Appendix F

Evaluation of the Effect of Subsidence on Flow Capacity in the Chowchilla and Eastside Bypasses

November 2013

SAN JOAQUIN RIVER
RESTORATION PROGRAM

California Department of Water Resources
South Central Region Office

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Table of Contents

Introduction

This preliminary study was performed by the Department of Water Resources (DWR), South Central Region Office (SCRO), to evaluate effects of ground subsidence on flow capacity in the Chowchilla and Eastside Bypasses between the San Joaquin River at the Chowchilla Bifurcation Structure and the Mariposa Bypass (**Figure 1**). The study focuses on changes in levee freeboard (the height of the top of the levee above the water level) and flow capacity in the bypass that has occurred between 2008 and 2011, and makes projections on potential changes in freeboard and capacity due to continuing subsidence through 2016. The goal of this study was to provide a planning tool for use by the San Joaquin River Restoration Program (SJRRP) in identifying potential impacts on the design and implementation of the projects to achieve the goals of the program. The information may also assist the flood agencies in informing and planning future flood operations and maintenance, as well as regional planning efforts as part of the Central Valley Flood Protection Plan. Using the data collected by DWR thus far, this study provides a general picture of flow capacity in the bypass and the effect of subsidence on the ability of that system to convey flood flows. As an overview of potential hydraulic issues for use as a planning document, DWR considers the conclusions presented in this study to be reasonable. However, this study does not take into account the potential capacity issues related to sediment transport, and how subsidence may change with time. Further work in these areas may be necessary prior to site-specific activities where more detailed information is required.

Information in this study may be updated as additional data is collected to validate the assumptions of the study. For example, DWR collected additional topographic data in the latter part of 2013 that is currently being processed, and may be used to validate or refine the findings of this study.

Background

Subsidence, which is the downward shift or sinking of the ground, is known to have occurred throughout the San Joaquin Valley and to varying degrees along the San Joaquin River and flood bypass channels. Various studies and mapping efforts that identify the extent and magnitude of subsidence have been completed by the United States Army Corps of Engineers (USACE), DWR, the Bureau of Reclamation (Reclamation), and the US Geological Survey (USGS). One of those studies within the project area is the *Sacramento-San Joaquin Comprehensive Study* completed by the USACE in 2002. This study highlighted the observed areas of subsidence, and provided historic rates based on previous surveys. The areas of greatest documented subsidence occur at the various control structures located along the river, including at Mendota Dam, Sack Dam, the Reach 4B1 Headworks and Sand Slough Control Structure (Reclamation, 2013). Continued subsidence is expected to change channel slopes which has the potential to affect the ability of levees and flow control structures to perform as designed, change sediment transport behavior, and reduce the long-term flow capacities of the flood and river systems.

In 2012, the SJRRP formed a subsidence coordination group to help address and study the impacts of subsidence and to share information between landowners, SJRRP stakeholders, and government agencies. The SJRRP is also conducting bi-annual surveys of the SJRRP Geodetic

Control Network to monitor the rate of subsidence. The bi-annual surveys are lead by Reclamation. The SJRRP is developing a technical memorandum *Subsidence Design Criteria for the San Joaquin River Restoration Program (DRAFT).* In *Technical Memorandum No. SUB-1*, the SJRRP documents subsidence specific within the SJRRP project area (Reclamation, 2013). The SJRRP plans to establish recommended subsidence criteria that will be applied to the designs for future site-specific projects in Reach 2B, Reach 4B, and near the Arroyo Canal in Reach 3. The Memorandum does not include subsidence design criteria for the Chowchilla Bypass or the Eastside Bypass from its confluence with the Fresno River to the Sand Slough Control Structure since these reaches are not included in future projects for the SJRRP.

The flood control bypasses that parallel the San Joaquin River include the Chowchilla, Eastside and Mariposa Bypasses, which are part of the Lower San Joaquin River Flood Control Project. The design flow capacities (shown in Table 2) and operating rules used in this evaluation for the bypasses and tributaries are based on the Operation and Maintenance Manual (O&M Manual) (Reclamation Board, 1967) for the Lower San Joaquin River Flood Control Project.

Methodology

The following methods, including assumptions and limitations described below, apply to this study:

1. Subsidence was assumed to occur at the same rate each year and to be uniform across each cross-section, and it is assumed that subsidence rates remain unchanged through 2016. Subsidence rates were estimated using the DWR data comparison of 2008 LiDAR and 2012 surveys. The topographic surveys collected by DWR in 2012 are ground surveys, while the LiDAR surveys are aerial surveys. Subsidence rates calculated in this study vary slightly from the rates presented in other studies. Individual differences in calculated subsidence rates may be a function of when the survey was conducted and which survey methods were employed, including data density. Differences between different studies should be considered when using or comparing the data. DWR did not attempt to determine the source of any discrepancies between the different studies, but for the purposes of this investigation the differences are not deemed to be significant.

2. Deposition and sediment transport were not considered in this study. Actual capacities and impacts may be significantly greater or less in some areas as a result of sediment deposition and erosion. The topographic data used in this study does show channel excavation that was completed near Sand Slough in 2011.

3. Design flows are taken directly from the O&M Manual, which was assumed to be the capacity prior to 2008. This study does not assess the how or why the capacity has or has not changed in the bypass prior to 2008. Design flows assume 4 feet of freeboard. In addition, actual channel capacities in the bypasses are subject to flood operations and potential concurrent inflows from various tributaries, as well as diversions in the Mariposa Bypass. This study assumes up to 8,500 cfs of initial flood flows would be diverted into the Mariposa Bypass, and that the boards that are put into the weirs to divert flows into the Merced Wildlife Refuge are not in place.

4. The analysis and findings in this study are based solely on a hydraulic comparison of the computed water-surface profiles and levee freeboard elevations. The analysis did not

consider levee and structure stability, suitability of the existing levee dimensions, levee seepage, high groundwater, and other potential failures.

Topography

Subsidence appears to have the greatest impact on areas along the Chowchilla and the Eastside Bypass between Road 9 and Sand Slough Control Structure. RBF Consulting performed ground control surveys in 2010 to confirm the 2008 LiDAR data; their evaluation identified an area showing extreme subsidence rates occurring near the Eastside and Chowchilla Bypasses between 2008 and 2010. Topographic data collected by USGS using Interferrogram data between 2008 and 2010 show similar trends as the RBF Consulting data. Bi-annual survey data collected by Reclamation between 2011 and 2012 show similar trends, but subsidence rates vary along the bypass depending on season, year type, and land use. However, general subsidence trends indicated by the Reclamation data are similar to the latest trends indicated by the RFB Consulting and USGS data.

DWR-SCRO collected topographic ground survey data in late 2012 to help further refine the estimated annual rates along the flood bypasses. DWR subsidence rates were estimated based on comparison of the levee profiles from the 2008 LiDAR aerial surveys and the surveyed 2012 levee profiles (**Figures 2 and 3**). **Table 1** summarizes the subsidence rates from various data sources. The DWR subsidence rates match reasonably well with the other data sources, though they are slightly higher near Road 4, Avenue 21, and Highway 152. DWR rates in the Eastside Bypass from Sand Slough to the Mariposa Bypass are slightly lower than other data sources including those near the Sand Slough Control Structure. In addition, the comparison of the survey data and LiDAR data at very downstream end of the study area shows that the ground appears higher during the 2012 DWR surveys when compared to the LiDAR data. Some of these differences may be a result of the placement of material on top of the levees after the LiDAR surveys, but this reconnaissance study did not investigate the cause of any changes in topography and so the source of this apparent anomaly is unknown. General differences in subsidence rates could also be a result of the time frames that the data was taken, as well as the accuracy and geographical coverage of the data. For example, annual subsidence rates calculated by the SJRRP near Sand Slough were 0.4 to 0.5 feet/year from July 2012 to December 2012, but 0.5 to 0.6 feet/year from December 2011 to December 2012. Additionally, the top of levee surveys provide additional survey data points in the areas along the bypass that have experienced subsidence, which may not be reflected in the Reclamation and USGS surveys. For example, the subsidence rates estimated by Reclamation for the bypass uses 61 surveyed control points, six of which are along or within the immediate vicinity of the bypass and the focus area of this study. This study estimates the subsidence rate based on several survey points that were collected along the bypass levee crown at 200 to 300 ft intervals.

Table 1. Annual ground subsidence rates along the Chowchilla and Eastside Bypasses

	RBF[1]	USGS[1]	Reclamation[2]	DWR[3]
Bridge Structures	**rate, ft/year**	**rate, ft/year**	**rate, ft/year**	**rate, ft/year**
Avenue 14	0.3 - 0.4	0.2 - 0.4	0.3 – 0.4	0.37
Road 9	0.4 - 0.5	0.2 - 0.4	0.3 – 0.4	0.48
Triangle T	0.3 - 0.4	0.2 - 0.4	0.3 – 0.4	0.39
Avenue 18 1/2	0.2 - 0.3	0.2 - 0.4	0.3 – 0.4	0.33
Road 4	> 0.5	> 0.75	0.3 – 0.4[4]	0.88
Avenue 21	0.4 - 0.5	0.4 - 0.5	0.3 – 0.4	0.52
Highway 152	N/A	0.2 - 0.4	0.3 – 0.4	0.52
Sand Slough Vicinity	N/A	N/A	0.4 – 0.5[5]	0.30
Merced Weirs	N/A	N/A	0.3 – 0.4	0.15

[1] Data collected in 2008 and 2010.
[2] Data collected in 2011 and 2012.
[3] Data collected in 2012 and compared with 2008 LiDAR.
[4] Recent surveys data from Reclamation that was not available at the time the model was developed show subsidence annual rates near Road 4 from July 2012 to July 2013 of 0.6 to 0.7 ft/year.
[5] Rates vary depending on time of year and year type.

Hydraulic Analysis and Results

The hydraulic study summarized in this report was completed as two separate evaluations. The first was to estimate the change in freeboard that has occurred from recent subsidence and may occur in the future as a result of future subsidence. The second evaluation included translating those changes in freeboard into potential changes in overall flow capacity. The following section summarizes the hydraulic model development, methodology used and the results of each of those evaluations.

Model Development

This study was conducted using calibrated Hydrologic Engineering Center's River Analysis System (HEC-RAS) models of the bypasses with 2008 topography and 2010/2011 bathymetry where available. HEC-RAS, version 4.1.0 (USACE, 2010) is a publicly available software package developed by the U.S. Army Corps of Engineers to perform 1-D steady-state step-backwater computations and a variety of other computations and analyses. Benefits of the HEC-RAS software include widespread industry acceptance, public availability, and ease of use. Using the annual estimated subsidence rates determined by DWR, two versions of the model were developed to reflect 2011 and 2016 conditions by adjusting the topography to reflect the subsidence between the date of the respective survey and the target date of the analysis. For 2011 conditions, the model was adjusted to reflect the amount of subsidence that occurred between 2008 and 2011. For 2016 conditions, the model was further adjusted to reflect the amount of subsidence that is projected to occur between 2011 and 2016. The same models were used for both of the study efforts.

Freeboard Analysis and Results

Hydraulic models were used to evaluate freeboard on bypass levees using flood design flow capacity rates published in the O&M Manual. The design flow capacities for the Chowchilla and Eastside Bypasses were input into the models to evaluate water surface elevations and evaluate freeboard under 2008, 2011, and predicted 2016 topographic conditions (**Figures 4 and 5**). Figures 4 and 5 show the left and right levee profiles for the study area. The modeled freeboard for the flood capacity flows in each reach for the 2008, 2011, and predicted 2016 time periods are shown in **Figures 6 and 7**.

Hydraulic models indicate that water surface elevations declined between 2008 and 2011, and are predicted to continue to decline in 2016. Because changes in topography represent the only variable between the model runs, changes in water surface elevation are caused by the lowering of the ground which, in turn, is the result of subsidence. Because the ground is subsiding at different rates along the reaches, the total amount of subsidence that has occurred at each cross section will not be the same as the total amount of water surface elevation change at each cross section. Furthermore, ground subsidence tends to steepen some segments of the reach which results in a decrease in water depth and an increase in freeboard. An area where this occurs is between Ash Slough and Road 4 where there is an increase in freeboard as shown in **Figure 6**. Other sections of the reach, such as from Road 4 to Avenue 21 have flattened out, resulting in increased water depth, and therefore reduced freeboards.

The results show that freeboard in 2008 and 2011 is generally above 3 to 5 feet along most of the bypass except between Sand Slough and West Washington Road, which is an area of recurring sediment deposition. From 2011 to 2016, it is expected that the continuing subsidence will reduce the freeboard in this area by about 0.5 feet. In the peak subsidence area between Road 4 and Avenue 21, ongoing subsidence is estimated to decrease the freeboard from 2011 to 2016 an additional 1.5 feet. For Highway 152, the projected decrease in freeboard is about 0.7 feet. The opposite is true within the proximity of Avenue 18 ½ where the freeboard is expected to increase from 2011 to 2016 by about 0.7 feet due to the increase of the channel slope, resulting in a higher channel capacity, as a result of the subsidence.

Flow Capacity Analysis and Results

The previous section discussed the effect of subsidence on freeboard, as determined by the hydraulic models. This section uses the same models to evaluate the change in flood flow capacity for the same channels for the same time periods. The focus of this evaluation was to estimate the change in flood flow capacity using the 4-foot levee freeboard criteria described in the O&M Manual. Using an assumed routing that considers typical flood operations, a range of flows up to the flood design flows were run in each segment of the bypass considering tributary inflows (including inflows from the Kings River). A maximum flow capacity was then determined as the flows that would not exceed the 4 feet of freeboard criteria or the assumed flood design flow. Estimated flow capacities for each segment of the bypass within the study area are summarized in **Table 2**.

Table 2. Estimated flow capacity in the Chowchilla and Eastside Bypasses based on 4 feet of freeboard (in cfs)

Bypass Segment	Flood Design Flow (cfs)[1]	2008	2011	2016
Chowchilla Bypass				
Bifurcation Structure to Fresno River	5,500	>5,500	>5,500	>5,500
Eastside Bypass				
Fresno River to Berenda Slough [2]	10,000	>10,000	>10,000	>10,000
Berenda Slough to [3] Ash Slough	12,000	>12,000	>12,000	>12,000
Ash Slough to Sand [4] Slough	17,500	9,500 -12,500[5]	7,500 - 11,500[5]	6,000 - 10,000[5]
Sand Slough to [6] Mariposa Bypass	16,500	16,000	14,500	13,000

[1] Referenced from the Lower San Joaquin River Flood Control Project Operation and Maintenance Manual.

[2] Capacity includes contribution of up to 5,000 cfs from the Fresno River.

[3] Capacity includes contribution of up to 2,000 cfs from the Berenda Slough.

[4] Capacity includes contribution of up to 5,000 cfs from Ash Slough

[5] Capacity range considers inflows from Reach 4A of the San Joaquin River

[6] Capacity assumes diversions into the Mariposa Bypass based on the O&M Manual operating rules

The flow capacity of the bypasses depends greatly on the quantity of tributary inflows and routing at Sand Slough and the Eastside Bypass Control Structure. In this analysis, flow capacity above Ash Slough will still handle published flood design flows. However, in the Eastside Bypass below Ash Slough, flow capacity is less than the assumed flood design flow. Continuing subsidence will further reduce the flood bypass' ability to convey flood flows. The flow capacity in the Eastside Bypass from Ash Slough to Sand Slough was 5,000 cfs less in 2008 than published design flows and from Sand Slough to the Mariposa Bypass was 500 cfs less (**Figure 9**). For 2011 (**Figures 10 and 11**) and 2016 conditions (**Figures 12 and 13**), subsidence further reduces the flow capacity in these segments of the bypass.

Along the Eastside Bypass from Ash Slough to Sand Slough, flow capacity from 2008 to 2011 was reduced an additional 1,000 cfs to 11,500 cfs and another 1,500 cfs to a total of 10,000 cfs in 2016. When flood inflows enter the Eastside Bypass from the San Joaquin River upstream of Sand Slough (a typical routing situation as flooding on the Kings River generally coincides with floods on the San Joaquin River) the backwater conditions inundates the upstream area and further reduces the flow capacity in this segment of the Eastside Bypass to 7,500 cfs and 6,000 cfs, respectively, in 2011 and 2016. This is a significant reduction from the flood design flow of 17,500 cfs in the segment of the bypass and is likely due to historical subsidence and sediment deposition in this reach as illustrated from the already reduced 2008 flood design capacity of 9,500 cfs. Along the Eastside Bypass from Sand Slough to the Mariposa Bypass, the flow capacity at 4 feet of freeboard was reduced from 2008 to 2011 by about 2,500 cfs to 14,500 cfs and by another 1,500 cfs to 13,000 cfs in 2016.

The results of this hydraulic analysis show that portions of the bypasses currently do not meet the assumed flood design flow. Subsidence documented since 2008 has further reduced the capacity of these segments of the bypass and will continue to reduce flow capacity if subsidence continues.

Conclusion and Recommendations

Subsidence is changing the amount of freeboard in the bypasses, which affects their ability to convey flows. Flow capacity in the bypasses has been reduced as a result of subsidence by up to 2,500 cfs since 2008. If subsidence continues, it is estimated that an additional loss in flow capacity up to 1,500 cfs from 2011 to 2016 depending on the segment of bypass. If future subsidence occurs as expected, continued subsidence would be expected to have an impact on future flood operations.

Continued monitoring and analysis could provide a better understanding of the future rates of subsidence and effect on future flow capacities. Periodic topographic and water-surface profile surveys could be conducted to monitor the rate of subsidence at the bypasses. Additional modeling of the Sand Slough area could be completed to better understand the hydraulic characteristics and associated impacts on capacity. Since the hydraulic analysis does not include the impact of future sediment deposition, it may not fully represent the overall impact caused by subsidence. A sediment transport study, by quantifying the rates and locations of likely sediment deposition, would offer a better understanding of how sedimentation could affect flow capacity and to provide information on the amount of dredging that may be required to maintain necessary design flow capacities.

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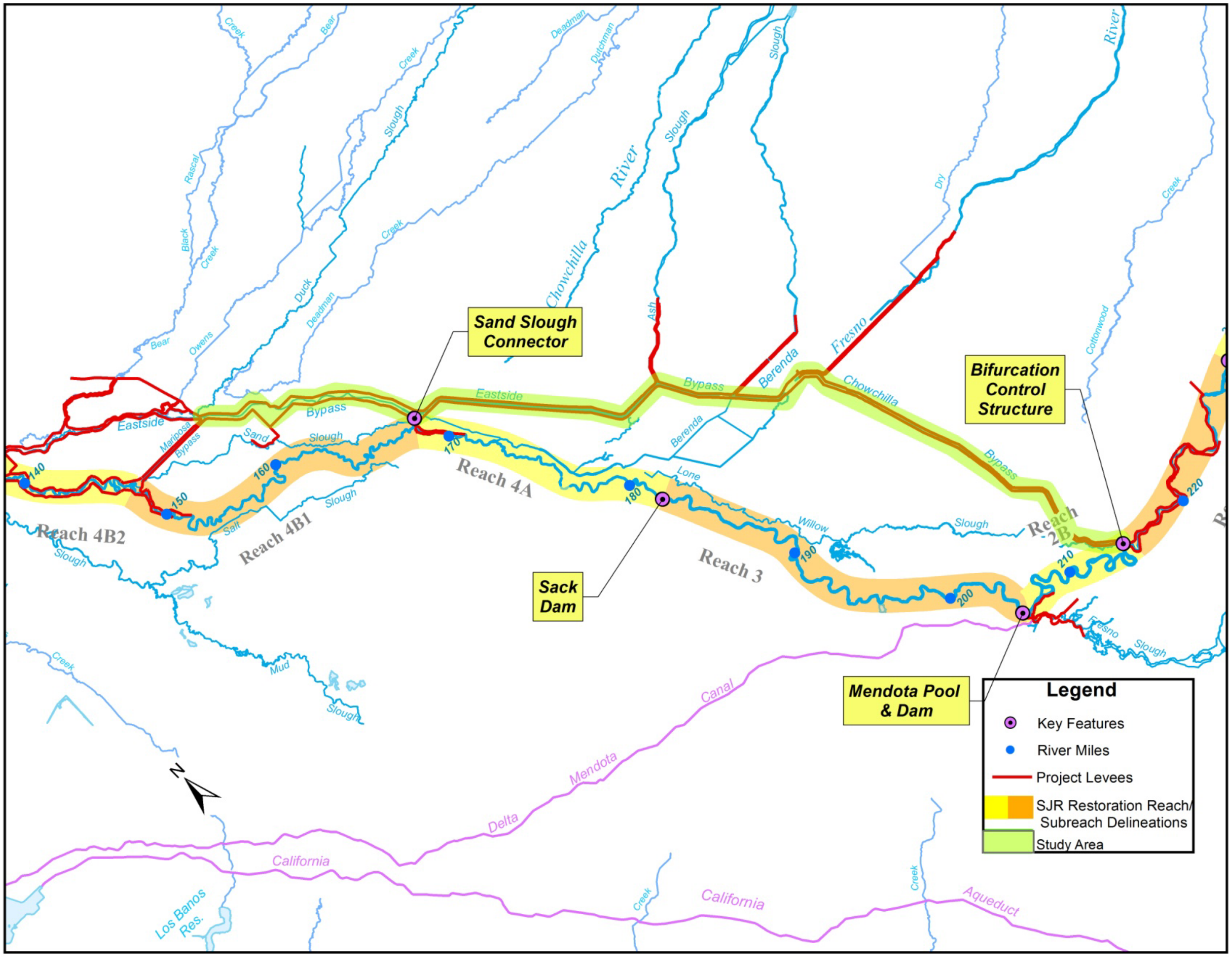

Figure 1. Study Area

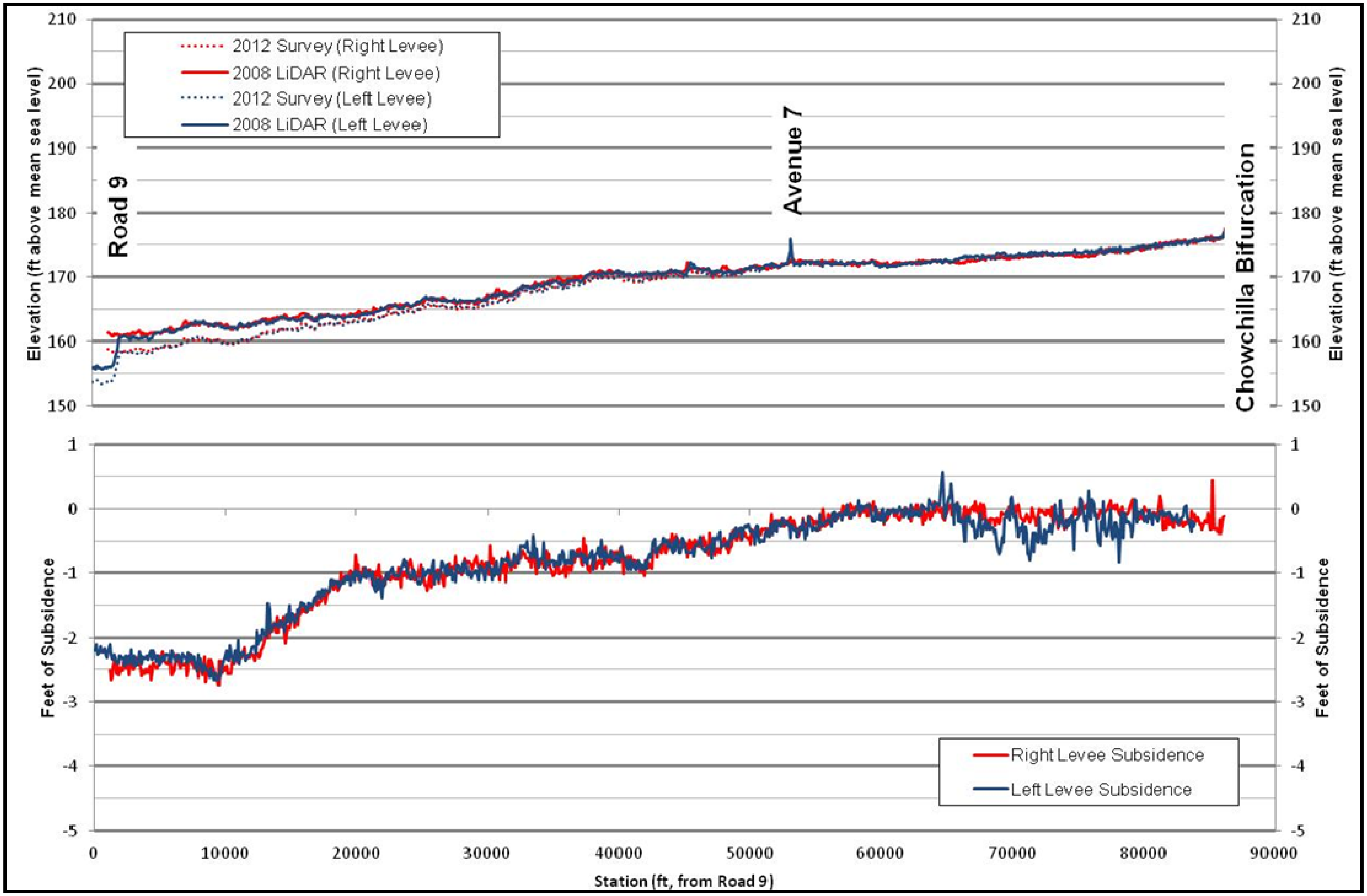

Figure 2. Ground subsidence along the Chowchilla Bypass from the Chowchilla Bifurcation Structure to Road 9 based on DWR 2012 survey and 2008 LiDAR.

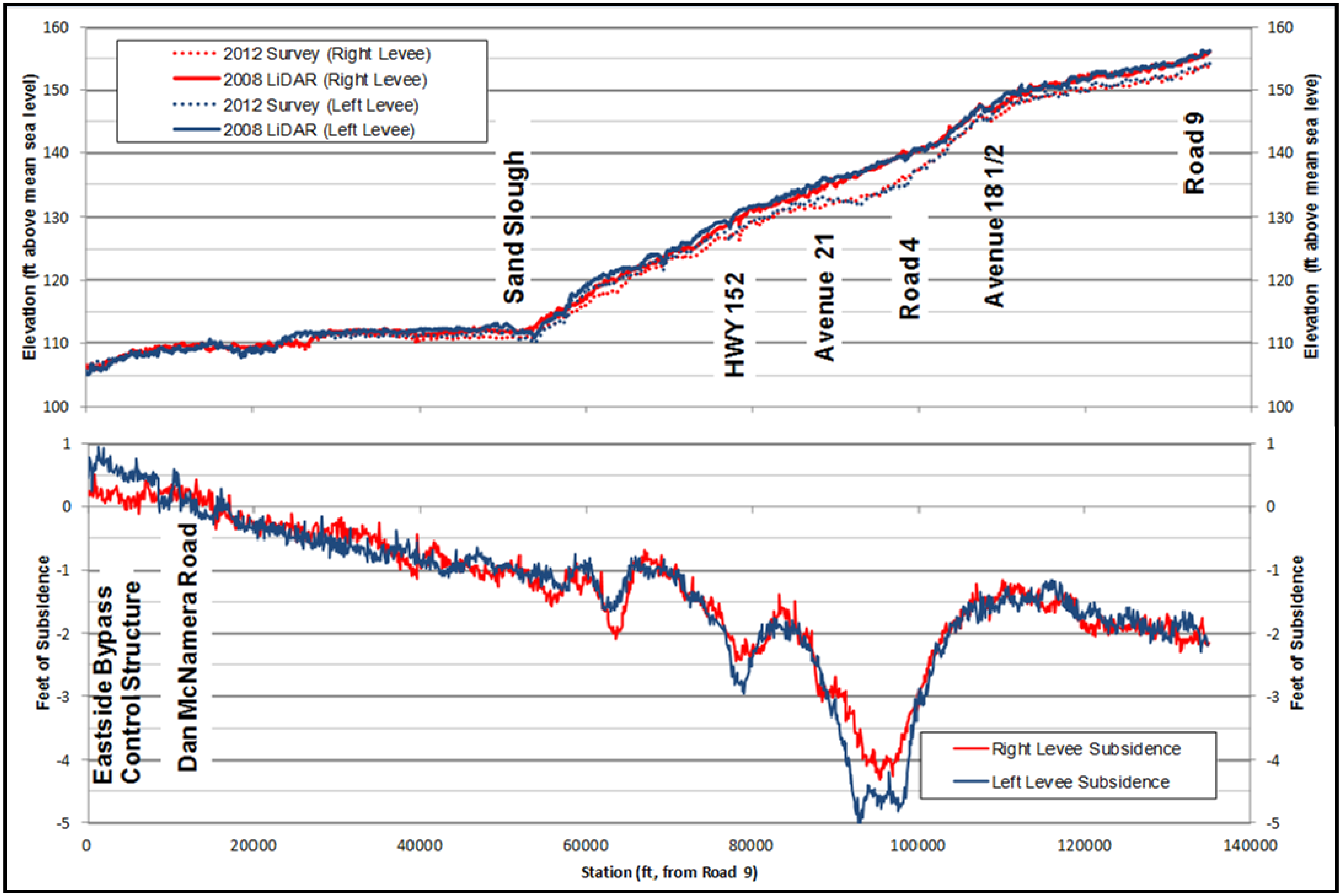

Figure 3. Ground subsidence along the Eastside Bypass from Road 9 to the Eastside Bypass Control Structure based on DWR 2012 survey and 2008 LiDAR

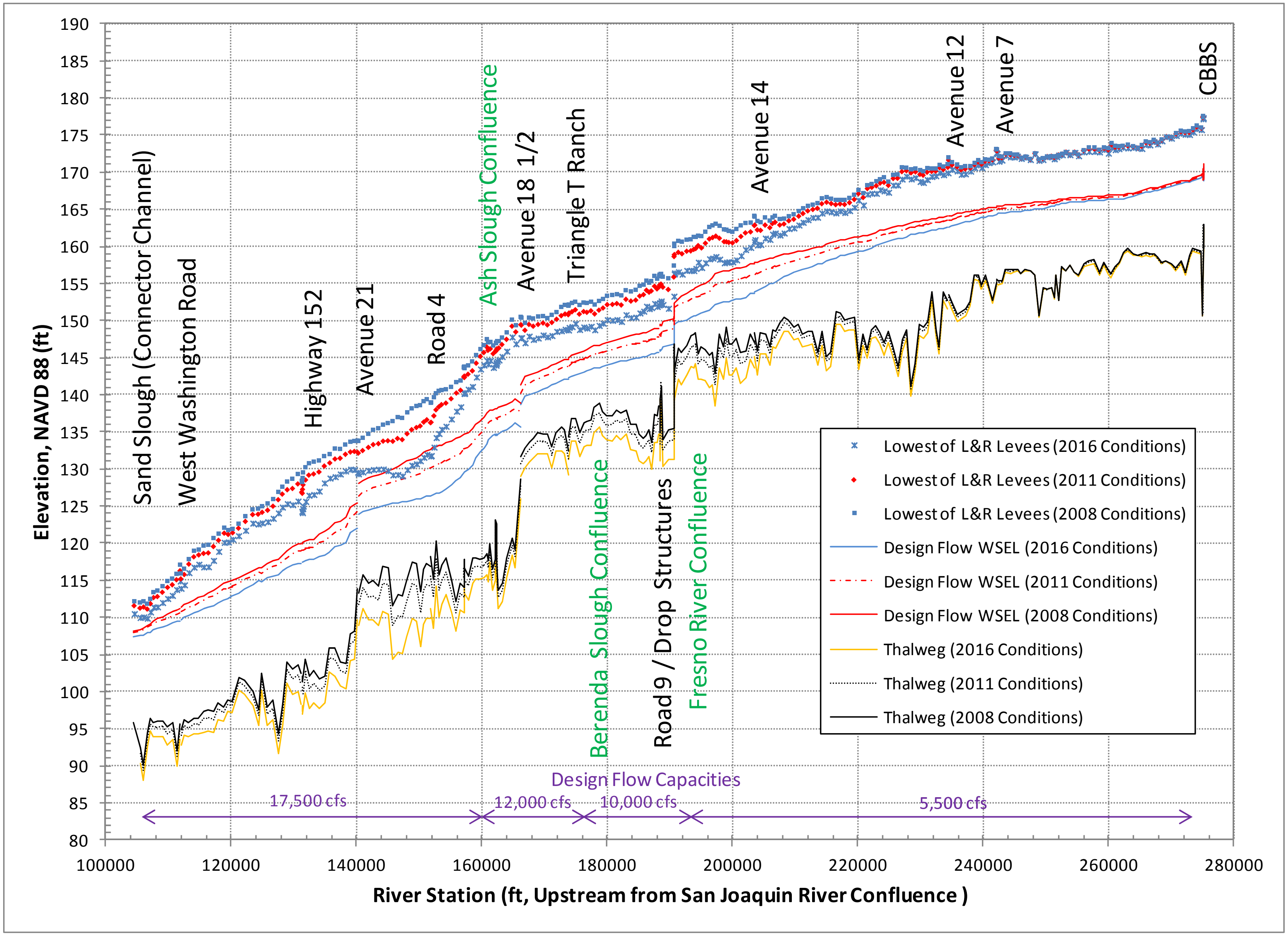

Figure 4. Design flow under 2008, 2011, and 2016 conditions in Chowchilla and Eastside Bypass from the Fresno River to Sand Slough.

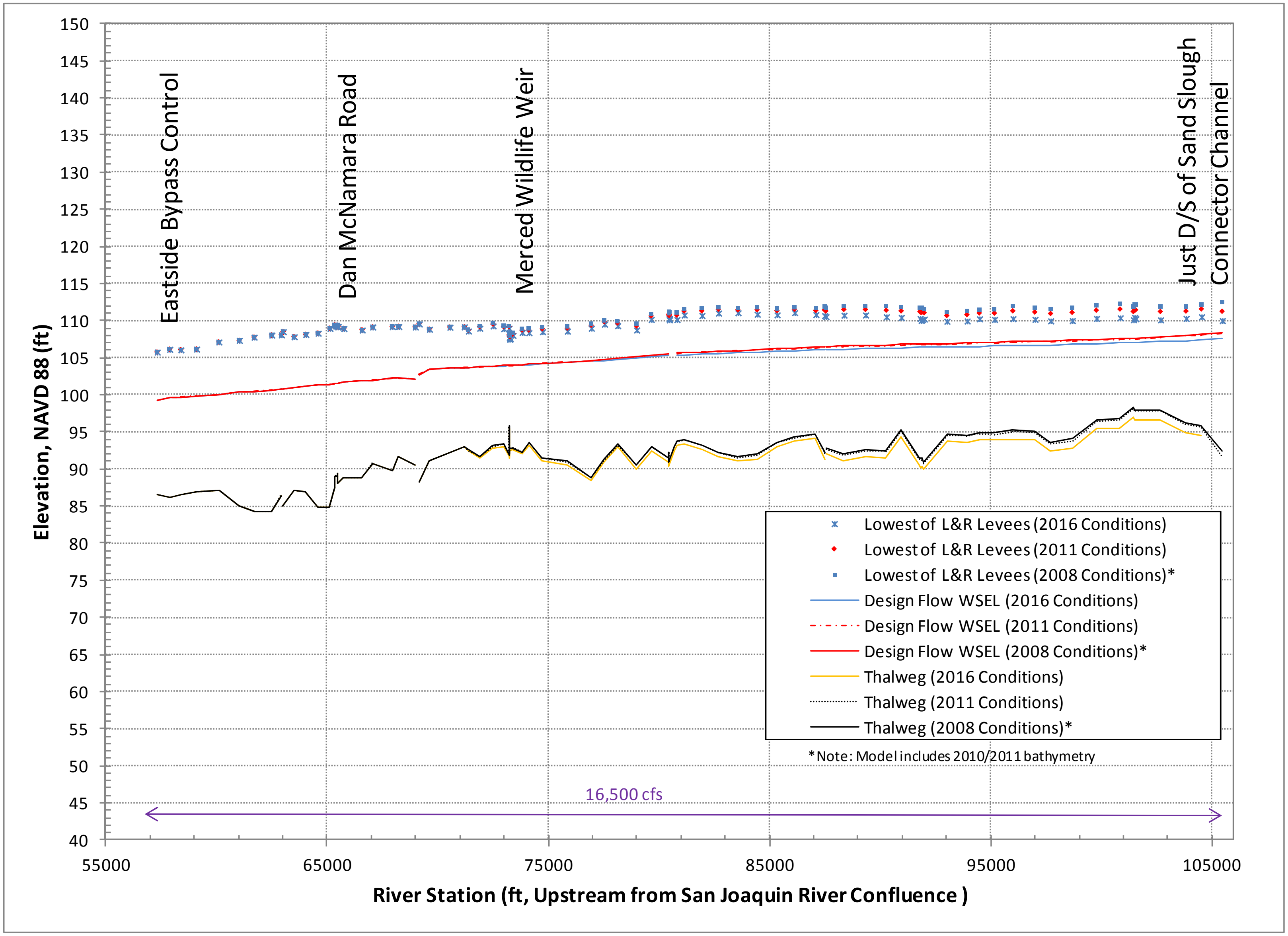

Figure 5. Design flow for 2008, 2011, and 2016 in the Eastside Bypass from Sand Slough to the Mariposa Bypass.

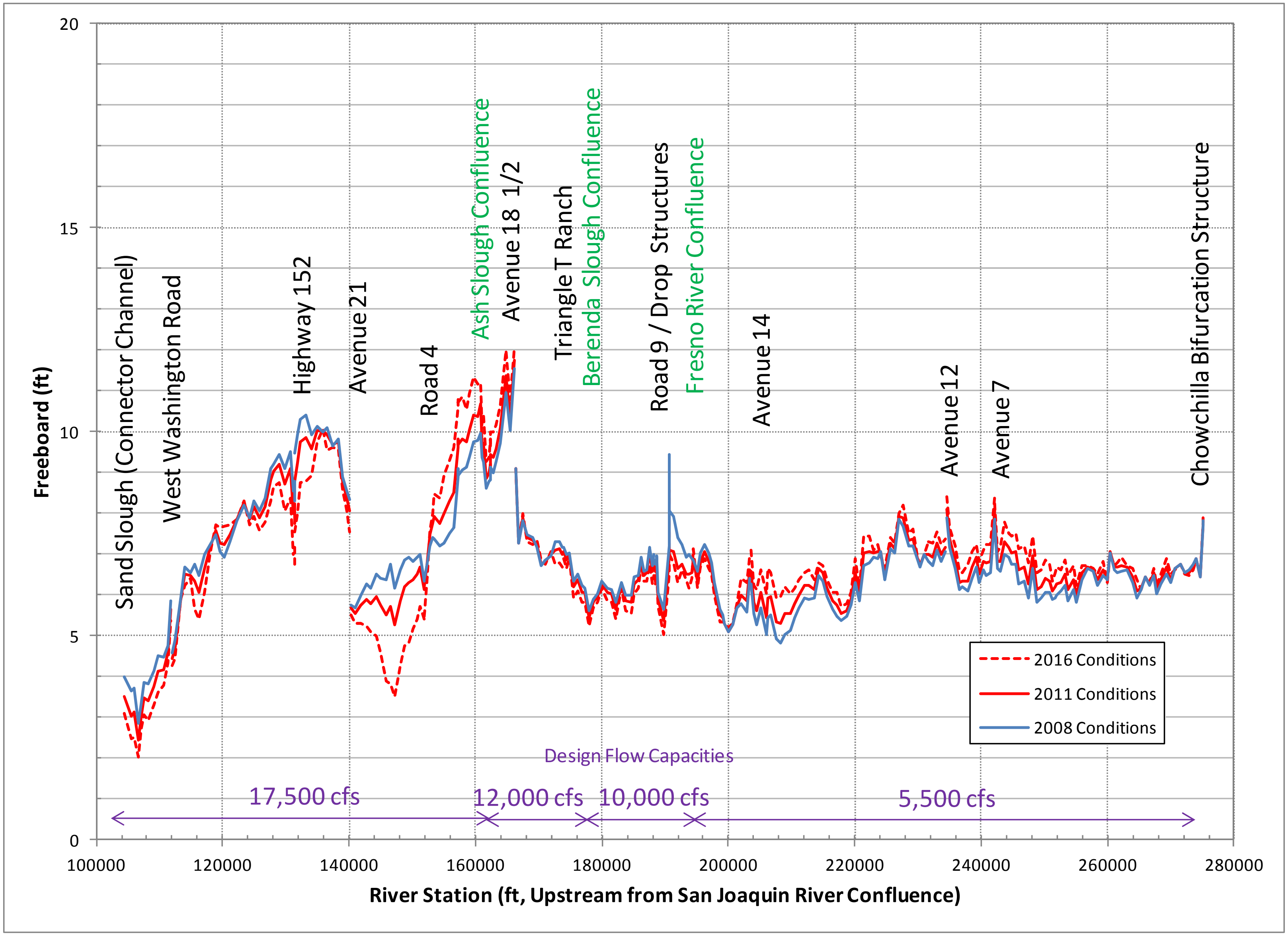

Figure 6. Freeboard conditions for the 2008, 2011, and 2016 conditions in Chowchilla and Eastside Bypass from the Fresno River to Sand Slough based on design flow capacities.

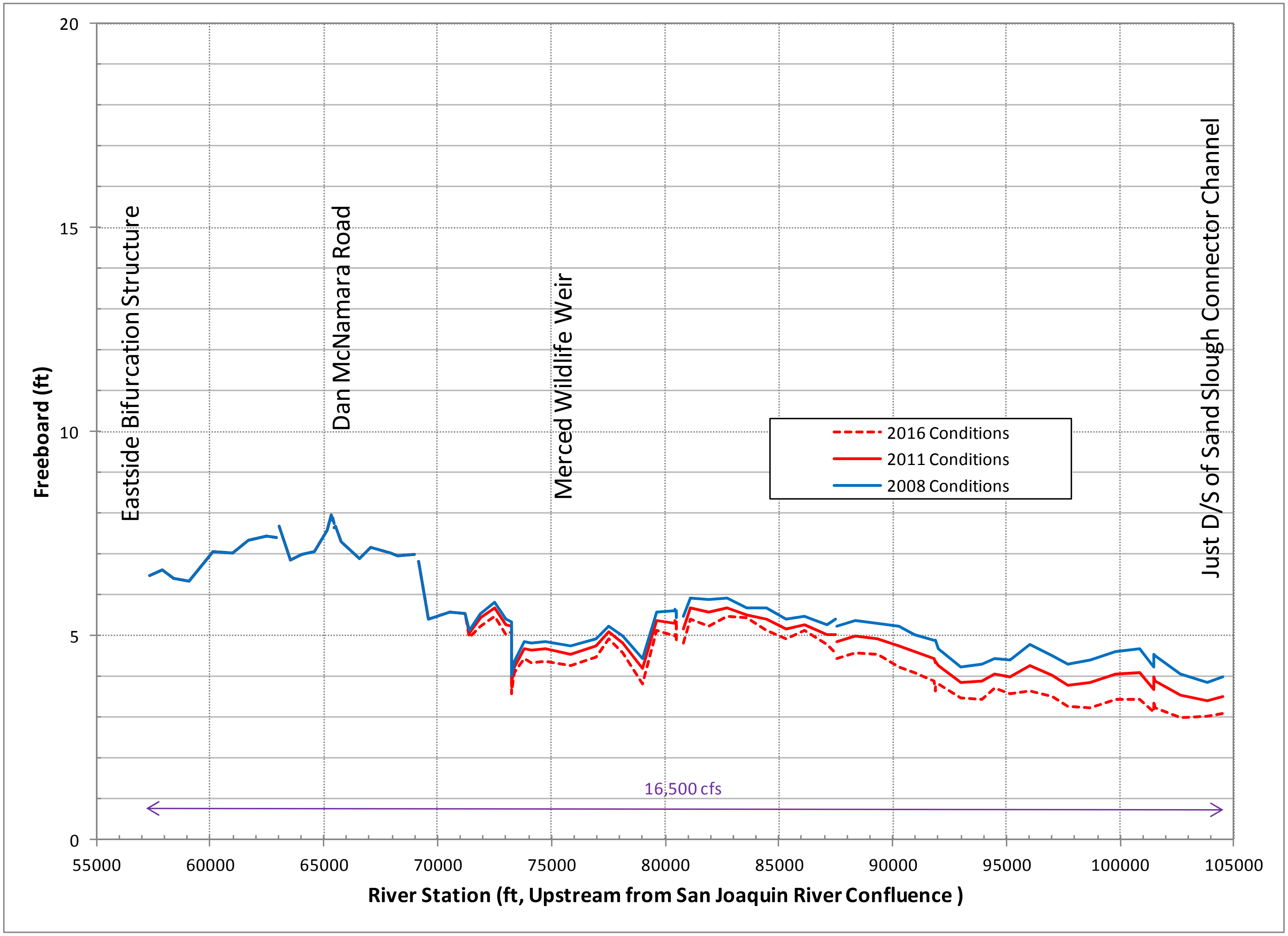

Figure 7. Freeboard conditions for 2008, 2011 and 2016 conditions for Eastside Bypass from Sand Slough to the Mariposa Bypass based on design flow capacities.

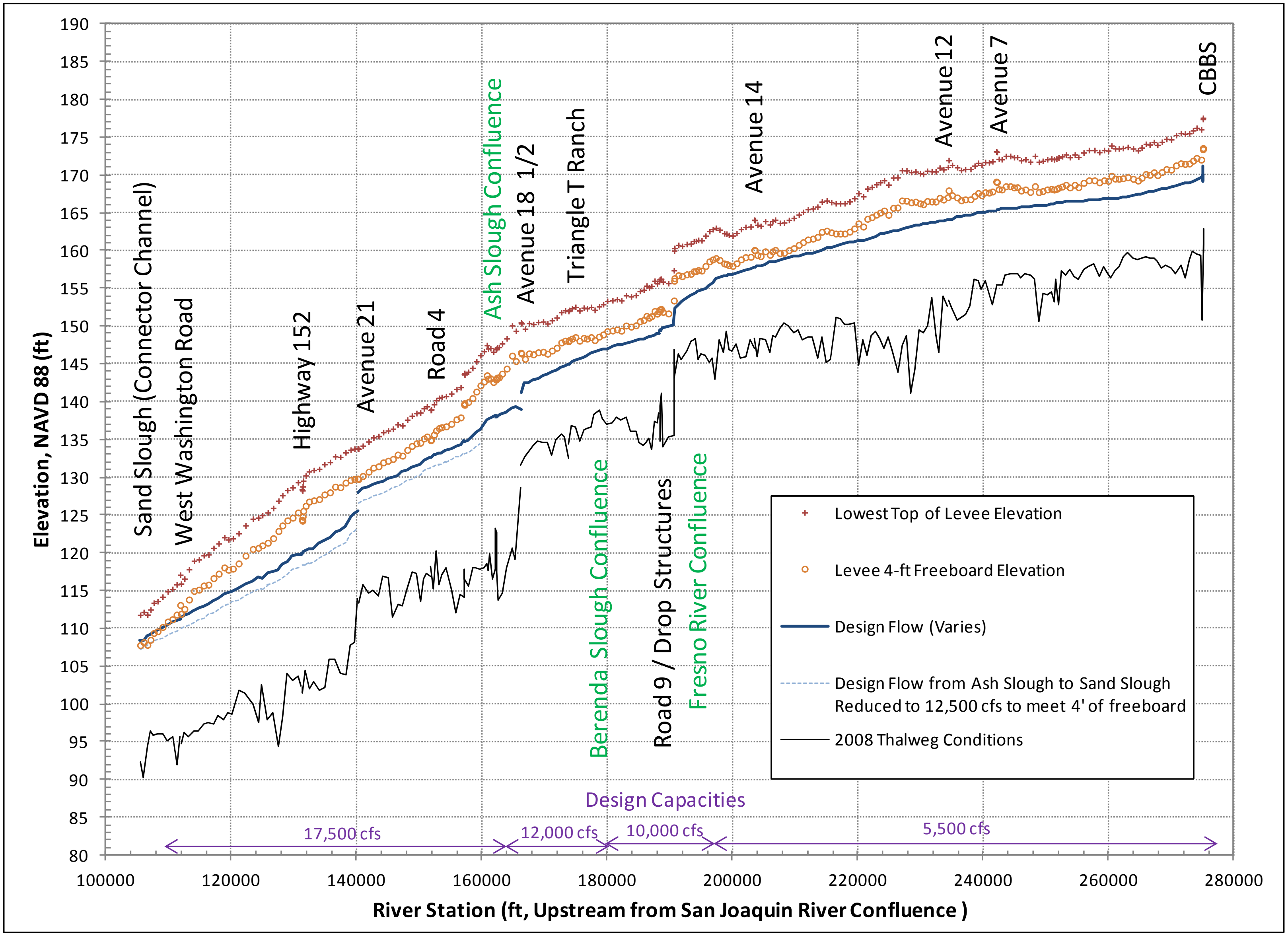

Figure 8. Water-surface profile for 2008 conditions from CBBS to Sand Slough

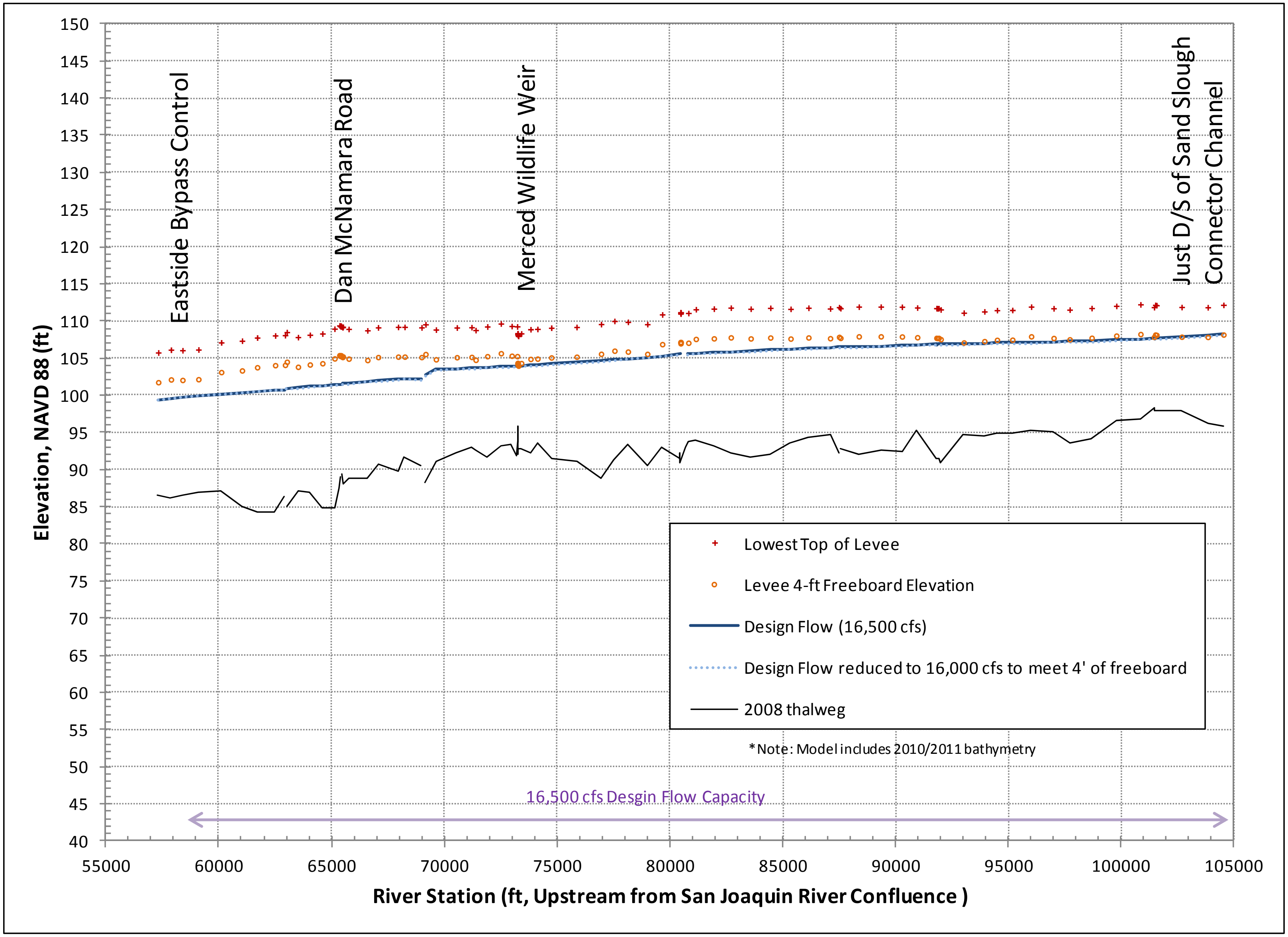

Figure 9. Water surface profile for 2008 conditions from Sand Slough to the Mariposa Bypass

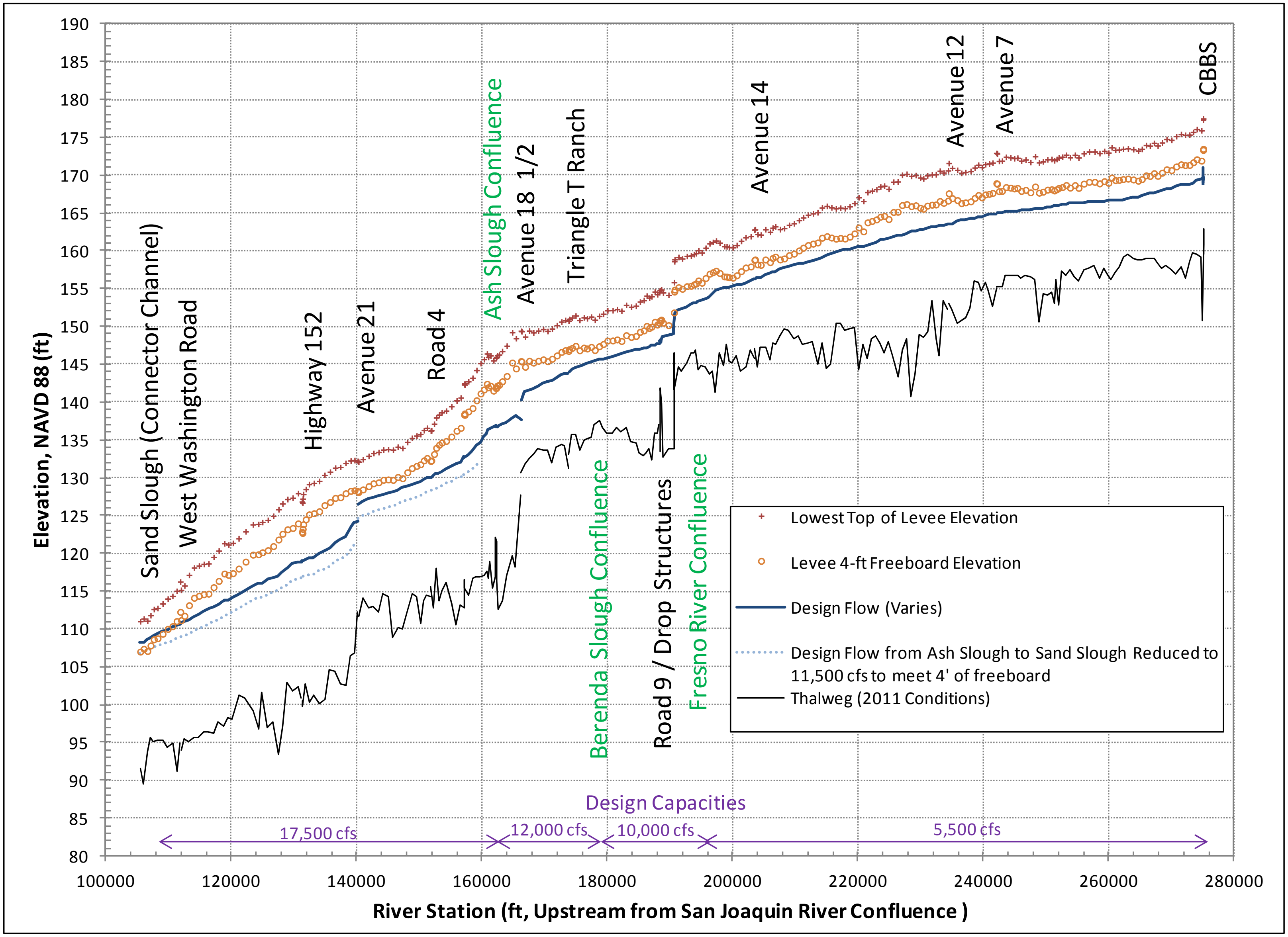

Figure 10. Water surface profile for 2011 conditions from CBBS to Sand Slough

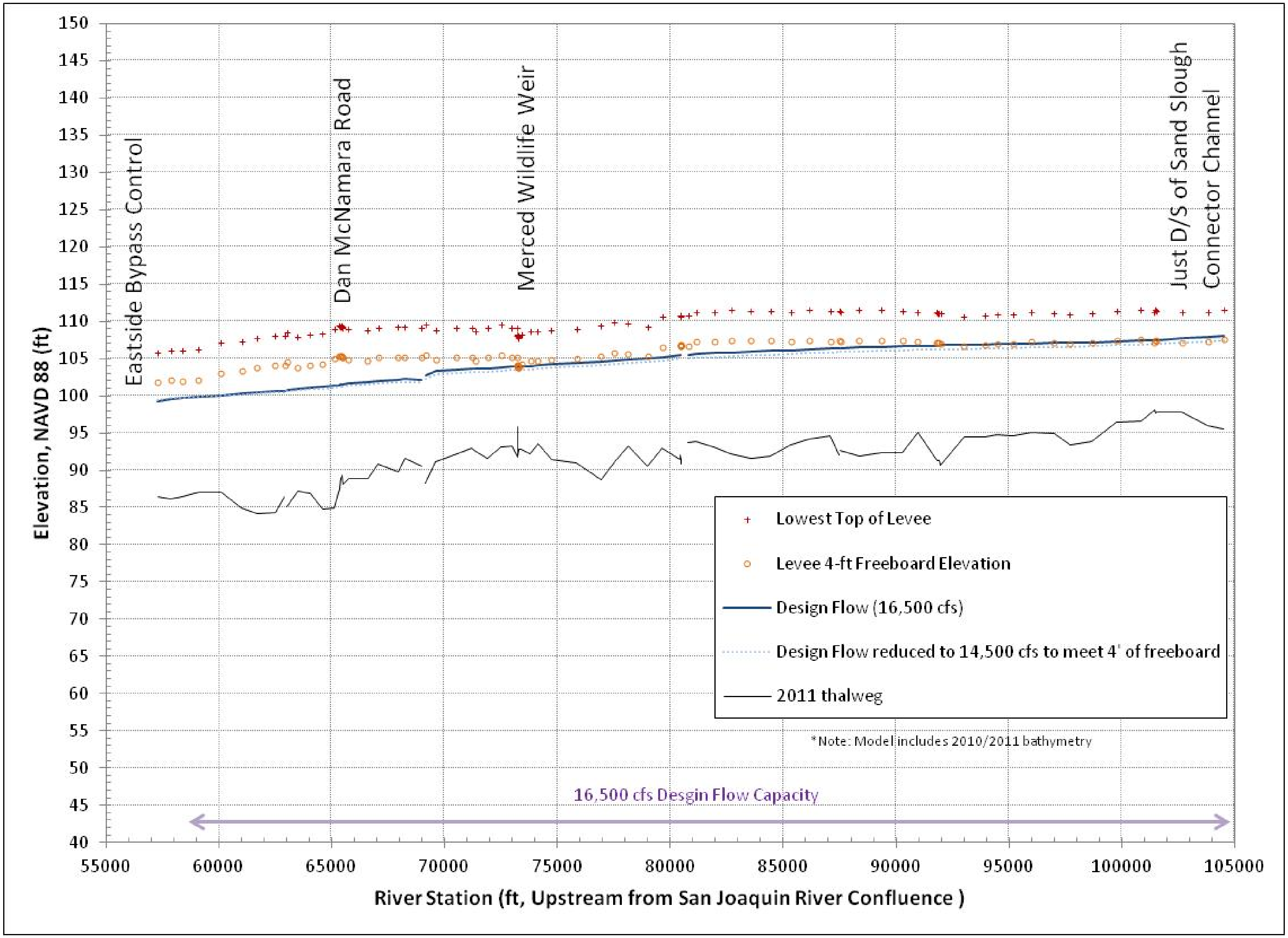

Figure 11. Water surface profile for 2011 conditions from Sand Slough to the Mariposa Bypass

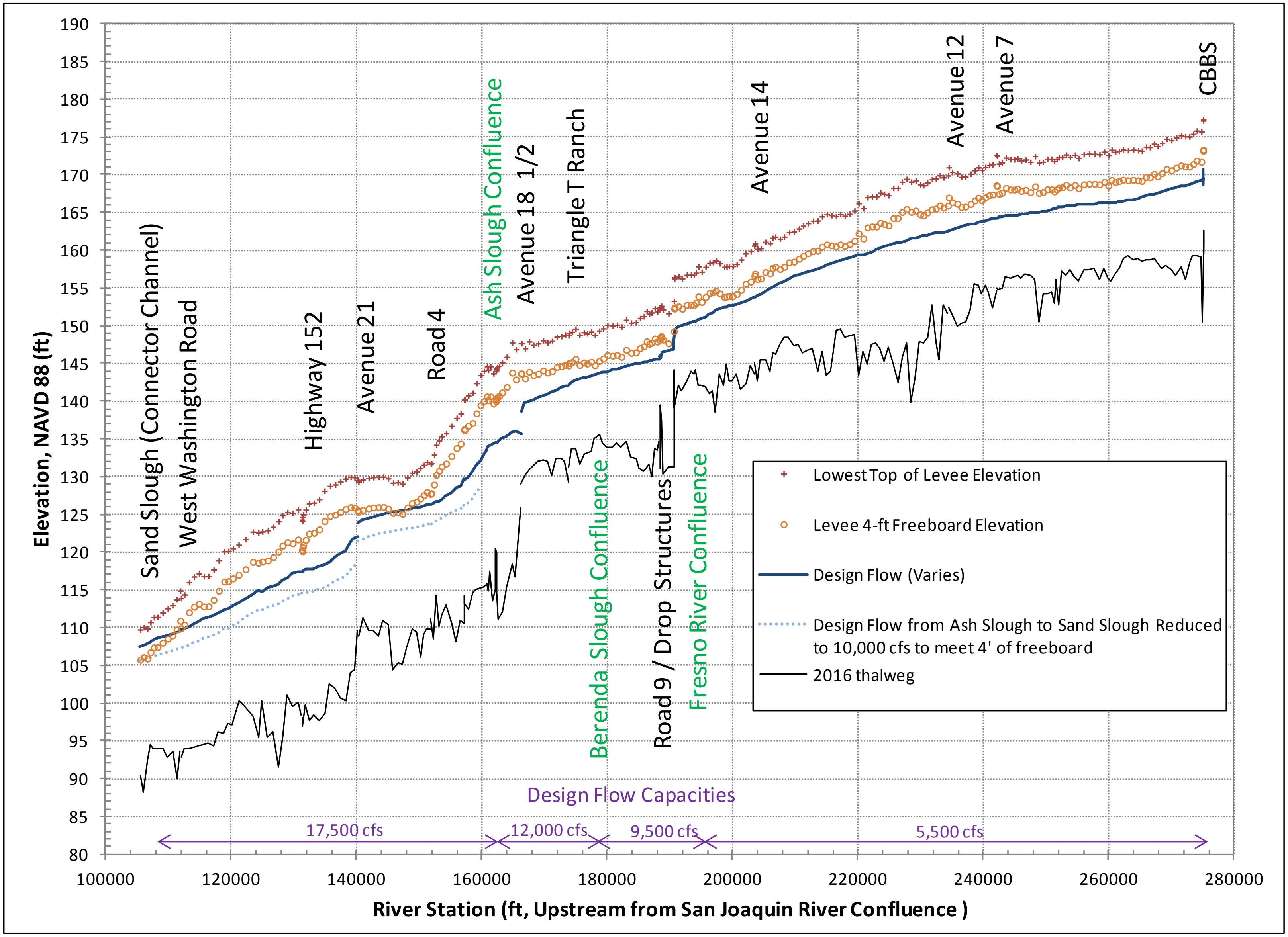

Figure 12. Water surface profile for 2016 conditions from CBBS to Sand Slough

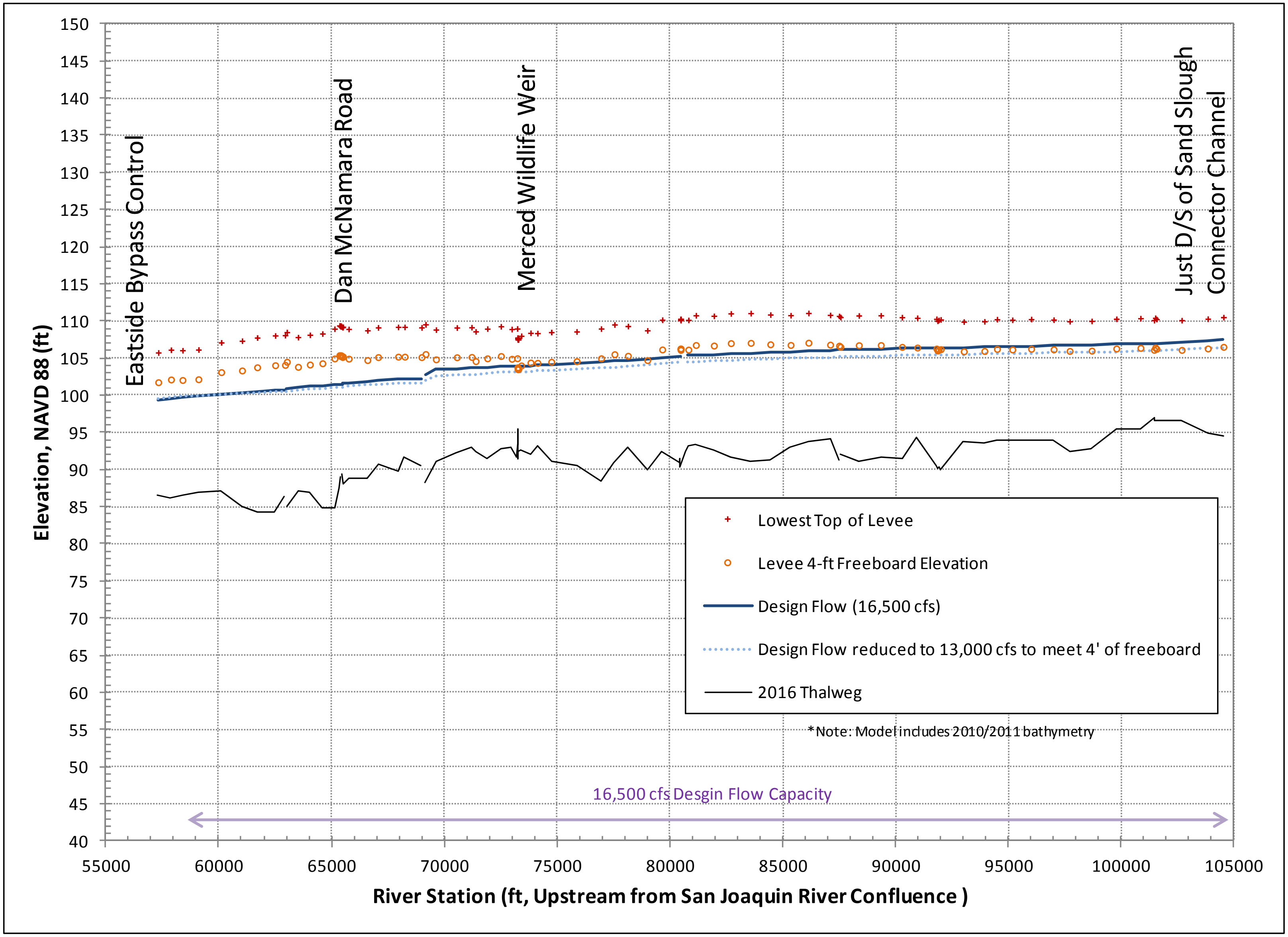

Figure 13. Water surface profile for 2016 conditions from Sand Slough to the Mariposa Bypass