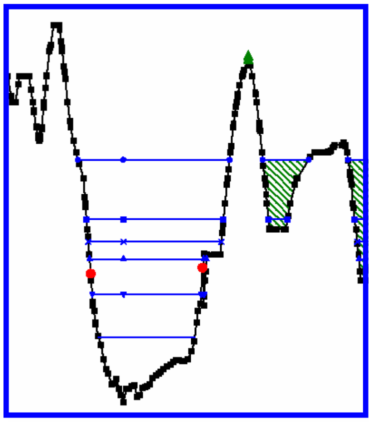
Merced River Corridor Restoration Plan
Phase IV: Dredger Tailings Reach


Technical Memorandum #2

Hydraulic Model of the Merced River Dredger Tailings Reach

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I INTRODUCTION

1.1 Report Structure

The purpose of this technical memorandum is to document the development, calibration, and results of a reach-scale hydraulic model used to assess flow conditions within the Merced River Dredger Tailings Reach (DTR). The model discussed in this report was developed to assess flow stages related to floods of different recurrence intervals under existing channel conditions. The model will be used in the future for assessing flow stages associated with potential design channel dimensions and for guiding vegetation planting patterns in channel and floodplain restoration efforts.

This technical memorandum describes the setting and context for the hydraulic model, the data, analyses, and parameters used as input to the model, and the model results under existing channel conditions, specifically:

- *Field reconnaissance and data collection*. Field reconnaissance was conducted to obtain topographic data, identify flow restrictions, such as bridges and diversion weirs, that could affect the model, and to evaluate channel and floodplain conditions to inform Manning's roughness values.
- *Flood frequency analysis*. Flow data from gauging stations in the DTR and recent flood frequency analyses were reviewed and updated to calculate the flow and flood frequency data needed for model input.
- *Channel geometry data.* Existing reach-scale channel cross-section and floodplain topography data were synthesized and used for input to the model.
- *Transition (contraction and expansion coefficients) and friction (Manning's roughness coefficients) loss parameters.* Contraction, expansion, and Manning's roughness coefficients were selected for input to the model and calibrated to simulate measured storm characteristics.
- *Model calibration and verification.* Water surface elevation measurements taken in the field were used to calibrate and verify the output of the model.
- *Results under existing channel conditions.* Model output is provided for floods of different recurrence intervals under existing channel conditions.

This report is the second in a series of technical memoranda that will detail the existing and potential post-restoration physical and biological conditions of the DTR.

1.2 Project Setting

The Merced River is a tributary to the San Joaquin River in the southern portion of California's Central Valley (Figure 1). The river, which drains an approximately 1,276-square-mile watershed, originates in Yosemite National Park and flows southwest through the Sierra Nevada range before joining the San Joaquin River 87 miles south of the City of Sacramento. Elevations in the watershed range from 13,000 feet at its crest to 49 feet at the confluence with the San Joaquin River. This report focuses on the DTR of the Merced River, which extends from Crocker-Huffman Dam (river mile [RM] 52) to approximately 1.2 miles downstream of the Snelling Road Bridge (RM 45.2) (Figure 1). The channel in this reach is confined by piles of dredger tailings, which have replaced the natural floodplain soils and floodplain forest, and have increased floodplain elevations along the river. Within this reach, riparian vegetation is sparse, occurring primarily in narrow bands along the river channel and in fragmented patches in low-lying areas among the dredger tailings piles.

Historically, this reach was part of a highly dynamic, multiple channel system. Under pre-colonial conditions, as the river exited the Sierra Nevada foothills near Merced Falls, the river spread out across a broad alluvial valley floor that ranged up to 4.5 miles in width (Stillwater Sciences 2001). Within this reach, the historic river was a complex, multiple channel system, including the mainstem river channel and several sloughs. Under pre-colonial flow conditions, the dominant, or "mainstem," channel likely switched between the multiple channels, and channel avulsions during large flows may have been common.

The hydrology of the Merced River has been altered by water supply requirements and flood control operations, which together have reduced flood frequency, reduced peak flow magnitude, altered seasonal flow patterns, and reduced the temporal variability of flows, spring snowmelt flows, and summer baseflows. These changes in hydrologic conditions have altered the frequency, duration, and magnitude of floodplain inundation, reduced the frequency of sediment transport and bed scour, but, in conjunction with channel incision, has increased the relative effectiveness of sediment transport in the remaining flood events (Stillwater Sciences 2001).

Since 1926, sediment supply from the upper 81 percent of the watershed has been intercepted at the original Exchequer Dam and then the New Exchequer Dam. This interception has eliminated the vast majority of the river's historical sediment supply, thus depriving the river of a basic component in maintaining its existing geomorphic equilibrium and causing a new equilibrium to be sought. Under pre-dam conditions, the bed was likely mobilized by small, relatively frequent floods that occurred about every 1–2 years. With the reduction in flood magnitude caused by flow regulation, the bed is currently immobile at flows up to the 5-year recurrence interval flow (Q_5) (Stillwater Sciences 2001). As a result, the channel bed and formerly active bars are largely static, and riparian vegetation has encroached into the formerly active channel.

In addition to the effects of flow regulation and loss of sediment supply from the upper watershed, this reach has been extensively modified by gold dredging. In the early-to-mid twentieth century, gold dredges excavated the river channel, floodplain, and valley floor. The dredges had earthmoving capacities of 1.4–3.4 million cubic yards/year and excavated the channel and floodplain deposits to bedrock, usually a depth of 20–35 feet (Clark 1969). After recovering the gold, the dredgers redeposited the remaining tailings in long rows on the floodplain. These tailings consist of fine sand and gravel overlain by cobbles and boulders (Goldman 1964), a stratification pattern that resulted from the sluicing and discharge process. As a result of gold dredging, the channel has been depleted of coarse sediment and the adjacent floodplain has been raised and covered with dredger tailings piles. An estimated 24 million cubic yards of dredger tailings currently cover approximately 7.6 square miles of the floodplain in this reach and in the dredged area upstream of Crocker-Huffman Dam (Stillwater Sciences 2001). An improved estimate of the total volume of dredger tailings will be calculated in a later phase of this project.

The combined effects of gold dredging, flow regulation, elimination of coarse sediment supply, and land use development have converted this reach from a complex, multiple-channel system to a simplified, single-thread system with a narrow floodplain adjacent to the channel. The complex slough channels that once dominated the floodplain have been converted to agricultural irrigation and return-flow ditches. The dredger tailings on the floodplain constrain the river channel so that high flow events are prevented from spilling onto the floodplain. As such, although high flow events are now rare, even moderate flow events are capable of resulting in high shear stresses that are highly effective at transporting sediment. Over time, the occasional high flow events combined with the lack of coarse sediment supply have acted to transport the majority of finer sediments from the reach. One result of this high sediment transport capacity is the very coarse bed surface of the reach, which is composed of coarse gravel and cobble. The D_{50} (the median particle size) of the bed surface ranges from 28 to 134 mm, and the D_{84} (value for which 84% of the particles are finer) ranges from 68 to 270 mm (CDWR 1994, Vick 1995, Stillwater Sciences 2001 and 2004). Another result has been that the channel is now typified by long, deep pools that are scoured to bedrock or to a coarse cobble armor layer. These pools are partly controlled by bedrock outcrops and some of them are quite likely the result of dredger mining in the channel. The pools are separated by riffles that are also partly controlled by bedrock, but many of which are also maintained through frequent gravel augmentation of spawning riffles and water diversion wing-dams. The channel slope averages 0.0023 (Stillwater Sciences 2004).

The primary restoration issues in the DTR include flow reduction and alteration of seasonal flow patterns, lack of bed-mobilizing flows, lack of coarse sediment supply, conversion of the floodplain to tailings piles, and the high bed load transporting capacity aided by channel confinement. The lack of coarse sediment supply and bed-mobilizing flows in combination with high bed load transporting capacity during rare flood events prevent the accumulation and retention of valuable salmon spawning gravel and result in encroachment of vegetation into the channel. The conversion of the floodplain to tailings and the confinement of the channel by the tailings piles prevent floodplain inundation during high flows and have eliminated the processes by which riparian vegetation is established and renewed, reducing riparian habitat.

1.3 Project Overview and Objectives

The hydraulic model reported in this technical memorandum was developed as a part of the Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach project (California Bay-Delta Authority [CBDA] ERP-02-P12-D), which will evaluate strategies for channel and floodplain restoration of the 318-acre Merced River Ranch and, by implication, for the 7-mile DTR.

The DTR has become a focus for restoration planning for several reasons. First, the DTR is now the primary spawning area in the Merced River for fall Chinook salmon (*Oncorhynchus tshawytscha),* an important management species and a candidate for listing under the federal Endangered Species Act, and, potentially, steelhead (*O. mykiss*) (Stillwater Sciences 2002), which is listed as threatened under the federal Endangered Species Act. Salmonid species that historically migrated up the Merced River now concentrate spawning in the DTR directly downstream of Crocker-Huffman Dam, the current upstream limit of salmonid migration. Lastly, past and current studies and restoration planning in the Merced River have provided a cursory understanding of the physical and ecological conditions of the reach and factors limiting ecosystem health. These studies include the Anadromous Fish Restoration Program's (AFRP) Comprehensive Assessment and Management Program; U.S. Geological Survey and Central Valley Regional Water Quality Control Board water quality monitoring; Merced Irrigation District (Merced ID) and the California Department of Fish and Game (CDFG) salmon population ecology studies; and Stillwater Sciences' AFRP and CBDA-funded geomorphic and riparian vegetation evaluations.

Partly in response to these studies, the CBDA Ecosystem Restoration Program funded the development of the Merced River Corridor Restoration Plan (Stillwater Sciences 2002). The restoration planning process was designed to provide a technically sound, publicly supported, and implementable plan to improve geomorphic and ecological functions in the Merced River corridor from Crocker-Huffman Dam to the confluence with the San Joaquin River. The Restoration Plan identifies restoration objectives and provides recommendations for the Merced River based on current scientific understanding of the river with input from the Merced River Stakeholders (MRS), Technical Advisory Committee (TAC), and the broader public. Since the restoration objectives were discussed by a broad spectrum of interests represented by the MRS, TAC, and public, they address not only geomorphic and ecological restoration in the river but also the concerns of local citizens, landowners, and other stakeholders. In the DTR, which is affected by flow reduction and alteration of seasonal flow patterns, lack of bed-mobilizing flows, lack of coarse sediment supply, conversion of the floodplain to tailings piles, and channel confinement, the following reach-scale restoration objectives were recognized:

- Balance sediment supply and transport capacity to allow the accumulation and retention of spawning gravel and prevent riparian vegetation encroachment;
- Restore floodplain functions to improve the establishment of riparian vegetation and the quality of riparian habitat;
- Increase in-channel habitat complexity to improve aquatic habitat for native aquatic species; and
- Scale low-flow and bankfull channel geometry to current flow conditions.

The Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach project begins to address the restoration objectives for the DTR developed in the Restoration Plan. The goals of the DTR project are to design pilot experiments in the channel and floodplain to test measures that will initiate the restoration of natural ecosystem function in the reach to the extent feasible. The current project is the precursor for conducting experimental pilot projects in floodplain and channel restoration, gravel augmentation, and floodplain re-vegetation. Removal of the tailings from the floodplain has the potential to yield multiple restoration opportunities and ecosystem benefits, but the actual detailed impact of such activities is largely unknown. The experiments designed as part of this project will increase the collective scientific understanding of the potential for dredger tailings removal and re-use (e.g., as material to fill the channel), and is intended to improve restoration effectiveness and reduce project uncertainty when implementing similar schemes in the future. Future projects will be implemented to increase coarse sediment storage in the Merced River channel, balance bed texture with sediment transport competence, remove dredger tailings to create diverse floodplain surfaces at functional elevations, and reconstruct a channel through a portion of the DTR.

A comprehensive understanding of the hydrologic and hydraulic setting in which the river currently functions is required to address the reach-scale restoration objectives described in the Restoration Plan and meet the goals of the DTR project. For this reason, a reach-scale hydraulic model was developed as a part of the DTR project. The objectives of the hydraulic model are:

- Compute existing and potential post-restoration project flood conveyance and water surface elevations, as required for project design considerations and to obtain a Reclamation Board permit for restoration implementation.
- Predict water surface elevations, flow depths, flow velocity, and shear stresses under existing and proposed conditions.
- Evaluate bankfull channel capacities and floodplain elevations for existing and potential post-project floodplain restoration designs.

The results of the existing conditions modeling are reported in this technical memorandum.

2 FIELD RECONNAISSANCE AND DATA COLLECTION

Field reconnaissance was conducted on September 3, 2003 to evaluate and document the existing site conditions along the DTR. A total of seven sites were visited in the reach, including Crocker-Huffman Dam, Snelling Bridge, and several channel and floodplain reaches that are considered representative of conditions in the river corridor. Selected photographs collected during the field visit are included in Appendix A. The data collected during this effort included channel and floodplain characteristics used to inform initial Manning's roughness values, as well as information on hydraulic constraints such as bridges. Some of the factors that affect the Manning's roughness coefficient include: type and size of channel bed materials; channel meandering, cross-section, and planform irregularities; and channel and floodplain vegetation types, heights and densities.

Detailed channel and floodplain geometry was obtained from channel cross-section survey data collected by Stillwater Sciences (in August and September 2003) and floodplain aerial topographic mapping data collected by KSN (in November 2003) along the DTR (Stillwater Sciences 2004). The Stillwater Sciences channel cross-section survey consisted of collecting main channel cross-section elevation and water surface elevation data for 40 transects along the DTR. Figure 2 presents an aerial photograph of the project area showing the locations of channel cross-section survey data collected and utilized in this analysis.

The channel cross-section survey was performed during the months of August and September, 2003. During this period, average flow releases from Crocker-Huffman Dam to Merced River ranged from 223 cfs to 267 cfs, as measured at the Merced ID's Crocker-Huffman gauge (RM 52). Table 2-1 summarizes the recorded flows in Merced River at Crocker-Huffman gauge and CDWR's Snelling gauge (No. B05170; RM 46.4) during the channel cross-section surveys.

Table 2-1. Merced River Flows during Channel Cross-section Surveys.

Date of Cross-section Survey	Flow at Snelling Gauge[1] (cfs)	Flow at Crocker-Huffman Gauge[2] (cfs)	Surveyed Channel Cross-section No.[3]
8/19/2003	178	223	4, 5
8/20/2003	174	220	2
9/2/2003	158	241	12, 13
9/3/2003	161	234	11, 14, 15, 16
9/4/2003	144	243	3, 6
9/5/2003	146	253	7, 9
9/8/2003	142	257	20, 21
9/9/2003	134	256	17, 18, 19
9/11/2003	136	262	10, 35, 37
9/12/2003	138	263	34, 38, 39
9/16/2003	138	247	40, 41
9/17/2003	142	250	22, 23, 24
9/18/2003	141	267	25, 26, 27
9/19/2003	143	265	29, 30
9/23/2003	143	265	31, 32
9/24/2003	139	264	33, 35.1, 42, 43
Average Flow	147	251	

1. Source: California Data Exchange Center, CDWR (2004)
2. Source: Merced ID (2004)
3. Source: Stillwater Sciences (2004)

3 FLOOD FREQUENCY ANALYSIS

Recently performed hydrologic flood frequency studies were reviewed in detail to determine design flood discharges for the hydraulic model. These studies include:

- Merced River Salmon Habitat Enhancement Project, Robinson Reach Engineering Report (Phase III) by California Department Water Resources (CDWR) (2001);
- Merced River Ranch Restoration Plan, by URS Corporation (2001); and
- Merced River Corridor Restoration Plan Baseline Studies, Geomorphic and Riparian Vegetation Investigations Report (Volume II) by Stillwater Sciences (2001).

For the Merced River Salmon Habitat Enhancement Project, CDWR (2001) used flow data from 1967 to 1999 recorded at the Merced River below Snelling gauge, which is located approximately four miles upstream from the Robinson Reach (RM 42 to RM 44). Using these data, they estimated the 1.5-year and project design discharges for the Robinson Reach Project as 1,700 and 8,000 cfs, respectively. The design discharge has an approximate return period of 30 years.

URS Corporation performed a flood frequency analysis for the Merced River Ranch Restoration Plan (URS 2001) using mean daily flow data from 1967 to 1999 recorded at the Crocker-Huffman gauge. Using these data they estimated the 1.5-, 2.5-, 5-, 10-, 30-, and 100-year design flow discharges at this site as 1,700, 3,200, 5,000, 6,000, 8,000, and 12,000 cfs, respectively.

For the Merced River Corridor Restoration Plan Baseline Studies, Stillwater Sciences (2001) estimated the 1.5-, 2-, 5-, 10-, and 50-year discharges as 1,338, 2,097, 4,675, 6,836, and 12,513 cfs, respectively, using instantaneous peak flow data (from 1968–1997) recorded at the Merced River Snelling gauge.

For this study, the URS (2001) flood frequency curve from the Crocker-Huffman gauge was updated using additional flow data from 1999 to 2003 obtained from Merced ID. The recorded daily flow data (1967 to 2003) obtained from Merced ID are included in Appendix B. This updated frequency analysis was performed using the Log-Pearson Type III distribution based on procedures presented in Water Resources Council Bulletin #17B (WRC 1981). The HEC-FFA3.1 software package developed by the U.S. Army Corps of Engineers (1992) was used to derive the updated flood frequency curve presented in Figure 3. The estimated peak discharges for flood events with return periods of 1.5- to 100-years are summarized in Table 3-1. Because high discharges in the reach are regulated, there is little difference in the discharges obtained using annual maximum daily mean flow data versus annual maximum instantaneous peak flow data. At discharges exceeding approximately 800 cfs, there is also little difference in the discharges recorded at the Crocker-Huffman and Snelling gauges.

Table 3-1. Estimated Peak Discharges in the Merced River at Crocker-Huffman Dam.

Return Period (Years)	Probability of Exceedance (%)	Peak Discharge (cfs)
1.5	66.6	1,400
2	50	2,030
5	20	4,530
10	10	6,640
20	5	8,940
50	2	12,200
100	1	14,900

4 HEC-RAS HYDRAULIC MODEL

The U.S. Army Corps of Engineer's HEC-RAS model, Version 3.1 (2002) was used to develop a reach-scale hydraulic model for the existing and potential post-restoration conditions. This model is widely used and accepted for hydraulic studies in environmental permitting applications. It is used as a hydraulic analysis tool to estimate hydraulic flow parameters including velocities, depths, and water surface elevations for open-channel river systems.

The model solves a one-dimensional energy equation by iteration to attain an energy balance between each successive cross-section along the study reach. The energy equation between two successive cross-sections is written as follows:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Where:

	Y_1, Y_2	= depth of water at each of the cross-sections
	Z_1, Z_2	= main channel invert elevations (thalweg) at each cross-section
	V_1, V_2	= average flow velocities at cross-sections
	α_1, α_2	= velocity weighting coefficients at each cross-section
	g	= gravitational acceleration
	h_e	= energy head loss between successive cross-sections

The velocity weighting coefficient (α) for each cross-section is determined based on the flow conveyance capacities of the cross-section sub-areas: main channel, left over-bank channel, and right over bank channel (USACE 2002).

The energy head loss (h_e) between successive cross-sections is comprised of transition (contraction or expansion) and friction losses. The equation for the head loss is as follows:

$$h_e = LS_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

Where: L = discharge weighted reach length
C = expansion or contraction loss coefficient
S_f = representative friction slope between the cross-sections

The friction slope (S_f) between two cross-sections is calculated using the following form of Manning's equation:

$$Q = \frac{1.486}{n} AR^{2/3} S_f$$

Where: n = Manning's roughness coefficient
A = flow area
R = hydraulic radius (area/wetted perimeter)

The following input data are required for the model to calculate flow velocities and water surface elevations along the reach:

- Geometric data including channel and floodplain cross-sections, channel longitudinal profile, and reach lengths between cross-sections;
- Hydrology data including design flow discharges and flow boundary conditions; and
- Transition and Manning's friction loss coefficients for main channel and channel floodplains.

5 CHANNEL AND FLOODPLAIN GEOMETRY

As discussed in Section 2, the floodplain topographic mapping and channel cross-section data provided by Stillwater Sciences (2004), a total of 40 cross-sections, were developed as geometric input data to the HEC-RAS model. Channel cross-section data was merged with aerial topographic data to extend the cross-section lengths across the entire flooplain. The locations of these cross-sections are shown in Figure 2.

The reach lengths between cross-sections were determined from the surveyed horizontal (x, y) coordinates of the cross-sections scaled along the channel thalweg. Table 5-1 presents the channel reach-lengths (between cross-sections) and channel thalweg profile surveyed by KSN, Inc. and Stillwater Sciences (Stillwater Sciences 2004).

Hydrologic data input to the model included an average calibration flow based on the data summarized in Table 2-1, and peak flows from the various flood frequency events summarized in Table 3-1.

Table 5-1. Channel Reach Lengths and Thalweg Profile Elevation.

HEC-RAS River Station No.[1]	Surveyed Channel Cross-section No.[2]	Reach Lengths Between Cross-sections (ft)	Cumulative Distance from Crocker-Huffman Dam (ft)	Surveyed Thalweg Elevation[3] (ft)
-	-	450	0	-
40	2	843	450	286.8
39	3	451	1,293	282.9
38	4	1,330	1,744	281.5
37	5	1,600	3,074	278.9
36	6	715	4,674	272.5
35	7	796	5,388	273.9
34	9	234	6,184	273.9
33	10	940	6,419	271.8
32	11	490	7,359	272.4
31	12	327	7,848	265.0
30	13	728	8,176	272.4
29	14	527	8,904	266.6
28	15	738	9,431	267.5
27	16	1,240	10,169	265.2
26	17	746	11,409	260.8
25	18	1,297	12,155	260.7
24	19	1,367	13,452	257.3
23	20	1,343	14,819	256.1
22	21	2,730	16,162	241.4
21	22	1,073	18,892	252.7
20	23	1,065	19,964	246.9
19	24	1,511	21,030	241.0
18	25	542	22,540	245.6
17	26	782	23,082	241.4
16	27	2,483	23,864	230.2
15	29	357	26,347	238.3
14	30	631	26,704	235.3
13	31	869	27,335	232.9
12	32	891	28,203	232.1
11	33	607	29,094	230.7
10	34	495	29,701	228.1
9	35	163	30,195	228.0
8	35.1	242	30,358	228.9
7	37	1,313	30,600	229.0
6	38	778	31,913	221.7
5	39	1,180	32,690	219.6
4	40	1,952	33,871	216.3
3	41	808	35,822	218.0
2	42	531	36,630	219.0
1	43	0	37,161	212.2

1. River Station No. assigned in the DTR HEC-RAS model
2. Refer to Figure 2 for surveyed cross-section locations
3. Source: Stillwater Sciences (2004)

6 TRANSITION AND FRICTION LOSS PARAMETERS

Energy losses associated with the calculation of water surface profiles in the hydraulic model include transition and friction losses. Contraction or expansion coefficients are used to compute transition losses (minor losses) and Manning's roughness coefficient is typically used to compute friction losses (major losses). A more detailed discussion on contraction and expansion coefficients and Manning's roughness values are provided in the HEC-RAS River Analysis System Manual (USACE 2002).

A contraction coefficient of 0.1 and an expansion coefficient of 0.3 were used for the majority of cross-sections for the hydraulic modeling because the expansion and contraction for most of the cross-sections along the study reach is considered to be "gradual" (USACE 2002). For cross-sections with "abrupt" changes in flow areas, contraction and expansion coefficients of 0.3 and 0.5, respectively, were used as recommended in USACE (2002). These coefficients are based on laboratory studies and are widely accepted for this type of analysis. Values of gradual and abrupt are based primarily on experience and judgment. Abrupt contraction and expansion was deemed to occur at cross-sections 9, 20, and 37.

Manning's roughness coefficients are the most important hydraulic parameter used in the model and need to be calibrated based on high water level data. For channel and floodplain areas, typical Manning's roughness values are often assumed (as initial values) based on vegetation and land cover types present in the river corridor. For natural streams with deep pools and sluggish reaches, typical channel Manning's roughness values can range from 0.05 to 0.1, and for floodplains with light vegetation, the roughness value is approximately 0.07 (Chow 1959). These roughness values were used as initial values for the DTR hydraulic model and then were refined during the model calibration, as discussed in the following sections.

7 CALIBRATION OF MODEL PARAMETERS AND MODEL VERIFICATION

Calibration involves adjusting model parameters to reduce the difference between predicted and measured values. In the case of HEC-RAS, this means reducing the difference between measured and predicted water surface elevation values. Since the results of any calibration process are conditional on several factors, it is good practice to test the performance of the calibrated model by using it to predict water surface elevations to compare to a different, independent, set of measured data, i.e., model validation. In addition, it is desirable to choose calibration and verification data that are relatively close to the range of data that will be used to produce the project model results. For instance, if the model results will be used bankfull channel elevations to determine proposed floodplain elevations, it would be ideal to have calibration and verification data relatively close to the bankfull condition.

For this analysis, available data for calibration was limited to dry weather flows recorded at two stations, and water surface elevations measured during the channel cross-section survey (Stillwater Sciences 2004). Verification data was limited to one peak storm flow measurement and associated water elevation data along the MRR property (URS 2001; Figure 1). Due to the lack of additional high water data for the entire reach, it was necessary to extrapolate the verification results to the entire DTR.

Acceptable calibration criteria are typically based on the way in which the results will be utilized, and are chosen based on the judgment and experience of the hydraulic engineer. A general rule of thumb for hydraulic reach models of this type includes an error in the range of ±1 foot (USACE 1993). The results of this study will be utilized to evaluate bankfull channel and floodplain elevations. These proposed elevations will help determine the extent of riparian and other habitat zones during restoration. These vegetative zones will migrate based on future hydrology and hydraulic conditions. For this reason, it was determined that a calibration error of ±1 foot is acceptable.

An average calibration flow of 250 cfs was calculated based on the data from the cross-section surveys shown in Table 2-1. In the model, flows within the channel were altered as necessary to reflect losses associated with irrigation and other flow diversions from Merced River. Diversions and hydraulic constraints, such as bridges, were identified during a field reconnaissance effort in September 2003. Diversions at cross-sections 13, 25, 29, 37, and 42 were included in the model to account for the flow losses. Flow losses at these diversion locations were estimated based on differences between the recorded flow data from the Crocker-Huffman and Merced River below Snelling gauge stations (see Table 2-1). An analysis of the flow differences at the two stations revealed that there was a significant difference at low flows, but the difference became insignificant for larger flow events, such as flows exceeding approximately 800 cfs. Therefore, it was not necessary to account for diversion flow losses for the design flood events analyzed (1.5-year through 100-year).

To calibrate the model roughness parameters, the HEC-RAS model was used to reproduce observed water surface elevations by adjusting the channel Manning's roughness values, without varying the floodplain Manning's roughness values. The channel roughness values of the hydraulic model were varied within a reasonable range (from 0.06 to 0.08) in order to reproduce the water surface elevations measured during the cross-section surveys. Figure 4 shows a comparison of the measured and the model-estimated water surface profiles for an average inflow of 250 cfs at the Crocker-Huffman gauge. On average, the overall model-estimated water surface elevation is about 0.4 feet lower than the average measured water surface elevation. Detailed HEC-RAS model calibration results are included in Appendix C.

For model verification, a peak flow of 3,200 cfs from the February 2000 flood event was applied to the model. Resulting model water surface elevations from cross-section 6 through cross-section 13 were compared to measured water surface elevations associated with the 2000 flood event at those locations (URS 2001). Figure 5 shows a comparison of measured high water surface elevations with the model-estimated water surface profile for the February 2000 flood event. On average, the overall model-estimated water surface elevation is about 0.4 feet higher than the average measured water surface elevation. Based on USACE (2003) recommendations this comparison confirms that the channel roughness values of the DTR HEC-RAS model are sufficiently calibrated. Detailed HEC-RAS model verification results are included in Appendix C.

As discussed previously, model calibration and verification was based on limited data. As additional data is collected during the implementation of the Dredger Tailings Reach restoration and baseline monitoring program, calibration and verification analyses may be updated and the results improved.

8 HYDRAULIC MODEL FOR EXISTING CONDITIONS

For existing conditions, a reach-scale HEC-RAS hydraulic model was developed for the DTR using the topographic and cross-section data and hydraulic roughness parameters described in Sections 5 through 7.

This model was used to estimate hydraulic conveyance parameters, including water surface elevations, flow depths, flow velocities, and shear stresses for the 1.5-year (1,400 cfs), 5-year (4,530 cfs), 10-year (6,640 cfs) and 100-year (14,900 cfs) storm events. These flow estimates were used to establish the baseline hydraulic characteristics along the reach for existing conditions.

Tables 8-1 through 8-4 summarize the modeled water surface elevations, flow depths, flow velocities, top widths, and shear stresses for the 1.5-, 5-, 10-, and the 100-year peak flows, respectively. For these flow conditions, the estimated water surface profiles are plotted on Figure 6, together with the channel thalweg and left and right bank profiles. This figure shows a general trend of bank overflow conditions for the peak flows analyzed. Detailed HEC-RAS model simulation results are included in Appendix C.

Table 8-1. Estimated Hydraulic Flow Parameters for 1.5-year Discharge (Q=1,400 cfs).

Surveyed Cross-Section No.	Water Surface Elevation (ft)	Channel Flow Depth (ft)	Channel Flow Velocity (ft/sec)	Top Width (ft)	Channel Shear Stress (lb/ft^2)
2	291.1	4.4	2.5	219	0.57
3	288.5	5.6	2.6	200	0.46
4	287.5	6.0	1.9	212	0.34
5	284.5	5.6	2.6	222	0.63
6	280.9	8.5	1.1	220	0.12
7	280.6	6.7	1.4	208	0.19
9	279.6	5.6	3.3	158	1.00
10	279.0	7.2	1.4	294	0.20
11	278.2	5.7	1.9	305	0.35
12	277.8	12.8	1.0	175	0.09
13	277.6	5.2	2.6	166	0.73
14	275.9	9.4	2.2	92	0.38
15	275.1	7.6	3.1	150	0.80
16	273.2	7.9	2.7	219	0.58
17	268.8	8.0	4.0	140	1.35
18	266.0	5.5	2.6	229	0.70
19	263.3	6.0	1.5	203	0.22
20	261.3	5.2	3.6	228	1.25
21	257.6	16.3	0.9	215	0.06
22	256.8	4.1	2.4	455	0.66
23	253.1	6.3	3.0	227	0.68
24	251.2	10.2	2.0	125	0.28
25	248.9	6.2	3.2	224	0.96
26	245.8	4.3	2.9	184	0.78
27	243.9	13.7	1.0	159	0.08
29	243.0	4.7	2.9	303	0.74
30	241.4	6.2	2.6	246	0.60
31	239.8	7.0	2.2	182	0.41
32	238.2	6.0	2.6	158	0.63
33	236.6	6.0	1.7	264	0.29
34	236.1	8.0	1.8	211	0.28
35	235.8	7.8	1.5	207	0.20
35.1	235.7	6.8	1.5	301	0.21
37	235.2	6.2	4.0	414	1.22
38	229.0	7.3	2.4	276	0.53
39	227.5	7.8	2.9	140	0.58
40	225.6	9.3	1.6	149	0.21
41	224.1	6.0	2.0	400	0.39
42	222.4	3.4	2.9	336	1.04
43	220.3	8.2	2.0	226	0.32

Note: See Appendix C for more detailed HEC-RAS model simulation results for the 1.5-year discharge of 1400 cfs.

Table 8-2. Estimated Hydraulic Flow Parameters for 5-year Discharge (Q=4,530 cfs).

Surveyed Cross-Section No.	Water Surface Elevation (ft)	Channel Flow Depth (ft)	Channel Flow Velocity (ft/sec)	Top Width (ft)	Channel Shear Stress (lb/ft^2)
2	294.0	7.2	3.7	245	1.02
3	291.6	8.7	3.5	263	0.76
4	290.6	9.1	3.0	262	0.72
5	287.6	8.7	3.5	284	0.88
6	285.0	12.6	2.1	303	0.34
7	284.5	10.6	2.5	244	0.50
9	283.4	9.4	3.5	552	0.89
10	283.1	11.4	2.2	547	0.38
11	282.3	9.9	2.7	518	0.56
12	281.9	17.0	2.1	198	0.34
13	281.6	9.2	3.4	329	1.02
14	279.8	13.2	4.4	203	1.34
15	278.8	11.3	4.0	334	1.07
16	276.8	11.6	3.9	369	1.03
17	272.0	11.2	5.2	340	1.91
18	269.8	9.2	3.7	464	1.05
19	267.5	10.2	2.5	247	0.48
20	264.9	8.8	5.6	653	2.41
21	260.9	19.6	1.9	298	0.27
22	258.9	6.2	2.8	547	0.75
23	256.7	9.8	3.1	500	0.63
24	255.1	14.1	3.4	297	0.73
25	251.5	8.7	4.3	308	1.36
26	249.2	7.8	4.0	232	1.16
27	247.9	17.7	2.2	281	0.36
29	245.7	7.4	3.8	496	1.01
30	244.7	9.4	3.5	414	0.83
31	243.4	10.5	3.5	310	0.86
32	241.4	9.3	4.0	459	1.19
33	239.9	9.3	2.6	526	0.53
34	239.2	11.1	3.1	223	0.80
35	238.4	10.4	3.2	355	0.83
35.1	238.1	9.2	3.4	485	0.95
37	237.0	8.1	4.8	505	1.64
38	232.4	10.8	2.9	290	0.68
39	231.2	11.6	3.8	316	0.90
40	229.2	12.9	3.1	195	0.72
41	226.4	8.4	3.0	513	0.79
42	225.0	6.0	2.7	702	0.72
43	224.1	11.9	2.9	650	0.54

Note: See Appendix C for more detailed HEC-RAS model simulation results for the 5-year discharge of 4530 cfs.

Table 8-3. Estimated Hydraulic Flow Parameters for 10-year Discharge (Q=6,640 cfs).

Surveyed Cross-Section No.	Water Surface Elevation (ft)	Channel Flow Depth (ft)	Channel Flow Velocity (ft/sec)	Top Width (ft)	Channel Shear Stress (lb/ft^2)
2	295.3	8.5	4.4	259	1.27
3	293.0	10.1	4.0	304	0.90
4	292.0	10.5	3.6	327	0.95
5	289.1	10.2	3.9	349	0.97
6	286.8	14.3	2.5	359	0.48
7	286.1	12.2	3.0	280	0.69
9	285.1	11.1	3.5	591	0.83
10	284.9	13.1	2.4	620	0.44
11	284.1	11.6	3.1	560	0.69
12	283.6	18.7	2.7	315	0.51
13	283.3	10.9	3.7	382	1.07
14	281.3	14.7	5.5	239	2.00
15	280.3	12.8	4.4	363	1.24
16	278.2	13.0	4.6	430	1.31
17	273.3	12.4	5.9	360	2.32
18	270.9	10.4	4.4	573	1.42
19	267.9	10.7	3.4	253	0.91
20	265.5	9.4	3.6	711	0.99
21	262.5	21.1	2.4	334	0.41
22	260.0	7.3	3.0	591	0.80
23	258.1	11.3	3.1	643	0.59
24	256.6	15.7	4.0	545	0.99
25	252.9	10.1	4.7	413	1.46
26	251.0	9.6	4.4	274	1.33
27	249.8	19.6	2.8	322	0.55
29	247.0	8.7	4.3	677	1.17
30	246.1	10.9	3.8	454	0.89
31	244.8	12.0	4.1	504	1.14
32	242.7	10.5	4.7	595	1.52
33	241.2	10.5	3.0	679	0.66
34	240.2	12.2	4.0	362	1.21
35	239.0	11.1	4.2	442	1.41
35.1	238.8	9.9	3.5	512	1.00
37	238.3	9.3	3.6	678	0.86
38	234.0	12.3	3.3	296	0.82
39	232.8	13.2	4.2	361	1.04
40	230.4	14.1	3.9	273	1.13
41	227.3	9.2	3.1	540	0.80
42	225.9	6.8	2.9	759	0.80
43	225.0	12.9	3.1	763	0.60

Note: See Appendix C for more detailed HEC-RAS model simulation results for the 10-year discharge of 6,640 cfs.

Table 8-4. Estimated Hydraulic Flow Parameters for 100-year Discharge (Q=14,900 cfs).

Surveyed Cross-Section No.	Water Surface Elevation (ft)	Channel Flow Depth (ft)	Channel Flow Velocity (ft/sec)	Top Width (ft)	Channel Shear Stress (lb/ft^2)
2	298.8	12.1	5.4	824	1.72
3	296.9	14.0	5.2	456	1.30
4	295.9	14.4	4.8	450	1.52
5	293.5	14.7	4.5	900	1.14
6	291.5	19.0	3.9	491	1.00
7	290.5	16.6	4.4	552	1.35
9	289.4	15.5	4.1	878	0.99
10	289.4	17.6	2.6	1,085	0.45
11	288.6	16.2	4.4	696	1.21
12	288.0	23.0	4.2	523	1.14
13	287.6	15.2	4.5	571	1.42
14	285.3	18.7	7.9	573	3.71
15	284.0	16.5	5.8	521	1.96
16	281.0	15.8	7.2	586	2.87
17	276.0	15.2	6.3	453	2.41
18	274.1	13.6	4.0	786	1.09
19	271.2	13.9	5.5	433	2.08
20	268.4	12.3	4.1	820	1.13
21	266.4	25.1	4.0	515	0.99
22	263.2	10.5	3.5	1,046	0.95
23	261.6	14.7	3.7	721	0.75
24	260.0	19.1	5.4	648	1.68
25	256.9	14.2	4.6	851	1.19
26	255.4	14.0	5.9	437	1.99
27	254.1	23.9	4.1	638	1.10
29	250.3	12.0	5.6	923	1.77
30	249.5	14.2	5.1	641	1.44
31	248.3	15.5	4.7	794	1.32
32	245.9	13.7	6.7	700	2.83
33	244.2	13.6	3.7	746	0.92
34	243.0	14.9	5.6	722	2.24
35	241.6	13.7	5.1	981	1.96
35.1	241.2	12.3	5.0	617	1.88
37	240.6	11.7	4.7	764	1.27
38	238.1	16.4	4.4	612	1.31
39	236.9	17.3	5.0	576	1.30
40	234.2	17.8	5.9	302	2.25
41	230.0	11.9	4.1	580	1.30
42	228.8	9.8	3.2	1,032	0.84
43	228.1	16.0	3.7	789	0.78

Note: See Appendix C for more detailed HEC-RAS model simulation results for the 100-year discharge of 14,900 cfs.

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10 FIGURES

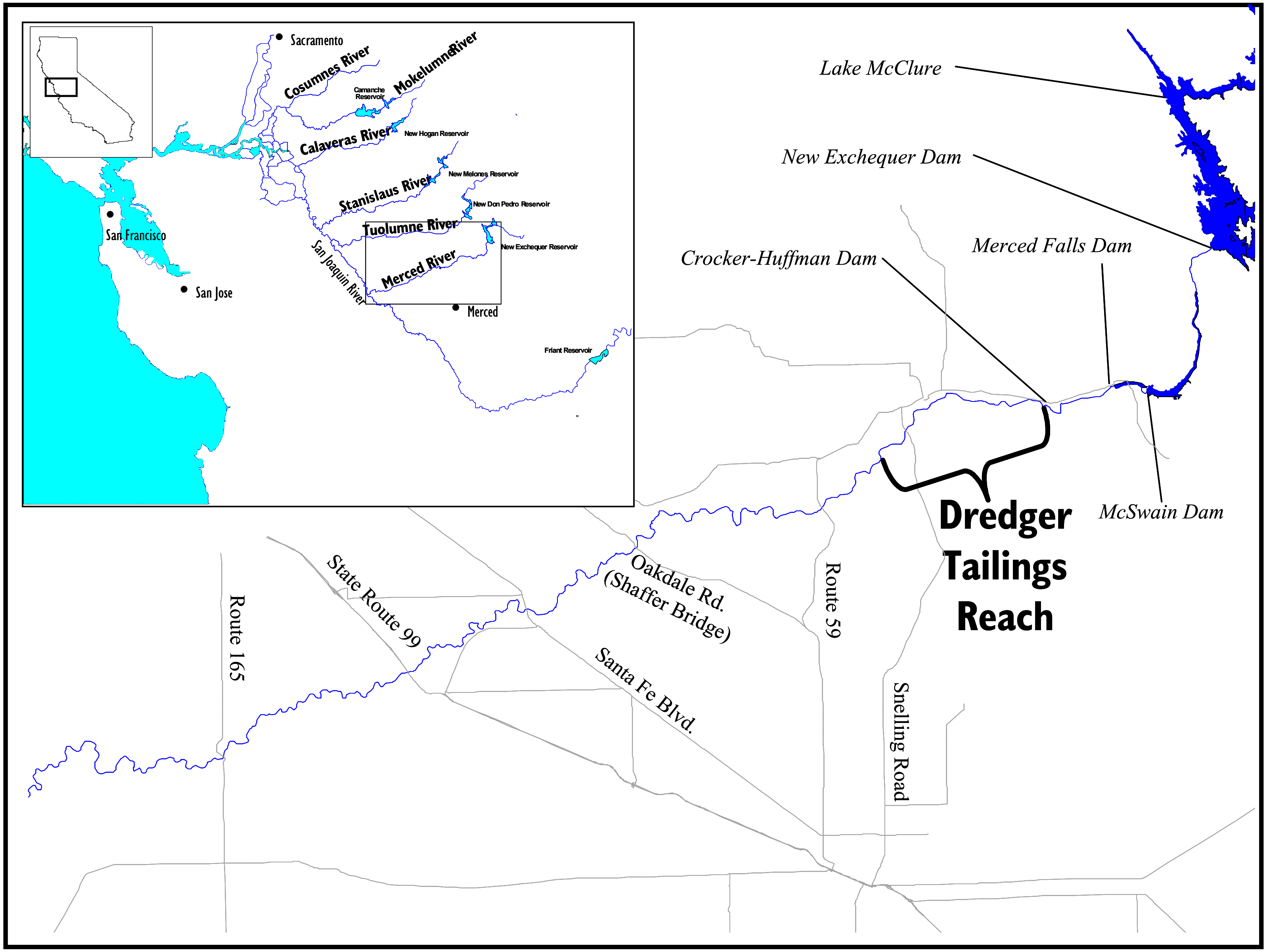

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FIGURE 1
Vicinity of the Merced River and the Dredger Tailings Reach.

FIGURE 2
Thalweg profile and cross-sections within the Dredger Tailings Reach (Stillwater Sciences 2004).

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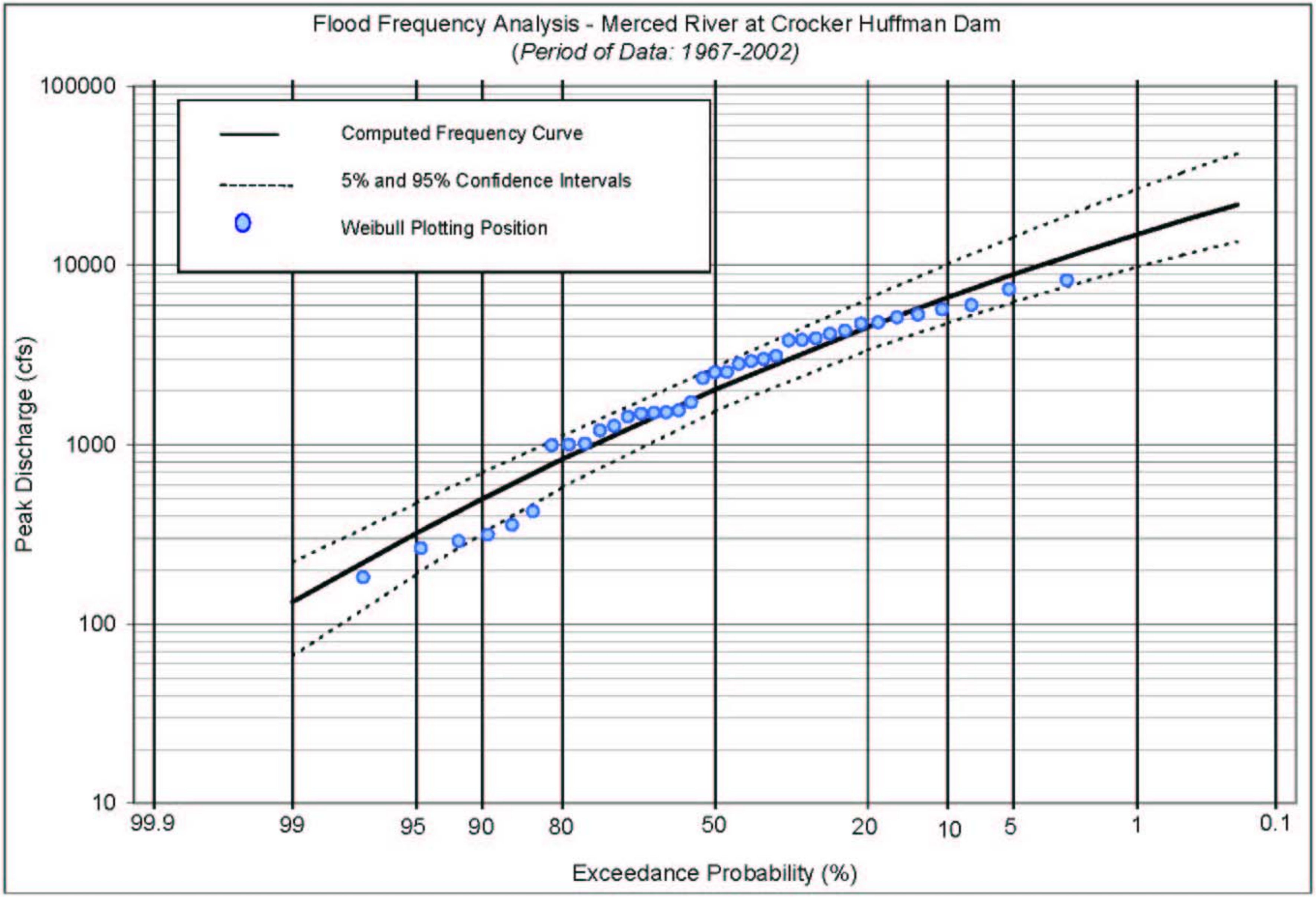

FIGURE 3
Flow exceedance frequency curve for Merced River at Cocker-Huffman Dam.

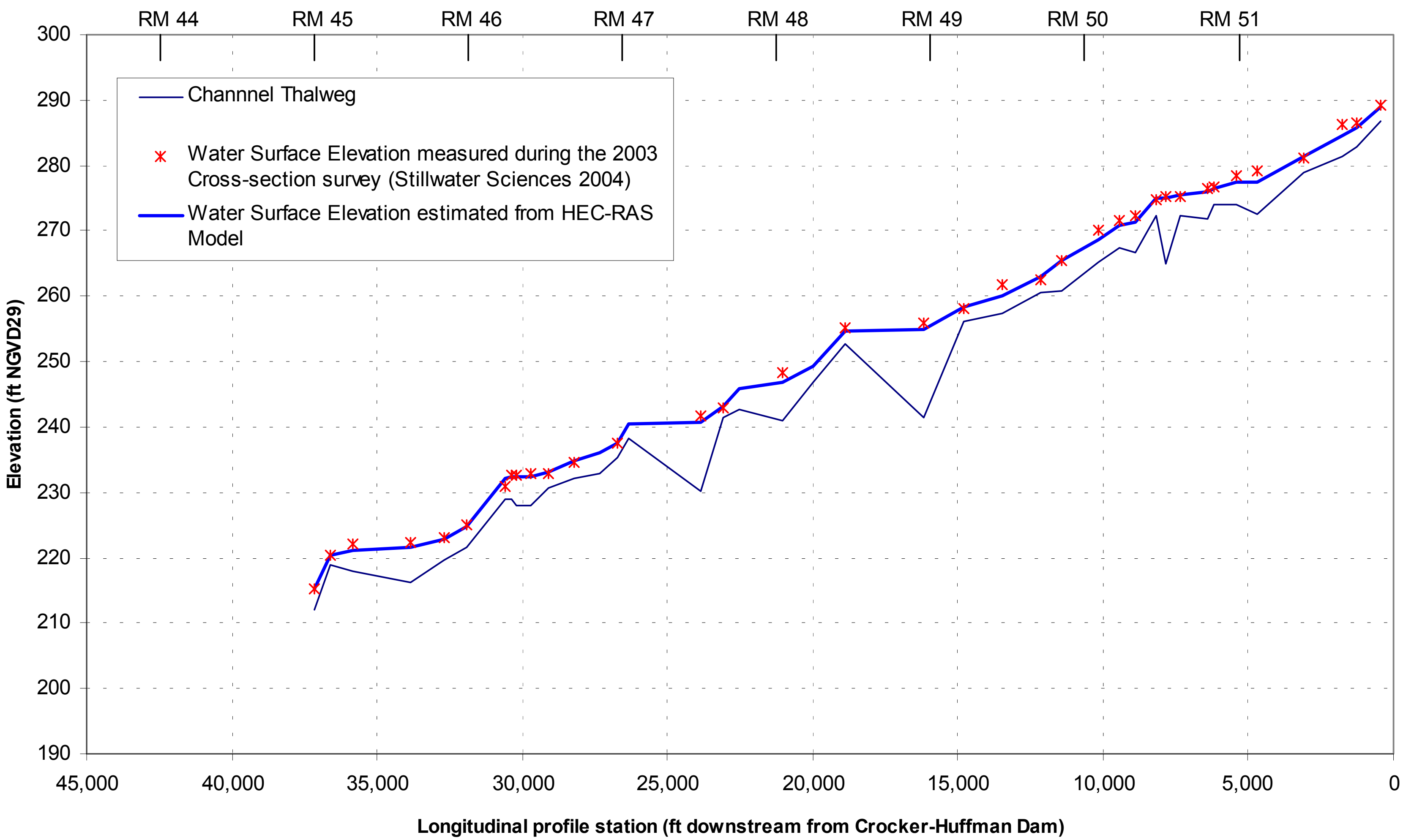

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FIGURE 4
Calibration of the HEC-RAS Model for the Dredger Tailings Reach using water surface elevations measured during the cross-section survey by Stillwater Sciences.

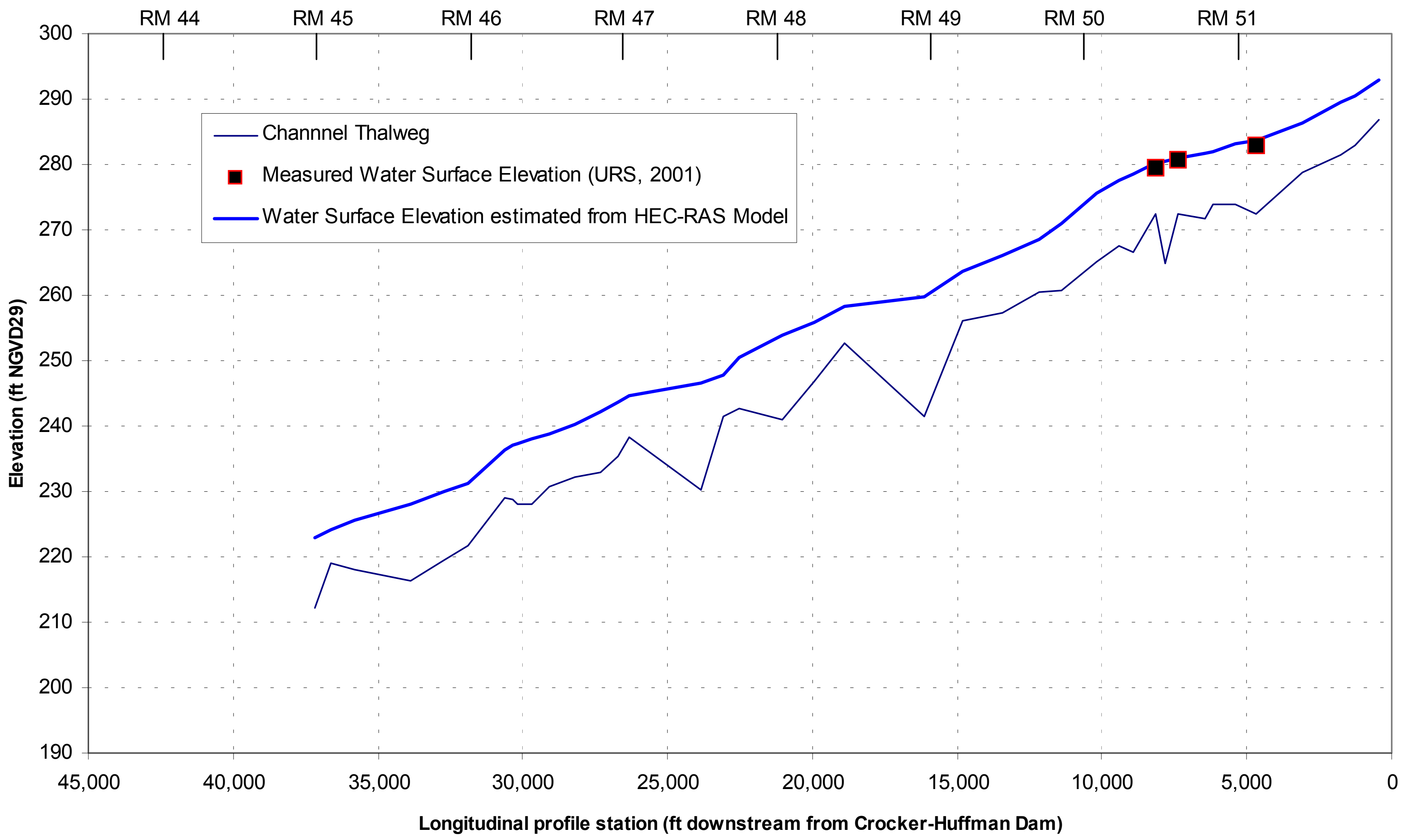

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FIGURE 5
Verification of the calibrated HEC-RAS Model using water surface elevations measured during the February 2000 flood event (Q=3,200 cfs) by URS.

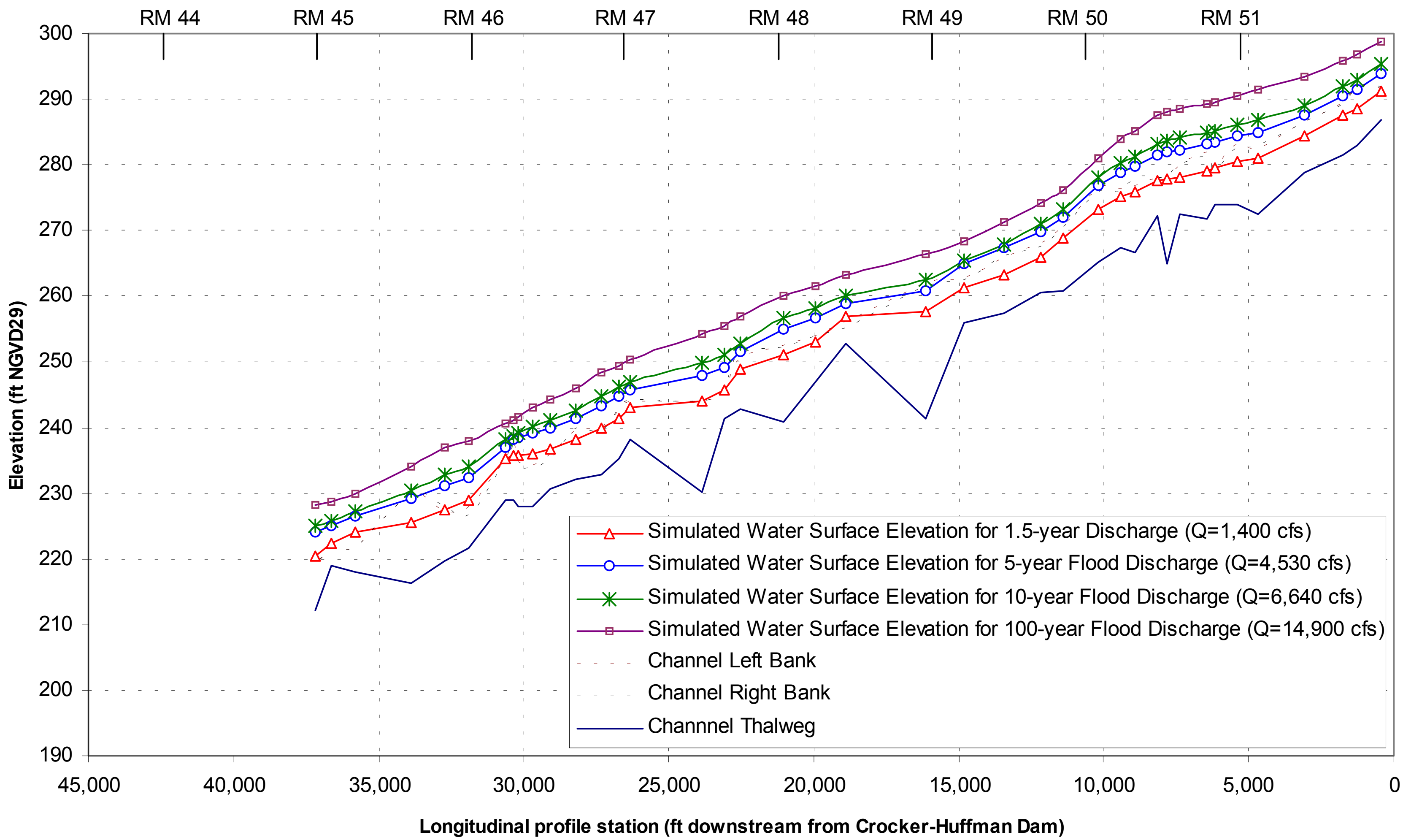

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FIGURE 6
Water surface elevations for selected flood discharges using the calibrated HEC-RAS Model.

Appendix A
FIELD RECONNAISSANCE PHOTOGRAPHS

Appendix B
Mean Daily Flows at the Merced River at Crocker-Huffman Dam Gauge, 1967-2003

Appendix C
DETAILED HEC-RAS MODEL RESULTS FOR CALIBRATION, VERIFICATION, AND SPECIFIC DISCHARGES

Appendix D
MODELED WATER SURFACE ELEVATIONS BY CROSS-SECTION