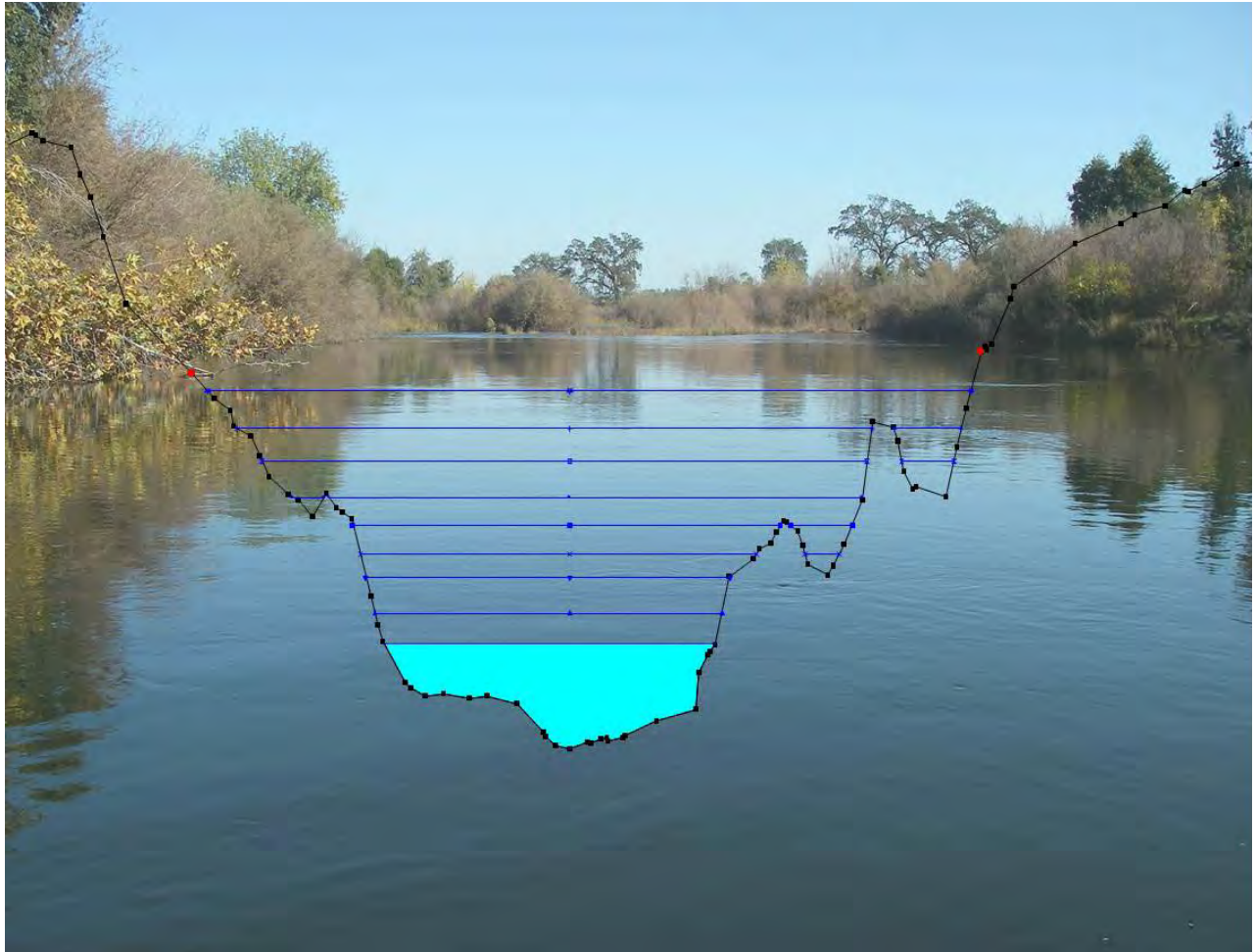


DRAFT

San Joaquin River and Bypass System 1-D Steady State HEC-RAS Model Documentation

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TABLE OF CONTENTS

1.	INTRODUCTION.....	1
2.	MODEL DEVELOPMENT	2
2.1.	Model Approaches	2
2.2.	Model Structure	2
2.3.	Topographic Data and Model Geometry	3
2.3.1.	Station Line.....	3
2.3.2.	Topography and Bathymetry	4
2.3.3.	Structures	6
2.3.4.	Modeling of Multiple Flow Paths and Ineffective Flow Areas.....	8
2.3.5.	Modeling of Roughness Zones.....	12
2.3.6.	Reach Naming Convention.....	18
3.	BOUNDARY CONDITIONS	19
3.1.	Reach 1A.....	19
3.2.	Reach 1B.....	21
3.3.	Reach 2A.....	21
3.4.	Reach 2B.....	21
3.5.	Reach 3	22
3.6.	Reach 4A.....	22
3.7.	Reach 4B1.....	22
3.8.	Reach 4B2.....	23
3.9.	Reach 5	23
3.10.	Chowchilla and Upper Eastside Bypass.....	23
3.11.	Middle Eastside Bypass	24
3.12.	Lower Eastside Bypass	24
3.13.	Mariposa Bypass.....	24
4.	MODEL CALIBRATION	26
4.1.	Refined Model Calibration	26
4.1.1.	Reach 1A Refined Model Calibration.....	26
4.1.2.	Reach 1B Refined Model Calibration.....	28
4.1.3.	Reach 2A Refined Model Calibration.....	29
4.1.4.	Reach 2B Refined Model Calibration.....	29
4.1.5.	Reach 3 Refined Model Calibration	30
4.1.6.	Reach 4A Refined Model Calibration.....	30
4.1.7.	Reach 4B1 Refined Model Calibration.....	31
4.1.8.	Middle Eastside Bypass Refined Model Calibration	31
4.2.	Simplified Model Calibration	32
4.2.1.	Reach 1A Simplified Model Calibration	32
4.2.2.	Reach 1B Simplified Model Calibration	32
4.2.3.	Reach 2A Simplified Model Calibration	33
4.2.4.	Reach 2B Simplified Model Calibration	33
4.2.5.	Reach 3 Simplified Model Calibration.....	33
4.2.6.	Reach 4A Simplified Model Calibration	34
4.2.7.	Reach 4B2 Simplified Model Calibration	34
4.2.8.	Reach 5 Simplified Model Calibration.....	34
4.2.9.	Chowchilla and Upper Eastside Bypass Model Calibration	35

4.2.10. Middle Eastside Bypass Simplified Model Calibration	35
4.2.11. Lower Eastside Bypass Simplified Model Calibration	36
4.2.12. Mariposa Bypass Simplified Model Calibration.....	36
5. SUBSIDENCE CONSIDERATIONS	37
5.1. San Joaquin River	37
5.2. Bypass System.....	37
6. SUMMARY and RECOMMENDATIONS.....	39
6.1. Summary	39
6.2. Recommendations for Future Refinements.....	39
7. REFERENCES.....	41

LIST OF FIGURES

Figure 1.1. Map of modeled reach of the San Joaquin River.	43
Figure 2.1. Aerial photography of a portion of the project reach in the vicinity of RM 203.5, showing the un-shaded roughness polygons and hydraulic model cross sections.	44
Figure 2.2. Aerial photography of a portion of the project reach in the vicinity of RM 203.5, showing shaded roughness polygons to indicate the different roughness zones.	45
Figure 2.3. Example of reach naming convention at Rank Island.	46
Figure 3.1. Schematic diagram of the San Joaquin River from Friant Dam to the confluence with the Merced River showing major tributaries, significant irrigation canals, and the Chowchilla/Eastside Bypass flood-control system.	47
Figure 3.2. Reach 1A geographic extents and major features.	48
Figure 3.3. Estimated flow loss curves for the San Joaquin River between Friant Dam and Gravelly Ford and between Gravelly Ford and the Bifurcation Structure.	49
Figure 3.4. Reach 1B geographic extents and major features.	50
Figure 3.5. Reach 2A geographic extents and major features.	51
Figure 3.6. Downstream boundary condition rating curve for Reach 2A at the Chowchilla Bypass Bifurcation Structure.	52
Figure 3.7. Reach 2B geographic extents and major features.	53
Figure 3.8. Downstream boundary condition rating curve for Reach 2B at Mendota Dam....	54
Figure 3.9. Reach 3 geographic extents and major features.....	55
Figure 3.10. Reach 4A geographic extents and major features.	56
Figure 3.11. Reach 4B2 geographic extents and major features.	57
Figure 3.12. Reach 4B2 geographic extents and major features.	58
Figure 3.13. Reach 5 geographic extents and major features.....	59

Figure 3.14.	Chowchilla and Upper Eastside Bypass geographic extents and major features.	60
Figure 3.15.	Middle Eastside Bypass geographic extents and major features.	61
Figure 3.16.	Lower Eastside Bypass geographic extents and major features.	62
Figure 3.17.	Lower Eastside Bypass geographic extents and major features.	63
Figure 4.1.	Computed (refined model) and measured water-surface profiles in Reach 1A at 350, 700, 1,100, and 1,360 cfs.	64
Figure 4.2.	Differences between computed (refined model) and measured water-surface profiles in Reach 1A at 350, 700, 1,100, and 1,360 cfs.	65
Figure 4.3.	Comparison of computed water-surface elevations with the rating curve at the San Joaquin River below Friant Gage (USGS Gage No. 11251000) near Sta 7768+80.	66
Figure 4.4.	Computed (refined model) and surveyed water-surface elevations in Reach 1B for calibration flow events between 566 and 6,950 cfs.	67
Figure 4.5.	Differences between computed (refined model) and measured water-surface profiles in Reach 1B at flows between 566 and 6,950 cfs. Positive values indicate computed values are above measured.	68
Figure 4.6.	Comparison of computed water-surface elevations with the rating curve at San Joaquin River at Donny Bridge (CDEC-DNB) at RM 240.8.	69
Figure 4.7.	Computed (refined model) and surveyed water-surface elevations in Reach 2A for calibration flow events between 500 and 7,290 cfs.	70
Figure 4.8.	Differences between computed (refined model) and measured water-surface profiles in Reach 2A at flows between about 500 and 7,300 cfs. Positive values indicate computed values are above measured.	71
Figure 4.9.	Comparison of computed and surveyed water-surface elevations with the rating curve at San Joaquin River at Gravelly Ford (CDEC-GRF) at RM 227.5.	72
Figure 4.10.	Computed (refined model) and surveyed water-surface elevations in Reach 2B for calibration flow events of 160 and 1,098 cfs.	73
Figure 4.11.	Differences between computed (refined model) and measured water-surface profiles in Reach 2B at flows of 160 and 1,070 cfs. Positive values indicate computed values are above measured.	74
Figure 4.12.	Comparison of computed and surveyed water-surface elevations with the rating curve at San Joaquin River below Chowchilla Canal Intake (CDEC-SJB) at RM 216.1.	75
Figure 4.13.	Computed (refined model) and measured water-surface profiles in Reach 3 for a range of flows between 700 and 3,600 cfs.	76
Figure 4.14.	Differences between computed (refined model) and measured water-surface profiles in Reach 3 at flows between 700 and 3,600 cfs. Positive values indicate predicted values are above measured.	77
Figure 4.15.	Computed (refined model) and surveyed water-surface elevations in Reach 4A for calibration flow events between 730 and 3,300 cfs.	78

Figure 4.16.	Differences between computed (refined model) and measured water-surface profiles in Reach 4A at flows between 730 and 3,300 cfs. Positive values indicate computed values are above measured.	79
Figure 4.17.	Comparison of computed water-surface elevations with the rating curve at San Joaquin River near Dos Palos (CDEC-SDP) at Sta 3335+20.	80
Figure 4.18.	Computed (refined model) water-surface profiles in Reach 4B1 based on original and updated conditions over a range of flows from 50 to 400 cfs.	81
Figure 4.19.	Computed (refined model) and surveyed water-surface elevations in the Middle Eastside Bypass for calibration flow events between 730 and 2,359 cfs (April 2010 data upstream of El Nido not shown).	82
Figure 4.20.	Differences between computed (refined model) and measured water-surface profiles in the Middle Eastside Bypass at flows between 730 and 2,359 cfs. Positive values indicate computed values are above measured.	83
Figure 4.21.	Computed (simplified model) and surveyed water-surface elevations in Reach 1A for calibration flow events between 350 and 1,360 cfs.	84
Figure 4.22.	Differences between computed (simplified model) and measured water-surface elevations in Reach 1A at flows between 350 and 1,360 cfs. Positive values indicate computed values are above measured.	85
Figure 4.23.	Computed (simplified model) and surveyed water-surface elevations in Reach 1B for calibration flow events between 570 and 6,950 cfs.	86
Figure 4.24.	Differences between computed (simplified model) and measured water-surface elevations in Reach 1B at flows between 570 and 6,950 cfs. Positive values indicate computed values are above measured.	87
Figure 4.25.	Computed (simplified model) and surveyed water-surface elevations in Reach 2A for calibration flow events between 500 and 7,290 cfs.	88
Figure 4.26.	Differences between computed (simplified model) and measured water-surface elevations in Reach 2A at flows between 500 and 7,290 cfs. Positive values indicate computed values are above measured.	89
Figure 4.27.	Computed (simplified model) and surveyed water-surface elevations in Reach 2B for calibration flow events between 160 and 1,070 cfs.	90
Figure 4.28.	Differences between computed (simplified model) and measured water-surface elevations in Reach 2B at flows between 160 and 1,070 cfs. Positive values indicate computed values are above measured.	91
Figure 4.29.	Computed (simplified model) and surveyed water-surface elevations in Reach 3 for calibration flow events between 670 and 3,600 cfs.	92
Figure 4.30.	Differences between computed (simplified model) and measured water-surface elevations in Reach 3 at flows between 670 and 3,600 cfs. Positive values indicate computed values are above measured.	93
Figure 4.31.	Computed (simplified model) and surveyed water-surface elevations in Reach 4A for calibration flow events between 730 and 3,300 cfs.	94

Figure 4.32.	Differences between computed (simplified model) and measured water-surface elevations in Reach 4A at flows between 730 and 3,300 cfs. Positive values indicate computed values are above measured.	95
Figure 4.33.	Computed (simplified model) and surveyed water-surface elevations in Reach 4B2 for estimated calibration flow events between 200 and 4,100 cfs. Exact surveyed discharges are unknown	96
Figure 4.34.	Differences between computed (simplified model) and measured water-surface elevations in Reach 4B2 at 4,100 cfs. Positive values indicate computed values are above measured	97
Figure 4.35.	Computed (simplified model) and surveyed water-surface elevations in Reach 5 for estimated calibration flow events between 2,990 and 11,300 cfs....	98
Figure 4.36.	Differences between computed (simplified model) and measured water-surface elevations in Reach 5 at estimated calibration flow events between 2,990 and 11,300 cfs. Positive values indicate computed values are above measured	99
Figure 4.37a.	Computed (simplified model) and surveyed water-surface elevations along the Chowchilla and Upper Eastside Bypasses for estimated calibration flow events between 5,800 and 7,470 cfs.....	100
Figure 4.37b.	Computed (simplified model) and surveyed water-surface elevations along the Chowchilla and Upper Eastside Bypasses for estimated calibration flow events between 3,820 and 4,120 cfs.....	101
Figure 4.38.	Differences between computed (simplified model) and measured water-surface elevations along the Chowchilla and Upper Eastside Bypass estimated calibration flow events between 6,000 to 7,000 cfs. Positive values indicate computed values are above measured.....	102
Figure 4.39.	Computed (simplified model) and surveyed water-surface elevations in MESB for calibration flow events between 730 and 2,359 cfs.....	103
Figure 4.40.	Differences between computed (simplified model) and measured water-surface elevations in MESB at flows between 730 and 2,359 cfs. Positive values indicate computed values are above measured.....	104
Figure 4.41.	Computed (simplified model) and surveyed water-surface elevations in the Lower Eastside Bypass for a calibration flow of 1,893 cfs.....	105
Figure 4.42.	Computed water-surface elevations in the Mariposa Bypass for flows between 100 and 4,500 cfs.	106
Figure 4.43.	Computed water-surface elevations in the Mariposa Bypass for flows between 100 and 4,500 cfs	107

LIST OF TABLES

Table 2.1.	Correlation between river miles and stationing used in the hydraulic models at features throughout the project reach.....	3
Table 2.2.	Dates of bathymetric surveys conducted in all reaches.	5

Table 2.3.	Summary of bridges and other hydraulic structures included in the hydraulic model along the river.	7
Table 2.4.	Summary of bridges and other hydraulic structures included in the hydraulic model along the bypass system.	9
Table 2.5.	Summary table of split-flow reaches in the steady-state San Joaquin River refined HEC-RAS models.	11
Table 2.6.	Summary of in-channel and overbank roughness categories.	13
Table 2.7.	Summary of base channel <i>n</i> -values used as fundamental basis for in-channel roughness in both refined and simplified models.	15
Table 3.1.	Summary of estimated flow loss distribution between Friant Dam and the Bifurcation Structure.	20
Table 4.1.	Summary of surveyed water-surface elevation data available for model calibration for all reaches between Friant Dam and the Merced River.	27

1. INTRODUCTION

One-dimensional (1-D) steady-state HEC-RAS hydraulic models of the 150-mile reach of the San Joaquin River (SJR) and Bypass System between Friant Dam [River Mile (RM) 267.6] and the mouth of the Merced River (RM 118.2) were developed and validated by Tetra Tech, Inc. (Tetra Tech) and the California Department of Water Resources (CDWR) to support the San Joaquin River Restoration Project (SJRRP) (**Figure 1.1**). These models provide a means of evaluating current 1-D hydraulic conditions along the river and bypass over a range of flows, including those specified in the Settlement Agreement and flood events.

This report provides a description of the methodology and assumptions used in developing the HEC-RAS models, including a description of the basis for which the boundary conditions for each reach was developed. The intent is that these models will provide a framework and tools to evaluate existing hydraulic conditions throughout the system. However, it is important to note that the end user should determine whether the boundary conditions or specific model-types (see below) for each reach are appropriate for their specific analyses and assumptions regarding hydrologic operating rules (e.g., existing or proposed future conditions), and modify them as necessary.

This report was developed by Tetra Tech and the CDWR under the River Engineering Services for the San Joaquin River Restoration Program Contract 4600009910, Task Order 3.

2. MODEL DEVELOPMENT

The following sections describe the data sources, methods, and assumptions used in developing the HEC-RAS models for each reach. In applying the models, users should carefully evaluate each of the assumptions, particularly those associated with stage and flow boundary conditions and flow splits, to ensure that they are appropriate for the case being analyzed.

2.1. Model Approaches

To provide a broader range of tools for the SJRRP, CDWR, Tetra Tech, and the Bureau of Reclamation (Reclamation) determined that two versions of the 1-D HEC-RAS models would be developed for many of the river reaches and bypasses, where appropriate. The two versions are as follows:

1. A refined version of the model that includes flow splits, horizontally varied overbank n -values, and vertically varied main-channel Manning's n -values based on a compositing algorithm developed by Tetra Tech (see Section 2.3.5), which allows for a more accurate means of accounting for changes in in-channel roughness such as those associated with changes to in-channel vegetation, and for improved model calibration over a range of flows that involves varying degrees of vegetation.
2. A simplified version of the models that would remove all flow splits, and only include a single, representative n -value for the main channel over the full range of discharges for defined subreaches within each reach. The horizontally varied overbank n -values from the refined model would be maintained.

The degree of calibration of the refined models is generally better over a full range of flows than the simplified models, because inclusion of the flow splits maintains consistent flows in each branch and allows for different water-surface elevations in the main channel and side channels. In addition, the hydraulic roughness is affected by the flow depth and the roughness of the wetted portion of the channel that is controlled by the boundary materials and vegetation. Without the complexity of the flow balances at the flow splits and the vertical variation in channel n -values, the simplified versions of the models are typically easier to set up and faster to run. The user should select the model version that best suits their particular application based on a balance between the required level of accuracy and level of effort to meet their particular needs. For example, it may be appropriate to use the refined models in situations where increased accuracy of water-surface elevations or channel hydraulics over a broad range of flows is important, such as for detailed levee height requirements or sediment-transport calculations. In contrast, the simplified version of the models may be more appropriate for gaming exercises or any other application where only general, comparative information is required. If a refined version of a model does not exist for a particular reach, the simplified should obviously be used for all necessary applications. Although the simplified versions of the models that are currently available are based on n -values that calibrate more closely to discharges near bankfull conditions, the simplified models could also be re-calibrated to a different target discharge (e.g., high flows only).

2.2. Model Structure

The mainstem San Joaquin River model is divided into nine reaches and the bypass system is divided into three reaches (Chowchilla and Upper Eastside Bypass reaches are combined) (Figure 1.1). This is to allow the user to evaluate hydraulic conditions within a single reach

without having to establish boundary conditions and flow distributions throughout the entire 150 miles of river and bypass system. As described in Section 3, boundary conditions for each reach are established based on known conditions at a downstream control structure or computed water-surface elevations from the next downstream reach for an assumed flow condition.

2.3. Topographic Data and Model Geometry

2.3.1. Station Line

A mathematically splined station line representing the center of the main flow path through the entire project reach was developed to facilitate development of the hydraulic model(s), with the origin (i.e., Sta 0+00) located at the confluence of the San Joaquin River and the Merced River. The station line representing the center of the main flow path through the entire SJRRP project reach is based on 2007 aerial photography. The stationing correlated to the SJRRP control line stationing described in SJRRP (2008) and river mile locations shown on the Reclamation (1993) San Joaquin River Atlas are summarized in **Table 2.1**. It is important to note that the SJRRP control line cannot be used for the model because it is oriented with increasing stations in the downstream direction, while the model requires the opposite convention. In addition, the SJRRP control line was developed from an older model station line that does not accurately reflect distances along the channel at all locations due to the changes that have occurred since 1998/1999.

A station line was also developed for the entire bypass system between the Chowchilla Bifurcation Structure and the confluence with the San Joaquin River at the head of Reach 5. All stationing along the bypass is based on the origin (i.e., Sta 0+00) located at the Lower Eastside Bypass confluence with the San Joaquin River at the head of Reach 5.

Table 2.1. Correlation between river miles and stationing used in the hydraulic models at features throughout the project reach.			
Control Line	Station (ft)	River Mile (RM)	Feature
7879+73	0	118.2	Hills Ferry Road
7878+20	200	118.3	Merced River Confluence
7815+20	6,650	119.5	Newman Wasteway
7714+60	17,180	121.2	Mud Slough
7497+20	39,484	125.1	Highway 140 (Fremont Ford Bridge)
7303+20	59,450	128.8	Salt Slough
7232+40	67,200	130.2	Levee to Nowhere
7088+80	80,795	132.7	Highway 165 (Lander Ave)
6942+80	95,500	135.7	Bear Creek
6328+20	154,150	147.2	Mariposa Bypass
6008+40	186,138	153.5	Road Crossing / Culvert (smashed)
5816+40	205,405	157.1	Turner Island Road
5725+60	215,100	159.2	Pick Anderson Bypass
5667+80	220,230	160.1	Eastside Canal
5617+60	225,400	160.1	Middle Ditch
5520+40	234,977	163	Culverts

Table 2.1. Correlation between river miles and stationing used in the hydraulic models at features throughout the project reach.			
Control Line	Station (ft)	River Mile (RM)	Feature
5235+80	263,467	168.1	Washington Road (SJR)
5214+80	265,567	168.4	Culverts near Eastside Bypass
4922+20	294,893	173.9	Highway 152 (Santa Rita Bridge)
4497+20	337,370	182	Sack Dam
4495+40	337,560	182.1	Arroyo Canal
4032+60	383,840	191	Buttonwillow Drain
3809+40	406,106	195.2	7 1/2 Ave (Firebaugh) (main and side channel)
3702+20	416,910	197.3	Firebaugh Wasteway
3312+60	455,739	204.6	Mendota Dam
3296+20	456,600	204.8	Delta-Mendota Canal
2941+20	492,900	211.7	Dip crossing-San Mateo Avenue
2718+20	515,130	216.1	Mainstem Gates at Chowchilla Bypass
2715+80	515,250	216.1	Chowchilla Bypass
2295+90	559,334	224.9	End LB levee
2149+60	570,345	226.9	End RB levee
2041+20	580,452	229	Gravelly Ford
1751+20	610,228	234.1	Hwy 145 / Madera Avenue (Skaggs Bridge)
1394+40	645,965	240.9	Donny Bridge
1269+60	658,639	243.2	Highway 99
1268+40	658,768	243.2	Southern Pacific Railroad
1163+60	669,313	245.1	Atchison, Topeka and Santa Fe Railroad
1043+40	681,325	247.3	Conc. rubble grade-control
772+40	708,437	252.9	Gravel-mine remnant access road
743+20	710,680	253.4	Failed gravel-mine access bridge
647+80	720,900	255.2	Highway 41 (Lanes Bridge)
489+20	736,620	258.2	Return flow from Rank Island split
474+80	738,105	258.5	Gravel mine access road (remnants)
379+40	747,470	260.4	DWR rock grade control at Rank Island
282+20	757,290	262.1	Ledger Island Bridge
43+40	781,177	266.8	North Fork Road Bridge
20	785,457	267.6	Friant Dam

2.3.2. Topography and Bathymetry

Topographic data were derived from different sources and methods throughout the project reach. In Reach 1A, the overbank topography is based on 2007 photogrammetric mapping, and the in-channel bathymetry is based on surveys conducted by DWR between October 2007 and April 2008 (Towill, Inc., 2009). The composite mapping was developed in a triangulated irregular network (tin) format using MicroStation® and InRoads Site®.

During calibration of the Reach 1A model, it was determined that the bathymetric survey data collected and incorporated into the mapping did not capture the in-channel topography at some of the hydraulic controls in the reach. As a result, cross-sectional geometry was adjusted within HEC-RAS based on supplemental survey data collected at the upper and lower drop structures at Lost Lake, a riffle just downstream from Lost Lake (Sta 7696+00), and the riffle near the upper end of Ledger Island (Sta 7634+00). In addition, fixed sediment elevations were added at 13 cross sections near Sta 7810+68 (three cross sections), Sta 7766+91, Sta 7716+60, Sta 7634+99, Sta 7532+62 (two cross sections), Sta 7490+82, Sta 7467+00 (Cross Section 612 at Rank Island Weir on split-flow reach 260.2), Sta 7343+22, Sta 6770+19, and Sta 6724+54 to represent the hydraulic control and improve calibration in areas where survey data were not available to fully describe the in-channel topography.

In most of the other reaches (Reaches 1B, 2A, 2B, 3, 4A, 4B2, 5, Middle Eastside Bypass [MESB], and the Lower Eastside Bypass [LESB]), the overbank topography is based on 2008 LiDAR mapping that was recently developed for CDWR in the North American Vertical Datum of 1988 (NAVD88), and in-channel topography is based on bathymetric data that were recently collected by the CDWR and Reclamation (**Table 2.2**). Composite mapping containing both the 2008 overbank LiDAR data and available bathymetric survey data was developed by Reclamation in NAVD88. To develop the mapping, Reclamation applied a splining technique to, in essence, create a raster of the entire channel bed based on the available survey data.

Table 2.2. Dates of bathymetric surveys conducted in all reaches.	
Reach	Date of Bathymetric Survey
1A	October 2007-April 2008 (CDWR)
1B	March-April 2010 (CDWR)
2A	March-April 2010 (CDWR)
2B	March, August, September, 2009 (CDWR) April 2010 (Reclamation)
3	March, August, September, 2009 (CDWR) April 2010 (Reclamation)
4A	April 2010, January 2011, April 2011 (Reclamation)
4B1	1998/1999 Topography (Ayres), 2002 (MEI)
4B2	April 2010, January 2011, April 2011 (Reclamation)
5	January 2011, April 2011 (Reclamation)
Chowchilla	None (channel dry during LiDAR survey)
UESB	None (channel dry during LiDAR survey)
MESB	April 2010, January 2011 (Reclamation)
LESB	January 2011 (Reclamation)
MB	None (channel dry during LiDAR survey)

The Chowchilla (CB), Upper Eastside (UESB), and Mariposa Bypasses (MB) were almost entirely dry during collection of the 2008 LiDAR data. Therefore, LiDAR data were used for both the overbank and in-channel topography in these reaches. In Reach 4B1, LiDAR data were not suitable for any of the channel topography due to ponded water and thick vegetation, and due to access limitations, recent bathymetric surveys of the reach have not been conducted. As a result, the composite mapping surface for this reach was based on 1998/1999 (Ayres) bathymetric data and supplementary survey data collected by MEI (2002a). Cross sections in this reach were developed from the composite mapping surface to reflect the improved

transitions between in-channel and overbank topography to ensure that available conveyance areas are reflected appropriately in the model.

It has been documented that varying degrees of subsidence have occurred in the bypass and portions of the river since the 2008 LiDAR data and some of the bathymetric surveys were collected. The area with greatest subsidence tends to occur within the Chowchilla and Upper Eastside Bypasses. To calibrate the models in these reaches, the elevations were adjusted to reflect recent changes caused by subsidence, as summarized in Section 5.2. Lesser degrees of subsidence may also affect other portions of the bypass and river that have not been adjusted in the models. It is important for the user to be aware that this condition exists, and that in many cases, the bathymetry in each reach was collected at a later date than the 2008 LiDAR, which suggests that if elevations have changed due to subsidence, that the overall magnitude of the change may be slightly greater for the LiDAR data simply because it was collected at an earlier date.

2.3.3. Structures

2.3.3.1 San Joaquin River

Geometric data for bridges and other hydraulic structures within the project reach were obtained from a variety of sources including the California Department of Transportation (CALTRANS), CDWR, the Merced County Road Department, the Atchison Topeka Santa Fe Railroad, a hydraulic model of the lower portion of the reach developed by Ayres Associates, Inc. [Jones & Stokes (JSA)/Ayres/MEI, 2000], a UNET model of the mainstem and bypass system developed for the Sacramento/San Joaquin River Comprehensive Study (USACE, 2002), and field surveys (**Table 2.3**).

The major hydraulic structures incorporated into the model include the Chowchilla Bypass Bifurcation Structure (CBBS), the San Joaquin River Control Structure (SJ RCS), and Sack Dam. Due to the complexity associated with operating rules of Mendota Pool, Mendota Dam is represented in the model using two different techniques. To provide an appropriate downstream boundary condition for Reach 2B that accounts for changes in stop board conditions for different flow scenarios, Mendota Dam is included in the model only as a rating curve. The basis for the rating curve at this location is described in more detail in Section 3.4. However, Mendota Dam is also represented in the upper end of the Reach 3 model as a series of cross sections (some containing lids to represent top of structure and gate openings) that define the various components of the structure so that users can also have access to that information if necessary. The CBBS consists of two independent multi-gated structures that control the distribution of flow into the Chowchilla Bypass and the downstream river leading to Mendota Dam (Reach 2B). Each structure is modeled with a series of cross sections (some containing lids to represent top of structure) that represent the complex structure geometry, including gate bays, baffles, and end sills. In the HEC-RAS model, it is assumed that all of the gates are fully open. The SJ RCS is also a gated structure that regulates flow into the downstream portion of the river, and is modeled similar to the Bifurcation Structure using only cross-sectional data under the assumption that the gates remain open. Sack Dam is a check structure near the downstream end of Reach 3 that consists of a weir and series of stop boards. This structure is modeled in HEC-RAS as an inline weir structure.

Table 2.3. Summary of bridges and other hydraulic structures included in the hydraulic model along the river.			
Reach	Structure	Station	Source of Data
Reach 5	Hills Ferry Road (J18)	0	USACE ¹
Reach 5	Highway 140 (Fremont Ford Bridge)	39,484	Main Channel: USACE ¹ Side Channel: Ayres Assoc. Inc. ²
Reach 5	Highway 165 (Lander Ave)	80,795	USACE ¹ and 2008 LiDAR data
Reach 4B1	Road Crossing / Culvert (smashed)	186,138	Field Survey (MEI, 2002a)
Reach 4B1	Turner Island Road	205,405	Merced County Public Works Design Plans
Reach 4B1	Road Crossing / Culvert (2.5-foot)	234,977	Field Survey (MEI, 2002a)
Reach 4B1	Washington Road (SJR)	263,467	Merced County Road Dept.
Reach 4B1	Reach 4B1 Headgate	265,475	DWR As-built plans
Reach 4B1	Culverts	265,567	Field Survey (MEI, 2002a)
Reach 4A	Highway 152 (Santa Rita Bridge)	294,893	USACE ¹
Reach 3	Sack Dam	337,370	San Luis Canal Co. Design Plans
Reach 3	7 ½ Ave (Firebaugh) (main and side channel)	406,106	City of Firebaugh Design Plans
Reach 2B	Mendota Dam	455,739	DWR As-built plans and Field survey data
Reach 2B	San Mateo Avenue Culverts	492,900	DWR Field Survey
Reach 2A	Bifurcation Structure	515,130	DWR As-built plans and Field survey data
Reach 1B	Hwy 145 / Madera Avenue (Skaggs Bridge)	610,228	CALTRANS
Reach 1B	Donny Bridge	645,965	Field Survey
Reach 1A	Highway 99	658,639	CALTRANS
Reach 1A	Southern Pacific Railroad	658,768	Southern Pacific Railroad ³
Reach 1A	Atchison, Topeka and Santa Fe Railroad	669,313	AT&SF Railroad
Reach 1A	New Highway 41 Bridge	720,720	CALTRANS
Reach 1A	Highway 41 (Lanes Bridge)	720,900	CALTRANS
Reach 1A	Ledger Island Bridge	757,290	SJR Conservancy ³
Reach 1A	North Fork Road Bridge	781,177	CALTRANS

¹ From input file for UNET model developed by USACE for the Sacramento / San Joaquin River Comprehensive Study (USACE, 2002).

² From input file for UNET model developed for the West Bear Creek Unit of the San Luis National Wildlife Refuge (J&S/Ayres/MEI, 2000).

³ Bridge plans currently unavailable.

2.3.3.2 Bypass System

A series of major structures also exist within the Bypass system (**Table 2.4**). As mentioned above, the CBBS is a gated control structure with a concrete sill, apron and baffle blocks at the head of the Chowchilla Bypass and Reach 2B that control flood flows into the Bypass System. The structure on the Bypass side is practically identical to the one that directs flow into Reach 2B, and is also modeled with multiple cross sections. The Upper Eastside Bypass begins at the confluence of the Chowchilla Bypass and the Fresno River (Figure 1.1). Two drop structures containing both downstream and upstream sills as well as baffle blocks are located in this reach and are modeled as cross sections. In addition, there are 11 bridges along the Chowchilla and Upper Eastside Bypasses which are modeled using the HEC-RAS bridge routines (Table 2.4), and a pipeline crossing near Sta 162,259.9 that is represented in the model by cross sections.

The Sand Slough Control Structure (SSCS) is an in-line concrete flume/weir structure that regulates flow into the Middle Eastside Bypass and creates backwater for diverting flow into the downstream portion of the river. This structure is modeled using a combination of typical river cross sections at the structure that contain lids to represent the top (deck) of structure the geometry of the gate openings. Similar to the SSCS, the Eastside Bypass Control Structure (EBCS) is located between the Middle and Lower Eastside Bypass reaches, is a relatively complex structure that contains stop log bays, baffles, and end sills, and is modeled using a combination of cross sections containing lids to represent the geometry of the gate openings. In addition, the MESB contains two weirs, which are located near the Merced National Wildlife Refuge. The purposes of these structures are to create backwater for diverting water and are modeled with a series of cross sections and blocked obstructions, but due to the lack of information regarding flows that are diverted from the bypass at these locations, flow change place holders are not included in the model (Table 2.4). The ground elevation was raised in order to simulate closed gates in one of the weirs. There are also a total of four bridges and one road crossing along the MESB that are modeled using the HEC-RAS bridge routines.

The Mariposa Bypass is bounded by two structures. The Mariposa Bypass Control Structure exists at the head of the reach and controls the amount of flow into the reach. It is a complex structure consisting of a combination of sills and gates, and is modeled using a combination of cross sections and in-line structure data. The Mariposa Bypass Drop Structure is located at the lower end of the reach and is modeled using a series of cross sections and in-line structures.

2.3.4. Modeling of Multiple Flow Paths and Ineffective Flow Areas

The following sections describe how multiple flow paths and ineffective flow areas were modeled in the refined and simplified models.

2.3.4.1 Refined Model

A total of 11 significant split-flow reaches are included in the refined versions of the hydraulic models between Friant Dam and the Merced River (**Table 2.5**). Three of the split-flow reaches in Reach 1A require more than two separate flow paths. Numerous other areas of divided flow also occur throughout the project reach, but the following criteria were considered in order to identify the most significant split-flow areas to include:

Table 2.4. Summary of bridges and other hydraulic structures included in the hydraulic model along the bypass system.			
Reach	Structure	Station ¹	Source of Data
LESB	Rock weir	4,919	LiDAR
LESB	Bear Creek Patrol Road	5,300	DWR As-built Plans
LESB	Howard Road/ Harney Access Bridge	20,450	DWR
LESB	Dickinson Ferry Road	41,100	USACE ²
MB	Mariposa Bypass Drop Structure	4,635	As built plans and DWR survey data
MB	Mariposa Bypass Control Structure	22,267	As built plans and DWR survey data
MESB	Eastside Bypass Control Structure	55,485	As built plans and DWR survey data
MESB	Hayfield Access Bridge	63,000	DWR As-built plans
MESB	Dan McNamara Road Crossing	65,454	DWR fish passage survey data
MESB	W. Sandy Mush Road	69,100	DWR design plans
MESB	MNWR Weirs	73,273	DWR fish passage survey data
MESB	Chamberlain Road	87,500	DWR As-built plans
MESB	El Nido Road	101,499	LiDAR data
Sand Slough Connector	Washington Road over entrance to Eastside Bypass	107,172	DWR As-built plans
Sand Slough Connector	Sand Slough Control Structure	107,600	DWR As-built plans and Tt-MEI survey data
Upper Eastside Bypass	West Washington Road	111,910	DWR As-built plans
Upper Eastside Bypass	Highway 152 Westbound	131,299	Caltrans
Upper Eastside Bypass	Highway 152 Eastbound	131,428	Caltrans
Upper Eastside Bypass	Avenue 21	140,219	DWR & Madera Co. & Caltrans
Upper Eastside Bypass	Road 4	151,853	DWR & Madera Co. & Caltrans
Upper Eastside Bypass	Avenue 18 1/2	166,253	DWR & Madera Co. & Caltrans

Table 2.4. Summary of bridges and other hydraulic structures included in the hydraulic model along the bypass system.			
Reach	Structure	Station ¹	Source of Data
Upper Eastside Bypass	Triangle T	173,845	DWR As-built plans
Upper Eastside Bypass	Road 9	188,304	DWR & Madera County
Upper Eastside Bypass	Drop Structures	188,529.8-190,674.6	DWR As-built plans and survey data
Chowchilla Bypass	Avenue 14	203,497	DWR As-built Plans
Chowchilla Bypass	Avenue 12 (Firebaugh Blvd.)	234,395	DWR & Madera County
Chowchilla Bypass	Avenue 7 1/2	242,111	DWR & Madera County
Chowchilla Bypass	Chowchilla Bypass Control Structure	275,161	DWR As-built plans

¹ Distance upstream from the confluence with San Joaquin River at the head of Reach 5.

² From input file for UNET model developed by USACE for the Sacramento / San Joaquin River Comprehensive Study (USACE, 2002).

Table 2.5. Summary table of split-flow reaches in the steady-state San Joaquin River refined HEC-RAS models.				
General Location	Reach	River Mile (U/S end)	Split Flow Identifier	Comments
Friant to Mendota	1A	266.8 ^{1,2}	Rch1A_S266.8	
	1A	263.3 ^{1,2}	Rch1A_S263.3	Ledger Island
	1A	261.8 ²	Rch1A_S261.8	
	1A	260.4 ^{1,2}	Rch1A_S260.4	Rank Island
	1A	257.2	Rch1A_S257.2	
	1A	255.7 ²	Rch1A_S255.7	U/S of Hwy 41 Bridge
	1A	251.2 ²	Rch1A_S251.2	
	1A	248.3	Rch1A_S248.3	
	1B	243.1 ²	Rch1B_S243.1	
	1B	236.8 ²	Rch1B_S236.8	
Mendota to Merced	3	195.5 ²	Rch3_S195.5	Firebaugh (Ave 7 1/2 Bridge)
¹ Split-flow complex with multiple side channels				
² Split-flow reaches require pilot channel				

1. Length of main-channel and side-channel flow paths,
2. Channel alignments,
3. Discharge at which side channels become activated,
4. Discharge at which high ground between flow paths is overtopped (i.e., evaluate flow at which the separate flow paths are reconnected of significant distances),
5. General significance of split flow (e.g., Ledger Island),
6. Hydraulic impacts of split flow, which was evaluated by comparing hydraulic parameters including computed water-surface elevations, channel velocities, and distribution of flow with and without the split, and
7. Associated impacts to hydraulic structures with and without the split (e.g., Sack Dam), and geomorphic significance of the split flow.

The determination of discharge in each flow split requires the balancing of energy using the HEC-RAS optimization function to obtain a solution. Although all of the secondary channels are not active over the full range of flows, the HEC-RAS software requires that at least some flow occurs in all branches. In some cases, this issue causes the model to predict unrealistically high water-surface elevations at the common cross section at the head of the split at low flows, or it results in non-convergence of the energy balance. Insertion of a pilot channel allows only a very small amount of flow in the side channel at the low discharges in which the issues occur and significantly reduces the problem. Pilot channels with widths ranging between 0.1 and 0.2 feet were incorporated into nine of the eleven flow splits (Table 2.5). To further improve stability, the bed elevation of each pilot channel was typically set to an elevation similar to adjacent bed elevations on the mainstem. Unfortunately, even with the pilot channels, the ability of the model to converge on an optimized solution at these flow splits also appears to be somewhat

erratically dependent on the distribution of the initial discharge estimate provided in the flow input file. As a result, initial flow distributions for each split that help result in an optimized solution of the energy balance were determined over a range of discharges, included in example model flow file, and are discussed in more detail in Section 3.1. Even with pilot channels and initial flow split guesses, a few of the split flow locations are sensitive to specific discharges and may not formally converge on an optimized solution. However, it is very important for the user to note that in almost all cases where a non-convergence warning occurs in the model, closer inspection of the resultant water-surface elevations and discharges at the head of the split flow will indicate that the results are, in fact, reasonable and should not cause any significant impacts to the overall model results.

In areas where minor side channels were not modeled separately, ineffective flow areas were used to prevent conveyance within the side channels at extremely low flows.

In addition, ineffective flow areas and blocked obstructions were added to the model outside of split flow areas in order to prevent inappropriate wetting or to reduce conveyance in areas that may become inundated but where conveyance is not likely to occur, such as within many of the gravel pits that exist in Reach 1A. These model refinements were used to reflect existing conditions and improve model calibration. Features such as the levee tool were also implemented as necessary in combination with the other tools (e.g., ineffective flow areas and blocked obstructions) to model each cross section as accurately as possible. It is important to note that while these features are sometimes applied at or near actual Project Levees, they are implemented to model each cross section accurately, and the user should not assume that they represent the location of all of the Project Levees throughout the system.

2.3.4.2 Simplified Model

All side channels that were modeled as a separate flow path in the refined models are removed in the simplified versions of the models by essentially combining both the main- and side-channel cross sections into singular cross sections spanning the entire width of the active channel (i.e., both branches). One exception is at Rank Island in Reach 1A where although the main channel and the small side channel adjacent to the weir were merged, the additional side channel on the far north side that runs along the Coombs/Arnold Channel was eliminated from the model and replaced with a discharge change location at the upstream and downstream end of this channel to allow the user to account for flow being diverted into this ditch. The second exception also occurs in Reach 1A at Ledger Island where the small side channel that runs along the far west side, and only contains flow when river discharges exceed about 2,000 cfs, was eliminated from the model and replaced with a discharge change location at the up- and downstream end of this channel to allow the user to account for flow possibly entering this side channel.

All side channel branches and corresponding junctions were removed in the simplified models for all reaches. Ineffective flow areas from the refined versions of the models were replicated in the same locations within the singular cross sections as appropriate. All ineffective flow areas, blocked obstructions, fixed sediment elevations, levees and bank stations remain in the same locations as the refined models.

2.3.5. Modeling of Roughness Zones

The spatial variation in roughness across the channel and floodplain was accounted for using the horizontal variation in n -values function with the ultimate goal of providing a means to

assess the hydraulic effects of future changes in the vegetation patterns. To accomplish this, zones within which the hydraulic roughness characteristics are expected to be approximately homogenous were originally identified and delineated from 1998 aerial photography and updated where significantly different on the 2007 (Reach 1A) and 2008 (all other reaches) aerial photography based on the physical appearance of the vegetation and the ground surface. Inspection of the later aerial photography (i.e., 2007 and later) indicated that near-channel vegetation had varied to some degree since the development of the original n -value polygons. A total of seven distinct zone types were identified, with n -values ranging from 0.035 for channel bed and open water that is free of vegetation to 0.1 for dense trees and brush (**Table 2.6**). These roughness coefficients were selected based on previous experience, field observations of the study reach, and information contained in a variety of references, including Arcement and Schneider (1989), Barnes (1967), Chow (1959), and Hicks and Mason (1991).

A typical delineated area in the vicinity of RM 203 to RM 204 showing the roughness polygons and cross sections is shown in **Figures 2.1 and 2.2**. (Figure 2.1 shows the polygons without shading so that the underlying aerial photograph can be more easily seen, and Figure 2.2 shows the polygons shaded to present the different roughness types.). Minor adjustments to the extent of the channel and near-channel horizontal n -value variations based on the bathymetry were necessary to improve model calibration.

Table 2.6. Summary of in-channel and overbank roughness categories.		
Category	Roughness Description	Manning's n
1	Channel bed / open water	0.035*
2	Agriculture (pasture, crops, and orchards)	0.045
3	Open / bare ground / scattered brush-weeds	0.045
4	Scattered trees / light brush	0.060
5	Medium density trees / brush	0.080
6	Dense trees / brush	0.100
7	Urban / industrial	0.080

*Manning's n -value of 0.035 was selected as a typical mid-range value to initially assign to the channel bed/ open water roughness category as a placeholder. This value was then adjusted within the hydraulic models to reflect the specific differences found within each reach, which is referred to in this document as the 'base' channel n -value.

As described above, both refined and simplified versions of the hydraulic models were developed for most of the reaches. In general, the refined models were developed by incorporating the horizontal n -value variations, refining the in-channel placeholder value of 0.035 where necessary to reflect local conditions (referred to herein as the base channel n -value), and applying a main-channel n -value compositing routine that is more appropriate for the conditions along this portion of the San Joaquin River than the default routine provided within HEC-RAS. The results of the compositing routine are implemented in the refined models as a vertically varied n -value table. In reaches where refined models exist, the simplified models were then developed based on the weighted channel n -values extracted from the refined models at a representative bankfull discharge.

To develop simplified models in the reaches where refined models were not produced (i.e., Reaches 4B2, 5, CB, UESB, LESB, and MB), an initial version of the model that incorporated the use of only horizontally varied n -values was implemented. Similar to development of the refined models, the in-channel placeholder n -value of 0.035 was then adjusted as necessary to develop a 'base channel n -value' that reflects local conditions and to improve calibration. After

the preliminary calibration was complete, the resultant weighted channel n -values at an approximately bankfull discharge were extracted from the summary output tables of that model, and the longitudinal variations in these values were evaluated and subreaches having similar roughness values were identified. The simplified longitudinal variations were then incorporated into the final model. Methods used to develop both the refined and simplified models are discussed in more detail in the following sections. The remainder of this section describes the selection of the base channel n -value for calibration purposes, which represents the basis for roughness for both model types.

In addition to geomorphic and substrate conditions, selection of the base Manning's n -value for the channel was partially developed based on information provided during the calibration process. Initial calibration results indicated that, due to the relatively coarse bed material that is present in Reach 1A, base main-channel Manning's n -values should be increased from 0.035 to as high as 0.06 in many locations, especially at significant riffles (**Table 2.7**). Significant energy losses associated with the numerous complex flow paths, channel-gravel pit interactions, and some geomorphic features, such as woody debris, bedrock exposures and overhanging vegetation, not fully captured in surveys also require the use of higher Manning's n -values in this reach. Manning's n -values of 0.08 and 0.10 were also required to better represent the energy losses that occur over two very significant and complex riffle/drop structures in Reach 1A near Sta 7696+56 and Sta 7716+60 (e.g., downstream rock weir structure at Lost Lake).

Reach 1B extends from Highway 99 (RM 243.2) down to Gravelly Ford (RM 227.5). It contains two split-flow areas and the width of the main channel varies along the length of the reach due to local constrictions, existence of gravel pits, and the presence of a few islands. A base main-channel roughness n -value of 0.035 was essentially used for the entire reach for the refined models (Table 2.7).

Reach 2A extends from Gravelly Ford (RM 227.5) to the Chowchilla Bypass Bifurcation Structure (CBBS) at RM 216. It does not contain any split flows and the main channel is generally uniform, with limited islands or abrupt changes in width. A base main-channel roughness n -value of 0.032 was used for the majority of the reach, which reflects a finer bed-material size (Table 2.7).

Reach 2B extends from the Bifurcation Structure (RM 216) down to Mendota Dam (RM 205). Base channel roughness for the majority of the reach was based on a Manning's n -value of 0.022, but the roughness was increased to 0.045 along a 3,000-foot section of the reach just downstream from San Mateo near RM 211.8 (Sta 4899+00 to Sta 4928+88) to represent the significant amount of in-channel vegetation that exists (Table 2.7).

Reach 3 extends from the Mendota Dam (RM 205) down to Sack Dam (RM 182). It contains a single split-flow area and the main channel is generally uniform, with few islands or dramatic changes in width. Final base channel roughness n -values varied between 0.026 at the lower end to 0.032 at the upper end to achieve calibration.

Reach 4A extends from Sack Dam (RM 182) down to the Sand Slough Control Structure (SSCS; RM 168.4). It does not contain any split flows and the main channel is generally uniform, with few islands or dramatic changes in width. Main-channel roughness was based on Manning's n -values ranging from 0.035 to 0.045 (Table 2.7).

Table 2.7. Summary of base channel <i>n</i> -values used as fundamental basis for in-channel roughness in both refined and simplified models.									
Reach 1A	<i>n</i> -Value	0.035	0.04	0.045	0.05	0.055	0.06	0.08 ¹	0.1 ²
	% of Reach	3%	61%	14%	7%	2%	12%	2%	1%
Reach 1B	<i>n</i> -Value	0.035	0.045						
	% of Reach	99%	1%						
Reach 2A	<i>n</i> -Value	0.032	0.035	0.045					
	% of Reach	87%	10%	3%					
Reach 2B	<i>n</i> -Value	0.022	0.035	0.045	0.015 ³				
	% of Reach	82%	1%	8%	10%				
Reach 3	<i>n</i> -Value	0.026	0.028	0.032	0.035 ⁴				
	% of Reach	34%	9%	55%	1%				
Reach 4A	<i>n</i> -Value	0.035	0.04	0.045					
	% of Reach	96%	2%	2%					
Reach 4B1	<i>n</i> -Value	0.035	0.04	0.045	0.055	0.06	0.065	0.07	
	% of Reach	61%	6%	5%	7%	0.4%	1%	20%	
Reach 4B2 ⁴	<i>n</i> -Value	0.04							
	% of Reach	100%							
Reach 5 ⁴	<i>n</i> -Value	0.035							
	% of Reach	100%							
Chowchilla/ UESB	<i>n</i> -Value	0.03	0.015 ³						
	% of Reach	90%	10%						
MESB	<i>n</i> -Value	0.025	0.03	0.035	0.04	0.044	0.045	0.05	0.015 ³
	% of Reach	14%	14%	41%	9%	6%	1%	2%	14%
LESB ⁵	<i>n</i> -Value	0.027	0.033	0.035	0.04				
	% of Reach	20%	17%	48%	15%				
Mariposa ⁵	<i>n</i> -Value	0.035							
	% of Reach	100%							

¹Complex Riffle/Drop Structure

²Rock Weir

³Concrete Structure

⁴Located on downstream side of Sack Dam in Reach 4A, but included in downstream end of Reach 3 model as boundary condition

⁵Only simplified model developed in this reach

Reach 4B1 extends from the near the Sand Slough Control Structure (SSCS; RM 168.4) downstream to the Mariposa Bypass (RM 147.2). Base channel roughness n -values in this reach range from 0.035 in open sand-bed reaches to 0.07 in areas severely choked by vegetation and debris.

The Reach 4B2 model extends from the confluence of Reach 4B1 and the Mariposa Bypass Channel downstream to the confluence with the Lower Eastside Bypass (Bear Creek). The main channel is generally uniform with no islands and few significant changes in width. This reach was modeled only as a simplified model and does not have a vertically varied channel n -value. Aerial photography indicates that vegetation commonly encroaches into the main channel. The base channel roughness n -value used as input in this entire reach was 0.04 (Table 2.7) and the resultant simplified n -values, which are generated from the resultant weighted channel n -value output, range from 0.047 in the upstream end to 0.06 at the downstream end.

The Reach 5 model extends approximately 18 miles from the confluence of the Eastside Bypass/Bear Creek and Reach 4B2 down to about 700 feet below the confluence with the Merced River. A levee exists along the right side of the river from the upstream extent down to approximately one mile above the confluence with the Merced River. Levees exist along the left side only in the upper and lower ends, leaving approximately 8 miles in the middle of the reach essentially unconfined on the left. This reach has a network of multiple flow paths that have been simplified into a single flow path along the mainstem that also extends laterally to include the side channels. Since this reach was only modeled in the simplified format, there are no vertically varied channel n -values. The base channel n -values used as input remained at 0.035 (Table 2.7), and the resulting simplified channel n -values range from 0.036 at the downstream end to 0.042 in the middle of the reach.

The Chowchilla Bypass and Upper Eastside Bypass models were combined into one, which extends from the CBBS to the SSCS, spanning approximately 32 miles. It does not contain any split flows and is bound by levees on both sides. The main channel is generally uniform, with limited changes in width. The major inflows include the Fresno River, Berenda Slough and Ash Slough. Based on aerial photography, the channel and overbank roughness along the bypass appear to be similar, with minimal variation. The in-channel and overbank n -values were 0.03 and 0.04, respectively, and are consistent throughout the reach (Table 2.7).

The Middle Eastside Bypass model extends from the lower end of Reach 4A near the Sand Slough Control Structure downstream to the Eastside Bypass Control Structure. The upstream end is defined by the confluence between the Sand Slough Connector Channel and the Upper Eastside Bypass. It does not contain any split flows and the main channel is generally uniform, with limited changes in width. Base channel roughness in the MESB ranges between 0.025 and 0.05 (Table 2.7). Based on aerial photography, portions of the channel in this reach showed signs of sedimentation and encroachment of in-channel vegetation (e.g., Sta 654+96 through Sta 670+59, Sta 718+98 through Sta 732+22 and Sta 986+81). The higher channel n -values were used to account for the additional energy losses in these areas.

The Lower Eastside Bypass model extends from the downstream side of the Eastside Bypass Control Structure to the confluence with Bear Creek, and then to the main channel of the San Joaquin River. This reach was modeled only in the simplified format and does not have vertically varied channel n -values. The base channel n -values used as input ranged from 0.027 to 0.04 (Table 2.7), and the resultant simplified channel n -values in the final model range between 0.028 and 0.04.

The Mariposa Bypass connects the lower end of the Middle Eastside Bypass with the upstream end of Reach 4B2. This reach was modeled only in the simplified format and does not have vertically varied channel n -values. The 2008 aerial photography and calibrated river and bypass reaches with similar characteristics were used for reference, and the resultant in-channel roughness was assigned a Manning's n -value of 0.035.

Details regarding the different techniques employed for the development of the in-channel roughness values for the refined and simplified versions of the models are described in the following sections.

2.3.5.1 Refined Model

Previous studies to evaluate the potential impacts of new vegetation in the main channel associated with the riparian habitat pilot flow releases, and ultimately, restoration of the riparian corridor, demonstrated that the standard methods available in HEC-2 and HEC-RAS to compute the composite in-channel roughness when multiple roughness zones are present within the main channel can produce unrealistic results under certain conditions (MEI/JSA, 2000; MEI, 2002b and 2008). As a result, a method was developed to provide more reasonable estimates of the composite roughness over the range of possible vegetation conditions that were being analyzed by considering the change in the relative effect of the vegetation with increasing depth (Tt-MEI, 2009). In the refined models, all main-channel n -values are based on composite roughness values for each cross section.

A Visual Basic program was developed to implement the compositing routine. The program uses the following basic steps to create a new geometry file with the composite main channel n -values substituted for the horizontally variable n -values in the base file:

1. Read base HEC-RAS geometry input file that reflects the horizontal variation in n -values based on the intersection of each cross section with the digitized roughness polygons.
2. Compute the initial composite main channel n -values associated with the horizontally variable n -values for the range of possible depths at each cross section by applying the compositing algorithm.
3. Compute the additional increment of roughness to be added to the initial composite values based on the sinuosity in each segment of the reach and the index hydraulic depth at which the sinuosity begins to affect the n -values.
4. Create a new HEC-RAS geometry file that with vertically variable main channel n -values at each cross section substituted for the horizontally variable values in the base geometry file.

2.3.5.2 Simplified Model

Simplified versions of the models that not only remove all flow splits, but also include only a single, representative n -value for the main channel for defined subreaches within each reach were developed. In the simplified versions of the models, however, the horizontally varied overbank n -values from the refined model are maintained.

To simplify the models, use of the vertical varied n -value tables were eliminated and a single channel Manning's n -value was selected based on an approximate bankfull flow for each reach.

The representative bankfull discharge was executed in the refined model and the resultant weighted channel n -values were extracted from the summary output tables. The longitudinal variations were evaluated in these values along the length of the reach, and subreaches having similar roughness values and geomorphic characteristics were identified. Average channel n -values were then assigned to each of these subreaches. Details regarding the representative n -values determined for each reach and the resulting effects on model calibration are described in Section 4.2.

2.3.6. Reach Naming Convention

Due to the large number of reaches, it can be difficult to quickly relate the reach designation to the specific location along the river. As a result, a naming convention was developed to improve the efficiency and user-friendliness of the model. The primary criterion for the naming convention was to provide information that is descriptive of the approximate location of the reach while using as few characters as possible. Along the mainstem, the model reaches were assigned names that include the primary SJRRP study reaches in which they occur along with the approximate River Mile (RM) at the *upstream* end of the reach. For example, the mainstem model reach segment at Rank Island is located within Reach 1A, and the upstream end of that segment is near RM 260.4. The name assigned to this model reach is, therefore, “Rch1A_RM260.4” (**Figure 2.3**). To associate a split-flow channel with its mainstem counterpart, a similar naming convention was used, except that the ‘RM’ notation along the mainstem was substituted with an ‘S’ to represent a split flow. For example, the name assigned to the split-flow channel at Rank Island is “Rch1A_S260.4” (Figure 2.3). Table 2.5 in Section 2.3.4.1 summarizes the naming convention of the remaining 11 split flows.

Additionally, the naming convention for the stream junctions was also modified to be consistent with the naming convention for the model reaches. The stream junction at the upstream end of the flow split that occurs at Rank Island near RM 260.4, for example, was renamed “Jct S260.4US”, where the characters ‘US’ represent the term ‘upstream’, and the junction at the downstream end of the split was renamed to “Jct S260.4DS” (Figure 2.3). A few of the other junctions are located at confluences or divergences such as at the Bifurcation Structure or the confluence with the Mariposa Bypass. At those locations, a more descriptive name was selected such as “Jct SJR-Mariposa” to better represent the junction.

Each cross section was also given a unique identifier. The reach name was given as the first portion of the identifier as well as an individual cross section number starting at the downstream end and increasing in number in the upstream direction. For example the most downstream cross section in Reach 1A is called “Rch1A_XS1”.

3. BOUNDARY CONDITIONS

The San Joaquin River and Bypass system consists of a complex system of irrigation canals and flood-control facilities that affect flows and boundary conditions throughout the project reach (**Figure 3.1**). As such, the model along the river is divided into nine separate reaches (**Figure 1.1**), which are characterized by significant geomorphic and hydrologic differences, as well as varying hydraulic controls and structures. Similarly, the bypass system model is divided into three reaches (Chowchilla and Upper Eastside Bypass reaches are combined). Boundary conditions for each reach are established based on known conditions at downstream control structures or computed water-surface elevations from the next downstream reach for assumed flow conditions, as described in the following sections.

3.1. Reach 1A

Reach 1A extends 24 miles downstream from Friant Dam to Highway 99 (**Figure 3.2**). Flows entering Reach 1A are controlled by releases from Friant Dam, as recorded at the San Joaquin River below Friant Dam gage (USGS Gage No. 11251000). Additional minor contributions in flow also come from Cottonwood Creek and Little Dry Creek, which occur approximately 1,200 feet and 37,000 feet downstream from Friant Dam, respectively. Cottonwood Creek actually enters the river just upstream of the upper end of the model.

Due to observed effects of channel percolation losses and diversions, the discharge regime varies significantly along the reach between Friant Dam and the Chowchilla Bypass Bifurcation Structure (CBBS). Various studies have been conducted to develop estimated flow-loss relations for the reach, which are typically related to Friant Dam release flows (Madeheim, 1999; MEI, 2002a). To help account for changes in flow associated with seepage loss, discharge change locations have been included as place holders in the example flow files that accompany the model, which occur at XS784246, XS720918, and XS658388. Although the decision of how and when to apply these loss relationships should ultimately be determined by the user depending on the constraints of their particular study, these estimates are likely to be independent of many of the operational rules that need to be applied to the model. Therefore, a summary of the seepage loss information is included as follows:

The loss curve that is currently still applied for the portion of the reach between Gravelly Ford and the Bifurcation Structure was developed by Mr. Huxley Madeheim, PE, for Reclamation based on the recorded 30-day flow volumes during Water Year (WY) 1995, WY1996 and WY1997 (Madeheim, 1999). A similar loss curve for the reach between Friant Dam and Gravelly Ford was developed by Mussetter Engineering, Inc. (MEI) using the recorded 30-day flow volumes during the 11-year period between 1988 and 1998 (MEI, 2002a) (**Figure 3.3**). It is important to note that most of the losses in the reach downstream from Gravelly Ford are likely due to infiltration. Losses in the Friant Dam to Gravelly Ford reach include infiltration losses, evaporation losses from the gravel ponds, and flow loss due to diversions. The estimated loss curve for the reach between Friant Dam and Gravelly Ford indicates that no flow has historically reached Gravelly Ford when the discharge at the “below Friant Dam” gage is less than about 100 cfs, and that about 150 cfs is lost at flows greater than about 200 cfs. Similarly, no flow reaches the Bifurcation Structure when the discharge at Gravelly Ford is less than about 75 cfs, and the amount of flow loss tapers to less than 5 percent at about 4,000 cfs. The user should be aware that these conditions will likely change in the future as more continuous flows occur in the river as part of the Restoration Program.

The loss curves shown in Figure 3.3 represent the total estimated discharge loss under existing conditions between Friant Dam and Gravelly Ford and between Gravelly Ford and the Bifurcation Structure. However, the user can distribute the total loss among as many locations as necessary. To provide an example for the user, the total flow loss was distributed among five locations along the river (**Table 3.1**). The distribution of the total loss (i.e., percentage of total loss relative to distance downstream from Friant Dam), was prorated based on the distance of each location downstream from Friant Dam or Gravelly Ford relative to the total distance represented by each loss curve (i.e., Friant Dam to Gravelly Ford of 205,005 feet and Gravelly Ford to the Bifurcation Structure of 65,322 feet).

Table 3.1. Summary of estimated flow loss distribution between Friant Dam and the Bifurcation Structure.				
Location	Reach	Station	Percent of Total Computed Loss	Reference Loss Curve (Figure 3.3)
Friant Dam	1A	785,457	0	--
Highway 41	1A	720,806	32	Friant Dam to Gravelly Ford
Highway 99	1B	658,692	62	Friant Dam to Gravelly Ford
Highway 145 (Skaggs Bridge)	1B	610,254	85	Friant Dam to Gravelly Ford
Gravelly Ford	2A	580,452	100	Friant Dam to Gravelly Ford
Upper end of Left Project Levee	2A	559,334	32	Gravelly Ford to Bifurcation Structure
Bifurcation Structure	2B	515,130	100	Gravelly Ford to Bifurcation Structure

Except for the flow contributions from tributaries and flow losses due to seepage discussed above, no other changes to the total discharge in the river are modeled within Reach 1A. However, eight split-flow reaches do exist within Reach 1A, which require place holders and initial guesses of the flow distribution at each split-flow reach. As described in Section 2.3.4.1, the ability of the model to converge on an optimized solution at the flow splits appears to be sensitive to the initial discharge guess provided in the flow input file. As a result, initial flow distributions for each split that result in an optimized solution of the energy balance were determined over a range of discharges. If discharges other than those provided in the example flow file are required, interpolation from the table is recommended.

The downstream boundary condition for Reach 1A is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 1B. No discharge changes are likely to occur at this location along the river, so it is reasonable to assume that any modeled discharge value at the lower end of Reach 1A can be applied directly to the rating curve provided without any change in flow.

3.2. Reach 1B

No in-channel structures exist at the upstream end of Reach 1B, and flows enter the reach directly from upstream in Reach 1A (**Figure 3.4**). Seepage losses in Reach 1A have been shown to affect the quantity of flow that enters Reach 1B. If desired, the user can estimate local discharges entering Reach 1B that account for upstream seepage losses by referencing Figure 3.3 and Table 3.1. The downstream boundary condition for Reach 1B is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 2A. Flow is not added or diverted at the lower end of this reach, so it is reasonable to assume that any modeled discharge value at the lower end of Reach 1B can be applied directly to the rating curve provided without any change in flow.

3.3. Reach 2A

No structures exist at the upstream end of Reach 2A, and flows enter the reach directly from upstream in Reach 1B (**Figure 3.5**). Seepage losses in Reaches 1A and 1B have been shown to affect flows entering Reach 2A. If desired, the user can estimate local discharges entering Reach 2A that account for upstream seepage loss by referencing Figure 3.3 and Table 3.1. No flow is diverted from the reach except at the downstream end where flow can be directed into either Reach 2B of the river or the Chowchilla Bypass via the Chowchilla Bypass Bifurcation Structure (CBBS). Because of the range of conditions associated with potential flow splits and gate settings, the downstream boundary condition for this reach is complex and highly variable. The downstream boundary condition for Reach 2A is currently based on a rating curve that was derived from surveyed water-surface elevations that correspond with elevations observed during a series of field visits between November 2009 and June 2011 (**Figure 3.6**). Actual gate settings during these measurements are unknown, but due to the limited capacity of Reach 2B, some flow was being diverted into the Chowchilla Bypass at the higher discharges. Due to the lack of more detailed information currently available regarding operation of the CBBS, this rating curve provides a reasonable estimate of the stage-discharge relationship under existing conditions. However, the user should determine if the boundary condition is appropriate for their specific analysis and assumptions.

3.4. Reach 2B

Flow enters the head of Reach 2B from Reach 2A via the Chowchilla Bypass Bifurcation Structure. Near the downstream end, immediately upstream of Mendota Dam, additional flows enter at the lower end of this reach (i.e. into Mendota Pool) via the Fresno Slough/King's River/James Bypass (**Figure 3.7**). Mendota Dam is at the downstream end of Reach 2B, and provides the hydraulic control for the reach. Mendota Dam is typically operated with the objective of maintaining a constant pool elevation, which is accomplished by removing stop boards at higher flows as necessary. However, even with all boards removed, the pool elevation begins to rise at discharges greater than about 6,000 cfs. A rating curve was developed that applies the normal pool elevation at flows less than about 6,000 cfs. For flows higher than 6,000 cfs, the rating curve is based on model results derived by running a range of flows through cross sections that represent Mendota Dam with the boards out (included in the Reach 3 model). Based on surveys conducted in October of 2010, the water-surface elevation of Mendota Pool is assumed to be maintained at 154.3 feet NAVD88), where possible. The rating curve used for the downstream boundary condition of this reach is shown in **Figure 3.8**. It is important to note, that the discharges in the rating curve represent flow over Mendota Dam, so the user must pre-determine whether any additional flow is entering the reach from the James Bypass. As

described in Section 2.3.3, the rating curve is used as a boundary condition for Reach 2B because it accounts for the typical operational conditions over a full range of flows.

3.5. Reach 3

Flows in Reach 3 are based primarily on flow releases from Mendota Dam as recorded at the San Joaquin River near Mendota gage (USGS Gage No. 11254000). Based on available flow measurements, the Firebaugh Wasteway contributed flow to the reach near RM 197, but the direct contribution is currently ungagged (**Figure 3.9**). During calibration, inflow from the wasteway was estimated based on discharge measurements up- and downstream from the inlet. Except for potential contributions from the Firebaugh Wasteway, flows in the model are assumed to remain constant throughout the reach until near the downstream end where Sack Dam pools water for diversion into the Arroyo Canal. Discharges up to about 600 cfs are typically diverted into the Arroyo Canal at the downstream end of the reach, but as with the wasteway, the user should determine the appropriate assumptions regarding flow changes within the reach. To help account for changes in flow associated with the Firebaugh Wasteway and Arroyo Canal, discharge change locations have been included as place holders in the example flow files that accompany the model, which occur at XS416981 and XS337652.

Sack Dam is located at the downstream end of the reach, but the Reach 3 model extends downstream just below the dam. The structure is modeled as an in-line weir. The downstream boundary condition for Reach 3, which is actually located just downstream of Sack Dam, is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 4A. In addition, the elevation of the Sack Dam weir/boards/structure was adjusted slightly to achieve the best calibration for the range of calibration flows available.

3.6. Reach 4A

All flow in Reach 3 that is not diverted into Arroyo Canal passes over Sack Dam into Reach 4A. No tributaries or diversions exist along Reach 4A. At the downstream end of the reach, the San Joaquin River Control Structure does exist to divert flows into Reach 4B1 of the river, but flows are typically routed into the Middle Eastside Bypass through the Sand Slough Control Structure (**Figure 3.10**). The downstream boundary condition for Reach 4A is based on the assumption that no flow is diverted into Reach 4B1, but is directed into the MESB. It is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, in this case, the Eastside Bypass Connector Channel. Water-surface elevations at the head of the connector channel, and the corresponding downstream rating curve for Reach 4A were established under the assumption that no additional flows enter the MESB from the Upper Eastside Bypass (UESB). If all flow in Reach 4A is being directed into the MESB, and no additional flow is in the UESB, it is reasonable to assume that any modeled discharge value at the lower end of Reach 4A can be applied directly to the rating curve provided without any change in flow. The user should determine whether the boundary condition is appropriate for their specific analysis and assumptions.

3.7. Reach 4B1

Any potential flow entering Reach 4B1 is diverted from the bottom end of Reach 4A through the SJRCS, which basically consists of a couple of headgates. No tributaries or diversions exist along Reach 4B1 (**Figure 3.11**). The downstream boundary condition for Reach 4B1 is based

on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 4B2. The rating curve assumes no additional discharge contribution from the Mariposa Bypass, so it is reasonable to assume that any modeled discharge value at the lower end of Reach 4B1 can be applied directly to the rating curve provided without any change in flow. It should be noted that the capacity of Reach 4B1 is limited to flows less than about 500 cfs. Model results for existing conditions at discharges greater than 500 cfs are not valid.

3.8. Reach 4B2

Flows can enter Reach 4B2 from both Reach 4B1 and the Mariposa Bypass, and no other tributaries or diversions occur along the reach until the downstream end at the junction with Reach 5 and the LESB (**Figure 3.12**). The downstream boundary condition for Reach 4B2 is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 5. The rating curve was developed under the assumption that no additional flow is being contributed from the Lower Eastside Bypass. If the conditions that the user is evaluating include flows in the Eastside Bypass, the combined discharges of both the LESB and Reach 4B2 should be applied to the rating curve.

3.9. Reach 5

Flows can enter Reach 5 from both Reach 4B2 and the Lower Eastside Bypass (which includes contributions from Bear Creek). Salt Slough, Mud Slough, and the Merced River (downstream end) can also contribute flow to this Reach (**Figure 3.13**). To help account for these changes in flow, discharge change locations have been included as place holders in the example flow files that accompany the model, which occur at XS59039, XS17105, and XS139. The downstream boundary condition in Reach 5 corresponds to a published discharge rating curve at the San Joaquin River at Newman gage, which is located just downstream of the confluence with the Merced River and is based on the total combined flow from both the San Joaquin and Merced Rivers. Therefore, it is important to note that the user must make an assumption regarding the contribution of flow from the Merced River in order for the rating curve to be applicable. Many options exist for estimating Merced River contributions, which are dependent on the conditions that the user is analyzing. For example, under existing conditions, one option would be to establish concurrent flows from the Merced River by assuming equal exceedence frequencies to the flows in the San Joaquin River. Under proposed restoration conditions, one option would be to estimate the flows based on the combination of an equivalent occurrence frequency and the hydrologic year type specified in the Settlement Agreement (Tt-MEI, 2012b). Regardless of the selected approach, the user must note that the boundary condition rating curve for this reach includes flow from the Merced River.

3.10. Chowchilla and Upper Eastside Bypass

Flows can enter the Chowchilla Bypass and Upper Eastside Bypass from Reach 2A via the CBBS, the Fresno River, Berenda Slough, and Ash Slough (**Figure 3.14**). To help account for these changes in flow, discharge change locations have been included as place holders in the example flow files that accompany the model, which occur at XS189737.1, XS176749.7 and XS160780.9. The downstream boundary condition is based on a rating curve derived from the computed water-surface elevations in the Middle Eastside Bypass model at the confluence between the two bypass reaches and the Connector Channel. The rating curve was developed under the assumption that no additional flow is being contributed from Reach 4A via the Sand

Slough Connector Channel. If the conditions that the user is evaluating include flows diverted into the MESB from Reach 4A, the rating curve will need to be evaluated. Backwater conditions in the Middle Eastside Bypass can greatly impact the downstream boundary condition for this reach. Also, because subsidence is occurring at a significant rate in this reach, as well in the downstream reaches, the user must evaluate the appropriate subsidence rates for the model used to generate the downstream boundary condition (see Section 5).

3.11. Middle Eastside Bypass

Flow enters the Middle Eastside Bypass from the Upper Eastside Bypass and Reach 4A through the Sand Slough Connector Channel (**Figure 3.15**). Flow can be diverted at the Merced National Wildlife Refuge weirs and also into the Mariposa Bypass through backwater created by the Eastside Bypass Control Structure (EBCS). To help account for these changes in flow, discharge change locations have been included as place holders in the example flow files that accompany the model, which occur at XS73410 and XS56770. The two refuge weirs also exist along the MESB, but due to the lack of information regarding the quantity of flow diverted at these locations, flow change place holders are not included for these structures. The downstream boundary condition for the MESB, which is located immediately downstream of the EBCS, is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, LESB. It is important to note that although the downstream boundary condition is provided, the EBCS acts as the primary hydraulic control for this reach, and will impact the water-surface elevations at the downstream end of the MESB (depending on the diversion of flow at the Mariposa Bypass Control Structure, the combination of the EBCS and MBCS can significantly affect water-surface elevations within this reach). The EBCS is located near the lower end of this reach, and is modeled using a combination of cross sections containing lids to represent the geometry of the six gate openings, which are currently modeled as open.

3.12. Lower Eastside Bypass

Flow enters the head of the Lower Eastside Bypass from the MESB via the EBCS (**Figure 3.16**). Bear Creek is the primary tributary to this reach, and to help account for any flow contributions, a discharge change is included as a place holder in the example flow files that accompany the model, which occur at XS8772. The downstream boundary condition for the LESB is based on a rating curve derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 5. It is assumed that no flow contributions from Reach 4B2 are likely to occur at this location along the river, so it is reasonable to assume that any modeled discharge value at the lower end of LESB can be applied directly to the rating curve provided without any change in flow.

3.13. Mariposa Bypass

All flow entering the Mariposa Bypass is diverted from the MESB through the Mariposa Bypass Control Structure. This is a very short and straight reach with no tributaries or diversions (**Figure 3.17**). The downstream boundary condition, which is located immediately downstream of the Mariposa Bypass Drop Structure, is based on the same rating curve used for Reach 4B1. It is derived from the computed water-surface elevations at the upstream cross section in the adjacent downstream reach, Reach 4B2. The rating curve assumes that no additional discharge contribution occurs from Reach 4B1. It is important to note that although the downstream

boundary condition is provided, the Mariposa Bypass Drop Structure acts as the primary hydraulic control for this reach, and will impact the water-surface elevations in the MB.

4. MODEL CALIBRATION

4.1. Refined Model Calibration

Various techniques were used in calibrating the refined models. Overbank roughness values, which were delineated based on aerial photography, were unchanged, but the horizontal location of the channel boundary was refined in some locations based on the elevation data contained in the cross sections to better reflect the interface of bank vegetation and river channel as defined by the new bathymetry. Channel roughness values were adjusted to model the progressive fining of bed sediment in the downstream direction. Averaged hydraulic depth parameters used in the Tt-MEI (2009) roughness compositing algorithm were recalculated. In-channel and overbank ineffective flow areas were adjusted as necessary based on the new bathymetry and high discharge calibration events. Cross sections were also added or moved in a few locations where the new bathymetry indicated that a hydraulic control was not reflected by the existing cross sections. Due to limitations in the data, the new bathymetry did not adequately define the hydraulic control in a few locations where surveyed water-surface profiles indicated that one existed. To account for this, cross sections in these areas were adjusted using small blocked obstructions to approximate the missing topography.

The models were calibrated over a large range of flows, some of which were considerable in magnitude. As a result, local conditions likely varied somewhat at the time of each water-surface profile survey, and may have also been somewhat different than what is represented by the topography in the hydraulic models. Although it was possible to calibrate the models very accurately to a particular discharge, the process would typically be at the expense of the calibration at a different discharge. Therefore, in order to develop a tool that could be used over the full range of flows, the selected approach was to calibrate the models by assessing the accuracy to all available water-surface profile data as a whole, rather than one particular discharge. As discussed in the following sections, comparisons of the predicted and surveyed water-surface profiles indicate good agreement throughout the reach over the range of available discharges.

Each of the refined model reaches were calibrated independently based on available stream gage data, measured discharges, and surveyed water-surface elevations. Flow events were measured and surveyed as part of an ongoing monitoring program and made available for calibration (**Table 4.1**). Predicted results over a range of flows were also compared with published rating curves, where available.

4.1.1. Reach 1A Refined Model Calibration

The Reach 1A refined model was calibrated using available stream gage data, and surveyed water-surface elevations that were collected during flows of approximately 350, 700, 1,100 and 1,360 cfs (Table 4.1). Model calibration was improved through the addition of fixed sediment elevations at 13 cross sections where survey data were not available to fully describe the in-channel topography that represents hydraulic controls. The resultant fixed sediment elevations were determined based on the elevation required to improve calibration, and checked based on a combination of field observations and nearby mapping. In addition, calibration was also improved through the increase in Manning's n -values to better reflect the coarse bed material that exists within this reach as well as to account for the significant energy losses associated with the numerous complex flow paths and channel-gravel pit interactions. Based on the final

Table 4.1. Summary of surveyed water-surface elevation data available for model calibration for all reaches between Friant Dam and the Merced River.

Reach	Date	Local Flow (cfs)
1A	October 19-21, 2009 ³	350 ¹
	November 9-10, 2009 ³	700 ¹
	April 20-21, 2010 ³	1,100
1B	April 19, 2010 ³	1,360
	October 18, 2011 ³	570
	April 22, 2010 ³	1,100 ¹
	June 9, 2011 ³	2,500 ¹
	May 5, 2011 ³	4,110
	January 7, 2011 ³	6,160 ¹
	March 31, 2011 ³	6,950 ¹
2A	November 11, 2009 ³	500 ¹
	April 26, 2010 ³	1,200 ¹
	June 10, 2011 ³	2,500 ¹
	May 6, 2011	4,150 ¹
	January 8, 2011 ³	5,700
	April 1, 2011	7,290 ¹
	November 12, 2009 ³	160 ¹
2B	April 27, 2010 ³	1,070 ¹
	April 28, 2010 ³	670 ¹
	January 10, 2011 ³	1,750
3	April 4-5, 2011 ³	3,600 ¹
	April 10, 2010 ³	730
	January 17, 2011 ³	1,200
4A	April 12, 2011 ³	3,300
	April 13, 2010 ²	211 ^{1,4}
	January 19, 2011 ²	516 ⁴
4B2	April 8, 2011 ²	4,107
	January 19, 2011 ²	4,140 ¹
	January 20, 2011 ²	3,630 ¹
5	January 21, 2011 ²	2,990 ¹
	April 9, 2011 ²	11,300 ¹
	January 9, 2011 ³	3,820 – 4,120
Chowchilla Bypass	April 6-7, 2011 ³	5,800 – 7,470
UESB	April 10, 2010 ²	730
MESB	January 18, 2011	2,359
	January 19, 2011 ²	1,986 ⁴
	January 20, 2011 ²	1,582 ⁴
	January 21, 2011 ²	1,270 ⁴
	May 23, 2011 ³	1,860
	May 23, 2011 ³	1,720
	January 19, 2011 ²	2,315 ⁴
LESB	January 20, 2011 ²	2,100 ⁴
	January 21, 2011 ²	1,893

¹ Approximate discharge: Actual discharge varied slightly along entire reach.

² Collected by Reclamation

³ Collected by DWR

⁴ Due to questions regarding the accuracy of the estimated discharge, channel conditions, or structure operating conditions, data were not included in the calibration.

results, comparison of the predicted and surveyed water-surface profiles indicates good agreement throughout the reach over the range of available discharges, with 94 percent of the predicted values within 0.5 feet of the measured values, 65 percent within 0.25 feet of the measured values, and no significant trend of over- or under-prediction along the reach (**Figures 4.1 and 4.2**). In addition to the measured profiles, the model was also validated at higher flows by comparing predicted water-surface elevations with the rating curve for the San Joaquin River below Friant Gage (USGS Gage No. 11251000) (**Figure 4.3**). As shown in the figure, the predicted water-surface elevations match the gage rating curve very well over the range of flows greater than about 1,000 cfs. At discharges less than about 1,000 cfs, the predicted water-surface elevations are slightly higher than the gage rating curve, but are in very good agreement with recently surveyed water-surface elevations in the vicinity of the gage (Figures 4.1 and 4.2).

4.1.2. Reach 1B Refined Model Calibration

The Reach 1B refined model was calibrated based on available stream gage data, and surveyed water-surface elevations that were collected during six flow events with upstream discharges ranging between about 550 cfs and almost 7,000 cfs (**Figure 4.4**). As mentioned above, the main-channel roughness in Reach 1B was based on a Manning's n -value of 0.035 for the entire reach. Comparison between measured and computed elevations indicates generally good agreement over this large range of discharges (**Figure 4.5**). Of the 554 points surveyed across the six flow events, 349 (63 percent) of the predicted values are within 0.25 feet of the measured values and 506 (91 percent) are within 0.5 feet. The calibration results show no obvious bias above or below the measured elevations with the exception of the January 2011 (6,160 cfs) flow event where the results appear consistently low. A review of the surveyed data reveals that the January 2011 survey points are at nearly the same elevations throughout the reach of those surveyed during the March 2011 (6,950 cfs) event, although the discharge was at least 10 percent lower (790 cfs). The January 2011 event corresponded with a dramatic increase in flow released from Friant Dam (an increase of approximately 5,000 cfs over 24 hours), and given that the reach had not experienced flows of this magnitude in quite some time, which would have cleared much of the debris from the preferred flow paths, it is feasible that a greater amount of debris captured during this initial rising limb would have resulted in water-surface elevations that were higher than would normally be expected. Because predicted results for all of the other flow events, including both March 2011 (6,950 cfs) and May 2011 (4,110 cfs), are in much better agreement with measured elevations than January 2011, this particular calibration data set was relied upon less for calibration.

Predicted water-surface elevations were also compared to the published rating curve at the California Data Exchange Center (CDEC) stream gage at Donny Bridge (Gage ID: DNB; RM 240.8), which shows good agreement at flows up to about 2,000 cfs (**Figure 4.6**). In general, the predicted curve is slightly flatter than the published rating curve, which does result in discrepancies of about 1 foot at flows between approximately 2,000 and 2,900 cfs (maximum reported discharge on published curve). At Donny Bridge, pressure flow begins at about 2,900 cfs and the bridge is completely overtopped at about 4,000 cfs. Calibration data for flows in this range are not available. However, at flows greater than 4,000 cfs, computed model results are in very good agreement (about 0.1 foot) with the surveyed water-surface profiles in this area.

Water-surface elevations in the vicinity of Donny Bridge are largely a function of a hydraulic control located approximately one-half mile downstream where the channel narrows significantly (near Sta 6430+00), especially at discharges between 1,500 and 2,900 cfs. Available data do not fully capture all of the controlling topography in this area. As a result, blocked obstructions

were included in some of the local cross sections to better reflect the hydraulic control and improve calibration. If necessary, these cross sections could be further refined in the future with the collection of more detailed survey data.

4.1.3. Reach 2A Refined Model Calibration

The Reach 2A refined model was calibrated based on available stream gage data, and surveyed water-surface elevations that were collected during six flow events ranging from about 500 to 7,300 cfs (**Figure 4.7**). As mentioned above, the channel roughness in Reach 2A was based on a Manning's n -value of 0.032 for the entire reach. Comparison of surveyed and computed water-surface elevations shows good overall agreement across all of the discharges (**Figure 4.8**). Based on the results, approximately 85 percent of the predicted values are within 0.5 feet of the measured values, 47 percent are within 0.25 feet, and no significant trend of over- or under-prediction exists along the reach.

Scatter in the differences between predicted and measured water-surface elevations is generally a little greater in this reach than in Reach 1B. This is likely because Reach 2A is a sand-bed reach, and the channel geometry adjusts to varying flows considerably more than the gravel bed in Reach 1B. Similar to Reach 1B, the results indicate that the predicted water-surface elevations associated with the January 2011 event are consistently lower than other surveyed events. For the same reasons described above, this particular calibration data set was relied upon less for calibration.

Predicted water-surface elevations in Reach 2A were also compared to the published rating curve at the CDEC stream gage at Gravelly Ford (Gage ID: GRF; RM 227.5), which indicate that the model results are generally lower, but within approximately 0.5 feet of the rating curve (**Figure 4.9**). The datum for this gage was calculated based on a field survey conducted on October 24, 2011, which indicated that a gage height of 5.74 feet corresponded with an elevation of 187.36 feet (NAVD88). As described above, changes in geometry of the sand-bed channel in Reach 2A are somewhat dynamic, and based on the available gage data, adjustments as high as 1.25 feet have been made to the CDEC rating curve to maintain its accuracy with measured flows. As a result, it is possible that the tendency for the computed results to be slightly lower than the rating curve is partially due to differences between channel conditions reflected in the model and those based on existing conditions at the gage, which could also explain differences between the gage rating curve and surveyed water-surface elevations at this location (Figure 4.9).

4.1.4. Reach 2B Refined Model Calibration

Water-surface elevations at two flow events with discharges at the head of the reach of 160 cfs (November 2009) and 1,098 cfs (April 2010) were surveyed and used for calibration of the Reach 2B refined model (**Figure 4.10**). As mentioned above, the majority of the channel roughness for Reach 2B was based on a Manning's n -value of 0.022, but the roughness was increased to 0.045 along a 3,000-foot section of the reach just downstream from San Mateo near RM 211.8 (Sta 4899+00 to Sta 4928+88) to represent the significant amount of in-channel vegetation that exists.

A comparison between measured and computed elevations indicates very good agreement for the two events (**Figure 4.11**). For the April 2010 event, computed results are within about 0.25 feet for the entire reach. For the November 2009 event, computed results are within about 0.5

feet. During the calibration process, a higher value was placed on fitting the April 2010 data because it represented a continuous water surface with little variation in channel discharge. In contrast, all 160 cfs in the November 2009 event is lost to ground seepage approximately four miles into the reach, reducing the ability to reliably model the local hydraulic conditions.

Predicted water-surface elevations in Reach 2B were also compared to the published rating curve at the CDEC stream gage on the San Joaquin River below Chowchilla Canal Intake (Gage ID: RM 216.1), which shows good agreement at flows up to about 3,300 cfs (maximum discharge on published rating curve) (**Figure 4.12**). In general, the predicted curve is slightly flatter than the published rating curve, which results in discrepancies of about 0.3 feet at flows near 3,000 cfs. The published rating curve was extrapolated to 4,500 cfs to compare with predicted results at the approximate design capacity of the reach. Based on the extrapolated rating curve, predicted results are in good agreement at flows near 4,500 cfs. The datum for this gage was based on a survey of the staff gage conducted by Reclamation, which indicated that a gage height of 6 feet corresponded with an elevation of 164.03 feet (NAVD88).

4.1.5. Reach 3 Refined Model Calibration

Calibration of Reach 3 was based on surveyed water-surface profiles at three flow events ranging between 670 and 3,600 cfs (**Figure 4.13**). As discussed above, final channel roughness n -values for Reach 3 varied between 0.026 at the lower end to 0.032 at the upper end. Sack Dam is located near the downstream end of the reach. The structure is modeled as an in-line weir with the gate/stop board bays completely open, but the elevation of the weir crest was adjusted slightly to achieve the best calibration for the range of calibration flows available.

Based on available flow measurements in the river upstream and downstream of the Firebaugh Wasteway near RM 197, it appears that the wasteway contributed flow to the reach during the time that the surveys were conducted, but direct measurements of the contribution are currently not available. During calibration, inflow from the wasteway was assumed based on the discharge measurements taken in the river. It is important for the user to consider this discharge source when using the model. Final calibrated results are in good agreement with the measured data, with approximately 98 percent of the predicted values within 0.5 feet of the measured values, 89 percent within 0.25 feet, and no significant trend of over- or under-prediction exists along the reach (**Figure 4.14**).

4.1.6. Reach 4A Refined Model Calibration

Three flow events with discharges ranging between about 730 and 3,300 cfs were available for calibration of the Reach 4A refined model (**Figure 4.15**). As discussed above, Reach 4A main-channel roughness was based on Manning's n -values ranging from 0.035 to 0.045. A comparison between measured and computed elevations indicates good agreement over the range of discharges to within ± 0.25 feet (**Figure 4.16**). The calibration also shows no obvious bias above or below the measured elevations.

Water-surface elevations collected in April 2010 downstream from near Highway 152 (Sta 2985+00) were also available for calibration. However, the April 2010 survey was actually conducted before a significant amount of excavation was done in the channel along the downstream end of the reach (the excavated condition was captured in the 2011 bathymetric surveys). As a result, these surveyed water-surface elevations reflect a channel condition that is

different from what is depicted in the model geometry, and were therefore, not considered in the calibration.

Predicted water-surface elevations were also compared to the published rating curve at the California Data Exchange Center (CDEC) stream gage near Dos Palos (Gage ID: SDP) (Sta 3335+20), which is located at the upstream end of the reach just below Sack Dam. The gage rating curve is based on the data published in June 2012, which is more recent than the surveyed water-surface elevations used to calibrate the model, but the comparison shows good agreement between the rating curve and computed elevations of within about 0.25 feet at flows up to about 2,500 cfs, and within 0.5 feet up to flows of about 3,500 cfs (**Figure 4.17**). The predicted curve is slightly steeper than the published rating curve at higher flows, which does result in a discrepancy of about 0.9 feet at 4,500 cfs. Computed model results are in very good agreement (less than 0.25 feet at 3,300 cfs) with the surveyed water-surface profiles in this area.

4.1.7. Reach 4B1 Refined Model Calibration

Calibration data are not available for Reach 4B1. As a check to ensure that the model is performing reasonably well with the revised bathymetry and composited channel n -values, water-surface profiles from the updated model were compared with results from the original model for this reach (**Figure 4.18**). The channel roughness n -values in Reach 4B1 range from 0.035 in open sand-bed reaches to 0.07 in areas severely choked by vegetation and debris. In general, the predicted water-surface elevations from the updated model are consistent with those from the original model throughout most of the reach. The differences are primarily due to the changes in the composite Manning's n -values resulting from the improved main-channel composite roughness algorithm (Tt-MEI, 2009), as well as some minor adjustments to ineffective flows areas in the vicinity of a smashed culvert near Sta 1861+38.

4.1.8. Middle Eastside Bypass Refined Model Calibration

The Middle Eastside Bypass refined model was calibrated based on available stream gage data, and surveyed water-surface elevations that were collected during four flow events ranging from about 730 to 2,360 cfs (**Figure 4.19**). With the exception of the April 2010 dataset, which was based on the CDEC stream gage at Dos Palos (SDP), discharges associated with the Reclamation's surveyed water-surface profiles in the Middle Eastside Bypass are based on the CDEC stream gages at El Nido (ELN) and at the Eastside Bypass below Mariposa (EBM). Unfortunately, discharges and boundary conditions between the MNWR weir and the EBM gage are difficult to estimate, largely because of the unknown diversions at the MNWR weir and at the Mariposa Bypass, especially at these higher flows. In addition, water surface elevations in this area are very dependent on the operating conditions of the Eastside and Mariposa Bypass Control Structures, but information regarding operation of these structures at the time of the surveys is not available. As a result, the actual discharges associated with other available surveyed water-surface data collected in January 2011 between the MNWR weir and the lower end of the reach are somewhat unknown, and therefore, were not used for calibration.

As described in sections above, the channel roughness in the MESB ranged between 0.025 and 0.05. Comparison of surveyed and computed water-surface elevations shows good overall agreement across all of the discharges (**Figure 4.20**). Based on the results, model calibration was generally achieved to within ± 0.25 feet, and no significant trend of over- or under-prediction exists along the reach.

4.2. Simplified Model Calibration

As discussed in Section 2.3.5.2, simplified versions of each of the models were developed that not only exclude all flow splits, but also include only a single, representative n -value for the main channel. The main channel Manning's n -values were selected based on an approximate bankfull flow for each reach. This bankfull flow was executed in the refined version of the model and the resultant weighted channel n -values were extracted from the summary output tables. The longitudinal variations in these values were evaluated along the length of the reach, and subreaches having similar roughness values and geomorphic characteristics were identified in each model. Average channel n -values were then assigned to each of these subreaches.

Final refined models for Reaches 4B2, 5, Mariposa Bypass, and the Lower Eastside Bypass were not developed. However, for the purpose of developing the simplified models in these reaches, an initial version of the model that incorporated the use of horizontally varied n -values was implemented. The simplified versions of the Chowchilla and Upper Eastside Bypass models were developed based on different a methodology. Because of the limited variability in the geomorphic characteristics of this reach, a single channel and overbank n -value was applied to the entire reach based on channel characteristics.

4.2.1. Reach 1A Simplified Model Calibration

Split flows occur in eight locations in the refined model for Reach 1A, with both main channel and one to two side-channel branches in the area of split flows. Except for at two locations, all side channel reaches are removed in the simplified model by replacing the main- and side-channel cross sections with singular cross sections spanning the entire width of the active channel (i.e., both branches). One exception is at Rank Island where although the main channel and the small side channel adjacent to the weir were merged, the additional side channel on the far north side that runs along the Coombs/Arnold Channel was eliminated from the model and replaced with a discharge change location at the up- and downstream end of this channel to allow the user to account for any diverted flow. The second exception occurs at Ledger Island where the small side channel that runs along the far west side, and only contains flow at discharges greater than about 2,000 cfs, was eliminated from the model and replaced with a discharge change location at the upstream and downstream end of this channel.

Channel Manning's n -values in the simplified model were selected based on an approximate bankfull flow for the reach, which was estimated to be about 3,000 cfs. The resulting channel n -values represented in the simplified model were averaged over a total of five different subreaches, ranging from 0.042 to 0.073. The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations at a range of discharges (**Table 4.1**). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 1.0 foot of the measured elevations over the range of available calibration flows (**Figures 4.21 and 4.22**).

4.2.2. Reach 1B Simplified Model Calibration

The bankfull flow was estimated to be about 2,500 cfs in Reach 1B, which was used to develop the simplified channel n -values. The resulting (subreach-averaged) channel n -values represented in the simplified model were averaged based on the weighted channel n -value

profiles from the refined model over a total of five different subreaches ranging from 0.043 at the downstream end to 0.055 at the upstream end.

The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations for a range of discharges (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 1.0 foot of the measured elevations over the range of available calibration flows (**Figures 4.23 and 4.24**).

4.2.3. Reach 2A Simplified Model Calibration

Similar to Reach 1B, the approximate bankfull flow used to develop the simplified channel n -values for Reach 2A was 2,500 cfs. The resulting channel n -values represented in the simplified model were averaged over a total of four different subreaches ranging from 0.032 at the downstream end to 0.036 at the upstream end.

The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations at a range of discharges (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 0.75 feet of the measured elevations over the range of available calibration flows (**Figures 4.25 and 4.26**).

4.2.4. Reach 2B Simplified Model Calibration

In Reach 2B, 1,500 cfs was used as the estimated bankfull flow to develop the simplified channel n -values. The resulting channel n -values represented in the simplified model were averaged over a total of five different subreaches, and with the exception of inside the Chowchilla Bypass Bifurcation Structure, which has an n -value of 0.015, range from 0.023 to 0.055.

The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations at a range of discharges (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are primarily within ± 0.50 feet, and all values are within ± 1.0 foot of the measured elevations over the range of available calibration flows (**Figures 4.27 and 4.28**).

4.2.5. Reach 3 Simplified Model Calibration

A discharge of 2,500 cfs was used as the estimated bankfull flow to develop the simplified channel n -values in Reach 3. The resulting channel n -values represented in the simplified model were averaged over a total of five different subreaches, ranging from 0.029 to 0.038.

The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations at a range of discharges (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 1.0 foot of the measured elevations over the range of available calibration flows (**Figures 4.29 and 4.30**).

4.2.6. Reach 4A Simplified Model Calibration

A discharge of 2,000 cfs was used as the estimated bankfull flow to develop the simplified channel n -values in Reach 4A. The resulting channel n -values represented in the simplified model were averaged over a total of nine different subreaches, ranging from 0.035 to 0.056.

The water-surface elevations using the generalized n -values were compared with surveyed water-surface elevations at a range of discharges (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 0.5 feet of the measured elevations over the range of available calibration flows, except for at 3,300 cfs which is within 0.75 feet at some locations (**Figures 4.31 and 4.32**).

4.2.7. Reach 4B2 Simplified Model Calibration

Surveyed water-surface profiles for Reach 4B2 were available for three different flow events (Table 4.1). However, direct flow measurements associated with the surveyed water-surface elevations in Reach 4B2 are not available. As a result, discharges associated with the surveyed water-surface profiles were estimated based on mean-daily flows at the CDEC stream gages at El Nido (ELN) and at the Eastside Bypass below Mariposa (EBM), where the flow in Reach 4B2 was computed by subtracting the discharge reported at EBM from the discharge reported at ELN (Table 4.1). The CDEC gage on the San Joaquin River near Stevinson (SJS), which is located at the downstream end of Reach 4B2 below the confluence with the Eastside Bypass, could have provided additional information regarding these assumptions, but was not operational during the time of these surveys.

Unfortunately, even with the available gage data, true discharges associated with the surveys were difficult to estimate due in part to discrepancies in the gage data, the significant number of control structures, distance between the gages and the study reach, and potential seepage at the lower flows. Questions also exist regarding how continuous the flow was at the lower discharges because the surveyed profiles on April 2010 and January 2011 did not cover the entire reach. As a result, since it was assumed that any error involved in the discharge estimation would be relatively less for higher flows, only the higher discharge of 4,100 cfs was used for calibration.

A refined version of the model for Reach 4B2 was not previously developed. Preliminary model calibration was conducted using the horizontally varied n -values for the April 2011 calibration event (4,100 cfs). After the preliminary calibration was complete, the resultant weighted channel n -values at a flow of 4,100 cfs were extracted from the summary output tables, and the longitudinal variations in these values along the length of the reach were evaluated and subreaches having similar roughness values were identified. Average channel roughness values were then assigned to each of these subreaches. The resulting channel n -values represented in the simplified model were averaged over two different subreaches ranging from 0.047 at the upstream end to 0.06 at the downstream end. Except for two locations near Sta 1240+00 and Sta 1444+00, model calibration was generally achieved to within ± 0.25 feet (**Figures 4.33 and 4.34**).

4.2.8. Reach 5 Simplified Model Calibration

Calibration data were based on surveyed water-surface elevations that were collected during four different flows (Table 4.1). However, direct flow measurements associated with the

surveyed water-surface elevations in Reach 5 are not available. Calibration discharges throughout the reach were estimated based on flow data available from CDEC at several gaging locations, and the main channel flows shown in Table 4.1 are based on data obtained in the middle of Reach 5 at the Fremont Ford Bridge gage (FFB).

A refined version of the model was also not previously developed for Reach 5. Therefore, to support the development of the simplified model in this reach, an initial version of the model that incorporated the use of horizontally varied n -values was implemented. A discharge of 3,500 cfs was used as the estimated bankfull flow to develop the simplified channel n -values. Given the inconsistency in the terrain beyond the main channel, varying amounts of flow can enter the floodplain. As a result, the actual bankfull discharge in this reach also varies significantly, and a conservatively low discharge was selected for the purpose of simplifying the weighted n -values. Longitudinal variations in these values along the length of the reach were evaluated, and the resulting channel n -values represented in the simplified model were averaged over three different subreaches ranging from 0.036 at the downstream end to 0.042 in the middle of the reach. Except for one location near Sta 690+00, model calibration was generally achieved to within ± 0.25 feet (**Figures 4.35 and 4.36**).

4.2.9. Chowchilla and Upper Eastside Bypass Model Calibration

Calibration data were based on surveyed water-surface elevations and direct flow measurements collected in January and April 2011 (Table 4.1). Flows ranged from 3,820- to 4,290 cfs in the Chowchilla Bypass during the January 2011 event and from 5,800- to 7,470 cfs in the Upper Eastside Bypass during the April 2011 event (**Figures 4.37a and 4.37b**).

The model topography was initially based directly on the 2008 LiDAR data. However, as described in Section 2.3.2, subsidence has been shown to impact this area. As a result, elevations were adjusted to account for subsidence using levee survey data collected by DWR in late 2012. Because the available topography, recent subsidence surveys, and calibration data was all collected in different years, adjustments to the elevations were made to reflect the timeframe of the calibration data, which is 2011. After elevations were adjusted to account for subsidence, Manning's n roughness coefficients of 0.03 for the main channel and 0.04 for the overbank resulted in calibration of generally within ± 1 foot (**Figure 4.38**).

4.2.10. Middle Eastside Bypass Simplified Model Calibration

A discharge of 1,500 cfs was used as the estimated bankfull flow to develop the simplified channel n -values for the Middle Eastside Bypass. Except at three significant structures in the reach, where calibration was dependent on maintaining the localized n -values, the resulting channel n -values represented in the simplified model were averaged over a total of five different subreaches, ranging from 0.032 to 0.043.

Computed water-surface elevations based on the generalized n -values were compared with surveyed water-surface elevations that were collected during the same four flow events as the refined models, ranging from about 730 to 2,360 cfs (Table 4.1). The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 0.5 foot of the measured elevations over the range of available calibration flows (**Figures 4.39 and 4.40**).

4.2.11. Lower Eastside Bypass Simplified Model Calibration

Model calibration was performed based on recorded discharges and surveyed water-surface elevations. Three flow events were surveyed as part of an ongoing monitoring program and made available for calibration (Table 4.1). Discharges associated with the surveyed water-surface profiles are based on the CDEC stream gage at Eastside Bypass below Mariposa (EBM). The discharges reported at the CDEC gage were very uniform on January 21, 2011, but varied significantly throughout the days on January 19 and 20, 2011. Because of the variability in flows, the actual discharges associated with the surveyed water-surface profiles on January 19 and 20, 2011, are somewhat unknown, and therefore, these data were used as a reference but not directly used for calibration.

Overbank roughness values were selected based primarily on aerial photography, but refined as necessary for calibration purposes. Channel roughness values were selected based on previous experience and knowledge of the reach and then refined to reflect sedimentation, in-channel vegetation, undefined channel geometry, or other features that cause increased energy losses, resulting in a range between 0.028 and 0.04. The predicted water-surface elevations associated with the simplified n -value approach are generally within ± 0.3 feet of the measured elevations over at a discharge of 1,893 cfs (**Figures 4.41 and 4.42**).

4.2.12. Mariposa Bypass Simplified Model Calibration

The Mariposa Bypass Model reach is primarily straight, with a low-flow channel and uniformly wide floodplain that is leveed on both sides. The Mariposa Bypass Drop Structure is a weir located at the downstream end and is the primary hydraulic control in the reach. Seepage loss is assumed to be negligible.

A refined version of the Mariposa Bypass was not previously developed, and calibration data are not available for the reach. The 2008 aerial photography and calibrated river and bypass reaches with similar characteristics were used for reference, and the resultant in-channel roughness was assigned a value of 0.035 and floodplain roughness was assigned a value of 0.045. The n -value compositing algorithm was not necessary for this reach due to the low variability in the channel characteristics. Computed water-surface elevations are based on a rating curve developed from the upstream cross section of the adjacent downstream reach, Reach 4B2 (**Figure 4.43**). However, as indicated in Figure 4.43, the primary hydraulic control for the majority of the reach is the drop structure located near the downstream limit of the bypass.

5. SUBSIDENCE CONSIDERATIONS

Subsidence is known to have occurred throughout the San Joaquin Valley and to various degrees along the San Joaquin River and flood bypass channels, including significant subsidence at Mendota Dam, Sack Dam, the Reach 4B1 headworks (San Joaquin River Control Structure), and the Sand Slough Control Structure (Reclamation, 2013). On a reach-wide basis, subsidence appears to have the greatest impact on areas along the Upper Eastside Bypass, Reach 3, and Reach 4A. Various studies and mapping efforts that identify the extent and rates of subsidence have been completed by DWR, Reclamation, and the US Geological Survey (USGS) (Provost & Pritchard, 2012a and 2012b).

The continuation of subsidence could potentially cause degradations to the levees and structures in the river channel, and changes in flow and sediment-transport behavior, flood-control capabilities, and the long-term flow delivery capabilities of the river system. As a result, it is important for the hydraulic models of the system to reflect the subsidence, and for the user to be aware of this process, so that the hydraulic modeling tools and subsequent results can be used appropriately.

In 2012, the SJRRP formed a subsidence coordination group to help address and study the impacts of subsidence and to share information between landowners, the general public, and government agencies. Reclamation is also conducting bi-annual surveys of various control points to monitor the rate of subsidence. The SJRRP is developing a technical memorandum that documents subsidence within the SJRRP project area, and will establish recommended subsidence criteria that will be applied to the design for future site-specific projects in Reach 2B, Reach 4B, and near the Arroyo Canal in Reach 3.

5.1. San Joaquin River

The HEC-RAS models for the various reaches of the San Joaquin River are based on the most recent available data, which typically consists of 2008 LiDAR topography and bathymetry collected between 2009 and 2011. In several reaches, the bathymetry was collected at the same time as the water surface elevations used for calibration. Because the models contain relatively recent bathymetry, the amount of subsidence since the data was collected is probably relatively small. As a result, the elevations in the current version of the models have not been adjusted to account for subsidence. If corrections for subsidence are applied, the user should be aware that different corrections would need to be applied to the overbank and in-channel portions of the topography because overbank portions of the model, including levees, are typically based on the older (2008) LiDAR, and the in-channel topography is based on more recent data (i.e., 2009-2011). The impacts of continued subsidence since the collection of topographic data used in the models has not been evaluated, but are currently assumed to be relatively minor in most reaches.

5.2. Bypass System

The HEC-RAS models along the bypasses are also based on the most recent available data, which typically consists of 2008 LiDAR topography and bathymetry collected between 2010 and 2011. Similar to the mainstem, many of the models along the bypass reaches include bathymetry collected between 2010 and 2011, and as a result, did not require elevation adjustments for subsidence. However, the greatest amounts of subsidence appear to have

occurred along the Chowchilla and Upper Eastside Bypasses, where recent bathymetry data have not been collected since the 2008 LiDAR (Reclamation 2013; Provost and Pritchard, 2012a and 2012b). Because the channels were dry in these two reaches when the LiDAR data were collected, all of the surveyed elevations in the model are from 2008, which based on recent surveys by Provost & Pritchard (2012a and 2012b), have experienced significant subsidence over the last approximately 5 years.

Due to greater amounts of reported subsidence, slightly older topography (i.e., 2008), and the fact that these bypass models did not calibrate well when comparing results from the 2008 LiDAR geometry with 2011 water surface profiles, the HEC-RAS models for the Chowchilla Bypass and Upper Eastside Bypass were adjusted to account for subsidence. To determine how much subsidence had occurred between 2008 and 2011, DWR completed a series of surveys along the Chowchilla Bypass, the Upper and Middle Eastside Bypasses, and the Mariposa Bypass. The survey data was compared to the LiDAR data and used to calculate an annual subsidence rate along these reaches of the bypass. The models for the Chowchilla and Upper Bypasses were adjusted accordingly. The elevations in the final models are intended to reflect 2011 conditions.

6. SUMMARY AND RECOMMENDATIONS

6.1. Summary

One-dimensional steady-state HEC-RAS models of the 150-mile reach of the San Joaquin River and Bypass System between Friant Dam and the mouth of the Merced River were developed and validated by Tetra Tech and CDWR. The models were developed to support the San Joaquin River Restoration Project (SJRRP), and to provide tools for evaluating current 1-D hydraulic conditions along the river and bypass.

Topographic data for the models were based on 2008 LiDAR data and various bathymetric surveys primarily conducted between 2009 and 2011. Elevations were subsequently corrected to account for considerable subsidence that has occurred in the Chowchilla and Upper Eastside Bypasses. Geometric data for bridges and other hydraulic structures were obtained from a variety of sources, including CALTRANS, CDWR, the Merced County Road Department, the Atchison Topeka Santa Fe Railroad, previously developed hydraulic models, and field surveys.

To provide a broader range of tools for the SJRRP, two versions of the 1-D HEC-RAS models were developed for many of the river reaches and bypasses, where appropriate. The two versions are as follows:

1. A refined version of the model that includes flow splits, horizontally varied overbank n -values, and vertically varied main-channel Manning's n -values based on an off-line compositing algorithm, which allows for a more accurate means of accounting for changes associated with in-channel vegetation, and for improved model calibration over a range of flows that involves varying degrees of vegetation.
2. A simplified version of the models that remove all flow splits, and only include a single, representative n -value for the main channel for defined subreaches within each reach. The horizontally varied overbank n -values from the refined model are maintained.

The models were calibrated, to the extent possible, using measured water-surface elevations, water-surface elevation rating curves from published gage records, and measured or recorded discharges. As such, these HEC-RAS models should provide tools and a sound basis for the evaluation of existing hydraulic conditions within the study area. It is important to note, however, that these models are intended to represent a general framework of the system, and that it is the end user's responsibility to determine appropriate boundary conditions, specific model-types (i.e. refined or simplified), flow distributions, structure settings, and assumptions regarding hydrologic operating rules (e.g., existing or proposed future conditions) for each reach based on the requirements of their specific analyses.

6.2. Recommendations for Future Refinements

The comparisons between the model results and measured data indicate good agreement in most areas. However, several recommendations to broaden the usefulness, refine the accuracy, and maintain currency of the model were identified, as follows:

1. Some of the structures within the reach, especially many of the bridges along the bypass system are based on information obtained from previous models developed for the U.S. Army Corps of Engineers (USACE). It may be appropriate to obtain current as-built design

plans and/or conduct field surveys of structures to ensure that they are represented correctly in the models.

2. Subsidence is expected to continue to occur within the study area. It may be appropriate to continue to monitor potential elevation changes due to subsidence, and update models as appropriate.
3. The existing Sack Dam structure has been recently modified, and may potentially be replaced by a new structure. It may be important to obtain current information about the structure and incorporate into the model.
4. Operation rules and structure settings within the Middle and Lower Eastside Bypasses and Mariposa Bypasses have not been clearly identified. It would be very beneficial to further investigate these issues for implementation in the models.
5. Flow losses downstream from Mendota Dam have not been studied in much detail. It may be appropriate to further investigate and identify whether significant losses occur along the lower portions of the study reach, and implement into the models as necessary.

7. REFERENCES

- Arcement, G.K. and Schneider, V.R., 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains. U.S. Geological Survey Water Supply Paper 2339.
- Ayres Associates, 1998. Topographic and Bathymetric Surveys for the San Joaquin River from Friant Dam to Gravelly Ford (RM 267 to RM 229). Prepared for Bureau of Reclamation, Fresno, California.
- Ayres Associates, 1999. Topographic and Hydrographic Surveys for the Sacramento and San Joaquin Comprehensive Study, California: Topographic and Hydrographic Surveying and Mapping for San Joaquin River, RM 40 to RM 230, Including Tributaries and Distributaries. Draft Report. Prepared for U.S. Army Corps of Engineers, Sacramento District, California.
- Barnes, H.H., 1967. Roughness characteristics of natural channels. U.S. Geological Survey Water-Supply Paper 1849.
- Bureau of Reclamation, 1993. San Joaquin River Atlas. Old River to Merced River, Sheets A2-A40.
- Bureau of Reclamation, 2013. Subsidence Design Criteria for the San Joaquin River Restoration (DRAFT). Technical Memorandum No. SUB-1, USBR Mid-Pacific Region, June 2.
- Chow, V.T., 1959. *Open Channel Hydraulics*. McGraw-Hill Book Co., New York, 680 p.
- Hicks, D.M. and Mason, P.D., 1991. Roughness Characteristics of New Zealand Rivers. Water Resources Survey, DSIR Marine and Freshwater, Wellington, New Zealand.
- Jones & Stokes, Ayres Associates, and Mussetter Engineering, Inc., 2000. Floodplain Restoration of the West Bear Creek Unit, San Luis National Wildlife Refuge, California. Prepared for the U.S. Fish and Wildlife Service, July.
- Madeheim, H.T., 1999. Effectiveness of Alternative 5 Releases from Friant Dam. Prepared for the U.S. Bureau of Reclamation, Mid-Pacific Region, April.
- Mussetter Engineering, Inc., 2002a. Hydraulic and Sediment Continuity Modeling of the San Joaquin River from Friant Dam to Mendota Dam, California. Prepared for the Bureau of Reclamation, Fresno, California, August.
- Mussetter Engineering, Inc., 2002b. Sensitivity Analysis of Composite n-values in Reach 2 of the San Joaquin River. Prepared for Friant Water Users Authority, Lindsay, California, February, revised June, 27 p.
- Mussetter Engineering, Inc., 2008. Estimation of Composite Manning's n Roughness Values, San Joaquin River. Draft technical memorandum prepared for the California Dept. of Water Resources, Fresno, California, May 28.
- Provost & Pritchard Consulting Group, 2012a. Chowchilla Bypass and Reach 2A Topographic Survey Results (DRAFT). Prepared for California Dept. of Water Resources, November.
- Provost & Pritchard Consulting Group, 2012b. Eastside Bypass Topographic Survey Results (DRAFT). Prepared for California Dept. of Water Resources, October.

- San Joaquin River Restoration Program, 2008. Location Referencing Standards: Projection, Control Line, and Mileposts. Draft Technical Memorandum, May 16.
- Tetra Tech (dba Mussetter Engineering, Inc.), 2009. San Joaquin River HEC-RAS Steady-state Hydraulic Model Refinements. Draft technical memorandum prepared for California Dept. of Water Resources, Fresno, California, June 19.
- Towill, Inc., 2009. Topographic and Bathymetric Mapping of the San Joaquin River from Friant Dam to Highway 99 (Reach 1A). Letter of Transmittal submitted with mapping to Tetra Tech-MEI for California Department of Water Resources, Fresno, California, April 24.
- U.S. Army Corps of Engineers, 2002. Sacramento and San Joaquin River Basins Comprehensive Study, Interim Report, December.

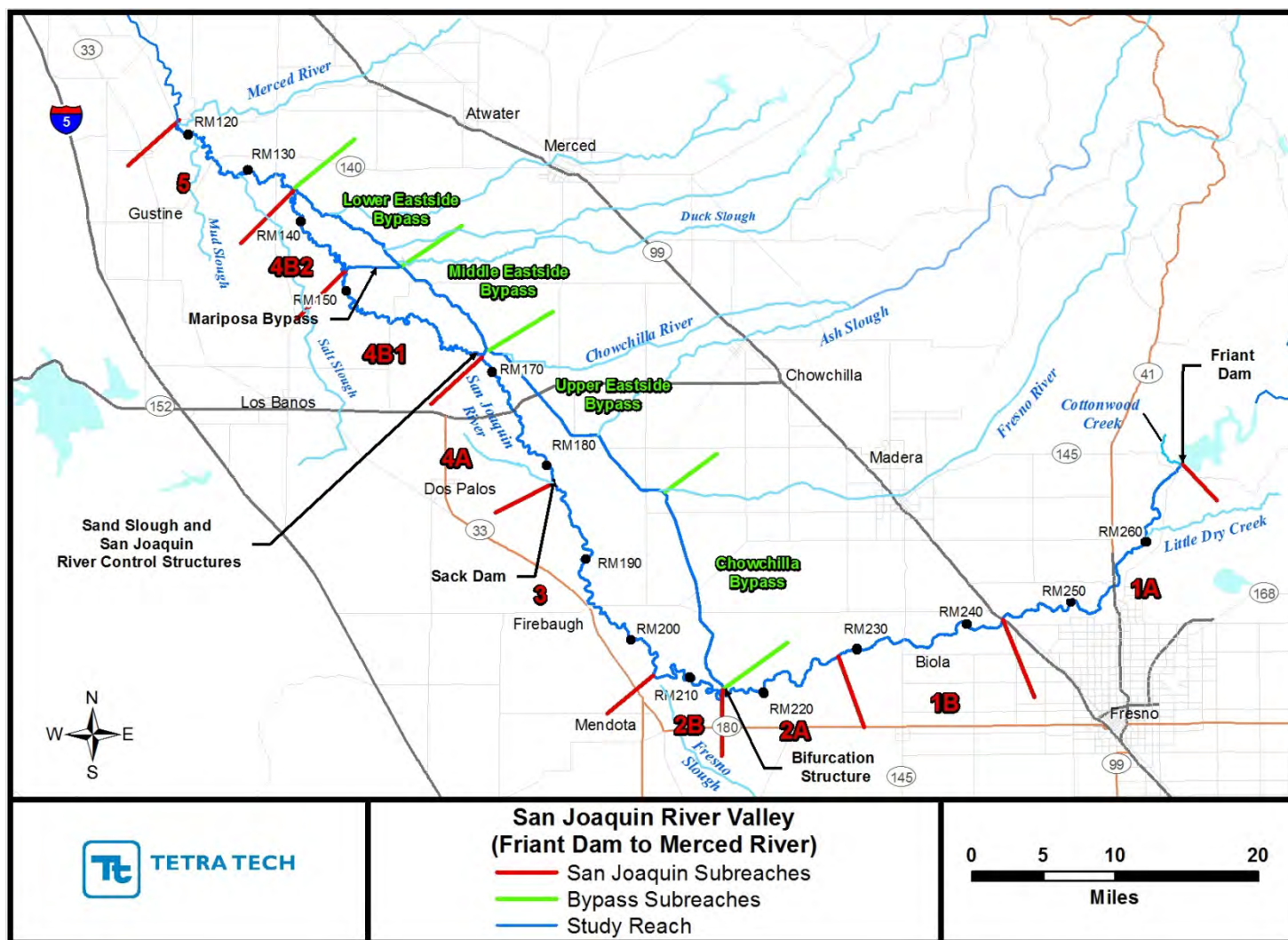


Figure 1.1. Map of modeled reach of the San Joaquin River.



Figure 2.1. Aerial photograph of a portion of the project reach in the vicinity of RM 203.5, showing the un-shaded roughness polygons and hydraulic model cross sections.



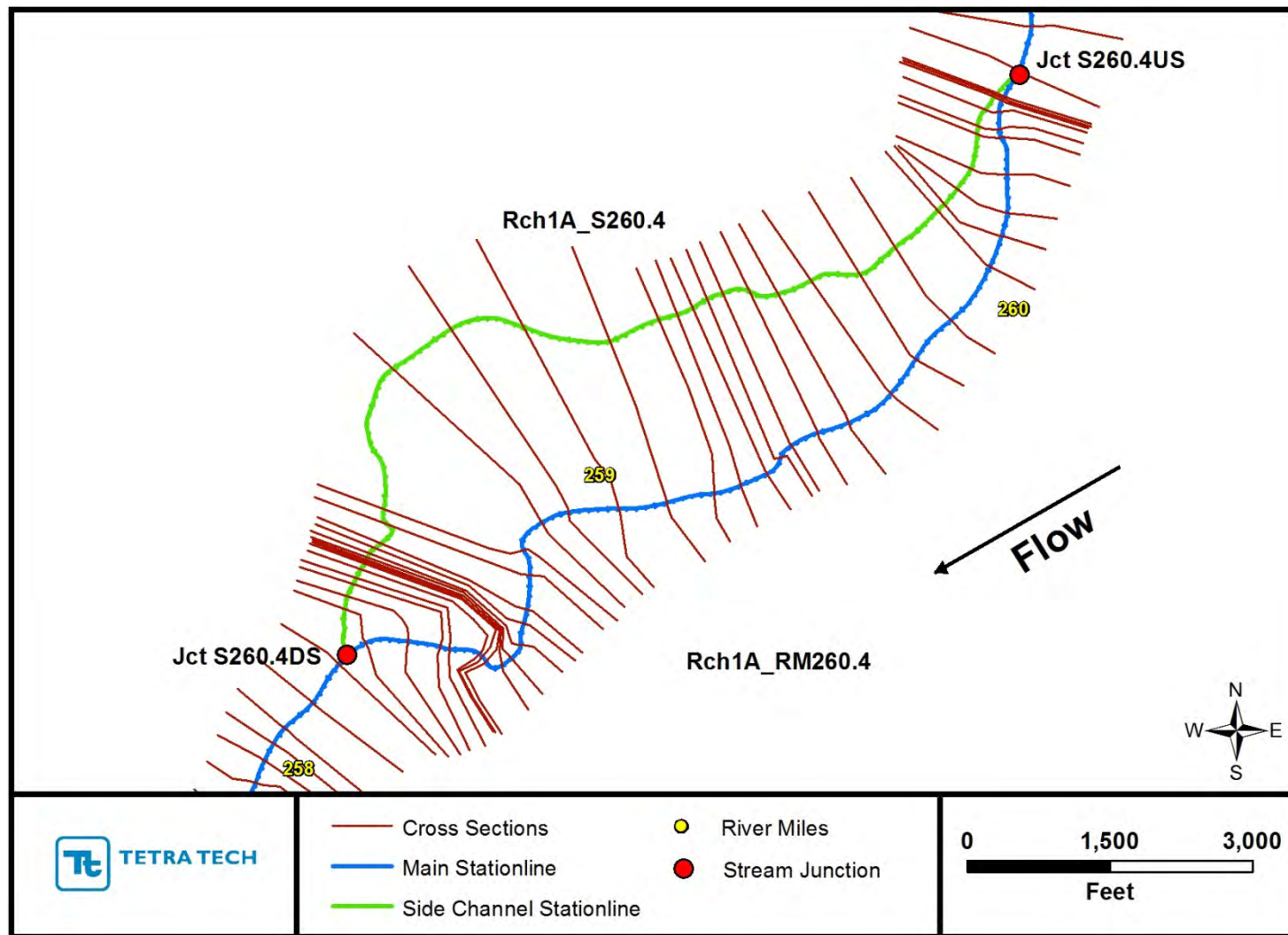


Figure 2.3. Example of reach naming convention at Rank Island.

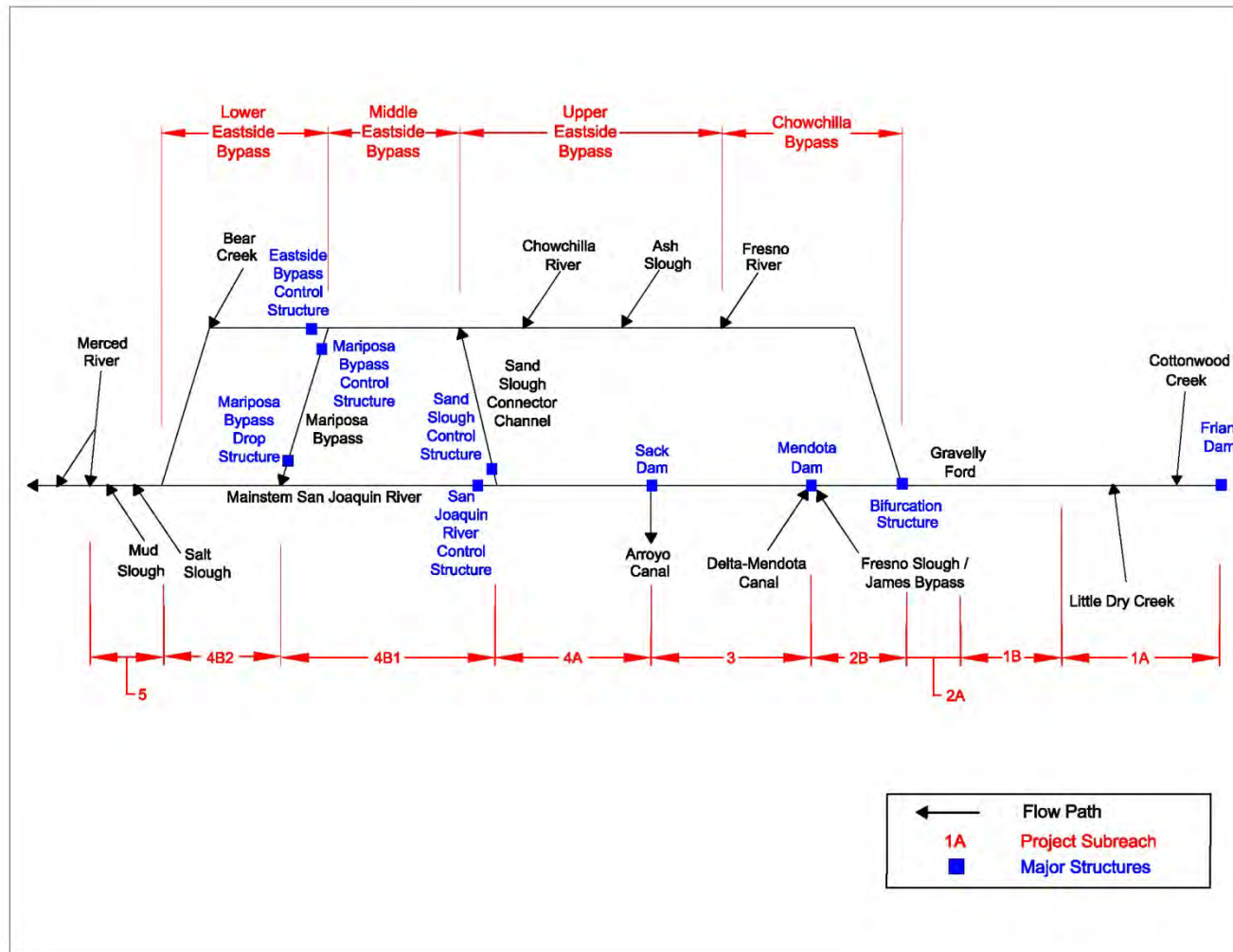


Figure 3.1. Schematic diagram of the San Joaquin River from Friant Dam to the confluence with the Merced River showing major tributaries, significant irrigation canals, and the Chowchilla/Eastside Bypass flood-control system.

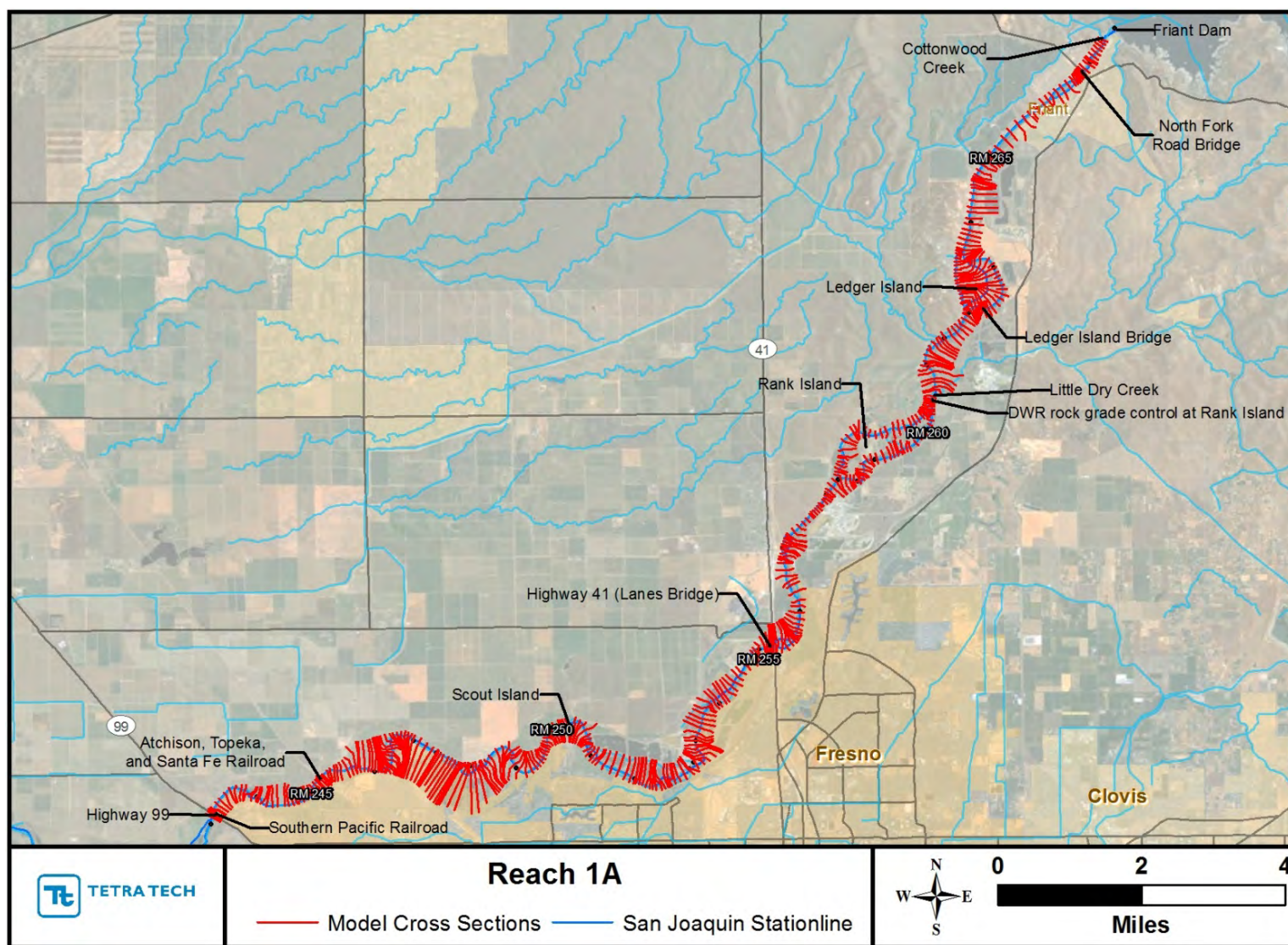


Figure 3.2. Reach 1A geographic extents and major features.

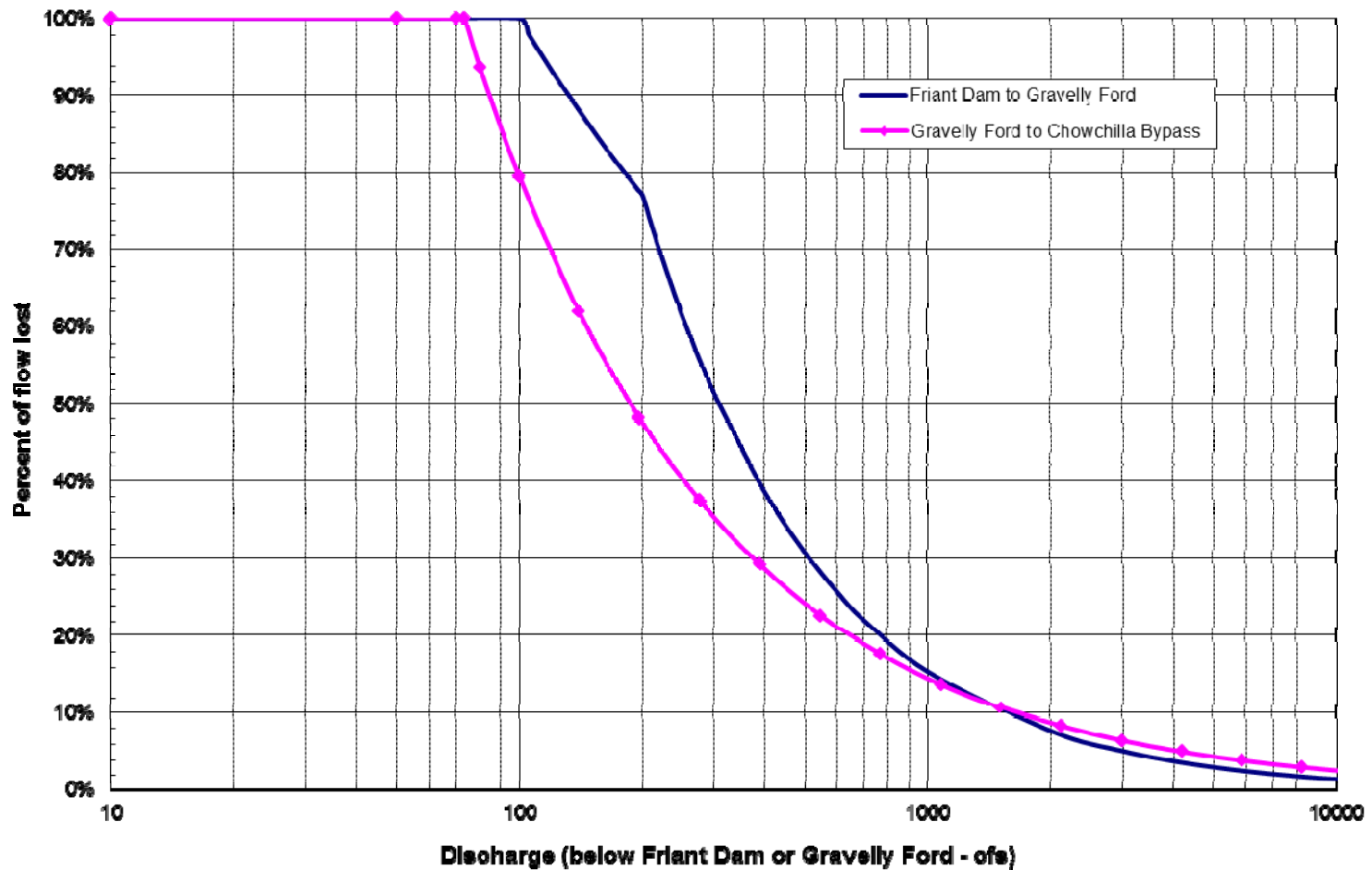


Figure 3.3. Estimated flow loss curves for the San Joaquin River between Friant Dam and Gravelly Ford and between Gravelly Ford and the Bifurcation Structure.

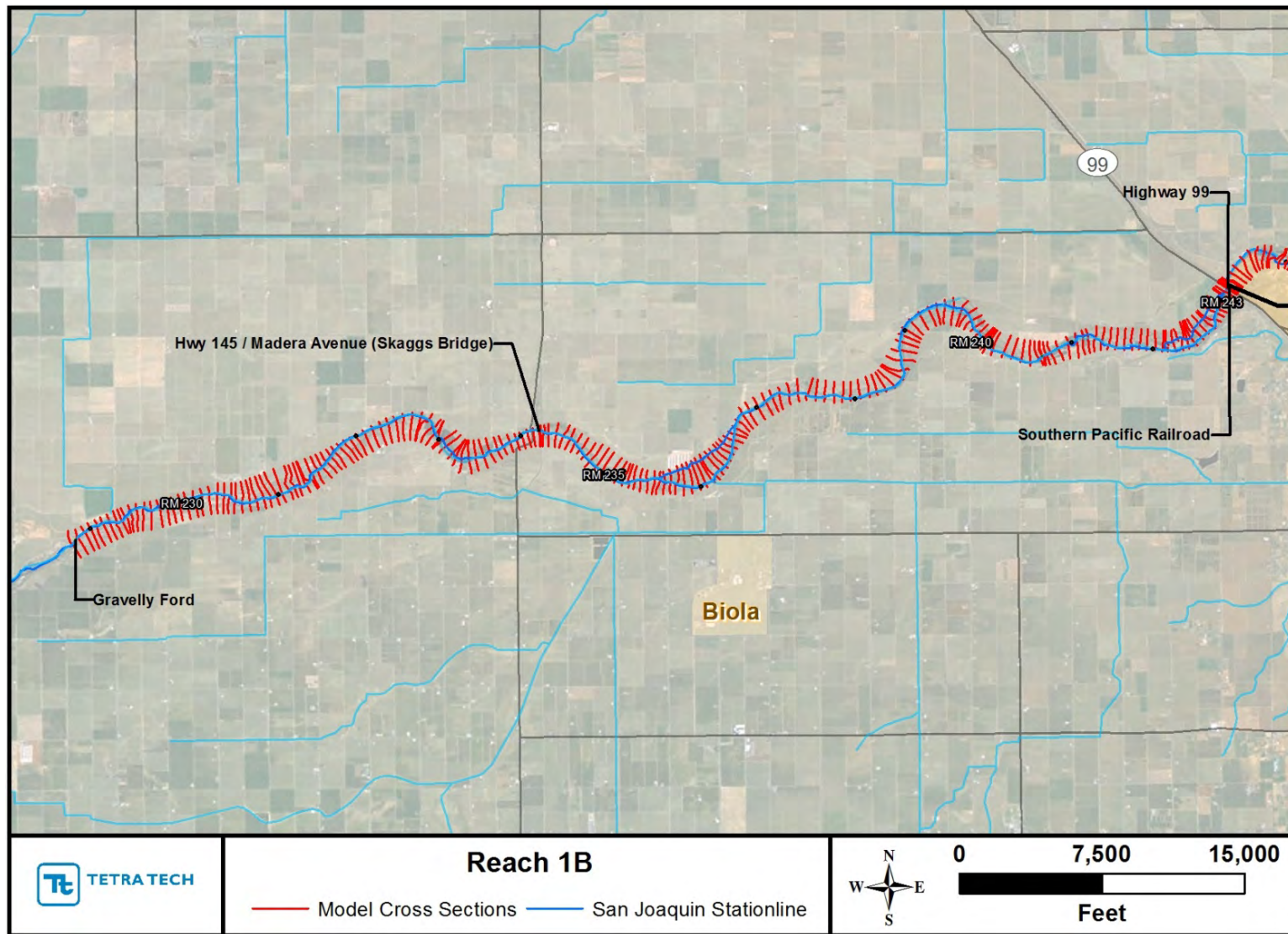


Figure 3.4. Reach 1B geographic extents and major features.

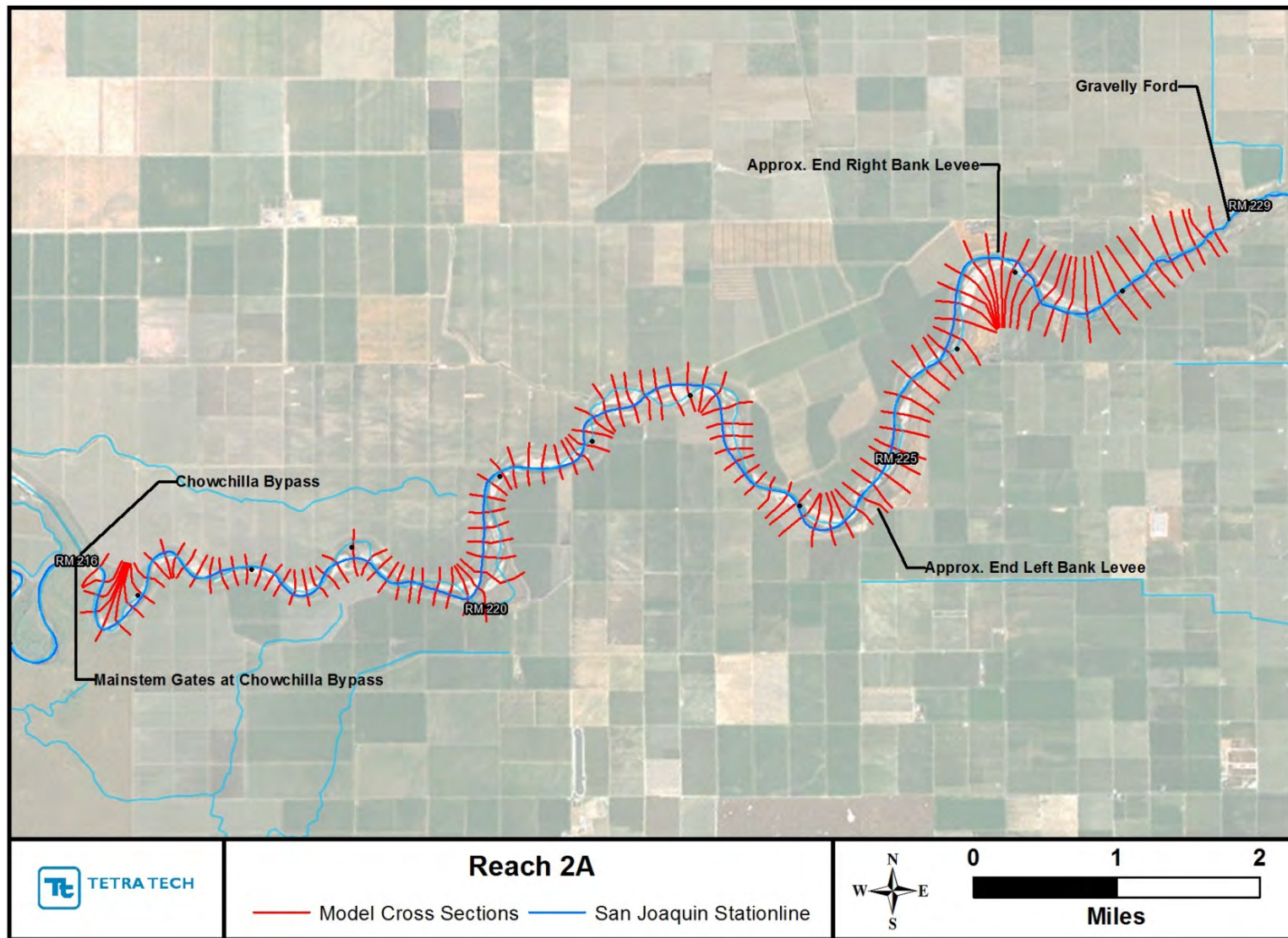


Figure 3.5. Reach 2A geographic extents and major features.

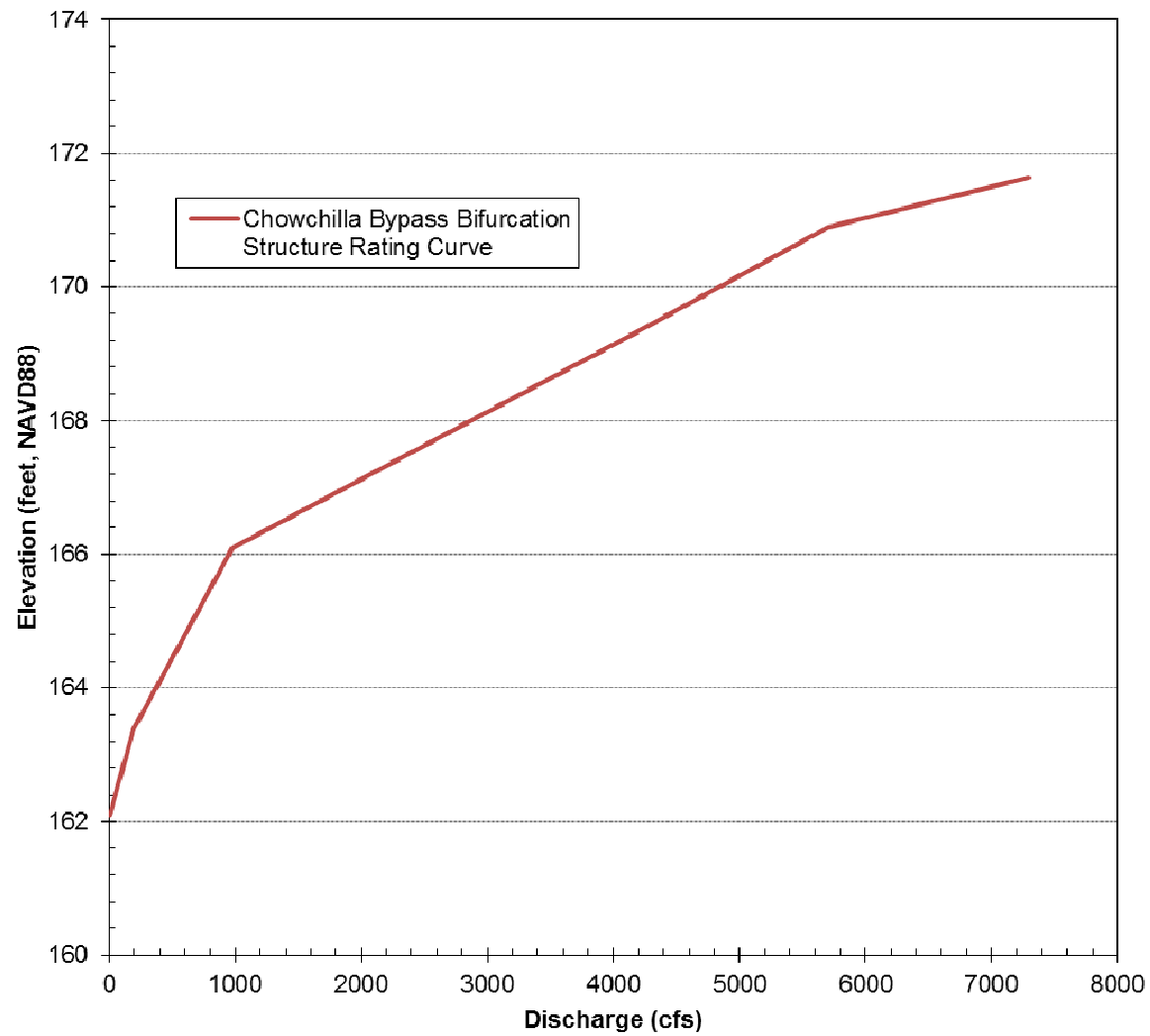


Figure 3.6. Downstream boundary condition rating curve for Reach 2A at the Chowchilla Bypass Bifurcation Structure.

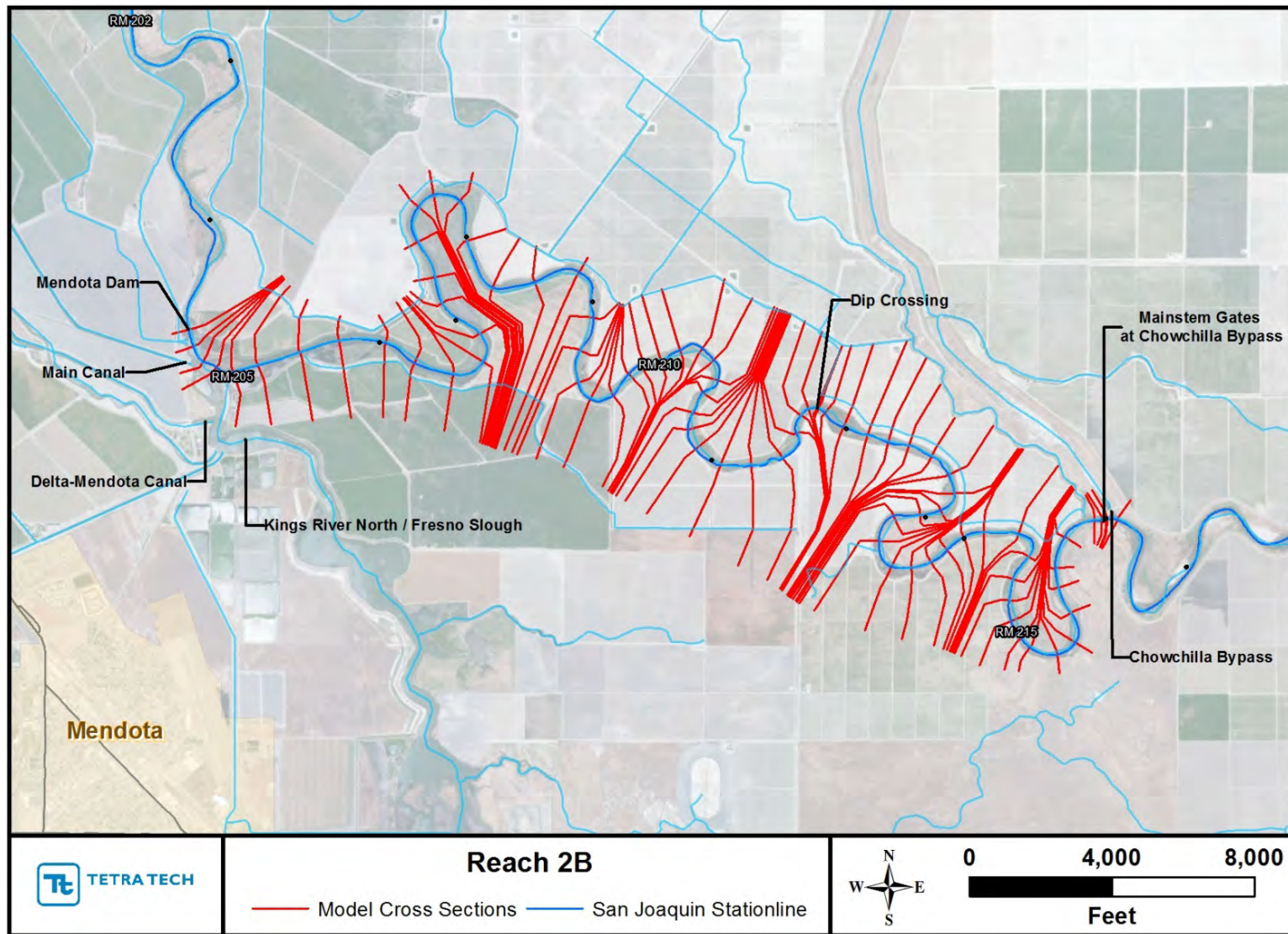


Figure 3.7. Reach 2B geographic extents and major features.

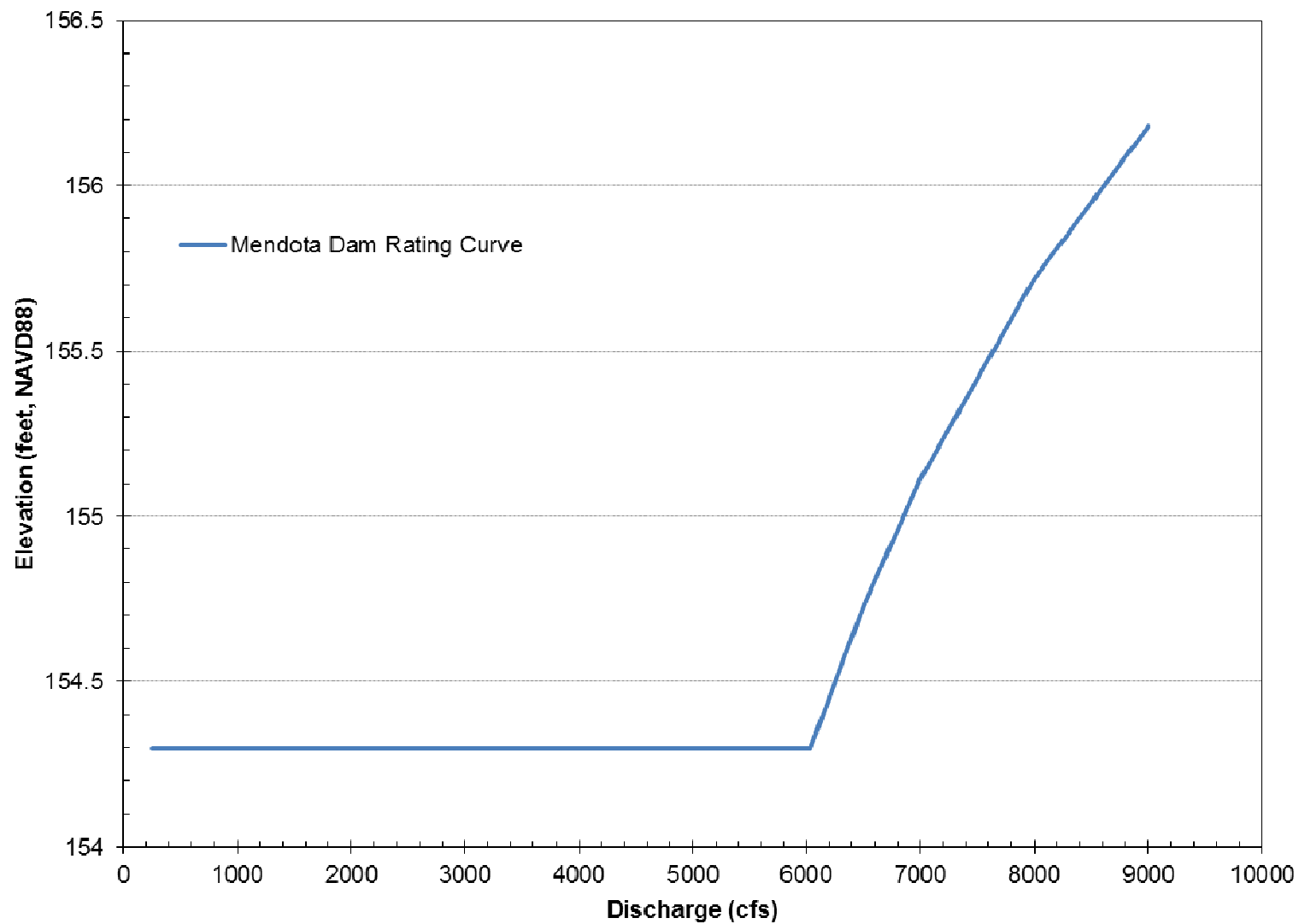


Figure 3.8. Downstream boundary condition rating curve for Reach 2B at Mendota Dam.

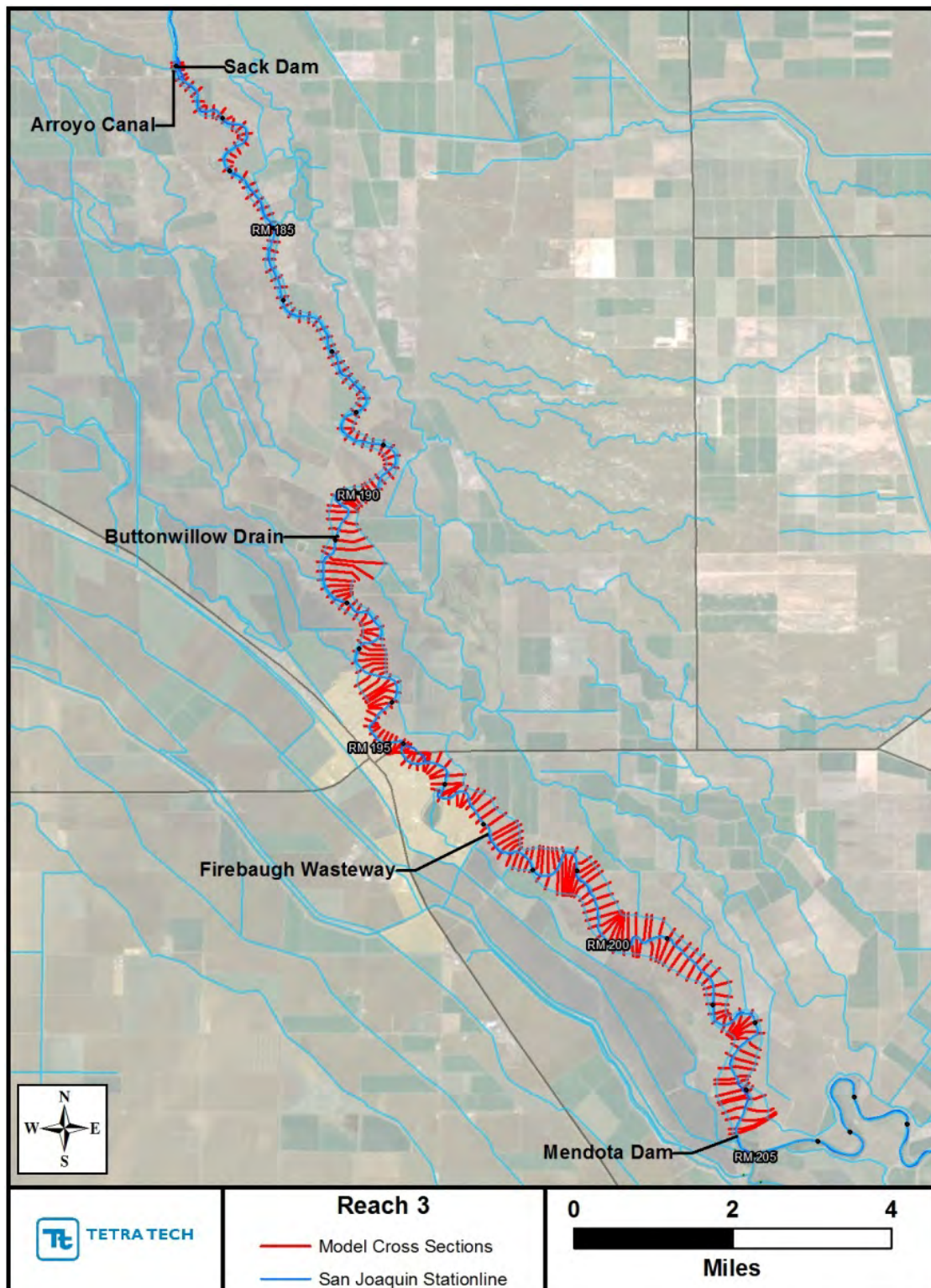


Figure 3.9. Reach 3 geographic extents and major features.

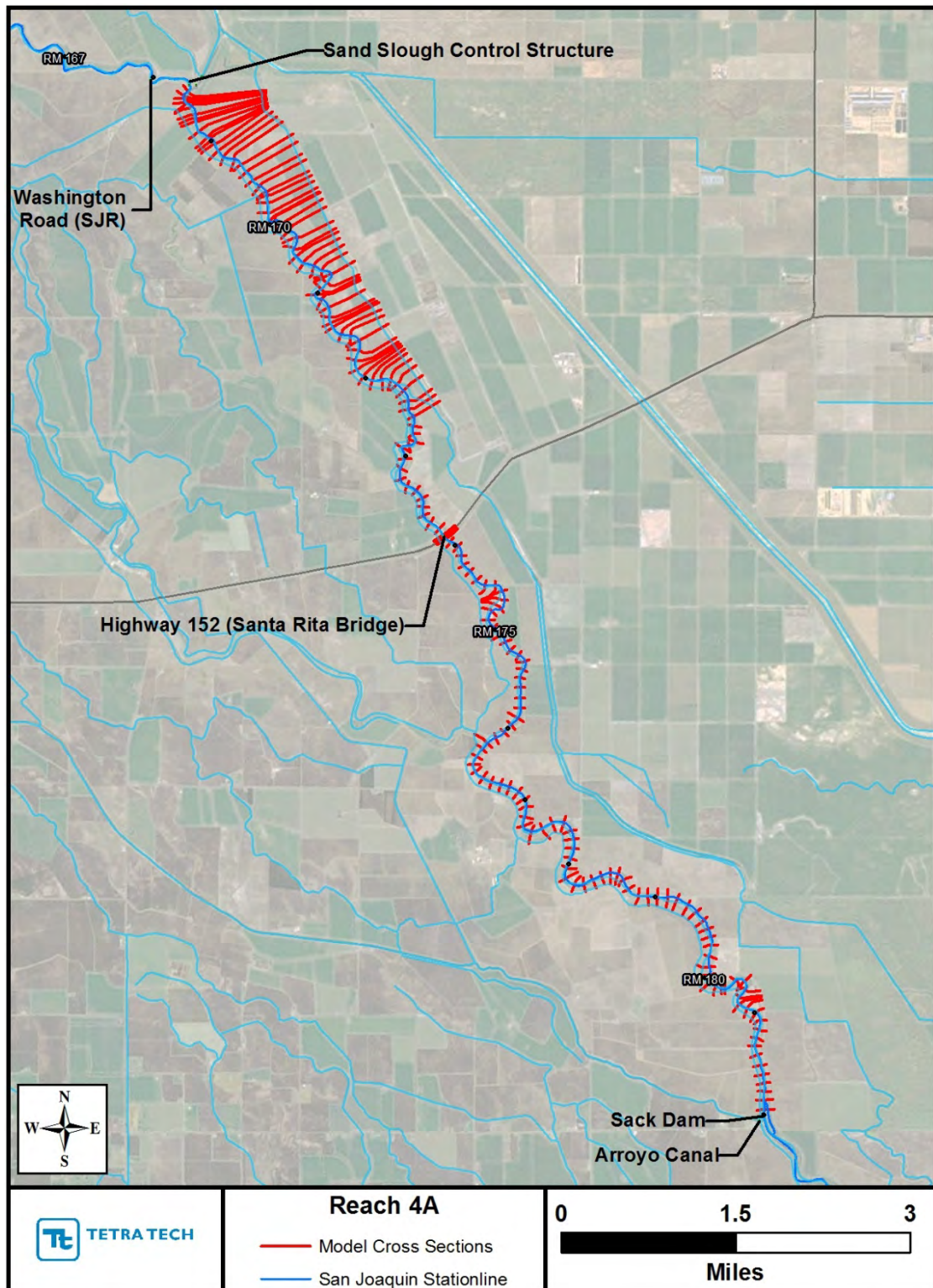


Figure 3.10. Reach 4A geographic extents and major features.

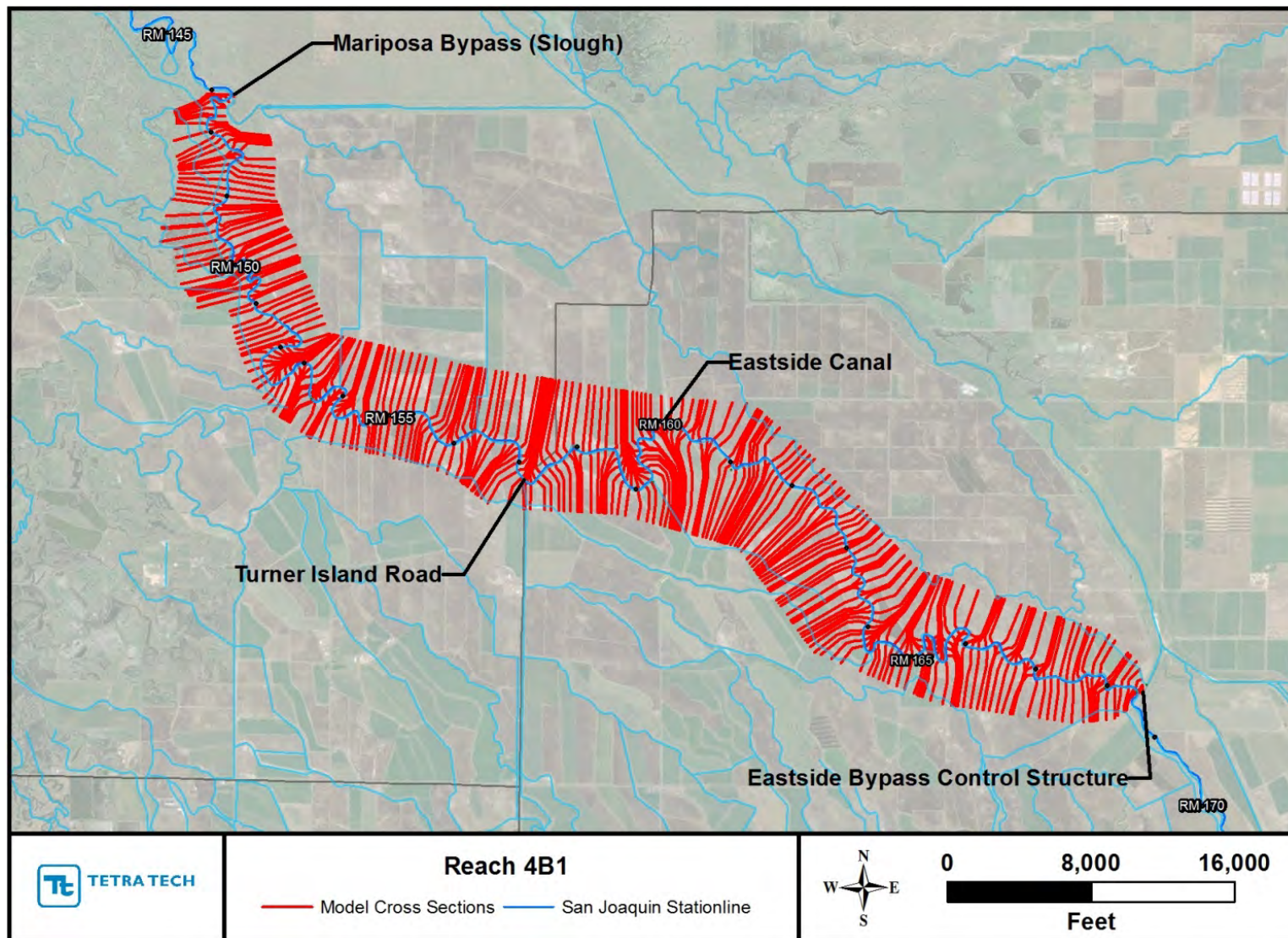


Figure 3.11. Reach 4B1 geographic extents and major features.

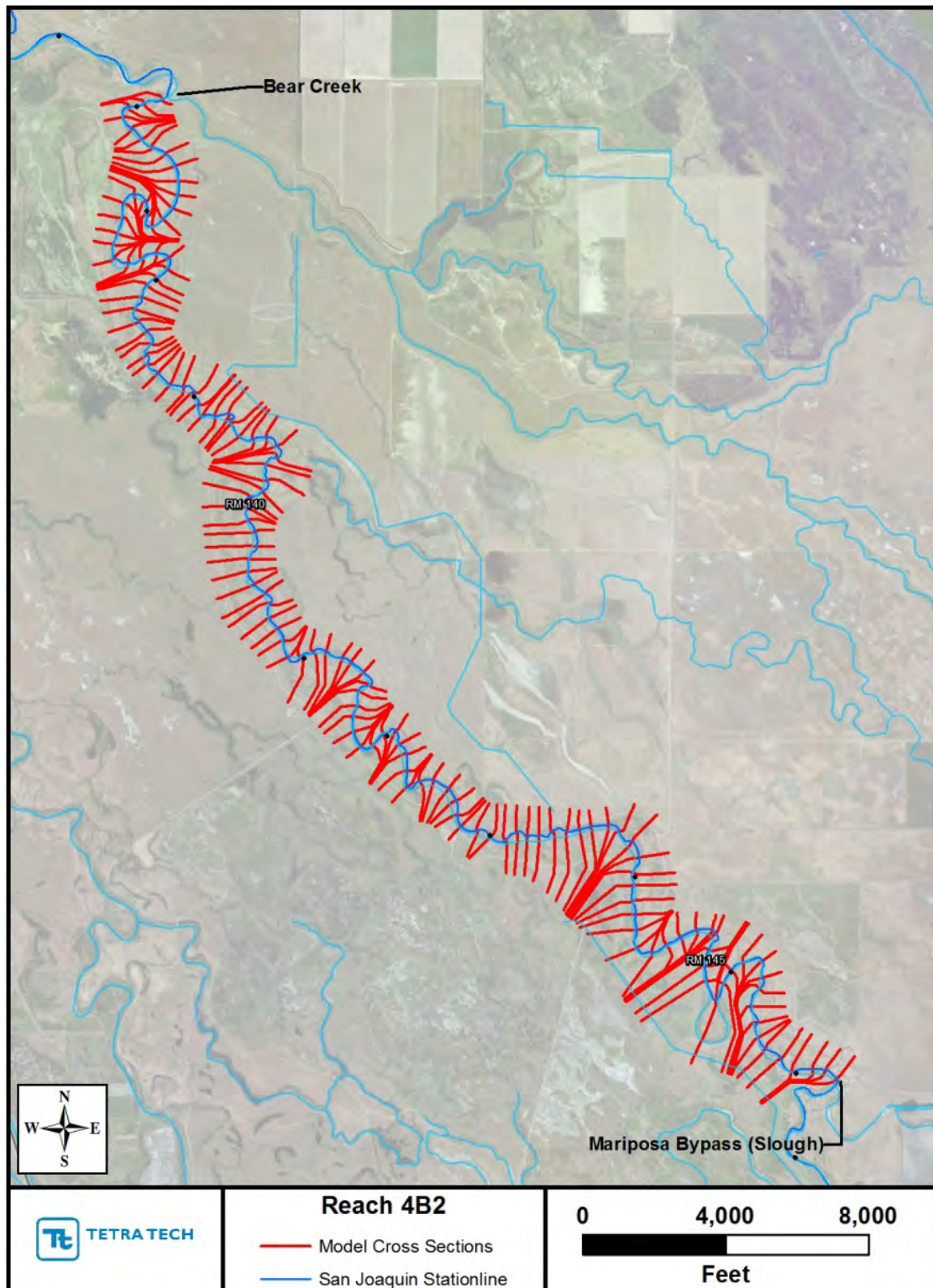


Figure 3.12. Reach 4B2 geographic extents and major features.

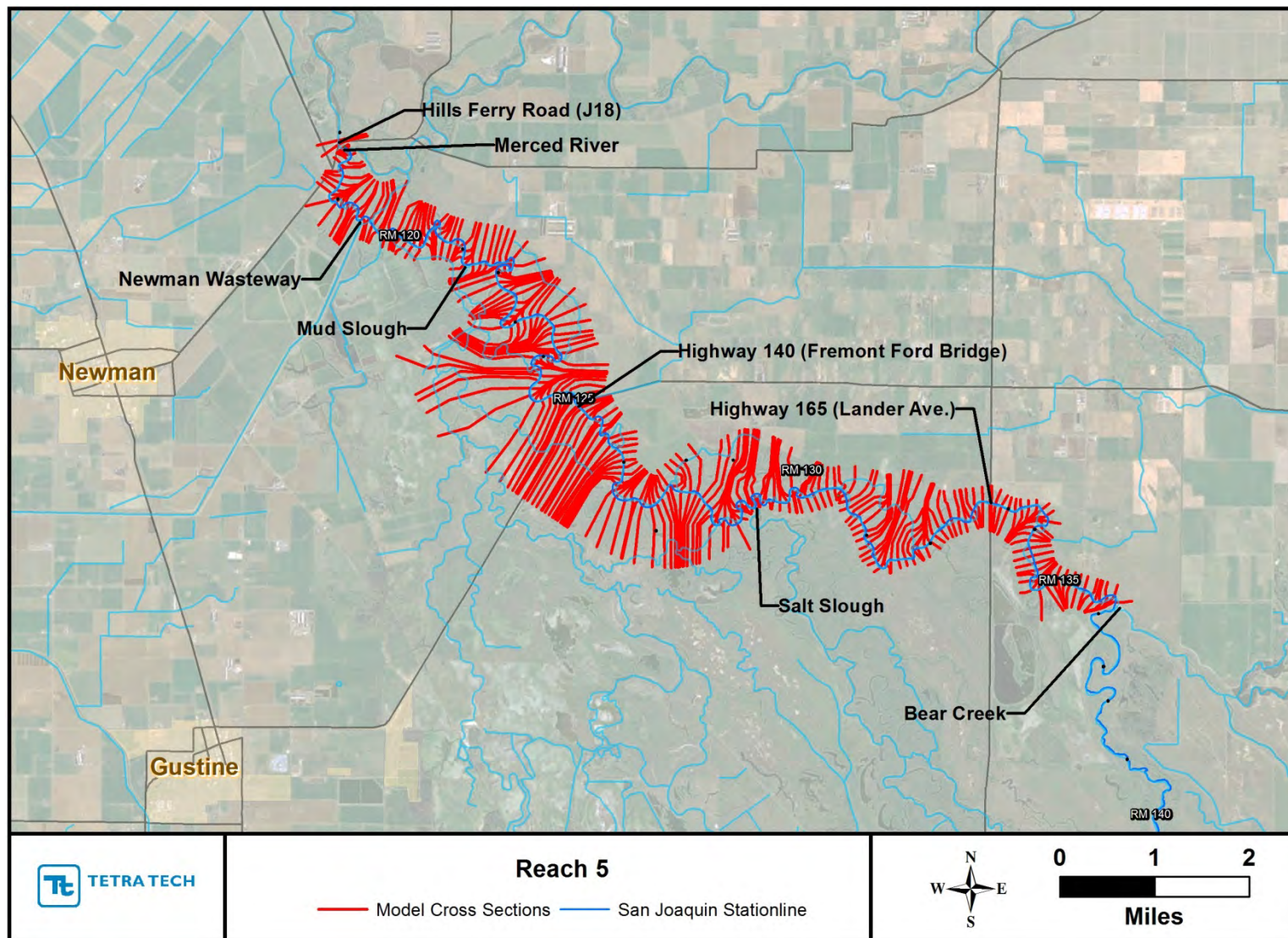


Figure 3.13. Reach 5 geographic extents and major features.

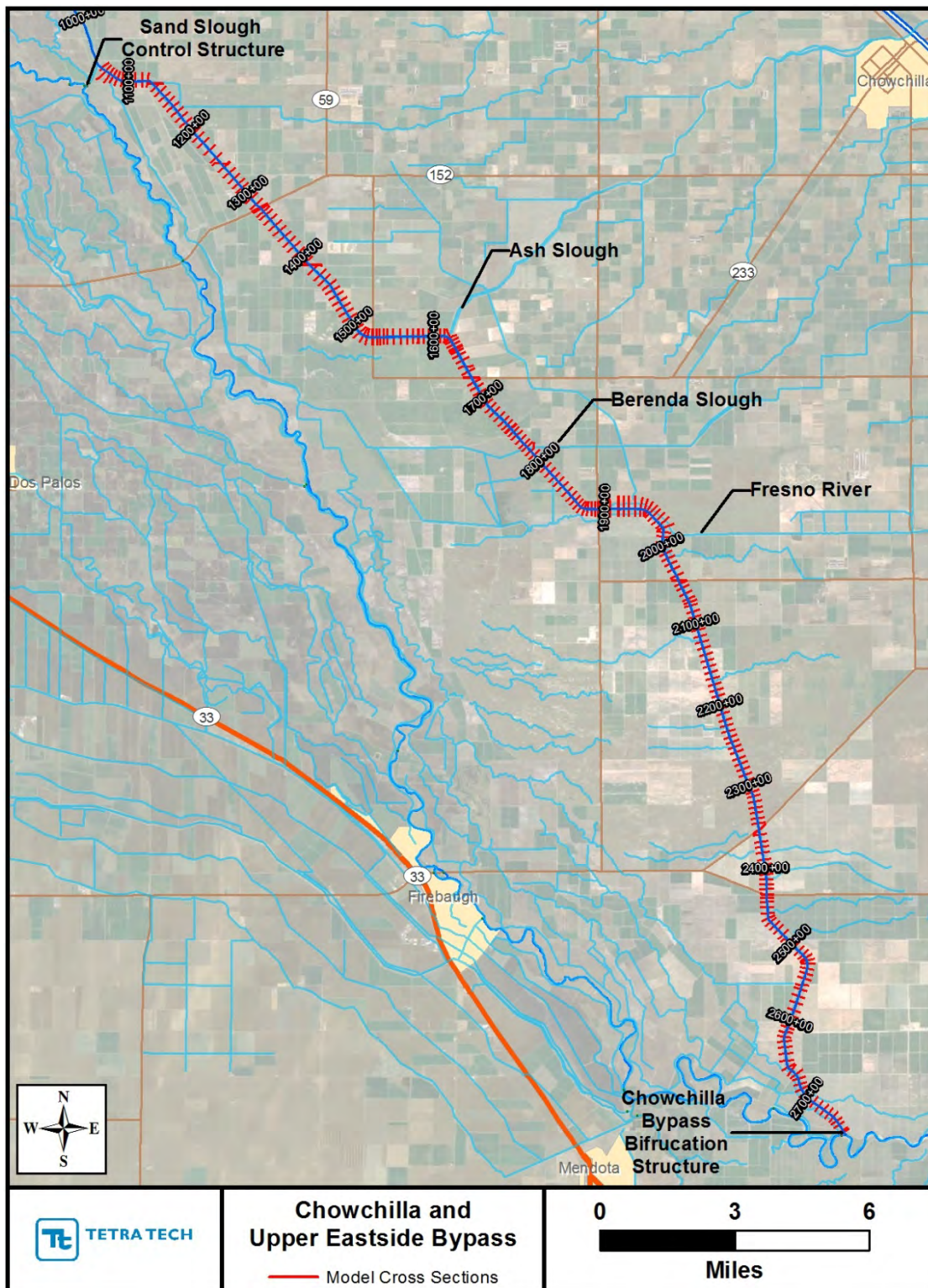


Figure 3.14. Chowchilla and Upper Eastside Bypass geographic extents and major features.

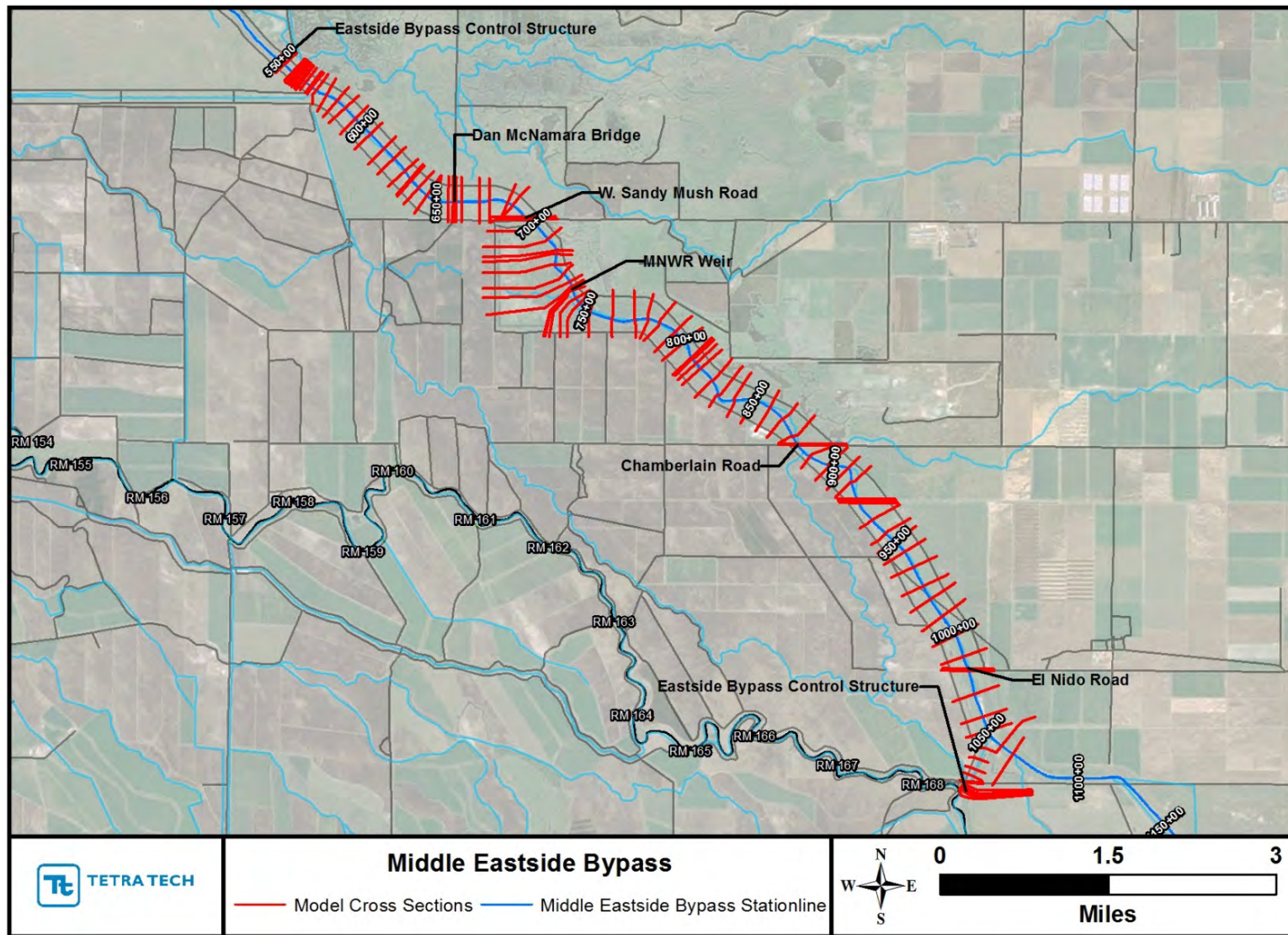


Figure 3.15. Middle Eastside Bypass geographic extents and major features.

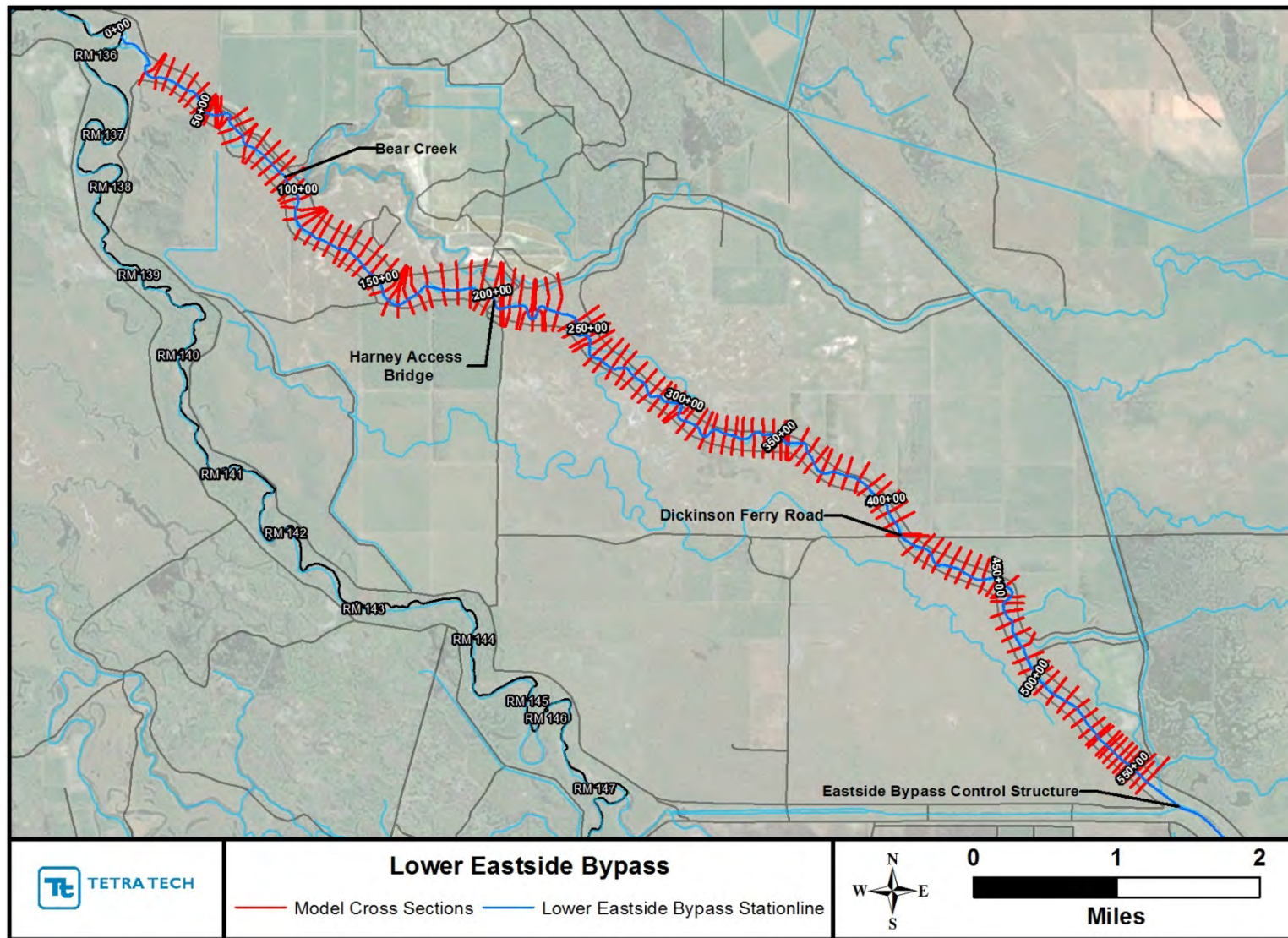


Figure 3.16. Lower Eastside Bypass geographic extents and major features.

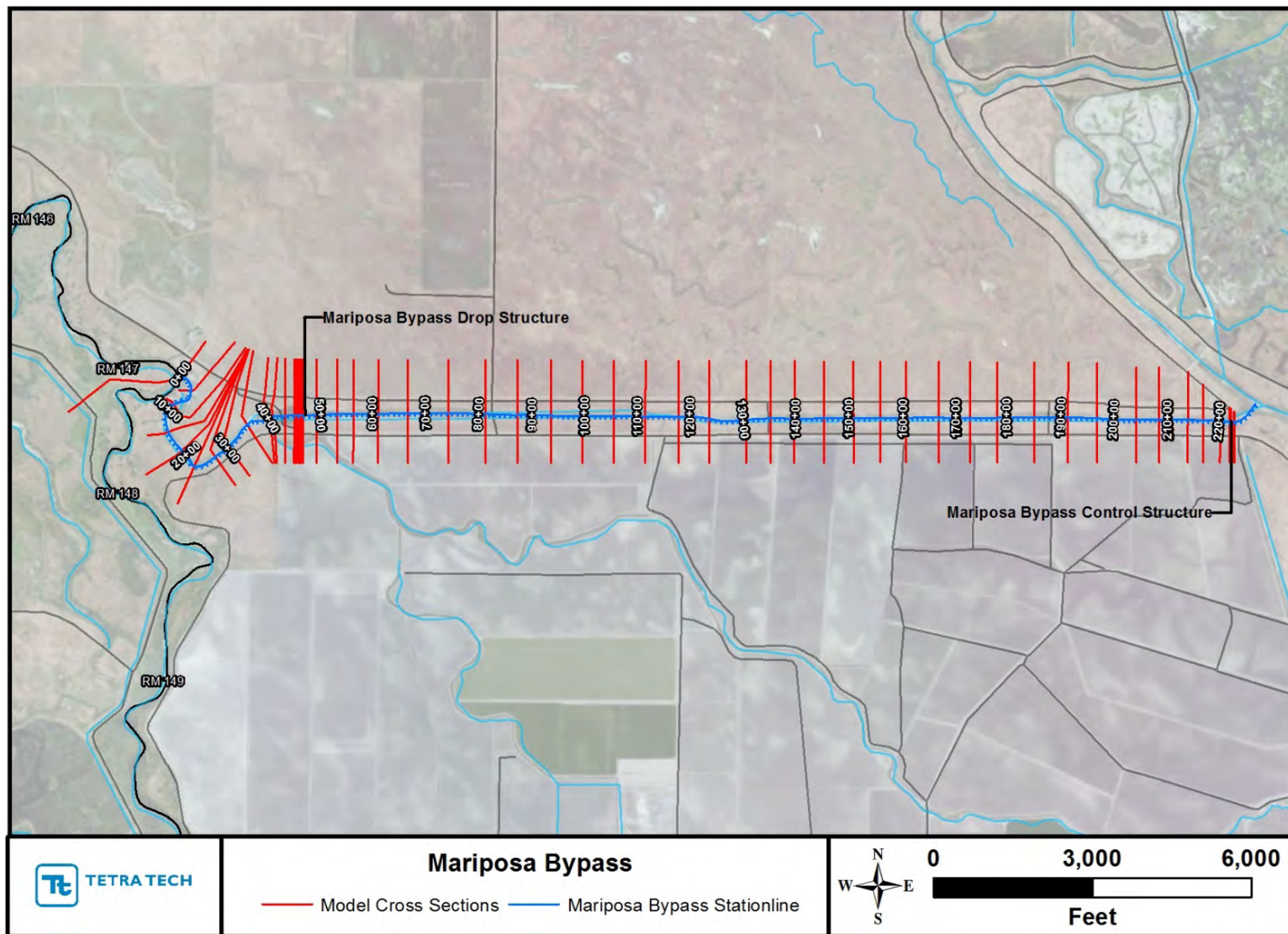


Figure 3.17. Lower Eastside Bypass geographic extents and major features.

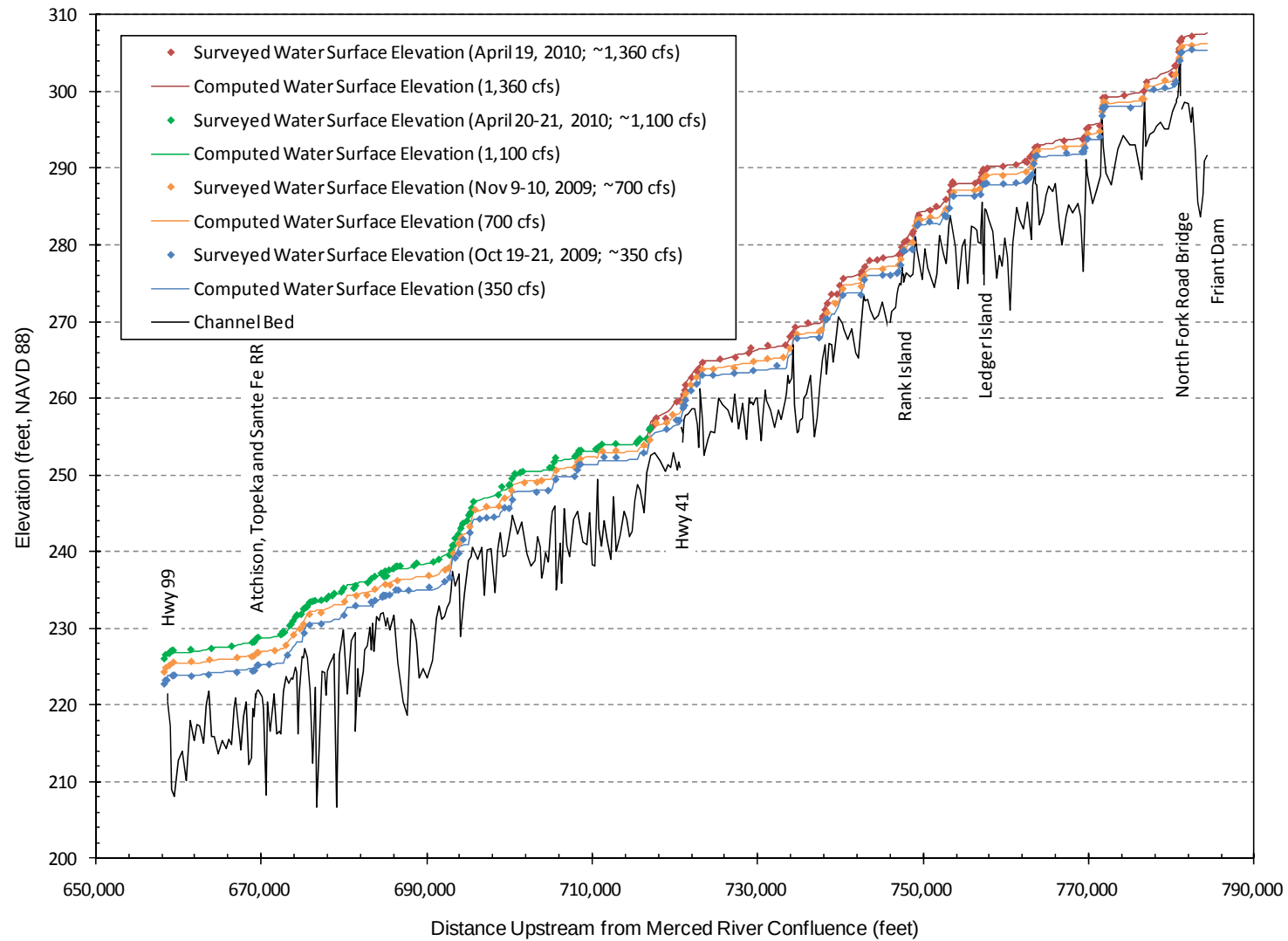


Figure 4.1. Computed (refined model) and measured water-surface profiles in Reach 1A at 350, 700, 1,100, and 1,360 cfs.

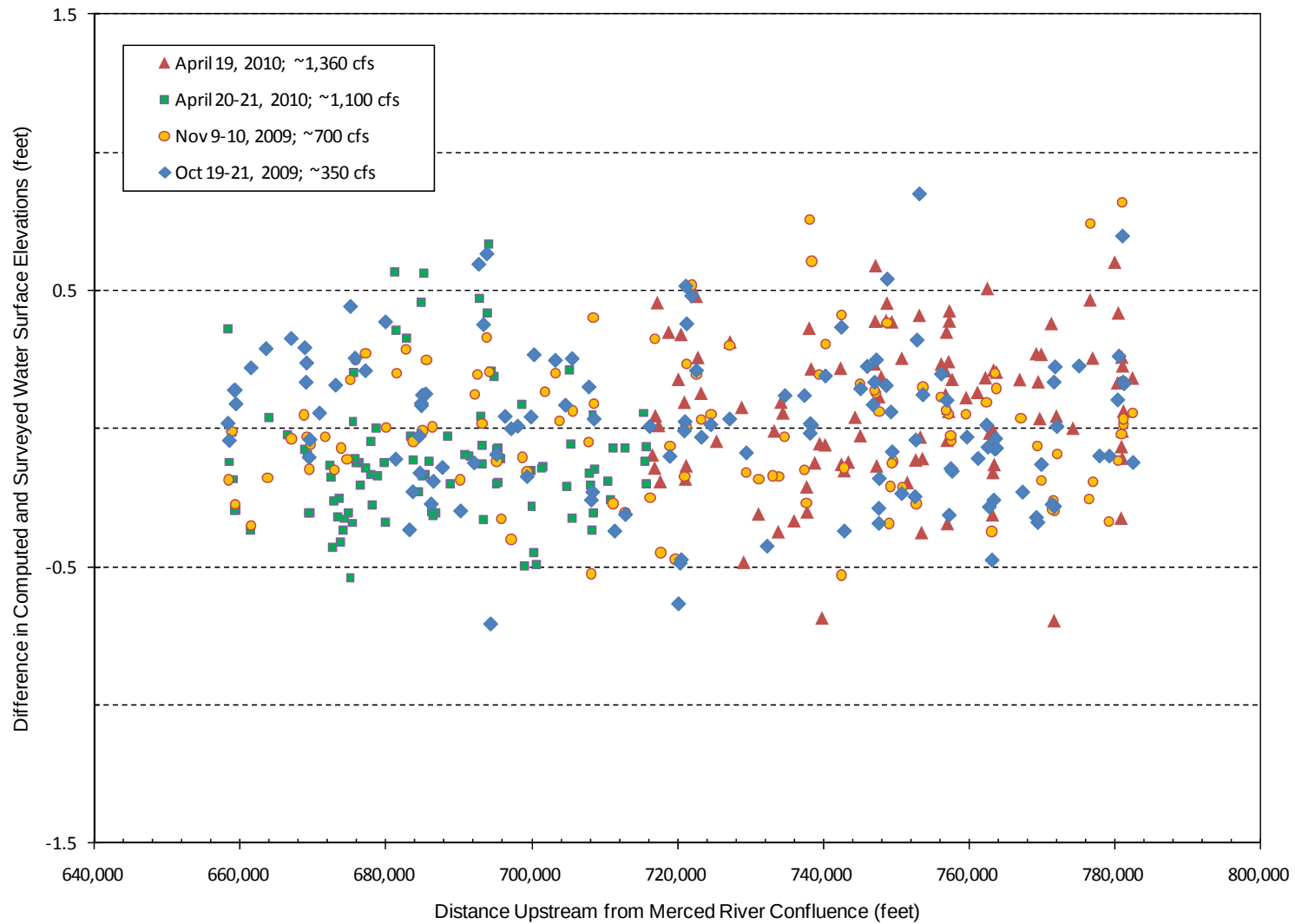


Figure 4.2. Differences between computed (refined model) and measured water-surface profiles in Reach 1A at 350, 700, 1,100, and 1,360 cfs.

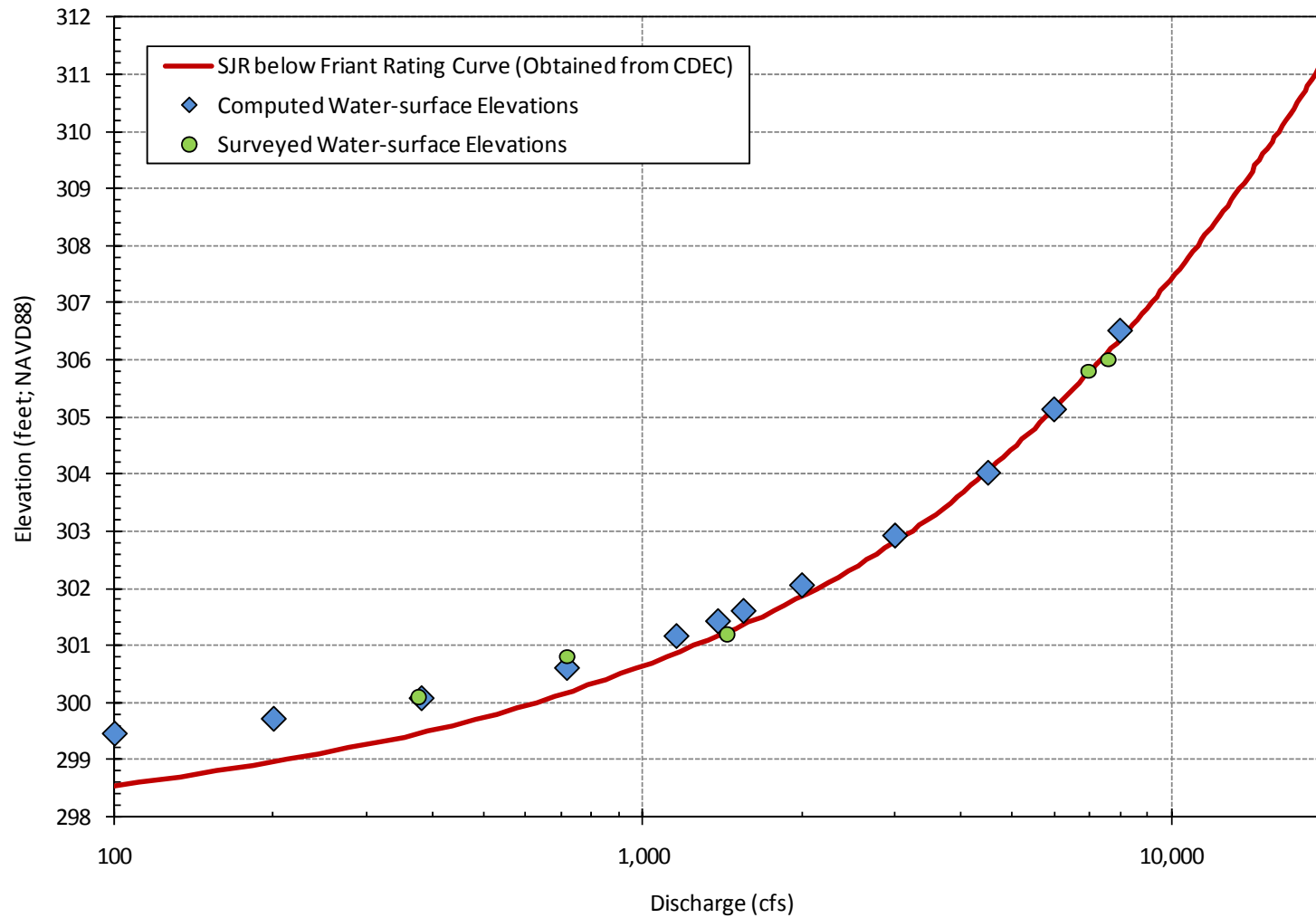


Figure 4.3. Comparison of computed water-surface elevations with the rating curve at the San Joaquin River below Friant Gage (USGS Gage No. 11251000) near Sta 7768+80.

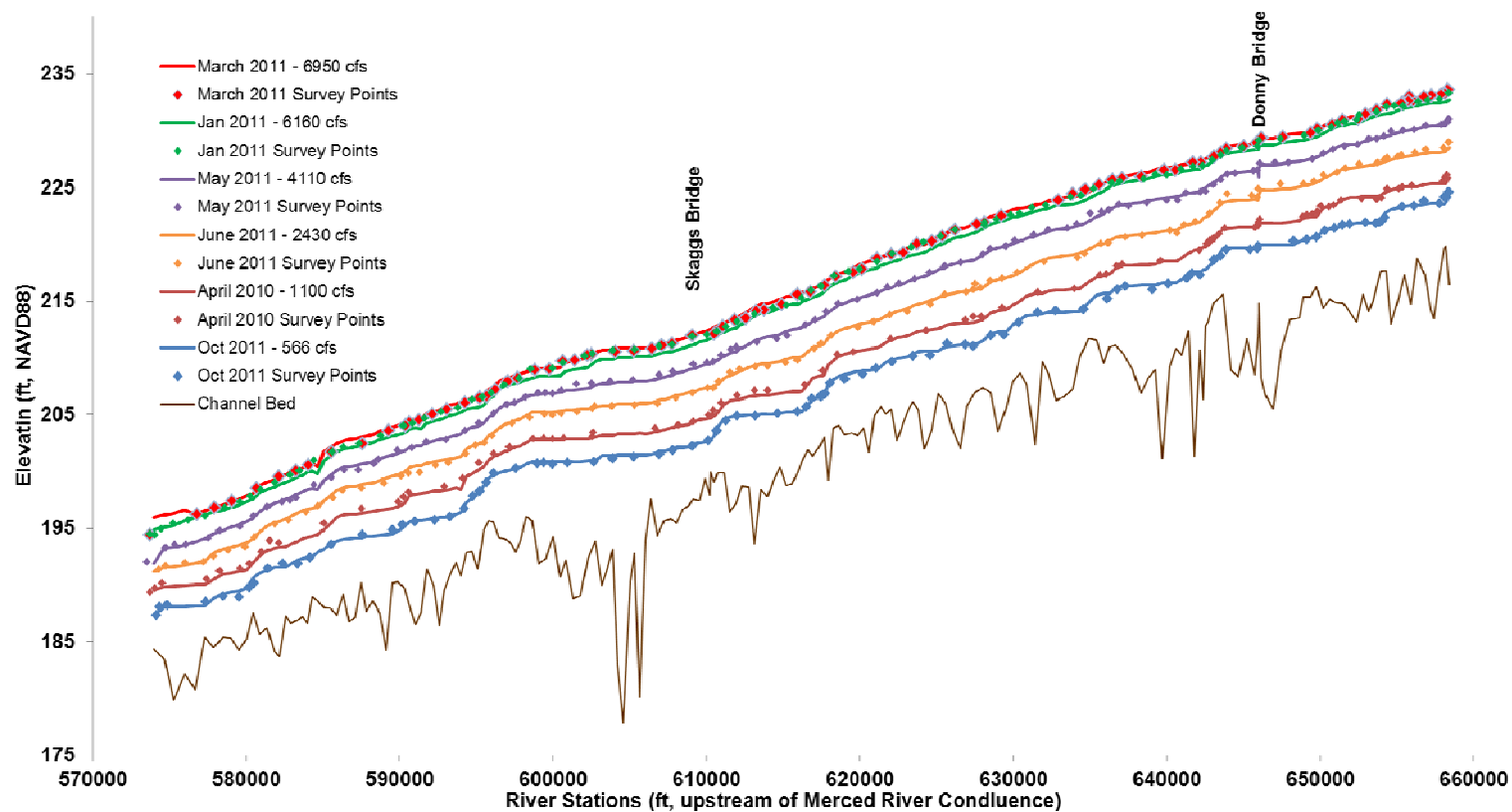


Figure 4.4. Computed (refined model) and surveyed water-surface elevations in Reach 1B for calibration flow events between 566 and 6,950 cfs.

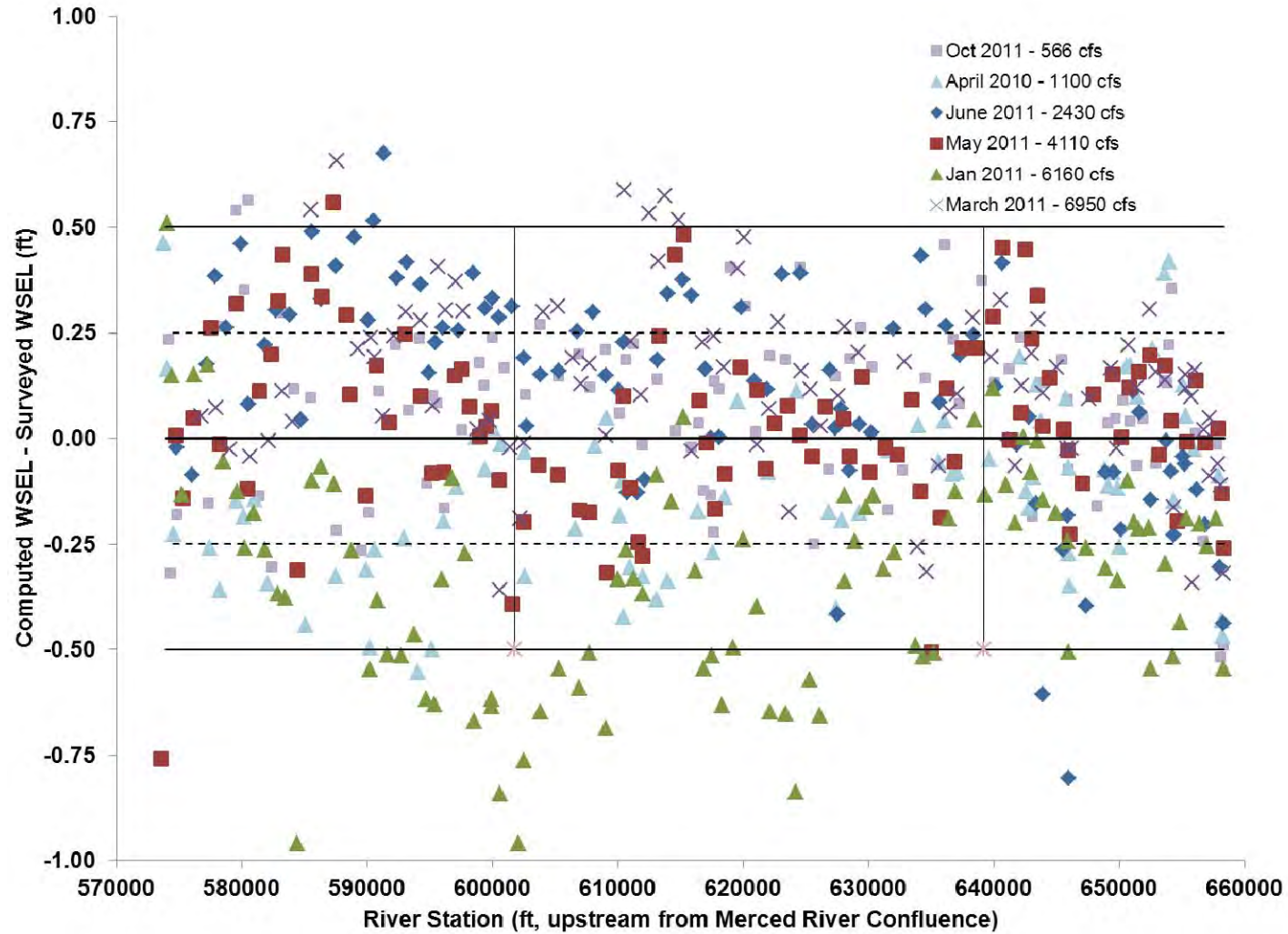


Figure 4.5. Differences between computed (refined model) and measured water-surface profiles in Reach 1B at flows between 566 and 6,950 cfs. Positive values indicate computed values are above measured.

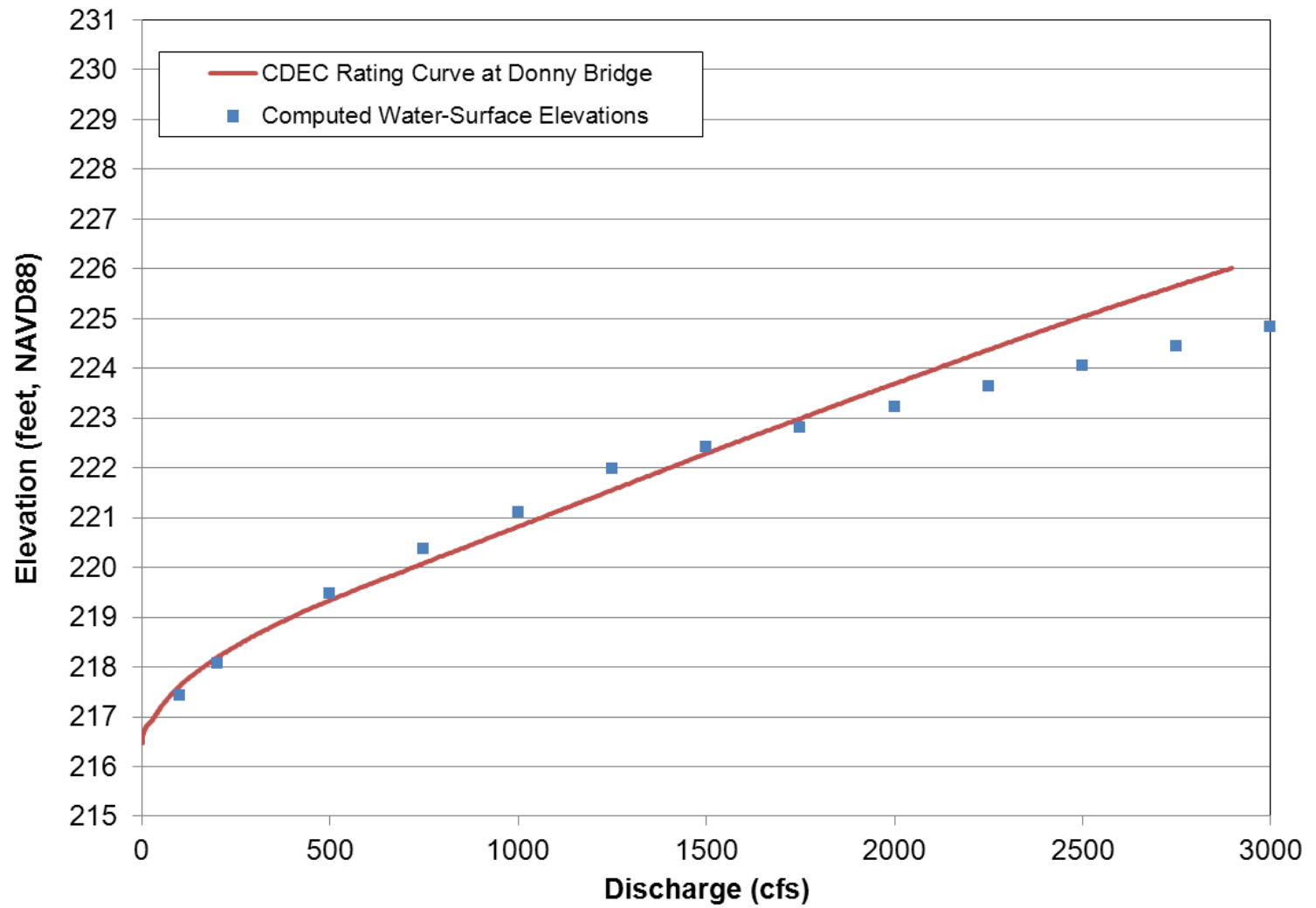


Figure 4.6. Comparison of computed water-surface elevations with the rating curve at San Joaquin River at Donny Bridge (CDEC-DNB) at RM 240.8.

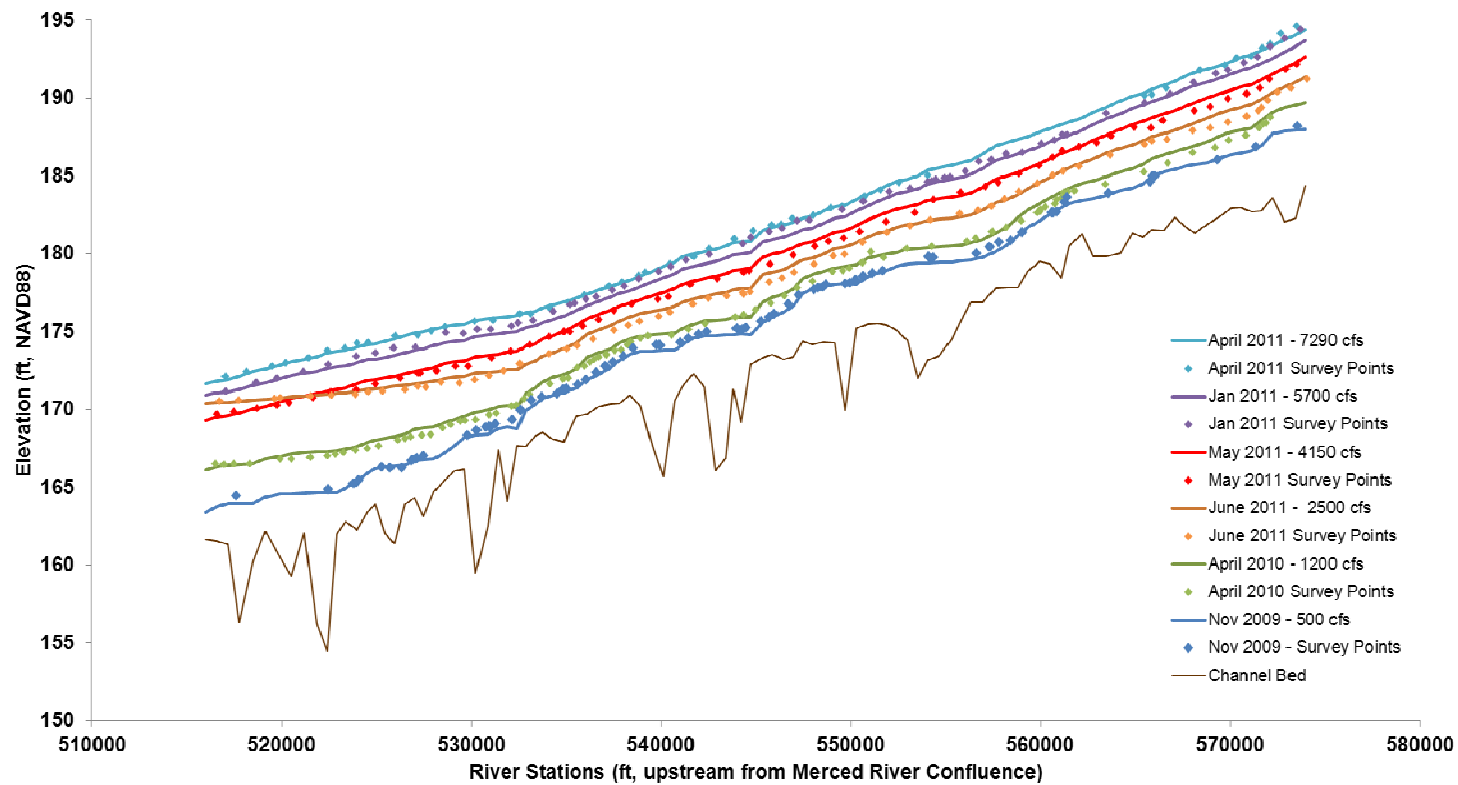


Figure 4.7. Computed (refined model) and surveyed water-surface elevations in Reach 2A for calibration flow events between 500 and 7,290 cfs.

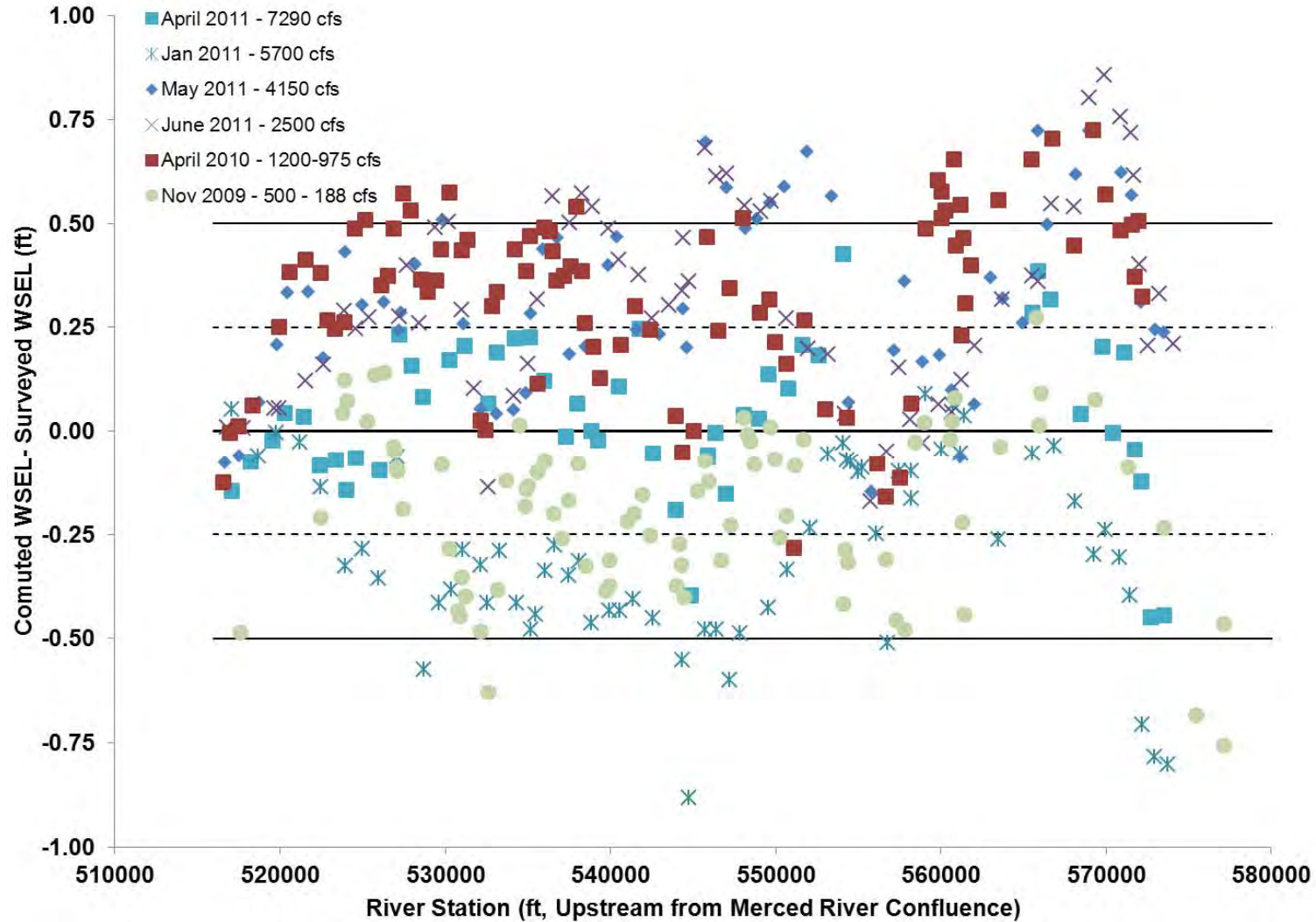


Figure 4.8. Differences between computed (refined model) and measured water-surface profiles in Reach 2A at flows between about 500 and 7,300 cfs. Positive values indicate computed values are above measured.

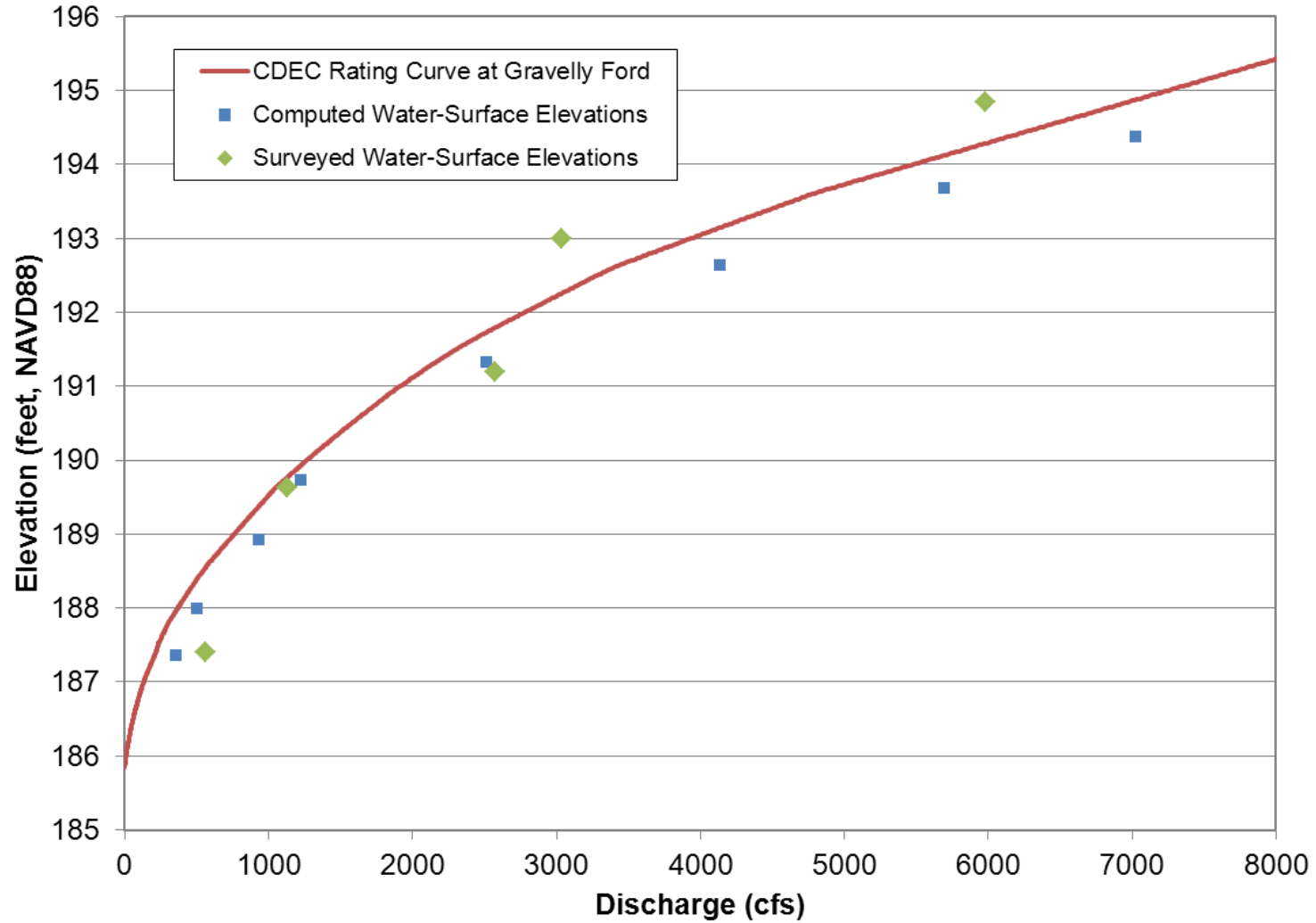


Figure 4.9. Comparison of computed and surveyed water-surface elevations with the rating curve at San Joaquin River at Gravelly Ford (CDEC-GRF) at RM 227.5.

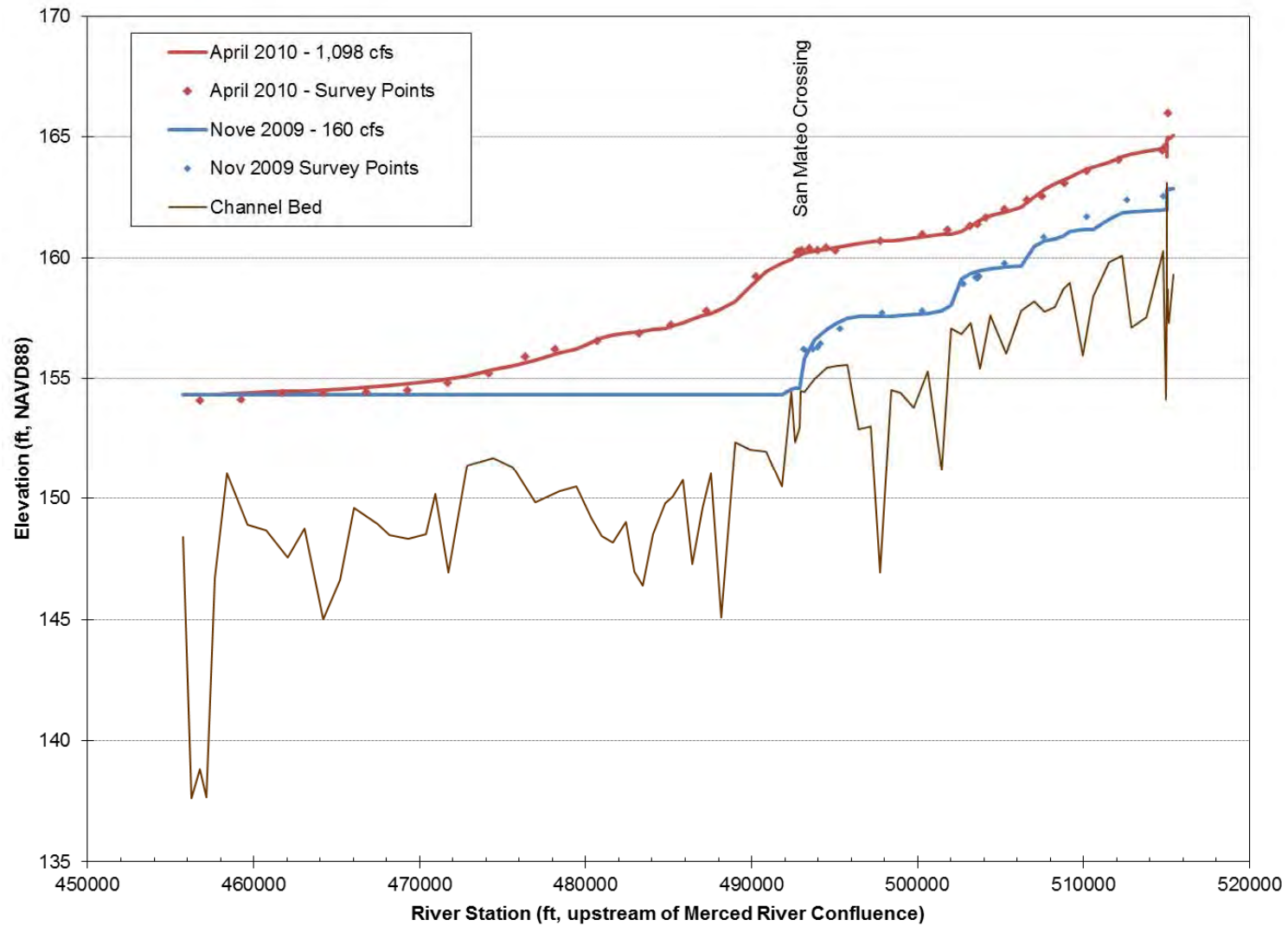


Figure 4.10. Computed (refined model) and surveyed water-surface elevations in Reach 2B for calibration flow events of 160 and 1,098 cfs.

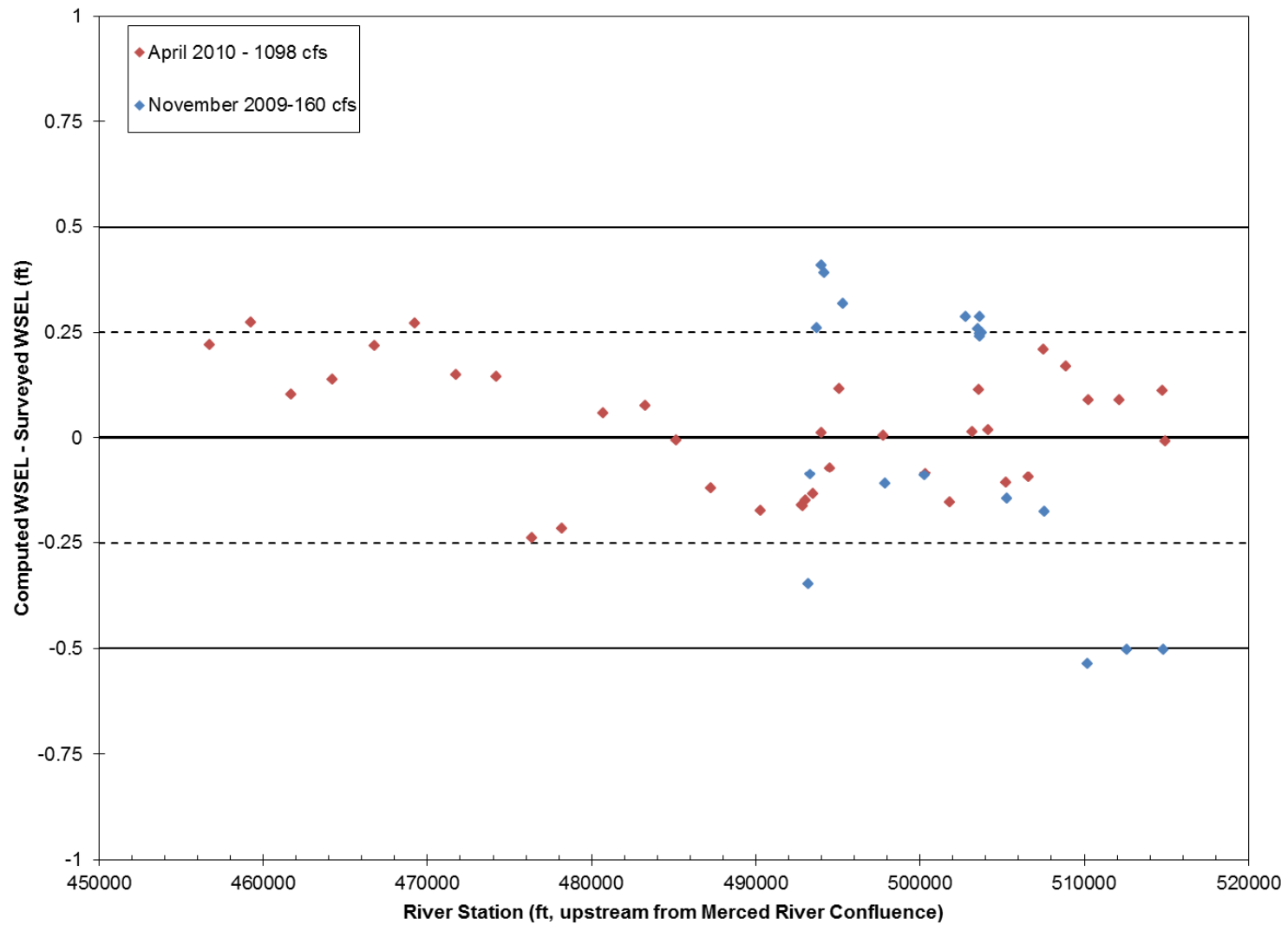


Figure 4.11. Differences between computed (refined model) and measured water-surface profiles in Reach 2B at flows of 160 and 1,070 cfs. Positive values indicate computed values are above measured.

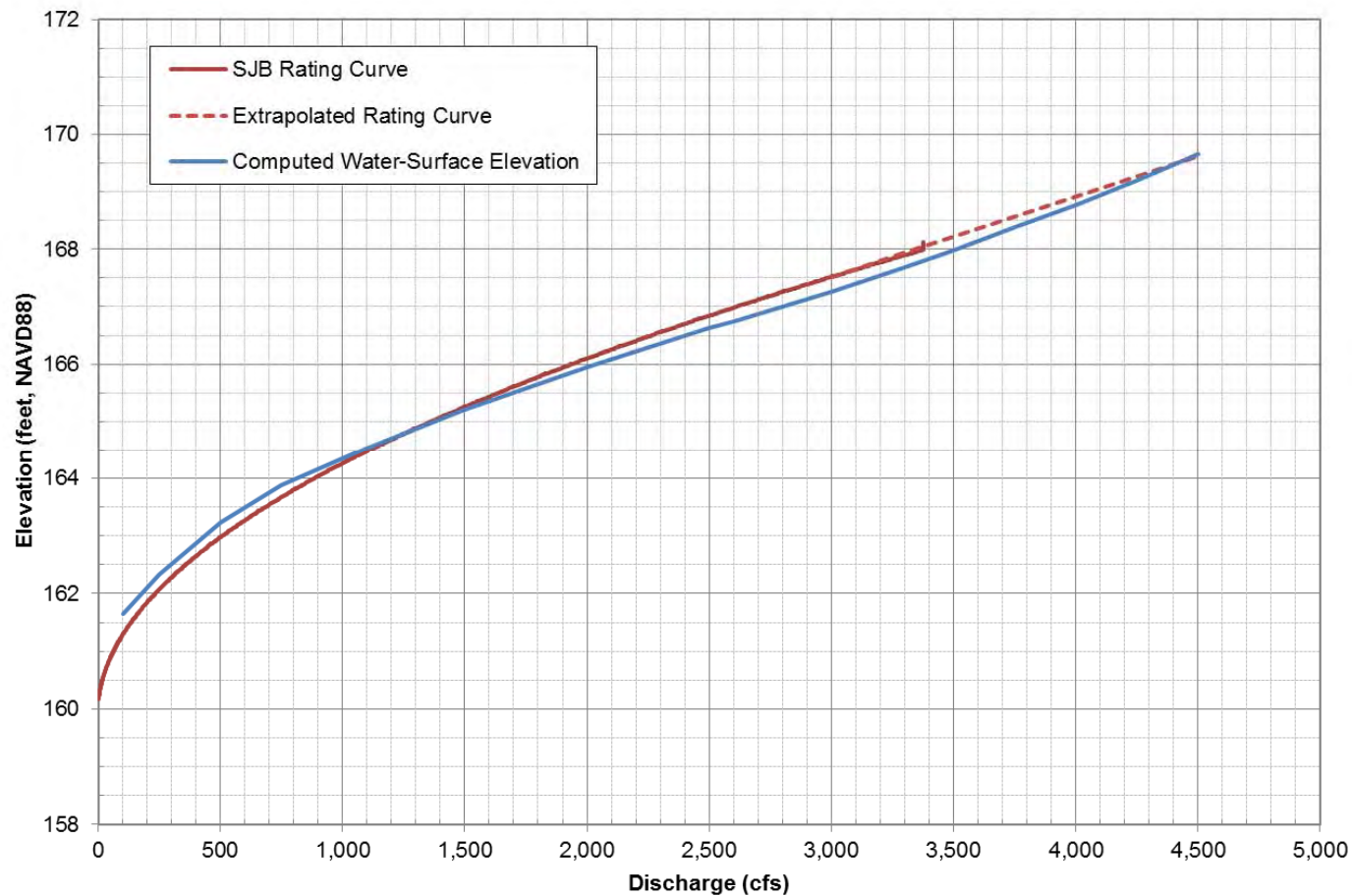


Figure 4.12. Comparison of computed and surveyed water-surface elevations with the rating curve at San Joaquin River below Chowchilla Canal Intake (CDEC-SJB) at RM 216.1.

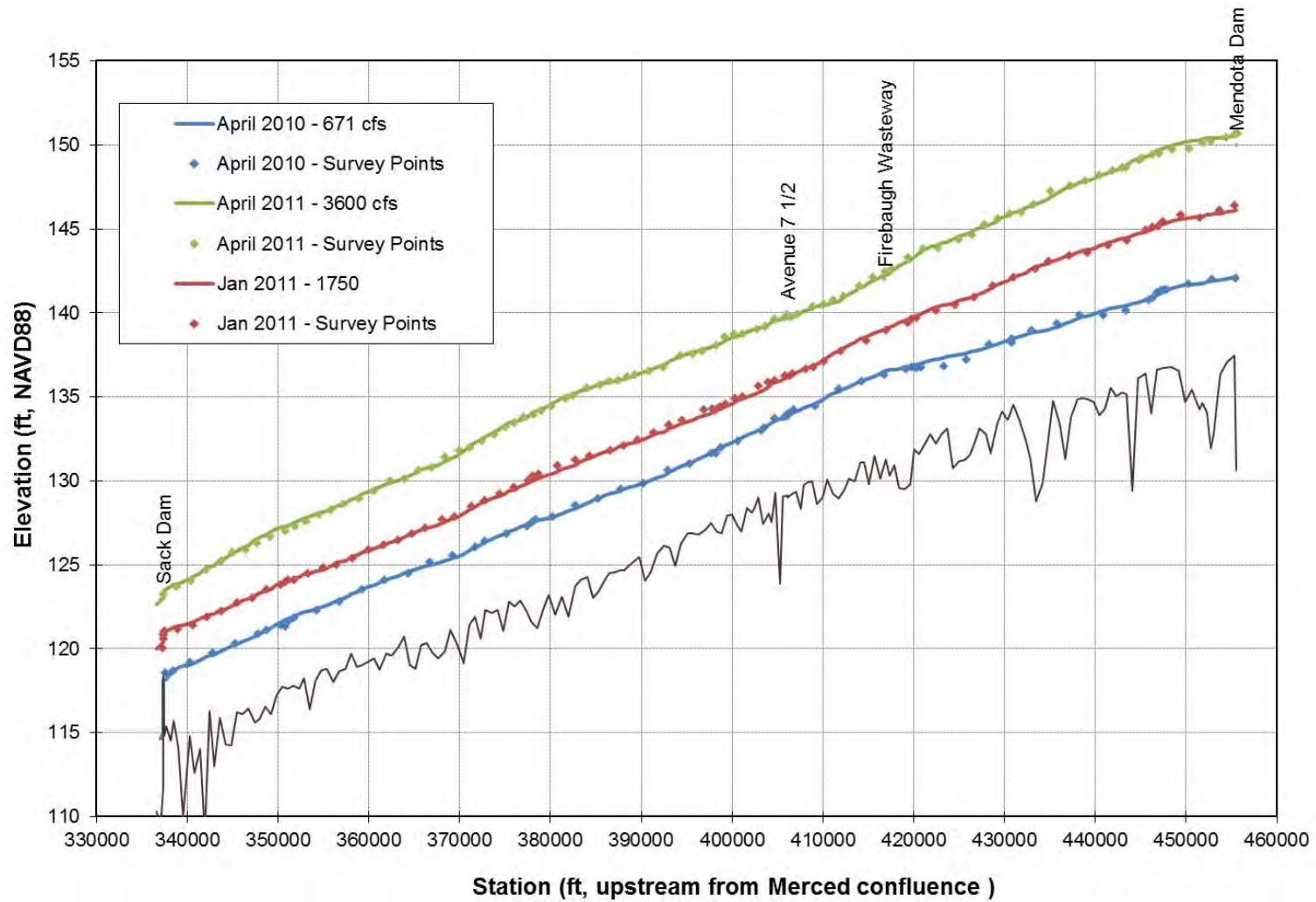


Figure 4.13. Computed (refined model) and measured water-surface profiles in Reach 3 for a range of flows between 700 and 3,600 cfs.

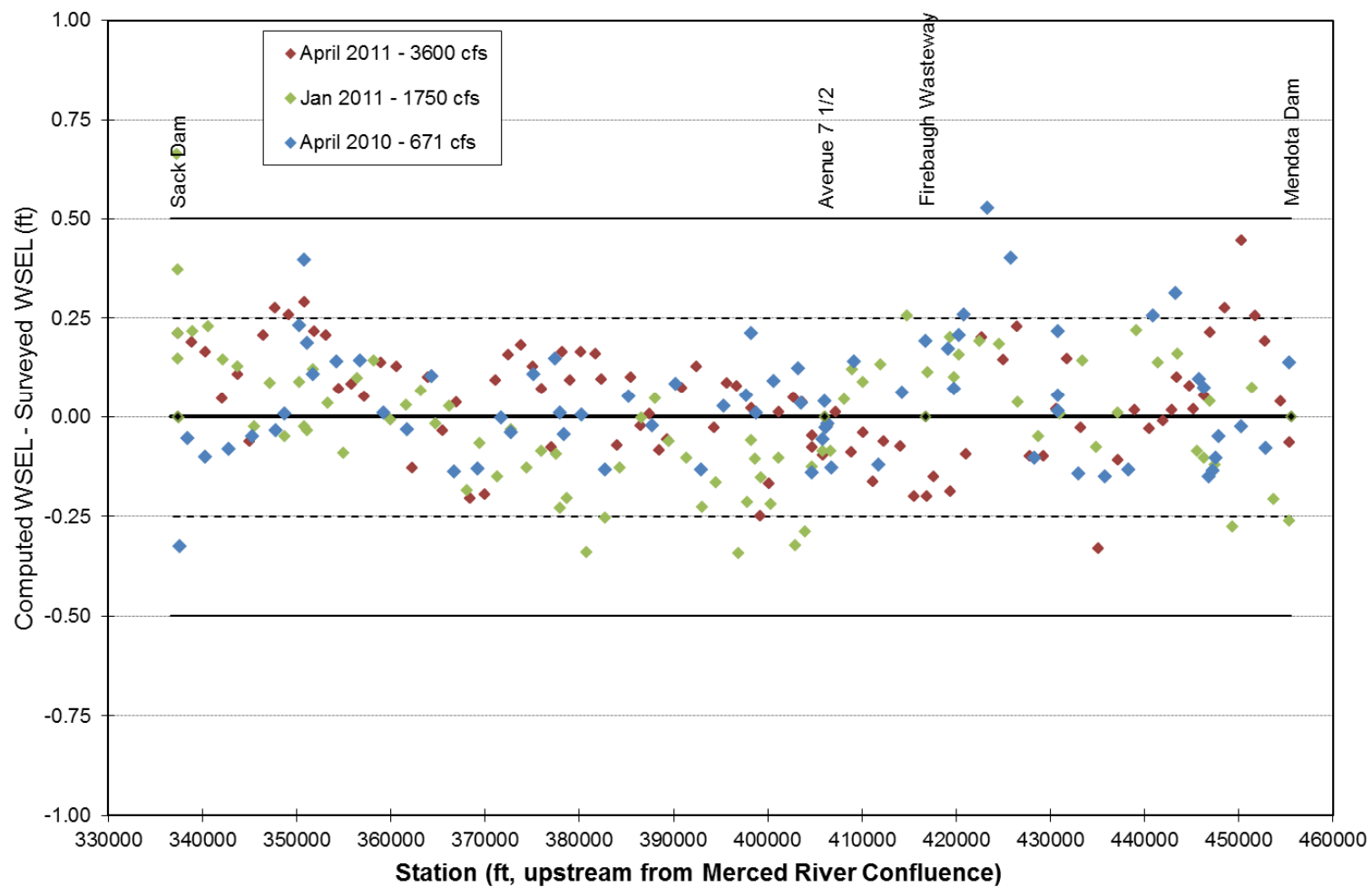


Figure 4.14. Differences between computed (refined model) and measured water-surface profiles in Reach 3 at flows between 700 and 3,600 cfs. Positive values indicate predicted values are above measured.

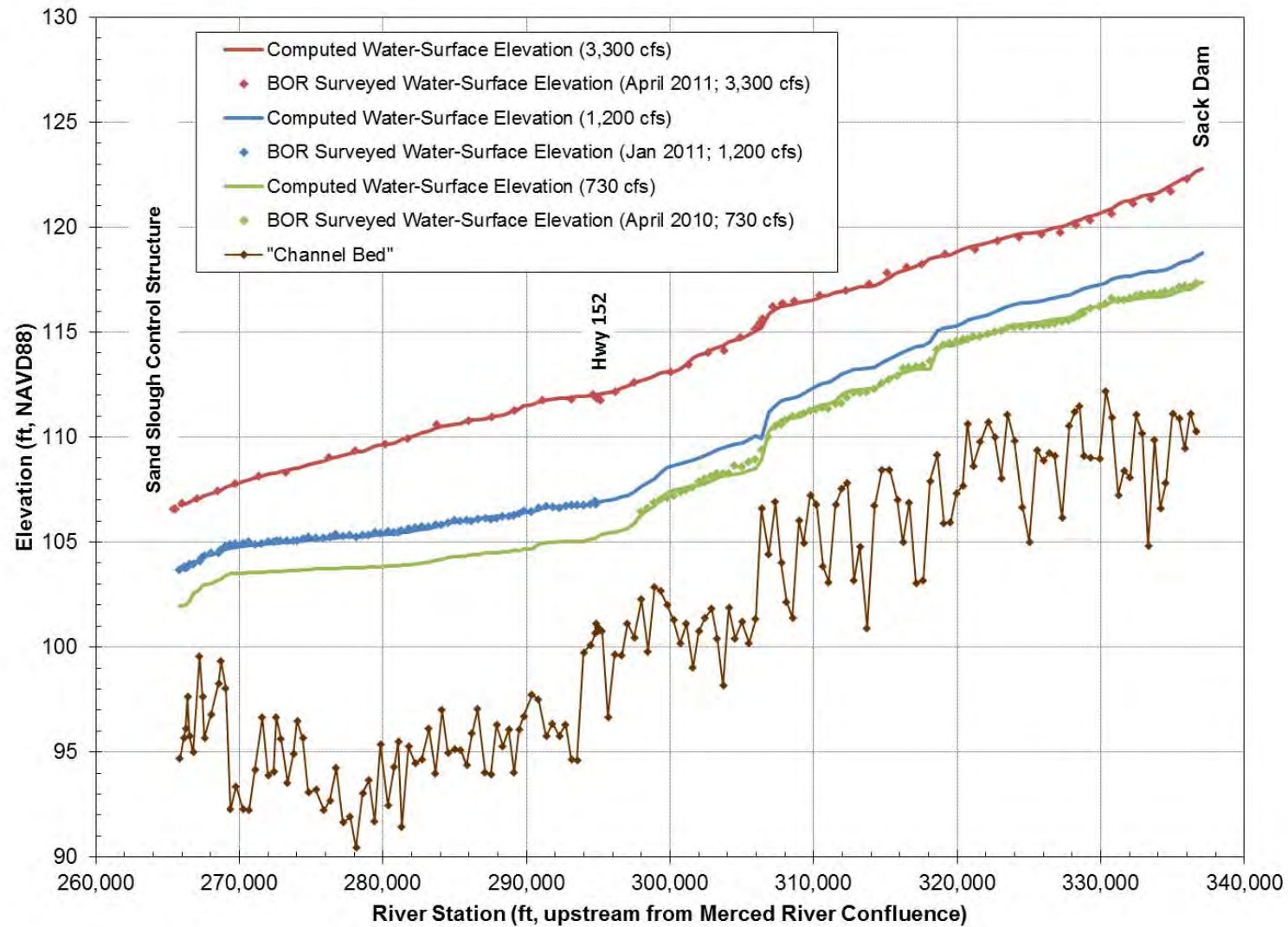


Figure 4.15. Computed (refined model) and surveyed water-surface elevations in Reach 4A for calibration flow events between 730 and 3,300 cfs.

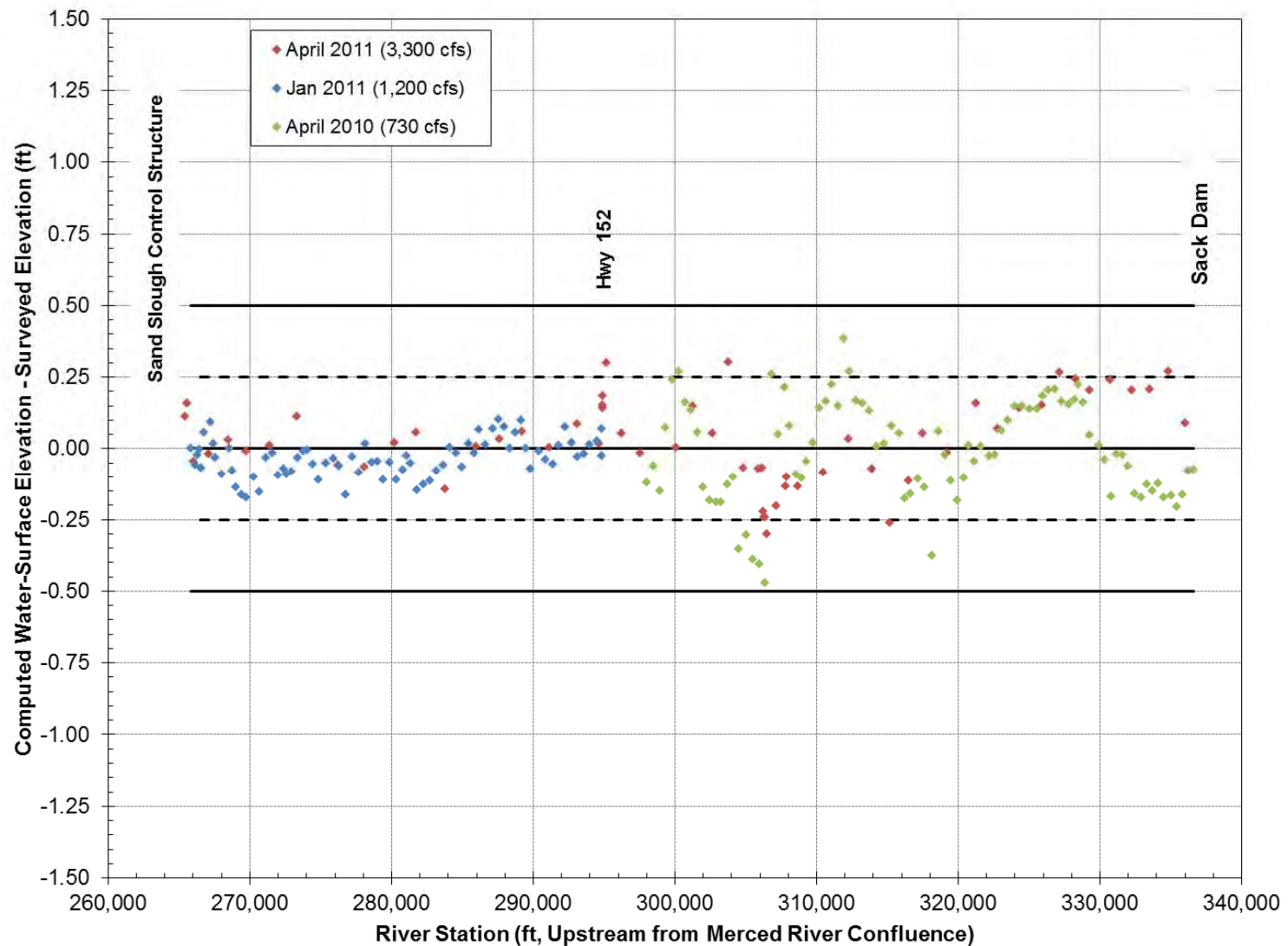


Figure 4.16. Differences between computed (refined model) and measured water-surface profiles in Reach 4A at flows between 730 and 3,300 cfs. Positive values indicate computed values are above measured.

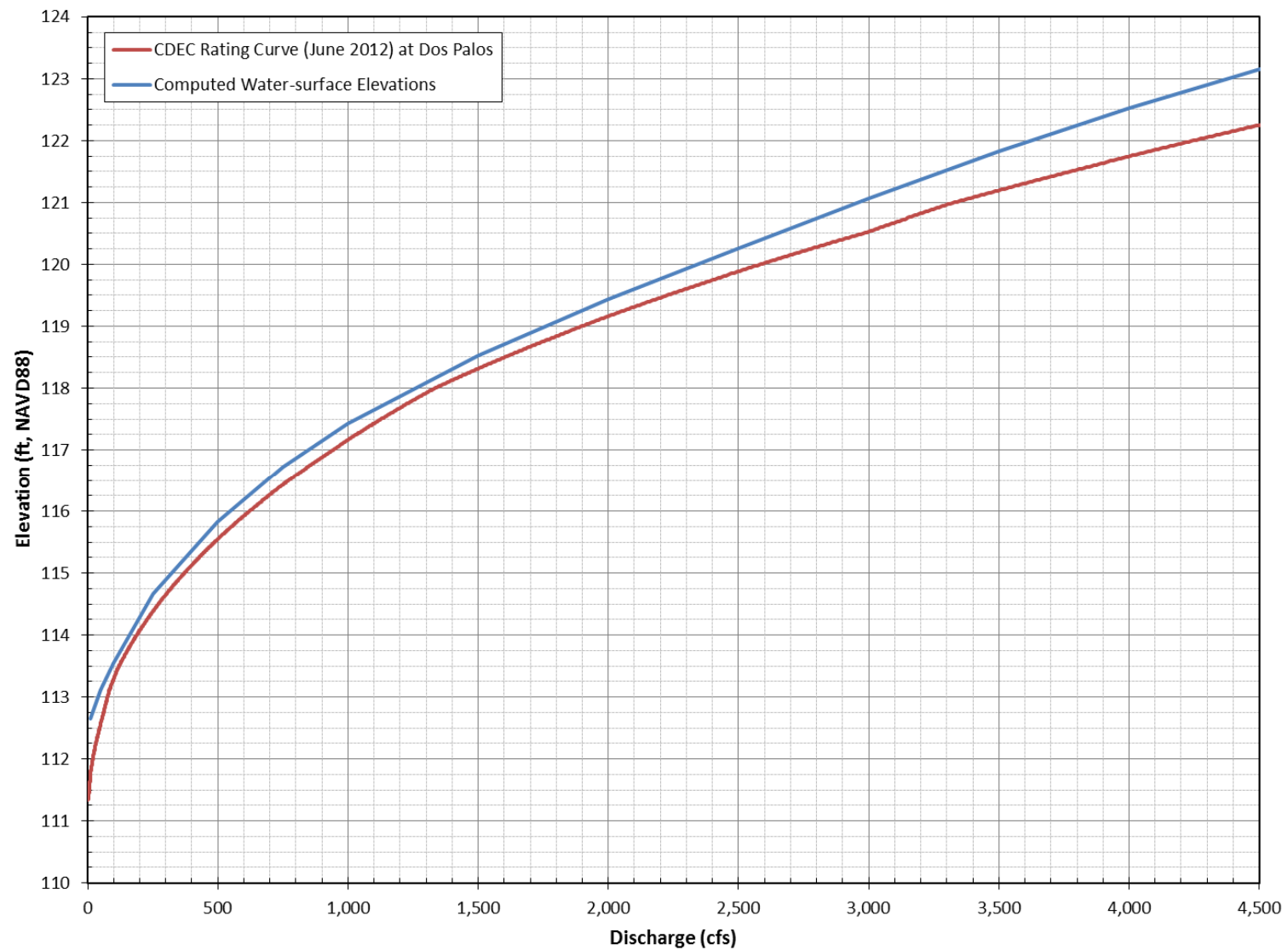


Figure 4.17. Comparison of computed water-surface elevations with the rating curve at San Joaquin River near Dos Palos (CDEC-SDP) at Sta 3335+20.

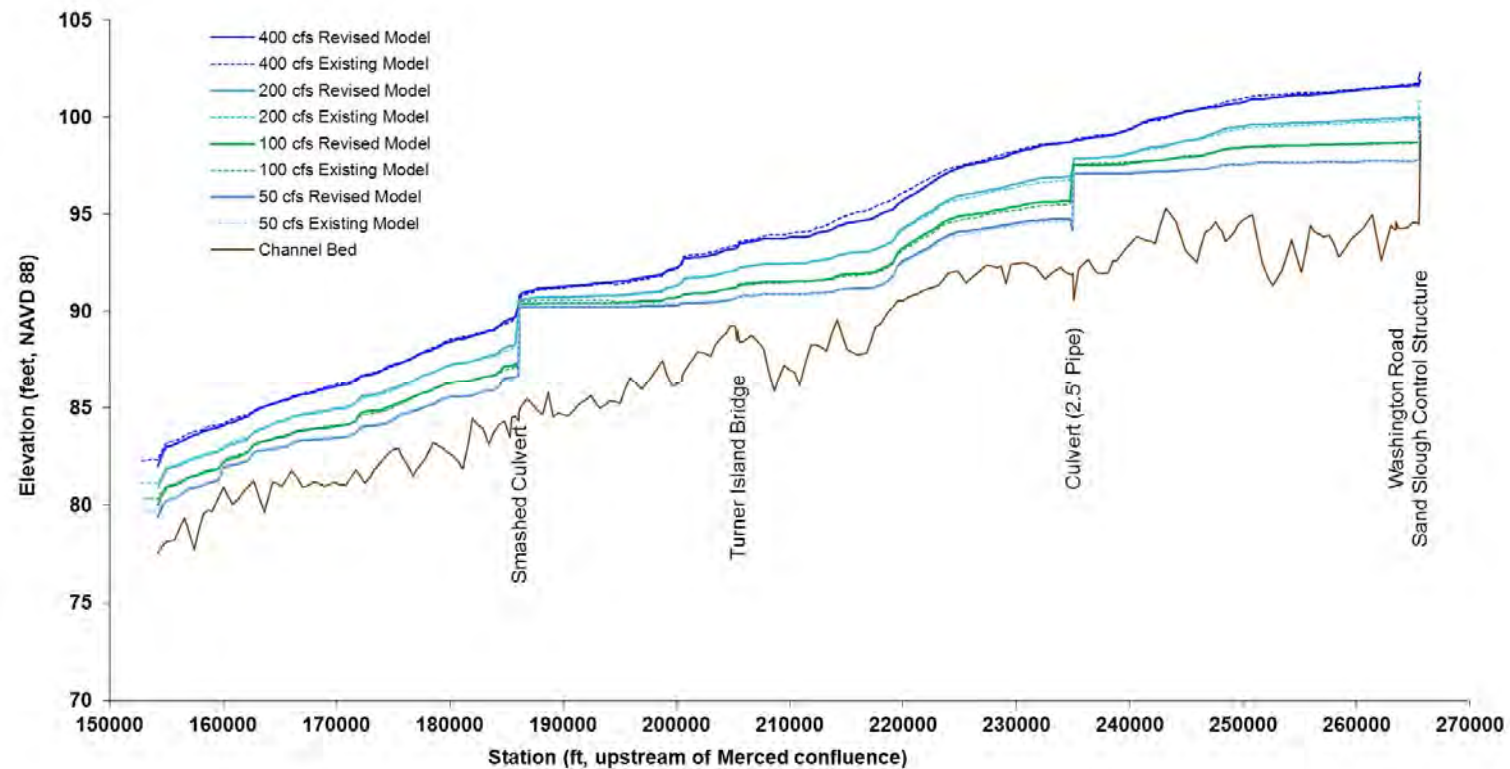


Figure 4.18. Computed (refined model) water-surface profiles in Reach 4B1 based on original and updated conditions over a range of flows from 50 to 400 cfs.

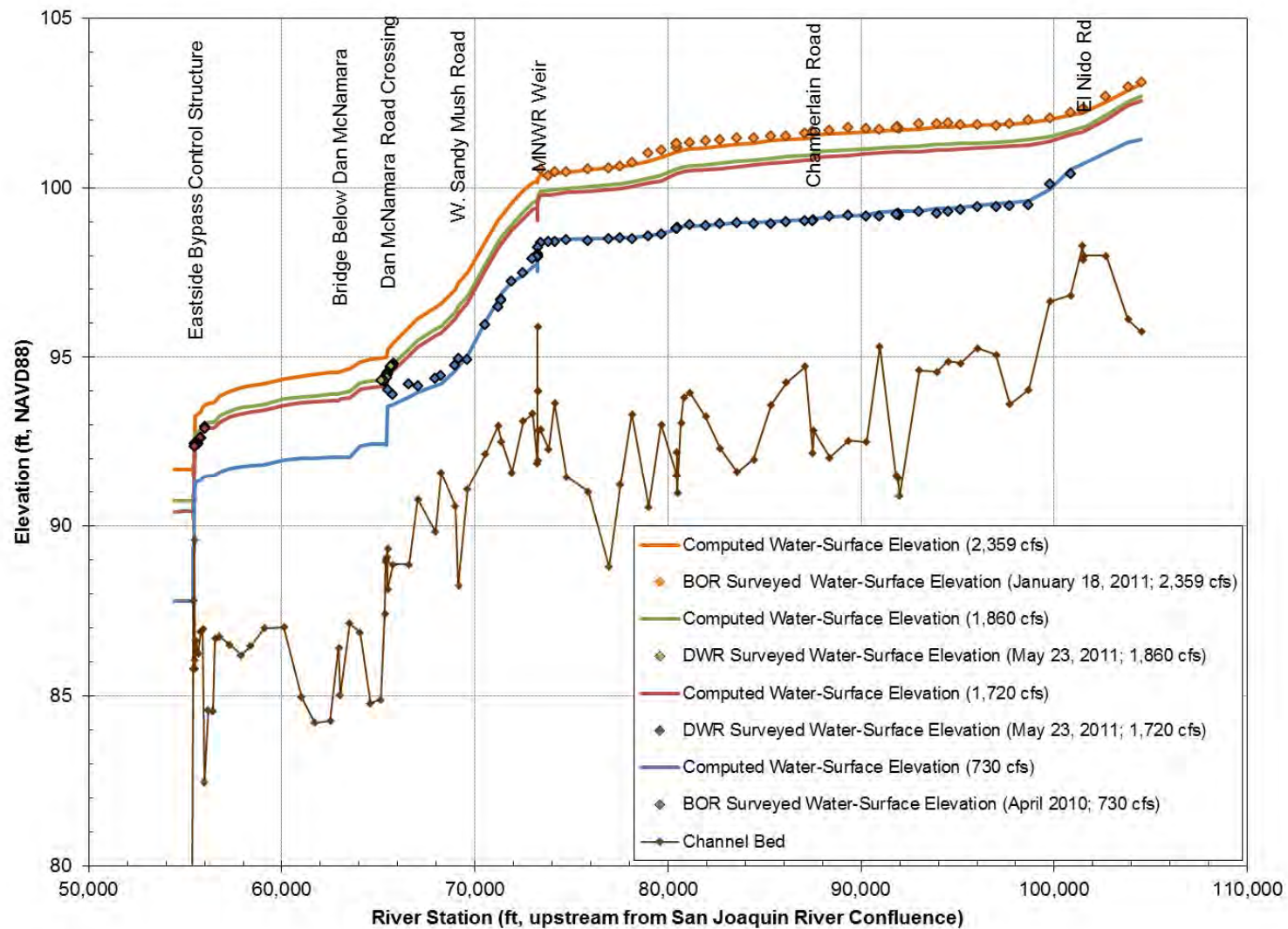


Figure 4.19. Computed (refined model) and surveyed water-surface elevations in the Middle Eastside Bypass for calibration flow events between 730 and 2,359 cfs (April 2010 data upstream of El Nido not shown).

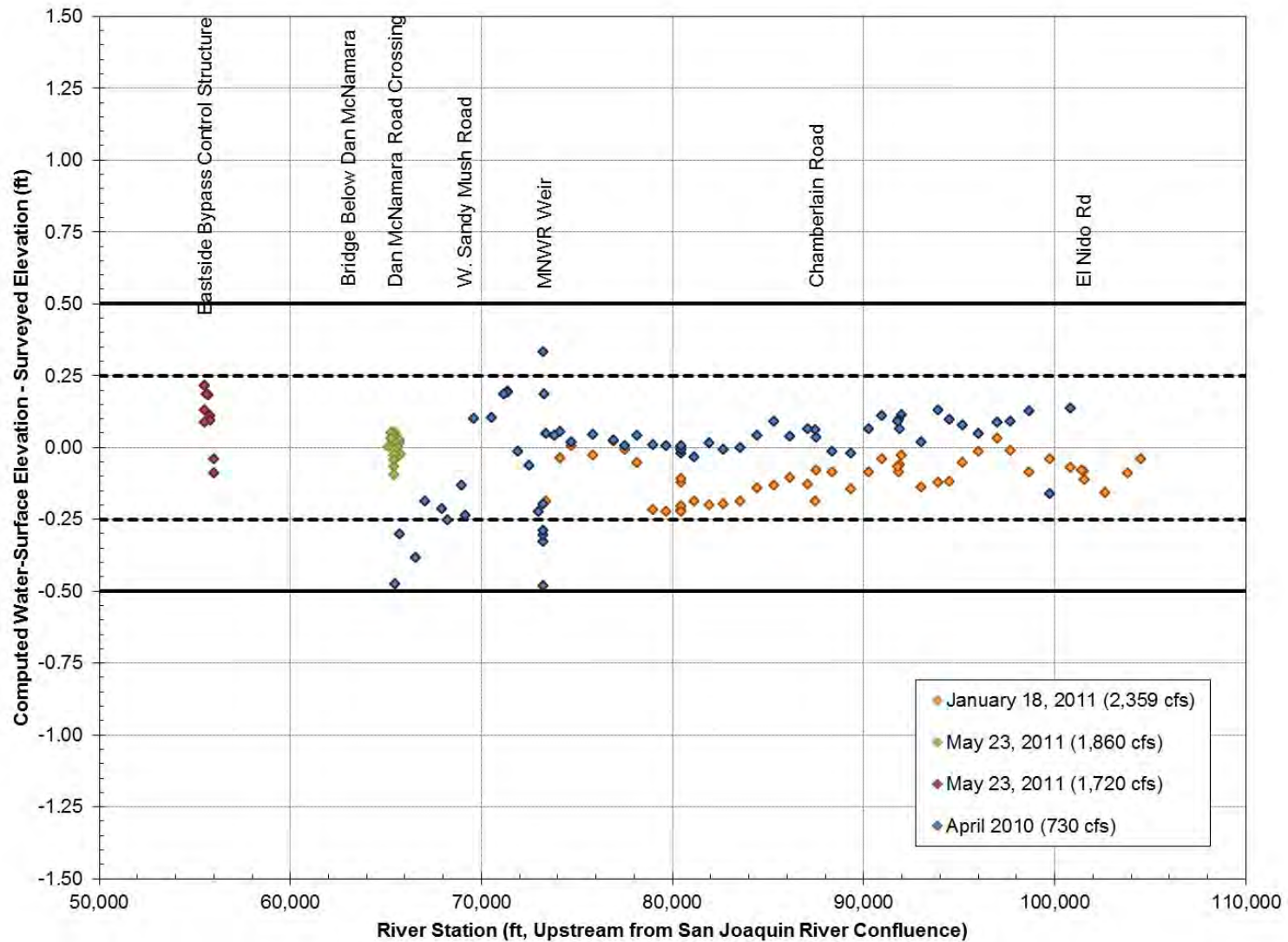


Figure 4.20. Differences between computed (refined model) and measured water-surface profiles in the Middle Eastside Bypass at flows between 730 and 2,359 cfs. Positive values indicate computed values are above measured.

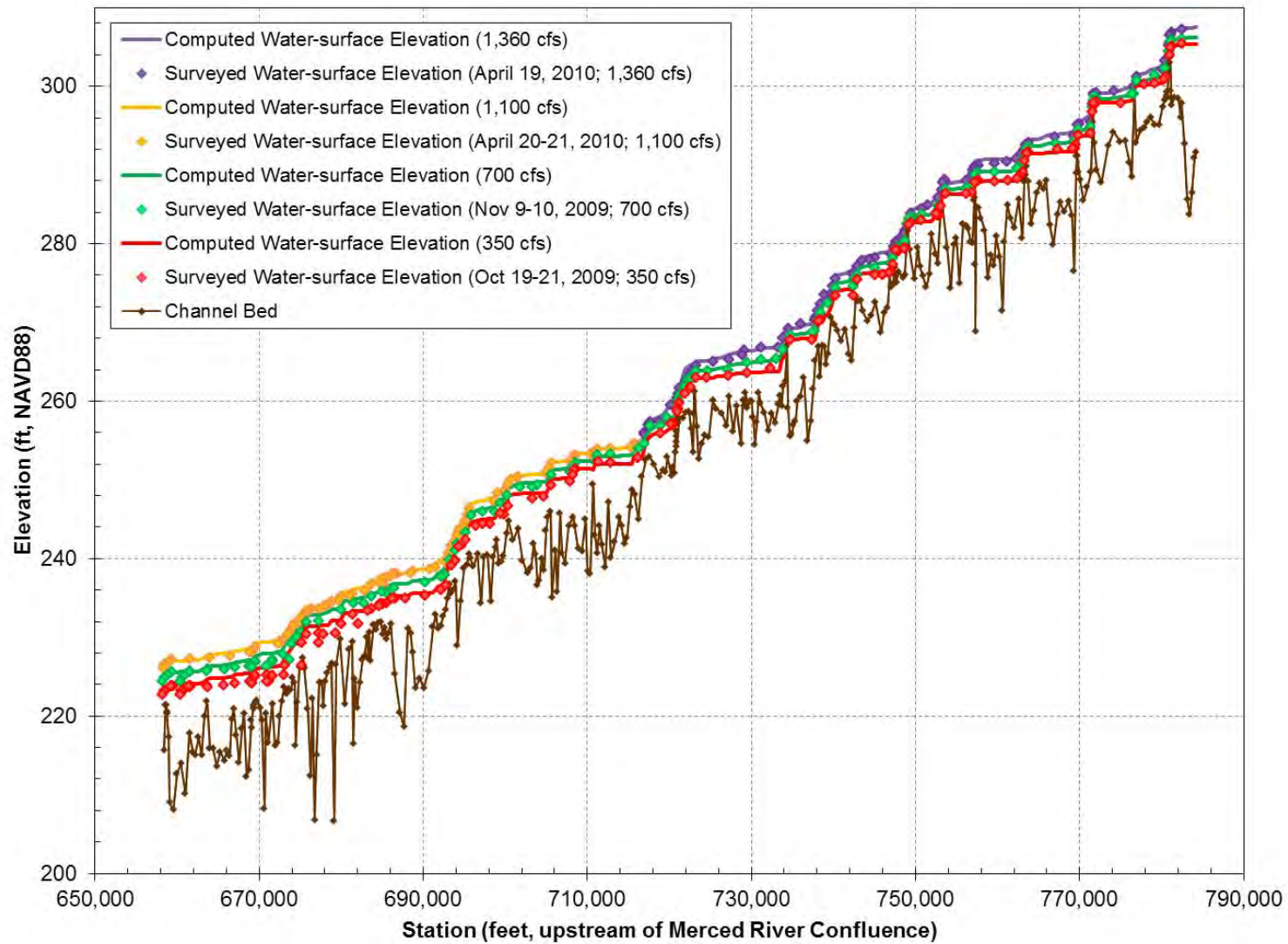


Figure 4.21. Computed (simplified model) and surveyed water-surface elevations in Reach 1A for calibration flow events between 350 and 1,360 cfs.

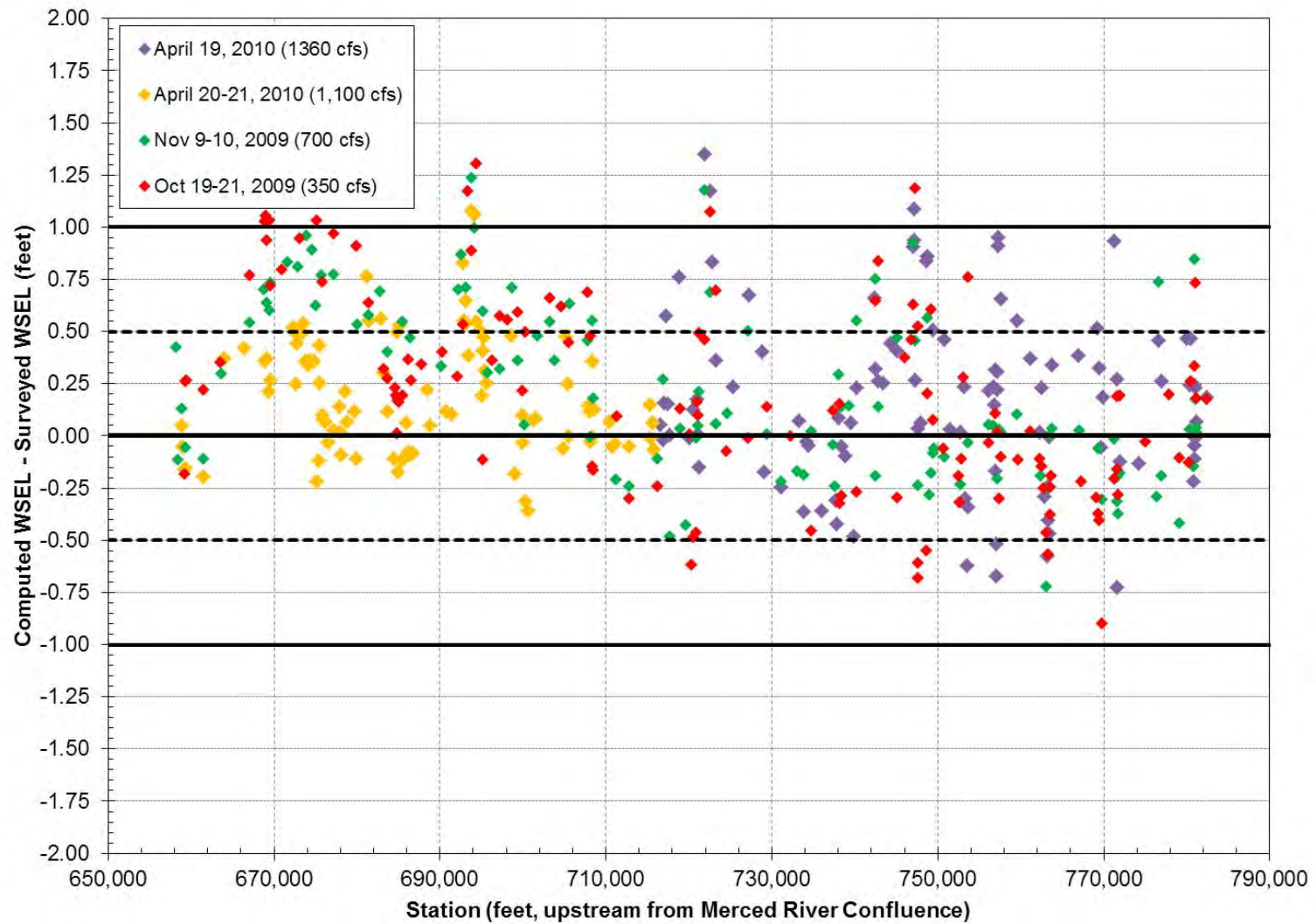


Figure 4.22. Differences between computed (simplified model) and measured water-surface elevations in Reach 1A at flows between 350 and 1,360 cfs. Positive values indicate computed values are above measured.

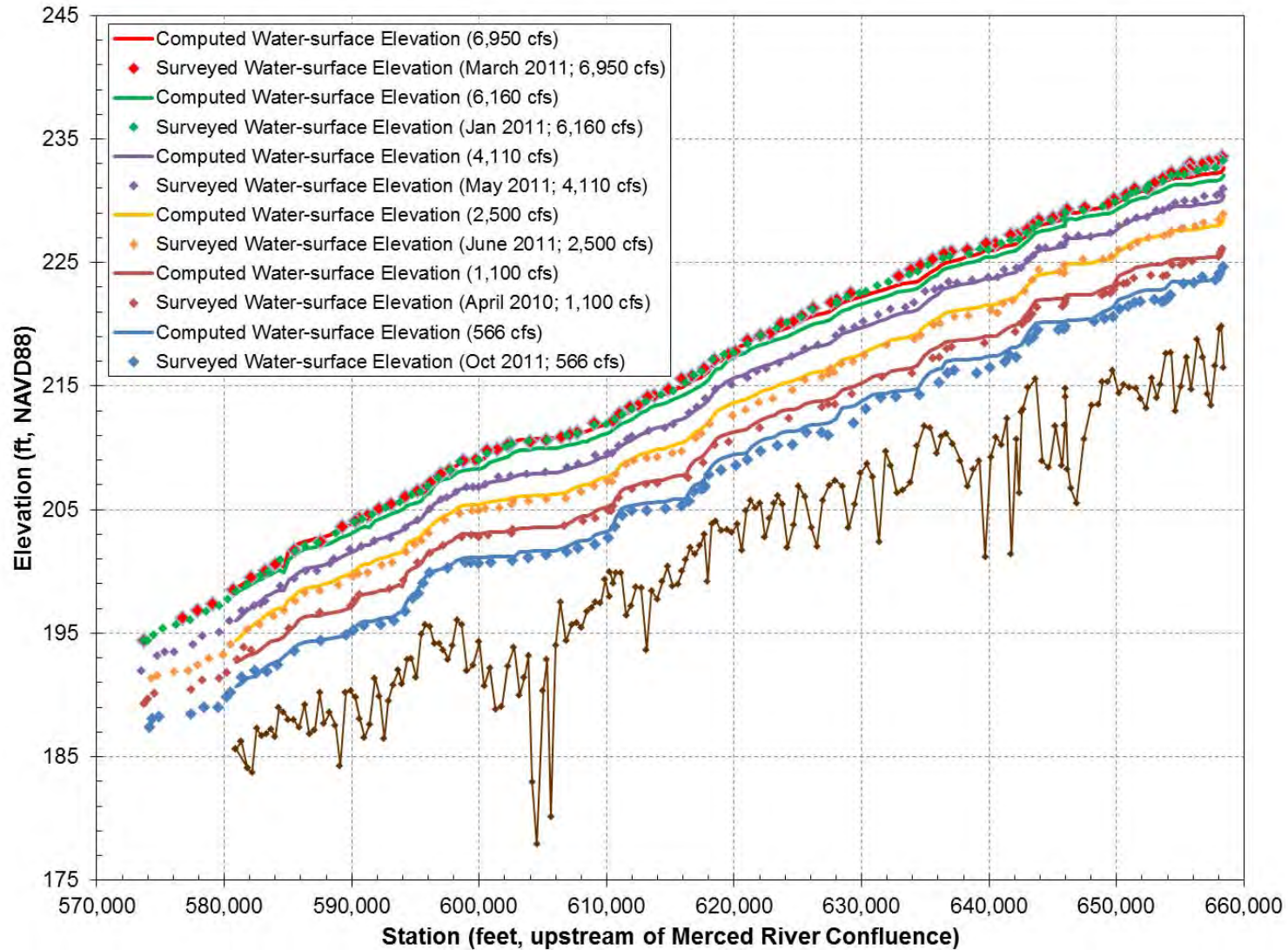


Figure 4.23. Computed (simplified model) and surveyed water-surface elevations in Reach 1B for calibration flow events between 570 and 6,950 cfs.

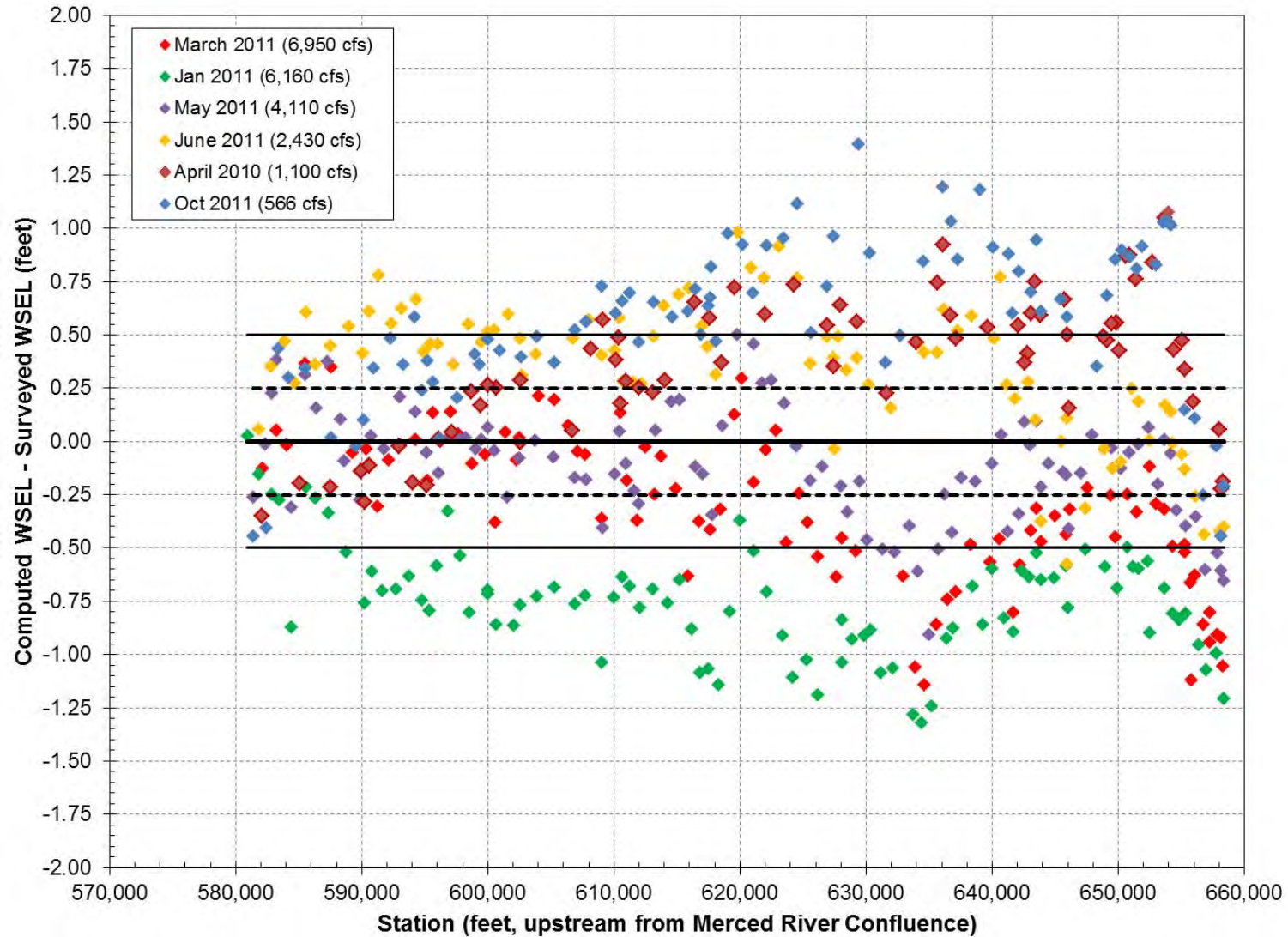


Figure 4.24. Differences between computed (simplified model) and measured water-surface elevations in Reach 1B at flows between 570 and 6,950 cfs. Positive values indicate computed values are above measured.

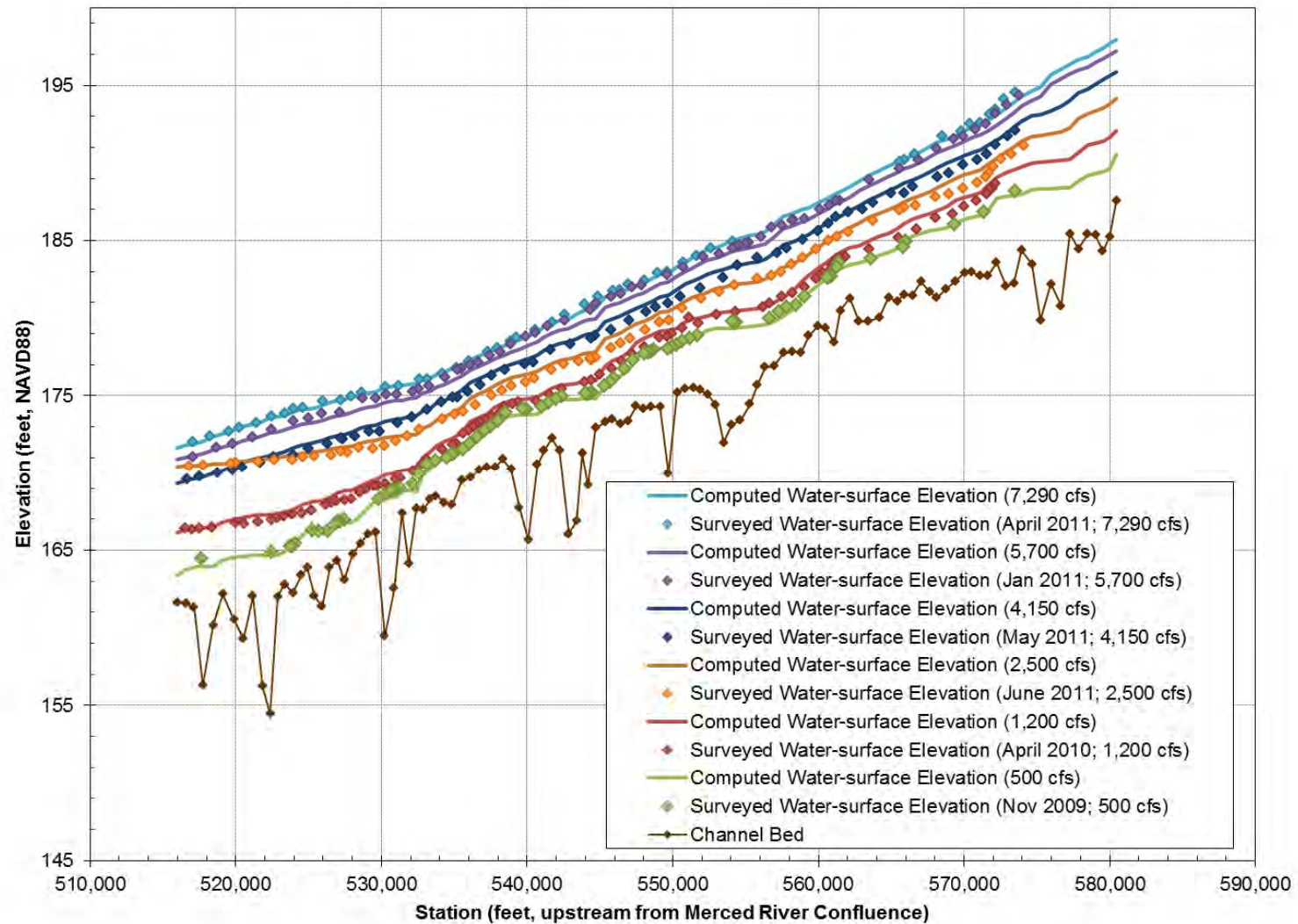


Figure 4.25. Computed (simplified model) and surveyed water-surface elevations in Reach 2A for calibration flow events between 500 and 7,290 cfs.

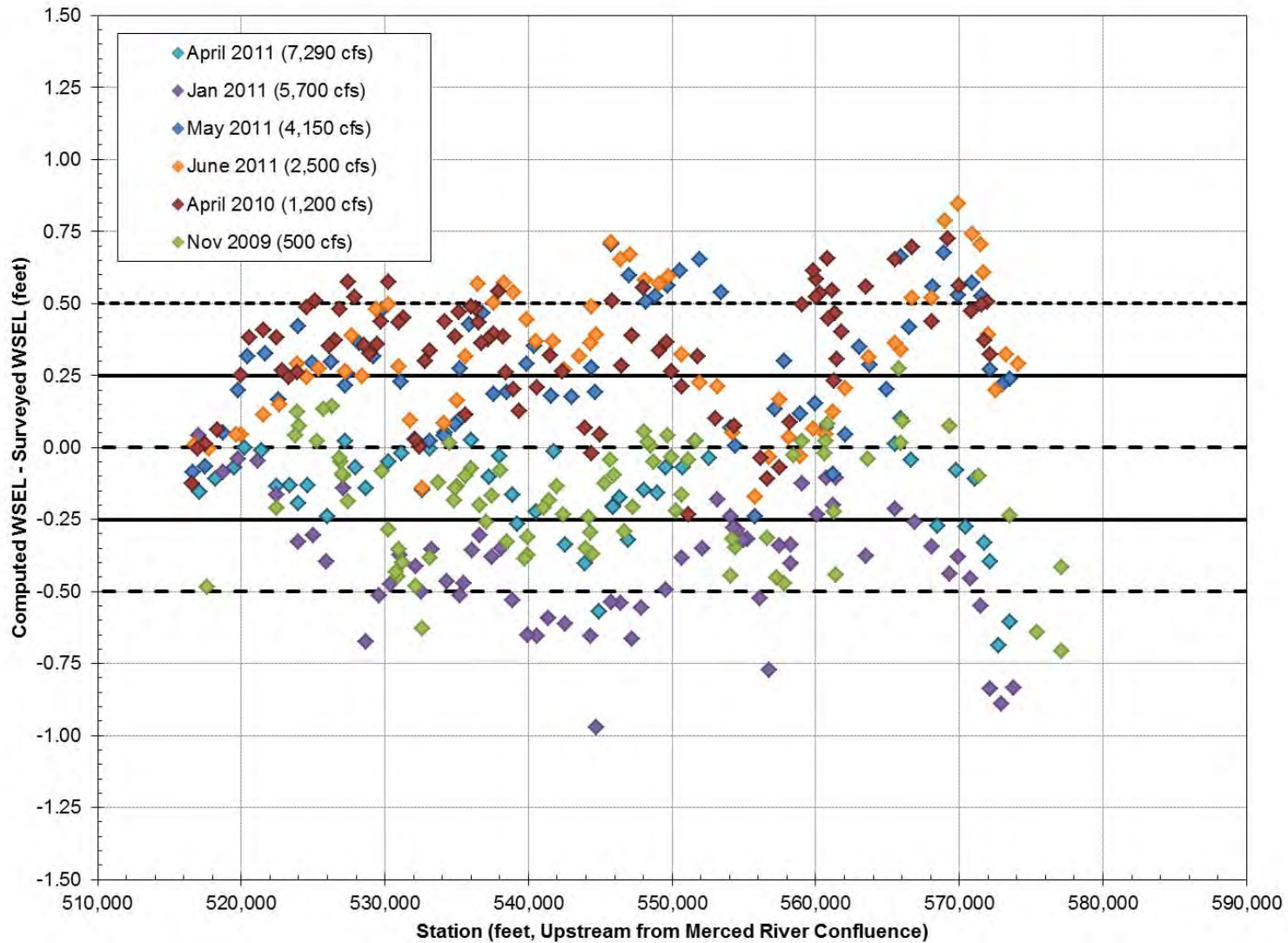


Figure 4.26. Differences between computed (simplified model) and measured water-surface elevations in Reach 2A at flows between 500 and 7,290 cfs. Positive values indicate computed values are above measured.

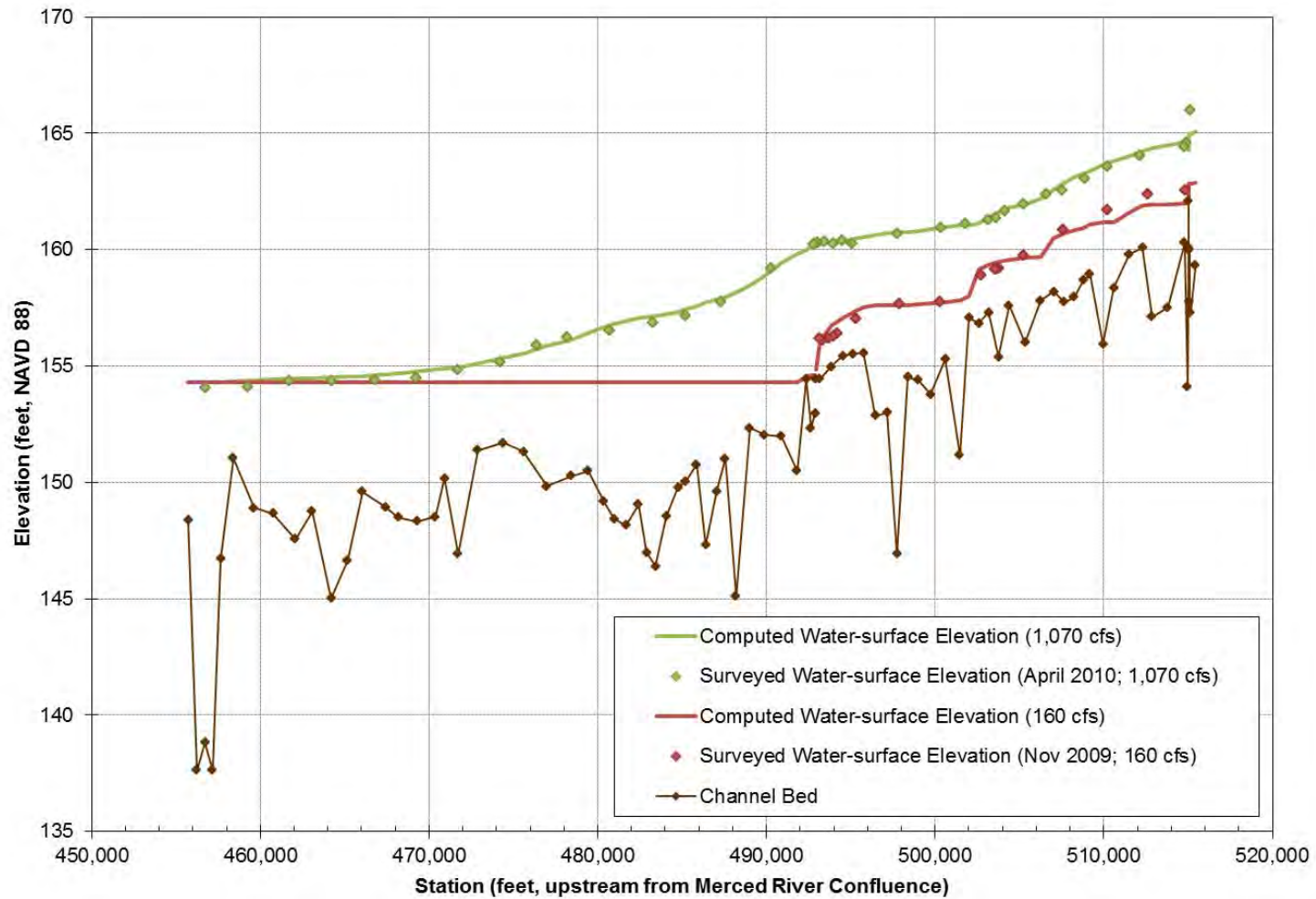


Figure 4.27. Computed (simplified model) and surveyed water-surface elevations in Reach 2B for calibration flow events between 160 and 1,070 cfs.

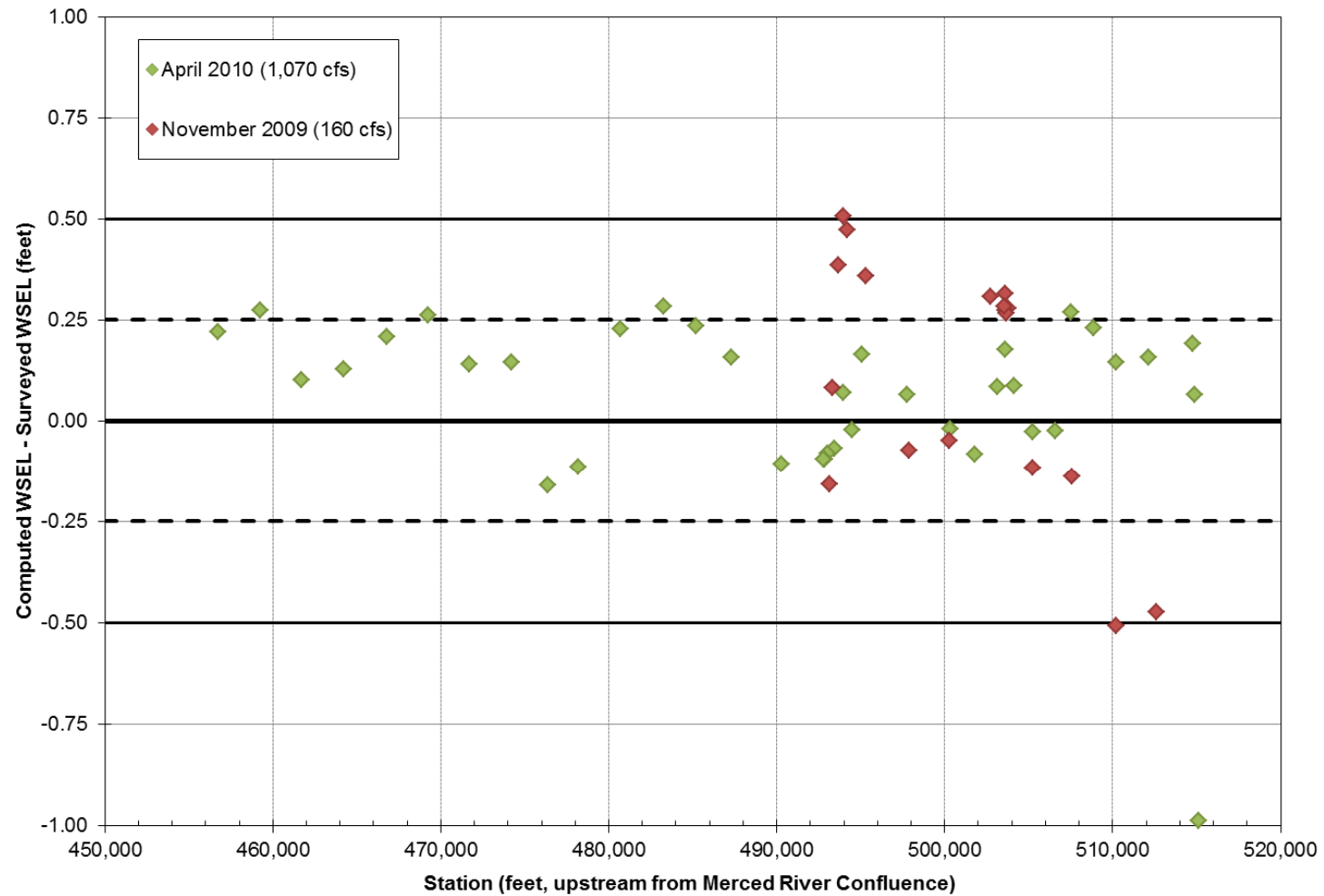


Figure 4.28. Differences between computed (simplified model) and measured water-surface elevations in Reach 2B at flows between 160 and 1,070 cfs. Positive values indicate computed values are above measured.

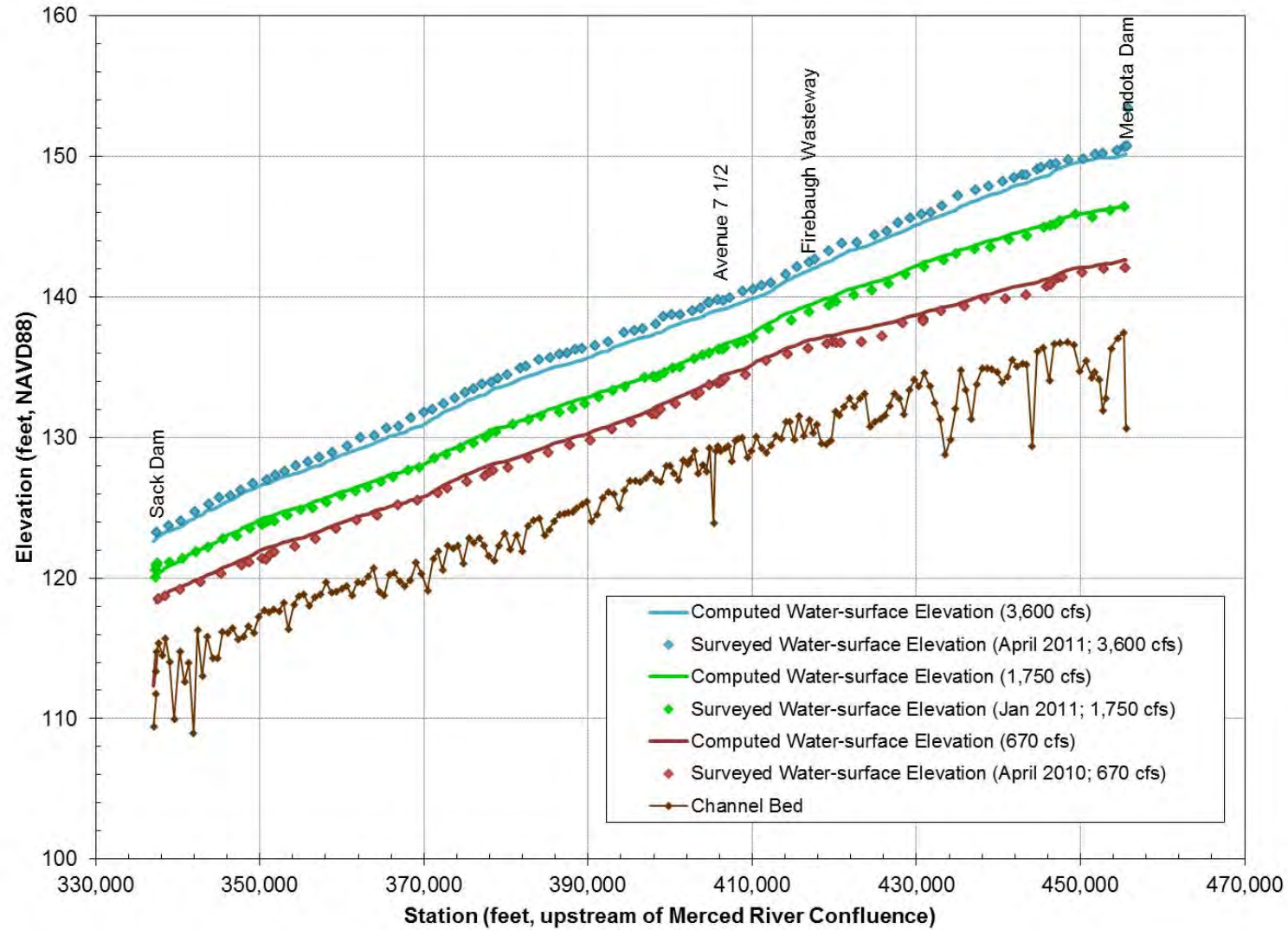


Figure 4.29. Computed (simplified model) and surveyed water-surface elevations in Reach 3 for calibration flow events between 670 and 3,600 cfs.

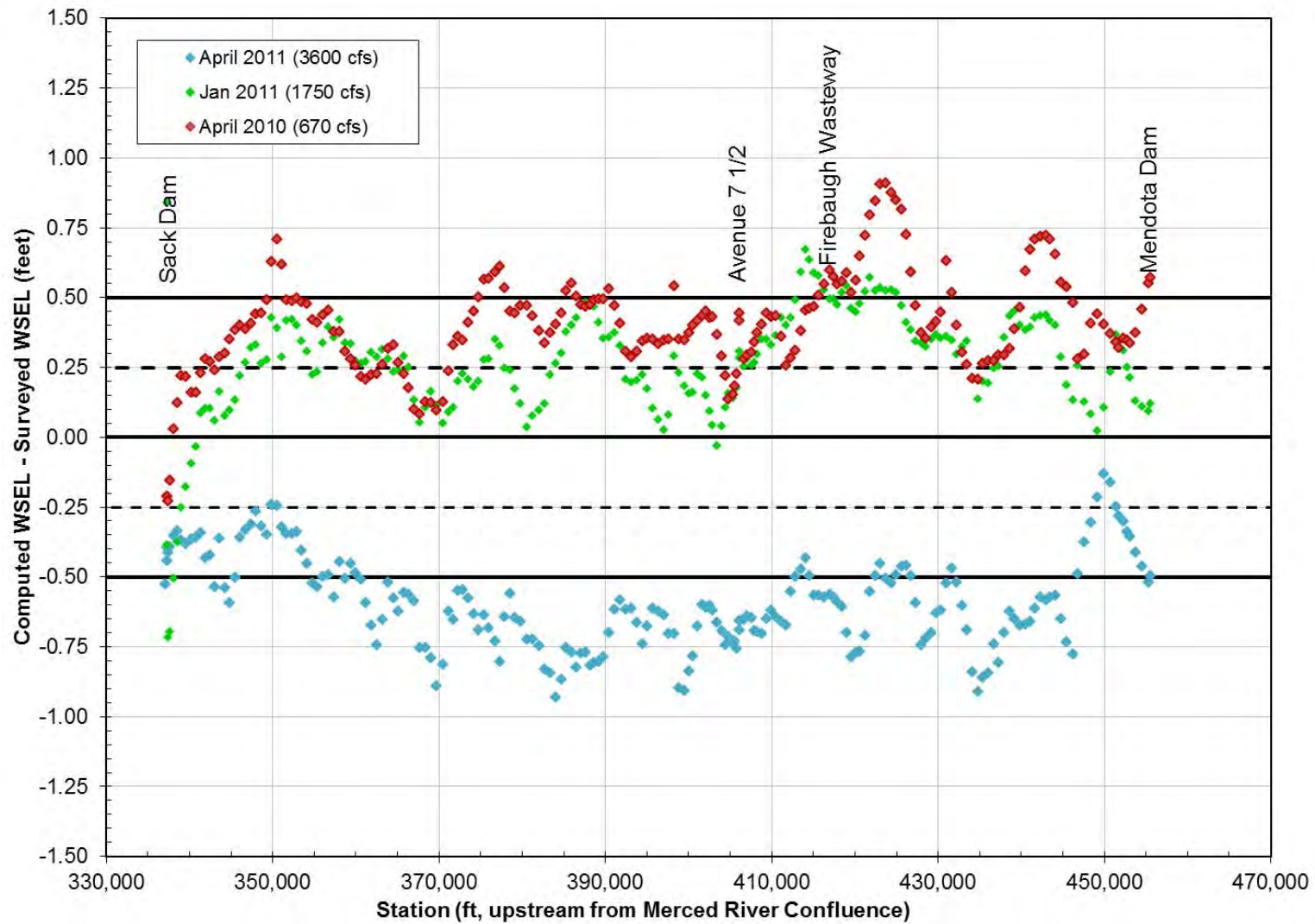


Figure 4.30. Differences between computed (simplified model) and measured water-surface elevations in Reach 3 at flows between 670 and 3,600 cfs. Positive values indicate computed values are above measured.

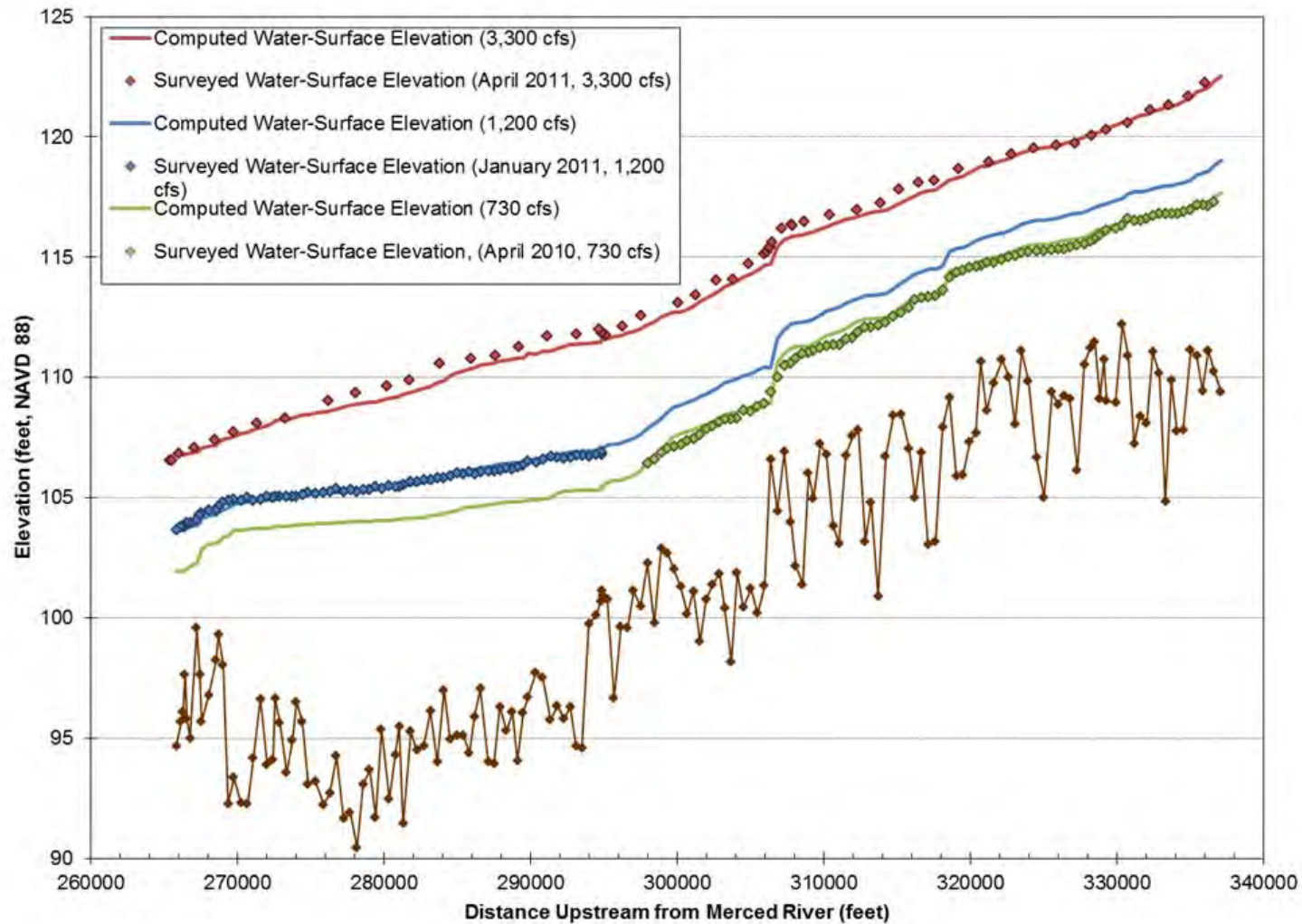


Figure 4.31. Computed (simplified model) and surveyed water-surface elevations in Reach 4A for calibration flow events between 730 and 3,300 cfs.

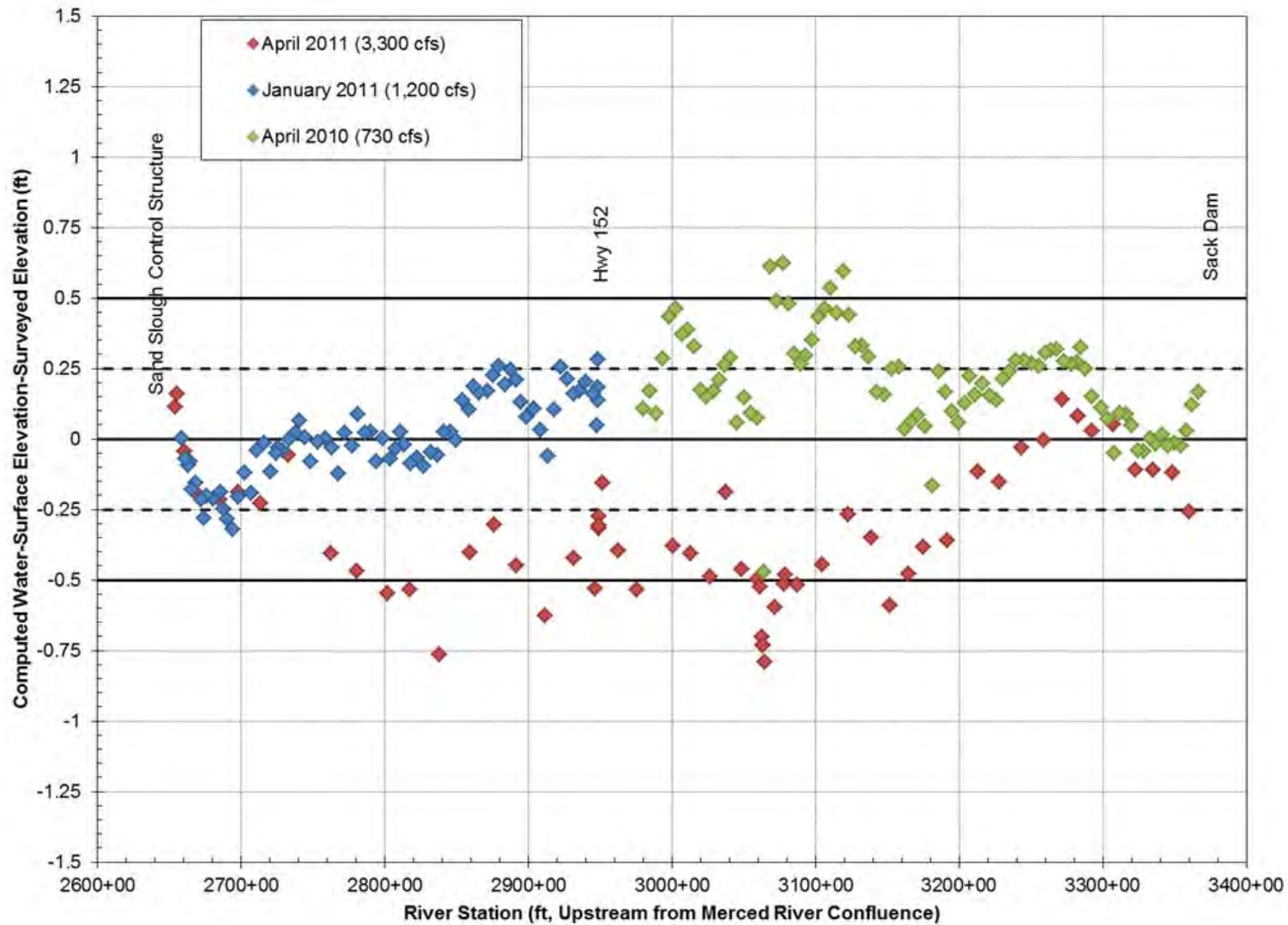


Figure 4.32. Differences between computed (simplified model) and measured water-surface elevations in Reach 4A at flows between 730 and 3,300 cfs. Positive values indicate computed values are above measured.

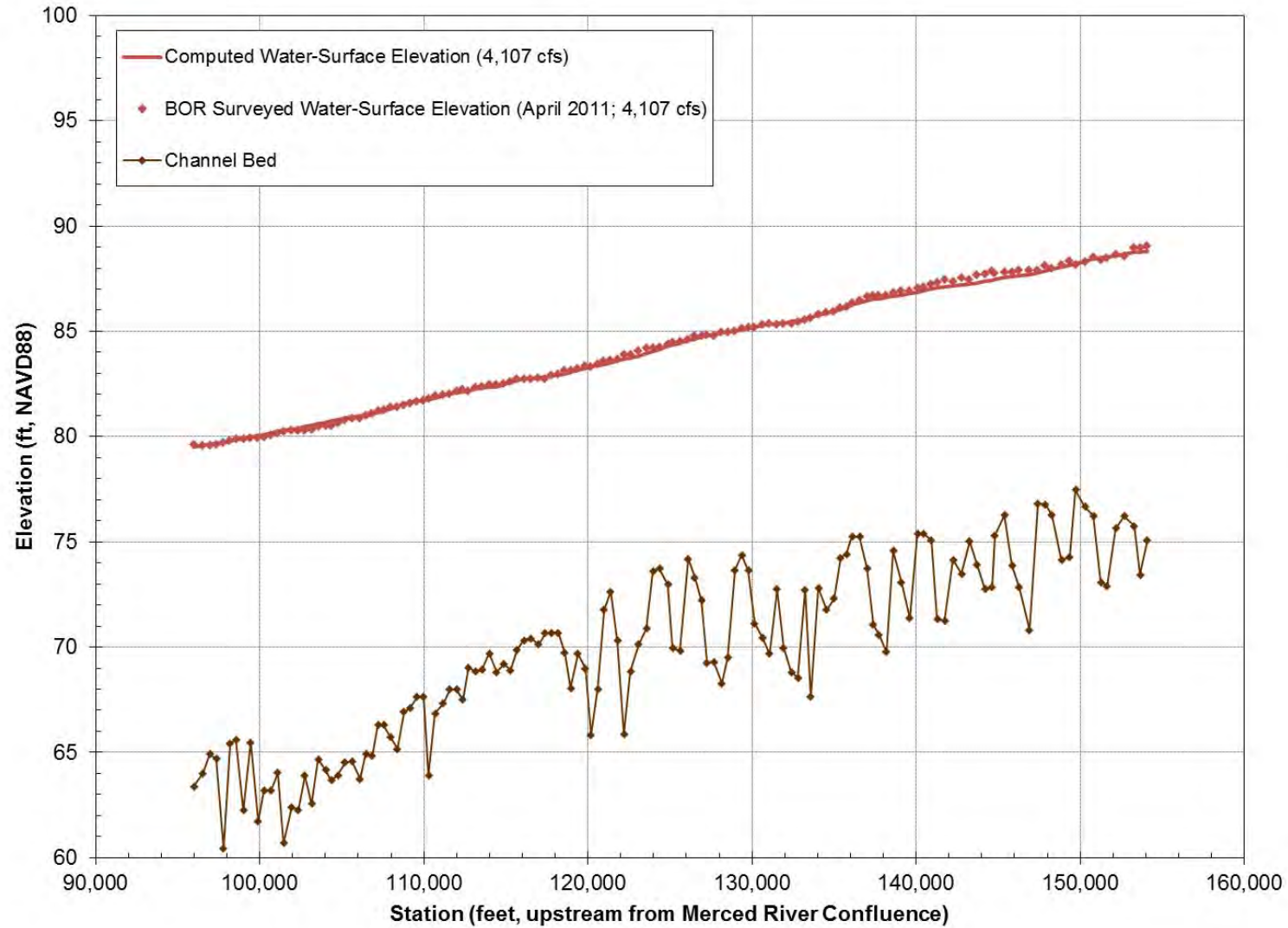


Figure 4.33. Computed (simplified model) and surveyed water-surface elevations in Reach 4B2 for estimated calibration flow events between 200 and 4,100 cfs. Exact surveyed discharges are unknown.

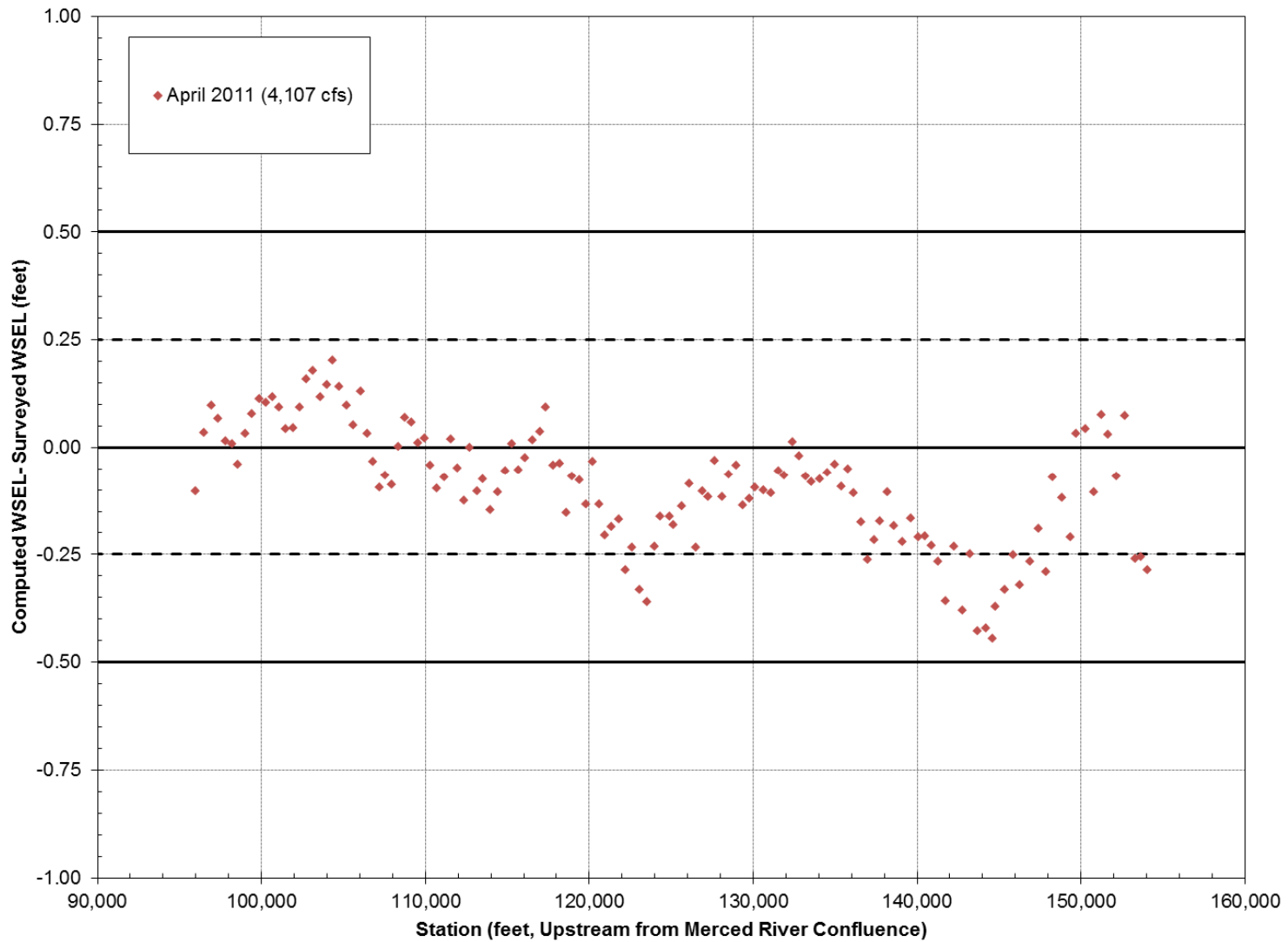


Figure 4.34. Differences between computed (simplified model) and measured water-surface elevations in Reach 4B2 at 4,100 cfs. Positive values indicate computed values are above measured.

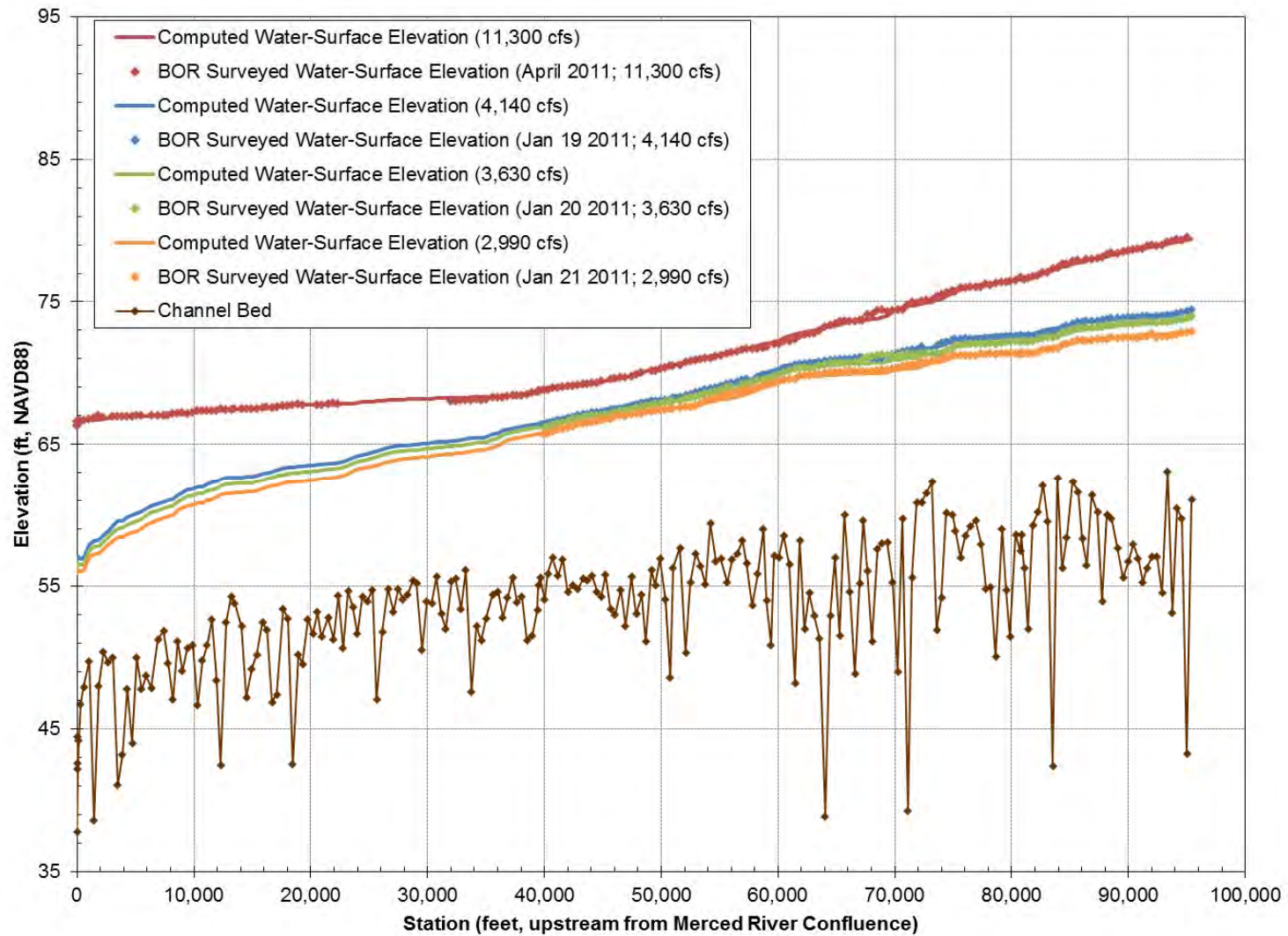


Figure 4.35. Computed (simplified model) and surveyed water-surface elevations in Reach 5 for estimated calibration flow events between 2,990 and 11,300 cfs.

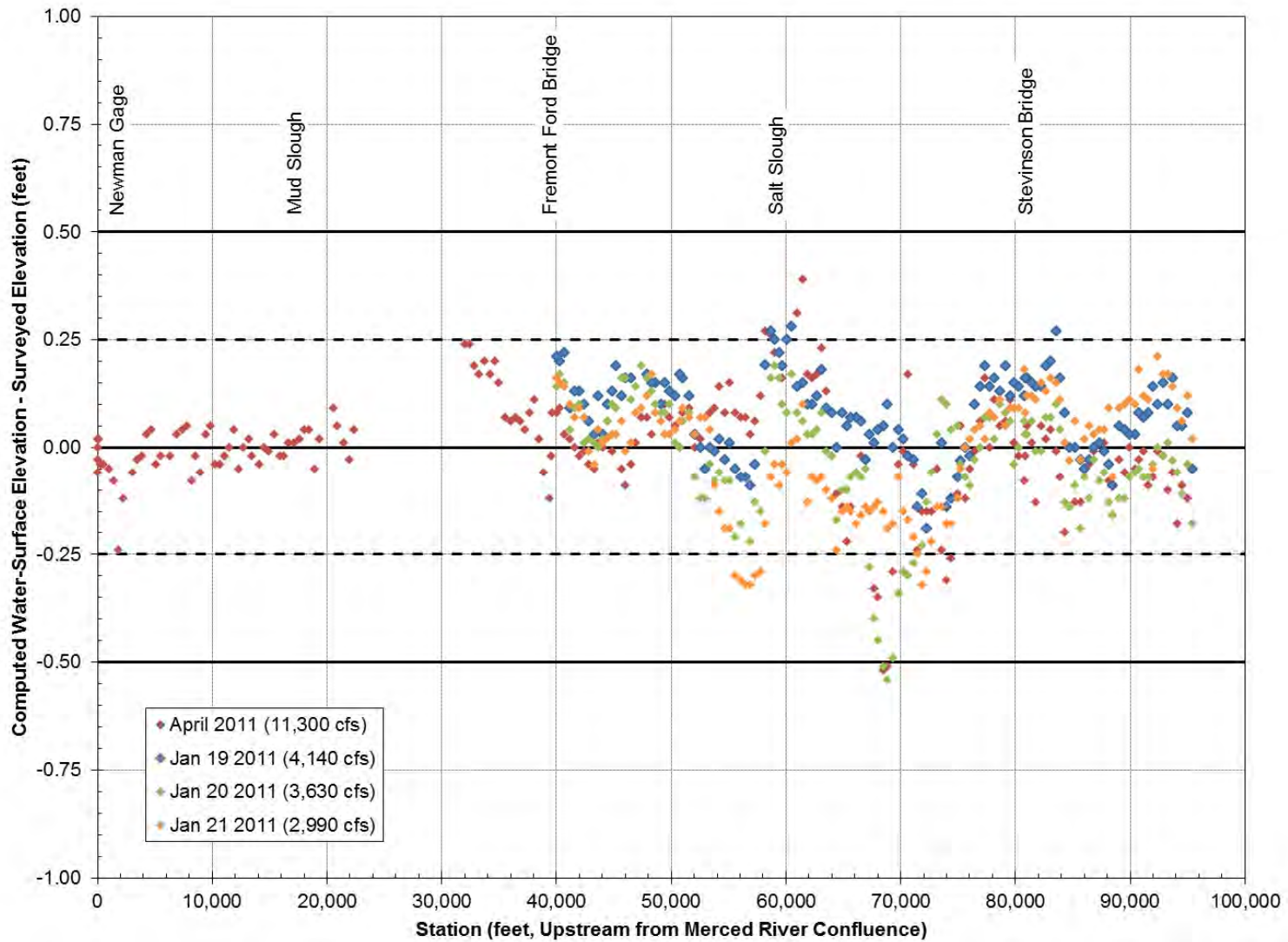


Figure 4.36. Differences between computed (simplified model) and measured water-surface elevations in Reach 5 at estimated calibration flow events between 2,990 and 11,300 cfs. Positive values indicate computed values are above measured.

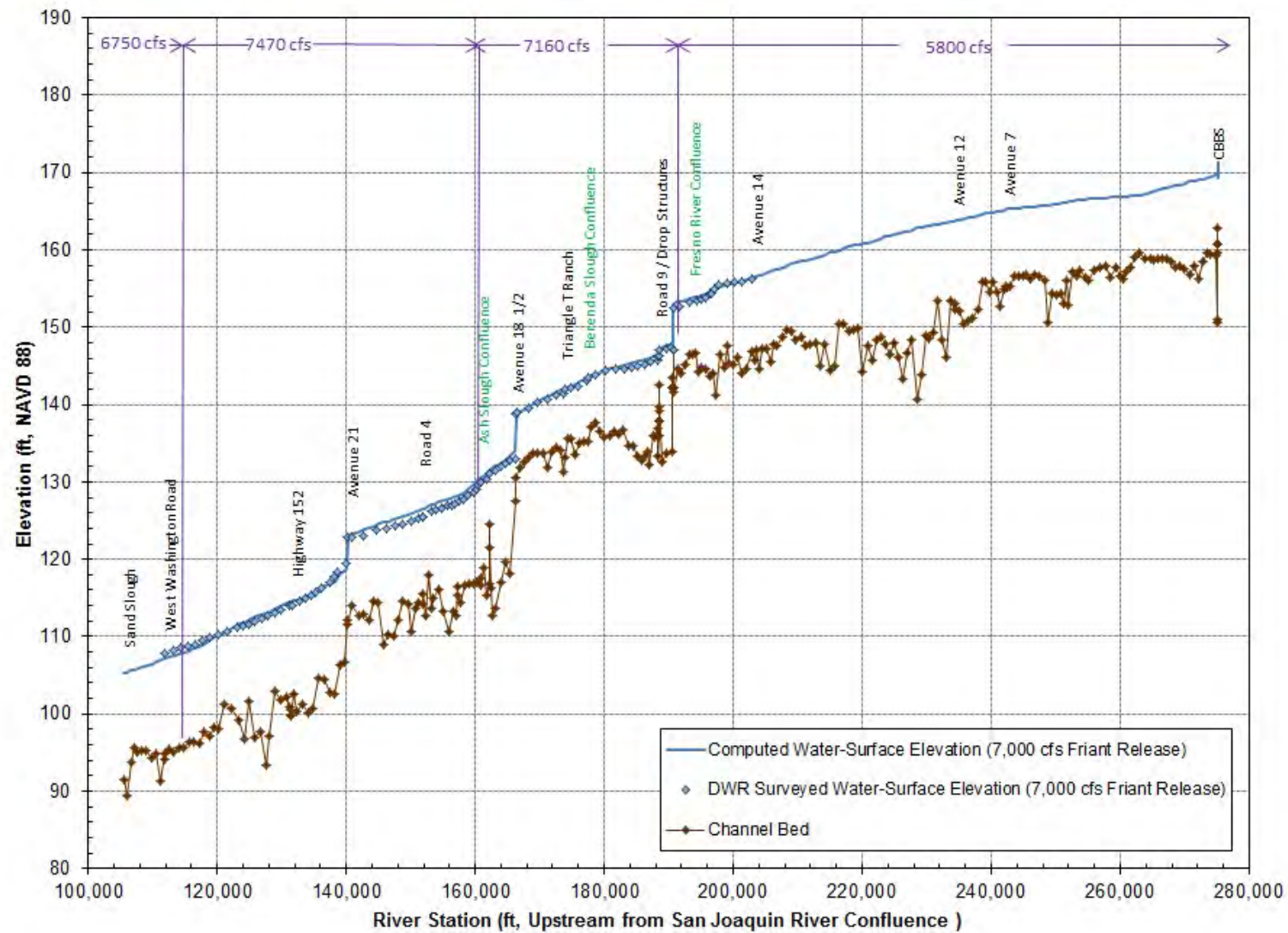


Figure 4.37a. Computed (simplified model) and surveyed water-surface elevations along the Chowchilla and Upper Eastside Bypasses for estimated calibration flow events between 5,800 and 7,470 cfs.

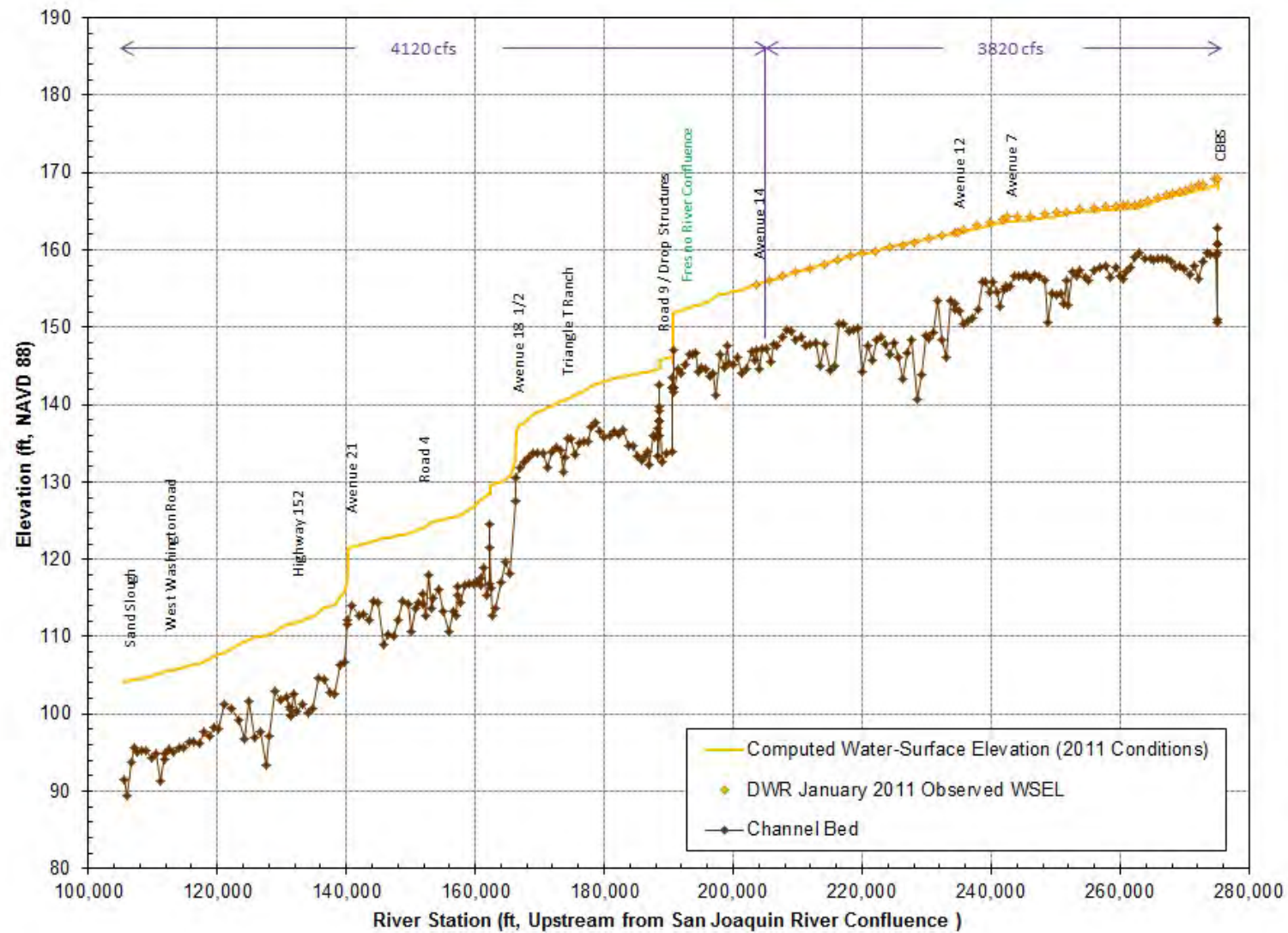


Figure 4.37b. Computed (simplified model) and surveyed water-surface elevations along the Chowchilla and Upper Eastside Bypasses for estimated calibration flow events between 3,820 and 4,120 cfs.

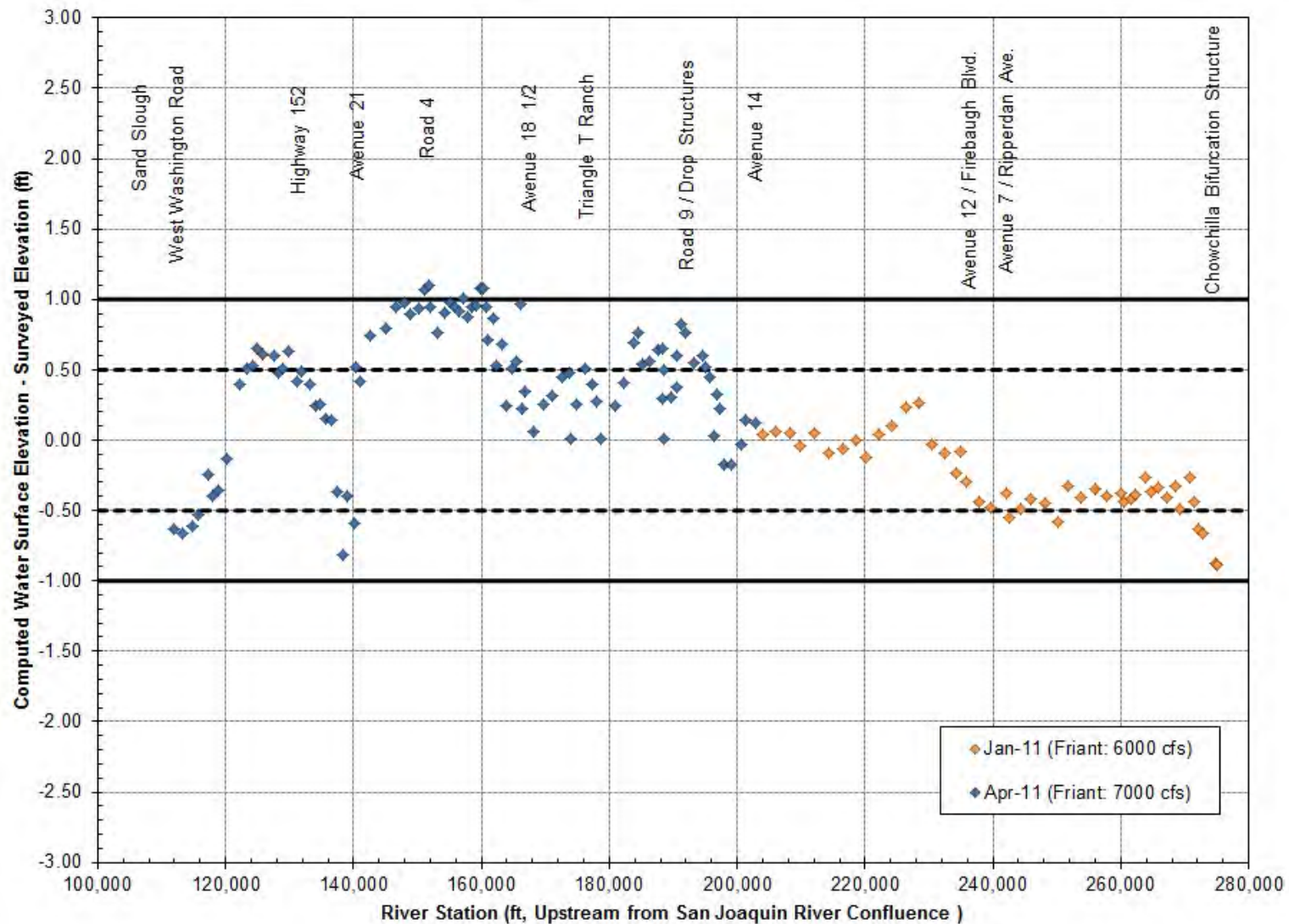


Figure 4.38. Differences between computed (simplified model) and measured water-surface elevations along the Chowchilla and Upper Eastside Bypass estimated calibration flow events between 6,000 to 7,000 cfs. Positive values indicate computed values are above measured.

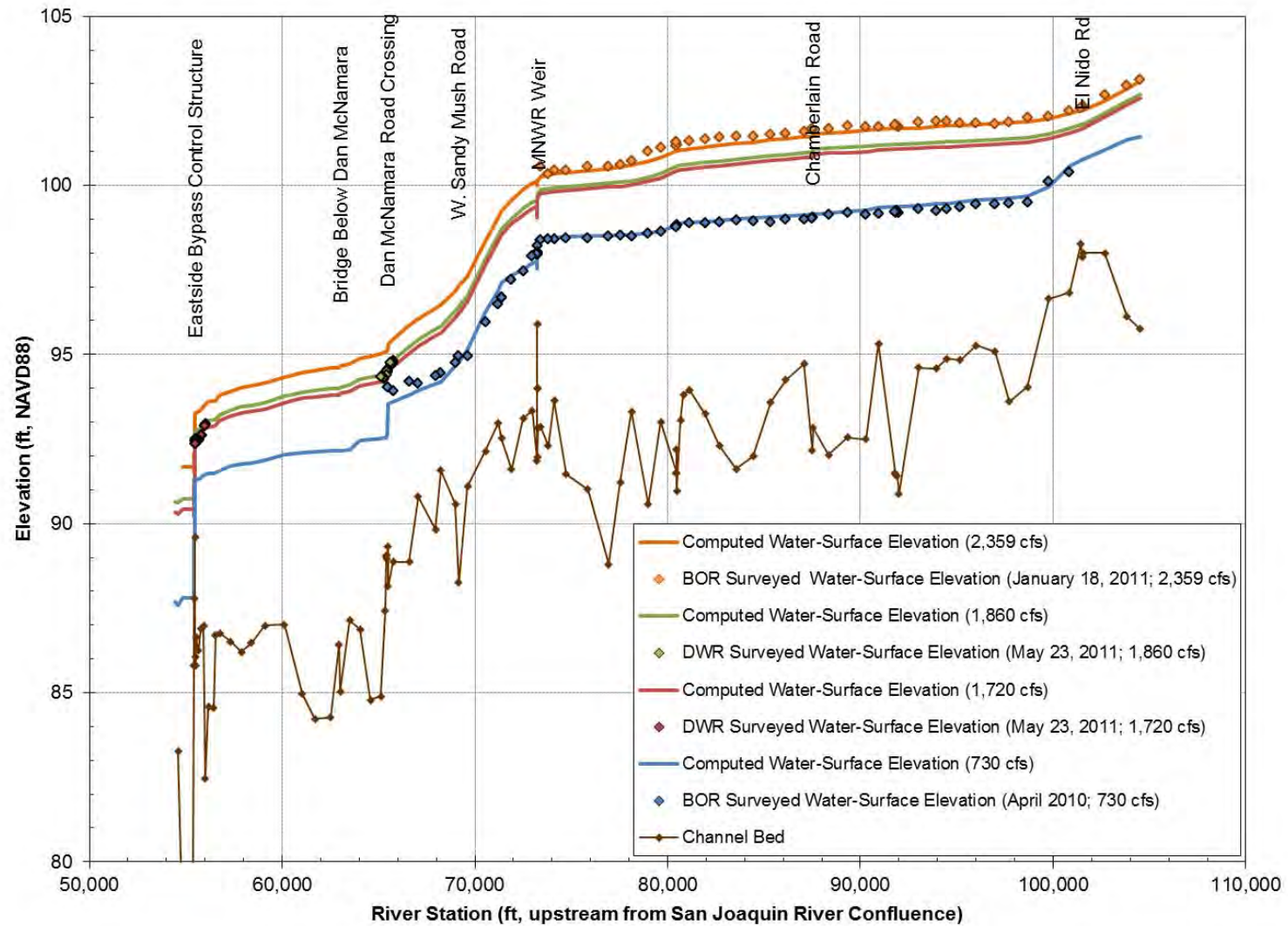


Figure 4.39. Computed (simplified model) and surveyed water-surface elevations in MESB for calibration flow events between 730 and 2,359 cfs.

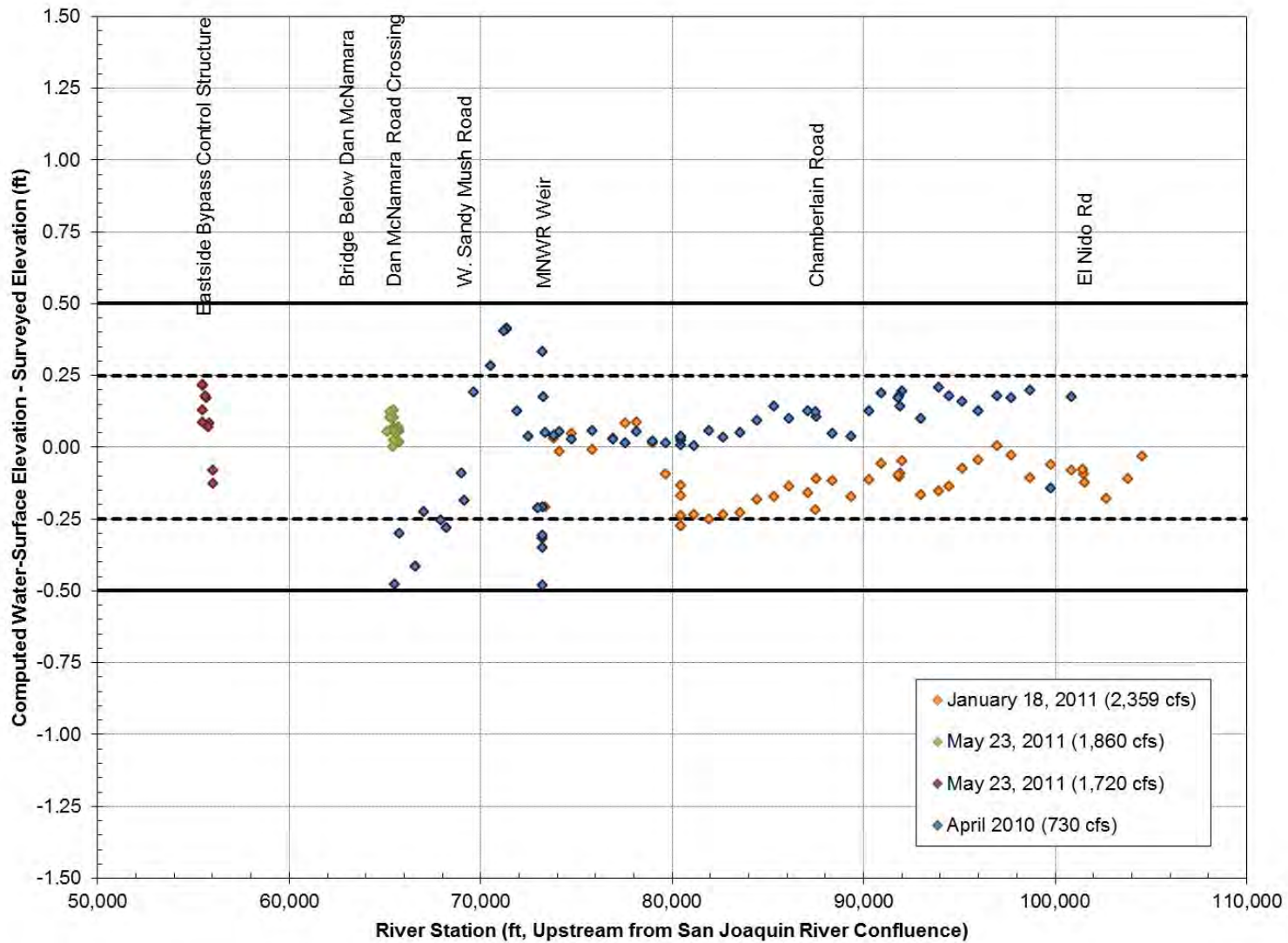


Figure 4.40. Differences between computed (simplified model) and measured water-surface elevations in MESB at flows between 730 and 2,359 cfs. Positive values indicate computed values are above measured.

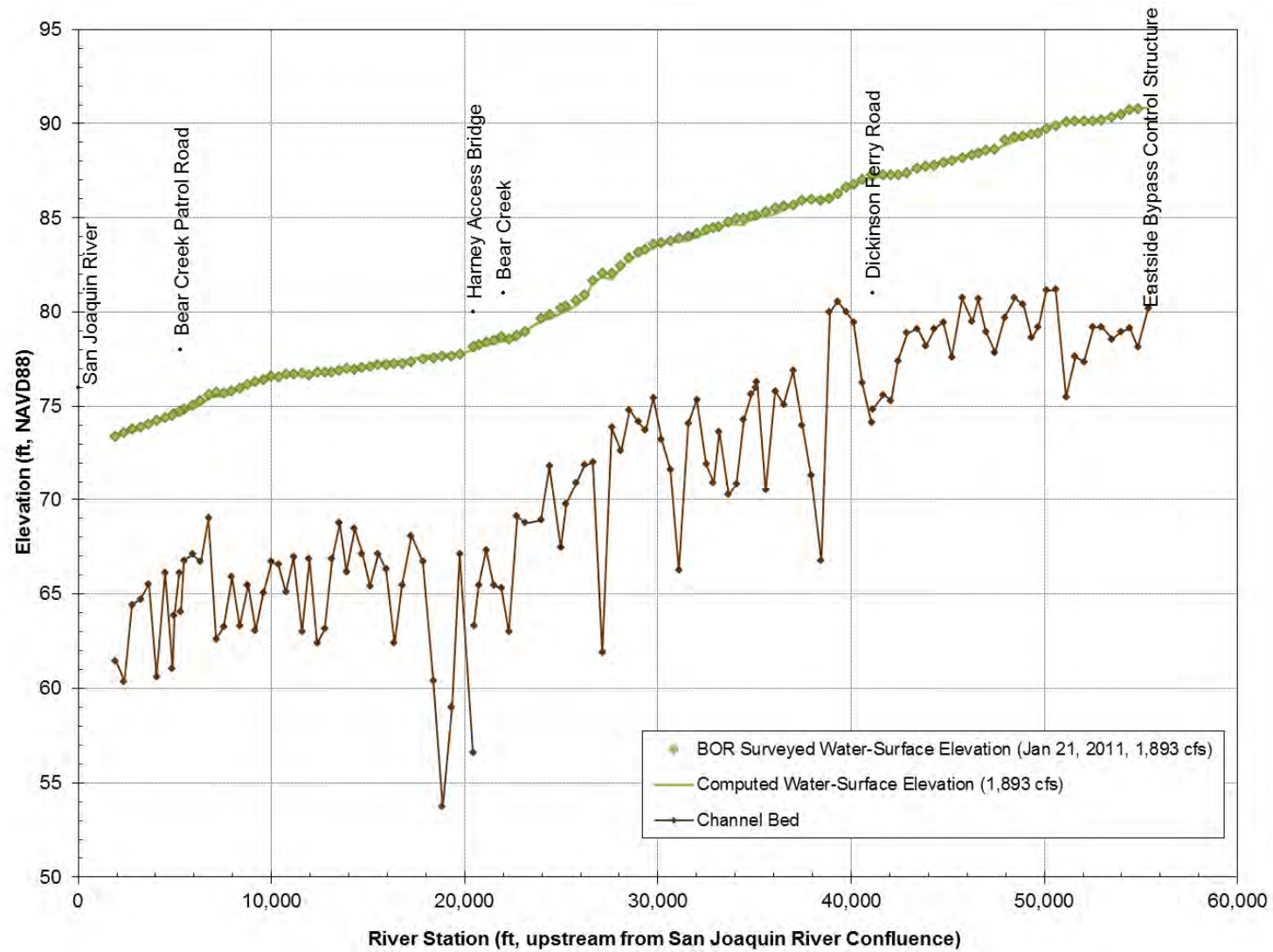


Figure 4.41. Computed (simplified model) and surveyed water-surface elevations in the Lower Eastside Bypass for a calibration flow of 1,893 cfs.

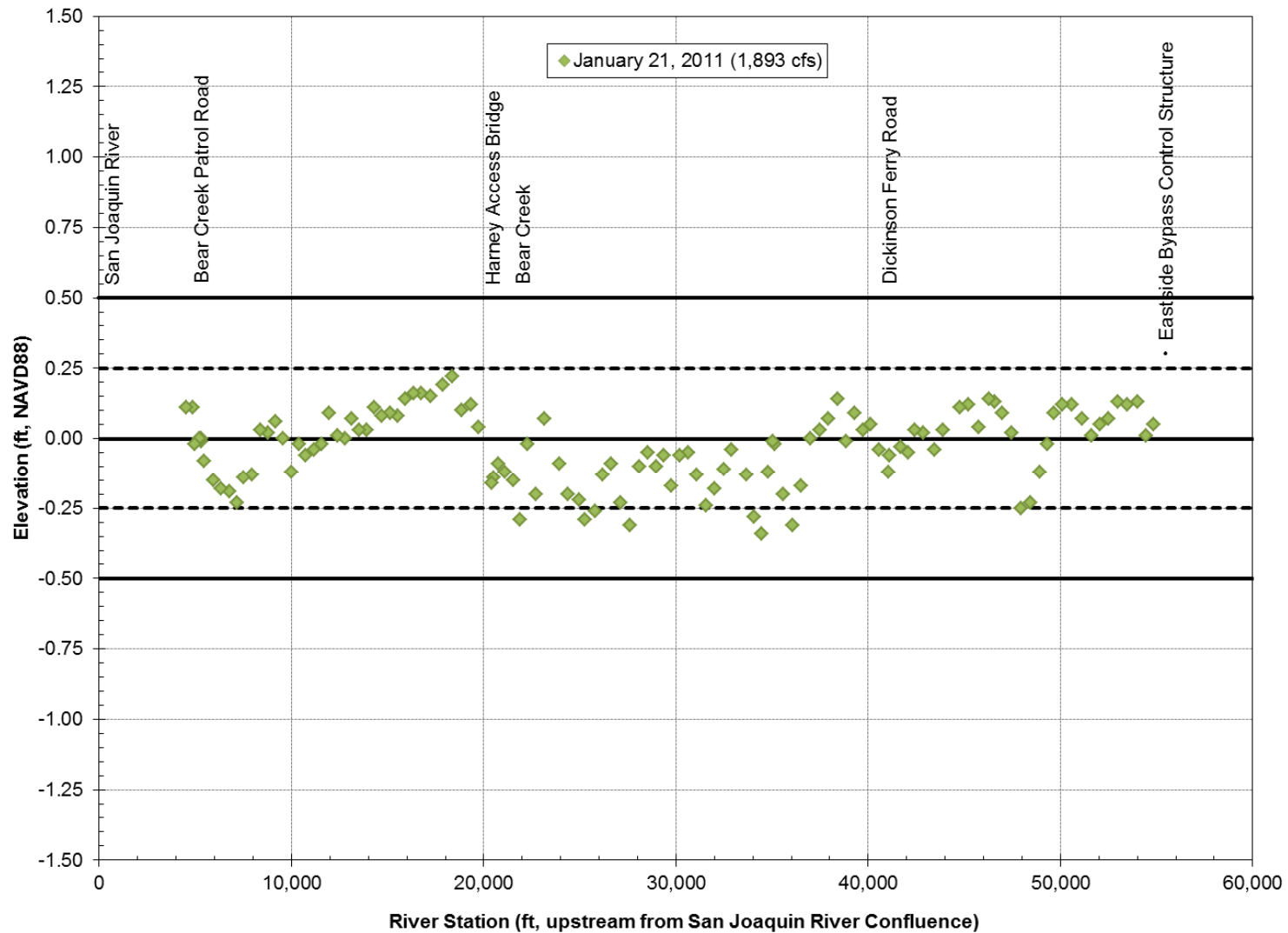


Figure 4.42. Differences between computed (simplified model) and measured water-surface profiles in the Lower Eastside Bypass at a flow of 1,893 cfs. Positive values indicate computed values are above measured.

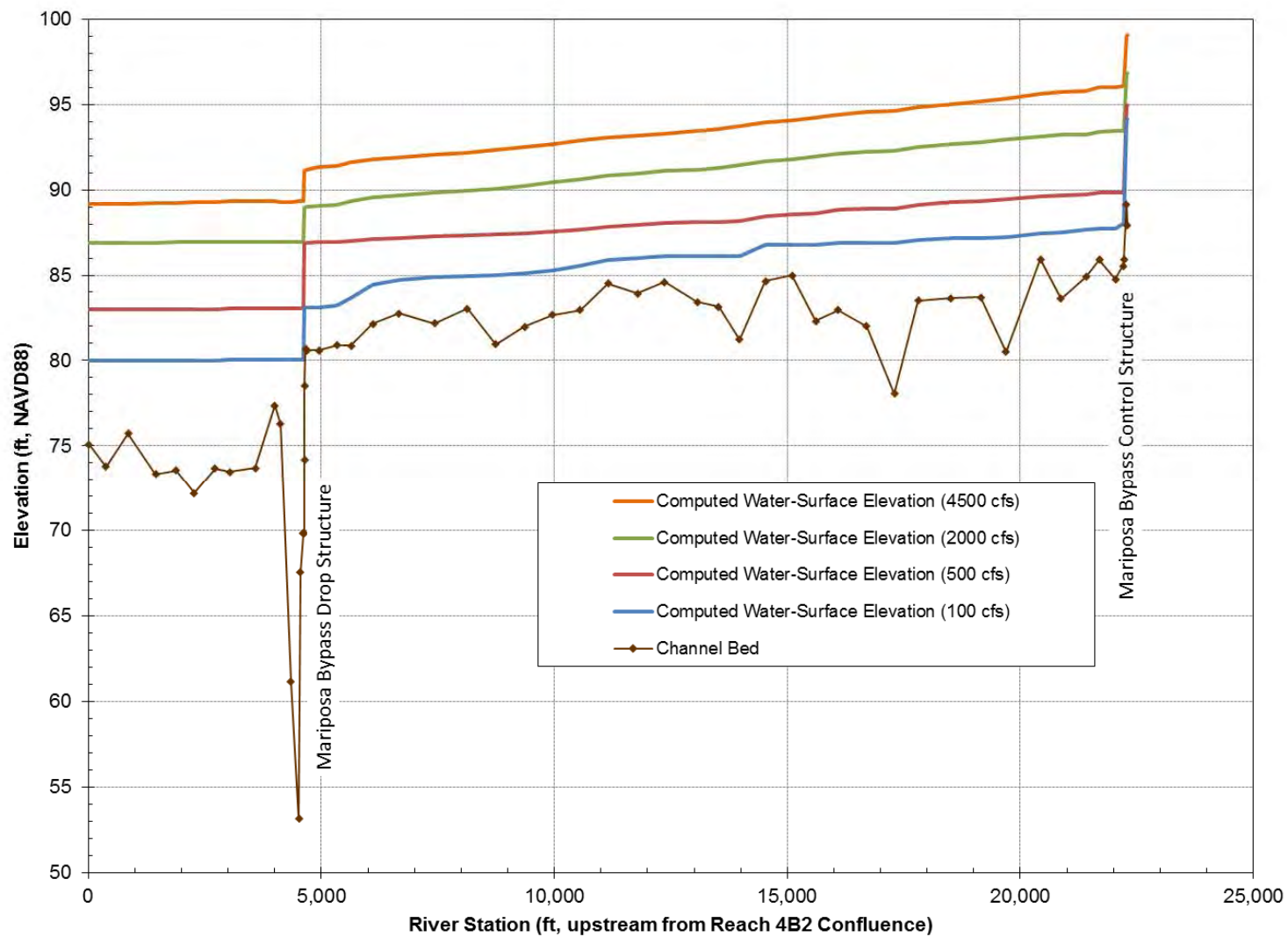


Figure 4.43. Computed water-surface elevations in the Mariposa Bypass for flows between 100 and 4,500 cfs