Appendix B

Hydraulic and Sediment Transport Modeling Strategy

May 2014

SAN JOAQUIN RIVER
RESTORATION PROGRAM

San Joaquin River Restoration Program
Hydraulic and Sediment Transport Modeling Strategy

The San Joaquin River Restoration Program (SJRRP) has developed hydraulic and sediment transport modeling tools to evaluate the flow, channel, and structural actions as part of meeting the Restoration Goal of the Settlement. This memorandum will describe the system of tools that have been developed by the Bureau of Reclamation (Reclamation) and the Department of Water Resources (DWR), and the coordination and application of these tools to accurately and effectively meet the needs of the SJRRP.

Introduction

Numerical modeling has been a key tool used by the SJRRP to develop designs for the site-specific projects and perform quantitative evaluation of SJRRP actions. A range of models have been developed and applied for this work, including hydraulic, sediment transport, vegetation, temperature, flow routing, and groundwater models. Attachment A includes a table that summarizes the modeling tools that are currently available to the SJRRP.

The hydraulic and sediment transport models have been extremely valuable to the SJRRP for evaluating flow, seepage, and sediment conditions in the channels. As shown in Attachment A, the SJRRP has determined that several hydraulic and sediment transport modeling tools will be necessary to evaluate the wide-range of flows, channel characteristics, and future SJRRP project conditions within the San Joaquin River and flood bypasses. No single model was deemed appropriate to effectively model all aspects that are necessary to understand the actions of the SJRRP. Having separate tools available for different modeling applications provides the flexibility to meet both efficiency and accuracy needs, and therefore, is in the best interest of the SJRRP. Reclamation and DWR have coordinated the development of these hydraulic and sediment transport modeling tools to ensure efficiency and consistency in their application.

The following includes a summary of the hydraulic and sediment transport modeling tools developed for the SJRRP, including development, calibration, and uncertainty, and the overall strategy on how the modeling tools will be reviewed, used, and distributed.

Hydraulic Modeling Tools

One-dimensional steady and unsteady models and two-dimensional hydrodynamic models are being employed by the SJRRP. These models were developed to address various needs of the SJRRP along various reaches of the mainstem and flood bypasses. The models are all based on the same foundational input data. The ground topography is based on the LiDAR surveys conducted by DWR in 2008; the bathymetry was developed from a mixture of DWR and Reclamation bathymetric surveys performed between 2009 and 2011; and the vegetation polygons were developed by DWR using 2008 orthophotography. Each polygon was assigned a base Manning's roughness n value (n-value) ranging from around 0.035 for the channel bed and open water areas that are free of vegetation to 0.1 for dense trees and brush. These models also use similar flow boundary conditions based on operations manuals and rating curves at control structures. Differences among the various models include the degree of refinement of the input parameters, the computational algorithm (i.e., step-backwater for the steady-state models, solution of the 1D or 2D equations of motion for the unsteady models), and level and types of output that can be obtained. As a result, the level of detail in the input data and approach to validation for each model varies.

Selection of the appropriate tool for any specific study will depend on the purpose of the study, level of detail needed, and the preference of the agency performing the analysis. The difficulty in employing different models that can generally meet similar objectives is to ensure that the appropriate models are being utilized for the appropriate purpose. In this regard, Reclamation and DWR will review model documentation and coordinate with each other to ensure the appropriate use. Furthermore, there is some concern that model distribution will cause confusion among outside entities on the appropriateness of the models for certain applications. The strategy discussed in the remainder of this memorandum, and documentation for each respective model provides information with which outside technical professionals can assess the most appropriate models for given situations.

One-dimensional Steady-state Hydraulic Model

One-dimensional (1D) steady-state hydraulic models of the 150-mile reach of the San Joaquin River and bypass system were developed by Tetra Tech, Inc. (Tetra Tech) (under contract with DWR) and DWR to support the SJRRP. The 1D steady-state models were developed using the U.S. Army Corps of Engineers HEC-RAS modeling system. These models provide a means of evaluating water-surface profiles and the associated cross-sectionally averaged hydraulic conditions along the river and flood bypass system over a broad range of flows. The methodology and assumptions used in developing the steady-state models, including the boundary conditions, Manning's n-values, calibration and uncertainty are summarized in the *San Joaquin River and Bypass System 1-D Steady State HEC-RAS Model Documentation* (Tetra Tech, 2014).

The SJRRP uses the 1D steady-state models for various studies under existing and future project conditions including evaluating channel capacity, fish passage in channels and at structures, and spawning and rearing habitat for fisheries. The model results may also be used to provide input to other modeling applications in evaluating sediment transport, temperature effects, levee underseepage and stability, growth and mortality of riparian vegetation and surface water/groundwater linkages.

The 1D steady-state model uncertainty for existing conditions is directly related to the degree of calibration within the measured flow range, and the accuracy of the specific calibration measurements available (e.g. measured water-surface elevations and discharges). Because validation data are not available for future conditions, model uncertainty is a more critical issue for future conditions analyses. The uncertainty in unvalidated parameters such as vegetation growth, n-values, and discharges will most likely be addressed through sensitivity analyses of these various model input parameters to assess their effect on bottom-line results, as appropriate for specific studies.

Two versions of the 1D steady-state models were developed to allow accurate and efficient evaluations for a range of SJRRP applications.

Refined 1D steady models

Refined 1D steady-state models were developed by Tetra Tech for most of the San Joaquin River and portions of the flood bypass to allow for detailed, site-specific project evaluation over a wide range of flows. The refined models include the addition of multiple flow splits, and the application of vertically-varied Manning's n-values in the main channel. Tetra Tech developed a compositing method for determining the main channel n-values (Tetra Tech, 2014) to address the effects of bank vegetation and sinuosity to facilitate model calibration over a broad range of flows. The models were calibrated over a range of flows from about 200 cfs to about 8,000 cfs, depending on the reach.

In using these refined models, Reclamation and DWR received several comments on the appropriateness of the composite main channel n-value method. The comments and formal responses to the channel capacity analysis are incorporated into Chapter 3.0 of the Program Environmental Impact Study/Environmental Impact Report (PEIS/R) (Reclamation and DWR, July 2012). In general, the theme of the comments in the PEIS/R is that a relatively complex, non-standard method was used to estimate the n-values. Reclamation and DWR have reviewed the method and believe it is reasonable when used within calibrated flow ranges for existing conditions. The method is based on a combination of the relationships that are currently available in HEC-RAS, supplemented by empirical relationships that account for the effects of sinuosity and turbulence created by the changes in roughness across the channel.

Simplified 1D steady models

Since the refined models are more complex to adjust and the resulting accuracy over a wide flow range may not be needed for all applications, a simplified version of the refined models for each reach were also developed. The simplifications included elimination of flow splits, and replacement of vertically varied main-channel n-values with single main-channel n-values that are applied over the full range of flows within subreaches having consistent roughness characteristics. The simplified main-channel n-values were selected to provide calibration at the approximate bankfull flow that was estimated by determining when flow generally begins to enter the overbanks within each reach. In general, the bankfull flows ranged from about 1,500 cfs for the bypass to about 3,500 cfs in Reach 5.

The purpose of the simplified models is to allow use by a wide range of users, and to provide more convenient tool for gaming and sensitivity analyses. The results of the refined and simplified models closely match for the bankfull flow. However, the simplified models may need to be re-calibrated to provide adequate results for discharges significantly different from bankfull. The simplified model will be useful in performing sensitivity analysis because a smaller number of model parameters need to be changed. It may also be easier for users who do not want to use the refined methods of compositing main channel n-values when analyzing project or future conditions where channel and vegetation conditions are significantly different than current conditions. Before using the simplified models, it is recommended that the user determine if the accuracy is sufficient for the specific purpose. Depending on the purpose, it may be necessary to recalibrate the model to a different target flow.

The decision to use either the refined or simplified model for any particular study or application, whether existing conditions or to predict future project conditions, will be at the discretion of the agency completing the study, given the suggestions above. However, independent on whether the refined or simplified models are being used, an understanding of the model uncertainties will be necessary when used in the design or evaluation of future project conditions.

One-dimensional Unsteady Hydraulic Model

1D unsteady hydraulic models of the San Joaquin River from Friant Dam to the Merced River, including the Chowchilla and Eastside Bypasses, were developed by Tetra Tech (under contract with DWR) to support the SJRRP. The 1D unsteady models were developed using the U.S. Army Corps of Engineers HEC-RAS modeling system. The 1D unsteady models were developed to simulate the translation and attenuation of hydrographs associated with Friant Dam releases through the open channel and storage areas along the restoration reaches of the SJRRP. The models were originally developed using the 1998-2000 topography. Reaches 1A, 1B, 2A and 2B were subsequently updated with the more recent LiDAR and bathymetric surveys that are also used in the current version of the steady-state HEC-RAS models. The models were calibrated using hydrographs for peak discharges near Friant Dam ranging from about 2,700 cfs to an estimated 13,160 cfs. Documentation of the methodology and assumptions used in developing the original and updated unsteady models are summarized in the *Development of San Joaquin River Unsteady-flow Model* (MEI, 2008), San Joaquin River Unsteady Model Geometry Refinements (MEI, 2009), and *San Joaquin River Reaches 1A, 1B, 2A, and 2B HEC-RAS Unsteady Hydraulic Model Geometry Updates* (Tetra Tech, 2011).

A significant difference between the steady and unsteady 1D models is that the unsteady model includes eight off-channel storage areas in the reach between Friant Dam and the Chowchilla Bifurcation Structure to represent the storage effects of the numerous gravel pits in this reach to improve calibration to observed flood-wave travel time and attenuation.

The unsteady models will be most useful in analyzing the attenuation and timing of shorter duration flow releases and flood peaks as they move through the system. With the exception of the dynamic effects of flood-wave translation and attenuation, model uncertainties are similar to those of the 1D models, as described above.

Two-dimensional Hydraulic Model

Two-dimensional (2D) hydraulic models were used to assess floodplain habitat for juvenile Salmon in Reaches 1B through Reach 4B2 by Reclamation and is documented in *Hydraulic Studies for Fish Habitat Analysis* (Reclamation, 2012a). The 2D models were developed using Reclamation's Sediment River Hydraulics (SRH-2D) modeling system. The 2D models use the depth-averaged St. Venant equations and an unstructured mesh to predict water-surface elevations, depths, local flow velocity vectors and eddy patterns, and bed shear stress. Reclamation also developed a 2D model for Reach 1A to assess spawning habitat for adult salmon, which is documented in *Two-Dimensional Modeling of Reach 1A of the San Joaquin River between Friant Dam and Highway 99* (Reclamation, 2014). The 2D models were calibrated to match the observed water surface profiles for flows between 125 cfs and 7,000 cfs, depending on the reach.

The 2D existing conditions models use the same topography, bathymetry and vegetation polygons as the 1D models; however, some adjustments to the n-values for the original polygons were incorporated into the model to improve calibration. The 2D model only specifies a single main channel n-value for each polygon for an entire range of flows being assessed. Differences in n-values between the 1D and 2D models are common because the 2D model geometry already accounts for some of the losses associated with channel shape and sinuosity that are not accounted for in the 1D model algorithms.

The 2D models are the most useful in providing depth and velocity information for fish passage and habitat studies, as well as to inform site-specific floodplain grading design. The 2D models can calculate the depth and velocity at a much higher resolution than the 1D models. They can also more accurately predict the area of floodplain inundation than the 1D models for use in the fish habitat studies, and they provide higher resolution output for depth averaged velocity, including the direction of flow, which is specifically useful for the gravel mobilization studies. A limitation of the 2D models is that the execution time can be quite long (hours to days, depending upon the size of mesh) than the 1D models. More effort is also required to post-process of model output. The current 2D models have relatively coarse grid spacing in the main channel and overbanks to facilitate evaluation of habitat conditions for the entire SJRRP. If site specific design or analysis is performed, it will likely be necessary to clip the models to the site of interest and refine some of the grid. Because of the limited ability to vary the n-values to calibrate the model over a wide-range of discharges, it may be necessary to re-calibrate the 2D model to different flow levels for specific applications. Many of the same uncertainties also exist for the 2D models as the 1D models.

Sediment Transport Modeling Tools

1D and 2D sediment transport models are also being employed by the SJRRP. These models were developed to evaluate the effects of SJRRP actions on sediment transport along the river and flood bypasses. The existing sediment transport models were developed using Reclamation's SRH modeling system and incorporate the same foundational input data used in the hydraulic models described above. The sediment input data in the models include bed material gradations from the available field samples. The SRH modeling system has been used, to-date, primarily because Reclamation has the ability to modify the source code to better simulate site-specific conditions. Future 1D sediment transport modeling could be performed using HEC-RAS if deemed appropriate. The following describes the general differences between the 1D and 2D sediment transport models developed by the SJRRP.

One-dimensional Sediment Transport Model

An SRH-1D sediment transport model was applied to assess the reach-averaged erosion and deposition impacts of the SJRRP to Reaches 1 through 5 in the PEIS/R. The model development and results are documented in *Sediment Transport and Channel Morphology Impacts of the San Joaquin River Restoration Program from Mendota Dam to the Merced River* (Reclamation, 2009). SRH-1D was also applied to evaluate reach-averaged sediment transport conditions for alternatives in the Reach 4B project, which is documented in *Hydrology, Hydraulic, and Sediment Studies for Reach 4B, Eastside Bypass, and Mariposa Bypass Channel and Structural Improvements Project* (Reclamation, 2012b). Prior to the completion of these models, there was limited calibration of the SRH-1D sediment transport model. However, with the collection of suspended-load measurements by USGS for Water Year 2010 through 2012, calibration of the sediment transport functions will be possible for future studies.

These models will be useful in simulating the future reach-averaged sediment transport, erosion and deposition in the project reaches under various flow routing scenarios. SRH-1D (and other 1D models) are limited in their ability to simulate local sediment transport conditions resulting from variability in bed topography, in bends, around structures (such as bifurcations), and the differences between channel and floodplain deposition.

Two-dimensional Sediment Transport Model

An SRH-2D sediment transport model was also developed by Tetra Tech (under contract with DWR) for the approximately 2.5 miles portion of Reach 2A immediately upstream from the Chowchilla Bypass Bifurcation Structure (CBBS). The model is being used by the SJRRP to provide a refined tool to predict the long-term sediment transport behavior of the downstream portion of Reach 2A, and to provide a more accurate estimate of sediment movement from Reach 2A through the San Joaquin River Control Structure (SJRCS), and into Reach 2B under various restoration conditions. The hydrodynamic portion of the model that was used in the sediment transport model was developed by Tetra Tech specifically for use in this site-specific study. The development of the hydrodynamic and sediment transport portions of the models are documented in *San Joaquin River, Reach 2B, Two-dimensional Sediment-transport Modeling to Evaluate Sediment Budget through the San Joaquin River Bypass Structure* (Tetra Tech, 2013).

The current version of the model was only applied for restoration releases; thus, it does not specifically evaluate the sediment load through the Chowchilla Bypass Control Structure into the Chowchilla Bypass from flood events. However, this capability can be added at a later date, as needed. The hydrodynamic portion of the model was calibrated for flows ranging from 977 cfs to 7,290 cfs. The sediment input data was based on suspended-load measurements by USGS at 2,690 cfs. The sediment-transport portion of the model was validated, to the extent possible, by performing a simulation of the 2010 flood event and comparing the predicted channel geometry at the end of the simulation with the measured 2010 bed geometry.

The SRH-2D sediment transport model will be useful in evaluating the influence of bifurcation structures on sediment transport and estimating sediment mobilization at the local scale. It will be difficult to apply the SRH-2D model to large reaches (i.e. greater than 10 miles) because the computational times may become unreasonably large.

Model Application and Distribution

The hydraulic and sediment transport models developed by Reclamation and DWR have been peer reviewed by DWR, Tetra Tech, and Reclamation. In the development and application of each model, Reclamation and DWR understand that each of the tools has different levels of detail with respect to both model resolution and applicability; thus, the models are applicable for different purposes. For example, some tools are calibrated over different ranges of flow, or contain more refined and detailed geometry. Each agency will determine the most appropriate model for its specific application.

Reclamation and DWR will also closely review and consider any additional models that are available from other efforts within the Restoration Area that may be helpful to the SJRRP. For example, DWR's Central Valley Flood Evaluation and Delineation Program is currently developing hydraulic models as part of the Central Valley Flood Management and Planning Program. This includes a 1D unsteady hydraulic model that was developed to assess hydraulic conditions during high flood events. This model is designed to be coupled with a 2D hydraulic model to evaluate flood elevations in the floodplains through the Restoration Area from Gravelly Ford to the confluence of the Merced River. The model uses similar topography as the SJRRP 1D steady-state model. However, the model has not yet been calibrated. DWR will continue to review this model as the development of the model progresses and consider bringing it into the tools available for use by the SJRRP.

Reclamation and DWR will continue to work with the U.S. Army Corps of Engineers, Lower San Joaquin Levee District, and Central Valley Flood Protection Board, and local agencies in applying existing modeling tools or developing new tools to evaluate the potential impacts associated with the SJRRP, including flood. Because of subsidence experienced in the Restoration Area, additional LiDAR surveys will be collected in the latter part of 2014. This may result in possible updates to the topography in the existing modeling tools. At that time, the SJRRP will reassess its existing tools and work with these agencies to determine if the overall modeling approach should be modified.

Furthermore, the modeling tools developed by Reclamation and DWR to support the SJRRP may be provided to third parties for their use, if requested. The level of documentation for these models varies. Some of the long-standing models have been fully documented with respect to the inputs, calibration and uncertainties, while others are only documented in project reports. It will be the responsibility of those entities to understand the basis and assumptions associated with the available tools, and to make their own determination as to the appropriateness of the tools for their particular application.

References

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Tetra Tech (2014). *Draft San Joaquin River and Bypass System 1-D Steady State HEC-RAS Model Documentation*, Prepared for California Department of Water Resources, March 2014

	Reaches													
	Reach 1A	Reach 1B	Reach 2A	Reach 2B	Reach 3	Reach 4A	Reach 4B1	Reach 4B2	Reach 5	Chowchilla	Upper ESB	Middle ESB	Lower ESB	Mariposa
Surfaces														
Digital Terrain Model	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	DWR	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation
Extent	Friant Dam to Hwy 99	Hwy 99 to Gravelly Ford	Gravelly Ford to Chowchilla Bifurcation Structure	Chowchilla Bifurcation Structure to Mendota Dam	Mendota Dam to Arroyo Canal	Arroyo Canal to Sand Slough Control Structure	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence of ESB	confluence with ESB to Confluence with Merced	Bifurcation Structure to just upstream of Sand Slough area	See Chowchilla terrain extents. Additional terrain for the Sand	Just downstream of Sand Slough to Mariposa Bypass	Mariposa Bypass to Confluence with SJR	Bottom of Middle Eastside Bypass to Head of Reach 4B2
Surveys Used	2007 photogrammetry with 2008/2009 DWR bathymetry, some areas of 1999 Ayers	2008 LiDAR with DWR 2010 bathymetry	2008 LiDAR with Reclamation and DWR 2009 bathymetry	2008 LiDAR with Reclamation and DWR 2009 bathymetry	2008 LiDAR with Reclamation and DWR 2009 and 2010 bathymetry	2008 LiDAR with Reclamation 2010 and 2011 bathymetry	2008 LiDAR with 2002 MEI bathymetry cross-sections	2008 LiDAR with Reclamation collected bathymetry in 2010 and 2011	2008 LiDAR with Reclamation collected bathymetry in 2010 and 2011	LiDAR Only	2008 LiDAR with Reclamation collected bathymetry in 2010 and 2011	2008 LiDAR with Reclamation collected bathymetry in 2010 and 2011	2008 LiDAR with Reclamation collected bathymetry in 2011	LiDAR Only
Vertical Datum	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft
Horizontal Datum	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft	SP CA Z III ft
Date Published	April-08	July-11	July-11	July-11	July-11	April-12	October-11	April-12	October-12	June-12	June-12	July-12	July-12	May-12
One-dimensional Hydrauilc Modeling Tools														
1D Hydraulic Model (HEC-RAS)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR
Extent	Friant Dam to Hwy 99	Hwy 99 to Gravelly Ford	Gravelly Ford to Chowchilla Bifurcation Structure	Chowchilla Bifurcation Structure to Mendota Dam	Mendota Dam to Arroyo Canal	Arroyo Canal to Sand Slough Control Structure	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence of ESB	confluence with ESB to Confluence with Merced	Bifurcation Structure to Confluence with Fresno River	Lower end of Chowchilla at Fresno River to Confluence with SJR and Sand	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence with SJR	Bottom of Middle Eastside Bypass to Head of Reach 4B2
Comments	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values and Simplified Model	Refined model w/ vertical N values	Simplified Model	Simplified Model	Simplified Model	Simplified Model	Refined model w/ vertical N values and Simplified Model	Simplified Model	Simplified Model
Cross Section Spacing	300-400 feet	350-450 feet	~500 feet	~500-900 feet	~600 feet	~450 feet	~350-400 feet	~400 feet	~400 feet	~500-700 feet	~500-700 feet	~500-800 feet	~500-700 feet	~500 feet
Terrain Used	Reach 1A DTM.	Reach 1B DTM.	Reach 2A DTM.	Reach 2B DTM.	Reach 3 DTM.	Reach 4A DTM.	Reach 4B1 DTM	Reach 4B2 DTM.	Reach 5 DTM.	Chowchilla DTM that has been updated to account for subsidence using 2012 DWR top of levee surveys.	Upper ESB DTM that has been updated to account for subsidence using 2012 DWR top of levee surveys.	Middle ESB DTM.	Lower ESB DTM.	Mariposa DTM
Calibration Data used	Refined (350 cfs, 700 cfs, 1100 cfs and 1360 cfs surveys). Simplified (Bankfull= 3,000 cfs).	Refined (570 cfs, 1,100 cfs, 2,500 cfs, 4,110 cfs, 6,160 cfs and 6,950 cfs surveys). Simplified (Banfull=2,500 cfs).	Refined (500 cfs, 1,200 cfs, 2,500 cfs, 4,150 cfs, 5,700 cfs and 7,290 cfs surveys). Simplified (Bankfull=2,500 cfs).	Refined (160 cfs and 1,070 cfs surveys). Simplified (Bankfull = 1,500 cfs).	Refined (670 cfs, 1,750 cfs and 3,600 cfs surveys). Simplified (Bankfull = 2,500 cfs).	Refined (730 cfs, 1,200 cfs and 3,300 cfs surveys). Simplified (Bankfull = 2,000 cfs).		Simplified (Bankfull = 4,100 cfs) (Survey used 4,107 cfs)	Simplified (Bankfull= 3,500 cfs) (Surveys used 2,990 cfs, 3,630 cfs, 4,140 cfs and 11,300 cfs)	Calibrated with 3,820 to 4,120 cfs survey.	Calibrated with 5,800 to 4,120 cfs survey.	Refined (730 cfs, 2,359 cfs, 1,860 cfs and 1,720 cfs surveys). Simplified (Bankfull=1,500 cfs).	Calibrated with 1,893 cfs surveys.	
Date Published	Sep-11	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13	May-13
Current Use	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)	Capacity and fish passage studies, and hydraulic input for other models (temp, seepage, etc.)
1D Unsteady Hydraulic Model (HEC-RAS)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	DWR	
Extent	Friant Dam to Hwy 99	Hwy 99 to Gravelly Ford	Gravelly Ford to Chowchilla Bifurcation Structure	Chowchilla Bifurcation Structure to Mendota Dam	Mendota Dam to Arroyo Canal	Arroyo Canal to Sand Slough Control Structure	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence of ESB	confluence with ESB to Confluence with Merced	Bifurcation Structure to Confluence with Fresno River	Lower end of Chowchilla at Fresno River to Confluence	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence with SJR	
Cross Section Spacing	300-400 feet	350-450 feet	~500 feet	~500-900 feet	~600 feet	~450 feet	~350-400 feet	~400 feet	~400 feet	~500-700 feet	~500-700 feet	~500-800 feet	~500-700 feet	
Terrain/ surveys used	Reach 1A DTM.	2008 LiDAR with 1999/2000 bathymetry	2008 LiDAR with 1999/2000 bathymetry.	2008 LiDAR with 1999/2000 bathymetry.	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	1998/99 Ayres Mapping	
Calibration Data used	Calibrated with 350 cfs, 700 cfs, 1100 cfs and 1360 cfs surveys.	Calibrated with 1,100 cfs	Calibrated with 2006 HWM, 500 cfs and 1,200 cfs.	Calibrated with 2006 HWM, 160 cfs and 1,070 cfs.										
Vertical Datum	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	NGVD 29 ft	
Horizontal Datum	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	CA SP Z III	
Date Published	Jun-11	Jun-11	Jun-11	Jun-11	Apr-09	Apr-09	Apr-09	Apr-09	Apr-09	Apr-09	Apr-09	Apr-09	Apr-09	
Comments	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Refined model w/ vertical N values	Overbank and channel n-values	Overbank and channel n-values	Overbank and channel n-values	Overbank and channel n-values	
Current Use	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	Attenuation and timing of the flood peak	

	Reaches													
	Reach 1A	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Two-dimensional Hydrauilc Modeling Tools														
2D Hydraulic Model (SRH-2D)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation (In			Reclamation		Reclamation
Extent	HW 41 to Sycamore Island	Highway 99 to downstream most gravel pit, overlaps with Reach 2A	Skaggs Bridge to Chowchilla, upstream overlaps with Reach 1B	Existing conditions model from Chowchilla Bifurcation Structure to Mendota Dam; levee to levee laterally	Mendota Dam to Arroyo Canal/ Sack Dam	Sack Dam to confluence with ESB	Existing conditions model available, also modeled portions of levee setbacks to evaluate alternatives	Mariposa Bypass to Confluence of ESB				Existing conditions model (based on preliminary terrain) and Reach 4B Project levee setback alternatives.		Existing conditions model (based on preliminary terrain) and Reach 4B Project levee setback alternatives.
Channel Grid Size	5-10' laterally, 20-30' longitudinally	20-30' laterally, 35-45' longitudinally	20-30' laterally, 35-45' longitudinally	25-30' laterally, 30-45' longitudinally	25-30' laterally, 30-45' longitudinally	25-30' laterally, 30-45' longitudinally	20' laterally, 50' longitudinally	25-30' laterally, 30-45' longitudinally				20' laterally, 50' longitudinally		20' laterally, 50' longitudinally
Terrain/ surveys used	Reach 1A DTM, 2011 gravel pit elevations and breaches	Reach 1B DTM	Reach 2A DTM	Reach 2B DTM	Reach 3 DTM	Reach 4A DTM	Reach 4B1 DTM	Reach 4B2 DTM				Middle ESB DTM		Mariposa DTM
Calibration Data used	350 cfs, 700 cfs, 1150 cfs, 4500 cfs, 7650 cfs surveys from 2009 to 2011	570 cfs, 1,100 cfs, 2,500 cfs, 4,000 cfs, 7,100 cfs	1,200 cfs and 7,290 cfs surveys	160 cfs and 1,070 cfs surveys	670 cfs, 1,750 cfs and 3,600 cfs surveys	730 cfs and 3,300 cfs surveys	no calibration data used	4,100 cfs				730 cfs, 2,359 cfs, 1,860 cfs and 1,720 cfs surveys		no calibration data used
Date Published	2014 (draft)	2012	2012	2012	2012	2012	2012	2012				2012		
Current Use	Spawning Area assessment and 2D temp model	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study	Reach 4B Project/ floodplain rearing study				Reach 4B Project/ floodplain rearing study		Reach 4B Project/ floodplain rearing study
One-dimensional Sediment Modeling Tools														
1D Sediment Model (SRH-1D)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation		Reclamation			Reclamation
Extent	Friant Dam to Hwy 99	Hwy 99 to Gravelly Ford	Gravelly Ford to Chowchilla Bifurcation Structure	Chowchilla Bifurcation Structure to Mendota Dam	Mendota Dam to Arroyo Canal	Arroyo Canal to Sand Slough Control Structure	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence of ESB	confluence with ESB to Confluence with Merced	Bifurcation Structure to just upstream of Sand Slough area	See Chowchilla terrain extents. Additional terrain for the Sand	Just downstream of Sand Slough to Mariposa Bypass	Mariposa Bypass to Confluence with SJR	Bottom of Middle Eastside Bypass to Head of Reach 4B2
Channel Grid Size	~ 2500'	~ 2500'	~ 2500'	~ 500'	~ 2500'	~ 500'	~350-400 feet	~ 2500'	~ 2500'		~ 500'			~ 500'
Terrain/ surveys used	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	2011 DTM	HEC-RAS (MEI, 2002)	2011 DTM	2011 DTM	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)		2011 DTM			2011 terrain
Calibration Data used	no calibration data	no calibration data	no calibration data	no calibration data	no calibration data	no calibration data	no calibration data	no calibration data	no calibration data					
Vertical Datum	NGVD29/ NAVD88ft	NGVD29/ NAVD88ft	NGVD29/ NAVD88ft	NGVD 29ft/ NAVD88ft	NGVD29 ft	NAVD88	NAVD88	NGVD29 ft	NGVD29 ft		NAVD88			NAVD88
Horizontal Datum	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet		State Plane CA Zone III feet			State Plane CA Zone III feet
Date Published	2009	2009	2009	2009/2011 draft	2009	Draft 12/19/2011	Draft 12/19/2011	2009	2009		Draft 12/19/2011			Draft 12/19/2011
Current Use	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R	Reach 4B Project	Reach 4B Project	PEIS/R	PEIS/R		Reach 4B Project			Reach 4B Project
Updates Needed	Update geometry	Update geometry	Update geometry	Reach 2B work is in progress	Update geometry			Update geometry	Update geometry					
Two-dimensional Sediment Modeling Tools														
2D Sediment Model (SRH-2D)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization			DWR											
Extent			Lower reach 2A to CBBS											
Channel Grid Size			20x30 ft											
Terrain/ surveys used			2008 LiDAR data											
Calibration Data used			Calibrated (hydrodynamic portion of model with 977 cfs, 4,170 cfs, 5,760 cfs and 7,290 cf), sediment-transport portion using 2010 flood event and measured 2010 bed											
Vertical Datum			NAVD88ft											
Horizontal Datum			State Plane CA Zone III feet											
Date Published			March 2013											
Current Use			Sediment deposition dynamics at the Chowchilla Bifurcation Structure											

	Reaches													
	Reach 1A	Reach 1B	Reach 2A	Reach 2B	Reach 3	Reach 4A	Reach 4B1	Reach 4B2	Reach 5	Chowchilla	Upper ESB	Middle ESB	Lower ESB	Mariposa
Other Modeling Tools														
1D Vegetation Model (SRH-1DV)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation	Reclamation		Reclamation			Reclamation
Extent	Friant Dam to Hwy 99	Hwy 99 to Gravelly Ford	Gravelly Ford to Chowchilla Bifurcation Structure	Existing conditions and Reach 2B Setback Levee Alternatives	Mendota Dam to Arroyo Canal	Arroyo Canal to Sand Slough Control Structure	Sand Slough Control Structure to Mariposa Bypass	Mariposa Bypass to Confluence of ESB	Confluence with ESB to Confluence with Merced		See Chowchilla terrain extents. Additional terrain for the Sand Slough area.			Just upstream of the Eastside Bypass Control Structure to Head of Reach 4B2
Channel Grid Size	~ 2500'	~ 2500'	~ 2500'		~ 2500'	~ 500'	~350-400 feet	~ 2500'	~ 2500'		~ 500'			~ 500'
Surveys Used	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)/ updated using LiDAR and 2009 bathymetry	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)	HEC-RAS (MEI, 2002)		HEC-RAS (MEI, 2002)			HEC-RAS (MEI, 2002)
Vertical Datum	NGVD29/ NAVD88ft	NGVD29/ NAVD88ft	NGVD29/ NAVD88ft	NGVD 29ft/ NAVD88ft	NGVD29 ft	NGVD29 ft	NGVD29 ft	NGVD29 ft	NGVD29 ft		NGVD29 ft			NGVD29 ft
Horizontal Datum	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet		State Plane CA Zone III feet			State Plane CA Zone III feet
Date Published	2009	2009	2009	2009/2011 draft	2009	2009	2009	2009	2009		2009			2009
Current Use	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R, Reach 2B	PEIS/R	PEIS/R	PEIS/R	PEIS/R	PEIS/R		PEIS/R			PEIS/R
Updates Needed	Update geometry	Update geometry	Update geometry		Update geometry	Update geometry	Update geometry	Update geometry	Update geometry		Update geometry			Update geometry
2D River Temperature Model (SRH-2D)	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization	Reclamation													
Extent	HW41 to Sycamore													
Channel Grid Size	10-15' laterally, 20-30' longitudinally													
Surveys Used	latest terrain model													
Vertical Datum	NAVD 88ft													
Horizontal Datum	State Plane CA Zone III feet													
Date Published	In progress													
Current Use	test temperature model in gravel pits													
Updates in Progress	temperature module not yet incorporated													
Updates Needed	incorporate tempertaure modelule													
3D Groundwater Model	**Reach 1A**	**Reach 1B**	**Reach 2A**	**Reach 2B**	**Reach 3**	**Reach 4A**	**Reach 4B1**	**Reach 4B2**	**Reach 5**	**Chowchilla**	**Upper ESB**	**Middle ESB**	**Lower ESB**	**Mariposa**
Built By Organization		USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS	USGS
Extent		5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses	5 mi. from SJR and bypasses
Channel Grid Size		1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile	1/4 mile
Surveys Used		Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010	Soil Texture: DWR Water Level Database well construction info, USGS well construction info, SJRRP well drill log data to 2010
Vertical Datum		NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft	NAVD 88ft
Horizontal Datum		State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet	State Plane CA Zone III feet
Date Published		2014 (draft)	2015 (draft)	2016 (draft)	2017 (draft)	2018 (draft)	2019 (draft)	2020 (draft)	2021 (draft)	2022 (draft)	2023 (draft)	2024 (draft)	2025 (draft)	2026 (draft)
Current Use		Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives	Estimation of SJR stream-aquifer interaction and potential benefits of seepage mitigation projects, comparison of baseline (no SJRRP flows) with several different SJRRP alternatives
Updates in Progress		Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data	Extend historic calibration period to present, utilize additional local data