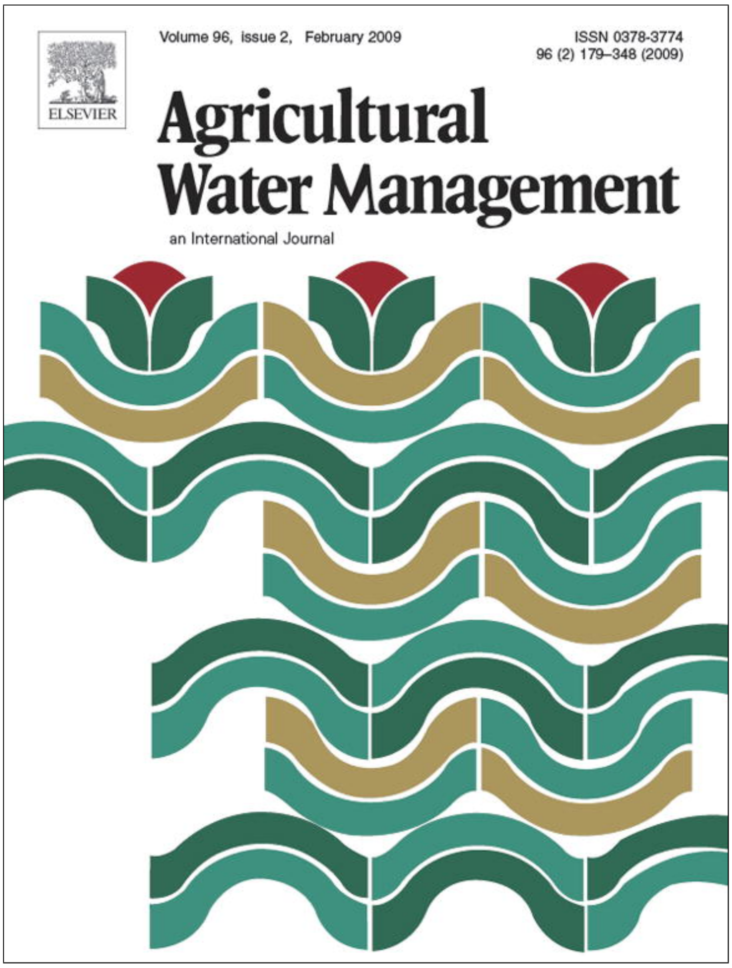
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# Environmental decision support system development for seasonal wetland salt management in a river basin subjected to water quality regulation

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ABSTRACT

Seasonally managed wetlands in the Grasslands Basin on the west-side of California's San Joaquin Valley provide food and shelter for migratory wildfowl during winter months and sport for waterfowl hunters during the annual duck season. Surface water supply to these wetlands contain salt which, when drained to the San Joaquin River (SJR) during the annual drawdown period, can negatively impact water quality and cause concern to downstream agricultural riparian water diverters. Recent environmental regulation, limiting discharges salinity to the SJR and primarily targeting agricultural non-point sources, now also targets return flows from seasonally managed wetlands. Real-time water quality management has been advocated as a means of continuously matching salt loads discharged from agricultural, wetland and municipal operations to the assimilative capacity of the SJR. Past attempts to build environmental monitoring and decision support systems (EDSS's) to implement this concept have enjoyed limited success for reasons that are discussed in this paper. These reasons are discussed in the context of more general challenges facing the successful implementation of a comprehensive environmental monitoring, modelling and decision support system for the SJR Basin.



## 1. Introduction

Seasonally managed wetlands in the western San Joaquin Basin of California's Central Valley provide overwintering habitat for migratory waterfowl and hunting opportunities during the annual duck hunting season. Two decades ago these wetlands received agricultural drainage return flows as a means of increasing water supply until it was discovered that evapoconcentration of the saline and seleniferous drainage in open ponds caused selenium teratogenicity in waterfowl embryos. Free of harmful concentrations of selenium, wetland water supply is now supplied by canal from the Sacramento—San Joaquin River (SJR) Delta but still contains inorganic salts which evapoconcentrate in the man-made, seasonally managed ponds, before being drained (between late March and early May) into channels that flow into the SJR. The wetland drainage (drawdown) schedule often coincides with the germination period of salt sensitive agricultural crops, irrigated with water pumped from the River more than 100 km downstream in the South Delta. Seasonal wetland drainage produced within a 50,000 ha wetland ecological complex, known as the Grasslands ecological area (GEA) must be eliminated to preserve salt balance and preserve habitat conditions that make them the most important migratory bird

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resource in the western United States. During dry and critically dry years dilution flows from the Sierran tributaries to the SJR diminish and can no longer prevent frequent violations of the State water quality objectives for salinity from occurring. The compliance monitoring station for salinity on the SJR is located at a site immediately upstream of any tidal influence.

Recent environmental regulation promulgated as total maximum daily loads (TMDL's) limit agricultural discharges of salt loads to the SJR—drainage salt loads from seasonally managed wetlands are subject to the same numerical constraints (CEPA, 2002). During dry and critically dry years the salt TMDL is especially restrictive allowing no salt load export to the SJR during the summer months when drainage return flows are typically highest and the impacts due to restricted drainage most severe. Seasonally managed wetlands, which mostly drain during the months of March and April each year will also be restricted in their drainage salt load export to the River. These restrictions could have significant impacts on wetland habitat quality and their long-term resource potential as overwintering habitat for waterfowl.

Real-time water quality management (RTWQM) has been advocated as a means of improving SJR water quality by better coordinating the discharge of salt loads from west-side San Joaquin Basin agricultural, wetland and municipal dischargers with east-side San Joaquin Basin reservoir releases and irrigation return flows that provide dilution. RTWQM is a concept that relies upon access to real-time flow and water quality data from networks of flow and water quality (electrical conductivity and temperature) sensors on the SJR (Quinn and Karkoski, 1998) and which involves watershed flow and water quality modelling, salt assimilative capacity forecasting in the SJR and information dissemination as part of an environmental decision support system (EDSS).

The ultimate goal of projects underway in support of RTWQM is to develop a comprehensive monitoring and modelling system that provides timely decision support to agricultural water districts and seasonal wetland managers—allowing them to improve the coordination of salt load export with the available assimilative capacity of the SJR (Quinn and Hanna, 2003). Although salinity management has been practiced within west-side SJR Basin agricultural water districts for more than 100 years and salinity management has only become a concern to seasonally managed wetlands since the announcement of the salt TMDL—progress towards RTWQM is more advanced in the wetland areas. This is largely because of the more serious long-term consequences of restricted salt export in the seasonally managed wetlands.

Alteration of the schedule of annual wetland drawdown comes at a potential cost to the sustainability of optimal moist soil plant habitat in seasonally managed wetlands (Fredrickson and Taylor, 1982; Quinn et al., 2005). Hence any project that suggests alteration of the hydrology of these lands needs to investigate long-term soil salinity and vegetation response as a result of the intervention and to quantify the environmental impact and cost of various altered drawdown management scenarios compared to traditional practices (Prato, 2005). Current projects addressing these questions are multidisciplinary collaborations between the Grassland Water District, Lawrence Berkeley National Laboratory, the Department of Fish and Game, the US Bureau of Reclamation and the University of California, Merced.

## 2. Legacy environmental decision support systems

Past attempts to build integrated environmental monitoring and decision support systems to improve salinity management in the SJR Basin and, more specifically, to implement the concept of RTWQM in seasonally managed wetland, have enjoyed limited success. Water quality management in large river basins and the use of EDSS's to guide decision making is still in its infancy in the US. Janssen et al. (2005), Denzer (2005) and Poch et al. (2004) describe European efforts in EDSS development – the Janssen et al. paper focusing on a project-relevant topic of wetland decision support – albeit for drained peat meadows in polders below sea level. What is striking from the European experience is the relative ease of implementation of data sharing networks, particularly exemplified in Denzer's paper.

Our experience in California is less impressive—the nature of a less centrally planned and more institutionally fragmented approach to environmental decision making makes the provision of decision support more complicated. To develop the comprehensive datasets needed to develop the simulation models, which in turn could be used to provide reliable decision support, requires the cooperation of stakeholders with no current incentive to share information about their operations and the salt loading to the River contributed by their return flows. Central-planning concepts are viewed with scepticism in a watershed where agriculture, municipal and industrial uses and the environment all compete for scarce water supply. Our home-grown EDSS's lag those of many European nations in the area of common data management frameworks and modular simulation models (e.g. models produced by the Danish Hydrologic Institute, Wallingford and Delft Hydraulics) that can be shared among water agencies, regulators and the private sector. Few California EDSS development projects enjoy long-term institutional support such as the European Community initiative known as ORCHESTRA (Denzer, 2005), a collaboration of more than a dozen countries and research institutions that have developed a common platform for water resource management and the provision of emergency response services. Data sharing is made possible between different countries, sectors and water agencies through a database architecture that is based on a common naming ontology.

In the SJR Basin many large budget projects are led by academic institutions, private consultants or agencies with a poor track record of long-term collaboration and data sharing. Many projects have a lifespan of only 3–5 years after which the project team disbands to be replaced by another following the next round of grant announcements. This is a difficult environment within which to build the type of institutional infrastructure needed to realize RTWQM. Projects appear to fail more through an inability to provide a long-term venue for the orchestra, to use a musical analogy, than the technical competence of any one of the instruments on the podium.

The remainder of this paper is a narrative on some of the observations made by the author over the past decade as he and others have attempted to implement the concepts of RTWQM within the SJR Basin. Seasonally managed wetlands provide the most compelling example of the merits of RTWQM—given that their salt loads exports coincide with periods of relatively high SJR assimilative capacity allowing significantly greater export volumes and loads than would be allowable under a typical salinity EPA-mandated salinity TMDL. For this reason the initial discussion focuses on our collective experience—success and failure in implementing RTWQM in the 50,000 ha GEA. It is likely that RTWQM applied to seasonally managed wetlands in the GEA will become the exemplar for RTWQM applied to the entire SJR Basin. Lessons learned from implementation of RTWQM in the GEA and some of the technologies that are being developed and evaluated may have direct relevance to implementation of the concept within the larger system.

### 2.1. *Development of an environmental decision support system should involve the end user at the conceptual and design phases of the project. Involvement should be more than mere inclusion, rather it should be an earnest effort to imagine the problem from the end-user's perspective and to extract pertinent information relevant to the design of the EDSS*

End user involvement has become a cliché within the EDSS developer community—however at every meeting of practitioners it is mentioned as the most common reason for non-achievement of project goals. Why can't we get this right? In California since many of our EDSS projects originate in the University environment – few research projects develop the level of collaboration needed, or have a sufficiently complete work product after 3–5 years, to allow a migration from conceptual to implementation phase. EDSS architectures designed to address the questions the student and the advisor or the study team think are most interesting and pertinent – are often very different questions that those relevant to the end-user who makes day-to-day decisions. Post-development adoption of an EDSS to the needs of the end-user are usually futile because the conceptual system behavior model is often fundamentally different for the developer and the practitioner – new technology take time to infiltrate current institutions and become adopted – by that time most projects have ended and the project team have moved on to new endeavors.

A relevant example of this issue was the collaborative development of an EDSS called the Natural Resources Workstation. This project was undertaken to improve understanding of wetland water balance and to assist in optimization of water use practices for federal and private wetlands within the GEA. The EDSS utilized the latest in Unix-based graphics libraries and was fully integrated with GRASS GIS software. In demonstrations to potential end-users of the software the feedback provided by wetland managers was very positive—most wetland water managers saw at least one or two features they really liked in the EDSS. The final version of the EDSS was turned over to one wetland water manager, after extensive beta-testing in the presence of his peers, together with the Unix workstation platform on which the software had been developed. Additional staff were trained in the use of the software on-site and the water manager flown to Colorado State University, where the EDSS was developed, for more intensive training.

However, the results of an informal survey of EDSS adoption, performed after the first year were disappointing. Feedback suggested that although the EDSS had been designed to accept continuous data inputs, it required certain input data that were not readily at hand or easily quantifiable. Our respondents felt the EDSS was more geared to developing a conceptual understanding of the system rather than solving problems at hand. Water managers were too busy to invest time calibrating the underlying conceptual model response to their own conceptual framework. If they could not obtain answers within minutes of posing a question they preferred to use their own best judgment. There is no recipe or universally applicable code of practice for user-involvement in EDSS development. It is in the details that many EDSS's succeed or fail.

### 2.2. *EDSS technology transfer and the institutional resources available to the long-term user(s) of the EDSS should be considered as part of the design and development process. These issues are typically only considered towards the end of a project after technical challenges have been addressed—leaving inadequate time to ensure continuity*

Eliciting pertinent information from the EDSS end-user should be an active not a passive activity since it often turns out to be the most critical element of EDSS design. Often the fun in EDSS design is in the interface and the integration of simulation models to describe the behavior of the system, ignoring the human element – which, in our case, is how water managers utilize environmental information. Understanding the human factors in EDSS design requires skill in fields of sociology and human psychology rather than in computer science – sadly skills that are not taught or easily acquired. Creativity is required in the development of system analogues and simulation prototypes to provide end-user early feedback on the EDSS architecture.

Stakeholder concerns within the GEA, prompted by the threat of future regulation of wetland salt export and exacerbated by a lack of watershed water quality data (to fully assess the contributions being made by managed wetlands to the salinity problem in the SJR)—created an opportunity to successfully implement one component of the EDSS design. One wetland partner, the Grassland Water District, found that web posting of flow and salt loading data from their major drainage outlets useful in improving understanding of the seasonality of their salt exports—wetland managers within the District began to develop an appreciation of the relationship between these salt exports and water quality conditions within the SJR. The Water District serves 160 individual duck clubs and used the website as a means of demonstrating to its customers as well as to State regulators its proactive response to improving water quality management. The public website for the EDSS data management system is shown in Fig. 1.

Despite the success in providing pertinent information to wetland managers and assurances to regulators—the EDSS failed to become self-sustaining after 4 years of operation.

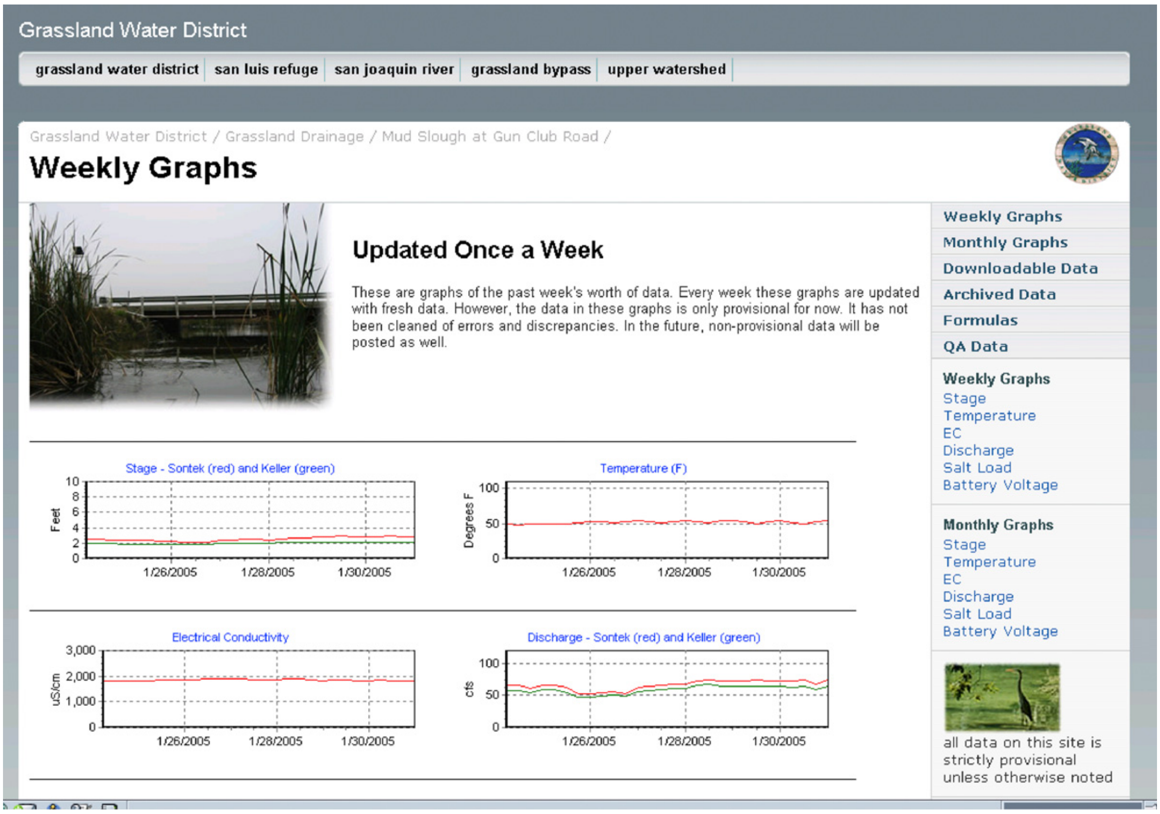


**Fig. 1 – Automated web posting of wetland discharge flow and salt loading data as part of a previous EDSS development project.**

Data continuously collected at each flow and water quality monitoring station was downloaded daily to a computer at Lawrence Berkeley National Laboratory (LBNL) where it was error checked and corrected where necessary, graphed and transformed to jpeg images as weekly and monthly plots. These graphical jpeg files were transmitted daily, via ftp, to a public web server based at LBNL. The project website was updated daily. However, when the student who was responsible for this work resigned after 2 years, the water district could not find the personnel who had the time or the technical skill to take over this function. Web delivery of the processed water quality data ceased for 3 years until a new product, YSI-ECONET was launched in 2005. This technology integrates sensor hardware (water quality sonde) and data-logger with software that performs the data downloading, data storage and visualization of the summarized 15 min data. This has become part of a custom service provided by the NIVIS Data Center (a remote data storage and processing facility) through a service contract with YSI Inc. Though more costly than the previous LBNL-provided system – it has conformed better to the District's existing staff resources and in-house expertise. Although we gained certain efficiencies by handling the data processing tasks at LBNL we later concluded that having the data processing tasks performed by the Water District, would have forced a closer working relationship between the water managers and those working with the data.

### 2.3. *Commercial environmental hardware and software products can be attractive alternatives to home-grown EDSS solutions—especially when backed by large corporations with the ability to support their technology. However innovators who are the first to implement a new technology should be cautious since system bugs are to be expected and a potentially successful EDSS project can be harmed if the system does not fully meet stakeholder expectations*

The procedures of downloading and validating monitoring station data so that it can be web posted are tedious and the volume of work can be overwhelming if large numbers of monitoring sites are involved. Wildlife biologists and wetland managers have chosen an outdoors lifestyle and are unhappy spending long hours in front of a computer. Hence automation of these processes was attempted, as previously described. However, software that was designed to automate the downloading, error-checking and parsing of data sometimes hiccupped—requiring daily checking. Visualization software designed to create gif formatted images for web posting of real-time flow and water quality data would freeze occasionally requiring system rebooting.

A commercial data telemetry and processing EDSS solution – YSI ECONET (YSI Inc., 2005) – was adopted to eliminate the operational constraints of the previous, custom-developed EDSS technology. YSI ECONET is a remote monitoring platform that provides wireless data acquisition, remote monitoring

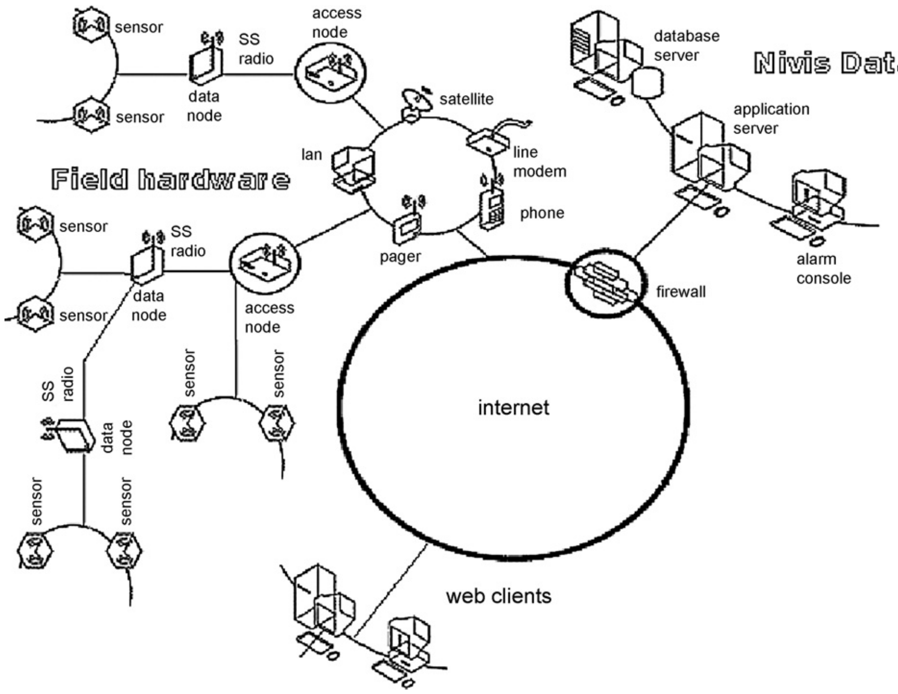


**Fig. 2 – System architecture linking field monitoring stations with external NIVIS Data Center which stores, maintains and serves real-time flow and water quality data on public and private website.**

and control over the Internet (Fig. 2). The system is comprised of a mesh of data nodes that collect data from water quality and flow measuring sensors at each monitoring location and access nodes that have the added capability of collecting data via a low power radio interface from surrounding data nodes. The access node transmits logged data to a remote Data Center via CDMA cellular phone or satellite modem from which the data is made accessible through the Internet. The data node can compare the acquired data against predefined alarm thresholds (minimum and maximum) and immediately notify the access node when the input values are outside the defined range. The wireless mesh network topology allows "point-to-point" or "peer-to-peer" connectivity and creates an ad hoc, multi-hop network. The mesh network is self-organizing and self-healing—hence loss of one or more nodes does not necessarily affect its operation. This increases the overall reliability of the system by allowing a fast local response to critical events in the rare event of a communication problem.

Elimination of tedious data acquisition and processing procedures through adoption of YSI-ECONET has freed up time in our current monitoring system deployments allowing more focus on bi-weekly sensor quality assurance checks including cleaning of sensors and checking the accuracy of staff gauge data from which flow is determined. Wetland biologists and wetland water managers appreciate the ability to review monitoring site data ahead of these checks which helps preparation for contingencies such as sensor failure prior to traveling to the site. In the GEA monitoring sites are as distant as 30 km apart.

Although our decision to embrace YSI-ECONET has been applauded by project advocates—it was the first major deployment of the technology on the west-coast of the United States and we suffered some of the technical issues that sometimes beset innovators. Modem failure was a problem at the beginning of the project. The software design did not allow direct communication with the dataloggers—as a result each monitoring site had to be taken off the network and the datalogger "brick" express mailed to the East Coast of the US for repair. This caused the loss of valuable data and in the case of access node modem failure data loss from more than one station. This problem was addressed by substitution with more reliable modems and with the provision of a supply of spare modems by the manufacturer which we were able to install ourselves.

Another technical issue was that the data posted on the website was preliminary data and there was no mechanism for correcting the posted data or migrating the preliminary data to another web location after quality assurance data validation had been performed. Inaccurate or absurd data posted to a project website can cause irreparable harm to a project and can quickly lead to a loss of confidence in the stakeholder community. Our MACE acoustic Doppler meters (MACE, 2008) provided very accurate measurements of water stage and velocity in culverts and small channels—however although totalized flow calculations were accurate when downloaded from the MACE data collection platform they were 100 times too high when transmitted using the SDI-12 protocol to the YSI-ECONET datalogger. This turned out to be a programming error in the firmware—a decimal point was omitted in the program and re-inserted during output processing. This error was caught by one of our project cooperators and took several months to resolve.

Environmental monitoring technology has improved significantly in the past decade—however every innovation comes with a new suite of potential problems. Adopters of new technologies need to vigilant—complacency can severely set back technology transfer and future adoption of potentially viable solutions for RTWQM.

### 2.4. *An ideal EDSS for RTWQM will guide the user through the sequential steps of monitoring site data acquisition, data processing and validation, simulation modelling and flow and water quality forecasting. Data acquisition and management protocols should be seamlessly linked through map-based interfaces for visualization by the stakeholder community and with simulation and forecasting models for ease of use by modelers. The EDSS needs to provide economic value to its users to ensure long-term provision of data essential for its use as a decision tool*

RTWQM involves the steps of monitoring, data acquisition, data processing and visualization, simulation modelling of basin hydrology and both flow and water quality forecasting. One of the most time consuming and onerous tasks is the conversion of raw data into information that simulation and forecasting models require to become useful as decision support tools within the EDSS. Forecasting models rely on continuous data feeds from the real-time network of flow and water quality sensors as well as information on future operations. These operations determine drainage return flows and reservoir releases to the River and its tributaries as well as pumped irrigation diversions that can affect the River's assimilative capacity. Full implementation of an EDSS for the GEA will require assessment of SJR assimilative capacity. Wetland salt load discharge from the GEA will constrained by daily salt load targets that may be formulated as a percentage of the total SJR assimilative capacity.

The first attempt at developing a forecasting EDSS for the SJR relied on a customized graphical user interface (GUI) which was developed to interact with a data-driven flow and water quality model of the main stem of the SJR—a 100 km reach between Lander Avenue and Vernalis. The San Joaquin River input–output model (SJRIO) used hydrologic routing techniques and conservative mass transport to calculate water quality at frequent (less than 1 km) intervals along the SJR and accounted for all major tributary inflows and diversions (Kratzer et al., 1987). The GUI facilitated the inspection of real-time flow and water quality data and featured internet communication and downloading capabilities that expedited the collection of agency hydrologic and water quality input data as well as the dissemination of flow and water quality forecasts. The easy-to-use features of the GUI included the point-and-click system of Windows™, on screen data entry, map-based outputs, and internet-based communication (Fig. 3). Routines were developed to upload operational schedules or to download model results. Reservoir operators were able to enter daily schedules of diversions and discharges and upload these schedules every 2 weeks to the person making the flow and water quality forecasts. Likewise, this person could also use the GUI to download operational schedules from agencies where data is routinely posted to a public ftp site. The user could scroll through a display of dates, viewing the temporal variations of water quality parameters at any map location on the screen and can display spatial color-coded changes in water quality at any given time. By clicking at a time advance button, the user

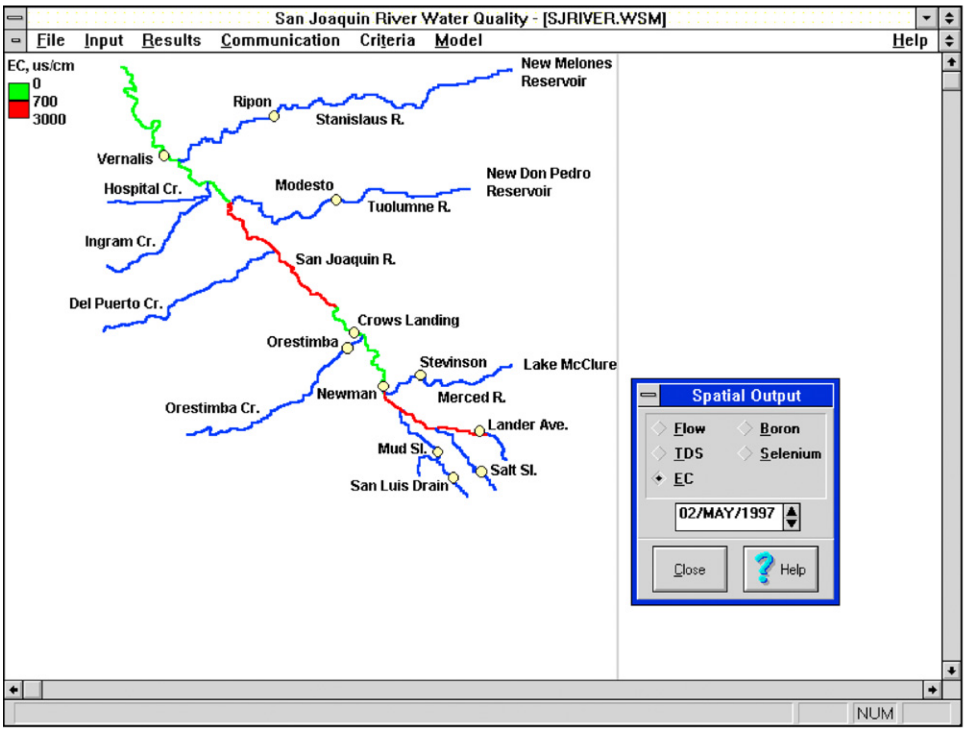


**Fig. 3 – Graphical user interface for an EDSS developed to aid forecasting of SJR salt assimilative capacity and allow model users to visualize the impacts of actions to limit salt loading from west-side tributaries.**

could create a near-animation of how a slug of poor quality water moves through SJR.

The GUI allowed 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 2 weeks projected operation. Water managers could then upload their operational schedule to the ftp site for use by the person responsible for making model runs, who would incorporate the information into simulation model input data. Water managers could download model run results from the FTP site, display the results and review the run-specific comments. Water managers who decided to change their operational schedule as a result of a review of model output could contact those responsible for making the forecast model runs by telephone or email. The model run input data could then be revised and the forecast model rerun and the revised output posted on the ftp site.

Despite the fact that the EDSS had anticipated and solved, technically, many of the essential data management issues associated with RTWQM—the institutional arrangements necessary to make sure that reservoir and drainage flow and water quality data was routinely uploaded to the ftp site were not sufficiently binding. For several months at the beginning of the project cooperating water districts and agencies were diligent at providing data weekly – however over time as staff became busy with other more pressing tasks and with changes in staff assignments – provision of data essential for developing model-based forecasts became less reliable. It became clear that unless we could demonstrate a clear economic rationale to these entities as to why they should continue to provide a service to our project, or support the effort with our own project funds that we could not rely on their long-term cooperation.

The original EDSS design relied on a dedicated computer housed in the Department of Water Resources in Fresno—EDSS user's would use the GUI, loaded on their own computer, to update the model with the latest data. This required connection to the centrally located computer. After the first 6 months of the project, noticing a significant decline in both co-operator data uploading activity and EDSS user downloading for model updates we decided to simplify information flow and EDSS system management by running the forecasting model in-house and posting weekly updates of the results. Responsibility for running the model was shared equally between the California Department of Water Resources (DWR), Berkeley National Laboratory and the California Regional Water Quality Control Board. All data compilation was assigned to the team responsible for each forecast. Automated data feeds were developed for web-served flow and water quality data from the California Data Exchange (CDEC) and the US Geological Survey. This basic EDSS design has been continued by DWR to the present although funding has limited the scope of the program and DWR has become the sole operator.

More recent development in the forecasting EDSS for RTWQM has been the replacement of the SJRIO model with the more comprehensive watershed model WARMF (Herr and Chen, 2006). WARMF-SJR simulates the hydrology of the watershed contribution to the SJR and tracks a broad suite of agricultural nutrients and contaminants in addition to river tributary inflow and salt loading. In WARMF-SJR wetland drainage from the GEA is partitioned by area according to component State, Federal and private wetland contributors as well as by Mud Slough, Salt Slough and Los Banos Creek which are the major tributary contributors of salt load to the SJR.

WARMF-SJR has been used for a number of studies during the past 18 months including studies of SJR flow recirculation, algal loading to the Stockton Deep Water Ship Canal and SJR restoration hydrology and water quality and has been independently peer reviewed by east-side Basin agricultural stakeholders. It is anticipated that the initial goal of the EDSS design will be realized with the advent of the WARMF-SJR model—given widespread financial support for WARMF-SJR modelling studies, the regulatory requirements of the salinity TMDL for dischargers of salt load and major agency backing for the concept of RTWQM.

### 2.5. *EDSS design should strive to include uncertainty in the conceptual, simulation and forecasting models that provide the decision support engine. This should be accomplished without confusing the end-user or causing the stakeholders to lose confidence in the EDSS*

The move away from deterministic models and EDSS's that incorporate them has been a goal of water resource systems professionals for more than a decade. There is a fear that without adequate recognition of uncertainty policy makers will make poor decisions and formulate water and water-related policies that may be unwise or potentially hazardous to sound water resources management. One of the prevalent fears among land owners in both the agricultural and wetland communities is the tendency among policy analysts to extrapolate limited data and formulate policies that work against Basin stakeholder interests. Given the dearth of reliable watershed water quality and pollutant loading data this is sadly a legitimate fear. Presentation of relevant information in a clear manner that describes the limitations of the data while keeping the EDSS simple, penetrable and non-intimidating is good practice to accommodate professionals charged with making decisions and advising those formulating policy.

The approach taken in the current RTWQM projects has been to address system heterogeneity and data uncertainty by standardizing technology to the extent possible. This objective has been applied to environmental monitoring and the types of sensors deployed and their manufacturer for flow and electrical conductivity measurements. Also to data collection platforms and telemetry systems which relay the data to agency or water district databases or in the case of YSI-ECONET to a commercial data storage facility where data is archived and made available through the company web server. Centralized storage of environmental data facilitates the development of software for automation of data feeds to simulation and forecasting models that form the basis of EDSS's used to provide decision support for RTWQM. Centralized data storage also makes it easier to take advantage of powerful data visualization software tools that can be used to explore trends and relationships within the dataset as well as provide information in a form that Basin stakeholders might more readily comprehend. Basin stakeholders are more likely to financially support an EDSS which is provides them with information with which they can make decisions or at a minimum understand the decisions made by others. It may be possible to develop rules of thumb or simple heuristics between factors such as flow and salt loading or to correlate salt loading from adjacent water district monitoring sites or wetland impoundments.

## 3. Conclusions

Significant technical advances in data acquisition and information dissemination technologies and an evolving, adaptive experiential knowledge of past EDSS successes and failures can lead to successful implementation of a real-time salinity management program in California's San Joaquin Basin. Lessons learned from the past decade of attempting to implement RTWQM in the San Joaquin Basin include: improving end-user involvement at the beginning of each EDSS project; EDSS design features that recognize the time constraints, technical expertise and work preferences of water district or wetland refuge personnel; EDSS features that provide value to a wide range of stakeholders and potential users that can be measured in economic terms; map-based model interfaces, automation and data visualization tools that allows users to populate their simulation and forecasting models efficiently and to produce output that basin stakeholders can understand and make better salt load and drainage management decisions.

New commercial technologies that promise to improve and streamline environmental management decisions often bring along their own unique problems and challenges. Software bugs and hardware malfunctions are common and early adopters are advised not to over-promise solutions, at least in the early stages of deployment, when these problems are being worked out. Commercial EDSS technologies do have some distinct advantages over their home-grown competition and are more likely to provide long-term solutions to the data acquisition, processing and dissemination tasks that are fundamental to RTWQM. Some of the innovations that will emerge as RTWQM becomes a reality in the San Joaquin Basin will have significant transfer value to other highly regulated river basins where water quality is a concern both in the US and the developing world.

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