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A Decision Support System For Adaptive Real-Time Management Of Seasonal Wetlands In California

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Abstract : This paper describes the development of a comprehensive flow and salinity monitoring system and application of a decision support system (DSS) to improve management of seasonal wetlands in the San Joaquin Valley of California. The Environmental Protection Agency regulates salinity discharges from non-point sources to the San Joaquin River using a procedure known as the Total Maximum Daily Load (TMDL) to allocate the assimilative capacity of the River for salt among watershed sources. Management of wetland sources of salt load will require the development of monitoring systems, more integrative management strategies and coordination with other entities. To obtain local cooperation the Grassland Water District, whose primary function is to supply surface water to private duck clubs and managed wetlands, needs to communicate to local landowners the likely impacts of salinity regulation on the long term health and function of wildfowl habitat. The project described in this paper will also provide this information. The models that form the backbone of the DSS develop salinity balances at both a regional and local scale. The regional scale concentrates on deliveries to and exports from the Grassland Water District while the local scale focuses on an individual wetland unit where more intensive monitoring is being conducted. The design of the DSS is constrained to meet the needs of busy wetland managers and is being designed from the bottom up utilizing tools and procedures familiar to these individuals.

1. INTRODUCTION

The Grassland Water District (GWD) together with the adjacent State and Federal refuges constitute the largest contiguous wetland in the State of California (Figure 1). The GWD comprises two interconnected units - the northern and southern GWD units – which together

provide water to more than 20,000 hectares of privately owned wetlands, mostly used as over-wintering habitat for wildfowl on the Pacific Flyway. The Northern GWD (NGWD) is larger in area than the Southern GWD and contains discrete drainage outlets which provide drainage to distinct sub-basins within the NGWD (Figure 2). For this reason, the NGWD was chosen as the subject of the study described in this paper.

Seasonal wetlands in the GWD are flooded in the fall and drawn-down in the spring to provide habitat for migratory waterfowl, shorebirds, and other wetland-dependent species. Due to alterations in natural hydrology, these wetlands are flooded with Central Valley Project water supplies delivered through GWD canals. In the spring, during the months of March-April, seasonal wetlands are drawn-down to mimic the natural dry cycle of a seasonal wetland. Wetland drawdowns are timed to make seed and invertebrate resources available during peak waterfowl and shorebird migrations and to correspond with optimal germination conditions (primarily soil temperature) to grow naturally occurring moist-soil plants. The seeds of moist-soil plants are recognized as a critical waterfowl food source, providing essential nutrients and energy for wintering and migrating birds (Fredrickson and Taylor 1982).
Optimal timing of wetland flood-up and release has been determined by trial and error for different species of moist soil plants and for different environmental conditions, although guidelines for these practices are poorly documented..

2. WETLAND MANAGEMENT

The seasonal wetlands of the GWD are managed to meet habitat requirements by flooding in the fall and releasing their waters in the spring. Spring releases are discharged into tributaries of the Lower San Joaquin River. These releases, in combination with agricultural drainage that flows through the GWD, contain varying amounts of total dissolved solids (TDS), boron, and selenium. These constituents have been identified as stressors that lead to frequent exceedance of water quality objectives established for the San Joaquin River by state and federal agencies.

Research conducted by Grober et al. (1995) suggests that wetland drainage from the GWD could be scheduled to coincide with peak assimilative capacity in the San Joaquin River to help improve downstream water quality (Figure 3). Assimilative capacity in the San Joaquin River occurs during periods when the average electrical conductivity (EC) at Vernalis is below the

seasonal running average concentration. Figure 3 shows that the irrigation season EC objective of 700 uS/cm between April 15 and August 15 each year is frequently violated. Between 1985 and 1998 the EC objective at Vernalis was violated more than 70% of the time.

Increased water supply allocations under the Central Valley Project Improvement Act (CVPIA) – environmental legislation that resulted in a large transfer of water between irrigated agriculture and the environment - have created opportunities to coordinate the release of seasonal wetland drainage with the assimilative capacity of the San Joaquin River. Coordinated releases will help to achieve salt and boron water quality objectives and improve fish habitat in the main stem of the San Joaquin River and Sacramento - San Joaquin Delta. Improved scheduling of west-side discharges can assist in avoiding critical time periods for fish rearing and remove an important stressor leading to improvements in the San Joaquin salmon fishery. To date, however, no systematic data collection program has been undertaken to evaluate the short and long-term consequences of real-time wetland drainage management. Drainage monitoring (Figure 4), undertaken as part of the project described in this paper, has been undertaken to address this deficiency.

Management of wetland drainage, through scheduling of releases to coincide with periods of San Joaquin River assimilative capacity, can help to improve San Joaquin River water quality. However, these actions may need to be considered relative to potential biological impacts of changes to traditional wetland management practices. Figures 5 and 6 show how water management for optimal productivity differ between smartweed and water. Peak assimilative capacity typically occurs between the months of January and April. This time period is often earlier than the traditional wetland draw-down period (March-April). Hence, the response of moist-soil plants and of migratory waterfowl and shorebirds to an altered draw-down regime needs to be assessed. This assessment will identify potential impacts to seed germination rates, waterbird foraging rates, habitat availability, and species diversity and abundance. It is possible that early, experimental drawdown may make food sources available to wildlife without negatively affecting wetland vegetation community and plant species diversity - hence benefiting both wildlife and the health of the San Joaquin River. This ongoing research phase of this project will have considerable technology transfer value to other agencies that operate seasonal wetlands and also discharge constituents of concern to the River.

3. WATER QUALITY MANAGEMENT

As a result of recent landmark environmental legislation that drastically change water allocations among agricultural, municipal and environmental consumers, increases in water supply have helped to improve the quality of wetland habitat in the Grassland Basin. Additional water allocations, while increasing the flexibility of operation of seasonal wetlands and improving the quality of their return flows, increase the total salt load discharged to the San Joaquin River. Exploitation of opportunities to improve coordination of seasonal wetland drainage with the assimilative capacity of the San Joaquin River can improve compliance with River water quality objectives (Figure 3). These objectives were established originally to encourage improvements in the management of agricultural and wetland return flows. These objectives were set to protect downstream riparian irrigators who use the San Joaquin River as their sole water supply and to protect the salmon fishery. Wetland releases that contain high salt loads during the months of April coincide with agricultural pre-season irrigation to propagate plant seedlings. Saline water can inhibit germination and reduce crop yields. Salmon can become confused during their annual migration when higher flows emanate from sloughs carrying drainage water than along the main-stem of the San Joaquin River.

Better coordination of agricultural and wetland releases with reservoir releases of good quality snow-melt water on the east-side of the San Joaquin Basin has been suggested as a means of improving San Joaquin River water quality for all beneficial uses (Quinn and Delamore, 1994; Karkoski, Quinn and Grober. 1995; Quinn et al., 1997; Quinn and Karkoski, 1998). Quinn (1999) described the results of a demonstration project of real-time monitoring and management of agricultural drainage and east-side reservoir releases that forecasts the assimilative capacity for salinity on the San Joaquin River (Figure 7). These forecasts are made weekly based on an analysis of current data at all monitoring stations on a Monday morning in combination with information directly obtained from east-side reservoir operators on the main tributaries, riparian diverters along the main stem of the San Joaquin River and those agricultural drainage districts that continuously monitor their drainage return flows. Wetland real-time water quality management project complements this existing program to coordinate seasonal wetland drainage with the assimilative capacity of the San Joaquin River. Since there exists little coordinated monitoring of salt loading leaving the GWD, this project has required the installation of wetland

monitoring stations at major drainage outlets from the district (Figure 2). To allow salt balance modeling, a similar station has been installed at the main GWD inlet at the Volta Wasteway channel. The decision support system, described below, was developed to help organize field monitoring data and to allow wetland managers make timely decisions regarding return flows to the SJR. These decisions are aided by the fact that the elements of the DSS will eventually be common for the San Joaquin River and wetland salt management projects.

4. REAL-TIME FLOW AND WATER QUALITY MONITORING

Flow transducers and electrical conductivity sensors have been installed at control structures within the GWD (Figures 2 and 4). These instruments take measurements every 15 minutes to provide an accurate measurement of salt loading in to and out of the GWD boundary. Flow and electrical conductivity data at each site is collected on a battery-powered datalogger that is attached to a phone telemetry system, allowing these data to be accessed 24 hours a day.

Flow measurements at the inlet and most of the outlet sites are being made using a state-of-the-art acoustic velocity transducers. These transducers utilize the Doppler principle whereby during operation, each transducer produces short pulses of sound at a known frequency along two different axes. Sound from the outgoing pulses is reflected ("scattered") in all directions by particulate matter in the water. These return signals have a frequency shift proportional to the velocity of the scattering material. By combining data from both beams, and knowing the relative orientation of those beams, the device measures 2D velocity in the plane defined by its two acoustic beams. Each transducer is equipped with two stage measurement sensors, a vertical beam and a pressure sensor which, with information on the stream cross sectional profile and the velocity, is used in the flow computation.

Temperature-compensated electrical conductivity (EC) sensors are being used to obtain real-time salinity and temperature data at each site. EC is a measure of the total dissolved solids, or the presence of ions, in the water. When compensation is made for the water temperature, EC readings provide an accurate count for the salinity in the water. Maps have been prepared locating water delivery and drainage turnouts in the GWD drainage system. These maps will document drainage hydrology within individual wetland basins. The location of the monitoring stations has been determined by GPS survey and located on the set of GIS maps of the study area.

These monitoring sites are strategically placed within wetland channels so as to allow computation of salt loads in real-time from different sectors of the Grassland Water District.

Real-time flow, electrical conductivity and temperature data from the GWD is provided by e-mail and through a website http://socrates.berkeley.edu/~nwquinn/Grassland_Realtime/Quinn-Grass/ as input to the real-time water quality model of the San Joaquin River operated by the SJRMP Water Quality Subcommittee (Figure 7) http://wwwdpla.water.ca.gov/sjd/waterquality/realtime/index.html. The SJRMP Water Quality Subcommittee has been funded to enhance the existing network of real-time monitoring stations along the main-stem of the San Joaquin River and to improve the coordination of agricultural return flows and scheduled east-side fish flows (Quinn et al. 1997). Installation of flow and water quality monitoring equipment and cellular telemetry equipment at key locations in the Grassland Water District helps to provide wetland and refuge managers with the data necessary to make scheduling decisions. Mean daily salinity loading from the GWD is calculated from the monitoring data and is compared with the daily assimilative capacity determinations on the SJR. Wetland discharge opportunities during the spring months, when the majority of saline discharges from seasonal wetlands occur, is evaluated weekly by the Project team, cooperatively with the watermaster and District biologist from the GWD.

5. HABITAT EVALUATION

The biological and ecological monitoring and data objectives of the project are to document the effects of changing traditional flood-up and wetland drainage discharge patterns on wetland habitat and bird species. Achievement of these objectives will assist in developing adaptive management approaches to optimize wetland habitat conditions while minimizing the negative effects of wetland drainage on the water quality in the San Joaquin River.

A program of wetland habitat assessment is proceeding concurrently with the real-time monitoring and water quality management program. Changing the scheduling of wetland drainage to the San Joaquin River affects the timing and rate of drawdown of wetland ponds and hence the forage value of the wetlands for migrating and wintering shorebirds and waterfowl. Wetland salinity management measures can also affect the productivity and diversity of vegetation that can be grown in the watershed. The research underway is documenting the

impacts of altering traditional wetland management practices and developing guidelines for multi-objective wetland operations including forage production, nesting cover establishment and salinity management. The concurrent program of habitat evaluation and salinity management could lead to optimization of wildlife and environmental benefits to the Grassland Basin and San Joaquin River.

Wetland habitat monitoring sites have been randomly chosen from available seasonal wetlands within the GWD. These wetlands correspondingly drain into locations where flow and EC monitoring sites are situated. At all wetland study plots, a paired study design is being used to directly assess differences in traditionally drained wetlands vs. non-traditionally drained wetlands. Biological monitoring is being conducted on adjacent traditionally and non-traditionally drained wetlands. The monitoring includes both a waterbird (waterfowl and shorebirds) usage component and a moist-soil plant production component. The waterbird component measures abundance and diversity and determine time-activity budgets of waterbirds through scan sampling and direct observation to assess foraging potential. The moist-soil plant production component determines the impacts, if any, to the vegetation by assessing changes in total plant biomass, percent coverage, and species composition through grid sampling and aerial photography.

6. DECISION SUPPORT SYSTEM DESIGN

The rationale for developing a decision support system (DSS) was to provide a set of analytical tools that assist in computation of GWD wetland water requirements, estimation of wetland salinity load in seasonal wetlands and in the selection of best management practices. A requirement of the DSS was that it be simple in design and intuitive, similar to data management tools typically used by the GWD. GWD staff spend much of their time in the field and do not have large blocks of time that they can devote to learning new software. The DSS was designed to interact with existing San Joaquin River water quality forecasting models and software to allow the partition of River assimilative capacity among the wetland releases.

7. WATER QUALITY MODEL

The wetland water and salinity model simulates seasonal and permanent wetland management in the Grassland Water District and mimics the wet/dry seasonal cycle that these wetlands

experience as well as the quantity and water quality of wetland releases. The main objective of the wetland water quality model is to predict the effects of salt loading to the San Joaquin River during spring drawdown (January-April). The model incorporates the weekly water use requirements of the major wetland habitat types in the Grassland Water District and the adjacent State and Federal refuges. Mapping of the wetland habitat has been limited to date to discriminating open water areas within the wetland complex. Evapotranspiration from moist-soil plants within the GWD is presently estimated and not specifically modeled owing to lack of field data for model calibration. There are no reliable techniques available using remote sensing technology to quantify the areal extent of the major moist-soil plants and other wetland habitat within the GWD. In spite of these limitations the model tracks salinity changes in each of the wetlands over the winter season and incorporates user-defined schedules for wetland drawdown in the spring months. By running scenarios of different weekly wetland fill and release schedules and annual changes in vegetation type and waterbird usage, managers are able to plan operations to minimize water quality impacts on the San Joaquin River while maximizing wildlife benefits.

The current model has been developed as a Microsoft Excel spreadsheet on account of the widespread familiarity with this product among wetland managers in the Grassland Basin. The model has been designed to perform historic hydrology simulations as well as seasonal alternatives (along with sensitivity analyses). Seasonal alternatives include different wetland drawdown protocols such as (a) early drawdown (critically dry to dry year), (b) traditional drawdown (dry to wet year), (c) late drawdown (wet year), and (d) preflushing . The wetland water quality model has been designed to allow easy linkages to popular software packages such as RAISON and ARCVIEW. In addition, the Excel spreadsheet model has been designed to predict salt loading from the NGWD watershed as well read salt assimilative capacity output directly from the Department of Water Resources' Delta Simulation Model II (DSM-2). First the wetland water quality model provides wetland outflow quantities and salt loads to DSM-2 at Mud and Salt Sloughs for use in its river forecasts and second, the wetland water quality model uses SJR assimilative capacity forecasts provided by DSM-2 as input .

7.1 Input Data

Input data for the wetland water quality model fall into four categories; static, annually constant, annually varying, and real-time. Static data, which do not vary with time, include soil properties,

land classifications, acreages, drainage basin allocations, and precipitation and ET qualities. Annually constant data, which are static year to year but vary within the year, include crop coefficients (for ET subroutines), best management practices, and water table depth. Annually varying data include precipitation, water year classification, air, water, and soil temperatures, irrigation schedule, and wetland flood-up schedule. Real-time data includes supply water quantity and quality, drainage water quantity and quality, evapotranspiration, precipitation, and San Joaquin River assimilative capacity. Much of the static and annually constant data are assumptions since intensive monitoring in these wetlands only commenced in water year 2000. A typical user will not need modify these data, once measured, except for system changes, calibration, or sensitivity analyses.

7.2 Model Runs

The model was applied to historical northern GWD drainage data collected during the 1998 – 1999 water year. The NGWD contains the major drainage outlets to the San Joaquin River and, since it is geographically separated from the southern GWD by the city of Los Banos, it can be considered as a hydrologically separate system. During the spring of 1999, NGWD wetland drawdown contributed over six percent of the total salt load in the SJR at the Crows Landing monitoring station, located downstream of the Mud and Salt Slough discharge points, on the San Joaquin River. The Mud Slough discharge to the San Joaquin River combines flow and salt loads from Mud Slough (north), Fremont Canal, Los Baños Creek, Hollow Tree Drain, and S-Lake Drain. Fremont Canal alone contributes flows and salt loads from approximately 2% of the total wetland acreage in the NGWD (GWD, 2001).

Model simulations have been made comparing SJR flow and water quality at Crows Landing under several different wetland management plans for the drawdown season between January 1999 and April 1999 (Figures 8 and 9). The different wetland management plans were simulated using calculated wetland water quality. The salt loads generated from this analysis were compared to river assimilative capacity, estimated by the DSM-2 river hydrodynamic model for the same period. The first step of the model run required developing high and low baseline flow and salt load values for the SJR. The high SJR baseline selected was the actual modeled (DSM-2) salt load at Crows Landing. The low SJR baseline was the salt load at Crows Landing assuming zero contribution of flow and salt load from the NGWD.

Once baseline values were established, the wetland water quality model simulated early and late drawdown release scenarios from the NGWD. For these historical model runs, early and late wetland drawdown scenarios were generated by skewing the actual drainage data by +/- 1 standard deviation. To view the impacts of the alternative wetland management plans, the modeled results were added to the low SJR baseline values. Although the actual NGWD salinity contribution to the SJR was roughly 6% during the 1999 wetland drawdown season, effects from altered drawdown schedules are apparent.

7.2.1 Scenario 1 : Baseline Values: DSM-2 Model Values (Actual) vs. DSM-2 w/o NGWD Contribution

This comparison shows the difference between the actual modeled (DSM-2) SJR qualities and quantities (high baseline) and the SJR had there been no contribution from the NGWD (low baseline).

7.2.1.1 Water Quantity

Completely removing the NGWD contribution considerably reduced the flow in the SJR at Crows Landing. The reduction in flow ranged from one to almost 11 percent, with the maximum observed deficit occurring in late March and early April (Figure 8).

7.2.1.2 Water Quality

Completely removing the contributions from the NGWD to the SJR had a marked effect by reducing the EC at Crows Landing by more than 4% during peak wetland withdrawals in February and March (Figure 9). It is interesting to note that during the week ending March 25th, removing the NGWD contribution actually increased the EC of the SJR at Crows Landing. Further review of the data confirms this, showing that indeed the EC of the SJR was higher during that time than the wetland releases. However, other than that one week, removal of the NGWD component decreased the EC, and hence increased the assimilative capacity, of the San Joaquin River at Crows Landing.

7.2.2. Scenario 2 : Wetland Water Quality Model Run 1 – Early Wetland Drawdown

This comparison is designed to show the difference between the actual modeled (DSM-2) SJR qualities and quantities (high baseline) and the SJR had there been an early wetland drawdown from the NGWD.

7.2.2.1 Water Quantity

An early wetland drawdown management plan from the NGWD to the SJR increased the flow in the SJR at Crows Landing during the early months and reduced it in the later months (Figure 8).

7.2.2.2 Water Quality

Applying an early wetland drawdown management plan from the NGWD to the SJR had a marked effect by increasing the EC by an average of 1.5% during the early months (January and February) and by reducing the EC by an average of 2.5% in the later drawdown months (March and April) – (Figure 9) .

7.2.3 Scenario 3 : Wetland Water Quality Model Run 2 – Late Wetland Drawdown

This comparison shows the difference between the actual modeled (DSM-2) SJR qualities and quantities (high baseline) and the SJR had there been a late wetland drawdown from the NGWD.

7.2.3.1 Water Quantity

A late wetland drawdown management plan from the NGWD to the SJR did not have as great an impact on the SJR as did the early drawdown management plan. The late drawdown did decrease the flow in the SJR at Crows Landing during the early months and increased it in the later months however on average, it did not change the flows by more than +/- one percent (Figure 8).

7.2.3.2 Water Quality

Because traditional drawdown management plans tend to be later in the season, applying a late wetland drawdown management plan from the NGWD to the SJR did not have as marked an effect on the water quality of the SJR. The late drawdown decreased the EC by an average of 0.5% during the early months (January and February) and increased the EC by an average of 0.25% in the later drawdown months (March and April) – (Figure 9).

7.3 Analysis

It was apparent that even though an early withdrawal management plan has the greatest effect on altering the quality of the San Joaquin River, this is mainly because wetland managers in the NGWD schedule traditional drawdown later in the season. These simulations will need to be performed on subsequent years to verify the findings from the one drawdown season of 1999.

7.4 Discussion - Adaptive Management Of Wetland Releases

The overall goal of the project is to provide basic monitoring information and will develop decision support tools to allow wetland managers in the GWD to respond to the long-term challenge of improving water quality while maximizing wetland functions and habitat values. The project considers two levels of monitoring and analysis – the first, at the water district scale, will develop inflow and outflow monitoring and a salinity loading mass balance for the entire North-Grasslands region. The second, conducted at the scale of a single duck club, in this case the most progressive and scientifically managed in the water district, which has designated functional wetland units to attract different bird species and which offer a great diversity of hunting experience. The project is fortunate in having enlisted the cooperation of one of the most innovative wetland managers in the GWD who has for years been experimenting with different regimes of wetland filling and release – primarily with the objective of optimizing wildfowl habitat under various regimes of water availability and supply water quality. The duck club will benefit by the more intensive level of water flow and quality monitoring while providing the wetland manager a test-bed to observe and evaluate alternative management regimes. More intensive monitoring of a suite of water quality factors is underway at the duck club with including flow, electrical conductivity, pH, turbidity, dissolved and particulate organic carbon concentrations and biochemical oxygen demand, which provide a comprehensive comparison of management-related impacts.

The synergy between the monitoring and research objectives of our project and the practical aspects of improving wetland function in a climate of increased environmental regulation and control of non-point source discharges provides a unique opportunity for advancement of the art and the science of wildfowl wetland management. By taking this "pre-emptive" action – the GWD is seen to be proactive in the eyes of the EPA and the Regional Water Quality Control Board (enforcement division for the EPA) which are presently laying the groundwork for salt load allocation and salinity water quality objectives on the San Joaquin River.

8. SUMMARY

Information obtained through this project will be likely be transferable and of significant value to all wetlands in the Grassland Ecological Area including those wetlands managed by State and Federal wildlife agencies. The successful implementation of this combined monitoring,

experimentation and evaluation program will provide the basis for adaptive management of wetland drainage throughout the entire 70,000 hectare Grassland Ecological Area. The project will involve local landowners, duck club operators, and managers of State and Federal refuges in the Grassland Basin. Although this pilot project has concentrated on the 20,000 hectares that comprise the GWD, the goal of the project is to disseminate the findings of the project more widely. The Grassland Water District has a successful history of local involvement through the District newsletter, published monthly; high school and college-level educational outreach programs; and through "Wild on Wetland" days which help to educate the public about the benefits and techniques of wetland management.

9. ACKNOWLEDGEMENTS

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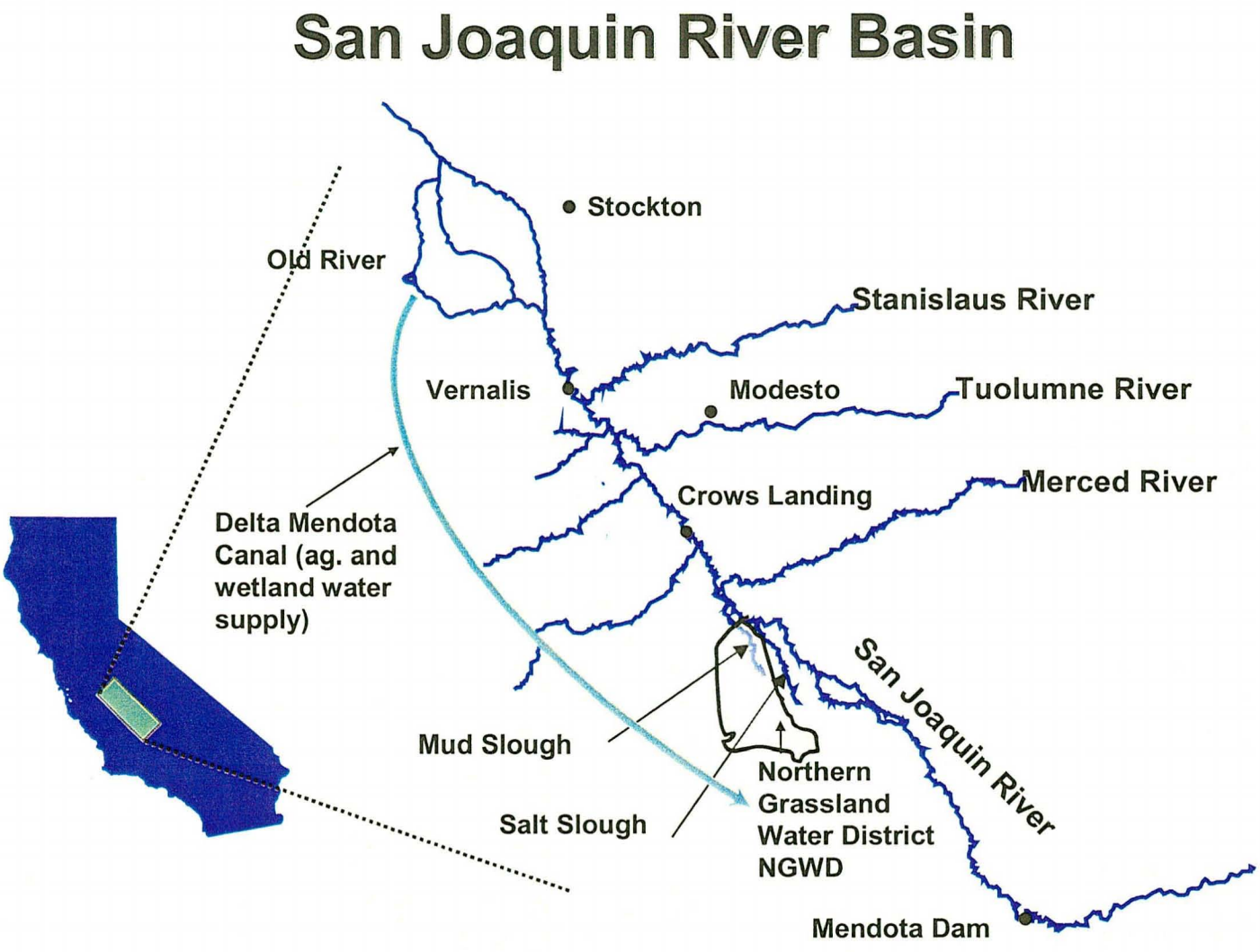

Figure 1. San Joaquin River Basin showing Northern Grassland Water District (NGWD) and the major west-side wetland drainage conveyances Mud and Salt Sloughs. Water supply to agriculture and wetlands in the Grassland sub-basin is provided through pumping from the Sacramento-San Joaquin Delta via the Delta Mendota Canal.

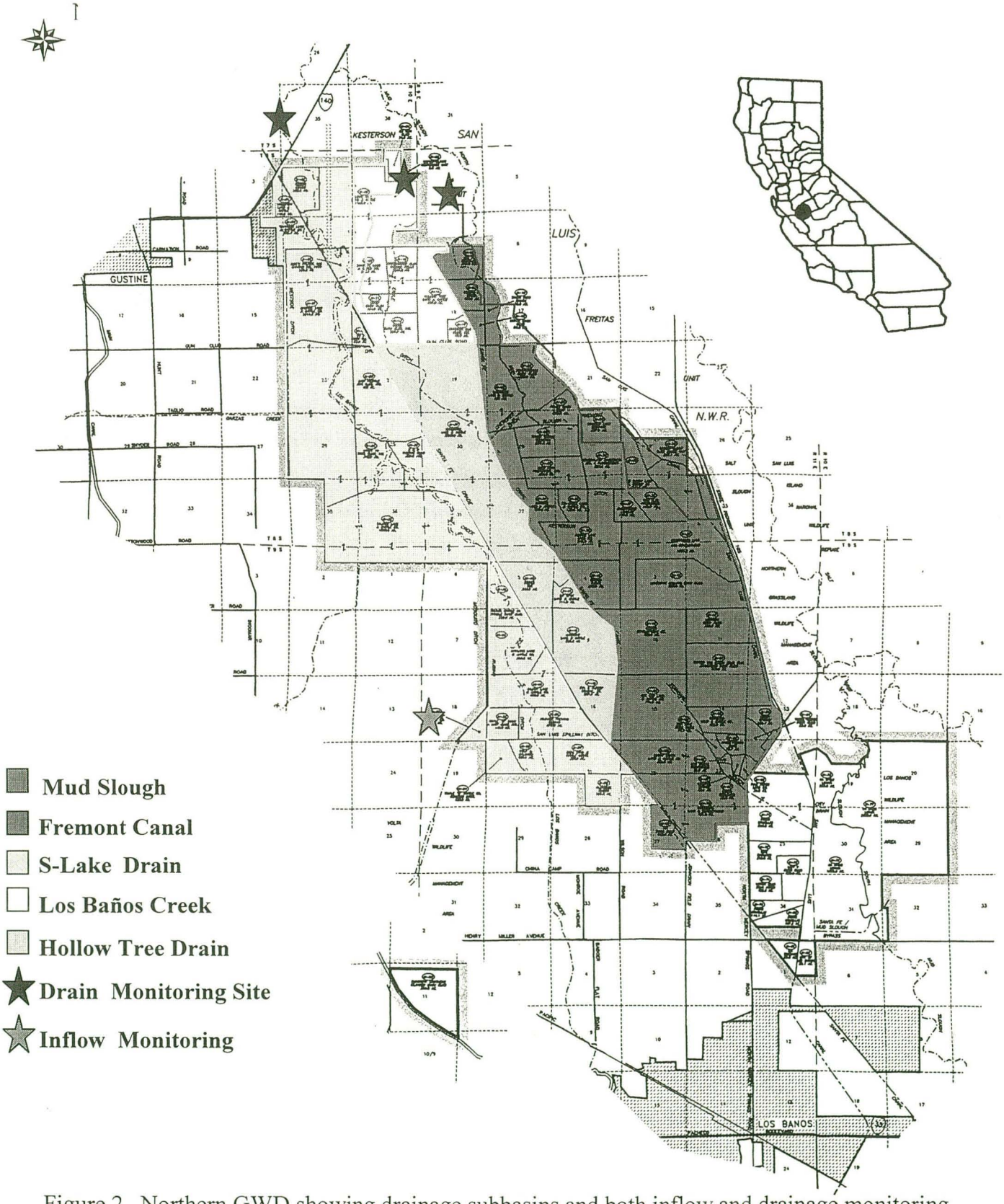

Figure 2. Northern GWD showing drainage subbasins and both inflow and drainage monitoring.

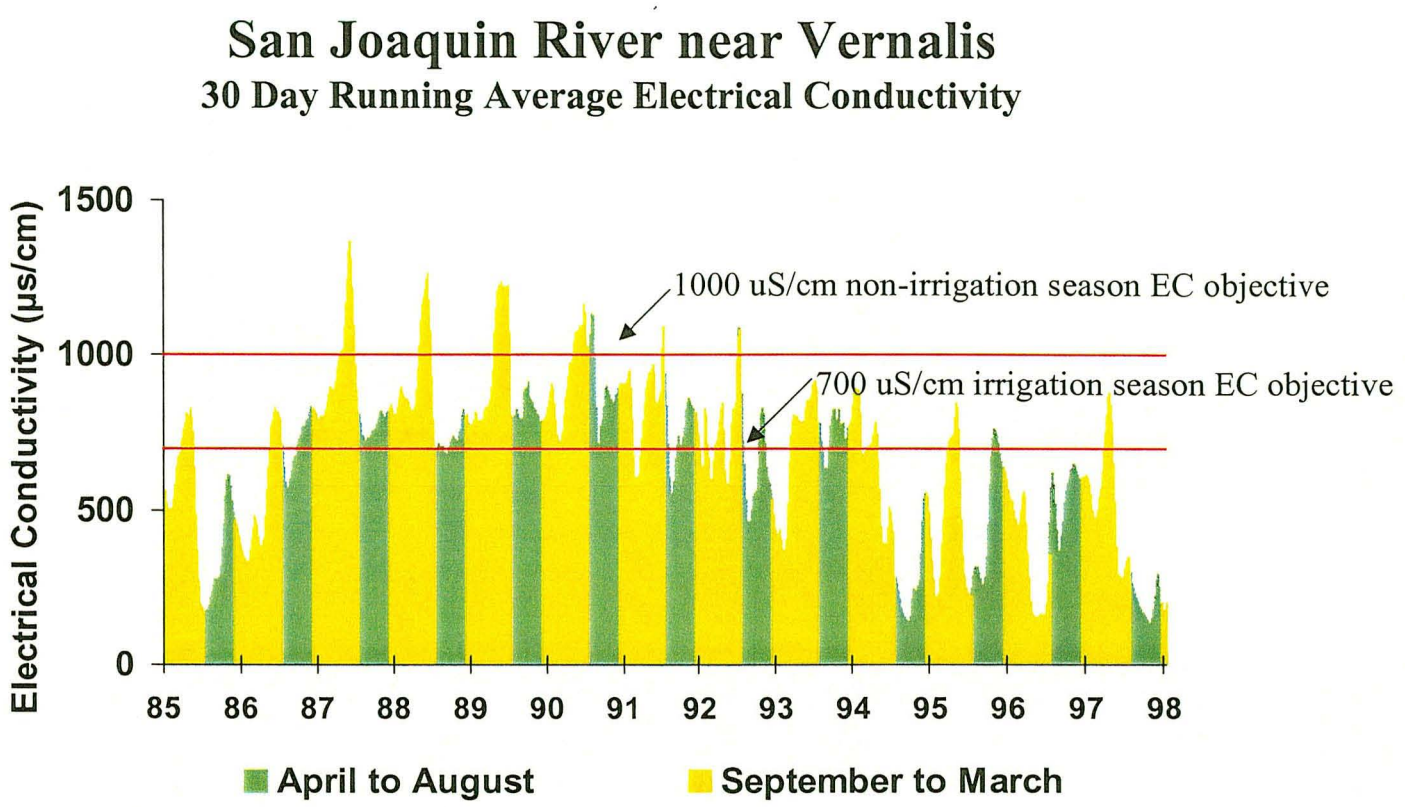

Figure 3. San Joaquin River 30-day running average electrical conductivity (EC) showing periods of assimilative capacity (graph below seasonal objective) and violation (graph above seasonal objective). Over the past 13 years salinity (EC) objectives have been violated approximately 70% of the time.

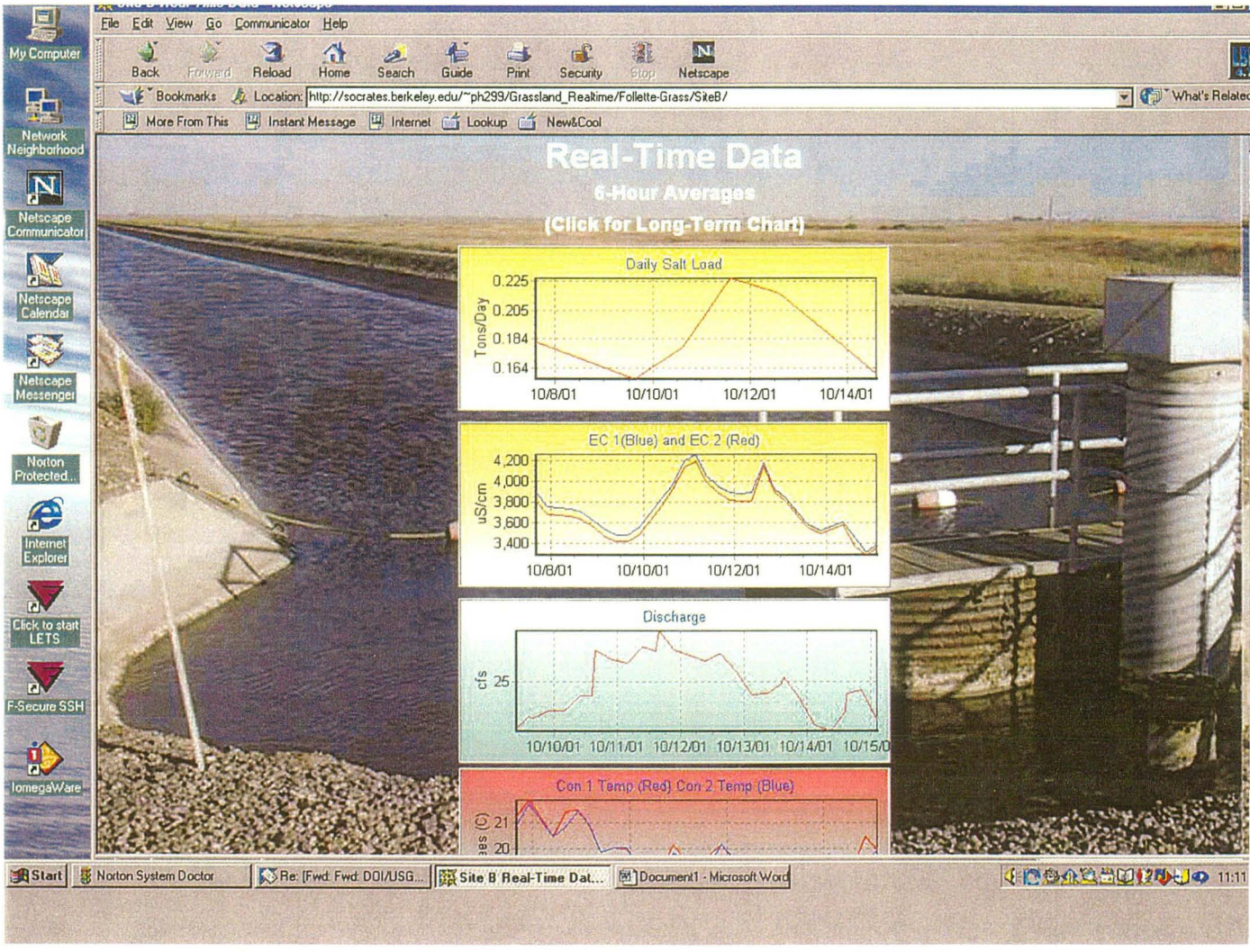

Figure 4. Example of the real-time data acquisition and reporting system installed at wetland sites and th San Luis Drain. Wetland drainage combines with agricultural drainage in the San Luis Drain (shown above) and the combined flow is discharged to the San Joaquin River via Mud Slough.

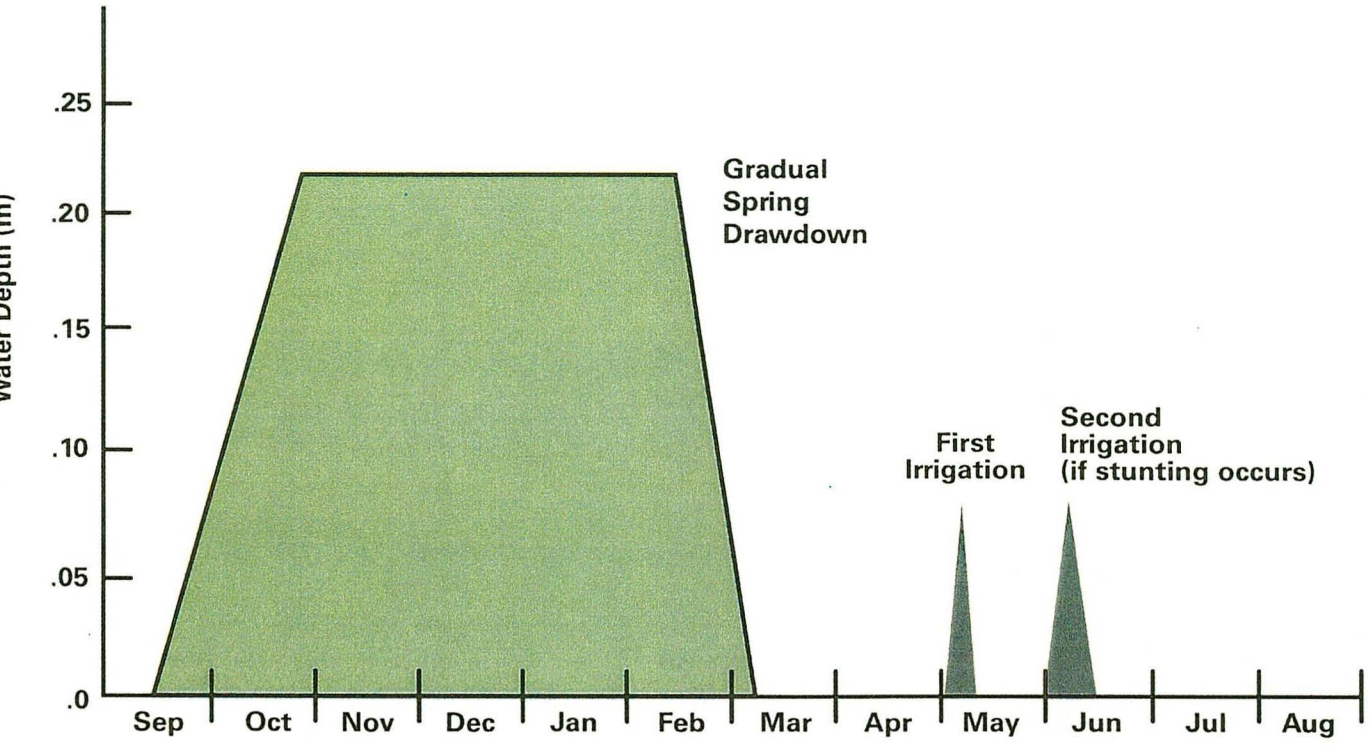

Figure 5. Wetland flood-up and return flow schedule for smartweed in the Grassland Basin

Figure 6. Wetland flood-up and return flow schedule for watergrass in the Grassland Basin

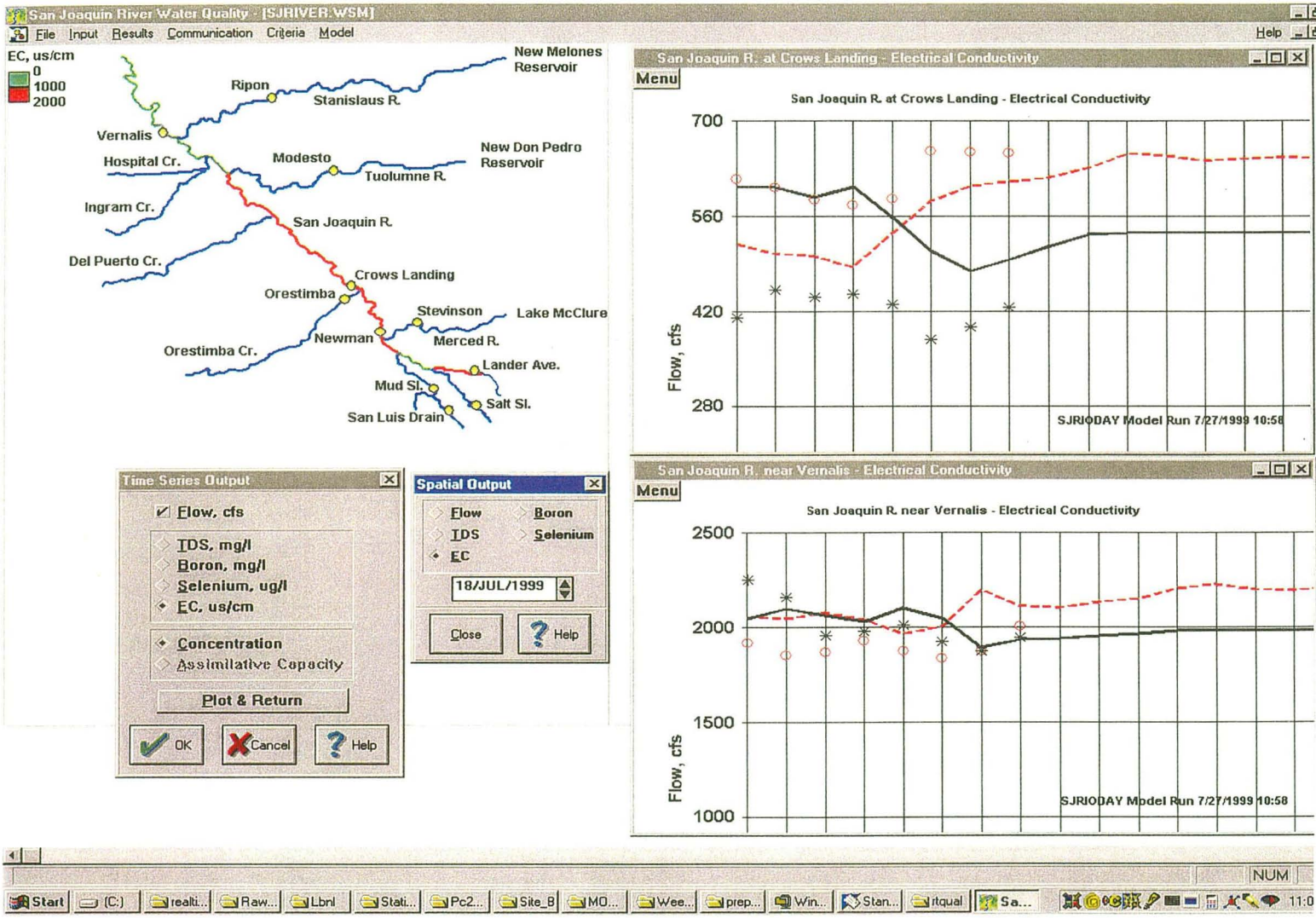

Figure 7. Graphical user interface for the San Joaquin River salinity forecasting model. Wetland drainage enters the San Joaquin River through Mud and Salt Sloughs and, when combined with agricultural flows, account for 37% of the salt load in the San Joaquin River at Vernalis.

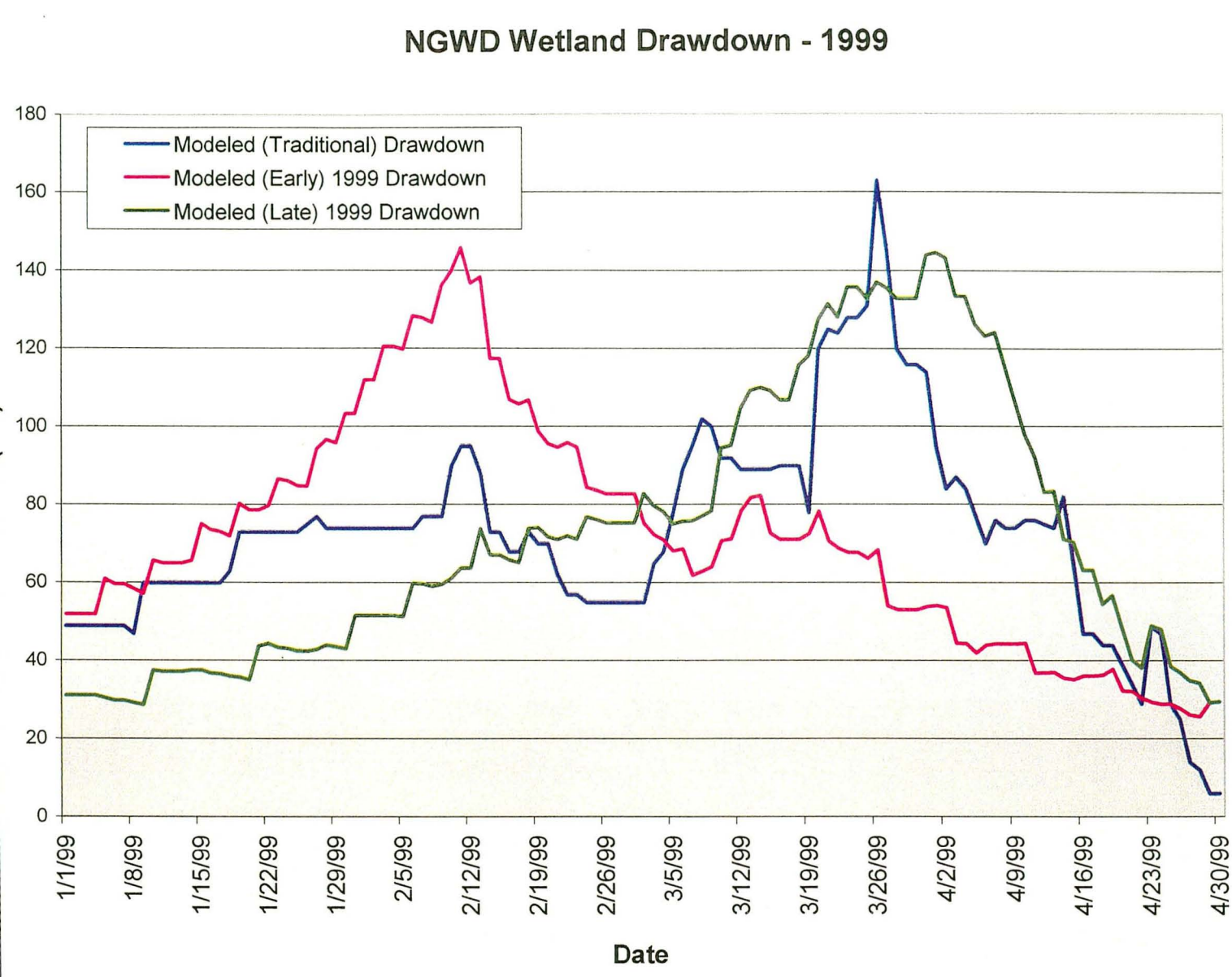

Figure 8. Comparison of drainage flow for traditional, early and late drawdown scenarios for NGWD

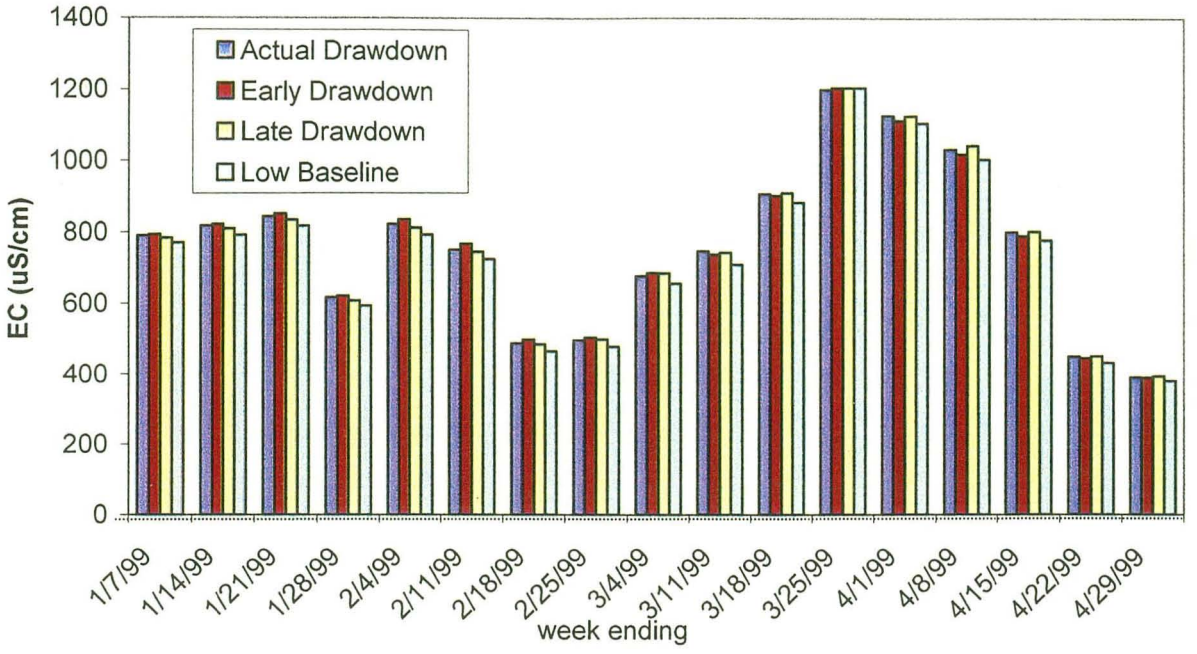

Figure 9. Average weekly electrical conductivity at Crows Landing for WY 1999 spring drawdown.

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