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Software Introduction

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ABSTRACT

The concept of real-time salinity management was incentivized by the Central Valley Regional Water Quality Control Board by promoting it in the Water Quality Control Plan as an alternative to Waste Discharge Requirements specified in the 2004 salinity TMDL for the San Joaquin Basin. Adherence to the principles of real-time salinity management increase annual average salt export from the San Joaquin River Basin and avoid potential fines associated with exceedences of monthly and annual salt load allocations which could exceed $1 million per year based on average year hydrology and TMDL-based export limits. The essential components of this program include the establishment of telemetered sensor networks, a web-based information system for sharing data, a GIS-based, basin-scale flow and salinity forecasting model and institutional entities tasked with performing weekly forecasts of San Joaquin River salt assimilative capacity and coordinating west-side drainage return flows. This paper provides an overview of progress made to date and describes an alarming finding of diminishing ungauged River accretions that threaten sustainability of the River resource made possible by the advances in modeling resolution resulting from this Program.

Keywords
salinity, TMDL, sensor networks, forecast modeling, stakeholder

1. Introduction

1.1 Salinity Management in the San Joaquin Basin

Salt export from agricultural, wetland and municipalities in the San Joaquin River Basin (SJRB) is regulated as part of a comprehensive Total Maximum Daily Load (TMDL) (CEPA, 2002; CVRWQCB, 2004a, 2004b). The TMDL is intended to identify, quantify and help control sources of pollution that affect attainment of water quality objectives and full protection of identified beneficial uses of water. The TMDL includes both point and non-point sources of salt load. Non-point sources of salinity (LA) are not amenable to the establishment of fixed monthly or seasonal salt load allocations because of the diffuse
nature of these non-point source loads in the watershed which makes it difficult to assign responsibility.

There are technical challenges to monitoring flow and EC at individual discharge points compounded by the high seasonal variation in export flows and salt loads. Base salt load allocations (LC) are made to account for the variable assimilative capacity of salt within the San Joaquin River (SJR)—these are calculated based on the lowest anticipated flow condition in the River and the SJR’s assimilative (load) capacity (LC) for salt during these episodes. Point source (WLAs), background salt loading, including salt loads contained in groundwater return flows to the SJR, are subtracted from the total River assimilative capacity to determine the salt load allocation to all non-point sources. (Holm, 2010).

\[
\text{TMDL} = \text{LC} = \Sigma \text{WLA} + \Sigma \text{LA} + \text{MOS} \quad \ldots \ldots \quad (\text{CVRWQCB, 2004b}) \quad (1)
\]

Where: LC = salt assimilative load capacity (tons of salt)
WLA = point source salt load allocation (tons of salt)
LA = non-point source salt load allocation (tons of salt)
MOS = margin of safety (%)

Much of the irrigation water supplied to the west-side of the SJRB is pumped from the Sacramento-San Joaquin Delta through the Delta Mendota Canal and contains low levels of salinity (usually between 300 and 450 ppm)–allowances have been made for the salt load contained in imported water supply and for the evapoconcentration of this water when consumptively used by crops or seasonally managed wetlands. The TMDL (CVRWQCB, 2004a, 2004b) applies a water supply salt load credit for the salinity of water imported from the Delta and a consumptive use allocation credit for agricultural and wetland use of the water (an incentive for these entities to discharge return flows that have not been degraded).

The success of the TMDL concept as a regulatory tool is testimony to the consistency of the methodology and its ability to provide quantitative measures of application outcome. The conceptual TMDL model breaks down in regions such as the western United States where hydrology is often extreme with wet hydrologic years, capable of causing severe flooding, interspersed with periods of severe drought—making attainment of load objectives very challenging, even with wet and dry year allowances. Another limitation of the TMDL approach is the inflexibility of the methodology to account for watershed undergoing adaptive change – where average conditions cannot be established and baseline salt loads are not applicable. In the SJRB TMDLs developed for salinity and dissolved oxygen problems in the San Joaquin River Deep Water Ship Channel can be in conflict – whereas the salinity TMDL limits can best be attained by reducing salt loading to the River, the loss of flow associated with a reduction in salt loading can exacerbate dissolved oxygen sag and creates an environmental barrier to fish passage.

1.2 Basin-scale Real-time Salinity Management

A unique provision in the published salinity TMDL for the SJRB was the addition of a “real-time” load allocation that can supersede the conservative base flow non-point source load allocation (LA) if the elements of a real-time salinity management program (RTSMP) are implemented in the SJRB. This has been elaborated in the current SJRB Water Quality Control Plan. The core requirements of this program include: the development of a basin-scale, sensor network to collect real-time monitoring of flow and salinity data; an information dissemination system for effective sharing of data among basin stakeholders; a calibrated simulation model of hydrology and salinity in the SJR and its contributing watersheds to allow forecasting and daily assessment of SJR assimilative capacity (Figure 1); and finally the sanction of the Central Valley Regional Water Quality Control Board (CVRWQCB). The impact of the additional real-time salt load allocation would be to permit greater export of salt load from the watershed during most years (Quinn and Karkoski, 1998; Quinn and Hanna, 2003; Quinn et al., 2005; Quinn, 2009; Quinn et al., 2011) and help to overcome salt accumulation within the shallow groundwater system which would ultimately degrade the groundwater resource within the SJRB.

Real-time salinity management (RTSM) relies on the provision of continuous flow and EC data from willing stakeholders to allow forecasting of SJR assimilative capacity so as to match those that supply assimilative capacity and those that consume it. East-side reservoir releases of high quality Sierran water provide dilution to the SJR that drains west-side salt-laden soils.. West and east-side agricultural return flows are highest during the summer irrigation season. Return flows from seasonally managed wetlands are highest during the months of March and April when the
The majority of the seasonal wetland ponds are drained to promote establishment of moist soil plants and habitat for migratory waterfowl. RTSM should provide timely decision support to agricultural water districts, seasonal wetland managers and municipal dischargers - allowing them to improve the coordination of salt load export with the available assimilative capacity of the SJR (Quinn and Karkoski, 1998; Quinn and Hanna, 2003).

2.1 Monitoring networks—data measurement and telemetry

The monitoring of flow and electrical conductivity (EC) at purpose-built monitoring stations is undertaken mostly by water agencies such as the California Department of Water Resources (CDWR), the US Geological Survey (USGS) and US Bureau of Reclamation (USBR) along the SJR and its major east-side and west-side tributaries (Figure 2). Water districts and local agencies are responsible for the majority of the flow and salinity monitoring within the watersheds that discharge to the River. Critical data on SJR diversions is currently only collected by the major SJR diverters. Recent California legislation requires estimation and reporting of SJR diversions by all riparians with an established right to SJR water supply.

Most agency flow monitoring is still performed using continuously recording pressure sensors and stage-flow ratings that are updated monthly during routine monitoring site maintenance. Over the past decade orifice bubbler technologies using compressed air produced on-site, manufactured by com-
companies such as Design Analysis™ have replaced more complicated nitrogen-based systems and solid state pressure transducers for most agency monitoring of the SJR and its major tributaries. However, real-time salinity management requires that water quality simulation and forecasting models have reliable data, leading to stakeholder pressure to introduce acoustic Doppler current profiler technologies using instruments such as the SONTEK/YSI Argonaut™ and TELEDYNE TRDI™ (Simpson, M.R., 2002; Teledyne RD Instruments, 2008; SonTek/YSI, 2000) to produce more accurate flow measurements that are accurate even under backwater flow conditions in the SJR.

During winter and spring high rates of discharge from east and west-side tributaries can create backwater conditions and retard flow at the SJR confluences that produce elevated stage at upstream monitoring stations unrelated to the actual flow. Since Acoustic sensors measure current directly they are not subject to the same errors. Acoustic sensors typically can be equipped with both acoustic and pressure sensors to measure stage—providing a measure of redundancy that can improve data quality assurance. Additional benefits will accrue in the reduction in field personnel staff time—field crews are typically mobilized to re-rate flow monitoring sites during backwater events—and in improvements in the quality of the data record. Water districts and local agencies have been more ubiquitous in their use of Doppler technologies for flow measurement in the past decade as the size of transducers has decreased, reliability has improved and cost reductions have occurred. Upward and side-looking acoustic Doppler transducers that have embedded pressure sensors such as those manufactured by MACE™ and SONTEK/YSI™ can be installed in both open delivery and drainage channels as well as closed pipes and culverts. The cross-section of these conveyances can be entered into each of these units allowing the discharge to be estimated by the product of mean water velocity and the calculated flow cross-section. Placement of these transducers depends on the turbidity of the water and the risk of sedimentation. Deployment on the sides of pipes or channels is appropriate where the unit could be buried by a layer of sediment.

Telemetry costs and options have also improved over the past decade with cellular data plans making it affordable to have individual accounts associated with each monitoring site. In the recent past integration technologies such as YSI-EcoNET™ found a niche primarily by allowing more costly cellular CDMA telemetry to interface with local RF-based systems. YSI-EcoNET™ enables a sensor network of RF-enabled “data nodes” that collect flow and water quality data from individual monitoring sites to deliver these data to a smaller number of CDMA-enabled “access nodes”. Access nodes transmit logged data to a remote Data Center from which the stored data is made accessible through the Internet. These Data Centers perform enterprise-level database access and web-based data visualization. The YSI-EcoNET wireless mesh “multi-hop” network topology has allowed “point-to-point” or “peer-to-peer” connectivity and is self-organizing and self-healing – hence loss of one or more nodes does not necessarily affect its operation. This has helped to increase the overall reliability of the system by allowing a fast local response to critical events in the event of communication problems.

YSI-EcoNET deployment (Figure 3) in 2005 within the Grassland Water District (GWD), a water purveyor responsible for the delivery of seasonal wetland water supply to 160 duck clubs and cattle operations on the west-side of the SJRB, has allowed wetland managers more time to perform bi-weekly sensor data quality assurance checks including cleaning of sensors and checking the accuracy of staff gauge data (used in the computation of flow). YSI-EcoNET is “middleware” technology that has provided a relatively inexpensive pilot sensor network solution that has proved to the District and adjacent state and federal wildlife refuges the benefits of real-time flow data for water conservation and local reuse.

Low cost cellular and satellite data plans with greater accessible data bandwidth, available since 2005, have created new opportunities in the past five years making it cost effective to bypass this “middleware” technology and have hydrologic data management systems (HDMS) housed in agencies and local water districts pull data directly from flow and EC monitoring stations. The WISKI (https://www.kisters.net/NA/products/wiski/) HDMS technology uses a data acquisition software module SODA that contains a suite of custom data transfer protocols that allows communication with a large array of commercial dataloggers and data modems. Data transfer technologies include IP-telemetry, remote call, file transfer, web services and e-mail. They accommodate push, pull, D-channel, remote call data transfer directions using telephone, GSM, UMTS, GPRS, internet, radio and satellite data transfer pathways. Having the sensor network, data storage and data processing tightly integrated helps to minimize monitoring network downtime, provides greater data integrity, lowers
overall system operational costs and lends itself to the introduction of real-time data quality assurance practices. GWD is currently making the transition from YSI-EcoNET to a turnkey WISKI-based real-time data acquisition and monitoring system prompted, in part, to the phase-out of YSI-EcoNET by XYLEM Inc., the new corporate owner of the YSI/SONTEK product.

2.2 Data quality control and assurance

A limitation of many environmental decision support projects that rely on the telemetry of monitored data to a stakeholder community is data quality assurance. Data quality assurance protocols for discrete environmental sampling are well established and data quality control plans are integral components of most environmental monitoring projects. For continuously recorded and reported data, however, the logistics of monitoring site visitation and procedures, data management, processing and error correction are not coherent throughout the SJRB. Established software tools used by local water districts (WISKI) the CDWR (HYDSTRA) and the USGS (AQUARIUS) facilitate and guide these tasks that use QA data to error-correct and apply averaging techniques to continuous records (Figure 4). This produces a reliable data record that can be publicly shared and readily utilized in flow and salinity forecasting models. Inaccurate or absurd data posted to a project website can cause irrepara-
ble harm to a project and can quickly lead to a loss of confidence within the stakeholder community.

These software tools can be used for data management and quality assurance for open and closed sensor networks. Open sensor networks such as the system developed by the GWD have the capability of incorporating data from monitoring stations accessible by SODA but outside the District’s portfolio of stations. Examples of closed sensor networks are those provided by SCADA which provide control capabilities not offered by typical dedicated monitoring sensor networks. However SCADA systems require technical skills that are beyond the staff resources of most smaller water districts. Post processing data quality assurance tools such as WISKI can be configured to work with both open and closed sensor networks. The WISKI HDMS, like the other software products, provides a user interface that lists site names associated with a number of parameter subcategories that are being logged together with the deployed sensors.

Each of the times series entries contains the original data (labeled “01. Continuous.O”, etc.), while each subsequent time series entry is modified as a result of quality control operations performed on the data. The second time series (“Continuous.V”) is an exact copy of the original data, but can be edited and modified (Figure 4). The next time series (“Continuous.P”) is the product time series, which displays the final data after all data quality assurance (QA) adjustments, drift corrections, missing value interpolations etc. have been completed. The next time series plots contain average, maximum and minimum values for the data over certain time periods (daily, monthly, yearly). For sites for which data QA has been performed through the WISKI data management system, an additional time series entry will be present. The time series “QA Points” represent the manual measurements taken in the field at the site while the “Drift Correction” time series shows the results of calculations performed to
Figure 4. WISKI hydrologic data management software showing station parameters and time series associated with each parameter. WISKI can be used to automate processing of preliminary data and to fit a new time series to an imported set of quality assurance data points for stage, flow and electrical conductivity.
Figure 5. WARMF-Online web portal (homepage) using the 34-North Open NRM visualization toolbox. The web portal provides data access, visualization of WARMF-SJR model output, weekly salt assimilative capacity forecasts and GIS-based data analysis.
adjust the final data. The final data field is still displayed within the “Continuous.P” time series plot.

### 2.3 Real-time operations, alerts and alarms

The WISKI software suite includes several advanced productivity tools such as KiDAT (data acquisition tool) and KiDSM–automated scheduler and data importer and the KISTERS Alarm Manager which sets alarms and set responses to pre-set conditions. This last development has significant advantages for real-time data management in that full SCADA was previously needed for a data collection platform or PLC to react to a field condition informed by a sensor or number of sensors working together. Alarm manager software allows the system to respond to data or combined data contained in the user database. For example having a sensor value rise above a set condition could trigger an alarm (such monthly target salt loading at an outlet). Similarly, the sensor value can be compared to any parameter value in the database or even a model calculation (such as computed salt load at Vernalis) or to SJR calculated salt assimilative capacity. KiDAT software is able to automatically download real-time data from various agency websites including: the USGS National Water Information System (NWIS); the California Data Exchange (CDEC) and Environmental Protection Agency (STORET). The software can “data scrape” any website once a template for that site has been established.

This software feature has narrowed the technical capability advantage that SCADA systems have had over monitoring network systems helping to drive down the cost of deployment and making these HDMSs more accessible to smaller water districts. It also allows the enhancement of sensor networks for decision support in those instances where web access to the public and data downloads in real-time is possible. Basin-wide real-time salinity management (RTSM) will require the both the development of new stakeholder initiated sensor networks and the synthesis of these networks into a basin-scale application where they are combined and made available for a computer-aided model simulation and forecasting tool capable of estimating future salt assimilative capacity conditions in the SJR. Real-time data quality assurance tools will play a significant role in encouraging the free sharing of data necessary for developing timely and realistic forecast of SJR flow, EC and salt assimilative capacity.

### 3.0 Data visualization and decision support system development

The web-based data synthesis tool under development that also has the capability of sharing forecasting model outputs is known as WARMF-Online (Figure 5). The Watershed Analysis Risk Management Framework application for the San Joaquin River (WARMF-SJR) provides the analytical backbone for the web-based data visualization system implemented within OpenNRM–open-source software developed by 34 North Inc. OpenNRM addresses the need for a collaborative software workspace for supporting, organizing, managing, analyzing, visualizing, archiving and reporting project and operations information. The software provides a number of features including: (a) compilations of existing data sets for regularly assessing, comparing and reporting on these datasets (b) simplification of data management and access by centralizing key datasets and management tools; (c) the creation of a collaborative workspace will facilitate analysis, synthesis, assessment and communication; (d) creation of a web based workspace for developing a credible process, in which stakeholders can participate, to ensure that data are appropriately assessed, interpreted, and reported; (e) visualization tools so that modeling and visualization runs can be easily modified, enhanced and repurposed for additional studies; and (f) analytics-status and trend monitoring is simplified by automation of many of these core activities (Figure 5).

When fully implemented within the OpenNRM system-WARMF-Online will supply real-time flow and salinity data from public water agency websites, cooperating water districts and other stakeholders, using an input format that enables reliable daily simulation and forecasts of SJR assimilative capacity to be made. Although at present, these model runs and assimilative capacity forecast are made within both the CDWR and USBR future forecasts will utilize a single web-based version of the model application which is kept up to date, continuously calibrated and upgraded with new algorithms and bug fixes. Future WARMF-SJR model forecast runs will be made by a small core group of stakeholder and/or agency personnel with write access privileges to the model. Model outputs and post-pro-
cessed visualizations will continue to be made available to the public through WARMF-Online.

3.1 Visualization of wetland flow, EC and salt load data for decision support

The WARMF-Online web portal is designed to serve all stakeholders in the SJRB that discharge to the SJR. Estimates of SJR assimilative capacity, determined using the WARMF-SJR forecasting model and exported to WARMF-Online are accessible to customized decision support tools developed at the water district-level. An example of this is the real-time data visualization tool developed for the GWD (Figures 6 and 7). This real-time data acquisition, data quality assurance and visualization system is built upon the YSI-EcoNET data acquisition system and WISKI data quality assurance toolbox. YSI-EcoNET data supplied to the District’s WISKI database is error-checked and exported to an external ftp server where it can be accessed by a customized GIS-based visualization tool provided by the USBR and housed at GWD. The tool provides updates of flow, EC (and calculated salt load) in GWD water supply and drainage conveyance channels as well as at crucial internal measurement and compliance points (Figure 7). A data file of 30 days duration containing hourly flow, EC and salt load data is continuously available to GWD personnel to support real-time decision making. The GWD will need, in the future, to monitor and control daily salt export so as not to exceed daily salt load targets either developed internally within GWD or in partnership with other wetland entities draining to Mud and Salt Sloughs.

Figure 6. A data visualization and decision support tool was developed for Grassland Water District as an exemplar of the type of information the water master suggested would be most useful to assist with salt load management. Colorized line segments rendered using the ArcGIS MapObject toolbox represent the length of canal associated with each monitoring station in the canal network. This rendering can be toggled to display flow, EC or calculated salt load. Current hourly values are shown in the tagged label associated with each monitoring station.
4.0 Flow/water quality modeling, simulation and forecasting

The Watershed Analysis Risk Management Framework (WARMF) model (Herr et al., 2001; Chen et al., 2001, Herr and Chen, 2006) is comprehensive decision support tool specifically designed to facilitate TMDL development at the watershed-level. The WARMF-SJR application simulates the hydrology of SJRB and performs mass balances for a broad suite of potential contaminants including total dissolved solids. The model (Figure 8) simulates tributary inflows from the major east-side rivers, agricultural and wetland drainage return flows, accretions from shallow groundwater, riparian and appropriative diversions and uses hydrologic routing to calculate flow and water quality at approximately 1.6 km intervals along the main stem of the SJR. Wetland drainage from the Grassland Ecological Area was partitioned into component State, Federal and private wetland contributors to SJR salt load.

A GIS-based graphical user interface (GUI) facilitates the visualization of model input flow and water quality data. Data templates expedite automated data retrieval from State and Federal agency hydrology and water quality databases and the automated updating of model input files. Water managers can enter daily schedules of diversions and discharges using the spreadsheet formatted model data interface. Standardized model output graphics aid the dissemination of flow and water quality forecasts (Figure 9).

A wetland water quality module for the WARMF-SJR model has been formulated that simulates water and salinity balances for individual ponded areas and that aggregates wetland discharge and salt loading at the watershed level enabling comparison with future salt load discharge schedules that will be developed by private, state and federal entities within the Grasslands Ecological Area. These wetlands are flooded in the fall and drained in the spring - ponded depth and outflow are a function of the cumulative inflow to the wetland.

Figure 7. Hourly values of flow, EC or salt load can be displayed over the period of a month using a slider to advance date and time forward or backward. The time series of flow, EC and salt load can also be visualized for each of the 50+ monitoring stations over the same period.
(i.e., precipitation plus applied water). Water levels of wetland ponds and wetland return flows are managed by means of controlled releases through pond outlets. The WARMF-SJR model includes the option to calculate surface water outflow based on inputs of average prescribed pond depth. This approach closely represents real management operations of retaining or releasing water to maintain desired pond depth in wetlands. This wetland simulation approach was tested using time series of pond depths from nine wetland impoundments that have been monitored since 2005. Salt load scheduling using weekly or monthly, seasonally adjusted loading targets is a salinity management strategy that could be implemented to help coordinate wetland drawdown and salt load export to the River from private, state and federal wetland entities. Where real-time telemetered data from both agricultural, wetland and municipal entities that discharge to the SJR is available, these data will automatically overwrite model-estimated values in the WARMF-SJR model. Engaging water district managers and water district staff to pay attention to web-posted information is made easier when their own data is made available and accessible on the web portal. We have demonstrated this during a decade of wetland monitoring on the State Refuge and in GWD. Having stakeholders pay attention and develop an appreciation for drainage return flows, discharge salinity and salt load export is the first step in participatory real-time salinity management.

**4.1 Data management coordination**

In early 2016 the San Joaquin Valley Drainage Authority (SJVDA) initiated informational quarterly stakeholder meetings on behalf of the Westside San Joaquin River Watershed Coalition (WSJRWC) on the topic of data management, data coordination and mechanisms for data sharing—a core requirement for RTSM. The WSJRWC ([www.sjvdc.org](http://www.sjvdc.org)) represents water districts and other agricultural and wetland stakeholders located within the Grassland and North-West Side subregions (Figure 1) and manages data collection and submits data reports to the CVRWQCB for a large number of regulatory (Irrigated Lands Program) monitoring sites. The WSJRWC has no mandate for and have little experience with the processing of real-time flow and salinity data however it is the logical administrative entity for real-time salinity management on the west-side of the SJRB. Similarly on the east-side of the Basin the East San Joaquin Water Quality Coalition (ESJWQC) ([www.esjcoalition.org](http://www.esjcoalition.org)) files required monitoring reports with the CVRWQCB on behalf of its 1000+ farmers and stakeholder entities, provides conditional waiver coverage for members of the coalition, develops and implements the real-time water quality monitoring program and communicates to landowners where water monitoring indicates problems exist and helps in the development of equitable solutions.

Ultimately the WSJRWC and the ESJWQC will need to develop a Memorandum of Understanding for joint implementation of the RTSMP Program recognizing the use of the WARMF-SJR model as a decision-making tool to forecast availability of SJR assimilative capacity through better coordination with eastside irrigation districts and upstream reservoir operators and through sharing this information with westside salt load dischargers to allow them to improve coordination and scheduling of drainage return flows and westside riparian diversions to manage their diversions to help meet and maintain SJR salinity objectives. Realization of the potential of RTSMP may require the formation of a basin-scale salinity management entity built upon the WSJRWC and the ESJWQC with the authority to encourage compliance with sub-basin salt load targets through incentives or penalties to ensure compliance with internally sanctioned salt load limits and mutually agreed-upon salinity compliance monitoring locations.

The CVRWQCB has recently completed a series of studies supporting a Basin Water Quality Plan amendment to introduce an upstream salinity concentration objective at Crows Landing on the SJR. This entity would have program oversight that would involve maintenance of monitoring stations, discrete sample collection and analysis and monitoring data record keeping, coordination of both drainage return flows and reservoir releases from east-side tributaries, synthesis of real-time data and dissemination of daily salt assimilative capacity forecasts for the SJR. The monitoring systems and data management systems used for real time management must be robust, reliable, and well maintained to function properly and provide accurate information. The WISKI data management system that is in common use by the Merced, Modesto and Turlock Irrigation Districts on the eastside and the GWD on the westside and the compatible HYDSTRA data management system (also a KISTERS Inc. product) used by the CDWR should be used as the IT backbone for the joint system. Development of an integrated data management system capable of combining all relevant east and west-side flow and EC data is made easier through the use of common IT ontologies and data sharing protocols.
4.2 Potential coordination and integration with ongoing activities

The development of a real-time water quality management system for the SJRB is a multi-million dollar endeavor requiring close coordination and cooperation with other water agencies such as CDWR and the CVRWQCB as well as landowners and the water districts that represent them - on both east and west sides of the SJRB. Given the potential expense of this undertaking—one cost-saving initiative that can be undertaken is the integration of the current real-time initiative with the significant information technology investment being underwritten by the congressionally-funded San Joaquin River Restoration Program (SJRRP). An important component of the $800 million SJRRP program is the Seepage Management Plan—a highly interactive, real-time monitoring and response program designed to maximize water flow along the critical SJR reaches newly re-watered, while protecting riparian agriculture from seepage inundation impacts. The real-

[Figure 8. WARMF-SJR model showing the disaggregation of watersheds contributing flow and salt load to the San Joaquin River into component drainages. The hydrology of the San Joaquin Basin is such that the political boundaries of individual agricultural water districts are the most appropriate primary unit (sub-watershed) for monitoring, management and control of salt loading to the San Joaquin River from the west-side. Sub-watersheds on the east-side of the San Joaquin River are determined by the irrigation supply and surface drainage network.]
time monitoring program is centered around a network of sentinel wells which rise during high river stage and provide an indicator of waterlogging in adjacent fields and in some cases, on property as much as a few miles from the SJR. The SJRRP has acquired an external data server to allow easier uploading of field data and easier access to the server from cooperating agencies and water districts. The SJRRP data server might offer a number of advantages for the RTSMP: (a) The current SJRRP monitoring network contains river flow and salinity monitoring stations which will eventually be needed by the real-time salinity monitoring program—since a large component of the SJR salt assimilative capacity will be generated in the river reach above the Merced River tributary confluence and in the domain of the SJRRP; (b) The real-time salinity management program has developed a data QA solution using WISKI license which does not currently exist in the SJRRP.

A single WISKI license could reside on the server and provide benefit to both programs; (c) Integration

**Figure 9.** The GOWDY Output is a unique post-processor for the WARMF-SJR model that toggles between views of flow, EC and salt load for the entire San Joaquin River between Lander Avenue and Vernalis (a 96 km reach) for a single day in the year. On the left panel flows into the River show as green horizontal columns superimposed over the input source whereas diversions from the River show up as red horizontal columns to the left of zero. In the top and bottom panels to the right of the screen are shown travel time showing an initial value of 1.8 days diminishing to zero days at the Vernalis compliance monitoring station. Flow is shown increasing from left to right as the east-side tributaries discharge into the River. The lower right-hand panel shows the same cumulative flow relative to cumulative River diversions.
of monitoring activities makes sense since programmatic releases by the SJRRP will affect river assimilative capacity for salt. Likewise flow forecasts made by the SJRRP to minimize landowner impacts will be useful for improving model forecasting capability for the salinity management program; (d) Overall cost-savings. This is perhaps the only way for the real-time salinity management program to make the sort of progress needed to meet the CVRWQCB expectations for a Basin-wide program that is on track to maintain salinity objectives at Vernalis.

5.0 Trend analysis based on WARMF-SJR model forecasts

Both the RTSMP and the SJRRP programs are concerned with improved management of flow and water quality in the SJR to meet State-imposed River water quality objectives and to restore the River’s Chinook salmon fishery. During winter of 2015-2016, measured inflow to the lower SJR from its major tributaries was uncharacteristically greater than the measured Vernalis outflow suggesting a higher rate of SJR depletion along the lower reach of the SJR. An analysis of measured flow data was performed to ascertain if there might be a longer-term decline of accretions to the lower SJR from groundwater or if the apparent losses were an artifact of prolonged drought conditions. Groundwater accretions were calculated as the difference between the sum of measured tributary inflows to the SJR and the measured outflow from the SJR at Vernalis. Daily flow data was collected from 1985-2016 for the gages on the SJR near Stevinson, Salt Slough, Mud Slough, Orestimba Creek, Del Puerto Creek, the Merced River, the Tuolumne River, and the Stanislaus River and added together to get total daily inflow (Figure 10).

In the late 1990’s groundwater accretions provided over 600 cfs of flow to the SJR-since then there has been a persistent downward trend leading to approximately zero net groundwater accretions in 2015 and net seepage loss from the river in 2016 (Figure 11). This trend is similar between the irrigation season, when there are substantial diversions from the SJR, and non-irrigation season (Herr 2016).

![Figure 10. SJR accretion reductions shown for two reaches during 2015/2016.](image-url)
Technical advances in data acquisition and information dissemination technologies have made possible the initial stages of implementation of a real-time salinity management program in California’s SJRB. Experience to date with respect to implementation of RTSM in the SJRB suggests the following principles moving forward, that have been discussed in the paper: (a) necessary stakeholder participation in the design and operation of existing and planned flow and water quality monitoring stations and web-based IT solutions that provide easy access to the real-time data being collected; (b) decision support system design should utilize technical expertise within the WSJRWC and ESJWQC at the earliest stage possible to work toward the design of a common system; (c) the WARMF-SJR simulation model, that forms the core of SJR salt assimilative capacity decision support systems, should be significantly enhanced with full GIS capabilities and made more robust in its ability retrieve real-time data through the current WARMF-Online web browsing tool and visualization engine. This would invite greater stakeholder understanding of the process and boost engagement; (d) provide more widespread support for data quality assurance technologies such as WISKI and HYDSTRA to improve accuracy of the real-time data being utilized by the WARMF-SJR forecasting model and reduce the fear of posting erroneous data. The process of implementing RTSM in the SJRB will further encourage innovation–successful implementation will have significant transfer value to other highly regulated river basins where water quality is a concern.

Figure 11. Trend in calculated SJR ungauged inflows over past decade.
Acknowledgements

The authors were provided support from the USBR that has financed development of essential tools to implement the concept of real-time salinity management. Thanks also to Ric Ortega, General Manager at GWD, an early adopter of many of these technologies and the Lower San Joaquin Committee of CVosalts, which is proving to be a fertile ground for new ideas and problem solving related to RTSM implementation.

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