**Appendix F**

# Hydraulic Evaluation of the Effect of Subsidence on Freeboard Capacity in the Chowchilla and Eastside Bypasses

**February 2013**

SAN JOAQUIN RIVER
RESTORATION PROGRAM

California Department of Water Resources
South Central Region Office

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The Department of Water Resources (DWR), South Central Region Office (SCRO) has performed a preliminary investigation of the potential impact of subsidence on levee freeboard in the Chowchilla and Eastside Bypasses between the San Joaquin River at the Chowchilla Bifurcation Structure and the Mariposa Bypass (Figure 1). Subsidence in the area is a known fact and was documented in the Sacramento-San Joaquin Comprehensive Study (2002). However, LiDAR control surveys completed between 2008 and 2010 identified an area showing extreme subsidence rates occurring near the Eastside and Chowchilla Bypasses as a result of recent land development. This subsidence has the potential to reduce levee freeboard, change performance of control structures, and alter sediment erosion and deposition patterns during future flood operations.

In order to evaluate the effect of current and future subsidence on levee freeboard in the bypasses, DWR-SCRO performed topographic surveys of the subsidence area and employed hydraulic models. The goal of this study was to analyze the change in freeboard in the bypass between 2008 and 2011 and make projections on potential changes in freeboard in 2016 due to continuing subsidence. The work was done to assist the San Joaquin River Restoration Program (SJRRP) identify potential impacts on the design and implementation of the projects to achieve the goals of the program. The information may also assist the local agencies in informing future flood operations and maintenance as well as regional planning efforts as part of the Central Valley Flood Protection Plan.

# Topography

Several surveys have been performed over the past two years to identify the magnitude of the subsidence in the area. RBF Consulting performed the initial survey that identified subsidence when they conducted surveys in 2010 to quality control the 2008 LiDAR data under DWR's CVFED program.  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 the rates do vary along the bypass depending on season, year type, and land use. However, general trends are similar to previous data collection efforts.

DWR-SCRO also collected topographic survey data in late 2012 to help further refine the estimated annual rates. DWR subsidence rates were estimated based on comparison of the levee profiles from the 2008 LiDAR and the surveyed 2012 levee profiles (Figures 2 and 3). Table 1 compares the subsidence rates from various 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 Middle Eastside Bypass are slightly lower than other data sources. These differences could be a result of the time frames that the data was taken, as well as the quality of the data. It is likely that subsidence is not occurring at the same rate year to year.

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

| Bridge Structures | RBF[1] rate, ft/year | USGS[1] rate, ft/year | Reclamation[2] rate, ft/year | DWR[3] 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 | 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[4] | 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 Rates vary depending on time of year and year type.

# Hydraulic Analysis and Results

This study was conducted using calibrated 1-D steady state HEC RAS models of the bypasses with 2008 topography and 2010/2011 bathymetry where available. 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 portion of the model that was based on 2008 topography was adjusted to reflect the amount of subsidence between 2008 to 2011. For 2016 conditions, the entire 2011 model was adjusted to reflect the amount of subsidence that is projected to occur between 2011 and 2016.

The hydraulic models of the bypasses were initially used to simulate the design flow rates published in the Lower San Joaquin River Flood Control Project *Operation and Maintenance Manual* of 1967 (Flood Manual) and shown in Figure 1. The design flows for the Chowchilla and Eastside Bypasses were input into the models to simulate water surface elevations and evaluate freeboard for 2008, 2011, and 2016 topography conditions (Figures 4 and 5). The freeboard each reach for the 2008, 2011, and 2016 time periods are shown in Figures 6 and 7.

The results of the analysis showed that the simulated water surface elevations for 2011 and 2016 are generally lower than those of 2008, corresponding to the lowering of the ground due to subsidence. Because the ground is subsiding at different rates along the reaches, the difference in water surface elevation does not directly correlate with changes in water surface elevation. 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. Changes in relative total subsidence, water surface elevation, and levee freeboard in key areas are summarized in Table 2.

**Table 2. Estimated Changes in subsidence, water surface and freeboard (in feet)**

| Bridge Structures | Past Subsidence (3 years) 2008 – 2011 | | | Future Subsidence (5 years) 2011-2016 | | |
|---|---|---|---|---|---|---|
| | Subsidence | Water Surface | Freeboard | Subsidence | Water Surface | Freeboard |
| **Chowchilla Bifurcation** | -<0.1 | -<0.2 | +<0.1 | -0.2 | -0.2 | +0.1 |
| **Avenue 14** | -1.5 | -1.5 | +<0.1 | -2.6 | -2.6 | +<0.1 |
| **Avenue 18 ½** | -0.9 | -1.5 | +0.5 | -1.5 | -2.3 | +0.7 |
| **Road 4 to [2] Avenue 21** | -2.8 | -2.3 | -0.5 | -4.9 | -3.4 | -1.5 |
| **Highway 152** | -1.4 | -1.0 | -0.4 | -2.3 | -1.6 | -0.7 |
| **Sand Slough Vicinity** | -0.8 | -0.5 | -0.4 | -1.5 | -1.0 | -0.5 |
| **Merced Wildlife Weir** | -0.21 | <0.2[1] | +<0.1 | -0.4 | -<0.1 | -<0.3 |
| **Dan McNamara** | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Water surface is compared with model with 2008 topography for levees and overbanks, and 2010/2011 bathymetry.

[2] Peak area of subsidence

The results of modeling the design flows in the bypasses 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.

In order to estimate the potential reduction in future flow capacity in the bypasses due to the reduction in freeboard, an additional analysis was completed for a few select areas. The analysis showed that the reduction in freeboard between 2011 and 2016 would reduce the ability of the bypass to convey flows between Road 4 and Avenue 21 by about 4,500 cfs. In other areas, such as between Highway 152 and Sand Slough, the bypass capacity would be reduced by up to 2,000 cfs if subsidence continued at the same rate.

## Assumptions and Limitations

Several assumptions were necessary to evaluate the flows, freeboard impacts, and flood capacities of the bypasses as a result of subsidence. These assumptions include:

1. Subsidence is occurring at the same rate each year, is uniform across each cross section and is not spreading to other areas. The rates were estimated using the DWR data comparison of 2008 LiDAR and 2012 surveys. These rates are slightly higher or lower than other rates calculated by other agencies. The overall error of the rates depends on the time

frame of the survey and the level and method of survey, which should be considered when using the data.

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 topography used in this study reflects some excavation near Sand Slough.
3. Design flows are taken directly from what is published in the Flood Manual. It should be noted that the design flows assume there is 4 ft 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 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.

# Conclusion and Recommendations

Ground subsidence is changing the amount of freeboard that exists in the bypasses for conveying flows. If subsidence continues, it is estimated that a loss of freeboard of up to 1.5 feet will occur between 2011 and 2016 in one reach of the Eastside Bypass, resulting in a reduction of flow capacity in that reach of up to 4,500 cfs. The reduction in freeboard and flow capacity will vary by location and further evaluation will be needed to determine the impact of these reductions on the most critical capacity reaches of the bypass for conveying future flood events. However, the above results may underestimate the overall impact caused by subsidence since they do not include the impact of sediment deposition, which would likely further reduce the freeboard in areas which already have reduced freeboard, like Sand Slough. In order to better understand the future impacts of continuing subsidence, it is recommended that periodic surveys be conducted to monitor the pace of subsidence at the bypasses. It is also recommended that a sediment transport study be undertaken to better understand and quantify how sedimentation will affect levee freeboard and provide information on the amount of dredging that may be necessary to maintain the necessary freeboard.

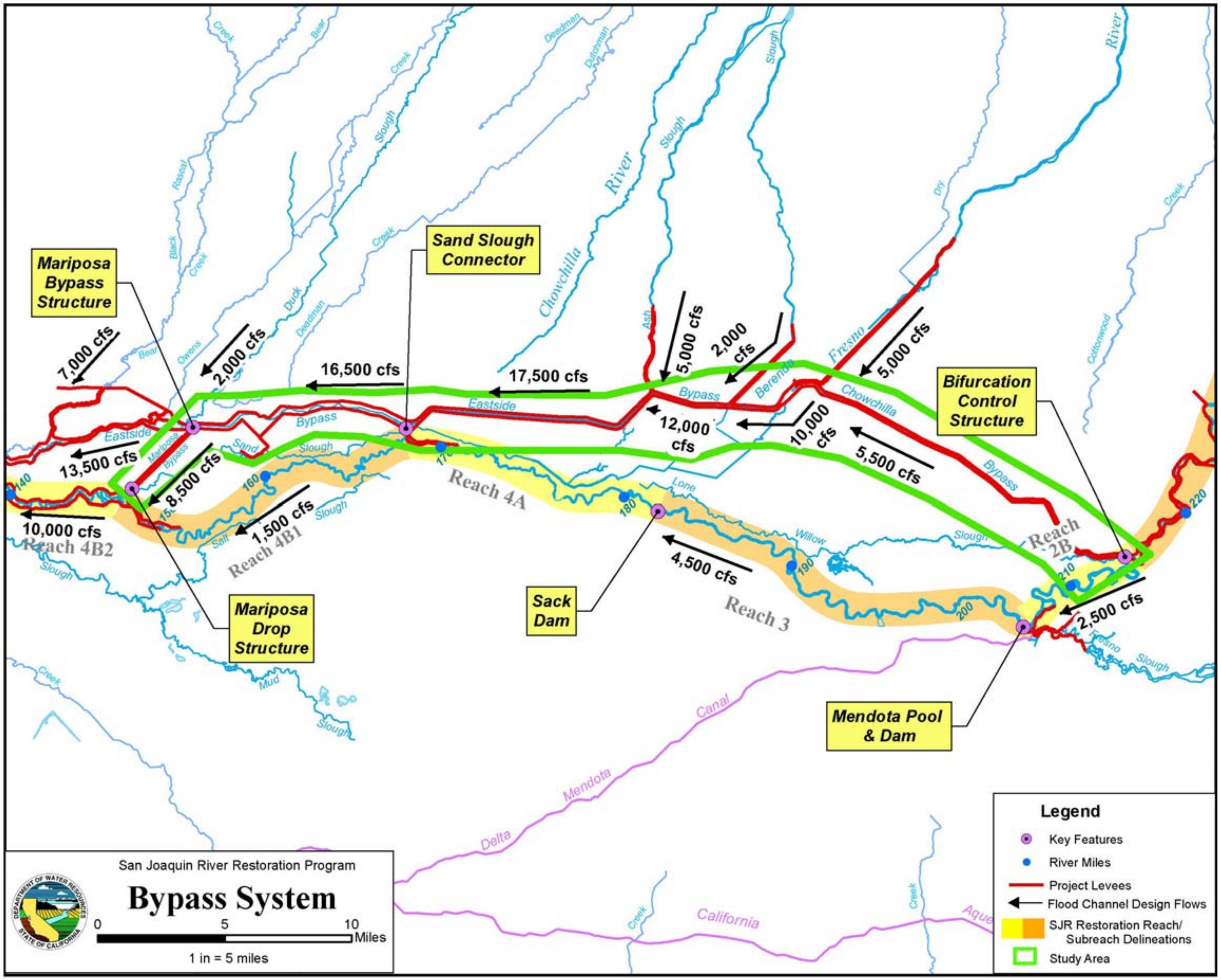


Figure 1. Study Area.

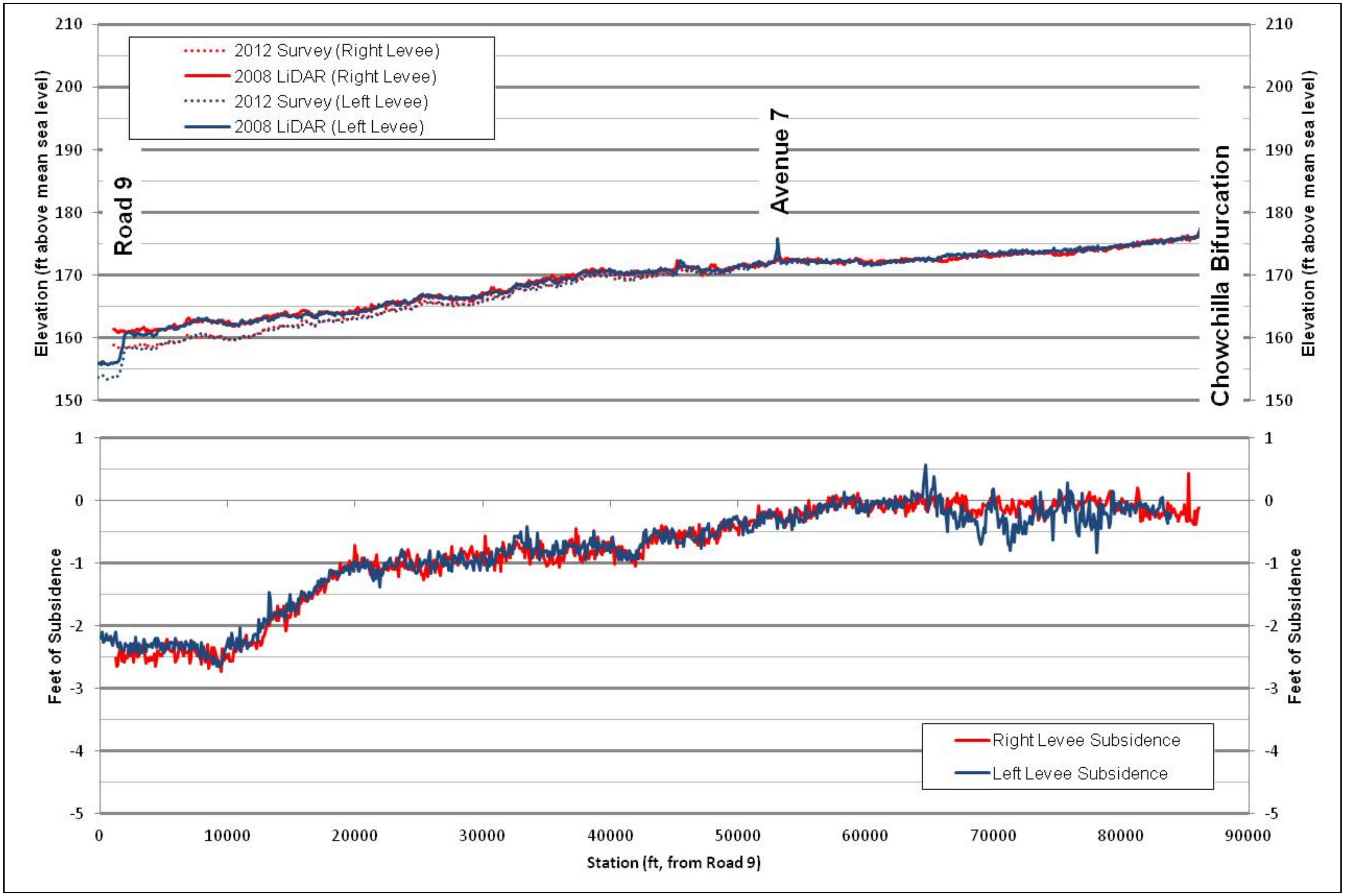


Figure 2. Ground subsidence along the Chowchilla Bypass from Road 9 to Chowchilla Bifurcation Structure based on DWR 2012 survey and 2008 LiDAR.

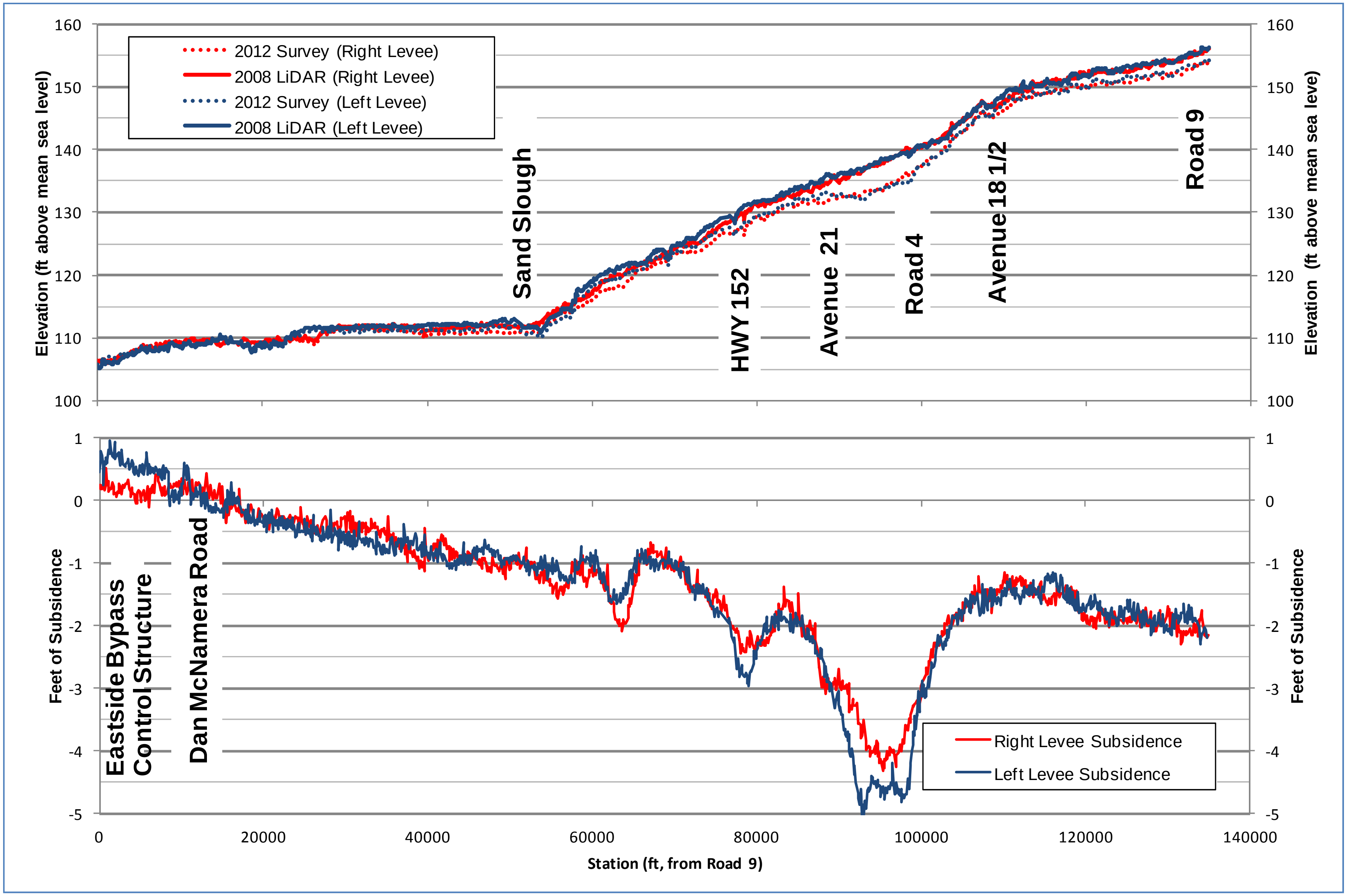


Figure 3. Ground subsidence along the Upper Eastside Bypass to the Eastside Bypass Control Structure based on DWR 2012 survey and 2008 LiDAR.

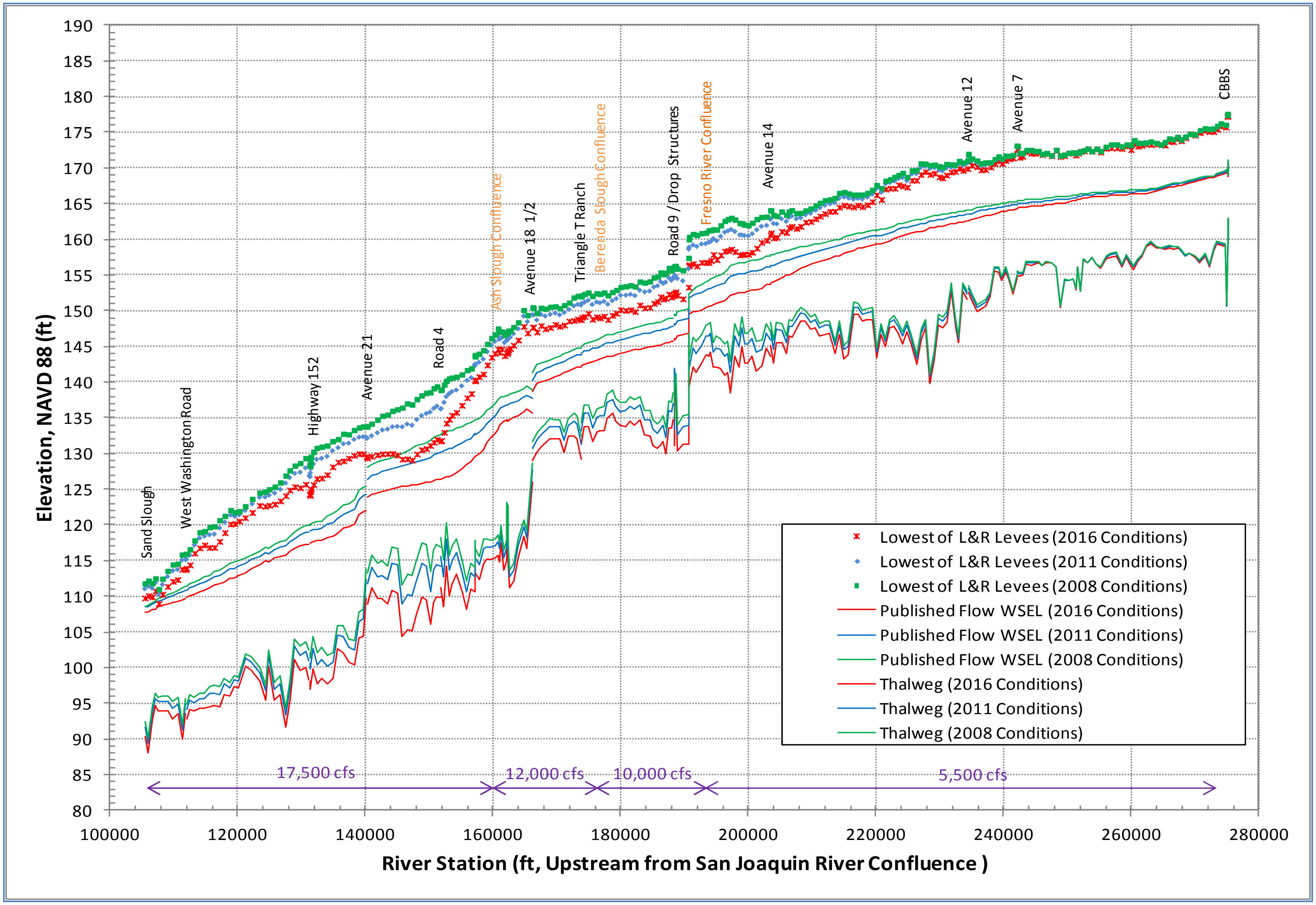


Figure 4. Design flow simulations for 2008, 2011, and 2016 conditions in Chowchilla and Eastside Bypass from the Fresno River to Sand Slough.

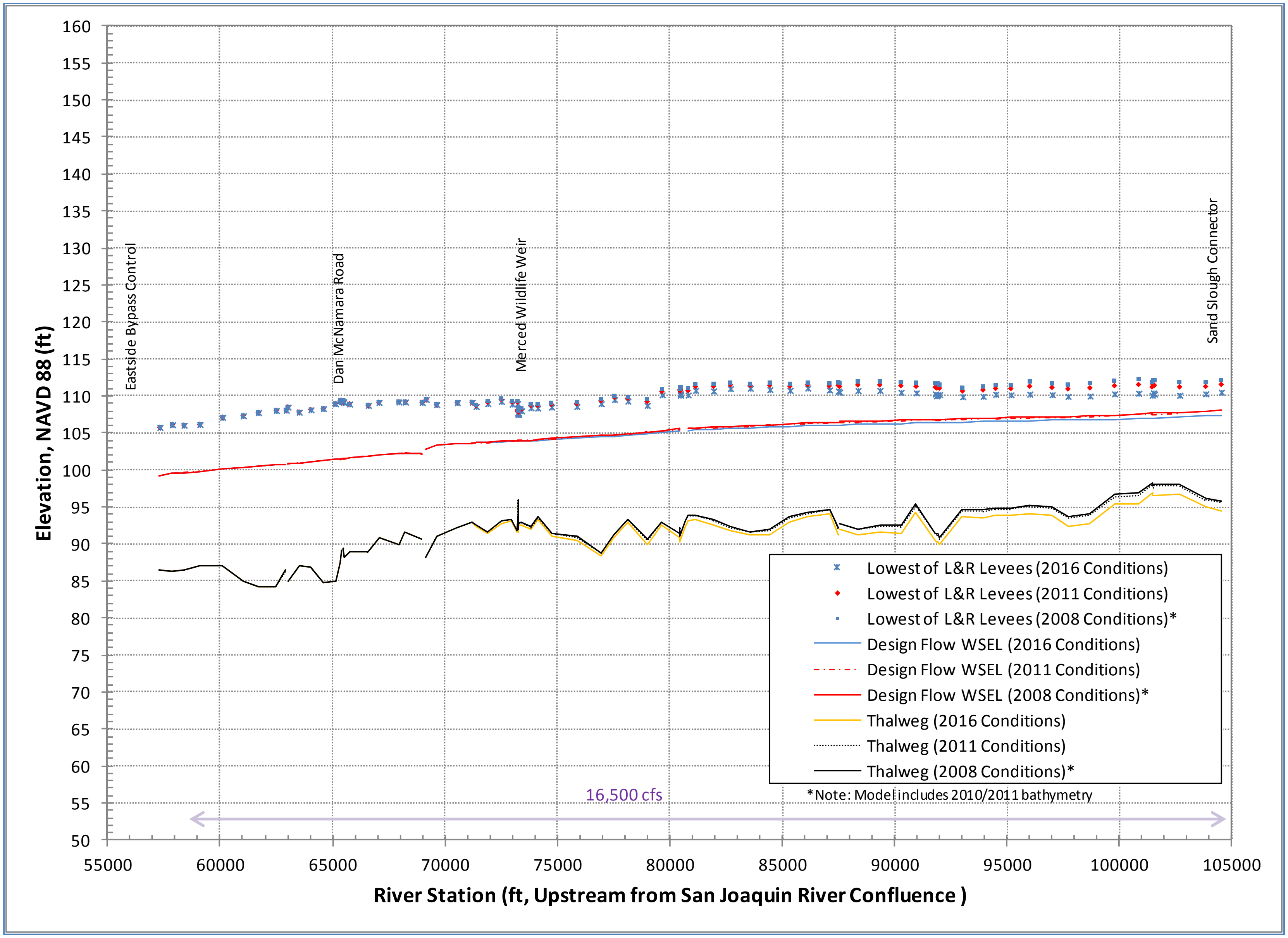


Figure 5. Design flow simulations for 2008, 2011, and 2016 in the Eastside Bypass from Sand Slough to the Mariposa Bypass.

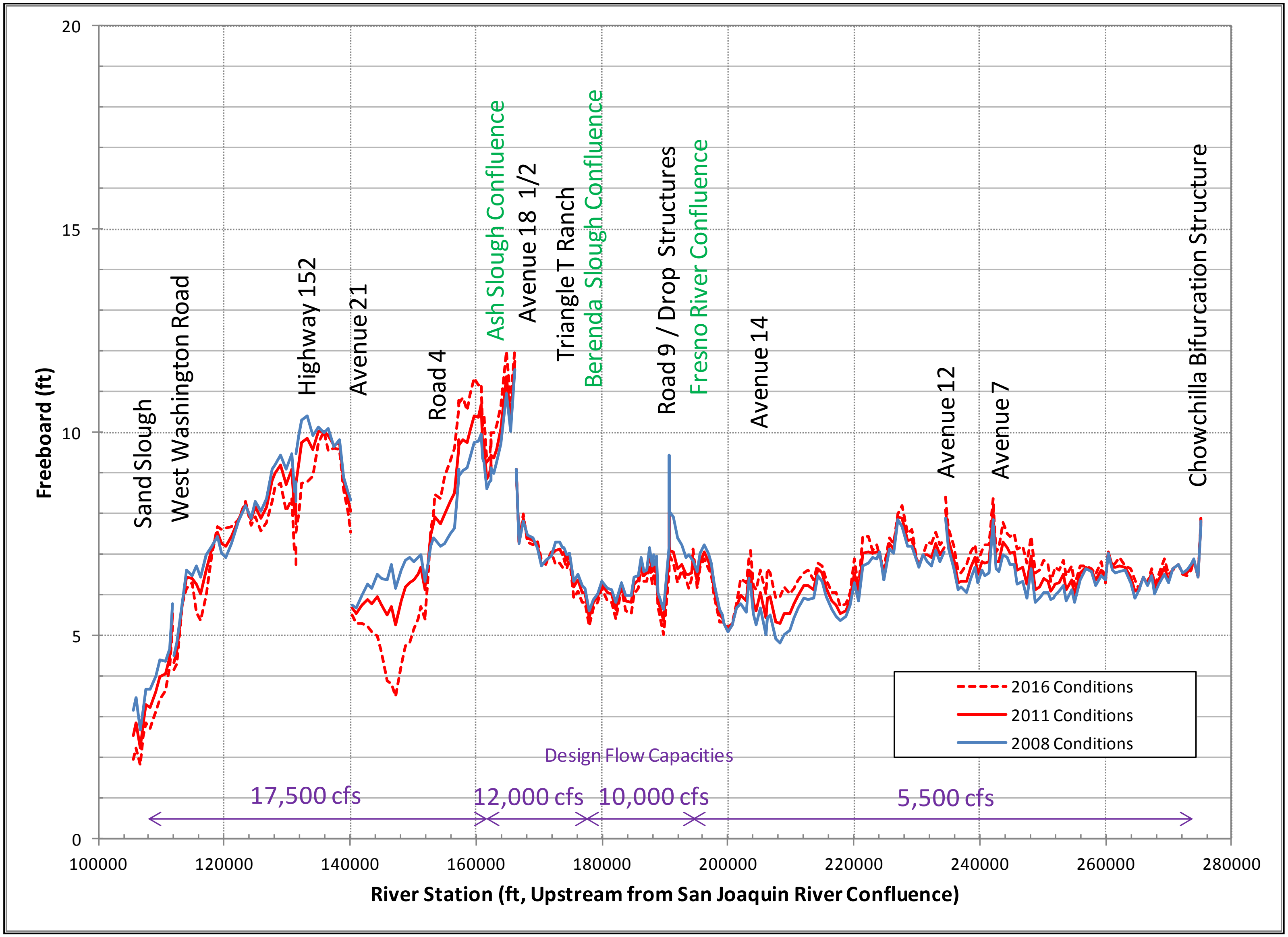


Figure 6. Freeboard conditions for the 2008, 2011, and 2016 conditions in Chowchilla and Eastside Bypass from the Fresno River to Sand Slough based on design flow simulations.

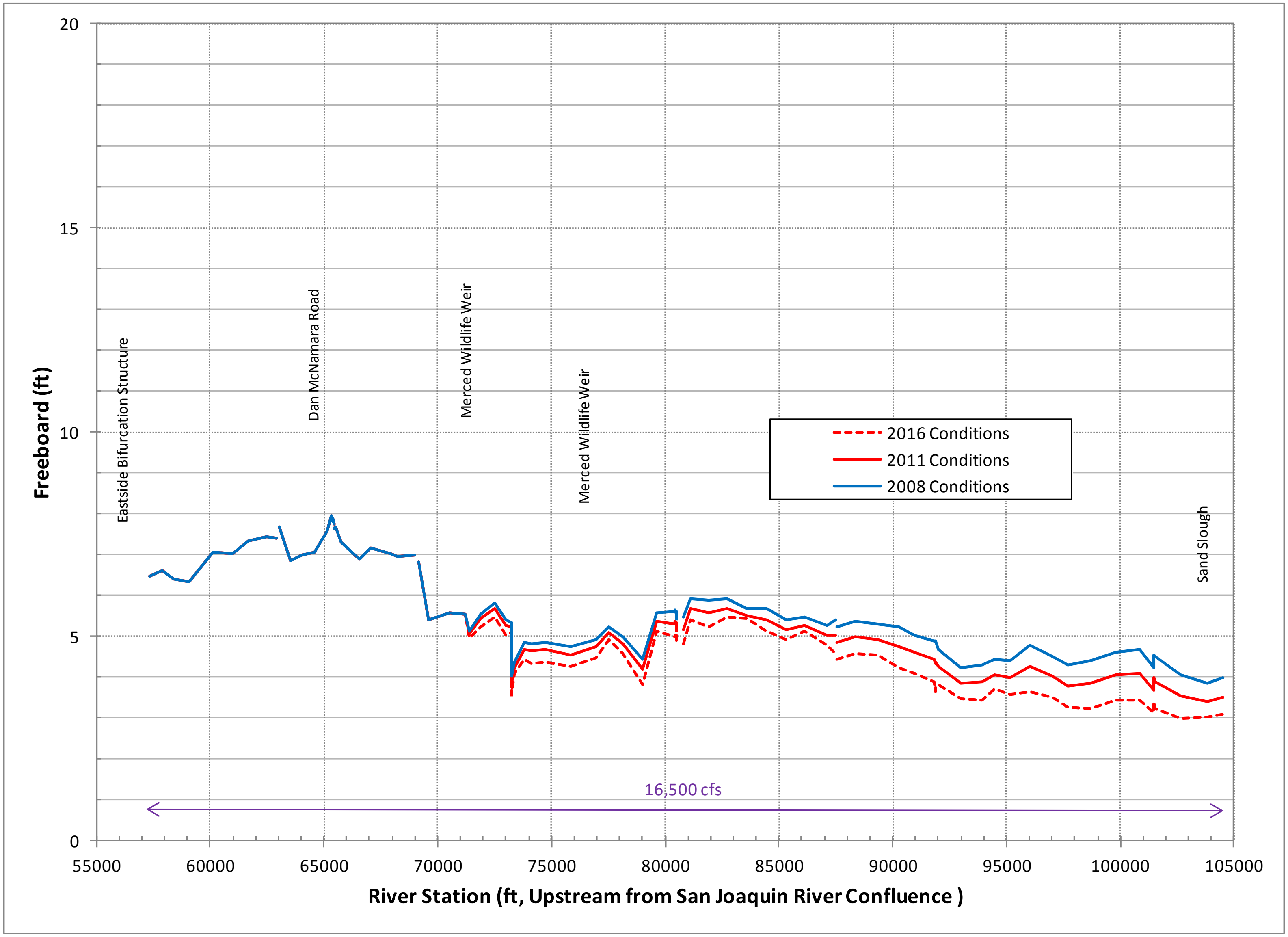


Figure 7. Freeboard conditions for the 2008, 2011 and 2016 conditions for Eastside Bypass from Sand Slough to the Mariposa Bypass based on design flow simulations.