Title

Promoting Stakeholder Engagement under Real-Time Salinity Management: A More Cost-Effective Alternative to Traditional TMDL Implementation

ISBN

9780784483060

Authors

Quinn, NWT
Deeds, D

Publication Date

2020

Peer reviewed

Promoting Stakeholder Engagement under Real-Time Salinity Management - A More Cost-Effective Alternative to Traditional TMDL Implementation

Nigel W.T. Quinn, Ph.D., P.E., D.WRE, F.ASCE, F.EWRI [1] and Daniel Deeds, PhD[2].

[1.] Research Group Leader, HEADS, Berkeley National Laboratory, 1 Cyclotron Road, MP-64-209, Berkeley, CA 94720; nwquinn@lbl.gov

[2.] Regional Water Quality Coordinator, US Bureau of Reclamation, Decision Analysis Branch, 2800 Cottage Way, Sacramento, CA 95825; email: ddeeds@usbr.gov

ABSTRACT

Salt export from agricultural, wetland and municipal dischargers to the San Joaquin River (SJR) is regulated as part of a comprehensive Total Maximum Daily Load (TMDL) for the San Joaquin River Basin (SJRB). The TMDL is intended to identify, quantify and control sources of salt loading that affect attainment of salinity objectives and protect agricultural beneficial uses of water. Non-point sources of salinity are not amenable to the establishment of fixed monthly salt load allocations because of the diffuse nature of these loads making it difficult to monitor individual discharge points and assign responsibility. Real-time salinity management (RTSM) has been advocated as a novel means of improving compliance with SJR salinity objectives by enhancing the coordination of west-side agricultural and wetland salt loads with salt load assimilative capacity provided by reservoir releases along east-side tributaries to the SJR. RTSM is a concept that relies upon continuous access to real-time flow and electrical conductivity data from SJR Basin sensor networks and the development of a decision support system that extends watershed monitoring to allow salt load assimilative capacity forecasting in real-time. This paper describes some of the web-based information dissemination and data sharing innovations that have been tried and are under development in the implementation phase of the real-time salinity management program with an emphasis on experiences with stakeholder engagement and participation.

INTRODUCTION

The Central Valley Regional Water Quality Control Board's (CVWB) Salt and Boron Total Maximum Daily Load (TMDL) for the San Joaquin River was approved on July 28, 2006. In response to the Salinity and Boron TMDL, the United States Bureau of Reclamation (USBR) developed a salinity control plan entitled "Actions to Address the Salinity and Boron TMDL Issues for the Lower San Joaquin River" and entered into a Management Agency Agreement (MAA) with the CVWB on December 22, 2009. The MAA describes the actions USBR will take to meet Salinity and Boron TMDL obligations, in particular maintaining compliance with salinity objectives of 700 µS/cm during the irrigation season (April 1 – August 31) and 1,000 µS/cm during the non-irrigation season (Sept. 1 – Mar. 31) measured as a 30-day running average electrical conductivity (EC) at the Vernalis compliance monitoring station. The Action Plan also describes procedures to manage and mitigate adverse impacts of salt and boron imported into the San Joaquin River Basin (SJRB) via the USBR's Delta Mendota Canal (DMC) as included in the CVWB's most recently amended Water Quality Control Plan for the Sacramento River and the San Joaquin River Basins (CVWB, 2018). The USBR routinely provides dilution flows from the New Melones

Reservoir on the Stanislaus River to meet the Vernalis 30-day running average salinity objectives when there is insufficient salt load assimilative capacity in the SJR.

TMDL salt load allocation methodology. The CVWB salinity TMDL methodology, supported by current science and available data, followed a protocol that the CVWB believed would be perceived as equitable and fair. The TMDL is unusual in that it recognized the federal water agency and purveyor of water supply as a primary stakeholder given that this supply introduced salt loads to the SJRB elevated above historic background levels for snowmelt runoff flowing to the SJR via the Stanislaus, Tuolumne and Merced Rivers. The source of the USBR water supply through the DMC to both the Grassland and Northwest subareas on the west-side of the SJRB is the Sacramento – San Joaquin Delta (Figure 1). The salinity of this water supply can further degrade along the DMC due to inflows of storm drainage, subsurface drainage from interceptor drains and supplemental supply from pumped agricultural groundwater wells along the canal alignment.

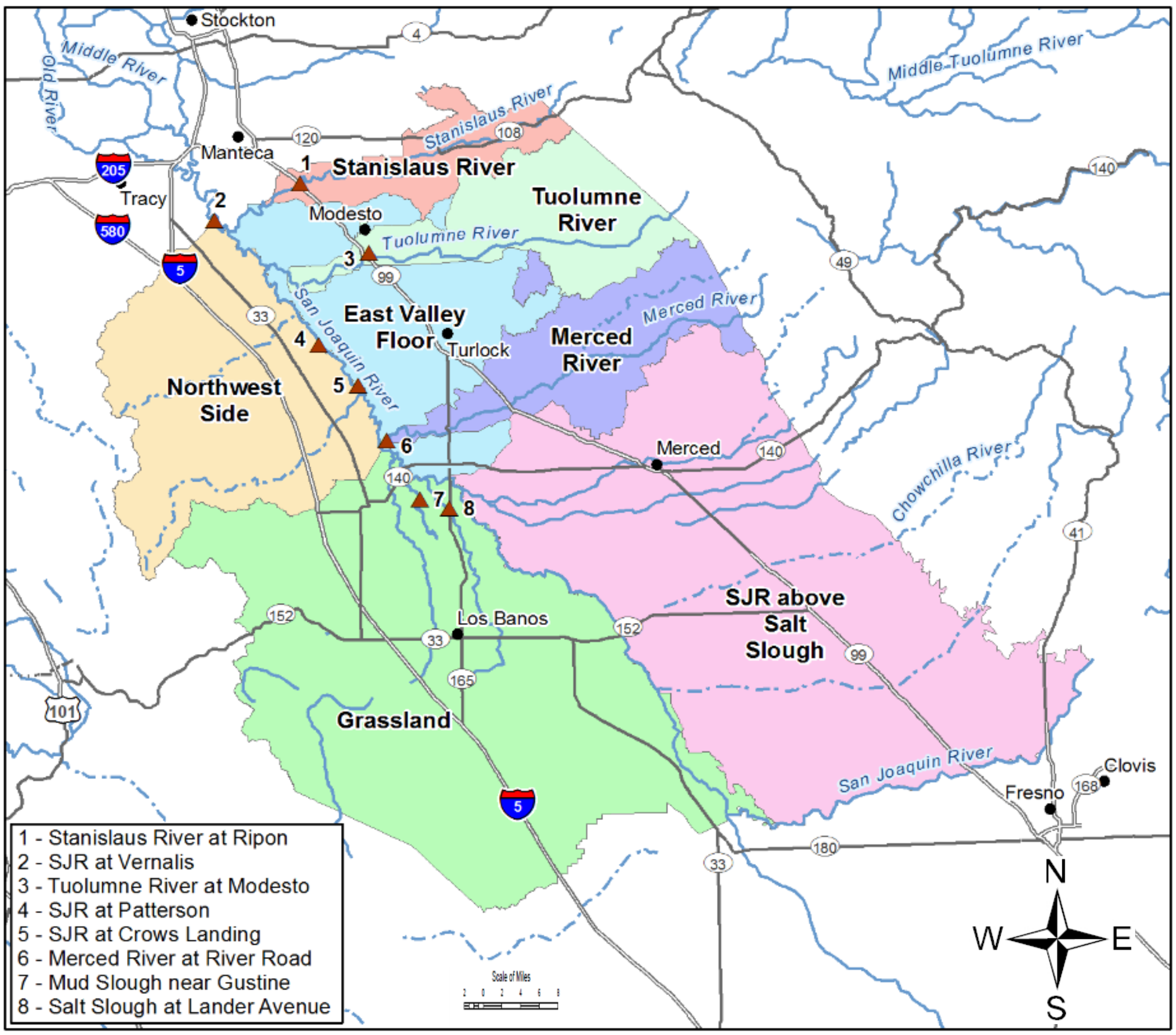

Figure 1. The San Joaquin River Basin (SJRB) covers 15,880 square miles and contains seven contributing subareas as defined in the 2002 TMDL.

West-side salinity sources. The CVWB periodically updates their SJRB Water Quality Control Plan that currently allocates a salt load to USBR for water supply delivered to stakeholder contractors on the west-side of the SJRB. The load allocation (LA) for these DMC deliveries to the Grasslands and Northwest side subareas was calculated as follows:

$$LA_{DMC} = Q_{DMC} * 52 \text{ mg/L} * 0.0013599$$

Where:

LA_{DMC} = Load Allocation of salt for DMC water deliveries (tons)
Q_{DMC} = monthly volume of water delivered to Grasslands and Northwest side subareas (acre-feet)
52 mg/l = "background" TDS of SJR water at Friant Dam (SJRB Basin Plan)
0.0013599 = TDS unit conversion factor (mg/L to tons/acre-feet)

Salt loading above this load allocation was considered an "excess" salt load which must be offset by watershed sources that increase SJR salt load assimilative capacity or that reduce non-point source salt loading. The USBR agreed upon a suite of actions described in the stakeholder-endorsed SJRB Action Plan that were designed to offset this excess salt load. Excess salt loads (EL_{DMC}) were calculated as:

$$EL_{DMC} = Q_{DMC} * (C_{DMC} - 52 \text{ mg/L}) * 0.0013599$$

Where:

EL_{DMC} = excess salt load above the Load Allocation (LA_{DMC}), in tons
C_{DMC} = monthly average (arithmetic mean) of salinity of the water delivered to Grassland and Northwest subareas, in mg/L

Q_{DMC} was calculated for each reach (i) of the DMC to the point of delivery and paired with the associated monthly average TDS (from measured EC) for the same reach to produce the following equation for the cumulative EL_{DMC}:

$$EL_{DMC} = 0.0013599 * \Sigma_{\iota}(Q_{DMCi} * (C_{DMCi} - 52 \text{ mg/L}))$$

Accordingly, the Grasslands and Northwest subareas were assigned independent salt load allocations described as water supply credits that are a function of the volume of water delivered to each subarea. Water deliveries were apportioned by subarea where the DMC supplied water across the subarea boundary. The calculated Consumptive Use Allowance is the product of the actual monthly flow volume and a trigger salinity value of 192 mg/L TDS which was assumed equivalent to the mean salinity of drainage return flows after accounting for seasonal crop evapotranspiration for an irrigation water supply with a salinity of 52 mg/L.

Quantification of east-side assimilative capacity generating flows. The US Congress authorized the construction and operation of New Melones Reservoir on the Stanislaus River as a multi-purpose facility, which includes water quality as a qualified use. Non-consumptive water releases from this reservoir are of high quality and provide significant dilution flow for salinity in the SJR. Other releases of stored water from New Melones are made for instream fishery benefits and to maintain the dissolved oxygen level in the Stanislaus River above the confluence with the SJR. Any time these routine releases are insufficient to decrease SJR salinity below the target 30-day running average salinity at Vernalis additional reservoir releases for salinity management are scheduled by the USBR to maintain compliance and offset excess salinity loads imported through the DMC.

The current CVWB Basin Water Quality Control Plan specifies that entities providing dilution flows obtain an allocation equal to the salt load assimilative capacity provided by this flow. This allocation is only applied if the quantified dilution flow provides measurable dilution in the SJR to the Vernalis compliance monitoring station and creates assimilative capacity without interfering with the Stanislaus River subarea's salt load allocation.

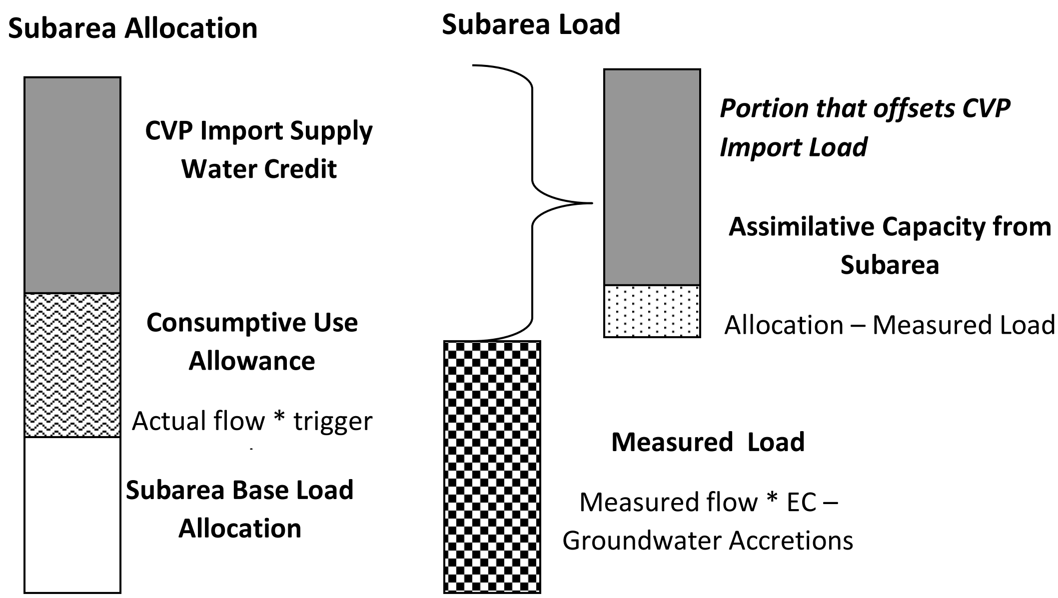

Figure 2. Assimilative capacity calculation for the Grassland subarea.

To calculate the assimilative capacity created by the USBR's operations on the Stanislaus River both the actual salt load and the salt allocation of the river were calculated. The monthly salt load was subtracted from the monthly salt load allocation to determine available salt load assimilative capacity. A site-specific ratio of 0.69 was used for all the east-side tributaries to convert EC to TDS. The actual salt loading was calculated as follows:

$$L_{actual} = Q_{actual} * C_{actual} * 0.69 * 0.0013599$$

Where:

L_{actual} = actual tributary salt loading (tons/month)
Q_{actual} = actual flow volume (acre-feet/month)
C_{actual} = monthly mean EC (µS/cm)
0.69 = TDS:EC ratio specific to Stanislaus River
0.0013599 = TDS unit conversion factor (mg/L to tons/acre-feet)

The salt load allocation to the Stanislaus River subarea was calculated as the sum of its Load Allocation (LA) and the Consumptive Use Allowance as previously defined.

Likewise salt load assimilative capacity allocations for the Merced River and Tuolumne River subareas were calculated as the sum of the Base Load and the Consumptive Use Allowance allocations. Flow data for the Tuolumne River was obtained from the USGS stream gauge station at Modesto (site ID: 11290000) and for the Merced River at the USGS stream gauging station near Stevinson (site ID: 11272500).

Fish and wildlife protection, restoration, and enhancement became important USBR project purposes with the passage of the Central Valley Project Improvement Act (CVPIA) in 1992. The

CVPIA committed 800,000 acre-ft of annual CVP project water, previously allocated to agriculture, to meet these objectives. A Water Acquisition Program (WAP) was created to acquire additional water supply, when needed, and to improve the USBR's ability to meet new regulatory water quality requirements under a new “Program to Meet Standards”.

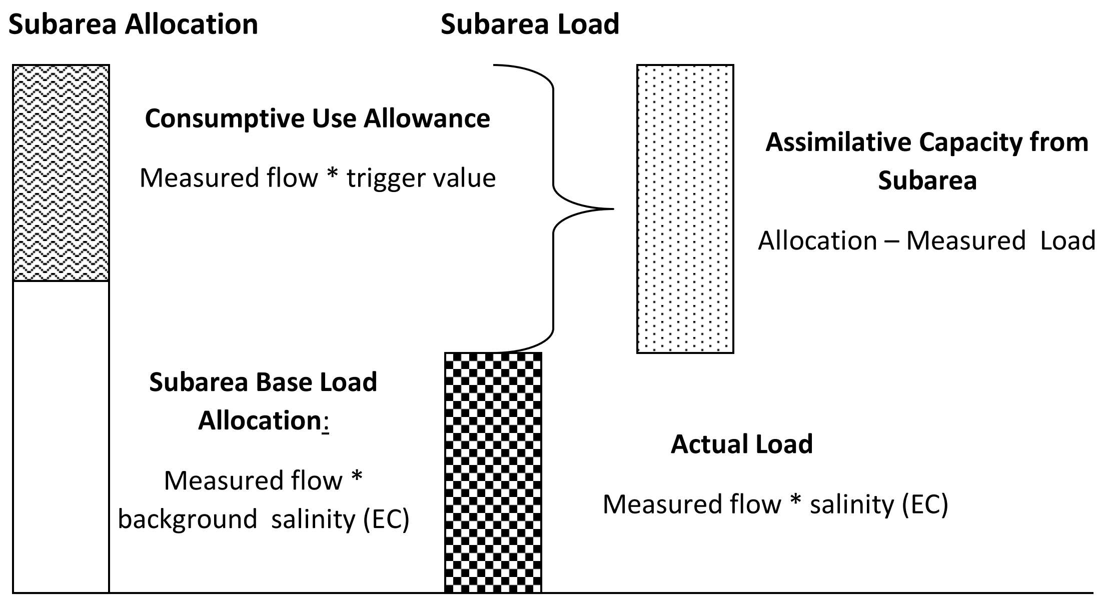

Figure 3: Assimilative capacity calculation for the Stanislaus River subarea.

These additional project water supply deliveries provide additional assimilative capacity that add to the USBR’s project area salt load allocation. Water supply dilution flow allocations were equated to the salt load assimilative capacity provided by this flow as follows:

$$A_{dil} = Q_{dil} * (C_{dil} - WQO) * EC:TDS * 0.0013599$$

Where:

A_{dil}	=	dilution flow salt load assimilative capacity allocation (tons of salt/month)
Q_{dil}	=	dilution flow volume (acre-feet/month)
C_{dil}	=	dilution flow EC (µS/cm)
WQO	=	salinity water quality objective for the LSJR at Airport Way Bridge near Vernalis in µS/cm
EC:TDS	=	TDS:EC ratio specific to the SJR River (0.64). This ratio is set to 0.66 for the Merced River and 0.67 for the Tuolumne River
0.0013599	=	TDS unit conversion factor (mg/L to tons/acre-feet)

Subarea allocation calculations are based on the Base Load Allocations and the Consumptive Use Allowance calculations for the Merced River and Tuolumne River subareas. Flow data were obtained from USGS stream gauge stations at Modesto for the Tuolumne River (site ID: 11290000) and near Stevinson for the Merced River (site ID: 11272500).

Salinity management policy implementation alternatives. Implementation of the salinity TMDL for the SJRB has been constrained by several factors:

(a) The salt load allocation process in the TMDL is complex. Individual subareas defined in the TMDL have had no easy way to ascertain their contribution to salt loading to the SJR.

Assessment of penalties for non-compliance with objectives is not transparent and may be onerous to enforce.

(b) Salt loading is a product of flow and TDS (often measured via EC) and salt load assimilative capacity is a concept that is understood by a limited number of stakeholders. There is an educational outreach activity needed to address this deficiency and to show the benefits of coordination of activities to improve compliance with salinity objectives.

(c) The TMDL provided no guidance with respect to the formation of an organizational entity with policing power for implementing the TMDL or how a market for salt load trading might be established.

(d) The TMDL was developed using existing agency and stakeholder publicly accessible data. No guidance was provided on the expansion of existing or development of new monitoring networks for additional flow and EC data needed to understand current patterns of salt export from subareas within the watershed and for improved salt control and management within each subarea.

In 2013 the CVWB presented to stakeholders an analysis to partly address criticism of the complexity of the TMDL development process and to provide an incentive to embrace a real-time management program alternative to the formal salinity TMDL accounting procedures. The Real Time Management Program was introduced in the 2004 CVWB Basin Plan Amendment as a stakeholder-driven effort to access shared "real-time" water quality and flow monitoring data to maximize the use of salt load assimilative capacity in the SJR. The CVWB defined salt load assimilative capacity as 85% of the product of the prevailing Vernalis salinity objective (30-day running average) and the current flow of the SJR minus the actual salt load in the river (i.e. the current SJR flow times the measured EC at Vernalis). This adaptive approach was suggested as a more flexible alternative to the published TMDL in that it was easier to understand, encouraged more stakeholder coordination for the control of salt loading and promoted maximum export of salt from the basin while still meeting the stated salinity objective. An upstream SJR objective was added as a further SJRB Water Quality Control Plan Amendment in 2017 to protect SJR riparian diverters in the reach between Crows Landing and Vernalis, especially during summer months of "dry" or "critically dry" years when River flows are low and salinity levels are elevated.

Another CVWB action to incentivize consideration of the RTSM Program and to provide more clarity to stakeholders was an analysis (Brownell, 2013) that showed a potential fine schedule for non-compliance with subarea TMDL load limits. This analysis was conducted using available SJR flow and the 30-day running average EC data at the Vernalis compliance monitoring station through 2012. From 2001 through 2012 was a period when there were frequent monthly violations of the salinity objectives at Vernalis as shown in Table 1. The table shows the water year classification over the time period analyzed and the number of times the 30-day running average monthly objective for EC was exceeded during each month. The Grassland subarea experienced the greatest number of exceedances prior to 2012 - primarily during winter and early spring when runoff from west-side agriculture and drainage drawdown from seasonally-managed wetlands (typically February through April) deliver salt loads to the SJR during periods of low SJR salt load assimilative capacity.

In Table 2, the exceedances shown in Table 1 are translated into hypothetical annual penalties using an assumed $5,000/day fine that would be applied for the number of days in each the month when the 30-day running average EC was exceeded. The average annual penalty for a subarea was calculated from the total penalties for the subarea (total number of daily exceedances multiplied by the daily penalty) divided by the number of years in the analysis.

Table 1. Enumeration of monthly San Joaquin River salinity objective exceedances of the 700 µS /cm irrigation season and 1,000 µS /cm non-irrigation season salinity objective at Vernalis for the period of record through 2012 (Brownell, 2013). (Note: the Vernalis Adaptive Management Program (VAMP) was active during this period and provided scheduled fishery flows in the LSJR between April 15 and May 15 each year).

Lower San Joaquin River Salt Discharge Exceedences

Sub Area and Period Studied	Water Type Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	VAMP	May	Jun	Jul	Aug	Sep
Northwest Side (1/1/2005-3/31/2012)	Wet (3[a])		1[b] of 3	1 of 3	2 of 3			2 of 3			1 of 3			
	Normal (1)													
	Normal (1)													
	Dry (1)			1 of 1	1 of 1									
	Critical (2)		2 of 3	2 of 3	3 of 3	1 of 3								
Grassland (1/1/2002-5/31/2011)	Wet (3)			3 of 3	3 of 3	1 of 3	2 of 3	3 of 3			1 of 3			
	Normal (1)			1 of 1	1 of 1		1 of 1							
	Normal (2)		1 of 2	2 of 2	2 of 2	2 of 2	2 of 2							
	Dry (2)				2 of 2	2 of 2	2 of 2							
	Critical (2)		1 of 2	2 of 2	2 of 2	2 of 2	2 of 2	1 of 2						
SJR Upstream of Salt Slough (1/1/2001-9/30/2010)	Wet (2)											1 of 2	2 of 2	
	Normal (1)													
	Normal (2)							1 of 2		1 of 2	2 of 2	2 of 2	2 of 2	
	Dry (3)							1 of 3		1 of 3	3 of 3	3 of 3	2 of 3	
	Critical (2)							1 of 2	1 of 2	1 of 2	2 of 2	2 of 2	2 of 2	
East Valley Floor (VAMP/2005-12/31/2007)	Wet (2)										1 of 2	1 of 2		
	Normal (0)	No Data Available for this period												
	Normal (0)													
	Dry (0)													
	Critical (1)											1 of 1	1 of 1	

a Number of water type years.
b Number of years that the salt discharge exceeded the monthly allocation.

The average annual penalty was also divided by the subarea area (acres) to obtain an annual average penalty per acre. The average annual subarea penalties of $303,750 and $569,500 per year, equivalent to $1.23 and $3.05 per acre per year (Table 2), are powerful incentives for agricultural and wetland stakeholders to seek an alternative regulatory salinity management solution such as the option to embrace Real-time Salinity Management.

Real-time Salinity Management Program (RTSMP). Salinity management in the SJRB is complex, involving agricultural, wetlands and municipal stakeholders within the basin and interested environmental groups and municipal entities downstream in the San Francisco Bay area. To illustrate the potential use of assimilative capacity, the USBR calculated the available daily salt load assimilative capacity in 2008, a year when violations of the salinity objective were still common. During 2008, SJR salt load assimilative capacity (dilution capacity) was available on 246 days of the year (conservatively estimated when the SJR salinity was less than 85% of the salinity objective) for a total of around 115,000 tons of salt (calculated on a daily basis). The salt load assimilative capacity of the SJR was exceeded on 119 days.

Table 2. Schedule of potential annual average penalties between 2001 - 2012 that could have been assessed for exceedances of salinity objectives at Vernalis under the salinity TMDL assuming a hypothetical penalty of $5,000/day for each monthly overage (Brownell, 2013). Northwest side (NWS); Grasslands (GL); Upstream San Joaquin River (SJR), East Valley Floor (EVF).

Potential Salt Discharge Load Exceedance Fees by subarea (2001 – 2012)					
Subarea		NWS	GL	SJR	EVF
Days exceeded by period	Oct	0	0	0	0
	Nov	90	60	0	0
	Dec	124	248	0	0
	Jan	186	0	310	0
	Feb	28	196	0	0
	Mar	0	279	0	0
	Apr	28	56	42	14
	VAMP	0	0	30	30
	May	0	0	51	17
	Jun	30	30	210	90
	Jul	0	0	248	91
	Aug	0	0	248	31
	Sep	0	0	0	0
Total days of exceedances		486	869	1139	273
$5,000 per day penalty		$5,000	$5,000	$5,000	$5,000
Total penalties		$2,430,000	$4,345,000	$5,695,000	$1,365,000
Years calculated		8	10	10	3
Average penalty per year		$303,750	$434,500	$569,500	$455,000
Subarea acreage		118,000	353,000	187,000	201,000
Average penalty per acre		$2.57	$1.23	$3.05	$2.26

The concept behind the RTSMP is to use existing or anticipated salt load assimilative capacity generated by dilution flows to increase the export of salt load from the SJRB when available and to improve the scheduling of salt load discharge into the SJR or temporary storage facilities when salt load assimilative capacity is more limited or not available. This could be extended to scheduling additional dilution flow releases such as those provided by the USBR through New Melones Reservoir and the Stanislaus River. Stakeholders from water districts that rely on New Melones Reservoir for a portion of their water supply have been supportive of the RTSMP concept since optimized control of salt discharged to the river from upstream sources would likely reduce the draw on New Melones Reservoir for water quality purposes. The CVWB (2004) prescribed the requisite components of a successful RTSMP as follows:

(a) The program maintains and (where necessary) expands existing accessible real-time monitoring networks that measure flow and EC necessary to assess daily SJR salt load assimilative capacity. The sharing of private water district drainage flow and EC data, as well as diversion data for those riparian districts that utilize the SJR for irrigation water supply, helps to expand the current environmental sensor network and is an important way for the agricultural and wetland entities to show their commitment to the RTSMP.
(b) The program provides technical support of the RTSMP that includes the development and maintenance of a computer-based water quality simulation model that can be used to estimate salt load assimilative capacity in the SJR. The simulation model would accommodate the inclusion of real-time drainage and SJR diversion data from cooperating stakeholders. The model would make 14-day forecasts of SJR flow, EC and salt load assimilative capacity based on advance schedules of east side tributary reservoir releases and other planned operations such as District diversion pumping schedules. Where these advance schedules are not available - archived data that match time of year and water year type can be used by the model to make provisional forecasts.
(c) An accessible data repository is a necessary feature of the Program that archives sensor network data and screens data to provide a minimum level of data quality assurance and control. Several large water districts and water agencies use commercial hydrological data management software such as WISKI™, AQUARIUS™ or HYDSTRA™ to perform real-time quality assurance on data downloaded from their sensor networks.
(d) The Program will require the construction of physical infrastructure such as temporary holding ponds, drainage control structures and drainage reuse and recirculation systems at the water district or sub-basin watershed level to provide rapid response to periods of potential non-compliance with salinity objectives.

Real-time monitoring. Over the past decade there have been significant technology improvements in the accuracy and reliability of flow and water quality sensors and sondes and in web-based data accessibility. Rotary wipers now allow the efficient maintenance of sensor electrodes permitting sondes to be deployed longer between service quality assurance checks. Calibration procedures are now built into the software of these instruments reducing the time needed to perform these checks. Data telemetry hardware and programming software procedures have also become more plug-and-play and at the same time cellular data service plans have become very low cost. Most of the current datalogger/modem devices on the market also allow two-way communication – overcoming a long-standing limitation of the Geostationary Operational Environmental Satellite (GOES) radio communication system that has been popular with water agencies because of its low cost. Real-time data access has also undergone significant improvement with vendor-supported web portals now available at low cost to store and allow flexible visualization of real-time and archived data. More recent datalogger innovations now allow some basic arithmetic operations to be conducted on the collected data such as calculation and display of salt loads after combining flow and EC data. Several vendors are also exploring adding basic data quality assurance functionality to their dataloggers by allowing access to basic Python scripting functions.

REAL-TIME SALINITY MODELING AND FORECASTING

Model-based forecasting of salt load assimilative capacity requires ready access to current flow and EC data within the SJRB and an underlying hydrology and water quality simulation model to relate these data to flow and salinity at the two SJR compliance monitoring stations. The model should be watershed-based if on-farm and water district-led management strategies for control of salt export are to be assessed. The Watershed Management Risk Management Framework (WARMF) model (Herr et al., 2001; Chen et al., 2001, Herr and Chen, 2006) is a comprehensive decision support tool that was designed specifically to facilitate TMDL development at the watershed-level and that has been applied to facilitate RTSM in the SJRB. 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 SJR from the west-side. The model performs mass balances for a broad suite of contaminants including total dissolved solids and simulates tributary inflows from the major east-side rivers, agricultural and wetland drainage return flows, accretions from shallow groundwater, riparian and appropriative diversions (Figure 4). The model uses hydrologic routing to calculate flow and water quality at approximately one mile intervals along the main stem of the SJR.

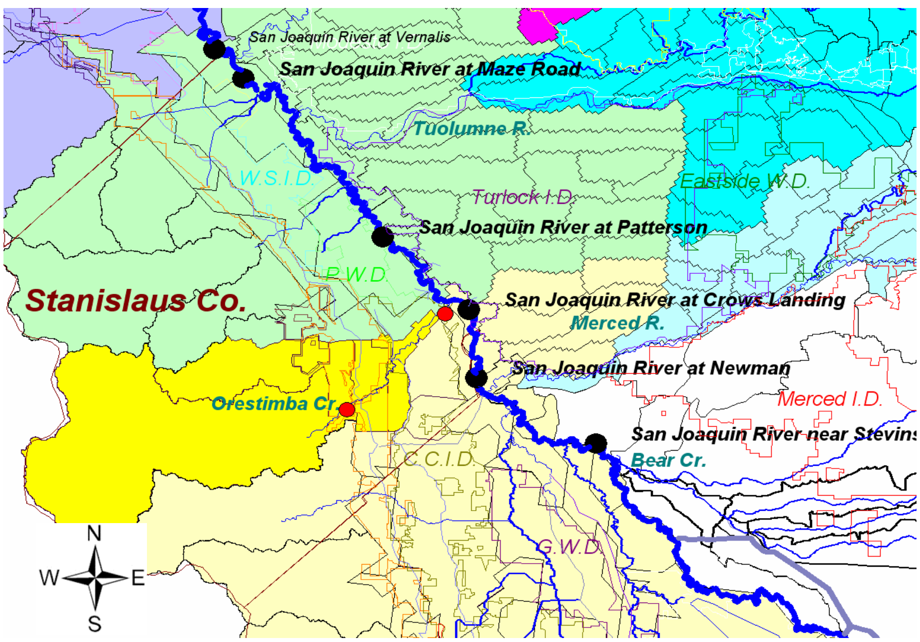

Figure 4. The WARMF model interface of the SJR shows the disaggregation of watersheds contributing flow and salt load to the SJR into component drainages.

Wetland drainage from the Grassland Ecological Area (a 140,000-acre tract in the Grasslands subarea) is partitioned into component State, Federal and private wetland subarea contributors to SJR salt load. A GIS-based model graphical user interface (GUI) facilitates the visualization of model input flow and water quality data. Data templates have been built-in to expedite automated data retrieval from State and Federal agency hydrology and water quality databases to facilitate the automated updating of model input files. Customized post-processed visual outputs such as the Gowdy Output (Figure 5) allow the user to directly access and interpret the simulation results and toggle between views of flow, EC and salt load for the entire SJR between Lander Avenue and Vernalis (a 60 mile reach) for a given day of 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. The top-right panel displays travel time with an initial value of 1.8 days diminishing to 0 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. The Gowdy Output (Figure 5) also provides the user with a detailed snapshot of past and current flow and water quality conditions in the SJR (Herr et al., 2008).

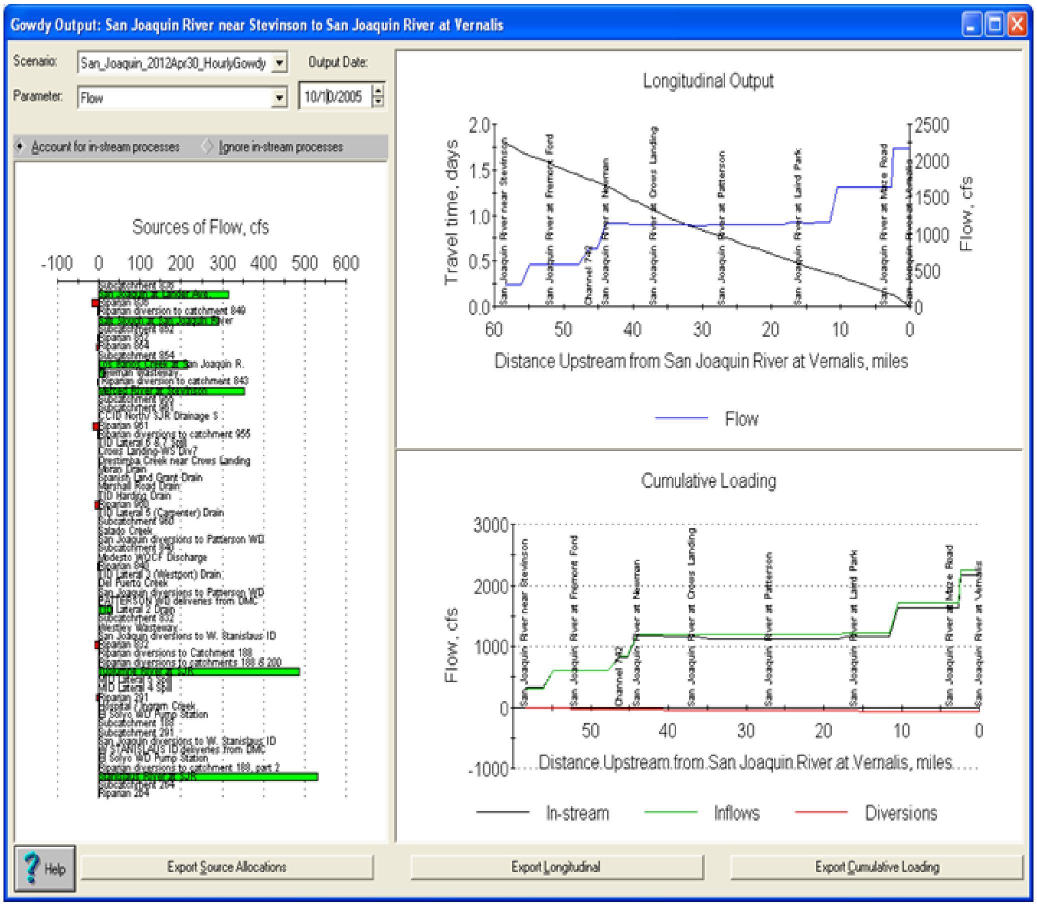

Figure 5. Gowdy customized outputs showing daily inflow and diversions every 1.6 km along the mainstem of the SJR for a chosen annual time series output from the WARMF-SJR simulation and forecasting model.

Collaborative Resource Management System for Data Visualization, Analysis and Decision Support. Collaborative RTSM is best facilitated when all stakeholders have a forum and toolset for aggregating and accessing the data and information used to inform management decisions and operations (Zu and Dale, 2001). The RTSMP began development of a comprehensive resource in 2014 - the SJR Real Time Management (SJRRTM) online web portal which provides real-time access to a full suite of watershed flow and EC data (Figure 6), including WARMF model inputs and salt load assimilative capacity forecasts. This web portal was designed to enhance stakeholder awareness of the current status of water and water quality conditions in the SJRB and support collaborative efforts to improve salinity management in the SJR by giving stakeholders access to available information resources (reports, GIS, and datasets) and reporting dashboards for viewing WARMF model output. A goal of the SJRRTM web portal was to provide stakeholders with basic information and analysis tools for coordinating system-wide salt loading schedules with reservoir releases of dilution flows from the east-side of the SJRB (Quinn et al., 2018).

The web-based data management platform was implemented using the opensource OpenNRM software, a commercial software tool (Quinn et al, 2018). The OpenNRM allows users to create, modify and manage data and content collectively, and provides a filtering capability to parse information based on subregion boundaries, specific areas of interest, and personalized data dashboard selections. Geo-coded information is enabled for all data types extending the maps and dashboards to include document libraries, project databases, datasets, visualizations, wiki knowledge bases, publications and miscellaneous file types related to specific map locations. What made the new SJRTM Online web portal unique was the integration of real-time watershed flow and EC data and WARMF model-generated flow, salinity and salt load assimilative capacity forecasts. These are typically separate information resource functions. The assembled data sets were re-formatted and parsed to make the data compatible for direct import into the WARMF forecasting model and online reporting dashboards. The OpenNRM software also generates base line data for modelers and stakeholders running independent analytics. A second key system feature is simplification of data access by centralizing key datasets and management tools. One stakeholder, who represents the South San Joaquin Irrigation District was sufficiently enamored by the customizable data dashboard capability to have engaged the developer to create a custom application to support her water quality-related oversight responsibilities which hitherto had involved accessing multiple websites and data providers.

Despite the unique capabilities of the SJRRTM Online web portal to help visualize and operationalize current SJRB data in combination with the WARMF model for salinity compliance assessment and decision support, the tool has not gained traction among stakeholders despite four years of promotion. Reasons may include:

(a) The web portal is comprehensive and allows easy access to all current, publicly accessible real-time flow and EC data - however stakeholder feedback suggests that the web portal is hard to navigate and there are often too many steps involved in accessing specific data. Although one stakeholder invested time and effort in building a custom dashboard with URL links to data she used routinely, others appeared less willing to commit the time. This can be attributed to the fact that their data access needs were less prescribed and more random, so the productivity gains from use of the tool were less profound.

(b) There are no current financial incentives with respect to salinity non-compliance that might encourage stakeholders to take advantage of the resources offered by the SJRRTM Online web portal. During periods of non-compliance, the imposition of fees associated with salt loads in excess of subarea monthly salt load targets would likely incentivize the quantification of salt loads and salt load assimilative capacity and comparisons between monthly subarea salt load targets and subarea performance with the SJRB.

Automated regression-based forecasting model. The WARMF model provides a framework for the analysis of flow and salinity data from tributaries to the SJR and for water district diversions from the main stem of the River. Salt load assimilative capacity forecasts require both the provision of current (real-time) flow and salinity data as well as information on anticipated actions impacting flow and salinity in the river over the chosen, two-week forecast period. The accuracy of these forecasts is a function of the level of stakeholder involvement and the sharing of information.

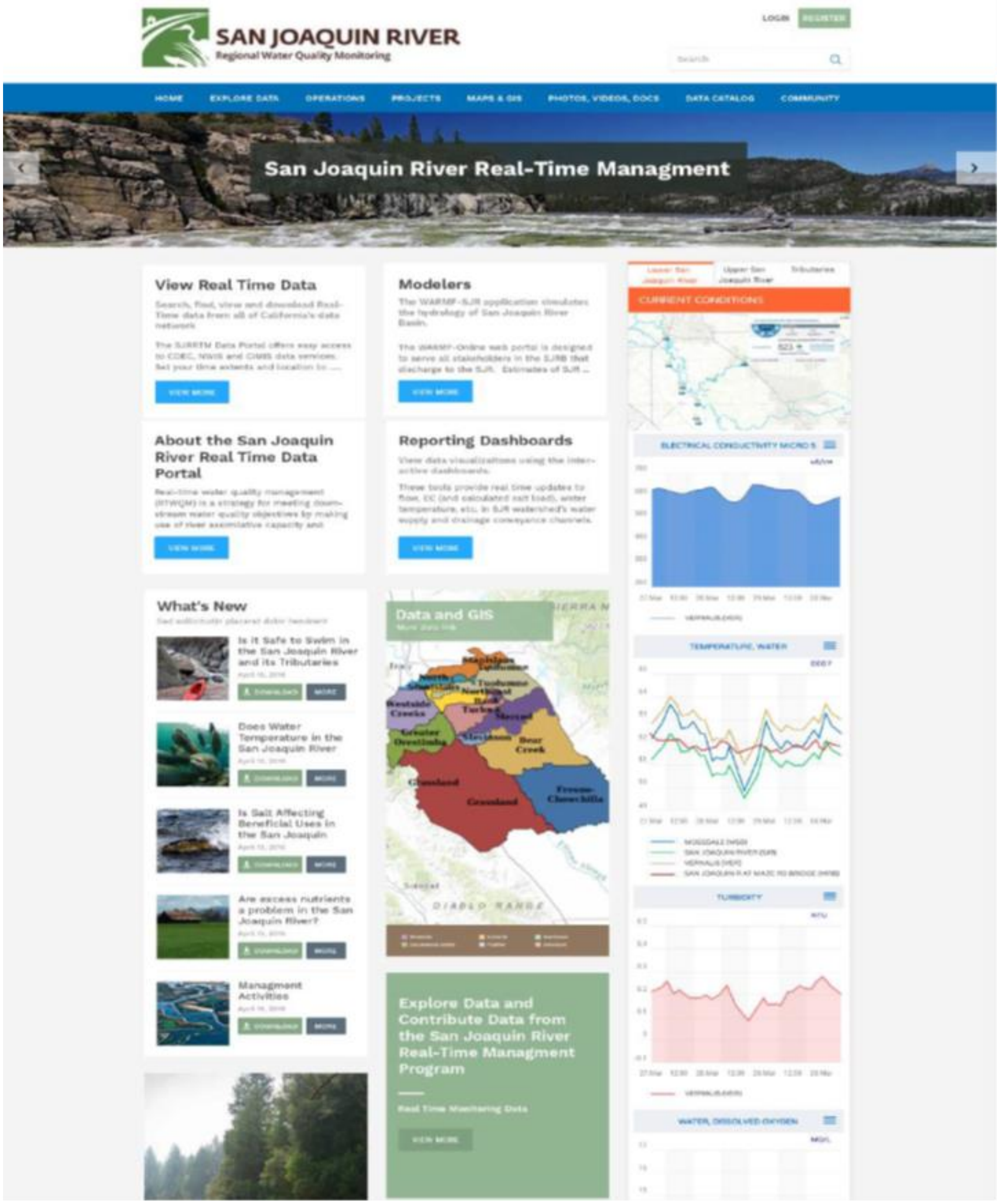

Figure 6. SJR Real-Time Management Online web portal using the OpenNRM visualization toolbox. The web portal provided data access to visualizations of WARMF-SJR model output.

The USBR recognized the need for simpler, screening-level decision support capability for daily River EC and salt load assimilative capacity estimation for the majority of time periods when no action may be necessary while retaining the functionality and watershed-based simulation capability of the WARMF forecasting model during more critical periods when the 30-day running average EC at Vernalis was in danger of being exceeded. The WARMF model is capable of comparing individual subarea salt load discharges over and above allowable load limits for periods of insufficient salt load assimilative capacity in the SJR. It has been recognized that with climate change and the propensity for extreme events and more severe drought events, the incidence of EC violations may again grow warranting a parallel forecasting approach. This novel hybrid approach to salinity forecasting in the SJR, undertaken by the USBR, is based on a data-driven regression model that relates flow to EC using an inverse gradient algorithm. This screening level approach for estimating EC has been applied to both the Vernalis and Crows Landing compliance monitoring stations on the SJR and will be applies to a new compliance monitoring station at Maze Road established in January, 2020.

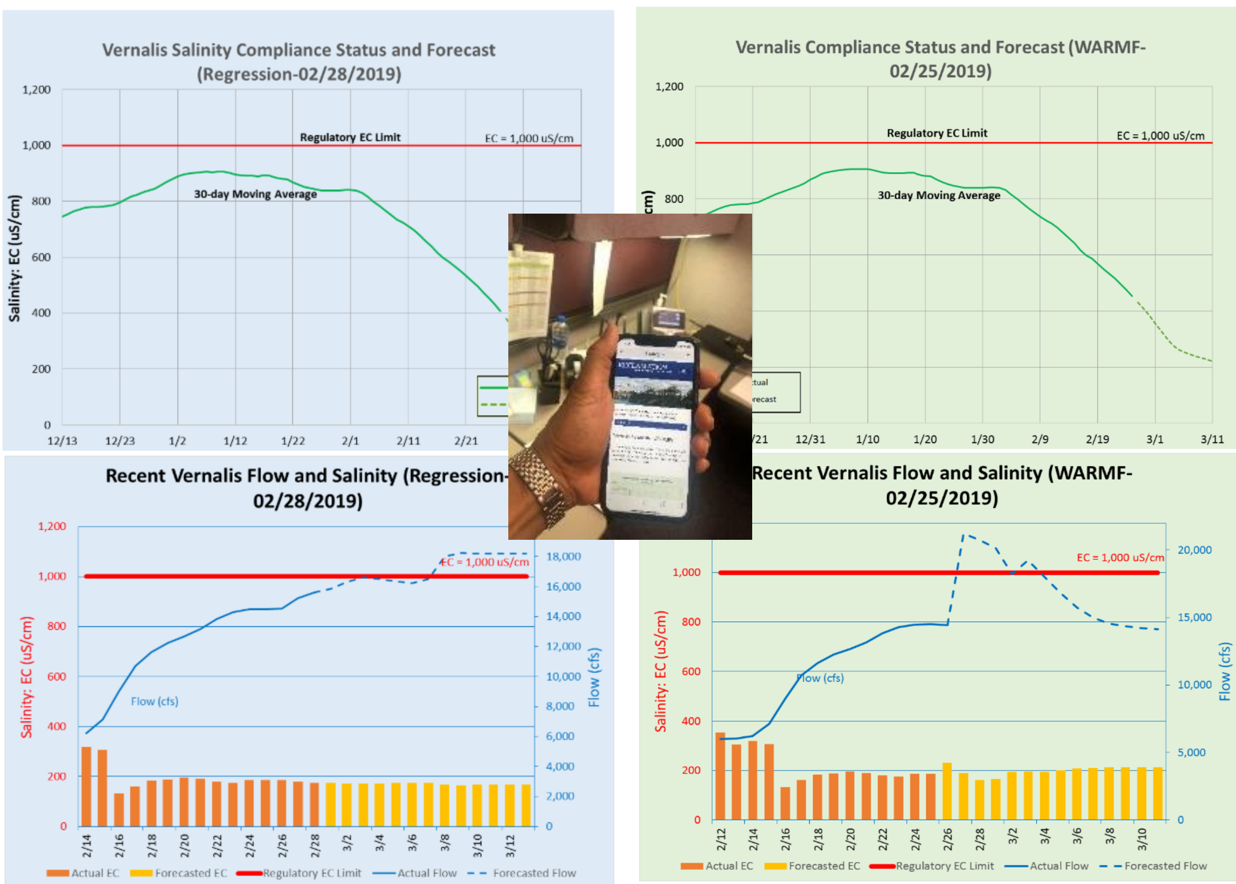

Figure 7. Comparison of regression-based and WARMF-based real-time salinity forecasting models. Inset (middle) shows the smartphone RTSM screening model interface that allows stakeholders to readily view both regression model and WARMF model forecasts.

The basis for the inverse gradient regression model is the observation that: (a) EC decreases when stream flow increases, and vice versa; and (b) the EC's rate of change is proportional to change in the River flow rate. The inverse gradient regression model appears to provide good forecast accuracy for EC and salt load especially when paired with independent 10-day SJR flow forecasts made daily by the NOAA River Forecast Center. One distinct advantage of this data-driven regression model approach is that it can be more easily automated than the WARMF model. Preliminary results, based on flow and EC data for the years 2004 to 2019, indicated that the regression model performs as well as the WARMF model for forecasting EC at the Vernalis and Crows Landing compliance monitoring stations (Figure 7). This screening-level approach can be used to alert stakeholders to conditions where EC forecasts approach the EC compliance objectives at either site that might warrant intervention to actively manage salt loading to the river. In such situations the WARMF basin-scale model aids stakeholders by providing estimates of load contributions from each of the seven subareas contributing salt load to the SJR. Awareness of current salt loading from each of these subareas and comparing these loads to those allowable under the salinity TMDL for each subarea allows more targeted interventions.

DISCUSSION

Adoption of RTSM, as a whole-basin alternative to a more restrictive and resource-inefficient salinity TMDL, has achieved some early success in the SJRB. However, long-term implementation of the concept will require a high level of cooperation and coordination among stakeholders which hitherto did not exist in the Basin. Realization of the full potential of RTSM will require the formation of a basin-scale, stakeholder-led, salinity management entity with the authority and policing power to enforce compliance with river water quality objectives and to impose penalties on stakeholder coalitions representing stakeholders within each subarea. In the SJRB, two major agricultural coalitions which exist representing stakeholders on the east and west sides of the SJR. These existing coalitions could play a more active role, not only in the funding and maintenance of flow and EC sensor networks and implementation of a data quality assurance program, but also in coordinating salt load management actions within each subarea and between subareas. The CVWB has envisaged a marketplace for salt load discharge to the SJR similar to the carbon offsets that can be purchased by CO_2 emitters who need to reduce their carbon footprint. This would help reduce reliance on New Melones Reservoir for the release of flows for salinity dilution purposes allowing more efficient allocation of water resources to junior water-right stakeholders who typically receive less than their contract water supply from the USBR. An entity known as the San Joaquin Valley Drainage Authority is financed by westside SJRB stakeholder contributions and retains a staff to oversee the activities of west-side agricultural, wetland and municipal dischargers of salt and other contaminants into the SJR. The Drainage Authority's role might be expanded to include east-side SJRB districts to fulfill the coordination and compliance enforcement activities identified above. Long-term implementation of RTSM will ultimately require coordination of both drainage return flows and reservoir releases from east-side tributaries, synthesis of real-time data, computer-based modeling of real-time salt load assimilative capacity, and effective dissemination of daily salt load assimilative capacity forecasts for the SJR.

SUMMARY AND CONCLUSIONS

Technical advances in data acquisition and information dissemination technologies have made possible the implementation of a real-time salinity management (RTSM) program in California's San Joaquin river basin (SJRB). RTSM relies on continuously recording sensors that form the backbone of a monitoring network and simulation models that are used to forecast flow and water quality conditions in the receiving water body and the tributary watersheds that export flow and salt load to the River. Effective implementation of RTSM has an educational and extension requirement that has yet to be realized which was evidenced by the limited success of the SJRRTM web portal which proved too complex and too demanding of stakeholder time to be fully utilized.

Our unique accomplishment of fusing real-time data reporting and dissemination and model-based salt load assimilative capacity forecasting only added to the complexity. Stakeholders did not fully appreciate our ability to apply their SJR drainage salt loading data and SJR riparian diversions in making forecasts. We believe the parallel model-based salinity forecasting approach that uses a screening tool to identify potential salinity compliance problems, backed-up by the application of the more comprehensive Watershed Management Risk Management Framework watershed-based simulation and forecasting model to explore salt management options, will prove a robust and resource efficient decision support system for the SJRB.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Bureau of Reclamation and the State of California from the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006 and through an agreement with the State Department of Water Resources and Grassland Water District. Stakeholder entities including Grassland Water District, Patterson Irrigation District, West Stanislaus Irrigation District and the California Fish and Wildlife Department have partnered on studies to advance the concept of RTSM.

REFERENCES

Brownell J. (2013). Presentation to Lower San Joaquin River Committee California Regional Water Quality Control Board, Central Valley Region, March 18, 2013.

California Environmental Protection Agency, (2002, 2004). Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River. Staff report by the Regional Water Quality Control Board, Central Valley Region.

Central Valley Regional Water Quality Control Board (CVWB) (2004, 2018). Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basin. Draft Final Staff Report and Technical TMDL report, Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVWB), (2006). Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basin. Draft Final Staff Report and Technical TMDL Report, Sacramento, CA.

Chen, C.W., J. Herr, J., and L.H.Z. Weintraub. (2001). Watershed Analysis Risk Management Framework: Update One: A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation, and Implementation. EPRI, Palo Alto, CA.

Herr J. and C.W. Chen. (2006). San Joaquin River Model: Calibration Report. CALFED Project ERP-02D-P63 Monitoring and Investigations for the San Joaquin River and Tributaries Related to Dissolved Oxygen. Systech Water Resources Inc. San Ramon, CA.

Herr J., C.W. Chen. and K. Van Werkhoven. (2008). Final Report for Task 6 Modeling of the San Joaquin River. CALFED Project ERP-02D-P63. Monitoring and Investigations for the San Joaquin River and Tributaries Related to Dissolved Oxygen. Systech Water Resources Inc. Walnut Creek, CA.

Quinn, N.W.T. and J. Karkoski, (1998). Real-time management of water quality in the San Joaquin River Basin, California. American Water Resources Association, Vol. 34, No. 6.

Quinn, N.W.T. and W.M. Hanna, (2003). A decision support system for adaptive real-time management of seasonal wetlands in California. Environmental Modelling and Software, Volume 18, Issue 6, pp. 503-511.

Quinn, N.W.T., B. Hughes, A. Osti, J. Herr and J. Wang. 2018. Real-time, web-based decision support for stakeholder implementation of basin-scale salinity management. IFIP AICT 507. In: Environmental Software Systems, Computer Science for Environmental Protection, ISESS 2017, J. Hrebicek, R. Denzer, G. Schimak and T.Pitner, Editors. Croatia, May 10-12, 2017. Springer.

Systech Water Resources, Inc , 2011. WARMF Forecasting, Automation, and Technical Support. For: Metropolitan Water District of Southern California, Walnut Creek, CA 94596.

Zhu X. and Dale A. (2001). JavaAHP: a web-based decision analysis tool for natural resource and environmental management. Environmental Modelling and Software, 16(3) 251-262.