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# Bottom-up, decision support system development : a wetland salinity management application in California's San Joaquin Valley

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**Abstract:** Seasonally managed wetlands in the Grasslands Basin 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 wetland contain salt which, when drained to the San Joaquin River during the annual drawdown period, negatively impacts downstream agricultural riparian water diverters. Recent environmental regulation, limiting discharges salinity to the San Joaquin River and primarily targeting agricultural non-point sources, now addresses return flows from seasonally managed wetlands. Real-time water quality management has been advocated as a means of matching wetland return flows to the assimilative capacity of the San Joaquin River. Past attempts to build environmental monitoring and decision support systems to implement this concept have failed for reasons that are discussed in this paper. These reasons are discussed in the context of more general challenges facing the successful implementation of environmental monitoring, modelling and decision support systems. The paper then provides details of a current research and development project which will ultimately provide wetland managers with the means of matching salt exports with the available assimilative capacity of the San Joaquin River, when fully implemented. Manipulation of the traditional wetland drawdown comes at a potential cost to the sustainability of optimal wetland moist soil plant habitat in these wetlands - hence the project provides appropriate data and a feedback and response mechanism for wetland managers to balance improvements to San Joaquin River quality with internally-generated information on the health of the wetland resource. The author concludes the paper by arguing that the architecture of the current project decision support system, when coupled with recent advances in environmental data acquisition, data processing and information dissemination technology, holds significant promise to address some of the problems described earlier in the paper that have limited past efforts to improve Basin water quality management.

**Keywords:** Monitoring, modelling, wetlands, salinity, decision support

## 1. INTRODUCTION

Seasonally managed wetlands in the Grasslands Basin of California's San Joaquin 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 caused selenium teratogenicity in waterfowl embryos. Free of harmful concentrations of selenium, wetland water supply is now imported from the Sacramento – San Joaquin River Delta but still contain inorganic salts which slowly evapoconcentrate in man-made impoundments before their annual release into the San Joaquin River between late March and early May. The timing of this wetland drawdown

typically coincides with the crop germination period of riparian agricultural entities in the Delta that divert water from the River. Water quality in the River during this period frequently exceeds State water quality objectives for salinity. These seasonal wetlands collectively form a 50,000 hectare wetland ecological complex must drain annually to preserve salt balance and preserve habitat conditions that make them the most important migratory bird resource in the western United States.

Recent environmental regulation limiting discharges salinity to the San Joaquin River, primarily targeting agricultural non-point sources, now includes return flows from seasonally managed wetlands. Real-time water quality management has been advocated as a means of matching wetland return flows to the assimilative

capacity of the San Joaquin River (Quinn and Karkoski, 1989). The ultimate goal of the current projects underway in these wetland areas is to develop a comprehensive monitoring and modeling system that provides decision support to wetland managers allowing them to match salt exports with the available assimilative capacity of the San Joaquin River (Quinn and Hanna, 2003). Alteration of the schedule of annual wetland drawdown comes at a potential cost to the sustainability of optimal moist soil plant habitat in these wetlands (Frederickson and Taylor, 1982, Quinn et al. 2005). Hence the current project also examines soil salinity and long-term vegetation response, using various forms of high resolution remote sensing, to evaluate the environmental impact and cost of various altered drawdown management scenarios compared to traditional practices. Current projects are a multidisciplinary collaboration 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 (EDSS)**

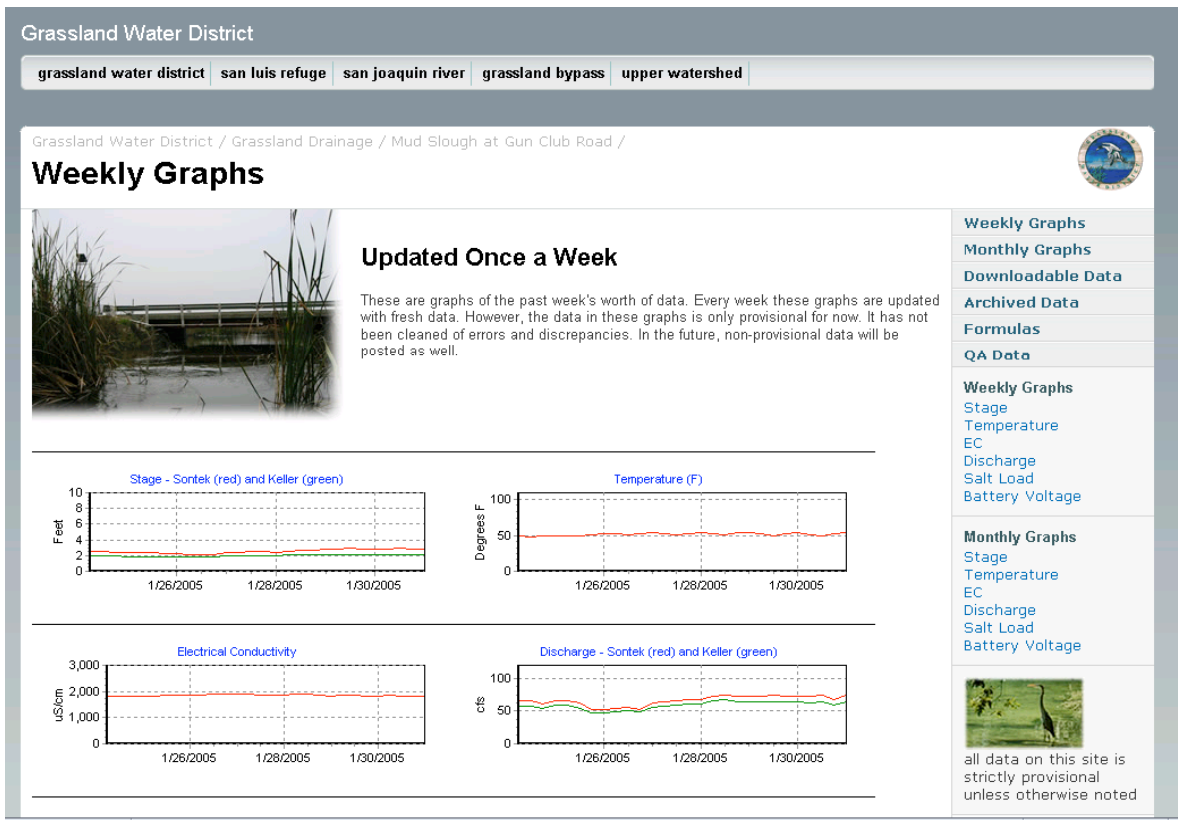
Past attempts to build integrated environmental monitoring and decision support systems to improve seasonal wetland management in California and, more specifically, to implement the concept of real-time water quality management, have mostly failed for reasons that are discussed in this paper. Janssen et al., 2005; Denzer, 2005; and Poch et al., 2004 describe European efforts in environmental decision support system 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 more free-market, adversarial approach to environmental decision making makes centralized decision support more complicated. Gaining widespread support for environmental decision support systems lags many European nations especially in the area of software and in gaining the type of institutional support necessary for successful implementation. Projects sometimes appear to fail more through an inability

to provide effective marketing than a lack of a technical solution to the problem at hand. Some additional lessons we have learned along the way are described in more detail below :

### **2.1 Development of a EDSS must involve the end user at the conceptual and design phases of the project.**

End user involvement has become a cliché within the environmental decision support system 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 many of our EDSS projects originate in the University environment - few contracts are let by funding agencies to develop these systems from scratch given the time it often takes to move between conceptual and implementation phases. EDSS architectures perhaps are designed to address those questions the student and his/her advisor think most interesting and pertinent – these are often very different questions that those relevant to the end-user who makes day-to-day decisions. Post-development adaption of the EDSS to the needs of the end-user may be futile because the conceptual frameworks system behaviour will likely differ between developer and end-user in this scenario.

A home-grown example of this assertion, from a decade ago, was the collaborative development of a Natural Resources Workstation to improve understanding of water balance and assist in assessment of water use practices for about fifty thousand hectares of managed wetlands. The EDSS utilized the latest in Unix-based graphics libraries and was fully integrated with GRASS GIS software. In demonstrations to potential end users the feedback we were given was very positive – most wetland water managers saw at least one or two features they really liked. The final version of the EDSS was turned over to the wetland water master, after extensive beta-testing in the presence of the water managers peers, together with the Unix workstation platform on which the software had been developed. Several wetland managers were trained in the use of the software on-site and one flown back to Colorado State University, where the EDSS was developed, for more intensive training. However, the results of a survey of EDSS adoption, performed after the first year were disappointing.



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

Feedback obtained from this informal survey 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 in calibrating the model response to their own conceptual framework. If they couldn't obtain answers within minutes of posing a question they preferred to use their own best judgement.

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 Involvement in EDSS development is more than mere inclusion, rather it is an earnest effort to imagine the problem from the end-user's perspective and to extract pertinent information to design an appropriate EDSS architecture.**

Eliciting pertinent information from the EDSS end-user is an active not a passive process and in many cases is the hardest part of effective EDSS design. Unfortunately the fun in EDSS design is

often in the interface and the integration of simulation models to describe the behaviour of the system, ignoring to a large extent the human component. Understanding the human factors in EDSS design is more sociology and human psychology than computer science – sadly skills that are not taught nor easily acquired. Creativity is required in the development of analogues and prototypes to provide end-user early feedback on the EDSS architecture.

Human interest in obtaining information about an aspect of a system that was previously obscure was perhaps an explanation of the success of one component of our previously described project, a component that survives more than 8 years after implementation. In this case one of our wetland partners, 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 and developing an appreciation of the relationship between these salt exports and conditions in the San Joaquin River. The Water District serves 160 individual duck clubs and used the website as a means of demonstrating to its client base as well as to State regulators its proactive attitude towards water quality management. The public website for the EDSS data management system is shown in Figure 1.

**2.3 Projects are sold to grant awarding agencies as big-ideas – however small steps are often needed to develop the firm foundation that will sustain long-term EDSS investment. Stakeholder ownership should be encouraged at every step.**

The backbone of our EDSS has been the network of continuously reporting monitoring stations that report drainage water flow, temperature, electrical conductivity, and salt load every 15 minutes. Data is telemetered by both CPDP cellular modem and via GOES satellite to a desktop computer which stores the data, whereupon a series of batch programs are activated in sequence after each data download which, in turn, error check the data, make automated adjustments according to a predefined set of rules, parse the data, create graphical images of the current and longer term data, invoke ftp and transfer the data to a web server.

Our early push to automate the system, attractive from a technical and academic perspective, did not serve the long-term sustainability goal of the project. Our other mistake was to have the information technology processing aspect of the project housed offsite – in this instance at Berkeley National Laboratory. Although we gained certain efficiencies by organizing our staff resources in this way, we eventually concluded that the data processing tasks such as error checking and parsing into data formats, if performed within the water district, would have forced a closer working relationship between the water managers and those working with the data. This was brought to sharp focus when we lost the services of our student technician at Berkeley National Laboratory and had to find suitable personnel to take over this function at the Water District, undertake a crash training class and develop a User Manual for the client software in short order to keep the system functioning.

The procedures of downloading and reducing monitoring station data into a format that could be web posted are tedious and the volume of work allowed very little time for innovation – reasons we initially sought automation. However, software that was designed to automate the downloading, error-checking and parsing of data sometimes failed. Visualization software designed to create gif formatted images for web posting of

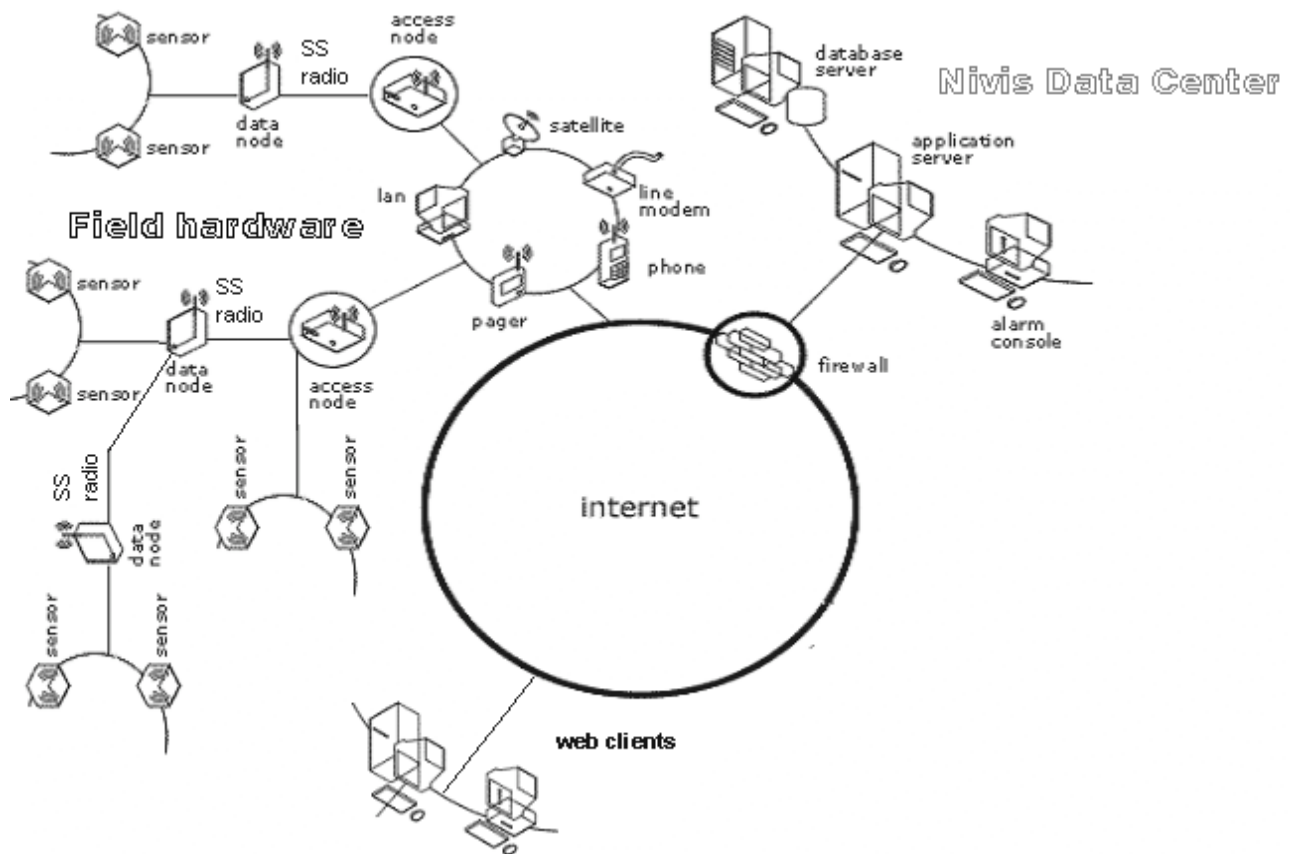
real-time flow and water quality data occasionally would freeze requiring frequent system rebooting.

Recently a state-of-the-art YSI-ECONET system architecture (YSI Inc., 2005) eliminates many of the operational constraints of the previous EDSS monitoring station platform design. YSI ECONET is a remote monitoring and control Platform that provides wireless (or wired) data acquisition, remote monitoring and control over the Internet (Figure 2). The system is comprised of Data Nodes that monitor and control water quality and flow measuring sensors. The mesh of multiple Data Nodes connects to an Access Node through a low power radio interface. The Access Node then connects to a remote DataCenter through the Internet via CDMA cellular phone or satellite modem. The Communication Server performs the communication with the Access Node, receiving data and any possible alarm messages and sending back commands and functioning parameters. 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. This feature will be used to control drainage salt loading from automated gate outlets in the next follow-on project.

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 is freeing up time in our current monitoring system deployments. The system allows point and click access to current monitoring data at a particular Data or Access Node within the network. Maintenance of the monitoring network can now focus on monthly sensor quality assurance checks including cleaning of sensors and checking the accuracy of gauge stage data from which flow is determined.

Perhaps the greatest virtue of the YSI-ECONET system is that software running on the Data Node is intuitive and the units are programmable by most technical staff in the Water District. The object-interface consists of a series of pre-built



**Figure 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 websites

routines that implement the data acquisition, control functions and communication protocols. A configuration file defines parameters such as the device ID, sampling rates, reporting frequencies, alarm thresholds and actions to be taken in case of alarms and can be readily changed through the project password protected website. The Access Node runs a small Linux Program that is independent of the application and handles the communication with the supervised Data Nodes, the Data Center and the digital input/outputs.

Evolution of the monitoring and data acquisition system has been incremental and systematic, after some initial missteps. The Water District Biologists and Water Managers can appreciate the virtues of the new system by their experience of less sophisticated technology.

**2.4 Ideally, EDSS's that combine monitoring, simulation and forecasting should be designed in a modular manner with user-friendly object-oriented interfaces that allows future developers to access to the underlying software**

Real-time wetland salinity management involves the steps of data acquisition and processing, that we have already discussed as well as simulation modeling, and salinity forecasting. In the past year we have seen a quantum leap in the ease of programming and operability of data acquisition and processing software such as YSI-ECONET – in future years we anticipate the same progress will come about in simulation and forecasting tools.

In our experience EDSS development has proceeded in one of two ways. In the first instance we have used existing modeling software such as the Danish Hydrologic Institutes Mike 11 and Mike-She codes to produce reasonable simulations of the problem we wish to address. Then we have developed custom user interfaces to allow our user community to interact with those features and parameters within the model that constitute what we consider the decision space. The advantage with this approach is that if changes are desired in the manner in which we simulate the system – the high-level computing environment of the Mike models makes these changes transparent to the analyst. The downside is that the Mike model environment comes at a significant cost which works against a State of California modeling dictum that all water resources decision support software reside in the public domain. This constraint has, in the past, limited our ability to fully share the EDSS which has limited the

EDSS's acceptance within the environmental management and water resources modeling community.

The second scenario is where simulation models and the EDSS that contains those models is written in computer code such as provided "C", Visual "C", Java, Visual Basic or other compilers. These are the products we typically get from University or University-affiliated colleagues and are typically conceived as a research project worked on by graduate students. EDSS's produced this way are sometimes difficult to adapt because the coding is often poorly documented and the programming logic hard to follow. Problems may occur in modifying the original EDSS to be relevant to changing system characteristics or to incorporate altered conceptual models of the system if end user needs are not satisfied with the first realization of the EDSS. Some very innovative EDSS's have been created and lost to the water resources community because of this very problem. Not only is this a waste of intellectual resources but also does harm to the reputation of the EDSS as an effective way of guiding policy makers in making informed and resource optimal decisions.

Appropriate EDSS design should be easily understood and transparent, be modular in design, adaptable by the end-user. Our experiences in these first two approaches have not been wholly successful in our projects dealing with wetland salinity management. A third approach has been followed in the most recent project, which has drawn upon past attempts using off-the-shelf model simulators and custom codes- the use of a simple spreadsheet model.

The monthly spreadsheet model WETMANSIM, formulated as a monthly water and salt accounting simulator geared to wetland hydrology was adapted to create a short-term forecasting model, primarily by reducing the model timestep to accept daily input data. The hydrologic and water quality inputs of the model are those most wetland managers use routinely for their own operations and for water accounting. The model was built iteratively – meetings were held with the water managers of the State, Federal and private wetland entities to explain the functioning of the model and to discuss the data inputs. Where hard data did not exist most wetland managers were able to develop reasonable estimates based on professional experience. An iterative process was followed to develop mutually agreeable realizations of wetland floodup and drawdown hydrology during interactive development sessions while running the wetland simulation model live.

Spreadsheet models are conducive to a modular approach. They allow insertion of more specialized software modules that can overwrite less physically based computations to create a more accurate

simulation in instances where better data is available. For example, a recently developed module simulating evapotranspiration (ET) demand in the California Sacramento – San Joaquin Delta (DETAW) is being adapted to improve forecasted wetland ET once better estimates of the areal extent of the varieties of emergent wetland vegetation and open ponded water are available.

#### **2.4 EDSS designers must strive to include uncertainty in their conceptual models without confusing or intimidating the end user or the end-user's clients.**

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 any 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 project to address system heterogeneity and data uncertainty is one of replicating the existing monitoring system architecture as widely as possible, using financing from State-sponsored research grants. Recently enacted environmental legislation to control of non-point source discharges and improve San Joaquin River water quality has provided unique opportunities to design and develop additional monitoring networks and provides a powerful incentive for Water Districts to train their staff to maintain these new monitoring stations, once installed. The heterogeneities of the managed wetland system and the uncertainties in the data will become self-evident as increased volumes of data are processed.

Collaborative science partnerships between the wetland community and the academic research community initiation has provided support for these types of projects at the upper management level in the State agencies that fund State, federal and private wetland entities. This in turn has provided us with a team of highly motivated and knowledgeable staff who are well respected by their

peers. Having these wetland biologists involved at project conception and initiation has provided a sense of mutual project ownership which has already had an impact on the rate of project implementation.

### 3. CONCLUSIONS

Significant technical advances in data acquisition and information dissemination technologies and an evolving, adaptive experiential knowledge of EDSS failures have created a synergy that may result in successful implementation of a real-time salinity management program in California's San Joaquin Basin. Past problems and some of the lessons learned were described in this paper and include inadequate end-user involvement at the beginning of the project, design features that failed to recognize the time constraints wetland water masters operate under and user interfaces to decision support tools that these individuals did not find intuitive. None of these problems are new, however they illustrate that each new application of decision support technology creates its own unique challenges. Data management and information dissemination within our current EDSS has been aided by the advent of a commercial environmental monitoring system, YSI-ECONET. Our experience to date has shown widespread acceptance among water managers in the State, Federal and in the private wetland areas and has helped to improve stakeholder involvement in our water quality management project.

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