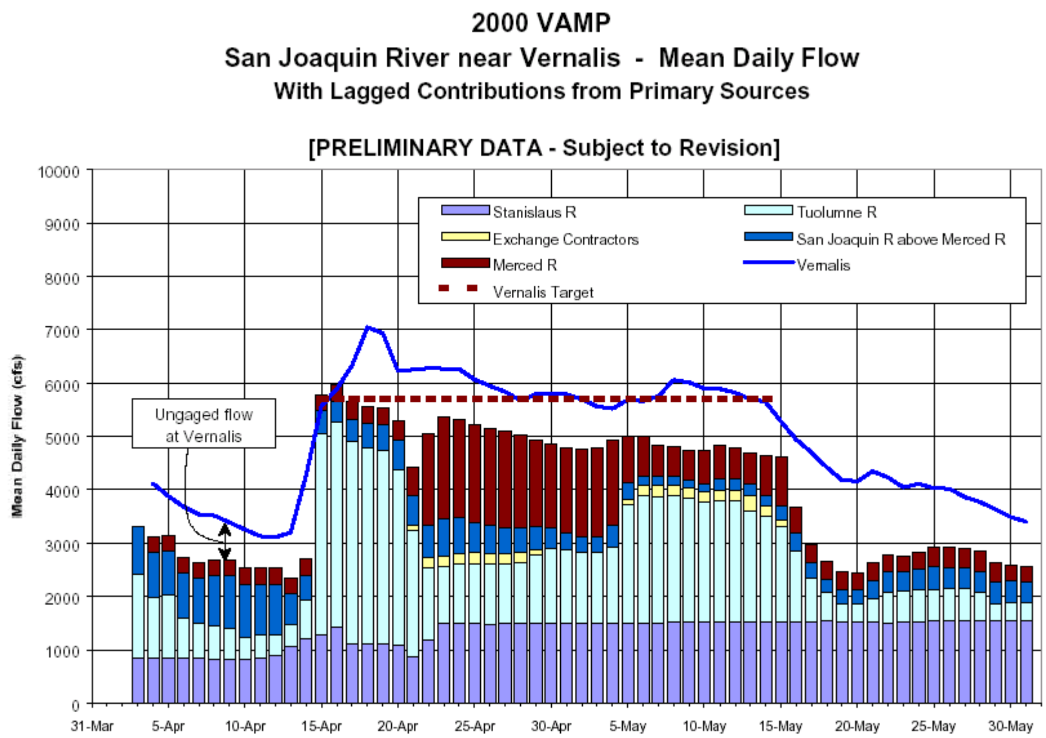


Figure 2. Mean daily flow during VAMP 200 showing relative flow volumes from east-side tributary and west-side water managers demonstrating the high degree of control possible through coordination.

VAMP hydrologists over the past three years providing flow forecasts and insights on river gains and losses during the critical month when flows are to be maintained within 7% of the negotiated flow targets.
Figure 2 shows the various contributions made by the various east-side and west-side entities to the year 2000 VAMP. The initial overshoot during 2000 was due to a combination of a shifting stage-discharge rating at the Vernalis gauge and a large spring storm that produced significant runoff within the Basin. Despite the difficulties presented by these factors the figure clearly shows what degree of control can be achieved within the basin by close cooperation between east and west-side water managers. What continues to be lacking is an institutional mechanism to foster the same degree of coordination during the remaining 11 months of the year.

3.2 Grasslands Bypass Project

The Grasslands Bypass Project was conceived in the early 1990's as a means of removing selenium contaminated agricultural drainage water from wetland channels within the Grassland Water District by diverting the drainage into the San Luis Drain. The San Luis Drain, which had previously been used to convey agricultural drainage to Kesterson Reservoir between 1980 and 1985, was returned to service as part of this project. Use of the federally owned facility, by the project proponents, was made 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 for the 94,000 acre drainage service area were established through a lengthy negotiated process between the water districts, state and federal resource Agencies, the Environmental Protection Agency and activist organizations .

Selenium load targets were set through a negotiated process based on average monthly selenium loads from the agricultural land contained in the six water districts participating in the project. Annual load targets 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 2009. In 2005 the selenium load targets are reduced incrementally to the Total Maximum Monthly Load

(TMML) limits, set by the Central Valley Regional Water Quality Control Board (CRWQCB). The TMML selenium load targets include a provision for water year type which offers some relief during wet years when assimilative capacity in the SJR is high. 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 took 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 the beginning of the project in September 1996.

In order to meet selenium load targets a number of innovations have been made at both the farm and water district level. Continuous flow meters have been installed at each of the main discharge points from the participating water districts. Radio and telephone telemetry systems were installed allowing real-time monitoring of individual water district's contribution to overall drainage flow. Water meters were retrofitted on drainage sumps and discharge points within each district in order to estimate the drainage flow contribution from each source and the mass contribution to each District's selenium load. With this knowledge water districts have developed customized selenium load targets for each tile sump whereby the tile drain flow can be directly correlated with selenium load. Since flow is readily measured at the field level and a fraction of the cost of daily selenium water quality sampling this has proved an efficient system for encouraging compliance from local farmers and allowing the District to meet monthly selenium load targets.

3.3 Wetland Real-Time Water Quality Management

Private wetlands and both state and federal refuges have not been exempted from the CRWQCB salinity discharge control plan for the San Joaquin Basin. The Grassland Water District (GWD) has initiated a project aimed at improving understanding of current salinity mass loading from private duck clubs and cattle ranches in the northern half of their 51,500 acre drainage area. Management of salts from private wetlands is more complex than from agricultural water districts because of the diversity of the system, the dearth of information relating soil salinity and moisture stress to weed propagation, and the lack of any decision support system to assist wetland managers select best management practices. A GIS-based salinity accounting model has been developed to improve the tracking of salt loads in wetland areas, within Northern GWD, that receive water from the same supply canals to remove one of the impediments to real-time salinity management. This software will also help the Water District assess potential future costs of more intensive water and salinity management.

The District has also overseen the construction of five new flow and salinity outflow monitoring sites and one inflow-monitoring site within the Northern GWD (Quinn and Hanna, 2001). 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 experimentation is providing information on salt mass loading during wetland drawdown from shallow, deep, early season and late season wetlands as well as assessing the long-term condition of waterfowl habitat under 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.

3.4 Panoche-Silver Creek Watershed Forecast System

The 380 square mile Panoche-Silver Creek watershed is the largest west-side tributary to the San Joaquin River and the primary source of selenium in the Grasslands Basin. Measures to limit these contaminant loads including early-warning systems of significant runoff events can help to reduce the impact on San Joaquin River 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 stream flow. 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 San Joaquin River, carrying significant sediment, salt, and selenium loads. Implementing new predictive modeling and measurement applications to the west-side drainage will expand the San Joaquin water quality monitoring network.

A CALFED-sponsored project run by the watershed-based Coordinated Resource Management Program is adding to the existing real-time water quality management network by adding rainfall, flow and water quality monitoring stations within the Panoche/Silver Creek watershed on three of the major tributaries (Quinn and

Eacock, 2002). A GIS-based rainfall-runoff and stream flow 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.

3.5 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 San Joaquin River 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 along with diminished inflow from the lower San Joaquin River. The past two years have witnessed intensive monitoring of a number of water quality indicators 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 and 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 San Joaquin Basin.

4.0 Real-time water quality monitoring for SJR Restoration

4.1 Project Objectives

The SJRRP has three main goals (Jones and Stokes, 2003) :

1. Reestablish and maintain a self-sustaining and naturally reproducing populations of Chinook salmon in the San Joaquin River from Friant Dam to the Delta.
2. Maintain and expand self-sustaining native riparian and wetland plant communities with a high degree of connectivity throughout the available floodplain between Friant Dam and the Merced River.
3. Reestablish and maintain geomorphic and hydrologic conditions at levels that will provide and sustain the ecological habitats and functions required to achieve salmon and riparian/wetland restoration goals and objectives.

4.2 Monitoring objectives

Water temperature is the primary water quality constituent of concern since it affects fish habitat conditions below Friant Dam which in turn can affect fish growth, egg incubations, disease, predation, migration and spawning. Water stage is also of importance since this affects the flow rate and opportunity time for warming of releases from Friant Dam. Stage is also correlated with predation – low river stage can lead to fish stranding in pools where predation is more likely.

Monitoring data collected in the San Joaquin River by Jones and Stokes (Brown, 2003) demonstrated the dramatic effect of pulse flow releases on the rate of change of downstream temperatures. A simple model developed for the San Joaquin system appeared to calibrate reasonably well and could be the basis for optimization analyses to determine the minimum size and duration of pulse flows consistent with achieving habitat and fishery objectives in the San Joaquin River.

4.3 Monitoring site selection

Monitoring site selection should weight a number of considerations :

1. Objectives of monitoring program
2. Site access and proximity
3. Site characteristics and ability to obtain representative data
4. Vandalism potential
5. Historic time series data availability
6. Distance between stations

A good monitoring site should be capable of providing good quality data year-round at low cost. Site access is important as is the proximity to the site. Sites on private land require owner permission to avoid trespassing. A change in land ownership, in the case of a site located on private land, might result in denial of access. This could be costly if it might mean the abandonment of a station. Proximity to a major all-weather road is also important. Long hikes to a station will restrict the equipment carried to the site to perform routine maintenance and can also reduce the time available at each site if a number of sites are visited during each monitoring trip.

Sites should if possible be located at bridges or crossings where possible where sensors can be strung along the bridge and dropped into the deepest part of the channel – hence obtaining the most representative readings of the mean stream temperature or water quality. Stage sensors should be located within stilling wells in good hydraulic contact with the river but in a position to avoid being struck by debris during high flow events. Stage sensors should not be mounted on a wall of a hydraulic structure where it is likely to be affected by pressure waves as water is deflected.

Sites which have a data history are more useful than new stations owing to the expense of data collection and the paucity, in general, of long-term data records for the San Joaquin River system. Sites that have had a history of monitoring are less likely to be vandalized. Those that have been vandalized in past are likely to be vandalized in the future.

Sites should also be spaced an adequate distance apart to cover the river reach of interest and along reaches of roughly even length if possible, assuming somewhat consistent hydrology, to make model calibration easier. It is more difficult to evaluate a flow, water quality or temperature model if sites are clustered at one end of the river system. The number of sites obviously depends on the available budget and data monitoring objectives.

For the San Joaquin River between Friant Dam and the Merced River the following sites are suggested. The site descriptions are supplemented with an explanation of the rationale for inclusion of each site.

STATION NAME	DISTANCE BELOW FRIANT DAM (miles)	CURRENT STATUS	RATIONALE
North Fork Bridge	0.7	USGS	low cost to upgrade existing station
SR 41 Bridge	12.2	new station	bridge site with relatively easy access
Santa Fe Railroad Bridge	22.4	new station	bridge site with relatively easy access
Gravelly Ford (Emmert Ranch)	39.3	USBR gauge house	existing gauge house
Mendota Pool	62.7	USBR gauge house	existing gauge house
Sack Dam	85.5	new station	most downstream station with occasional flow

Table 1. Suggested network of real-time temperature, stage and water quality monitoring stations.

4.4 Monitoring sensor selection

The selection of the most appropriate sensors for deployment is of great significance in determining the cost effectiveness of the monitoring site and the quality of the data recorded. Five factors should be considered :

1. Monitoring budget
2. Duration of monitoring
3. Desired accuracy
4. Desired maintenance frequency
5. Vulnerability for vandalism
6. Skill, training and experience of station operator

The monitoring budget includes both fixed capital expenditures and cost of maintenance. A certain contingency should be allowed for sensor failure, maintenance and repair. Many of the current sensors on the market have a finite life – information on which is not typically provided in user manuals. Some monitoring equipment is difficult to set up but provides reliable service once installed. This type of equipment may not be suitable for short-term or temporary monitoring locations.

The real-time monitoring equipment of choice, given the constraints of the SJRRP is consistent with the recommendations of the US Geological Survey (USGS). Although the USGS will most likely make the transition to Yellow Springs International (YSI) sensors over the next decade, Campbell Scientific sensor hardware and dataloggers will continue to provide the majority of the real-time data collected by the Agency. The following discussion describes each of the components of the system recommended to the SJRRP based on over 15 years of experience with various types of monitoring equipment in the San Joaquin Valley

4.4.1 Datalogger

The Campbell Scientific International (CSI) CR-10X datalogger (Figure 3) is a robust 12 volt logger that has seen service in the Space Shuttle. Programming of the CR-10X has been simplified in the past 5 years through the development of easy-to-use software that guides the novice through the programming of the logger for various instruments. The major virtue of the CSI system is that most of the complexity is built into the software and the sensors are robust, easy to replace and cheap. Most other water quality sensor manufacturers such as YSI, HydroLab Inc., Turner Designs Inc. and Hach Chemical Inc. produce self-contained water quality sondes which contain solid-state electronics to allow data storage and programming functionality in the sonde itself. As a result the sondes typically cost in the range of $2,400 to $6,000 apiece. In a somewhat remote area such as the San Joaquin River in the reach between Friant Dam and Mendota Pool, vandalism could become extremely expensive to the SJJRP. The use of a single datalogger, protected within a steel building with relatively inexpensive external sensors in a more risk-adverse approach. CSI sensors contemplated in this project range are typically 10% of the cost of the more sophisticated sensors. The cost of the CR-10X is $1200 (see Appendix A).

The CR10X consists of a Measurement and Control Module and a detachable Wiring Panel. The Mean Time Between Failures (MTBF) for the CR10X is over 180 years.

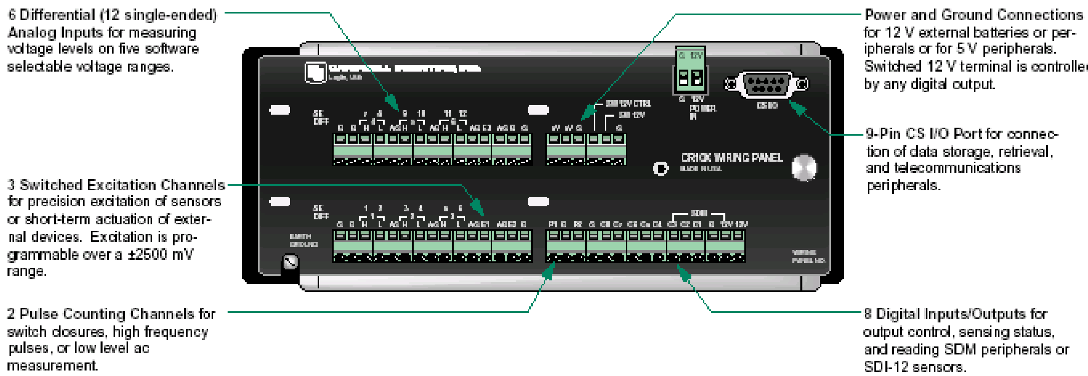


Figure 5. CR-10X datalogger from Campbell Scientific.

4.4.2 Temperature sensors

Although one can obtain temperature information from temperature compensated electrical conductivity sensors – the CSI 107 or 108 temperature probe is one of the most robust on the market and costs less than $100. These sensors are connected to single ended inputs on the datalogger console.

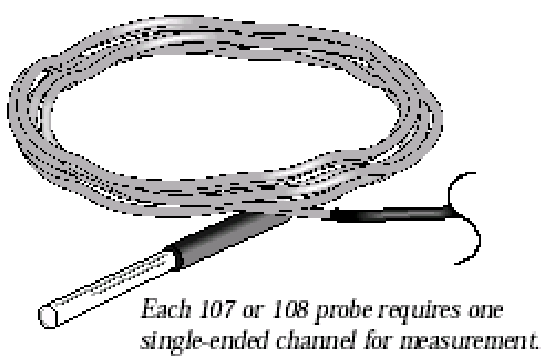
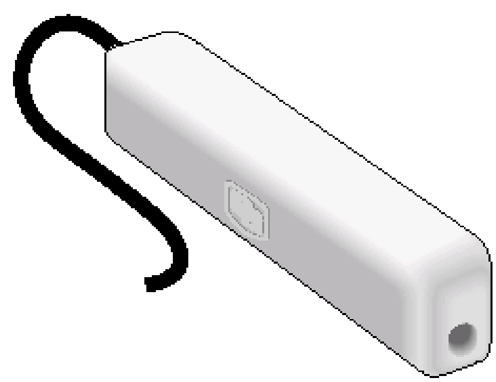


Figure 6. CSI 107/108 temperature sensor

Figure 7. CSI Electrical Conductivity sensor

4.4.3 Electrical conductivity sensors

The CSI 547 sensor is small, simple and easy to protect from vandalism. The sensor is connected to the datalogger through a serial interface box allowing the sensor to be replaced with ease without having to remove the datalogger panel wiring. Although the CSI electrical conductivity sensors have an expected life of about 3 years in most applications – under harsh conditions sensor life has sometimes been less than 12 months. The greater potential frequency of replacement is more than compensated for by its price and robustness.



The CS547A is suitable in most surface water, laboratory, and industrial applications. A weighted version is available to facilitate stand-alone submersion.

4.4.4 Stage sensors

The Design Analysis H350XL pressure sensor and the recent H-355 CO2 bubbler have been use by the USGS with considerable success for many years. The H-355 replaces the gas site-feed regulator system which is reliable and very robust – but requires occasional (1-4 times per year) exchange of heavy nitrogen gas cylinders. This system is inexpensive but very unsuitable for remote locations which would make gas cylinder exchange difficult and in some cases dangerous. The H350XL adds a second datalogger to the system at a cost of less than $300 over the H350-lite as well as a terminal display which is convenient for instrument troubleshooting and calibration. The accuracy and consistency of bubbler sensor technology make it the system of chouice. In addition the only external component of this system is the orifice line and orifice – neither of which exceeds $50 in cost. The bubbler system communicates with the CR-10X datalogger using the SDI-12 interface which is accessed through one of the CR-10X control ports. SDI-12 is a standard communications protocol

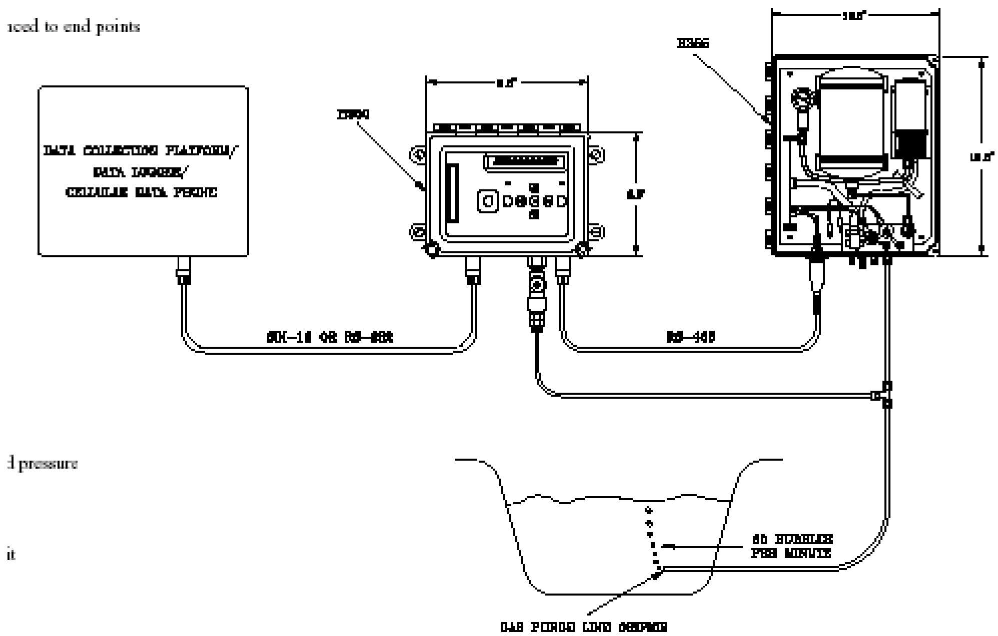


Figure 8. Design Analysis Inc. H350Xl and H-355 stage monitoring system

4.4.5 Enclosures and housing

The most effective gauge houses are those constructed from 1/8 inch mild steel. These can withstand shotgun shells and when designed according USGS specifications, with adequate head-space, are very functional. The gauge house is secured with a padlock which is accessed through a lockbox welded to the front of the door, which prevents bolt cutters or similar tool from gaining a purchase on the padlock. Figure 9 shows a gauge house fabricated for Panoche Creek which contains the Campbell Datalogger and Design Analysis 350XL and

Figure 9. Suggested interior configuration of Design Analysis 350XL and 355 bubbler stage sensor (on left) and the Campbell CR-10X datalogger and associated sensors in center-right.

355 sensor and compressor/bubbler units. A moisture-tight enclosure is typically mounted vertically on the wall and used to house the CSI datalogger and other sensitive electronic components such as GOES transmitters, cellular or satellite phones to avoid corrosion of the circuit boards. A deep cycle, gel battery is essential to retain electrical power to the sensors 24 hours a day. A 20 W solar panel has been shown to be adequate to power all the sensors recommended for the SJRRP. A 12V regulator is used to prevent overcharging of the battery and to protect the logger from power surges.

4.5 Site maintenance and quality assurance

Site maintenance is essential to ensure continuous good quality data. This involves cleaning and calibrating the probes on a regular maintenance cycle. For EC, temperature and stage sensors – a 4 - 6 week interval between scheduled maintenance visits should be adequate once all the bugs have been worked out of the system. Calibration involves comparing reading to standards. In the case of EC a standard solution is typically used in the range of the EC sensor. Any drift in the sensor over time should be corrected if greater than 5%. Temperature calibration is also quite straight-forward and requires an accurate thermometer. In the case of stage calibration a permanent staff gauge should be established at the site and set to the mean depth of water at the thalweg of the river. This is used as a permanent reference against which the bubbler stage sensor is calibrated. A annual survey of the channel is also advisable to note any bed aggradation or deposition as this will affect the true river stage.

4.6 Data acquisition and telemetry

One of the most costly and time consuming aspects of maintaining a real-time water quality monitoring network is the retrieval and processing of flow, temperature and water quality data. Dataloggers are used to store data produced by stage, temperature and electrical conductivity sensors. The data can be retrieved (a) directly by connecting a laptop or other retrieval device to the datalogger; by telephone, cell phone, satellite radio or via GOES satellite link. Analog cell phones have been in use for more than a decade at some locations and although expensive to maintain have offered a good alternative to site visits, especially at remote sites. Analog cellular phones have been phased out by local phone companies and new analog service is almost impossible to obtain from these companies. Unfortunately there are no standard satellite or CPDP network phone alternatives, that have been well tested, at the present time. Experience in the Grasslands Water District with a Raven CPDP phone from CSI has not been positive – signal strength was insufficient at all monitoring sites. This problem may also in the SJRRP project area In the short term cell phone telemetry options will be restricted until coverage has a chance to catch up with the new cell phone communication protocols. In areas close to urban areas regular dial-up phone service is still the best and cheapest remote telemetry option.

Figure 10. Example of a station installed at Wolfsen Road Bridge showing protective piping to house sensors and avoid damage due to vandalism. This site benefited from close access to power and a telephone line which avoided the cost of a solar panel and expensive telemetry.

For State and Federal agencies GOES telemetry is a viable option. GOES high rate transmitters are more expensive than cell phone or LAN telemetry. Licensing is also a tedious process taking up to 3 months to receive an allocation of bandwidth from NOAA. GOES also suffers from the problem that transmission is one-way from the data collection platform to the GOES satellite. Hence this system cannot be used to make changes to the datalogger program. The greatest advantage of the GOES system, once installed, is that O&M costs are minimal since the satellite system is subsidized by the Federal government. One does need to cooperate with a Federal or State agency such as the California Data Exchange (CDEC) in order to access the data. This requires persuading the agency to add the site to their existing monitoring network.

Figure 11. Installation in Volta State Wildlife Area showing the use of a solar panel mounted above the gauge house to power the sensors. This site suffered from frequent vandalism resulting in frequent damage to the velocity and electrical conductivity sensors. This was overcome using heavy gauge water pipe through which the sensor could be lowered into the water. The cable was secured inside the gauge house to prevent the sensor from being pulled further than a few inches beyond the submerged end of the sloping pipe.

The CPDP cellular network phone is an exciting intermediate term prospect. Unfortunately, as previously described, coverage is limited at present restricting the use of this technology in the San Joaquin Basin. The main advantage of CPDP-based phones is the ability to have direct web access to each monitoring station – since each station can be allocated an IP address which makes it directly addressable with a web browser. This has the further advantage of making it easier to load current data in our water quality forecasting model without intermediate data reduction and processing steps.

4.7 Institutional considerations

One of the difficulties in a multi-agency undertaking such as the current real-time water quality management project is ensuring continuity of the monitoring network. Early on in this project severe budget cuts in the State's general fund budget resulted in the elimination of large numbers of stations including the Mud Slough and Salt Slough stations, which together account for approximately 60% of the salt load to the San Joaquin River. One of the first actions of the San Joaquin River Management Program Water Quality Subcommittee (SJRMP-WQS) was to restore these stations and to purchase equipment for these stations so that the equipment in the stations would be owned by the Subcommittee and not the contractor assigned for stations maintenance. Over the past 5 years the SJRMP-WQS has managed to keep the base monitoring network intact and has added main stem river and tributary stations at Lander Avenue (EC), Crows Landing (EC and flow), Orange Blossom Bridge (EC) and Stevinson (EC). A continuous monitoring station for both flow and EC was installed in the West Stanislaus Irrigation District diversion along the first lift canal. This diversion is the largest along the main stem of the SJR and typically ranges between 100 and 150 cfs during the summer months. The SJRMP-WQS has also been working with both West Stanislaus Irrigation District and Patterson Irrigation District to develop flow and EC gauging on the ephemeral west-side streams including Ingram, Hospital and Del Puerto Creeks. Weirs for measuring flow in all of these sites were installed in early summer 2002.

The SJRMP-WQS continues to play a role in coordination of monitoring activities in the watershed and provides technical assistance to local water districts needing advice on the choice of monitoring equipment and on monitoring station installation.

4.8 Data processing, storage and access

Data processing, storage and data access are the least exciting and most often neglected components of a real-time flow and water quality monitoring and management project.

Data processing is typically performed on CSI-based data retrieval systems using software called SPLIT. This program reads in the comma delimited data file from the datalogger and parses the data into summary tables according to the averaging interval specified by the programmer. The program has capabilities for error checking, data interpolation and other forms of data estimation. When combined with a telemetry system the CSI software is capable of automatically dialing the stations at pre-determined intervals (usually daily or weekly) and running the SPLIT software after data retrieval is complete. Another program, marketed by CSI, called RTDM (real-time data management) allows the parsed data to be converted to GIF images and posted to a website. The software allows customized graphics to be created for display.

Data storage is an important consideration because, over time, data files become large and unwieldy and may be unsuitable for processing with Microsoft EXCEL. A database such as ACCESS should be considered to store data if it is important to keep all the raw data. The Interagency Ecological Program (IEP) maintains a large Oracle database for those agencies involved in the program. Although the SJRRP project is not strictly a Bay-Delta project, the data would likely be considered of enough widespread interest that they might consider hosting the data collected. Karl Jacobs in the Department of Water Resources (kjacobs@water.ca.gov) should be contacted if this suggestion is of interest. This would substantially reduces the cost of data storage and provide easy access to the data through the DWR – IEP web site.

Data access is likely to be of great importance once the transition is made from real-time monitoring to real-time management. For example, for real-time management of temperature, it is essential that reservoir operators be provided real-time data access to the river stage and temperature sensors so that flows can be adjusted to meet river temperature objectives along certain reaches. It is equally important not to expend too much reservoir storage on achieving such an environmental goal, especially if this would reduce available water to temperature regulation later in the year. Real-time data access can help to optimize the utility of reservoir storage devoted to SJR temperature control.

4.9 Costs identified

The following tables list the equipment costs for a typical installation. The cost of labor, piping, concrete and other materials will vary from site and site and can only be estimated by site reconnaissance and survey. This is beyond the scope of this concept paper. All equipment costs listed are on a GSA schedule which usually provides a 5-10% discount on the purchase. No account is made for equipment or sensor redundancy. Because of typically long delays between equipment ordering and shipping it is advisable to have at least one spare datalogger and set of sensors for every five installations. This helps to minimize loss of data in the event of sensor or datalogger failure. Campbell Scientific Inc. (CSI) recommends an average service life of about 3 years for most electronic environmental sensors (Clyde Best, CSI – personal communication).

ITEM	CATALOG No.	NUMBER	SOURCE	COST ($)
GAUGE HOUSE				
Steel gauge house		1	Country Welding School	1200
Concrete pad		1	Local concrete supplier	150
DATALOGGER/ SENSORS				
Datalogger	CR10X	1	Campbell Scientific Inc.	1165
20 watt regulated solar panel	MSX20R	1	Campbell Scientific Inc.	450
Sealed rechargeable battery	BP24	1	Campbell Scientific Inc.	140
Weather resistant enclosure	15875	1	Campbell Scientific Inc.	195
Mounts for enclosure	7839	1	Campbell Scientific Inc	35
Temperature sensor	107-L	1	Campbell Scientific Inc.	68
Cable for temperature sensor	107-L	100 ft	Campbell Scientific Inc.	26
Electrical conductivity sensor	CS-547A	1	Campbell Scientific Inc	291
Cable for EC sensor	7359	100 ft	Campbell Scientific Inc	65
Conductivity interface	A547	1	Campbell Scientific Inc	97
Optically isolated interface	SC32B	1	Campbell Scientific Inc	87
H350XL/H355 logger sensor and bubble gas purge system	H350XL H355	1 1	Design Analysis Inc.	3495
Dessicating air dryer	H355DES2	1	Design Analysis Inc.	248
Instrument mounting panel	H250BRD	1	Design Analysis Inc.	215
SOFTWARE				
Datalogger support software * (only 1 needed)	Loggernet	1	Campbell Scientific Inc	384
TOTAL				**8341**

OPTIONAL TELEMETRY				
A. GOES satellite radio	HDR GOES	1	Campbell Scientific Inc	2480
GPS antenna	13945	1	Campbell Scientific Inc	30
GOES Yagi antenna	12261	1	Campbell Scientific Inc	615
B. Cellular digital modem (Airlink)	15842	1	Campbell Scientific Inc	555
Mounting kit and antenna	14394 14453	1	Campbell Scientific Inc	225
C. Telephone modem w/surge	COM210	1	Campbell Scientific Inc	361

4.9.1 Labor costs

The labor costs associated with monitoring station reconnaissance, design, construction and maintenance will vary between sites. Reconnaissance can be accomplished in 1 day and involves such tasks as the measurement of distances between the gauge house and sensors to determine sensor and connector tubing lengths. Design may take about 0.5 day per site. Construction of the site may take up to 1 week (seven days) to accomplish with two people. Initial calibration of the sensors, placement of staff gauges and other troubleshooting may take an additional day at the site. Maintenance should be carried out every 2 weeks for the first three months and then at monthly or 6 week intervals after that, depending on the performance of the monitoring station. Most agencies insist on a two crew for safety reasons). A contingency should be allowed for vandalism or damage due to flooding or other natural hazards (perhaps an additional man-day per month). Total man days for the first year of installation will be approximately 55.5 man days/year per station. For multiple stations there may be some time saving since it might be possible to perform site quality assurance on more than one station in one day.

One cost savings approach would be to train local university students or student field technicians to perform the routine downloading of data, site quality assurance and site maintenance. This could be accomplished with students hired through the California Water Institute at Fresno State University. The students would heed to be supervised by a faculty member familiar with real-time water flow and water quality monitoring instruments. A technical expert on some of these issues could be retained for occasional problems that required greater field experience. This would also cut down on travel costs which could exceed $4,000 per year if labor were to be supplied from Sacramento or Berkeley.

5.0 Modeling and Real-time Forecasting for SJR Restoration

5.1 Modeling and Real-time Forecasting

Modeling and forecasting future short-term conditions is a key component of the current Real-time Water Quality Management Program. Since April 1999 weekly forecasts of flow, water quality, and assimilative capacity in SJR have been provided to water mangers and the public through the real-time program website. Project water quality forecasts have been developed using data collected from the real-time network and model output. These forecasts are intended to facilitate water management decisions. For example, if a real-time forecast predicts that water quality will exceed objectives for the forecasted period water mangers could potentially reduce discharges to the river; likewise fresh water could be released to dilute salt loads.

Project water quality forecasts employ the SJR Input-Output (SJRIO-2) model because of its simplicity, utility and availability. SJRIO is a mass balance water quality model originally developed by SWRCB and University of California, Davis staffs as part of the SWRCB Order No. 85-1 Technical Committee Report (SWRCB, 1987). SJRIO-2 is a more detailed and mechanistic model than the original SJRIO code, that includes algorithms to estimate rainfall runoff, irrigation return flows and improve the computation of groundwater inflows. SJRIO-2 is coded in FORTRAN to be run on a PC under Windows™. A daily version of the SJRIO-2 model was developed in 1998 to produce daily and water quality output. The input hydrology, apart from the gauged tributary data, is largely based on the monthly SJRIO-2 model. Since the model is a key feature of SJR real-time water quality management, a review of its history, assumptions, and data requirements is necessary prior to any discussion of its use in the demonstration project.

5.2 SJRIODAY model description

SJRIODAY has been used to perform weekly flow and assimilative capacity forecasts in the SJR since 1998. An extensive database for water years 1977 to 1995 has been assembled to run the model. The original model, and the database created to run it, were developed to meet the following objectives:

- To quantify the waste loads of TDS, boron and selenium in the SJR from each type of discharge (e.g., subsurface agricultural discharges, municipal and industrial discharges, groundwater accretions, etc.).
- To quantify the concentrations and loads of TDS, boron and selenium in the SJR.
- To project future levels of TDS, boron, and selenium in the SJR based on the possible implementation of various management alternatives for meeting proposed water quality objectives in the river.

The monthly model has been extensively tested and calibrated using historical. SJRIO uses hydrologic routing techniques and conservative mass transport to calculate water quality. The model performs a mass balance accounting of discharge, TDS, boron, and selenium for a 60 mile (96 km) reach of the lower SJR, bounded by the gauging stations at Lander Avenue in the south and Vernalis in the north. The SJR at Lander Avenue was chosen as the upstream boundary of the model for three reasons: (1) it is downstream of the effects of the east-side bypass on SJR flows, (2) it is upstream of wetland discharges and agricultural drainage inputs from Mud and Salt sloughs, and (3) it has a full set of historical data with which to validate the model. The SJR near Vernalis was chosen as the downstream boundary because it is upstream of Delta tidal effects and it has a full set of historical data to calibrate the model.. The following tributary river segments, from a gauging station to the confluence with the SJR, are also considered within the model boundaries:

- Five miles of the Merced River below the gaging station near Stevinson.
- Fifteen miles of the Tuolumne River below the gaging station at Modesto.
- Nine miles of the Stanislaus River below the gaging station at Koetitz Ranch.
- Six miles of Salt Slough below the gaging station at Lander Avenue.
- Nine miles of Mud Slough below the gaging station near Gustine.
- Several miles of three west-side tributaries: Del Puerto, Orestimba and Hospital/Ingram Creeks.

Figure 1 previously depicted the locations of key lower SJR basin stream flow and water quality gaging stations.

In addition, the following sources and sinks are considered as model components:

For selected points along the SJR and the three east-side tributaries within the model boundaries:

- Appropriative and riparian diversions (41 points)
- Subsurface agricultural (tile drainage) discharges (9 points)
- Surface agricultural discharges (e.g., tail water and operational spill water) (35 points)
- Municipal and industrial discharges (2 points)
-

For every river mile along the SJR and the three east-side tributaries

- Groundwater accretions and/or depletions
- For every five mile reach of the SJR and the three east-side tributaries
- Riparian vegetation water use
- Evaporation and precipitation

5.3 Description of method

The modeling and forecasting process begins with collection of and compilation of flow and water quality data from key sites in the SJR system. Spreadsheets are used to convert these data into FORTRAN compliant text files that are used as input to the SJRIODAY model. Once the data is preprocessed, the SJRIODAY model is run for the appropriate time period. Typically the model is run to generate output for the previous seven days and 14-day forecast period. Model output for the historical seven-day period is compared to real-time data and the model is iteratively calibrated and re-run until modeled results are within ten percent of the actual data. Calibration is achieved through adding or removing flow and salt load at user specified river reaches. The same flow and salinity adjustments made to calibrate the model during the 7-day calibration period are applied to the 14-day forecast period. The modeler must therefore use best professional judgment to decide where to make adjustments in the SJR system and to determine if a particular calibration scenario can be reasonably explained given the physical constraints of the SJR system. The structure of a typical 21-day SJRIO model run is depicted in Figure 12.

Once the model is satisfactorily calibrated, the SJRIODAY model output files are converted to web-ready HTML documents and uploaded to a server. An e-mail is sent out to notify interested parties and Real-time Water Quality Management Program MOU signatories each week when the website has been updated with a new forecast. The real-time forecasts consist of series of tables and graphs that provide data on flow, EC, and assimilative capacity in the SJR at Crow's Landing, the Maze Road Bridge, and Vernalis. Each week the forecast also includes discussion of the model results, the major model assumptions, and the model inputs.

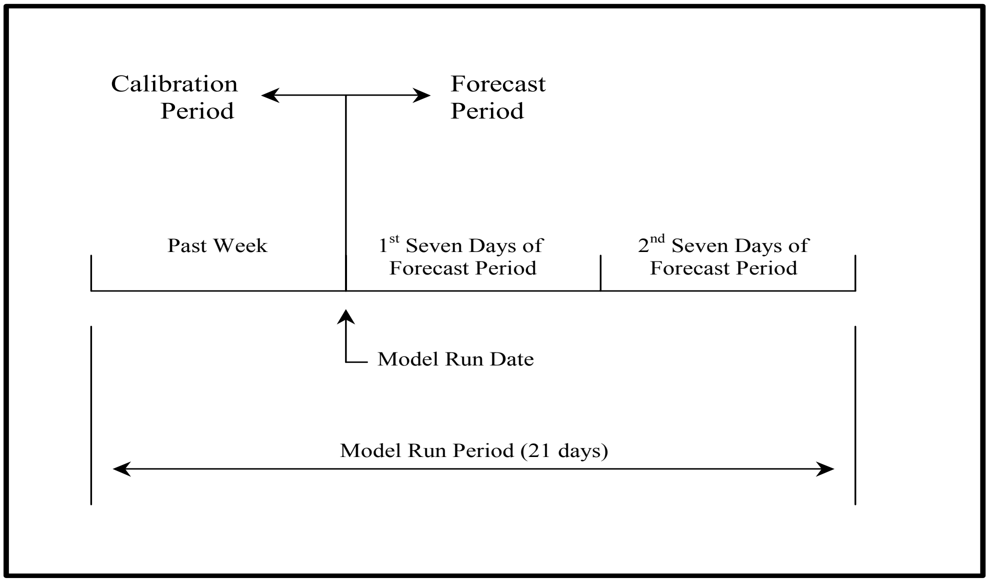


Figure 12. SJRIODAY forecast structure

Figure 13 is a screen capture from an actual forecast that was posted in May of 2002. The forecast period depicted in Figure 3 coincides with the latter portion of the VAMP pulse flow period. The San Joaquin River Group Authority and the VAMP participants develop projections of supplemental VAMP pulse flow releases from the Stanislaus, Merced, and Tuolumne Rivers. These projections are used by the RTWQMP staff as input

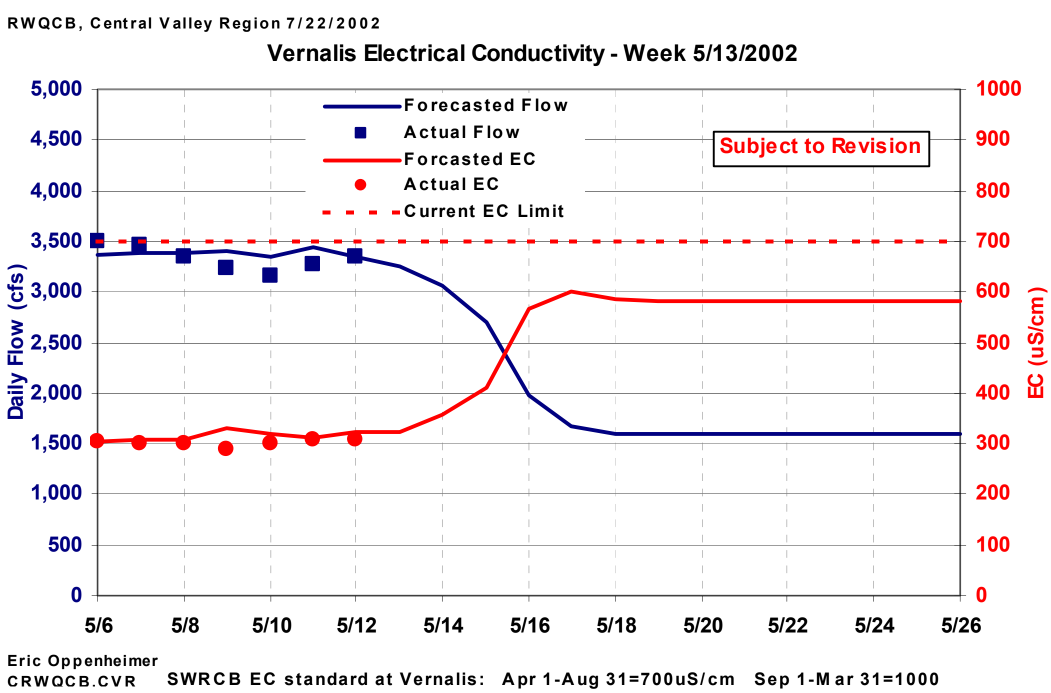


Figure 13. Example forecast from SJRMP Real-Time Program website

to SJRIO when developing forecasts during the VAMP period. In this example, a sharp drop in flow and a corresponding increase in EC are forecasted during mid May, which coincides with conclusion of VAMP pulse flow period. This example forecast illustrates that VAMP pulse flows provide increased assimilative capacity in the river, which provide opportunity to discharge salt loads built-up during times of restricted discharge.

5.4 Ongoing model development

During 2001 a hydrodynamic version of the SJRIODAY model was developed by DWR in partnership with the SJRMP-WQS. The DSM2-SJR model utilizes the DSM-2 model code and was calibrated for flow and electrical conductivity for 1998 – 2001 using 15 minute gauge station data. Although the model was not used by the SJRMP-WQS for its routine forecasting, the model has been used by DWR planning staff and others involved in the Stockton Dissolved Oxygen TMDL. This has significance to the SJRRP because the DSM-2 model contains the functionality to perform temperature modeling and considers algal growth and cycling of important water borne nutrients. Since DWR has interest in extending the current DSM2-SJR model up the major tributaries including the San Joaquin River, this is a potential enterprise the SJRRP may want to pay close attention to. A model will be essential to the SJRRP if it plans to optimize the potential benefits of temperature releases from Friant by banking water and estimating properly sized release volumes to maximize benefits to spawning and migrating fish.

6.0 Summary

The SJRRP has recognized the potential importance of real-time monitoring and management to the success of the SJR restoration endeavor. The first step to realizing making real-time management a reality on the middle San Joaquin River between Friant Dam and the Merced River will be the installation and operation of a network of permanent telemetered gauging stations that will allow optimization of reservoir releases made specifically for fish water temperature management. Given the limited reservoir storage volume available to the SJJRP, this functionality will allow the development of an adaptive management program, similar in concept to the VAMP though with different objectives. The virtue of this approach is that as management of the middle SJR becomes more routine, additional sensors can be added to the sensor network, initially deployed, to continue to improve conditions for anadromous fish.

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7.0 Appendix A

This appendix contains price quotations from Design Analysis Inc and Campbell Scientific Inc. whose equipment are recommended as part of a network of permanent real-time stage, temperature and water quality monitoring stations in the San Joaquin River between Friant Dam and the Merced River confluence.

Dear Nigel:

The WaterLOG Division of Design Analysis Associates, Inc., is pleased to provide the following price quote for our WaterLOG products.

Part Number	Description	Unit	Unit Cost
H350XL/H355	High level Data Logger/Sensor with Gas Purge System. Please state 0-15 or 0-30 PSI when ordering.	each	$3495.00
H355DES2	Desiccating Air Dryer (4400 cubic ft.)	each	$247.50
H250BRD	Instrument Mounting Panel	each	$214.50
Total Instrument Costs			$3957.00

Optional Accessory:

H355OL	Orifice Line, 1,000 Ft. Roll (sold only in 1,000 Ft. rolls)	per roll	$295.00

Warranty: 1 year
Delivery: 4 - 6 Weeks
Terms: Net 30 Days
F.C.A.: Destination

Prices listed are GSA prices. All items are on GSA Contract No. GS-24F-1443C.

Nigel, if the purchasing entity is not a Federal agency, please have them provide a letter of authorization to purchase off the GSA Contract from the Federal agency they are working with.

Thank you for the opportunity to provide this quote. This quote shall remain valid for 30 days.

If you have any questions, please contact me or Gary Baker.

Regards,

Robin Downs
Design Analysis Associates, Inc.
75 West 100 South
Logan, Utah 84321
Phone: (435) 753-2212
rdowns@daa-utah.com

CAMPBELL SCIENTIFIC, INC.

815 W 1800 N · Logan, UT 84321-1784 · USA · (435) 753-2342
FAX (435) 750-9540 · www.campbellsci.com
Fed. I.D. #87-0305157 · DUNS#06-798-0730

*** Please reference our Quote number on your Purchase Order ***

PROFORMA INVOICE **PRICE QUOTATION**

Quote Number: 37291
Quote Date: 13-MAR-03
Page: 1 of 2
Valid Through: 12-MAY-03

USER ADDRESS:

NIGEL QUINN
LAWRENCE BERKELEY LAB
BLDG 70A-3317H
1 CYCLOTRON RD
BERKELEY, CA 94720-8015

TEL: (510) 486-7056
FAX: (510) 486-7152

DO NOT INSURE. GOVERNMENT ORDER SELF INSURED.

RFQ#	Terms	Freight Terms	Est. Ship Date	CSI Contact
	NET 30 DAYS	PREPAID & ADD	30 DAYS ARO	CURTIS MAUGHAN

Line	Item	**CO	Description	Qty Ord	Unit	Selling Price	Ext. Price
1	CR10X	US	**MEASUREMENT & CONTROL MODULE W/ WIRING PANEL & 128K MEMORY	1	EACH	1,154.30	1,154.30
2	MSX20R	IN	20 WATT REGULATED SOLAR PANEL	1	EACH	450.00	450.00
3	15875	BE	ENC 12/14 WEATHER-RESISTANT ENCLOSURE 12 X 14 INCH	1	EACH	195.00	195.00
3	5961	US	ENC 12/14 OPTION W/1 CONDUIT FOR CABLES	1	EACH	0.00	0.00
3	7839	US	ENC SINGLE NOTCH MOUNTS FOR USE W/TRIPODS OR TOWERS FOR 12 X 14	1	EACH	35.00	35.00
4	CS547A-L	US	**WATER CONDUCTIVITY PROBE	1	EACH	291.00	291.00
4	7359	US	WIR 22 AWG 4 COND SHLD/POLYUR JKT 60MIL-	100	FEET	0.65	65.00
5	A547	US	**CS547A CONDUCTIVITY INTERFACE	1	EACH	97.00	97.00
6	15663	US	**SC32B OPTICALLY ISOLATED RS-232 INTERFACE	1	EACH	87.30	87.30
7	LOGGERNET	US	**DATALOGGER SUPPORT SOFTWARE	1	EACH	383.15	383.15
8	FRGT		FREIGHT – ESTIMATED FREIGHT TO BERKELEY CA	1	EACH	22.00	22.00

NOTE: ** ITEMS REFLECT GSA PRICING (INCLUDING ANY QTY DISCOUNTS), FOB DESTINATION; ALL OTHER ITEMS ARE OPEN MARKET, FOB LOGAN, UTAH GSA CONTRACT NUMBER: GS 25F 6042D, EFFECTIVE THROUGH NOV 2005

**Country Of Origin

AUTHORIZED SIGNATURE
x Curtis Maughan

WARRANTY POLICY: CSI warrants products manufactured by CSI to be free from defects in materials and workmanship under normal use and service for twelve (12) months from date of shipment unless specified otherwise, subject to the following conditions: CSI's obligation under this warranty is limited to repairing or replacing (at CSI's option) products which have been returned prepaid to CSI. CSI will return warranted equipment by surface carrier prepaid. This warranty shall not apply to any CSI products which have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. Batteries are not warranted. Under no circumstances will CSI reimburse the claimant for costs incurred in removing and/or reinstalling equipment. This warranty, and CSI's obligation thereunder, is in lieu of all other warranties of suitability and fitness for a particular purpose. CSI is not liable for consequential damages.

CAMPBELL SCIENTIFIC, INC.

815 W 1800 N · Logan, UT 84321-1784 · USA · (435) 753-2342
FAX (435) 750-9540 · www.campbellsci.com
Fed. I.D. #87-0305157 · DUNS#06-798-0730

PROFORMA INVOICE   PRICE QUOTATION

Quote Number: 37291
Quote Date: 13-MAR-03
Page: 2 of 2
Valid Through: 12-MAY-03

* Please reference our Quote number on your Purchase Order *

USER ADDRESS:

NIGEL QUINN
LAWRENCE BERKELEY LAB
BLDG 70A-3317H
1 CYCLOTRON RD
BERKELEY, CA 94720-8015

TEL: (510) 486-7056
FAX: (510) 486-7152

DO NOT INSURE. GOVERNMENT ORDER SELF INSURED.

RFQ#	Terms	Freight Terms	Est. Ship Date	CSI Contact
	NET 30 DAYS	PREPAID & ADD	30 DAYS ARO	CURTIS MAUGHAN

Line	Item	**CO	Description	Qty Ord	Unit	Selling Price	Ext. Price

Subtotal: $2,779.75
Tax: $ .00
* TOTAL USD * $2,779.75

NOTE: ** ITEMS REFLECT GSA PRICING (INCLUDING ANY QTY DISCOUNTS), FOB DESTINATION; ALL OTHER ITEMS ARE OPEN MARKET, FOB LOGAN, UTAH GSA CONTRACT NUMBER: GS 25F 6042D, EFFECTIVE THROUGH NOV 2005

**Country Of Origin

AUTHORIZED SIGNATURE
x Curtis L. Maughan / MKD

WARRANTY POLICY: CSI warrants products manufactured by CSI to be free from defects in materials and workmanship under normal use and service for twelve (12) months from date of shipment unless specified otherwise, subject to the following conditions: CSI's obligation under this warranty is limited to repairing or replacing (at CSI's option) products which have been returned prepaid to CSI. CSI will return warranted equipment by surface carrier prepaid. This warranty shall not apply to any CSI products which have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. Batteries are not warranted. Under no circumstances will CSI reimburse the claimant for costs incurred in removing and/or reinstalling equipment. This warranty, and CSI's obligation thereunder, is in lieu of all other warranties of suitability and fitness for a particular purpose. CSI is not liable for consequential damages.