APPENDIX D

RMA2 Delta Modeling

RMA2 DELTA MODELING FOR THE SAN JOAQUIN RIVER SCOUR HOLE HYDRODYNAMIC EVALUATION: DESCRIPTION AND CALIBRATION

DRAFT, March 31, 2023

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INTRODUCTION AND PURPOSE

The RMA2 Delta-scale hydrodynamic model was applied to evaluate the potential flood flow impacts and benefits of the initial set of alternative designs for a San Joaquin River scour hole mitigation project.

Versus a more local scale model, the use of the Delta scale model for the analysis allows for a less constrained development of the downstream stage boundaries for the San Joaquin River and Old River reaches below their junction and the partitioning of the flow from the junction to the two rivers.

The objective of this Technical Memorandum is to provide a brief description of the RMA Delta-scale model, outline the model conditions and operations for the simulation of the flood scenarios. This document describes the Delta model setup and calibration, first for the February 2017 high flow event, then for the 100-yr flood flow scenario to be used for the flow impacts alternatives evaluation.

BACKGROUND

The RMA Bay-Delta model has been applied for numerous Bay-Delta studies for hydrodynamics and water quality. These are typically for lower flow conditions where levee breaching or overtopping do not occur. High flow versions of the Bay-Delta model were developed over the years to support modeling studies for the Central Valley Flood Protection Plan (DWR 2022, Maendly, 2018). The Bay-Delta model was applied for a range of Delta flood event scenarios to compute downstream Delta stage boundary conditions for the California Dept. of Water Resources (DWR) Sacramento River Basin and San Joaquin River Basin HEC-RAS models. The Bay-Delta model to served couple the hydrologies of the two river systems and propagate tidal conditions at the Golden Gate at current levels and with future sea level rise (SLR) to provide an improved estimate of Delta stages for the hydraulic models and for the analysis of Delta stages in general (Figure 1).

For the current analysis, historical tidal boundary conditions were applied for the model calibration and flood flow simulations, thus the model grid was trimmed to the Delta only, with the tidal boundary condition set to a Martinez location. Most of the overbank Delta islands were also removed from the grid for the level of flows for the calibration and analysis. The resulting RMA2 Delta grid and boundary condition locations are presented in Figure 2.

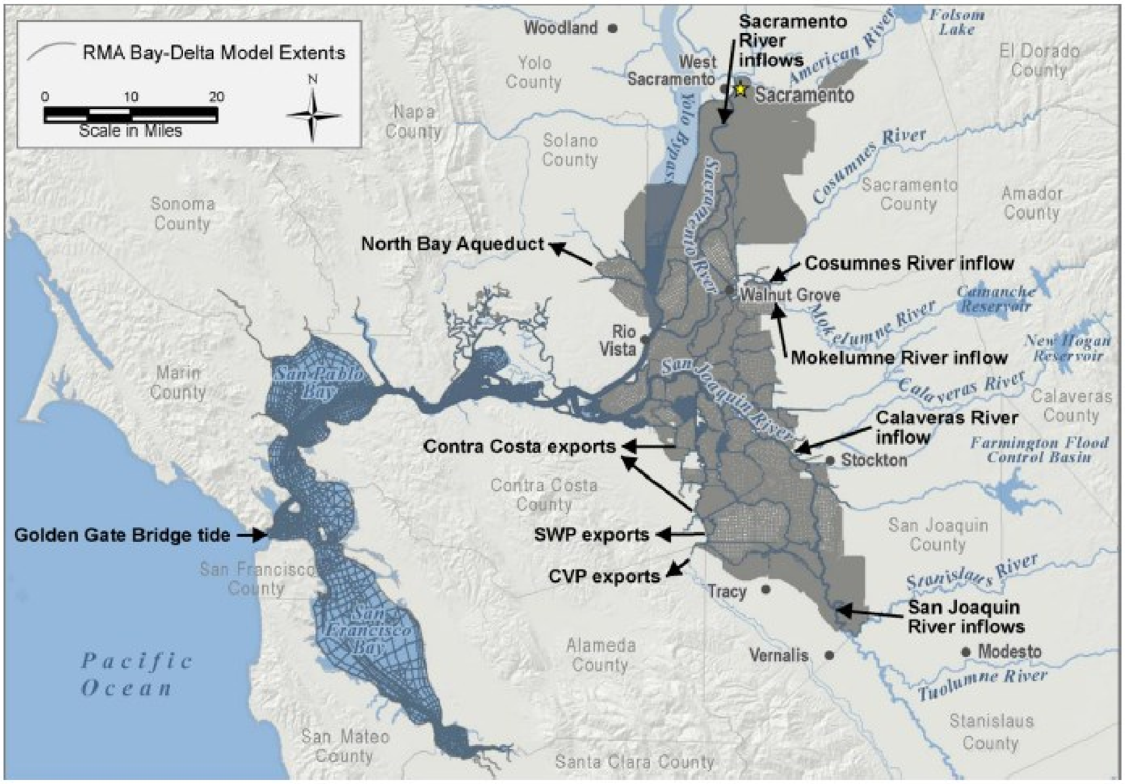

Figure 1 RMA Bay-Delta model used for providing the downstream stage boundary conditions to the CVFED HEC-RAS models (from DWR, 2022).

Figure 1 shows the geographic extent of the RMA Bay–Delta hydrodynamic model domain across the San Francisco Bay and Sacramento–San Joaquin Delta region. The mapped area includes major tributary inflows from the Sacramento River, San Joaquin River, Mokelumne River, Cosumnes River, and Calaveras River, as well as tidal forcing at the Golden Gate Bridge. The figure also identifies key water export locations, including the Central Valley Project (CVP), State Water Project (SWP), and Contra Costa exports, and infrastructure features such as the North Bay Aqueduct. A scale bar and north arrow provide spatial reference.

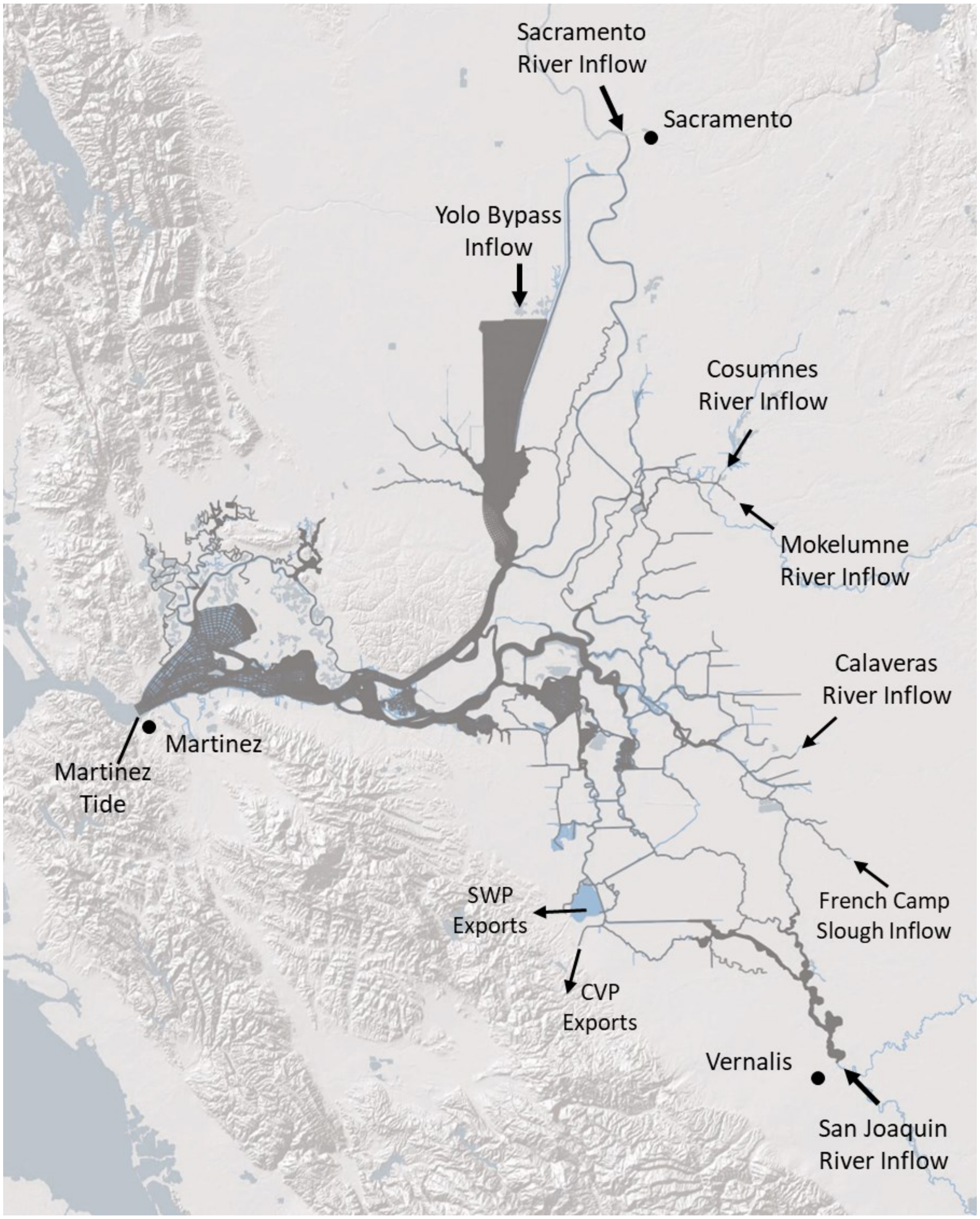

Figure 2 Delta boundary conditions and model grid for the flood impacts analysis of the San Joaquin River scour hole alternatives.

Figure 2 shows the Sacramento–San Joaquin Delta model domain and boundary condition locations used for the flood impacts analysis of the San Joaquin River scour hole alternatives. The figure identifies major inflow boundaries at the Sacramento River near Sacramento, Yolo Bypass, Cosumnes River, Mokelumne River, Calaveras River, French Camp Slough, and the San Joaquin River near Vernalis, as well as tidal forcing at Martinez. Export boundaries for the State Water Project (SWP) and Central Valley Project (CVP) are also shown. The shaded area represents the model grid extent within the Delta region.

RMA2 SIMULATION PROGRAM

The hydrodynamic simulation program used for the study is the RMA2 finite element based program for the computation of two-dimensional depth-averaged steady and unsteady flow. The model computes water surface elevations and horizontal flow velocity in two dimensions. The model also utilizes one-dimensional channel elements, with cross-sections defined by a simple trapezoidal geometry or an irregular cross-section geometry similar to the HEC-RAS model 1-D channels.

The RMA2 numerical model program was initially developed for the USACE in 1973 and has been revised and extended over the years. The USACE version of RMA2 (RMA2 WES) has been maintained and supported by the USACE at its Engineer Research and Development Center (ERDC). The governing equations and the model use are documented in detail in the "Users Guide to RMA2 WES Version 4.5" (USACE, 2011). The RMA2 WES v. 4.5 has been commercially distributed with the Surface Water Modeling System (SMS) package from Aquaveo, LLC.

RMA maintains its own version of the RMA2 program and has applied the code to numerous Bay-Delta water quality and hydrodynamic studies. At its core, RMA's version of the RMA2 program is the same as the RMA2 WES. RMA has updated the equation solver to use the PARDISO solver available in the Intel Fortran package. The PARDISO module is an efficient parallel direct sparse solver that is many times faster than the standard RMA2 solver for the size of the Delta model.

The RMA2 in-house model includes simulation of 2-D Levee/Weir elements, and 1-D and 2-D structures for gates, culverts and weirs either singly or in combination. The RMA2 program does not have the capability of modeling bridge hydraulics as is available in the HEC-RAS program.

DELTA MODEL CONFIGURATION AND SIMULATION CONDITIONS

The RMA Delta model for the study (Figure 2) extends from the west end of Suisun Bay up the Sacramento River to the confluence with the American River, and up the San Joaquin River near Vernalis. A two-dimensional depth-averaged approximation is used to represent the open water, large channels, flood plains and overbank areas of the Bay-Delta system. 1-D channel representations were utilized for tightly leveed channels such as the Sacramento River upstream of Cache Slough. The 1-D channels are represented using an irregular cross-section, similar to the 1-D cross-sections in the HEC-RAS, or approximated with a simplified trapezoidal cross-section. For channels such as the 1-D upper Sacramento River at high flow, a trapezoidal cross-section approximates change in channel flow area with change in stage relatively well. Irregular 1-D channel cross sections were primarily utilized for the 1-D portions of the Grant Line Canal, Old River and Middle River downstream of the Paradise Cut Bypass.

The San Joaquin River in and above the project area is represented with 2-D elements, as well as the Paradise Cut bypass and its connecting parts to Old River and Doughty Cut. The model grid detail in and around the project area was enhanced for the study and is presented in Figure 3.

Bathymetry for the South Delta and San Joaquin River was checked and updated from DWR's south Delta 2m DEM (dem_ccfb_south_delta_san_joaquin_rvr_2m_20200625[1]). Bathymetry and topography for the channels and levees in the vicinity of the scour hole project were updated from the DEM provided by cbec from the 2019 survey and DWR's 2017 Delta Lidar DEM.

MODEL CALIBRATION, FEBRUARY 2017

The RMA Delta model was first calibrated for the historical February 2017 high flow conditions. On February 23, 2017, the peak flow at Vernalis reached 41,000 cfs (Figure 4), and was the highest flow recorded at the Vernalis station since January 1997. The simulation proceeded for the full month of February 2017 to evaluate the model for the dynamic range of San Joaquin River and Delta inflow conditions.

MODEL BOUNDARY CONDITIONS

The Delta flow and stage boundary conditions developed for February 2017 simulation were applied for the locations shown in Figure 2. Boundary conditions were derived from observed historical data sources available from the USGS National Water Information System (NWIS) website, DWR's Water Data Library (WDL) and California Data Exchange Centers (CDEC) websites and NOAA's Tides and Currents website. These boundary condition data were also supplemented from DWR's model DSM2 historical input dataset. The major Delta inflows and export flows for the February 2017 simulation are plotted in Figure 4 to Figure 8, with discussion of the data sources provided below.

TIDAL STAGE BOUNDARY AT THE MARTINEZ

- 6-minute interval data from the NOAA tide station at Martinez-Amorco pier (ID 94102), smoothed with a 3-point moving average window.

SAN JOAQUIN RIVER FLOW AT VERNALIS

- USGS Vernalis station (ID 11303500) 15-minute flow smoothed with 5-point moving average window. (Figure 4)

SACRAMENTO RIVER INFLOW

- USGS Sacramento River at Freeport station (ID 11447650), tidally averaged. (Figure 5)

YOLO BYPASS DELTA INFLOW

- Estimated from flow balance for north Delta flow stations (USGS Cache Slough and Miner Slough (CDEC IDs RYI-HWB), USGS Sacramento at Freeport and Rio Vista and Georgiana Slough (SRV – (FPT-GSS)), and the DSM2 Yolo Bypass flow. Utilizing the north Delta flow station records incorporated the flow routing effects of the Yolo Bypass versus solely applying the DSM2 Yolo Bypass flow. (Figure 5)

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[1] San Francisco Bay and Sacramento-San Joaquin Delta DEM for Modeling, Version 4.2

EAST DELTA INFLOWS

- Mokelumne River and Cosumnes River – Routed flows from UC Davis, David Ford Consulting Engineers (Tomkovic and Whipple, 2020). (Figure 6)
- Calaveras River – CDEC, Mormon Slough at Bellota (MSB). (Figure 7)
- French Camp Slough – Flow difference of the USGS SJR Garwood station (ID 11304810) and DWR's SJR at Brandt Bridge station (WDL B95740Q, CDEC BDT). (Figure 7)

SWP, CLIFTON COURT FOREBAY INTAKE FLOW

- 15-minute CCFB intake flow estimated from flow differences of the DWR stations near the forebay entrance, WDL B95338 (CDEC WCI) and WDL B95341 (CDEC ORI), DSM2 CCFB gate opening times, and SWP daily export flow. (Figure 8)

EXPORT FLOWS FOR CVP, CONTRA COSTA WATER DISTRICT (CCWD) AND NORTH BAY AQUEDUCT (NBA)

- Daily flows from the DSM2 historical data set.
- CVP (Figure 8)
- Altogether, the CCWD and NBA exports averaged about 220 cfs for February 2017.

CONTROL STRUCTURES

- DCC gates – Closed
- South Delta Temporary Barriers – All out

No wind forcing was applied.

Figure 3 Baseline grid detail for the SJR scour hole project area.

Figure 3 shows an aerial view of the San Joaquin River scour hole project area with the baseline hydrodynamic model grid overlaid on the river channel and adjacent floodplain. The computational mesh is displayed in yellow, illustrating grid resolution and alignment along channel bends, overbank areas, and surrounding developed and agricultural lands. The grid extent follows the river corridor through the project reach and captures adjacent levees and floodplain features relevant to hydraulic modeling. A scale bar provides spatial reference.

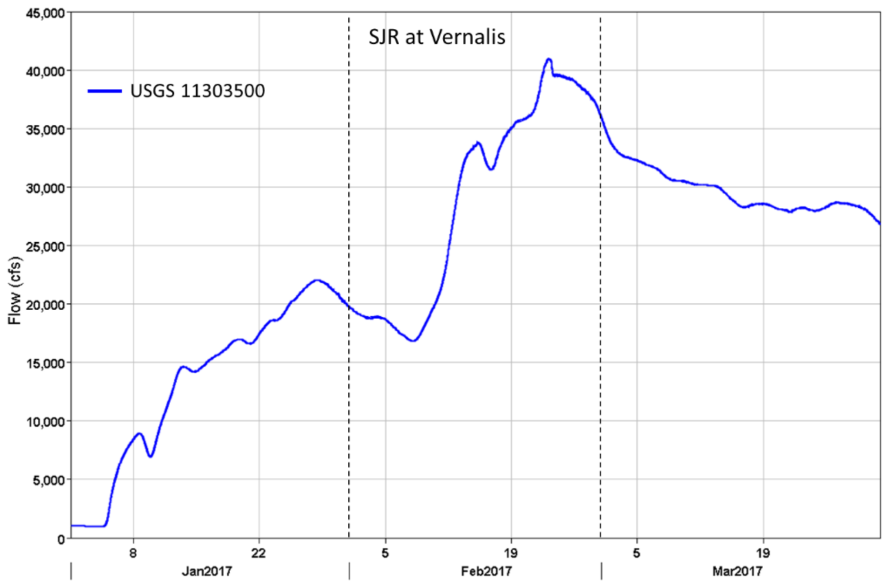

Figure 4 San Joaquin River flow at Vernalis for January through March 2017.

Figure 4 shows daily flow at the San Joaquin River at Vernalis (USGS gage 11303500) from January through March 2017. Flows increase rapidly in early January from near 1,000 cubic feet per second (cfs) to more than 15,000 cfs and continue rising through late January before declining briefly in early February. A second, larger peak occurs in mid-February, exceeding 40,000 cfs, followed by a gradual recession through March with flows remaining above approximately 27,000 cfs by the end of the period. Vertical dashed lines indicate the analysis period used for evaluation.

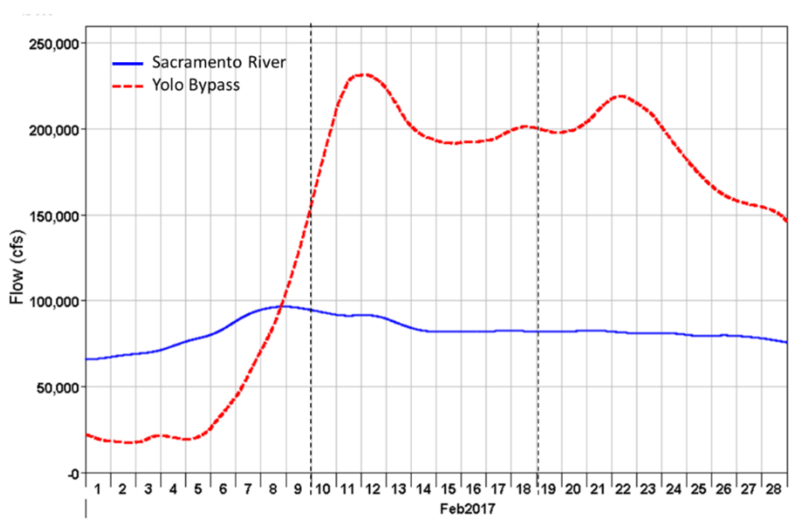

Figure 5 February 2017 north Delta inflow for the Sacramento River and the Yolo Bypass.

Figure 5 shows daily inflow to the north Delta from the Sacramento River and the Yolo Bypass during February 2017. Sacramento River flows remain relatively steady, generally ranging between approximately 75,000 and 95,000 cubic feet per second (cfs) throughout the month. In contrast, Yolo Bypass flows increase sharply in early

February, peaking above 230,000 cfs around mid-month, and remain elevated through late February before gradually declining. Vertical dashed lines indicate the analysis period used for evaluation.

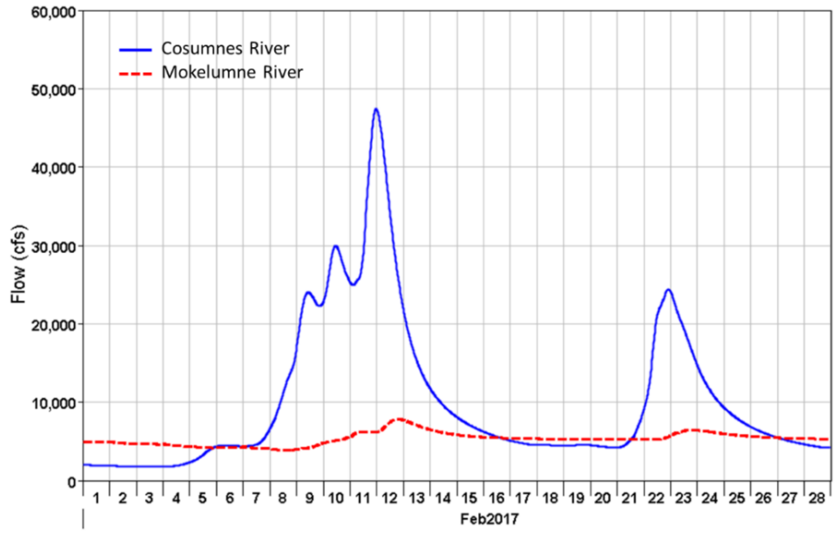

Figure 6 February 2017 northeast Delta inflow for the Cosumnes River and the Mokelumne River.

Figure 6 shows daily inflow to the northeast Delta from the Cosumnes River and the Mokelumne River during February 2017. Cosumnes River flows increase rapidly in early February, peaking near 48,000 cubic feet per second (cfs) around mid-month, followed by a decline through late February with a secondary peak exceeding 20,000 cfs near February 22. Mokelumne River flows remain comparatively steady throughout the month, generally ranging between approximately 4,000 and 7,000 cfs with a modest mid-month increase.

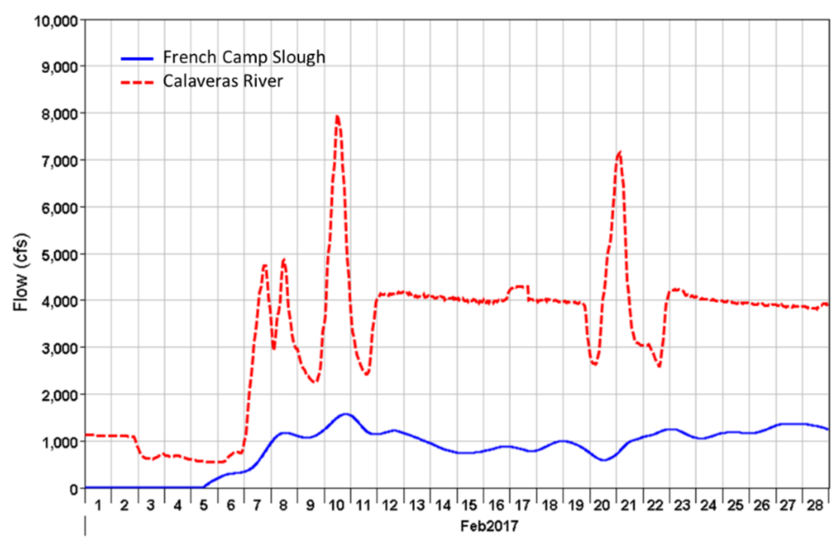

Figure 7 February 2017 inflow to the San Joaquin River from the Calaveras River and French Camp Slough.

Figure 7 shows daily inflow to the San Joaquin River from the Calaveras River and French Camp Slough during February 2017. Calaveras River flows vary substantially throughout the month, with multiple short-duration peaks including a mid-month peak approaching 8,000 cubic feet per second (cfs) and another peak exceeding 7,000 cfs near February 21, followed by relatively steady flows near 4,000 cfs during intervening periods. French Camp Slough flows remain lower and more gradual by comparison, generally ranging between approximately 500 and 1,500 cfs, with modest increases during early and late February.

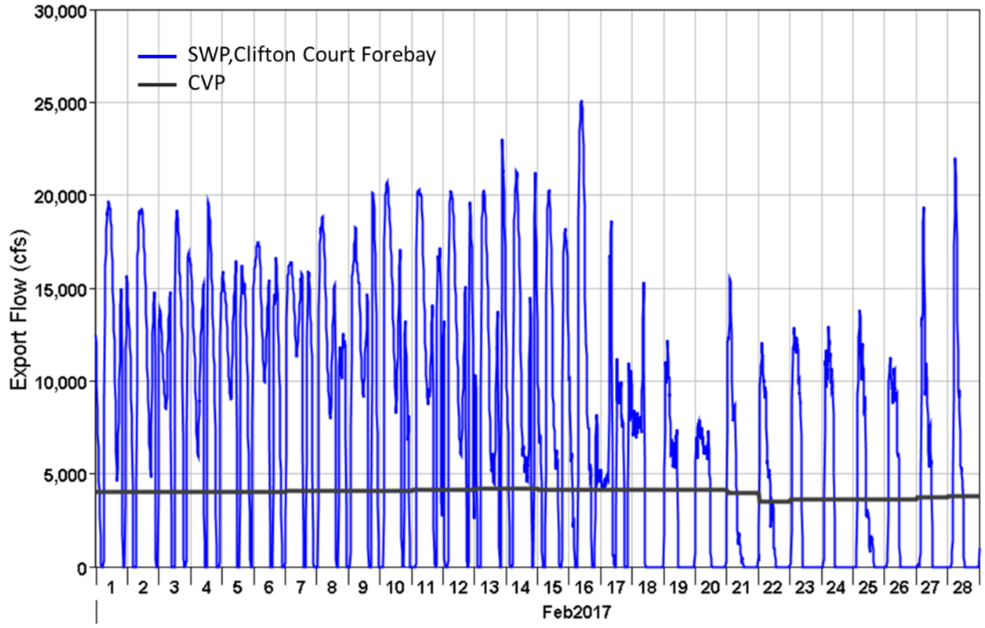

Figure 8 South Delta export flow to the SWP, Clifton Court Forebay and to the CVP intake at Tracy.

Figure 8 shows daily export flows from the south Delta to the State Water Project (SWP) Clifton Court Forebay and the Central Valley Project (CVP) intake at Tracy during February 2017. SWP exports vary substantially throughout the month, with frequent short-duration pulses ranging from near zero to peaks exceeding 25,000 cubic feet per second (cfs). In contrast, CVP exports remain relatively steady, generally near 4,000 cfs with minor variation over the analysis period.

RESULTS

Computed stage and flow time series for the February 2017 period were compared to monitoring station data for the set of south Delta San Joaquin River and Old River system locations shown in Figure 9. The stage comparisons are presented in Figure 10 to Figure 14, and the flow comparisons shown in Figure 15 to Figure 21. The time series plots are for 15-minute interval data. At the higher flow levels both the observed stage and flow hydrographs exhibited somewhat “noisy” records. Thus the observed time series were smoothed with a 5-point moving average window to reduce the visible scatter when overlying the observed time series with the computed.

Near the times of peak stage and flow, model stages were generally within 0.1 to 0.2 ft of observed stage for the MSD, SJL, BDT and OH1 locations. No observed stage was available for the Old River station at ORX for February 2017. As such the next downstream station at Doughty Cut (DGL) was evaluated for the downstream water level condition for the Old River branch. At times of higher flow and stage, the model stage was generally within 0.2 ft of observed stage for the location.

The RMA2 model flow hydrographs were a somewhat rougher approximation of the observed flow hydrographs. Of note, several of the observed flow records showed visible shifts in the flow ratings, with the times of the rating changes noted in the station site reports available from the WDL website. Some of the rating shifts were minor, for example at BDT – the San Joaquin River at Brandt Bridge (Figure 17). However, a notable rating shift was apparent for the OH1 – the Old River at Head location on February 22. For three stations, SJR, ORX and PDC, the observed flow data were not available after February 15 and thus missed the time of peak flow.

The model San Joaquin River flow matches the observed flow at Brandt Bridge (Figure 17) throughout the period, while slightly over predicting the flow at the more upstream SJD station before that data ends on February 16 (Figure 18). Predicted flow on the Old River reach is somewhat overpredicted at OH1 after the rating shift (Figure 16). Downstream at ORX, the model matches the observed data before February 13, then overpredicts the flow the three days until the observed data terminates (Figure 19). Model flow underpredicts the observed flow for the Middle River reach below the Old River near time of the peak flow (Figure 20). Before the observed data terminates on February 15, the model somewhat overpredicts the flow at the Paradise Cut station, PDC (Figure 21).

The main tuning parameters for the model calibration were the Manning’s n friction coefficients for the 2-D and 1-D elements. The frictions coefficients for the reaches near the project area developed from the 2017 calibration are listed in Table 1.

Table 1. Manning's n coefficients for RMA2 model areas.

Channel Element	River Reach, Area Type	Manning's n value
SJR Main Channel Elements	above Paradise Cut	0.040
SJR Main Channel Elements	Paradise Cut to above Mossdale Bridge	0.038
SJR Main Channel Elements	above Mossdale Bridge to Old River	0.035
SJR Main Channel Elements	below Old River	0.035 to 0.033
SJR Main Channel Elements	below Old River, 1-D	0.033
Other Channel Elements	Old River below SJR	0.038
Other Channel Elements	Old River below SJR, 1-D	0.037
Other Channel Elements	Channel banks and levee banks	0.040 to 0.075 depending upon riprap and vegetation
Other Channel Elements	Floodplain, overbank	0.040 to 0.075, depending upon vegetation.

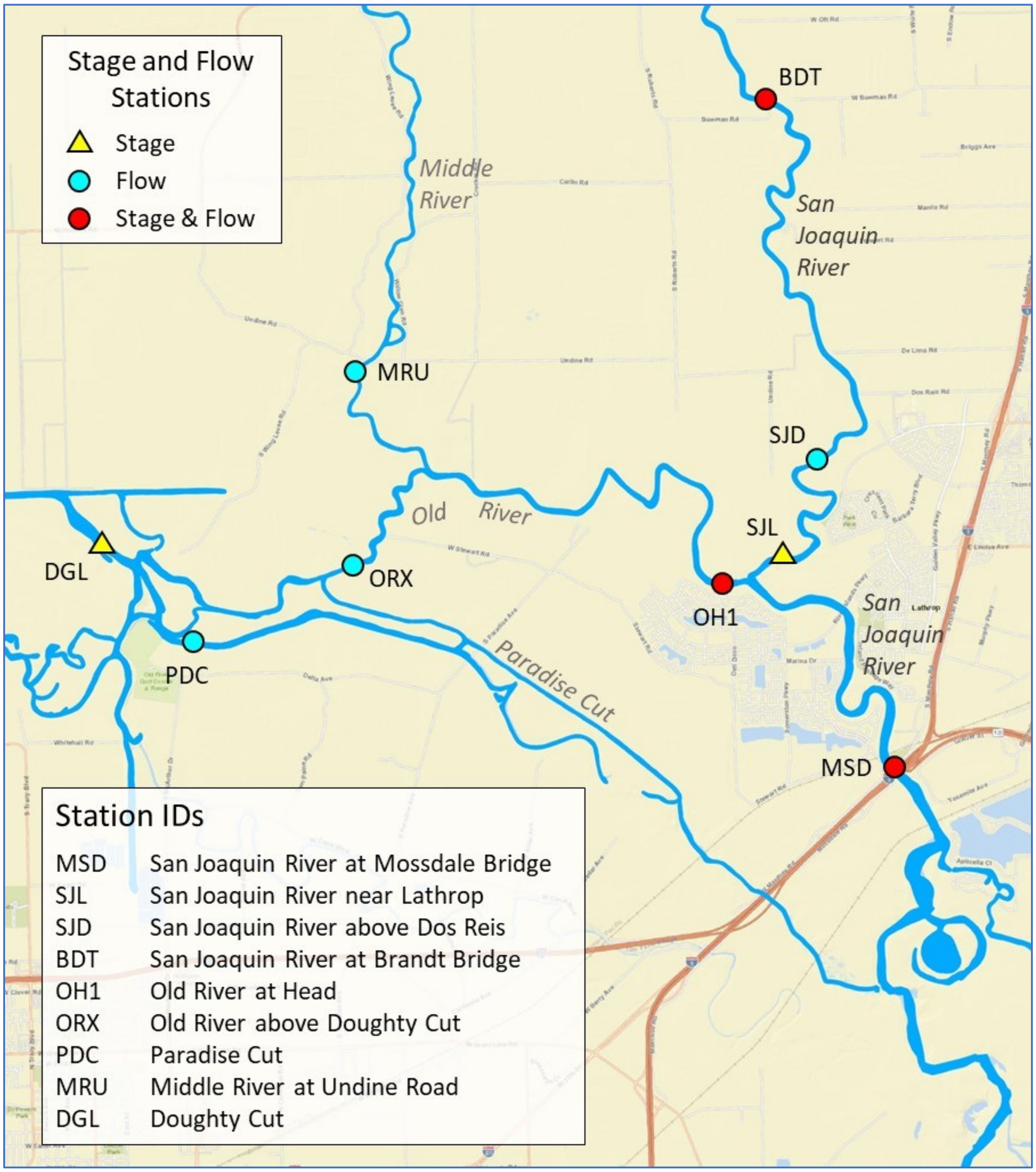

Figure 9 Flow and Stage monitoring stations along the San Joaquin River and Old River system used for the RMA2 model calibration for the February 2017 high flow event. The monitoring stations are identified by the CDEC ID.

Figure 9 shows the locations of flow and stage monitoring stations along the San Joaquin River, Old River, Middle River, Paradise Cut, and Doughty Cut used for calibration of the RMA2 hydrodynamic model for the February 2017 high-flow event. Stations are symbolized by measurement type, including stage-only stations, flow-only stations, and stations with both stage and flow observations. Monitoring locations are identified by their California Data Exchange Center (CDEC) station IDs, including MSD, SJL, SJD, BDT, OH1, ORX, PDC, MRU, and DGL.

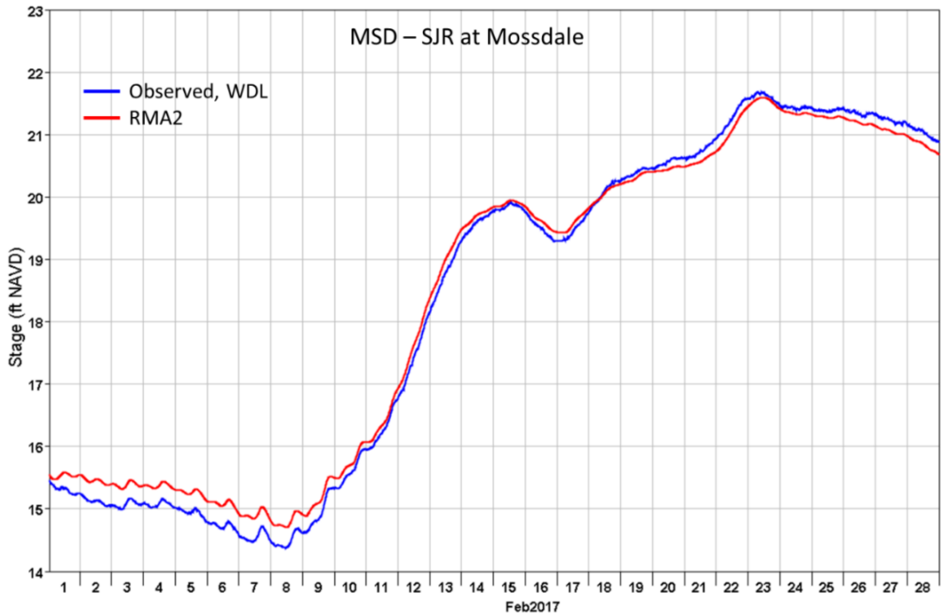

Figure 10 Observed and model stage for the San Joaquin River at the Mossdale Bridge (MSD).

Figure 10 shows observed stage at the San Joaquin River at Mossdale Bridge (MSD) compared with RMA2 model results for February 2017. Observed water surface elevations (blue) and simulated stage (red) follow similar trends throughout the month, with stage decreasing slightly during early February before rising rapidly beginning around February 10 and peaking near 22 feet NAVD in late February.

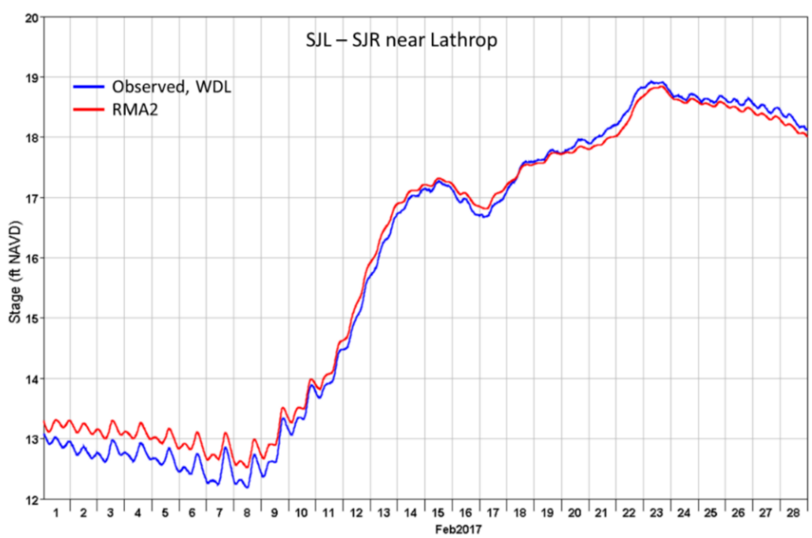

Figure 11 Observed and model stage for the San Joaquin River near Lathrop (SJL).

Figure 11 shows observed stage at the San Joaquin River near Lathrop (SJL) compared with RMA2 model results for February 2017. Observed water surface elevations (blue) and simulated stage (red) follow similar trends throughout the month, with stage decreasing slightly during early February before rising rapidly beginning around February 10 and peaking near 19 feet NAVD in late February.

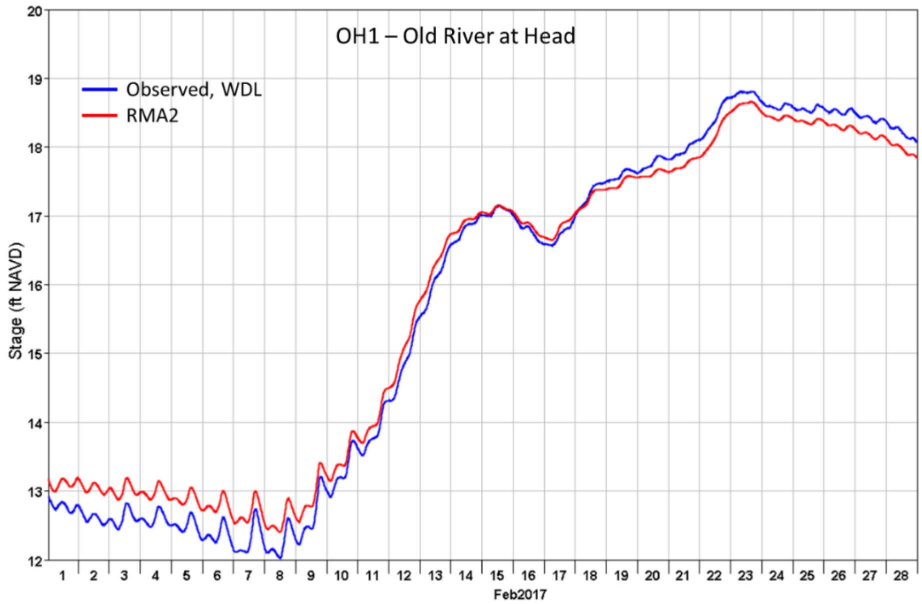

Figure 12 Observed and model stage for the Old River at Head (OH1).

Figure 12 shows observed stage at Old River at Head (OH1) compared with RMA2 model results for February 2017. Observed water surface elevations (blue) and simulated stage (red) follow similar trends throughout the month, with stage decreasing slightly during early February before rising rapidly beginning around February 10 and peaking near 19 feet NAVD in late February.

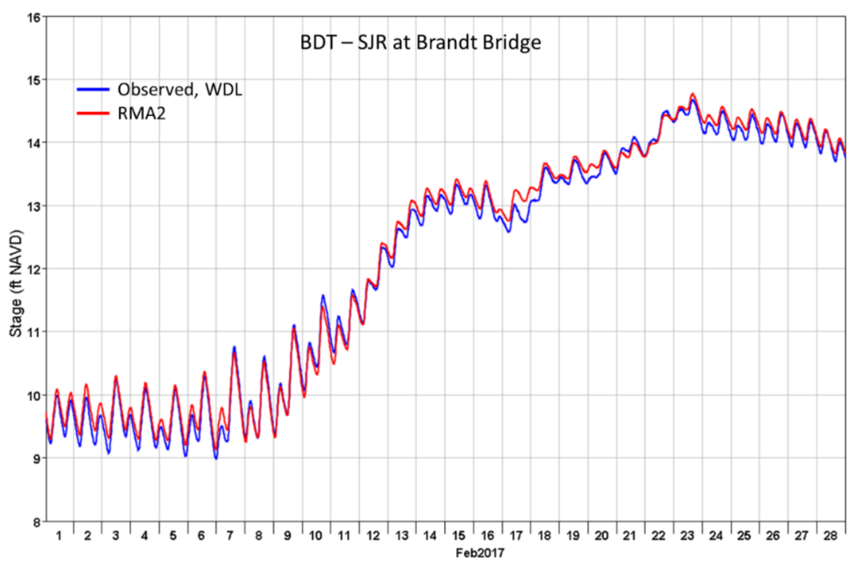

Figure 13 Observed and model stage for the San Joaquin River at Brandt Bridge (BDT).

Figure 13 shows observed stage at the San Joaquin River at Brandt Bridge (BDT) compared with RMA2 model results for February 2017. Observed water surface elevations (blue) and simulated stage (red) follow similar trends throughout the month, with stage gradually increasing from about 9.5 feet NAVD in early February to a peak near 14.5 feet NAVD in late February.

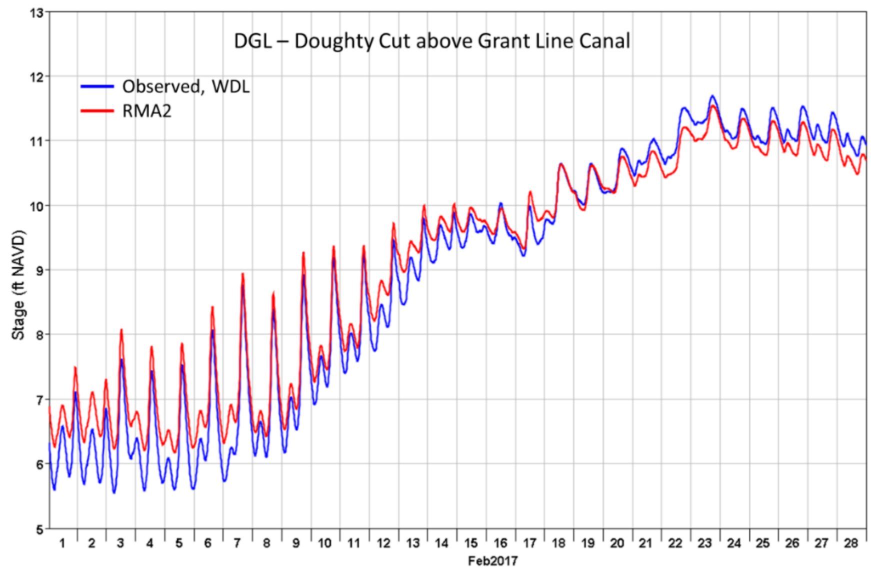

Figure 14 Observed and model stage for the Doughty Cut above the Grant Line Canal (DGL).

Figure 14 shows observed stage at Doughty Cut above Grant Line Canal (DGL) compared with RMA2 model results for February 2017. Observed water surface elevations (blue) and simulated stage (red) follow similar trends throughout the month, with stage increasing from about 6 feet NAVD in early February to approximately 11.5 feet NAVD in late February.

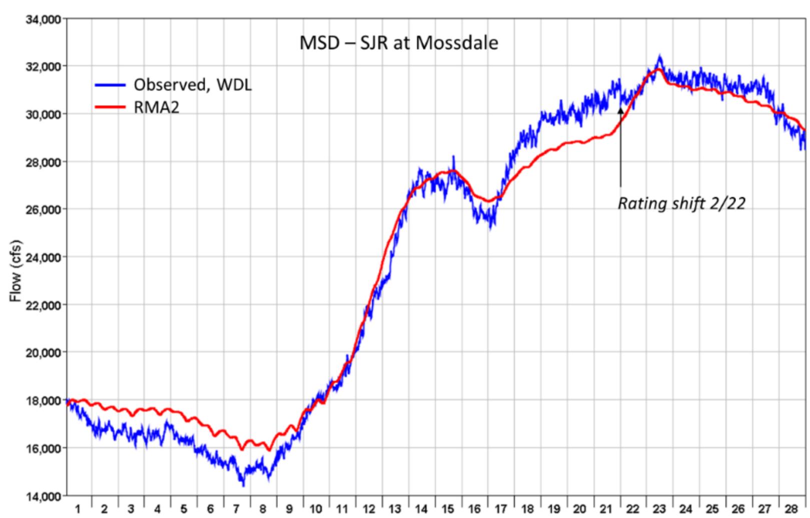

Figure 15 Observed and model flow for the San Joaquin River at the Mossdale Bridge (MSD). Indicated rating shift from WDL site report for the station.

Figure 15 shows observed flow at the San Joaquin River at Mossdale Bridge (MSD) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends throughout the month, with flows decreasing slightly during early February before rising rapidly beginning around February 10 and peaking above 32,000 cubic feet per second (cfs) in late February. An indicated rating shift on February 22 from the Water Data Library (WDL) site report is noted on the figure.

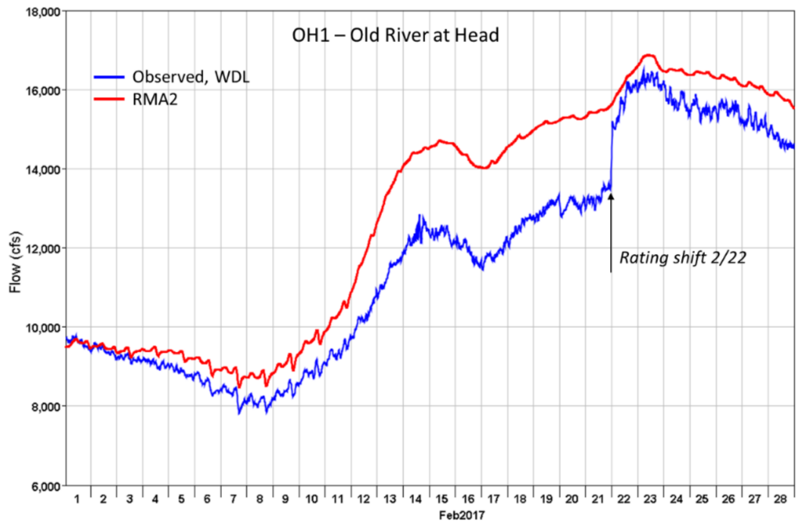

Figure 16 Observed and model flow for the Old River at Head (OH1). Indicated rating shift from WDL site report for the station.

Figure 16 shows observed flow at Old River at Head (OH1) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar overall trends throughout the month, with flows decreasing slightly during early February before increasing rapidly beginning around February 10 and peaking above 16,000 cubic feet per second (cfs) in late February. An indicated rating shift on February 22 from the Water Data Library (WDL) site report is noted on the figure.

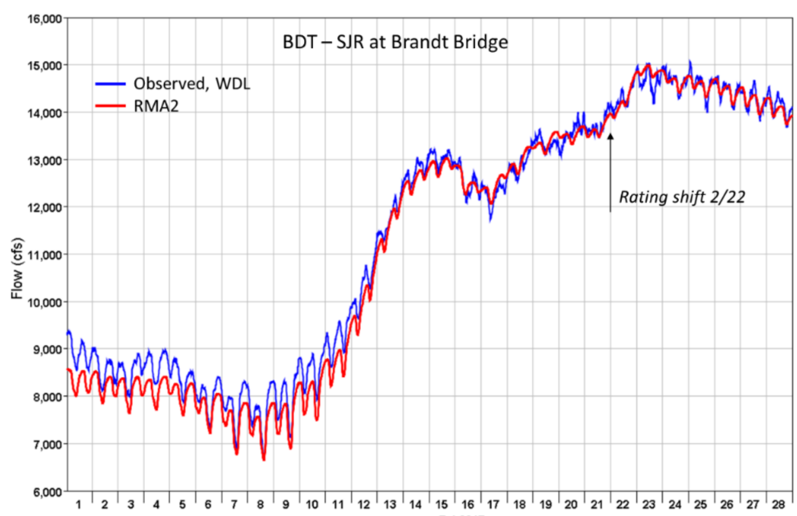

Figure 17 Observed and model flow for the San Joaquin River at Brandt Bridge (BDT). Indicated rating shift from WDL site report for the station.

Figure 17 shows observed flow at the San Joaquin River at Brandt Bridge (BDT) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends throughout the month, with flows decreasing slightly during early February before increasing rapidly beginning around February 10 and peaking near 15,000 cubic feet per second (cfs) in late February. An indicated rating shift on February 22 from the Water Data Library (WDL) site report is noted on the figure.

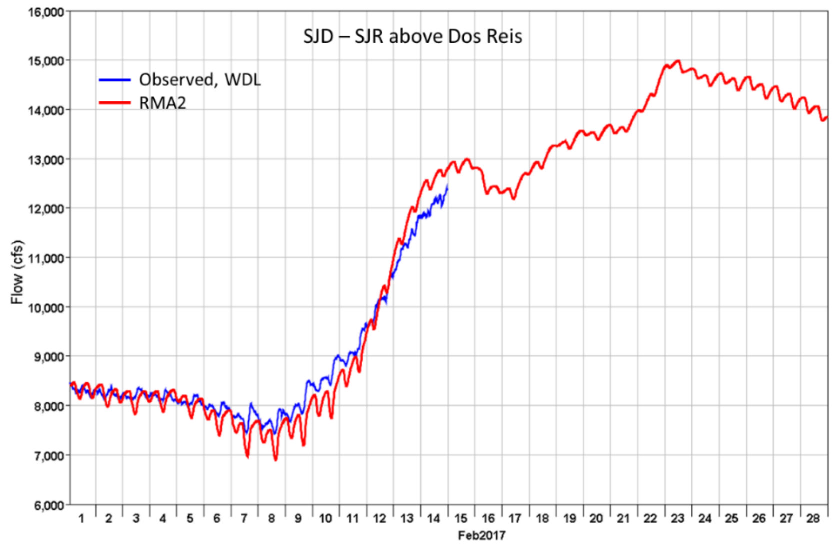

Figure 18 Observed and model flow for the San Joaquin River above Dos Reis (SJD).

Figure 18 shows observed flow at the San Joaquin River above Dos Reis (SJD) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends during early February, with flows decreasing slightly before increasing rapidly beginning around February 10. The model reproduces the timing of the observed rise but overestimates discharge magnitude through much of the mid- to late-month period, with simulated flows approaching 15,000 cubic feet per second (cfs) compared to lower observed values near mid-month.

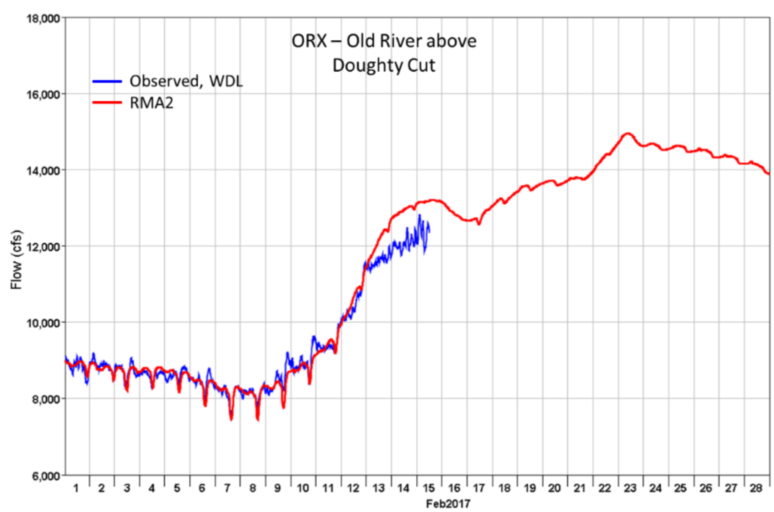

Figure 19 Observed and model flow for the Old River above Doughty Cut (ORX).

Figure 19 shows observed flow at Old River above Doughty Cut (ORX) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends during early February, with flows decreasing slightly before increasing rapidly beginning around February 10. The model reproduces the timing of the observed rise but overestimates discharge magnitude during much of the mid- to late-month period, with simulated flows approaching 15,000 cubic feet per second (cfs) compared to lower observed values during the available observation period.

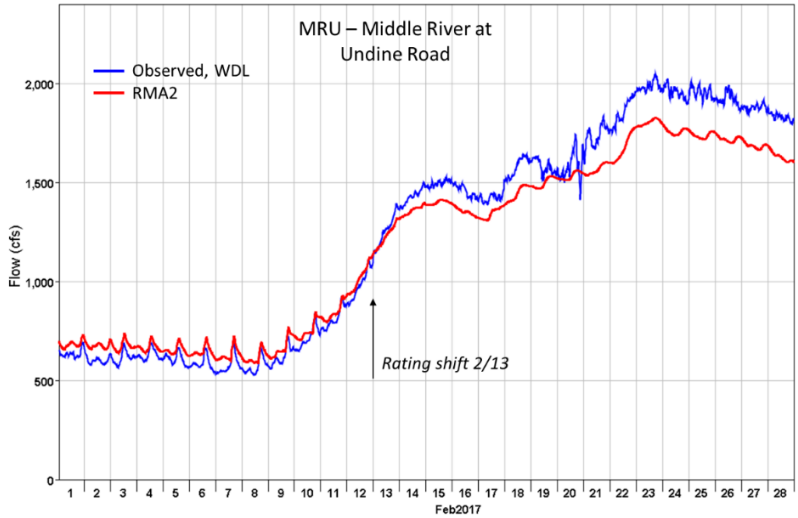

Figure 20 Observed and model flow for the Middle River at Undine Road (MRU). Indicated rating shift from WDL site report for the station.

Figure 20 shows observed flow at Middle River at Undine Road (MRU) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends throughout the month, with flows decreasing slightly during early February before increasing rapidly beginning around February 10 and peaking near 2,000 cubic feet per second (cfs) in late February. The model reproduces the timing of the observed rise but slightly underestimates discharge magnitude during the mid- to late-month period. An indicated rating shift on February 13 from the Water Data Library (WDL) site report is noted on the figure.

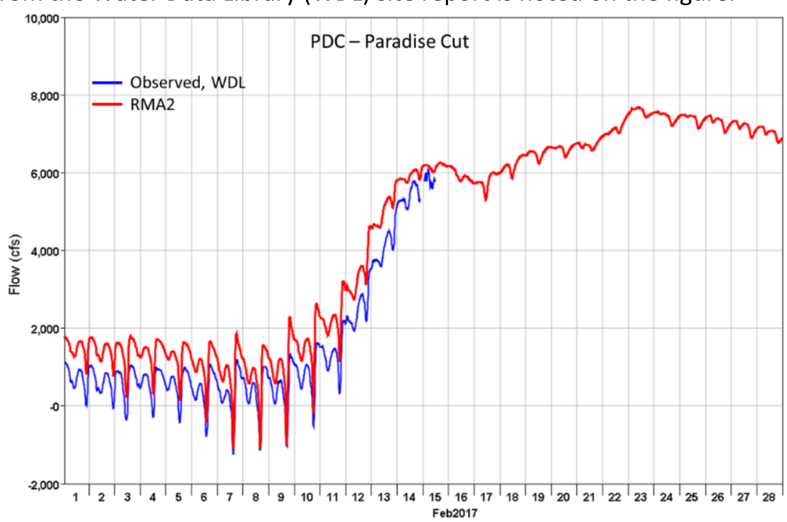

Figure 21 Observed and model flow for the Paradise Cut station (PDC).

Figure 21 shows observed flow at Paradise Cut (PDC) compared with RMA2 model results for February 2017. Observed discharge (blue) and simulated flow (red) follow similar trends during early February, with flows fluctuating around low values before increasing rapidly beginning around February 10 and peaking above 6,000 cubic feet per second (cfs) in mid-February. The model reproduces the timing of the observed increase but overestimates discharge magnitude during much of the mid- to late-month period, with simulated flows approaching 7,500 cfs.

MODEL CALIBRATION, 100-YR EVENT FLOW

For the scour hole consequence analysis, the scour hole alternatives were to be evaluated for flood impacts under conditions of a 100-yr flood event. The 100-yr event flows for the project area were selected from the 2009 FEMA Flood Insurance Study for San Joaquin County (FEMA, 2009). The 100-yr event flows along the San Joaquin River from the 2009 FEMA study are listed in Table 2. The objective of the RMA2 model setup/calibration for the baseline condition was to reproduce the flow at the San Joaquin River above the Old River junction and the San Joaquin River flow below the Junction (SJR at mouth of French Camp Slough), and to reproduce the FEMA water surface elevations for the river reaches.

Table 2. 100-year event flows along the San Joaquin River the from 2009 FEMA study.

Location	**Peak Discharge (cfs) 1% Annual Chance**
San Joaquin River at Paradise Dam	71,800 cfs
San Joaquin River at Mossdale	44,500 cfs
San Joaquin River at Head of Old River	43,500 cfs
SJR at mouth of French Camp Slough	21,100 cfs

Observable from Table 2 are the flow decreases moving downstream along the San Joaquin River, attributed to overbank losses and distributary type flows from the study reach (FEMA, 2009). Of note are the flow decreases for the San Joaquin River just above Paradise Cut to the junction with Old River. Details of the hydraulic modeling supporting the FEMA study, with the locations and quantity of overbank flow, were not available. The target for the setup of the RMA2 modeling was to reach the approximately 43,500 cfs for the San Joaquin River flow above the junction with Old River. As a result, for the model setup the San Joaquin River flow above the Paradise Dam was set to 70,800 cfs and friction lowered in the Paradise Cut bypass to accommodate the diversion of 27,300 cfs from the San Joaquin River.

A constant 70,800 cfs flow was applied for the San Joaquin River at the Vernalis inflow boundary condition (Figure 2). To establish the downstream stage boundary condition for the 100-year flood analysis, the historical inflows and tide from the January 1997 flow event were applied for the remaining Delta boundary conditions. The Yolo Bypass and Sacramento River flows for the January 1997 event are presented in Figure 22. Inflow for the Sacramento River was based upon the hourly gauged USGS flow at Freeport. The Yolo Bypass inflow was extracted from the RMA2 Yolo Bypass model of the January 1997 event (RMA, 2013). Stage in the San Joaquin River downstream of the Old River junction is somewhat influenced by the inflow from French Camp Slough (Figure 2). A constant 2,840 cfs was applied for the inflow, using the 10-year event flow for the French Camp Slough from the 2009 FEMA study.

The object of the 100-yr event calibration was to approximate the surface elevations (WSE) and flow splits at the San Joaquin River-Old River junction of the FEMA study. To accomplish this, some increase of the San Joaquin River and Old River channel friction values from the 2017 event calibration were required. Table 3 lists the adjusted friction values used for the 100-year event simulations.

The 100-year flow event was run as an unsteady flow simulation with a constant San Joaquin River inflow, but with time varying tidal and other Delta inflow conditions. The model results were post-processed to extract the peak WSE for the San Joaquin River and south Delta.

For providing model comparison, WSE for the San Joaquin River were read off from FEMA flood profile plots published with the 2009 study. WSE from the Delta model and FEMA profiles at selected points along the San Joaquin River (Figure 23) compared in Table 4. The Delta model WSE are lower than the FEMA values by 0.3 to 0.7 feet. However, further raising the model friction values for the river channels would depart from the model calibration to the 2017 flow event. The model calibration did successfully approximate the FEMA flows for the San Joaquin River flow at the Old River junction with 43,442 cfs and San Joaquin River flow below the junction with 20,960 cfs.

Table 3 Manning's n coefficients for the San Joaquin River and Old River main channel elements for the 100-year event flow.

River Reach	Manning's n value
SJR Main Channel Elements	
above Paradise Cut	0.040
Paradise Cut to above Mossdale Bridge	0.039
above Mossdale Bridge to Old River	0.039
below Old River	0.036
below Old River, 1-D	0.036
Old River Main Channel Elements	
Old River below SJR	0.040
Old River below SJR, 1-D	0.040

Table 4 Comparison of the Delta model computed WSE to the 2009 FEMA profile elevations.

Location	FEMA %1 WSE Profile NAVD88 ft	RMA2 100-yr, peak WSE NAVD88 ft
SJR at Paradise Cut	28.7	28.32
SJR at Mossdale Bridge	27.3	27.08
SJR at Old River	24.8	24.10
SJR at Brandt Bridge	19.8	19.28
SJR at French Camp Slough	14.3	13.86

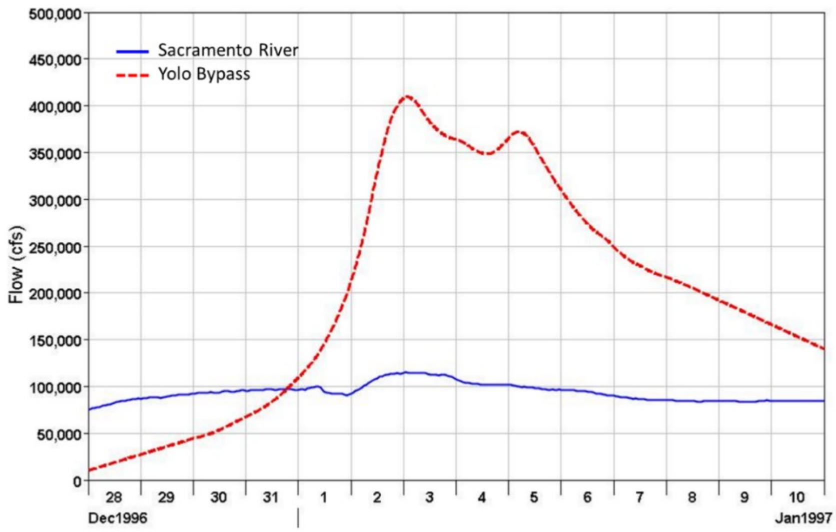

Figure 22. Yolo Bypass and Sacramento River inflow used for the 100-year flood event.

Figure 22 shows Sacramento River and Yolo Bypass inflows used to represent the 100-year flood event for the model simulation. Sacramento River flows remain relatively steady, generally ranging between approximately 80,000 and 115,000 cubic feet per second (cfs) from late December 1996 through early January 1997. In contrast, Yolo Bypass flows increase rapidly beginning around January 1, peaking above 400,000 cfs near January 3, and then gradually declining through January 10.

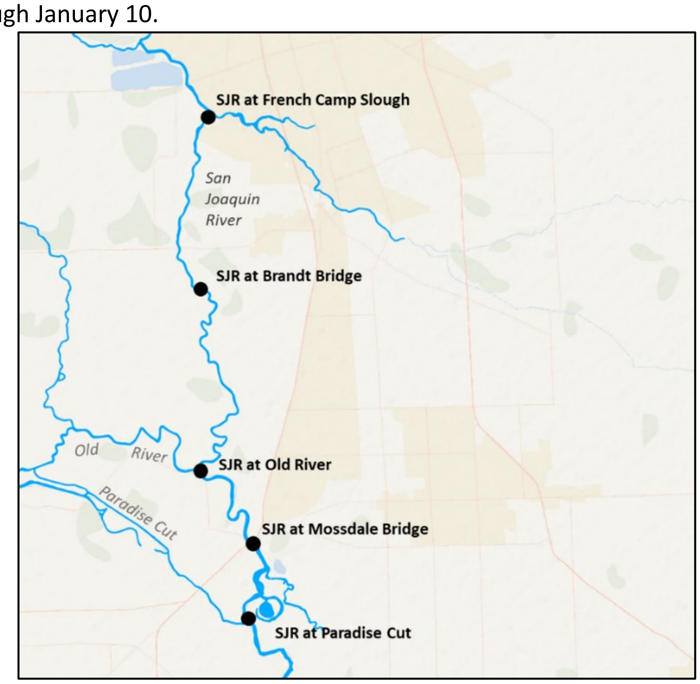

Figure 23 Locations for comparing the Delta model 100-yr flow event WSE to the 2009 FEMA profiles.

Figure 23 shows locations along the San Joaquin River where modeled water surface elevations (WSE) for the Delta model 100-year flow event are compared with the 2009 FEMA flood profiles. Comparison points are identified at French Camp Slough, Brandt Bridge, Old River, Mossdale Bridge, and Paradise Cut, representing key locations along the lower San Joaquin River corridor used to evaluate model performance relative to FEMA profile elevations.

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