BANK PROTECTION WORKING GROUP
DRAFT EROSION ASSESSMENT
SACRAMENTO RIVER EAST BANK EROSION ASSESSMENT
AMERICAN RIVER (RM 60.1) TO FREEPORT (RM 45.2)

DRAFT REPORT

Prepared for:

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DISCLAIMER

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE), the California Department of Water Resources (DWR) and the Sacramento Area Flood Control Agency (SAFCA) are implementing the American River Common Features Project, which includes improving the stability of levees protecting urban areas along the east bank of the Sacramento River from the confluence with the American River at river mile (RM) 60.2 to Freeport RM 45.2. The needed improvements were identified in the 2015 General Reevaluation Report (GRR, USACE 2015) and included erosion protection from flood flows up to a maximum release from Folsom Dam on the American River of 160,000 cfs. The efforts to protect urban areas of Sacramento from floods extends back to the 1850s. Documentation of erosion protection measures date back to the 1910s and presently over 90% of the banks and levees have some form of erosion protection. The GRR concluded that reliable, modern erosion protection installed since 2000 covers only 13 percent of the 14 + miles of levee protecting Sacramento. Federal and State funding for GRR prescribed erosion protection as well as other measures and was acquired in 2017.

This report presents the results of an erosion assessment of the east bank Sacramento River levee that was conducted in Spring and Summer of 2019. The report provides technical data and analysis to support the USACE in choosing the location and design of new erosion protection. The goal is to provide reliable erosion protection for flood flows estimated to occur over the next 50 years. The erosion assessment report will be used by the local sponsor SAFCA, agency stakeholders of the Bank Protection Working Group (BPWG), and an expert opinion elicitation panel (EOE) in order to select and prioritized sites for engineering design, construction and management of environmental mitigations. A similar planning and selection process were completed for Subreach 2 of the Lower American River in 2018 and is now in the engineering design phase slated for construction in 2020. The objectives of this erosion assessment are:

1) Understand the erosion, sediment transport and geomorphic processes of the Sacramento River and how future channel conditions might evolve and affect levee stability.

2) Compile an existing revetment database in order to document the locations and extents of bank protection structures and whether the designs are adequate to meet the 50-year objective.

3) Conduct a field survey to assess present erosion conditions and processes and to inspect bank protection structures and identify individual reach segments for detailed analysis.

4) Analyze the bank erosion potential for using existing hydraulic modeling to estimate erosional force and geotechnical and field data in order to estimate bank and levee materials and erosional resistance.

5) Estimate potential peak flow scour depths and erosion along the bank toe and levee face and assess potential lateral erosion extents and the slope stability.

6) Summarize erosion risks for each segment by compiling all data and analyses.

A geomorphic assessment of the east bank of the Sacramento River from the American River confluence (RM 60) to Freeport (RM 45) has found a high degree of historical stability in channel pattern and width since the 1850s. Vertical stability underwent dramatic changes as a result of hydraulic mining sediments introduced in the 1860s. This filling or aggradation raised the bed at Sacramento by over 10 feet and, at its peak, to elevations well above mean sea level () and tidal influence. The aggradation began dissipating by the early 1900s and ended in the 1950s with channel bed elevations recovering to pre-1850 levels. Bed elevations are presently stable with year to year fluctuations on the order of several feet, due to sand wave movement and ephemeral scour hole development. Localized erosion has been an ongoing challenge since at least the 1930s, necessitating ongoing efforts of installing bank protection. Since the 1950s, erosion has been managed by close monitoring and piecemeal treatment of damaged banks or revetments. Based upon available evidence described in this report, no long-term changes in ongoing geomorphic processes and resultant channel form are anticipated. However, local erosion is very important to monitor and address in a timely manner.

Numerous revetment designs have been implemented in the study area since the modern levees were originally constructed in the early 20th century. Prior to and in some cases after 2000, many structures were installed without plans as part of regular operations and maintenance or patching of recently erosion spots. From the 1920s to 1960s, a combination of materials were used including gunite with timber foundation walls, broken concrete, and cobble and a variety of large and small rip rap. Large revetments constructed after 2000 are well documented with as-built plan sets and other documentation. In estimating future erosion, only those bank protection sites with as-built plans documenting adequate rock size and volumes were credited with being able to withstand the design flood events; all others were deemed inadequate, even if they were installed after 2000.

The results of erosion estimates and the conditions of banks and levees to resist erosion found significant risks to levee stability from ongoing and potential future erosion due to fine bank and levee materials combined with long duration flood events and moderate to high erosive force. Eight of the 33 segments analyzed were rated high for overall erosion potential at locations where the levee prism has already been encroached or could be impinged in the near future. Estimates of scour and lateral erosion of the levee toe and face were found to be low in most places, however some levee slopes are at risk and there are multiple locations that have been repaired since 2006.

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LIST OF ABBREVIATIONS AND ACRONYMS

BPWG	Bank Protection Working Group
CVFED	Central Valley Floodplain Evaluation and Delineation
DWR	State of California Department of Water Resources
EOE	Expert Opinion Elicitation panel
ERM	Erosionally Resistant Material
ESP	Erosion Screening Process
GIS	Geographic Information System
GRR	General Re-evaluation Report
HEC-RAS	Hydraulic Engineering Center's River Analysis System, 1-d hydraulic model
kcfs	thousand cubic feet per second
LMA	Local Maintaining Agency
LiDAR	Light Detection and Ranging
NAVD88	North American Vertical Datum of 1988 coordinate system
NHC	Northwest Hydraulic Consultants, Inc.
psf	pounds per square foot
RM	River Mile
SAFCA	Sacramento Area Flood Control Agency
USACE	U.S. Army Corps of Engineers
WSE	Water surface elevation
mH:1V	Slope gradient in m horizontal feet to 1 vertical foot

1 INTRODUCTION

1.1 Background and Objectives

The U.S. Army Corps of Engineers (USACE) and the Sacramento Area Flood Control Agency (SAFCA) are implementing the American River Common Features Project, which includes improving the stability of levees protecting urban areas along the east bank of the Sacramento River from the confluence with the American River at river mile (RM) 60 to Freeport RM 45 (Figure 1-1). The needed improvements were identified in the 2015 General Reevaluation Report (GRR, USACE 2015) and included erosion protection from flood flows up to a maximum release from Folsom Dam on the American River of 160,000 cfs. The efforts to protect urban areas of Sacramento from floods extends back to the 1850s. Documentation of erosion protection measures date back to the 1910s and presently over 90% of the banks and levees have some form of erosion protection. The GRR concluded that reliable, modern erosion protection installed since 2000 covers only 13 percent of the 14 + miles of levee protecting Sacramento. Federal and State funding for GRR prescribed erosion protection as well as other measures and was acquired in 2017.

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SAFCA
Sacramento Area Flood Control Agency

nhc
northwest hydraulic consultants

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, ©

Legend

Study Area

Sacramento River

Landmark

Scale = 1:125,000

0 7,000 14,000 Feet

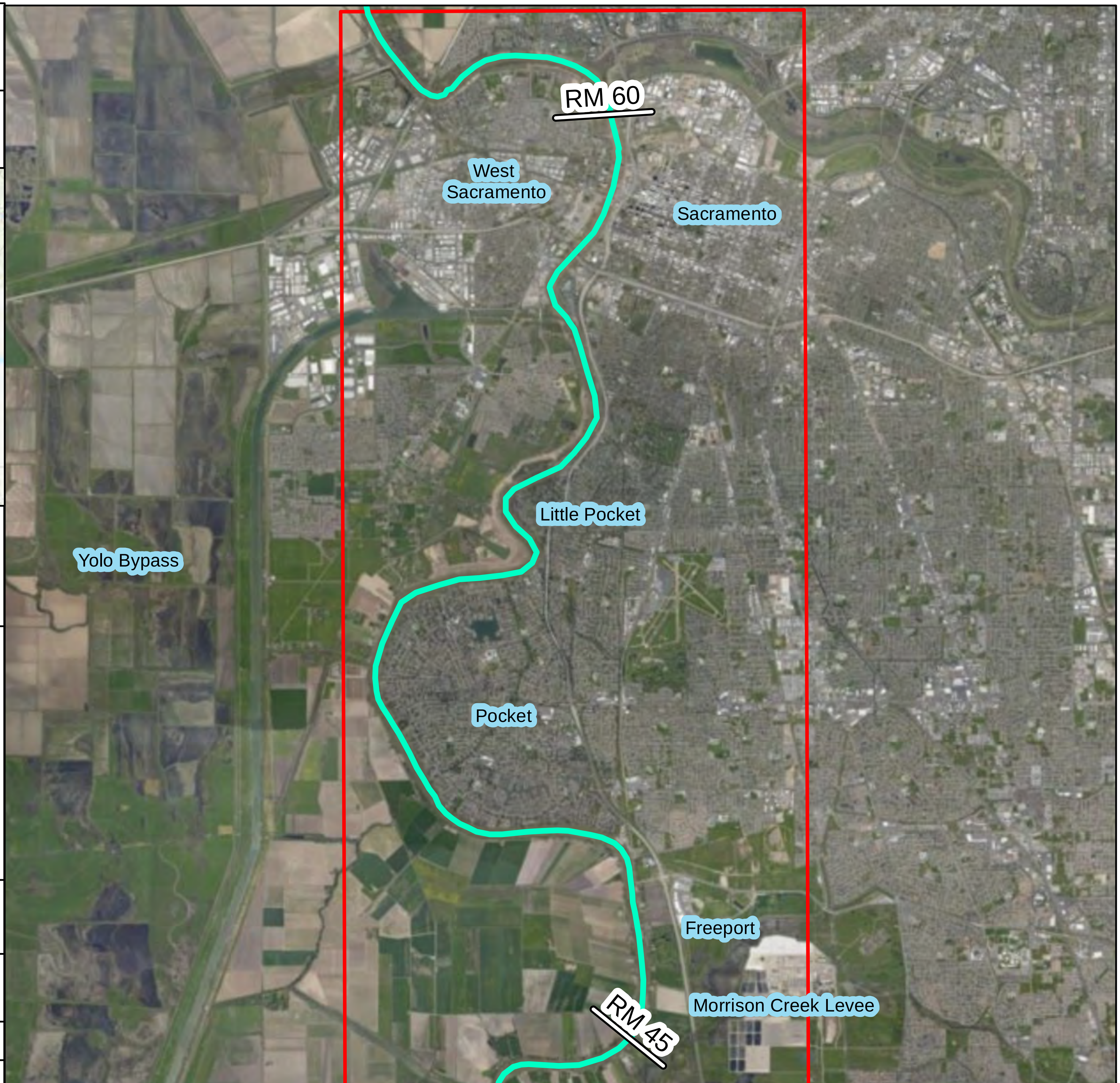
N

Sacramento River Erosion Assessment

Project Area Map and Regional Location

FIGURE 1-1

Job: 5004539	Date: JULY 2019



5) Estimate potential peak flow scour depths and erosion along the bank toe and levee face and assess potential lateral erosion extents and the slope stability.

6) Summarize erosion risks for each segment by compiling all data and analyses.

1.2 River Mileage and Datums

The U.S. Geological Survey river mileage (RM) is used to locate features and segments of the project study area. The 0.0 mile marker is located at the mouth of the Sacramento River, in Collinsville, located in the Sacramento – San Joaquin Delta. The project study reach downstream boundary is at RM 45.6, where the Sacramento east levee meets the Morrison Creek levee. This area ties into high ground to the east and any levee failure from this point upstream to the American River (RM 60.2) would threaten the urban areas of Sacramento.

All elevations referenced in this report are relative to the North American Vertical Datum of 1988 (NAVD88).

1.3 Definitions and Nomenclature

The Sacramento River east bank levees are often referenced as being on the "left bank" using the downstream view; West Sacramento and its levees are on the right bank. Figure 1-2 shows a typical river channel bank, bed and levee configuration in cross section profile with the various components. The levee "prism" refers to the minimum geometry defined by the USACE (2008), with the design top of levee elevation (DTOL) being: a) 3.0 feet above the projected 1957 water surface elevation hydraulic profile for 110kcfs (USACE, 2007), b) a minimum levee top (or crown) width of 20 feet; 3) the projected levee face slopes are no steeper than 3H:1V on the waterside and 2H:1V landside and 4) centered on the centerline of the existing levee crown. The subsurface projection of the 3H:1V levee waterside prism slope defines the levee foundation extent towards the river bank and the area to be protected from lateral bank erosion. The toe of the waterside levee slope is an important location for the erosion assessment since it is where the deepest flows impinge on the levee structure.

The "berm" (or bench) area is a generally flat and discontinuous geomorphic feature that separates the channel bank from the levee toe. In many places, the berm is absent and the actual waterside levee slope extends directly into the channel bank. The berm areas are often vegetated along the bank edge which provides a buffer to the levee from erosional forces along the channel bank. The toe of the channel bank is an important location for bank and levee stability as it is subject to scour, which can affect overall bank stability. One of the more significant levee erosion risks results from the progressive erosion and/or sudden toe erosion and scour that destabilizes the upper bank slope and triggers an instantaneous "mass failure" during flood conditions (discussed further below).

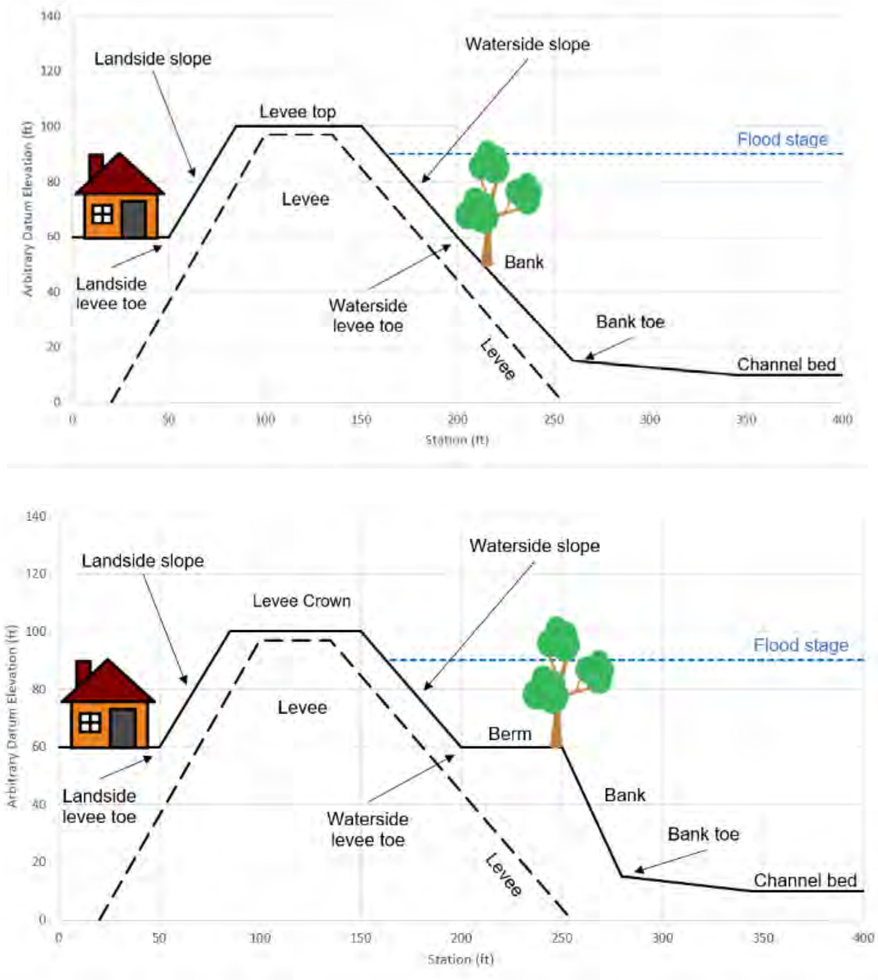


Figure 1-2. Nomenclature for East Bank Sacramento River Banks and Levees, Upper Panel with a Berm and Lower Panel without Berm.

1.4 Processes of Interest

Levees along the Sacramento River are subject to erosion hazards by three processes:

1. Direct fluvial erosion of the levees by water flowing directly along the waterside surface.

2. Failure of the river channel bank by lateral erosion in close proximity to the levee structure where there is little or no berm (generally less than 50 feet).

3. Long term geomorphic change, if present, caused by past and present human impacts.

Fluvial erosion refers to dislodgement and removal of soil material by the hydraulic forces exerted by flowing water and/or waves. Table 1-1 provides a description of several types of fluvial bank erosion mechanisms adapted from the USACE channel rehabilitation manual (USACE, 1999).

Direct levee erosion is assessed by comparing the anticipated hydraulic force of flow calculated by hydraulic modeling with the erosional resistance of the soils and vegetation cover. If the velocity and duration of flows along the levee are higher than the predicted resistance of levee soils and vegetation cover, then erosion could be expected. Field evidence of erosion after floods is strong evidence of potential erosion hazards and is highly monitored and rectified if needed by Local Maintaining Agencies (LMAs).

Lateral bank erosion processes are more complex, highly episodic and historically more threatening to levees as it occurs abruptly and during peak flow conditions when immediate treatment through “flood fighting” is difficult at best. Generally, lateral erosion involves progressive erosion of the bank toe, channel bed scour and sudden mass failure of the upper bank larger floods. Bank erosion becomes critical when the berm between the channel bank and the levee toe is narrow or absent, erosion control structures are deficient or absent and/or protective vegetation is lost. In some locations, the channel bank and levee slope are the same with little or no berm width. In the past, progressive erosion into the extended plane of the waterside levee slope (or levee prism template see Figure 1-2) and/or is less than 50 feet of berm width was considered cause for installing bank protection.

The history of installing bank protection on the Sacramento River dates back at least to the early 1900s and now comprises almost 90% of the total east bank length. The levees were built atop the original natural levees, placing the channel banks close to the levee toe in many places. In many places, rock revetments have been placed on the waterside levee face to repair progressive erosion. Bank failures most commonly occur through multiple flow events by progressive erosion of the bank and berm. Many factors such as boat and wind wake erosion, tree-fall, direct rainfall, local runoff and rill/gully erosion, overflow from floodplain areas over the bank and human disturbance may contribute.

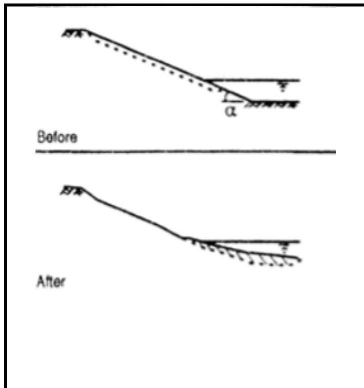
Table 1-1. Description of Fluvial Bank Erosion Processes.

Fluvial Process	Typical Conditions or Evidence of Erosion[1]
Parallel flow	Observation of high flow velocities close to the bank; near bank scouring of the bed; under-cutting of the toe/lower bank relative to the bank top; a fresh ragged appearance to the bank face; absence of bank vegetation.
Impinging flow	Observation of high flow velocities approaching the bank at an acute angle; bars directing flow toward the bank; tight meander bends; strong eddying adjacent to the bank; near-bank scouring of the bed; under-cutting of the lower bank; ragged appearance to the face; absence of vegetation.
Scour	Local bed lowering near the bank and/or levee toe due to local scour processes or channel incision. Scour may cause translational sliding of the upper bank, particularly when revetment has been placed, leaving scars on the bank. Local bed scour occurs around obstructions and scour holes are often visible where flow dives over or around spurs, intakes or other bank features.
Wind-generated waves	Large channel width or long, straight channel with an acute angle between eroding bank and long stream direction; a wave-cut notch just above normal lower water plane; a wave-cut platform or run-up beach around normal low-water plane.
Vessel-generated waves	Use of river for navigation; large vessels moving close to the bank; high speeds and observation of significant vessel-induced waves and surges; a wave-cut notch just above the normal low-water plane; a wave-cut platform or "spending" beach around normal low-water plane.

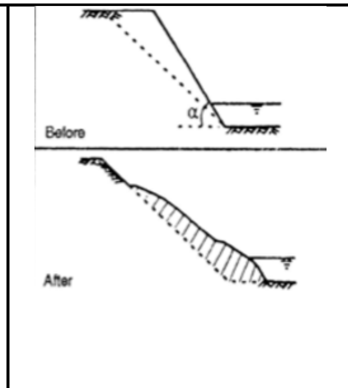
1. Adapted from USACE (1999)

Figure 1-3 on the following page classifies common slope failures.

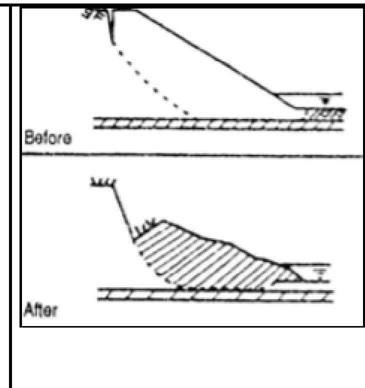
Both fluvial bank erosion and mass failure are influenced by the bank height, slope gradient, soil material characteristics and the effects of vegetation cover (roots reinforcing soils and adding hydraulic roughness to reduce impinging hydraulic force). Resistance to hydraulic force is dependant on soil particle size, cohesive strength (i.e. usually clay content), and bulk density. Due to the unique geologic and historic influences, the channel banks of the Sacramento River are relatively high (30+ feet on average), steep and composed of highly erodible sands.



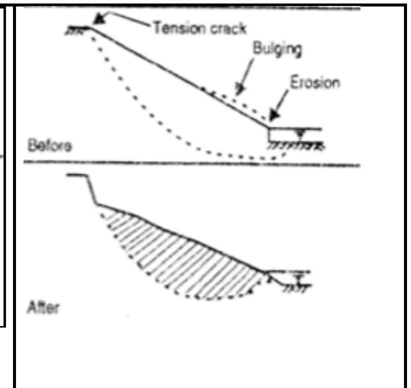
Shallow Failure
- Shallow bank angle
- Usually non-cohesive banks
- Failure nearly parallel to slope
- Water Seepage from bank can substantially reduce stability
- Vegetation normally helps stabilize



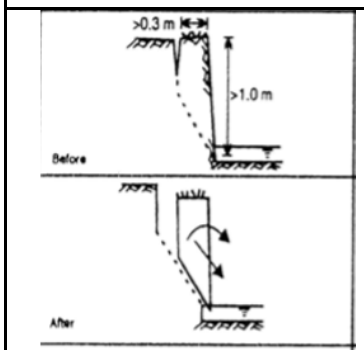
Planar Failure
- Steep or Vertical Bank Angle
- Frequently in non-cohesive banks
- Water table channel WSE usually low



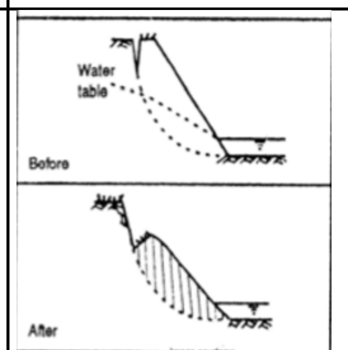
Rotational Failure with Weak Zone
- Failure surface dictated by weak Zone



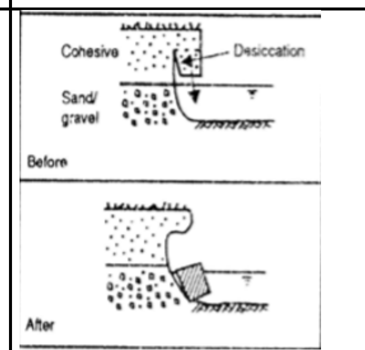
Massive Rotation Failure/Landslide
- Mass Failure can threaten levee
- Very large volume of slipped materials Tension cracks, headscarp, bulging slope or toe and/or noticeable movement are signs of mass failures



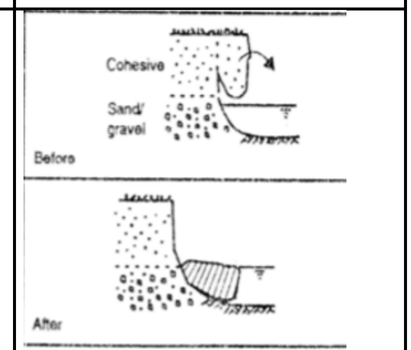
Planar/slab failure
- Steep or near vertical banks
- Deep Tension Cracks
- Failure Occurs by Sliding and/or Toppling
- Failure more Likely if Crack Fills with Waters\
- Little Affected by Groundwater Table



Rotational Failure in Homogeneous Materials
- Usually on Moderately High or Steep Banks
- Usually on Cohesive Materials
- Tension Cracks Reduce Stability especially when water-filled
- Failure may extend beyond toe



Partial Failure/Undercut of Composite Bank
- Occurs only where upper cohesive layers overlies erodible sand/gravel
- Failure by Tension of Lower Part of Overhanging Block



Failure of Composite Bank
- Undercutting of Erodible Materials underlying Cohesive Materials

Figure 1-3 Modes of Bank Failure (Thorne et al 1997)

Vegetation has highly variable effects on bank erosion resistance depending on conditions (Hicken, 1984). Vegetative cover generally reduces erosion rates of the soil (Wynn, 2004). The erosion resistance of vegetation can vary seasonally due to dormancy (Kowen and Li, 1980) and generally decreases with duration of inundation, although the reduction in strength varies with type of vegetation and quality of coverage (Fishchenich, 2001). Some types of grasses and forbs may provide less long-duration resistance than shrubby woody vegetation due to lower stem strength, lower cover height, shallower root systems, and dormancy during inundation (Pizzuto , 2008).

Large trees such as Fremont Cottonwood and Valley and Live Oaks occur along the banks of the Sacramento River and add resistance through root strength and hydraulic roughness, but they also add additional weight which may increase the potential for mass slope failure. Large trees have extensive root systems that extend below the top of the bank to tap into soil moisture. As root systems of large trees are exposed by fluvial erosion, they can locally enhance erosion by increasing impinging flow and local scour. Sudden treefall by fluvial erosion and/or windfall instantly exposes areas of easily erodible bank sediments often during flood events. This can lead to rapid erosion and mass failure instantly shrinking the berm and bringing the bank towards the levee. A key factor in large tree failure on banks of the Sacramento River is undercutting of the root zone by slow but progressive erosion from winter flows and possibly summer period boat wake waves. Some bank and berm locations may have formed as geomorphic floodplain surfaces in late 1800s due to hydraulic mining sediments aggradation and have since become terraces (surfaces elevated above present geomorphic floodplain forming elevations) after channel bed incision. More extensive floodplain surfaces are shown on 1908 maps (USACE 1908) with labels indicating willow and cottonwoods.

Established woody vegetation along the lower bank can help resist slope failure by reducing near-bank velocities and reinforcing bank soils with root systems. Field observations found that natural recruitment of native woody vegetation such as willow and cottonwood by seed is limited along the study reach. This appears to be due to the lack of slackwater zones where fine sediment deposition occurs with suitable soil moisture conditions. This leaves many banks barren of woody native species and a potential niche for other tree, vine and herbaceous species, some invasive non-natives, which may not be as effective for soil protection. In some cases, root systems of cottonwoods and willow species are exposed by erosion and sprout “clone” trees on the channel banks which extends coverage and protection. However, most banks are unsuitable due to steepness, aridity or being too exposed to winter flow scour to support seedings and young native woody plant growth. Many locations have older trees that were germinated under very different historical conditions. There has been generally good success in planting riparian vegetation for habitat mitigation within soil trenches of modern bank protection structures built since 2000.

Table 1-2. Description of Slope Failure Processes.

Failure Process	Typical Conditions or Evidence of Failure (adapted from USACE, 1999)
Rotational slips	Banks formed in cohesive soils; high, but not especially steep banks; deep seated, curved failure scars; back-tilting of the top of failure blocks toward intact banks; arcuate shape to intact bank line behind failure mass; tension cracks or openings in soil behind mass.
Planar slips	Weakly cohesive bank materials; thin slide layers relative to their area; planar failure surface; no rotation or toppling of failure mass; ragged edge at detachment point.
Cantilever failure	Composite or layered bank stratigraphy; cohesive layer underlain by less resistant layer; under-mining; overhanging bank blocks; failed blocks on the lower bank and at the toe.
Slab type block failures	Cohesive bank materials; steep bank angles; deep seated failure surface with a planar lower slope and nearly vertical upper slope; deep tension cracks behind the bank-line; forward tilting failure mass into channel; planar shape to intact bank-line behind failure mass.
Piping failure	Pronounced seep lines, especially along sand layers or lenses in the bank as indicated by vegetation; pipe shaped cavities in the bank; notches in the bank associated with seepage zones; run-out deposits of eroded material on the lower bank.

1.5 Report Organization

After Section 1 overview, the remainder of this report is organized into 4 sections.

- Section 2 provides a summary of relevant data and background information used in the assessment and includes the design flows of interest, topographic and bathymetric data, hydraulic studies and conditions, the locations, extents and quality of existing revetments, stratigraphic soil investigations of the channel bank and bed, and field observations.
- Section 3 provides a geomorphic assessment to address local conditions, including the estimated channel forming processes that govern bank erosion and the potential for long term change in channel geometry (width and depth) and channel planform (channel path as viewed from above).
- Section 4 provides the potential estimates of bank and levee erosion to occur during a range of high flow events under existing conditions.
- Section 5 couples the results of Sections 3 and 4 to provide an overall assessment of potential bank erosion at each segment.

Appendix A provides detailed information regarding the 33 segments identified in the study reach and details of erosion estimates and calculations.

2 BACKGROUND INFORMATION

2.1 Overview

The data and information used in this study is described below. A primary source was provided by previous erosion and channel stability studies prepared for the USACE and SAFCA dating back to 1991. This includes information used for Section 3 Geomorphology and Long Term Processes. The GRR (USACE 2015) report's Appendix E provides an excellent summary of previous reports. In addition, these studies and inspection reports provided lists of erosion trouble spots dating back to 1990.

Existing data sources were used for input to erosion estimate calculations including hydrology, hydraulics, topographic and bathymetric and geotechnical information. Field inspections were conducted from land and water side in Spring 2019 in order to bring inspection information up to date, provide data on protection provided by vegetation and existing erosion control structures, identify critical locations and to understand erosion processes.

2.2 Soils Information

A significant volume of subsurface soils data and analyses exist for the east bank Sacramento River levees as a result of Federal, State and Local flood agencies efforts to upgrade the levee system since 2006. The focus of these studies was primarily seepage erosion risks of levee structure and foundation materials. Since the levees are close to the channel bank and berms and river channel (usually within 100 feet), the data was deemed good representation of channel bank materials.

NHC used boring data from two sources in order to characterize bank and levee foundation materials subject to erosion:

- URS (2011, 2014, and 2015) and completed extensive soil borings along the east bank levees as part of the California Department of Water Resources (DWR) Urban Levee Evaluation program (ULE).

- HDR/GEI (2016) completed geotechnical assessment supporting engineering designs addressing underseepage.

Another source of surface and subsurface materials characterization was the surficial geomorphic mapping and geomorphology report prepared by Fugro WLA (2010).

2.3 Topographic and Bathymetric Information

Topographic and bathymetric data used for the hydraulic and erosion analysis was derived from the 2008 Central Valley Floodplain Evaluation and Delineation Program (CVFED) dataset which combined separate terrestrial Lidar and below water bathymetric surveys.[1] Below water bathymetric data was collected in 2008 by the USACE (Fugro West, Inc. 2008) using a boat during summer low water period. In order to create a continuous digital surface, the above ground lidar data was merged to the bathymetric by interpolating gaps along the shoreline and between bathymetric cross sections.

2.4 Hydrology

Hydrology data from two separate USACE studies was used to develop flow magnitude and durations for the hydraulic and erosion analyses. The USACE Folsom Water Control Manual Update Project (WCM) provided hourly outflows from Folsom Dam for the new WCM operating conditions for a 81-year period of record. The USACE Central Valley Hydrology Study (CVHS) provided individual n-year storm events with 1/5, 1/10, 1/25, 1/50, 1/100, 1/200, and 1/325 Annual Chance Probability (ACE). The WCM hydrology was used to evaluate more frequent flow events and flow duration statistics as it provided a broader range of storm types and conditions. The CVHS hydrology was used to evaluate the less frequent storm events which were likely not in the WCM period of record (i.e. 1/200, 1/325 ACE events).

Since the reach of interest is located downstream of the confluence of the American and Sacramento Rivers, as well as the Sacramento and Fremont weirs, USACE one-dimensional HEC-RAS models were used to route hydrologic inflows to the study reach. Both hydrologic data sources were provided with specific project HEC-RAS models. The WCM HEC-RAS model (created circa 2015) extended from Nimbus Dam on the American River, Verona on the Sacramento River, and downstream to RM 40 on the Sacramento River. This model did not include the proposed widened Sacramento Weir however the model was used to evaluate lower magnitude flows where the weir would be less effective. The CVHS data was simulated through the USACE WRDA 2016 ARCF HEC-RAS Release 6.2. which included the proposed widened Sacramento Weir.

Table 2-1 summarizes the four flows of interest evaluated in the hydraulic and erosion analysis. The 115,000 cfs event is the expected peak flow which would occur due to the 160,000 maximum design outflow at Folsom Dam and the widened Sacramento Weir in place. 115,000 cfs was the peak discharge during both the 1986 and 1997 high flow events. The 110,000 cfs event is the peak outflow for both the 1/100 ACE and 1/200 ACE events. The 100,000 cfs event occurs frequently during wet winters, and also occurs for a sustained period ahead of peak flows during the 1/100, 1/200, and 1/325 ACE. This was also the peak flow in the reach during the 2017 high flow event.

The 50,000 cfs event was determined to be the estimated geomorphically effective or dominant discharge (the flow that completes the most work over time) in the reach using the historical streamflow record at the USGS Freeport gage and the HEC RAS 1D model output. The duration of 288 hours was taken from the average days per year of 50,000 cfs using projected hydrology with the Common

[1] Note: A new bathymetric and partial Lidar topographic survey (collected from boat with partial lidar bank coverage due to limited line of sight) was completed by USACE and released in summer 2019. Although some differences were found through comparison of the older and new surveys (See Appendix C), the changes were not deemed to be significant enough to change the results and conclusions of this study. A new HECRAS 2D model is in preparation by SAFCA and is expected in Fall 2019 after this Erosion Assessment is complete.

Features improvements in place. This flow corresponds to a prevalent erosional cut found along the banks as observed in the field.

Table 2-1. Summary of Selected Peak Flows and Durations for Current and Future Conditions (USACE 2019) and Q1.5 for Geomorphic assessment by NHC.

Annual Chance Exceedance	Flow (cfs)	Duration (hours)	Notes
1/325 years	115,000	24	American River Common Features Design maximum flow for Sacramento River when 160,000 cfs is release from Folsom Dam on the Lower American River.
1/100 1/200	110,000	48	Both the 1/100 and 1/200 ACE events centered at Fair Oaks produce peak flows on the Study Reach of 110,000 cfs
~1/3	100,000	82	The 1/100, 1/200, 1/325 ACE events have sustained 100,000 cfs flows prior to the peak. This flow also occurs more frequently with updated WCM operations, increasing from a ~1/5 ACE to ~1/3 ACE.
~1/1.5	50,000	288	Based upon the Flood Frequency Plot for the Sacramento River at Freeport USGS gage and based upon maximum number of days of Effective Stream Power at RM 54 and field observations of erosion cut banks.

2.5 Hydraulic Model

NHC used a simplified version of the USACE 1-D WCM HEC-RAS model to evaluate hydraulics for the erosion analysis. NHC removed lateral connections, storage areas, and upstream reaches from the model to simply leave the reach of interest. All roughness values, expansion/contraction coefficients, ineffective flow areas, and other geometric settings were kept consistent with the WCM model. The downstream rating curve provided in the WCM was also used. The model was then run as a steady state model for the flows of interest. Figure 2-1 shows a sample of the model HEC-RAS results for the maximum flow of 115,000 cfs.

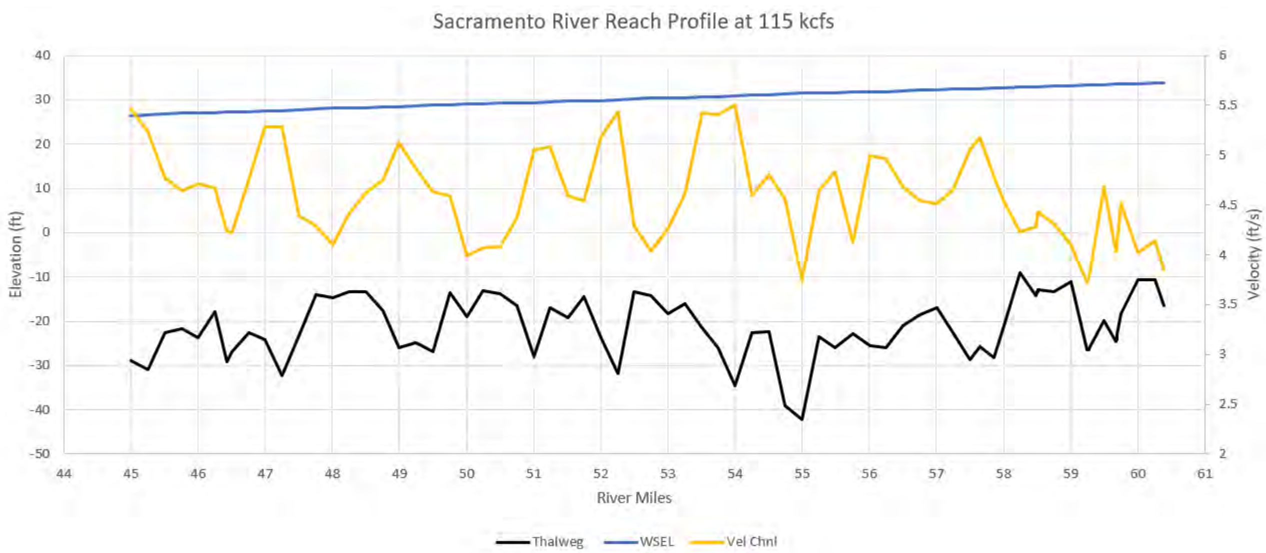


Figure 2-1. Longitudinal Profile of Sacramento River from RM 45 to 60.5 from HEC RAS 1D Modeling showing Thalweg, Mean Channel Velocity and Water Surface during Peak Discharge of 115 kcfs.

2.6 Revetment Inventory

Numerous revetment designs have been implemented in the study area since the modern levees were originally constructed in the early 20th century. The types of revetments encountered in field inspection are found in Table 2.2. Prior to and in some cases after 2000, many structures were installed without plans as part of regular operations and maintenance or patch recently erosion spots. From the 1920s to 1960s, a combination of materials were used including gunite with timber foundation walls, broken concrete, and cobble (which reportedly was readily available as a waste product from aggregate mining on the American River [June 2019 personal communication with Dave Williams, DWR]) and a variety of large and small rip rap. The pre-2000 installation locations were documented through field inspection, some limited design information (i.e. 1 page plans with single typical cross section and location but no details on rock size and revetment dimensions) and examination of current and historical aerial photographs dating back to 1927 and maps dating back to 1908. After Governor Schwarzenegger's 2006 emergency declaration and Executive Order S-01-06, the State of California DWR and the Federal Sacramento River Bank Protection Project funding was increased dramatically for emergency repairs; this resulted in many installations but without documentation or as built plans. In many locations PL 84-99 repairs were conducted to restore pre-flood damage events and usually done without engineering plan sets. Large revetments constructed after 2000 are well documented with as-built plan sets and other documentation.

NHC assembled design information from the U.S. Army Corps of Engineers archives (plans and previous technical reports), field inspection reports by DWR and USACE, aerial photographs, interviews with Local Maintain Agency staff, and NHC field inspections in 2019. Table 2-3 summarizes the existing post 2000 modern revetment designs. Older bank protection structures are documented in segment descriptions found in Section 5 and Appendix A.

Table 2.2 Sacramento River East Bank Erosion Assessment Bank Protection Types and Terminology.

Sacramento River Erosion Assessment			
East Bank from American River to Freeport (RM 60.1 to 45.6)			
Bank Protection Types and Terminology			
(prepared by NHC 2019)			
Term	**Description**	**Bank (B), Levee (L),or both (BL)**	**Example (All left/east bank SAC R.)**
Modern	Post-2000 rip rap (quarry stone) design with soil trench and toe rock for scour	BL	
with plans	Plans in hand to confirm design	B	RM 47.2
without plans	No plans in hand to confirm design	B	
Retaining/Floodwall	Engineered Vertical Concrete wall (various ages) or Steel Sheet pile		
older	Older concrete structures unknown plans (circa 1950s or earlier)	BL	Old Sacramento train Museum to Tower Bridge
modern	Modern Design with Plans	BL	Embassy Suites Prominade
Rip Rap	Various		
2006 era	Patch repairs after 2006 after Governor's emergency executive action (distinct gray green rock)	BL	
Older rip rap	Angular quarry stone of various sizes and rock lithologies 1930s thru 1990s.	BL	
Cobble	Rounded natural river stone approximately 4 to 8 inches in diameter (pre_1970s)	BL	
Concrete rubble	Broken concrete blocks of various sizes often with sandy matrix (natural and man made)	BL	
Gunnite	Poured concrete with rebar	BL	RM 55.9 to 56.1
Broken Asphalt	Broken Asphalt pavement blocks with soil and degraded asphaltic sandy gravel matrix	B	RM 58.2 LB Near I-5 and oil storage facilities
	Note: River Miles (RM) are USGS reference		

Modern with plans

Older retaining/floodwall

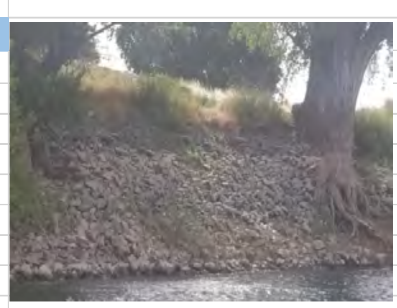
Modern without plans

Modern retaining/floodwall

2006 era riprap

Cobble

Older riprap



Concrete rubble

Gunite

Broken asphalt

Table 2-3 – Modern Revetment Inventory East Bank Sacramento River RM 45 to 60.

Extents	Location	Rock Type	Date	Plans	Segment
RM 58.65-59.0	Bank	Urban Levee Reconstruction – Old Sacramento Floodwall	1997	Yes	3
RM 56.7-57.1	Bank/Toe	Modern: soil trench with rock toe	2004	Yes	6
RM 55.9-56.1	Levee/Bank	Gunite	1920's	No	10
RM 53.5-53.8	Levee/Bank/ Toe	Rock bank protection, stone toe wall, embankments and excavations	1970	Yes	18
RM 53.08-53.12	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	19
RM 52.65-52.7	Bank	Possibly Modern: riparian bench with rock toe (unconfirmed)	N/A	No	20
RM 52.35-52.6	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	21
RM 52.2-52.4	Bank/Toe	Modern: riparian bench and wetland bench with rock toe	2009	Yes	21
RM 51.4-51.6	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	23
RM 51.15-51.3	Levee/Bank	Length of riprap cover with no vegetation	N/A	No	24
RM 50.95-51.15	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	25
RM 50.77-50.85	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	26
RM 50.65-50.66	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	26

Extents	Location	Rock Type	Date	Plans	Segment
RM 49.81-49.87	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	29
RM 49.79-49.8	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	29
RM 49.55-49.6	Bank/Toe	Modern: riparian bench with rock toe	2008	Yes	29
RM 49.48-49.55	Bank/Toe	Modern: riparian bench with rock toe	2006	Yes	29
RM 46.9-47.15	Bank/Toe	Modern: riparian bench with rock toe	2007	Yes	32

For purposes of this erosion assessment, existing bank protection must have documentation that includes as-built plans showing the rip rap extent in plan view and cross section in order to be rating adequate against erosion. This is due to the likelihood of deep channel bed scour of the Sacramento River during floods when slope stability can been compromised due to bank toe scour under peak flow conditions. For this study, rip rap rock sizes and volumes need to be documented with as-built plans and adequate to withstand erosion in the maximum 1/325 year event of 115,000 cfs. This is discussed in greater detail in Section 4 of this report.

2.7 Field Observations 2019

NHC performed field observations of site conditions throughout the study area, from both the water and land. The boat field survey was conducted on May 14th, 2019, during a flow of 40,800 cfs. Observations and photos were taken traveling downstream from the confluence with the American River to the end of the study area (RM 45.3) below Freeport bridge. The boat was navigated close to the bank to identify erosion sites, existing protection, and areas of concern.

A landside field survey was conducted from June 11th, 2019 to June 14th, 2019 with flows decreasing from 40,700 to 28,600 cfs during this period. The levees were walked or driven and frequent stops were made to observe and document the bank top, slope, berm and toe where visible. Erosion sites, existing protection, and areas of concern were observed and noted. Cooperation and communication with the LMAs the City of Sacramento Department of Utilities and DWR Maintenance Area 9 supervisors allowed for a more detailed understanding of the study area. Figures 2-2 through 2-14 show a sample of bank conditions and typical conditions of critical sites.

Figure 2-2a and 2-2b - RM 59.55 Land and Waterside Views of Bank Located Near the I St Gage and the I St Bridge with an Abandoned Building, Power Poles, Older Rip Rap, Cobble and Rubble Line a Slumping Bank.

Figure 2-3 - RM 58.65 is at the downstream end of the Old Sacramento River floodwall where a variety of rip rap, cobble and broken concrete has been placed over the erosion and slumping that has occurred.

Figure 2-4 - RM 58.45 is located at the Pioneer Reservoir. Recent erosion behind existing rock and concrete rubble has prompted emergency repairs with black plastic sheeting.

Figure 2-5 - RM 58.2 North of Miller Park and Marina where concrete and asphalt waste rubble has been placed ongoing erosion is evidenced by the crumbling asphalt road and slumping bank slope.

Figure 2-6a and 2-6 b - RM 56.5 Views from boat (top) and levee top (bottom) of erosion around storm drain outlet.

Figure 2-7 - RM 55.55 looking upstream at levee top near the Westin Hotel parking lot showing tension cracks, possibly indicative of landslide headcut and evidence of past repairs to the bike path on the waterside levee slope. This location has no berm and the waterside levee face extends into the left bank of the river.

Figure 2-8a and 2-8b – Land and waterside views of RM 53.8 at Oak Hall Bend has evidence of ongoing erosion and a narrow berm at the outside edge of the apex of a bend near Little Pocket.

Figure 2-9a and 2-9b – Land and waterside views at RM 51.9 at the north-west corner of the Pocket area has shows extreme erosion around tree roots, a narrow berm and spot repair rip rap.

Figure 2-10a and 2-10b - RM 51.75 has a bare silty-clay outcrop. Upstream (top) and downstream (bottom) views of erosion location where clay rich outcrops are visible in blocky steps and in vertical banks. Upper photo shows extensive natural seedling recruitment of willow and cottonwood on gently sloping eroding bank.

Figure 2-11 - RM 48.8 shows an unprotected erosion area with limited vegetation. Note large tree roots being undermined.

Figure 2-12- RM 48.3 is a large barren gap caused by loss of a large tree in the recent past and old concrete rubble.

Figure 2-13 - RM 48.2 showing gaps in vegetation no bank protection and large tree roots being undermined.

Figure 2-14 - RM 46.0 has both bank and levee slope erosion.

3 LONG-TERM RIVER PROCESSES

3.1 Overview

This section concerns the geomorphic and erosion processes affecting levee stability along the east bank of the Sacramento River from the confluence with the American River (RM 60.1) to Freeport (RM 45.2) (Figure 3-1). This will support engineering analysis by identifying the key erosional processes affecting channel stability and assess whether current conditions will persist into the future or are subject to change. This work is based upon review and analysis of existing information, field inspection and application of geomorphic principles associated with channel forming processes and evolution.

The 14-mile long study reach on the east side of the Sacramento River bounds the City of Sacramento and Southern Sacramento County with a levee system that protects the major economic center of the Central Valley. Since founding of the City in the 1840s, the Sacramento River has played an essential role in agricultural, urban and industrial development by providing important transportation links to San Francisco and the Pacific Ocean. This natural geographic advantage of being along the major waterway route also presented great risks from devasting floods, as history as shown, and major efforts to control them. The implementation of the Sacramento River Flood Control Project and Yolo flood bypass (Figure 3-2) in the early to mid-1900s finally provided relief from damaging floods that had occurred, on average, once every 10 years. However, it also required significant and comprehensive maintenance and upgrades, including management of sediment and erosion.

The purpose this section is to:

1) Describe and document the geologic and historical evolution of the study reach;
2) Identify historical trends in channel forming processes up to the present; and
3) Assess the potential for change in geomorphic processes over the next 50 years that could affect erosion and levee management.

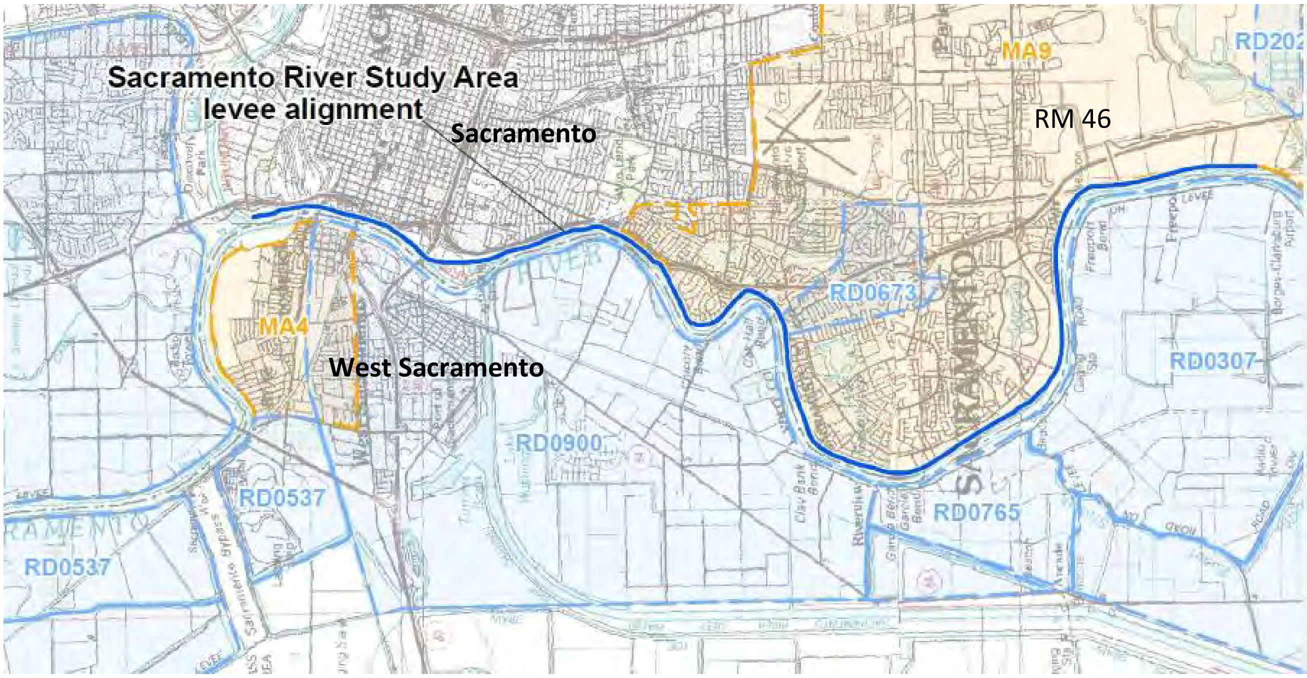


Figure 3-1 Sacramento River East Side Levee Study Area, RM 46 Freeport to RM 60 Mouth of American River (North is Left on This Figure).

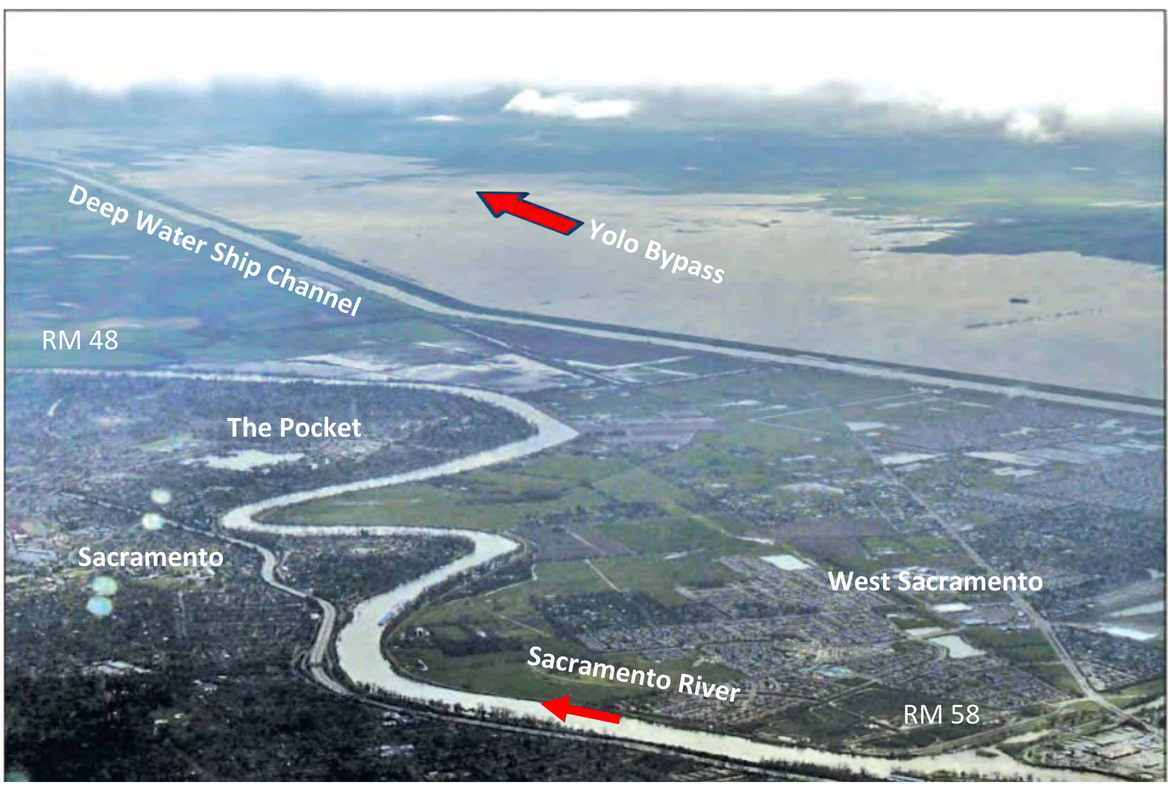


Figure 3-2 Aerial View Southwestward Over Sacramento River From RM 58 (Lower Right Corner) to RM 48 (Middle Left Edge) and flooded Yolo Bypass (Upper Half) (Source: USGS).

3.2 Setting

The study reach extends along the east bank of the Sacramento River, from the American River confluence at RM 60 to Freeport at RM 46. This entire reach has a uniform shaped channel, 600-900 foot wide, bounded by levees that are closely aligned with the banks. Channel bed elevations range from -10 to -50 feet below mean sea level (msl)[2] with levee tops ranging from elevation +30 feet to over +50 feet above. The left bank levees protect the City of Sacramento's densely urbanized floodplain lands that are in places below 10 feet . Levees on the right bank protect the City of West Sacramento.

The river channel banks have been highly altered by land use activities. This includes raising levees on channel banks, clearing of vegetation, installation of bank protection, placements of fill, and hydraulic structures (such as water diversion facilities) at RM 59.8 and 47.2; and the Port of West Sacramento barge canal entrance channel and locks at RM 57.5. These have supported a variety of industrial, transportation and urban developments such as roads, stormwater and sewage outfalls, bridge and railroad embankments, marinas, and pipelines. Geomorphic floodplain surfaces actively formed by recent fine sediment deposition at river stages less than a 1 in 2 year peak flow, are found in limited areas where channel and berm width are relatively wide (e.g. RM 53.8 to 54). These form a fraction of berms situated between the channel bank and levees which are topographically higher terraces and have been reduced or eliminated by erosion. The widest berms (400 and 1,500 ft wide) occur on the inner portion of several river bends, most notably at Miller Park and Sacramento Marina (RM 57 to58) and Little Pocket (RM 54 to 55). Typical berm widths are less than 50 ft (NHC 2012).

In most places, urban development begins immediately behind the landside slope of the levees, including Interstate 5, industrial, commercial, and residential developments. These developments have necessitated installation of bank protection over time to prevent erosion into the levee structure. The bank protection works and levee structures have also contributed to the loss of natural soil and hydrologic conditions supporting recruitment and sustenance of native vegetation and habitats on the remnant berms.

3.3 Long Term Geomorphic Processes

An immediate concern for levee stability is the vertical and lateral stability of the Sacramento River channel, which can affect hydraulic performance and stability. A fundamental question is whether there are evolutionary trends in channel forming processes that could result in future expansion of erosion or additional unforeseen threats beyond those that have been managed for decades. In order to address this, it is necessary to understand how the present Sacramento River was formed and how those formational processes have been altered by flood control and other efforts. Historical analysis allows for projection of future conditions based upon empirical trends, and provides a basis for predictive mdeling and engineering assessment at a site-specific level.

[2] Mean Seal Level (msl) 0.0 feet is presently using the NAVD88 vertical datum. Some of the figures in Section 3 are using the NGVD 1929 which is 2.37 feet lower at the DWR CDEC I Street gage.

This assessment is based upon the wealth of existing information and reports that date back to the 1850s. This includes detailed research conducted for the California Department of Water Resources (DWR) Urban Levee Evaluation (ULE) project (URS 2011, 2014, 2015), as well as detailed geomorphic mapping and geotechnical analyses by Fugro WLA 2010. The ULE analysis, as well as numerous inspection reports by DWR and the US Army Corps of Engineers (USACE), identified potential erosion risk sites. An important source of historical information is from the San Francisco Estuary Institute Aquatic Science Center (SFEI) (2012) *Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process*. Numerous other sources were used including mapping in 1908 and 1933 by the US Army Corps of Engineers (USACE 1908, 1933; US House of Representatives, 1908).

Another source of information stems from the Sacramento River Bank Protection Project (SRBPP), which is a long-standing federal program implemented by the USACE Sacramento District in partnership with Central Valley Flood Protection Board and DWR. This project included routine inspections, evaluations, planning and installing bank protection revetments. An Environmental Impact Statement (EIS) was prepared for the most recent authorization in 2014 (USACE 2014), and information regarding earlier bank protection efforts (dating back to the 1930s) was acquired from the USACE records. The Sacramento Area Flood Control Agency (SAFCA) has also contributed to bank protection efforts along the Sacramento River with evaluations (e.g. NHC 2005) as well as the present effort to support project developments stemming from the US Army Corps of Engineers Common Features Project, as described in the 2015 General Re-evaluation Report (GRR) (USACE 2015). Investigation of sediment transport and channel stability was carried out by NHC for the USACE in 2012 (NHC 2012), which included new data collection, analysis, modeling and projection of future sediment supply and transport conditions.

3.4 Geologic Background

The current configuration of the Sacramento River and the east side levee system has resulted from long term geologic conditions, geomorphic processes, and land use development since the 1850s. The study reach is located within the Sacramento Valley of the Great Valley geologic region, a 150-mile-long tectonically subsiding basin bounded by the Coast Ranges to the west and the Sierra Nevada to the east. Its geologic history includes filling with sediments that has eroded away from the surrounding uplifted terrains and periods of marine seawater inundation. Over the past 2.0 million+ years, the Sacramento area has been dominated by the formation of large alluvial fans emanating from canyons of the Sierra Nevada to the east and, at times, extending westward beyond the current Sacramento River alignment.

During the Pleistocene period, multiple glaciations lead to deposition of the alluvial fans, followed by periods of deep erosion and entrenchment. Intervening interglacial periods are relatively quiescent with conditions similar to those that currently prevail. Each glacial cycle included a period of global lowering of sea level during peak glacial periods, then rising from glacial meltwater in interglacial periods. The current landscape of the east side Sacramento River area was formed primarily by sediment deposition processes since the end of the last glacial period 12,000 years ago and the related 400 +/- feet of sea level rise. This time coincided with the formation of the Sacramento / San Joaquin Delta, whose hydrologic and tidal influence extends northward into the Sacramento area.

The Sacramento River flows through the center of the valley with much wider adjacent low flood basins. The original physiography and hydraulic function was recognized by Gilbert (1917) (Figure 3-3) and is well documented by early maps and reports. At the latitude of Sacramento, the predominant volume of flood flows was carried by the flood basins, the Yolo Basin to the west (Figure 3-4) and Sacramento Basin (now isolated by levees) to the east. The relatively narrow Sacramento River channel was bounded by natural levees that were topographically higher than surrounding land. The peak elevations occurred near the channel banks and then lowered gently landward for up to a mile in some areas towards the flood basins. The natural levees formed by deposition of silty sands along the fringes of the channel, which induced dense vegetation growth. Finer silty clay deposits accumulated in the flood basins.

The genesis of the present physiography was the 400-foot rise in sea level, most of which occurred between 10,000 and 6,000 years before present. Prior to this sea level rise, the Sacramento River initially would have been within an entrenched valley flowing to a Pacific Ocean shoreline many miles west of the Golden Gate. As sea level rose, freshwater runoff and sediment deposition would gradually be controlled by progressively higher base levels and tides. Sediment deposition over the past 3,000+ years has created today's natural levee / flood basin terrain, topography and bathymetry (Atwater 1982).

The original natural conditions were documented during the early Euro American settlement period that began around the 1840s. These early historical accounts include descriptions of flooding problems in the City of Sacramento. An excerpt from SFEI (2012) (Figure 3-4) shows an early 1851 sketch of the layout of natural levees with the wide landside backslopes into the Sacramento and Yolo flood basins. Figure 3-5 shows decreasing channel flood capacity from Chico Landing (RM 200) downstream to Cache Slough (RM 14), and the dominance of flood basins in handling most of the flood discharge away from the channel and natural levees.

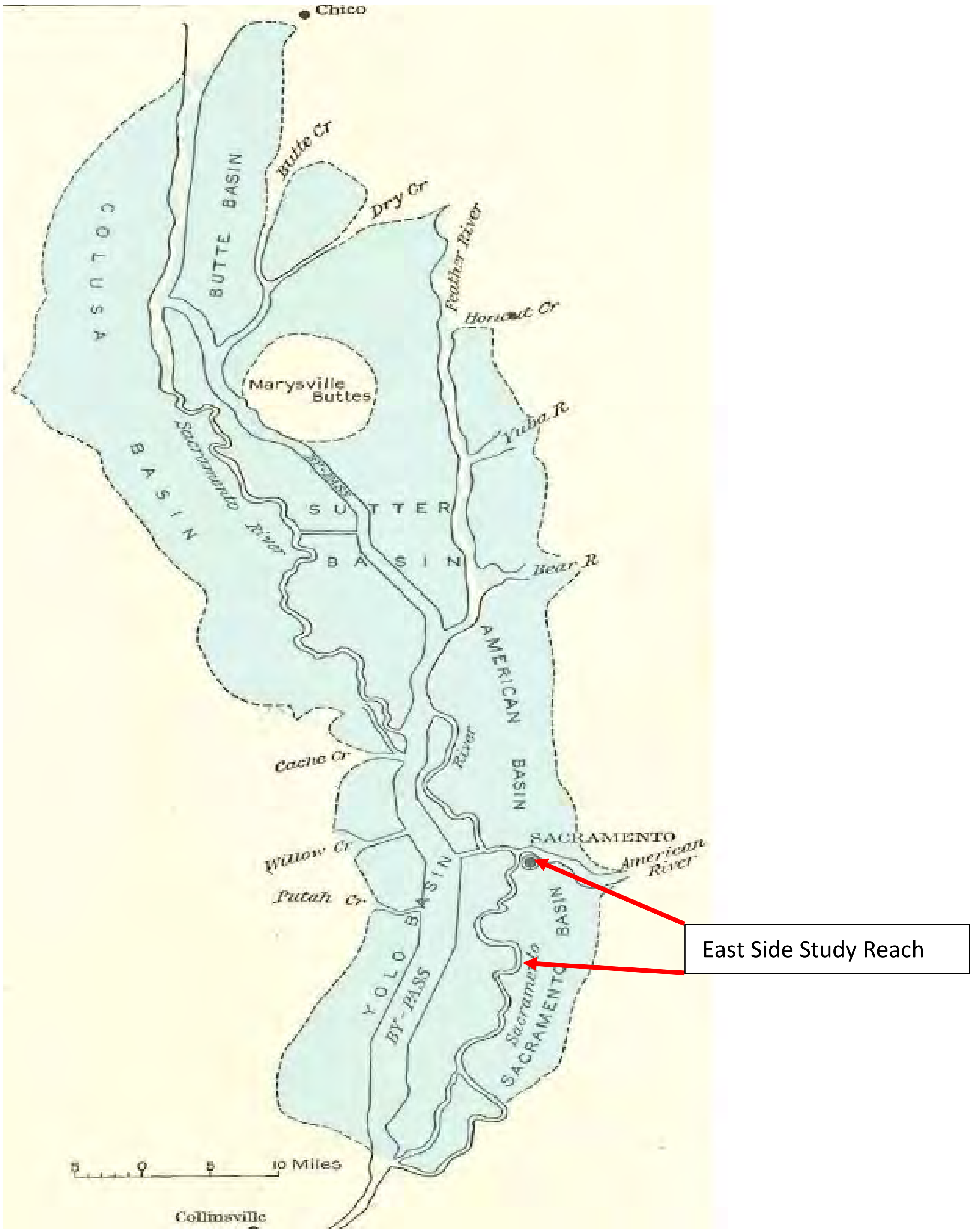
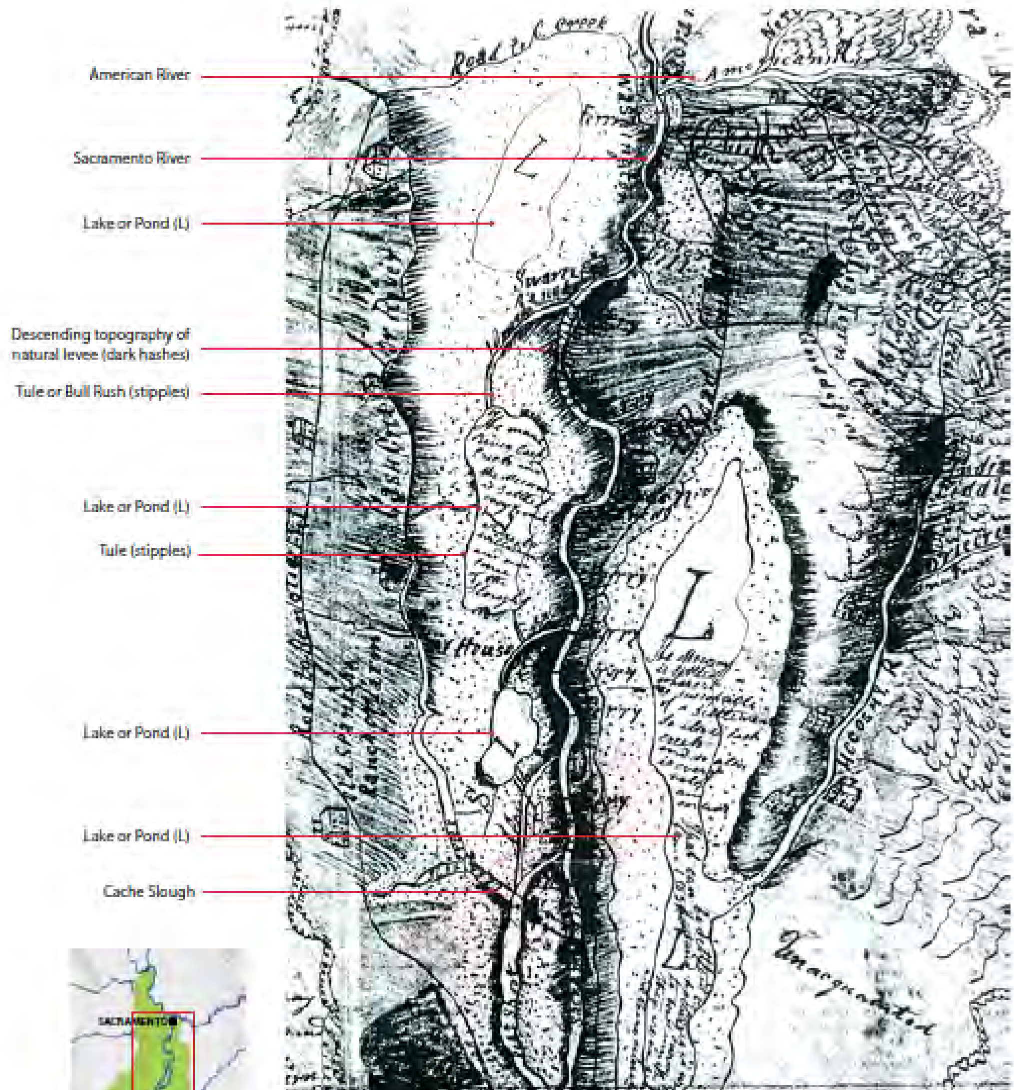


Figure 3-3 Sacramento River and Flood Basins (Gilbert 1917).



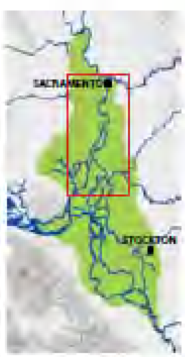


Figure 5.9. An 1851 sketch of the basin landscape pattern. Though the author of the letter and this map got few of the facts wrong (e.g., Cache Creek did not connect directly to Cache Slough), he does convey the character of the basin landscape. To describe the pattern and his map, George Browning (1851) stated that the land near the river descends (the dark pencil hashes), "then comes the Tola or Bull Rush [stipples]…and then comes the Lake or Pond [marked with 'L']." (Browning 1851, courtesy of The Bancroft Library, UC Berkeley)

Figure 3-4 1851 Sketch of Sacramento Area by Browning (1851). Excerpt from SFEI (2012).

Figure 5.22. Minimum Sacramento River channel capacity was recorded at the Feather River confluence (blue line, Knights Landing) in a 1910 report by State Engineer William Hammond Hall. The channel increased in capacity downstream from that point (blue line), but was only a fraction of the estimated capacity required to carry most flood flows (purple line). The corresponding channel widths for these locations, as listed in the same report, are shown as red dots and correspond with the right-hand axis. (California Debris Commission 1910)

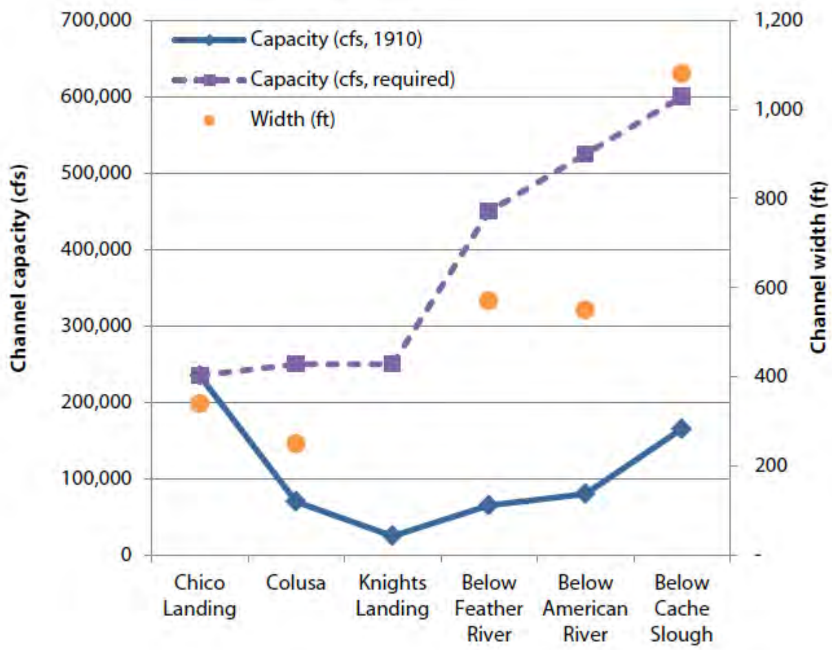


Figure 3-5 from SFEI (2012).

In the study reach, the Sacramento River's channel capacity was below 100,000 cfs compared to an overall flood discharge of over 500,000 cfs. This natural configuration would eventually be used to control flooding in the early 20th century by construction of bypass overflow weirs into the Yolo Basin (e.g. Fremont and Sacramento Weirs). Under today's conditions with levee, bypass, and dam storage systems, the capacity of the Sacramento River between the American River confluence and Freeport is 110,000 cfs.

3.5 Early Historical Period (1840s to early 1900s)

The rough map and description of Browning (1851) (Figure 3-4) and early maps and accounts describe, the east side Sacramento River channel was bounded by the natural levees and the Sacramento Flood Basin to the east. The natural levee on the bank of the Sacramento River channel was perched many feet above the flood basin lands to the east where the City of Sacramento would grow.

The pattern of the channel shown on a map in 1850 (Figure 3-6) is very close to today's alignment with the south flowing river channel making several distinct bends, most notably what is now known as Chicory Bend (at "Little Pocket" RM 54-55) Oak Hall Bend (RM 53-54) and Clay Bank Bend (opposite "The Pocket" RM 53-48).

Figure 3-7 shows evidence of early efforts to raise the natural levees along the Sacramento River in order to provide greater flood protection. The main area of development in 1850 was near the American River confluence, as can be seen in Figure 3-6 upper left panel. Floods in the 1850s prompted construction of three to six foot high mounds atop the natural levees from the American River mouth, at about RM 59.5 (later realignment of the lower American River moved to the confluence to its present location at RM 60.5, where it is today today) to about 31st street. This effort extended further south to the Sutterville area (RM 56) where natural levees were raised 15-20 feet above the “natural surface of the country” (SFEI 2012).

The catastrophic floods of 1861/62 forced rethinking of flood control strategies for Sacramento. In repeated flood events, the main source of flooding was from the American River overflowing its bank east of the City, then backing up behind the natural levee of the Sacramento River. In accounts of the 1861/1862 flood, relief to deep ponding in the City was accomplished by breaching the levee along the Sacramento River, which quickly lowered flood levels 6-8 feet. In response to the devastating 1862 flood, the entire city was raised up to 15 feet and greater efforts were made to construct a sufficient levee along the American River as well as the south side of the city along railroad embankments. This strategy of raising levees and developing areas was coupled with architectural flood proofing (i.e. raising living space floors) to counter what had become a once in ten year event.

The early flooding problems in Sacramento (1862) were greatly exacerbated by the transport and deposition of hydraulic mining sediments from the American and Feather Rivers (which includes the Bear and Yuba Rivers) into the Sacramento River. Recorded as a factor in the 1862 flood, sediments raised the river channel bed (aggraded) significantly (5-7 feet in the study reach) and decreased flood capacity and navigation. Accounts of pre-hydraulic mining around 1850 found adequate depth for boats traveling to Sacramento with no less than a 7-foot depth, and usually 10 to 11 feet at high tide. Artificial raising of levees and the closure of small overflow channels along the west bank in the 1850s further enhanced navigation for boats with up to a 12-foot draft. By the 1880s, channel aggradation had raised the bed well above tidal ranges (Figure 3-8) and channel dredging projects to help restore navigation were implemented between 1882 and 1892 (NHC 2007). An account in 1908 indicated that the main source of sediments to the study reach was from the American River and was most disruptive during low flow periods (May to September). A total of 8 million cubic yards were deposited in low flow months which was partially flushed during higher flows in winter, allowing for navigation. Dredging continued in the 1920s to 1940s in order to maintain a 10 foot deep navigation channel up to Sacramento (Freeport Water Authority 2004). By 1940, (WET) (1991) estimated that approximately 186 million cubic yards had been dredged from the river downstream of Sacramento.

Another significant flood control project was moving the mouth of the American River 1.0 mile northward in the 1860s (Figure 3-7). This was designed to increase the capacity of the American River channel and to more efficiently flush sediments.

Additional efforts to flush sediment in the study reach included narrowing the channel with installations of log, brush and rock wing dams, each 150 to 300 feet long (URS 2011). An 1899 bid notice through the USACE placed these in front of the City of Sacramento up to the high water mark. Subsequent announcements called for 5,000 to 6,000 lineal feet of wing dams from Sacramento to the mouth, consisting of 20 inch diameter pine logs driven 20 feet deep, with rock fill and brush (likely willow) and soil layering. Portions of these wing dams are clearly visible on aerial photographs in 1937 and as recent as 1952 and are still visible in 2018 sonar bathymetry surveys.

In contrast to vertical channel instability of the channel bed caused by deposition of hydraulic mining sands, channel widths in the study reach were not significantly affected. Channel widths before and after hydraulic mining debris (1850s to early 1900s and later) were found to be roughly the same 500-900 feet, as shown from a post-mining survey (SFEI 2012). Bank stabilization was likely needed but specific records are lacking, except for installation of wing dams described previously within the 1890s to early 1900s. Maps from 1908 show the locations of rock wing dams but no revetments. The first maps showing several types of bank protection were produced by the USACE in 1933 (USACE 1933), these are discussed in Section 3.3 below.[3]

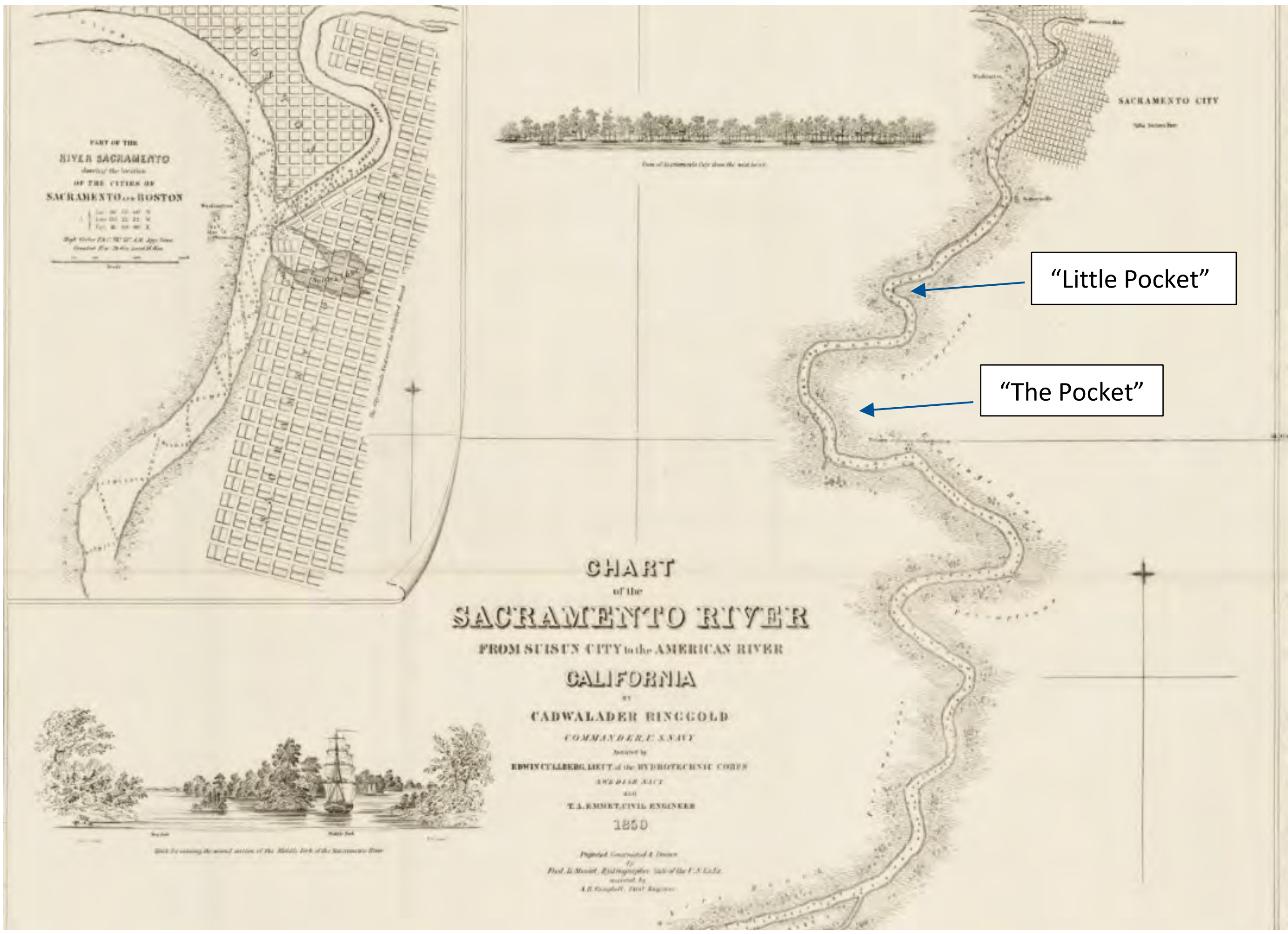


Figure 3-6 1850 Map of Sacramento River.

[3] Historical notes from 1936 (URS 2011, page 2-9, last paragraph) indicate that wing dams actually accelerated otherwise slow erosion at Chicory Bend (RM 53.9 to RM 54.2).

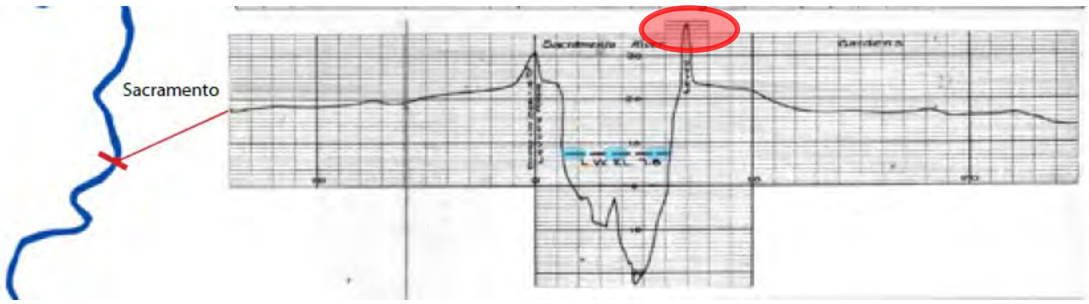


Figure 3-7 1908 Cross Section of Sacramento River Looking Upstream Near RM 56 Near Present Day Sutterville Road. Note Topographically Higher East Levee (Red Oval) Which Has Been Artificially Raised (Excerpted from SFEI 2012).

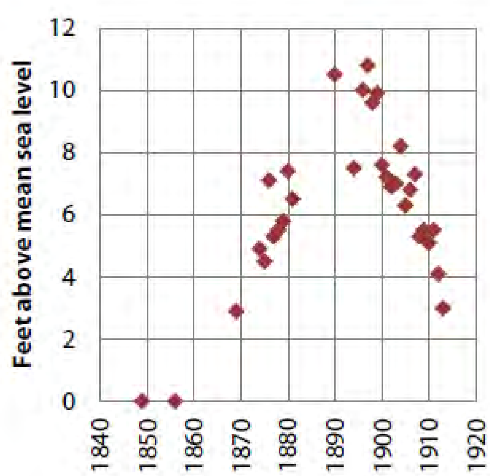


Figure 3-8 Rising Low Water Levels in the Sacramento River at Sacramento From SFEI (2012).

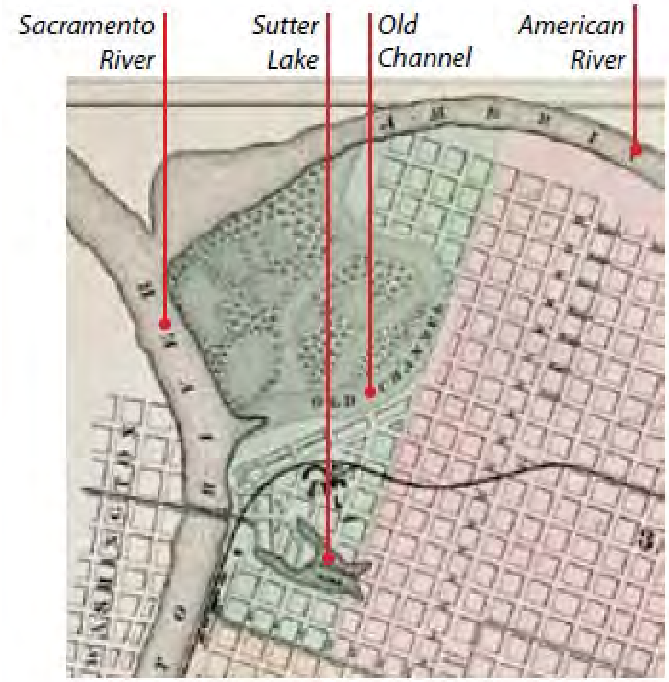


Figure 3-9 Excerpt From SFEI 2012 Showing the Northward Relocation of the American River Confluence in the 1860s

3.6 Sacramento River Flood Control Project (1911 to present)

Despite continuing problems with repeated flooding, the City of Sacramento continued to grow south and eastward after 1900. A major flood in 1904 created a breach just south of Sutterville Road at RM 56 (called the Edward's Break), devastating areas to the east and south, all the way to the Mokelumne River (25 miles to the south). In 1917, a federal and state agreement for a single organized flood control project was settled and included raising levees to set elevations, and installing new weirs and flood bypasses. In the Sacramento area, the American and Sacramento River levees were raised and strengthened and the majority of flood flows were siphoned into the Yolo basin, through the Sacramento Bypass at RM 63 and the Fremont Weir at RM 82 to RM 84. This hydraulic arrangement set the maximum operational flood capacity at 110,000 cfs for the Sacramento River south of the American River. This capacity has been reached several times since completion of the weirs in the 1920s and was exceeded once in 1986 to a record of 117,000 cfs (USACE 2014) due to high releases from Folsom Dam on the American River.

URS (2011) reviewed documents related to the construction and maintenance of levees along the Sacramento River, dating back to 1913. Although the historical records prior to 1913 show continuous levees along the entire study reach (USACE 1908), these were mostly constructed by local and private entities. The 1917 federal plan set forth the design for the east side levees to be 3 feet above the "adopted floodplain" of 23.5 feet at Grands Island (RM 32.5), to elevation 35.0 feet at the American

River (RM 60) (RMs current USGS and elevations USACE Datum at that time). These were to be constructed using the existing levees to the extent possible with a 2 ½H to 1V waterside slope.

The presence of extensive berms between the channel bank and levees is shown on the 1908 maps with periodic labels of "willow" and "cottonwood" and "timber" (presumable valley oaks). These berm areas were probably enhanced by hydraulic mining sand deposition from 1860s to 1900, however when the channel was flushed of sediments and incised after 1900 (enhanced by wing dams as described above), the channel bank slopes likely become higher, steeper and less stable. Early 20th century construction methods for new levees in 1913 (URS 2011) described in documents, make reference to the importance of berms to protect levees from erosion:

> *"Construction of the main levee along the Sacramento River involves several novel features. The levee is located some distance back from the river bank, protected from wave wash and direct current scour, by trees on the berm (i.e. bench)."*

The extent of the 1908 map berms has been significantly diminished by erosion, extension of levee slopes, land use changes and installation of bank protection. The following excerpt from URS (2011) provides some insight into levee and bank protection treatments in the 1930s:

> **Letter from USACE to U.S. Engineer, War Department, 1937**
>
> *"This correspondence pertains to work along the left bank of Sacramento River at Clay Bank Bend, near River Mile 52.0. The work was to consist of building a small rock wall along the toe of the existing riverward slope of the levee; below the existing wing dam, correspondence proposes to build out the riverward slope of the levee to an approximate 2 ½H:1V with material excavated from the river channel. Standard woven lumber mattress and standard bank paving was to be laid on this new fill; the portion of the fill above the bank paving was to be surfaced with a compact layer of loam.*

Figure 3-10 shows photos of bank erosion protection projects in the 1920s, including use of concrete and wire mesh on the Yolo Bypass near Lisbon (top photo) and treatment near Riverside / Pocket area.

With completion of the Sacramento River Flood Control Project and the construction of dams on all major rivers by the mid-1950s, urban expansion continued during the post world war two era. This included the low floodplain areas of South Sacramento (RM 54 to 58) and "The Pocket" (RM 47 to 54) that were densely urbanized, up to the landside toe of the east side levee. Records from the USACE indicated that over 80 percent of the banks in the study reach had protection installed between the 1930s and 1980s (WET, 1990). Records of bank protection placements since the late 1920s show a variety of installations, including rip rap, cobbles, poured concrete revetments (e.g. RM 56) and concrete rubble. There are notations shown on a 1933 map (USACE 1933) marking bank protection installations into the 1950s, mostly short segments covering several hundred feet, suggesting that erosion issues were treated as they occurred.

After recognizing systemwide erosion problems, the federal government authorized the Sacramento River Bank Protection Project (SRBPP) in 1960 for an initial phase of levee and bank stabilization/rehabilitation covering 430,000 linear feet of levee and banks. This was followed by the 1974 Water Resources Development Act, which added another 405,000 linear feet; and an additional 80,000 linear feet was requested in 2007 (for a total of 915,000 linear feet). Rip rap placements after 1960 continued to replace natural banks or replaced/repaired damaged structures. New rip rap placements and repairs increased after major floods (1986, 1997) and after periods of extended high flows in wet winters (e.g. 2006). There is a report of flood fighting erosion near RM 46 in 2010 when peak flow was only 59,600 cfs (less than a 2-year peak flood event).

Modern bank protection structures built after 2000 account for roughly 13% of the study area and are designed to withstand channel bed scour by adding a deep trenches of launchable rip rap on the toe of the structure. These structures include placement of soil trenches that are designed to support shoreline riparian vegetation and instream woody materials (logs) in order to improve habitat conditions. Research has shown that these environmental features have improved habitat conditions for juvenile Chinook salmon over traditional rip rap revetments (Hellmair, et al 2018).

The Lisbon Levee in the Yolo Basin, part of Reclamation District 307, receives a concrete facing in 1911. The four inch thick concrete, reinforced by a wire mesh, was the first such large scale application to a river levee, covering two and a half miles.

Sacramento Archives & Museum Collection Center
Natomas Company Collection
1981/037/2252

Crews work to reinforce this Sacramento River levee in the Pocket-Riverside area of Sacramento, c.1920.

Sacramento Archives & Museum Collection Center
Sacramento Valley Photographic Survey Collection
1981/001/0491

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Figure 3-10 Photos of Levee Slope Stabilization Techniques From the 1920s (Source: Sacramento County Historical Society 2006).

3.7 Channel Stability Trends

Channels are stable when they can transport the flows and sediment loads imposed from upstream without dramatic changes in geometry (width and depth) or pattern (straight, meandering, or braided). Hence, "equilibrium" depends upon the balance of flow and sediment load influencing the shape of the channel. Channel changes can occur over short periods of time during single flood events, over the course of decades, or longer. The rate of change in channel morphology over time can indicate whether the geomorphic processes reflect a level of equilibrium. This can have great implications for levee stability as increases in channel width or depth can change erosive forces that act on bank and in term levee stability.

Historic channel stability analysis (Kondolf and Sale, 1985) assesses past changes (in this case the past 160 years of records) to identify current trends and, with some prudent judgement, project them into an estimate of future conditions. Future trends could differ from the historical records and requires consideration of factors associated with climate change, including sea level rise and hydrologic change. Assessing these factors requires modeling different scenarios of climate change intensity.

As discussed above, the Sacramento River reflects the current quiescent interglacial times with relatively low levels of erosion and sediment supply compared to the extensive erosion and sediment supply of earlier glacial peak and transition periods. The governing geomorphic processes and the physical characteristics of the channel can be greatly affected by land use activities. Most notably, the release of hydraulic mining sediments during mid to late 1800s which caused a significant rise in channel bed elevation (aggradation) and disrupted flood control and navigation. In response, historical flood control countermeasures revolved around channelization activities designed to increase the channel flood capacity and pass floods around the low lying floodplain areas but also to flush sediments. The channelization measures included raising levees, dredging the main channel and blocking overflow channels (e.g. Babel and Elkhorn Sloughs). These acted as natural relief valves that dispersed flood waters and erosive forces away from the channel. These were either well established breaks in the natural levee, such as Elkhorn (RM 42) and Babel Sloughs (RM 49.5), or sudden ephemeral breaks, such as the 1907 flood Edward's Break at RM 56. In both cases, significant sediment loads were diverted towards the low energy flood basins. Artificially blocking overflow channels helped navigation and sediment flushing, but it also increased erosional forces in the main channel and likely led to more bank erosion and deeper channel bed scour.

Channelization was an intentional strategy to increase hydraulic and erosive forces to flush hydraulic mining sediments (James 1993). Later, dam closures between the 1940s and 1960s trapped sediments from upstream watersheds and modified flows. It is estimated that 60% of the total sediment load to the lower Sacramento River now comes from bank erosion (James 1993), some of which has been removed by stabilizing bank protection structures. Overall, sediment supply appears to be decreasing as a result of trapping behind dams, deposition in flood bypasses, protection of river banks, and diminishment of the hydraulic mining sediment pulse (Schoellhamer, et al 2012).

As previously discussed, the Sacramento River channel in the study reach has generally remained in the same pattern since the 1850s and channel width has not varied greatly. Lateral erosion has occurred in some places, however it has been halted by the placement of a variety of bank protection structures dating back to at least the 1930s (WET 1991). Based upon mapping that was conducted in 2009, over 80% of the study reach is armored.

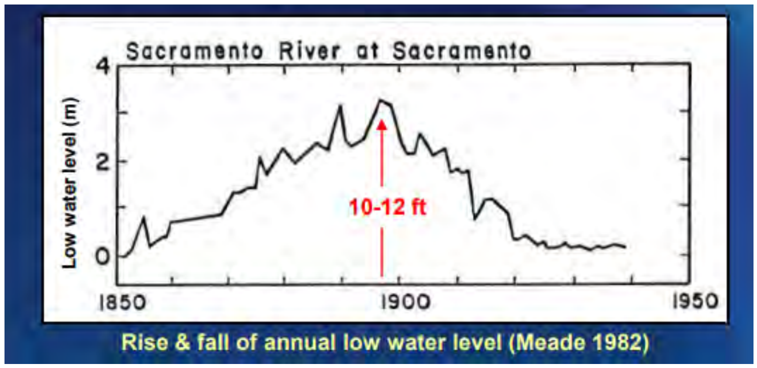

Figure 3.11 Changes in Low Water Level at Sacramento From Meade 1982 (As Shown in NHC 2005).

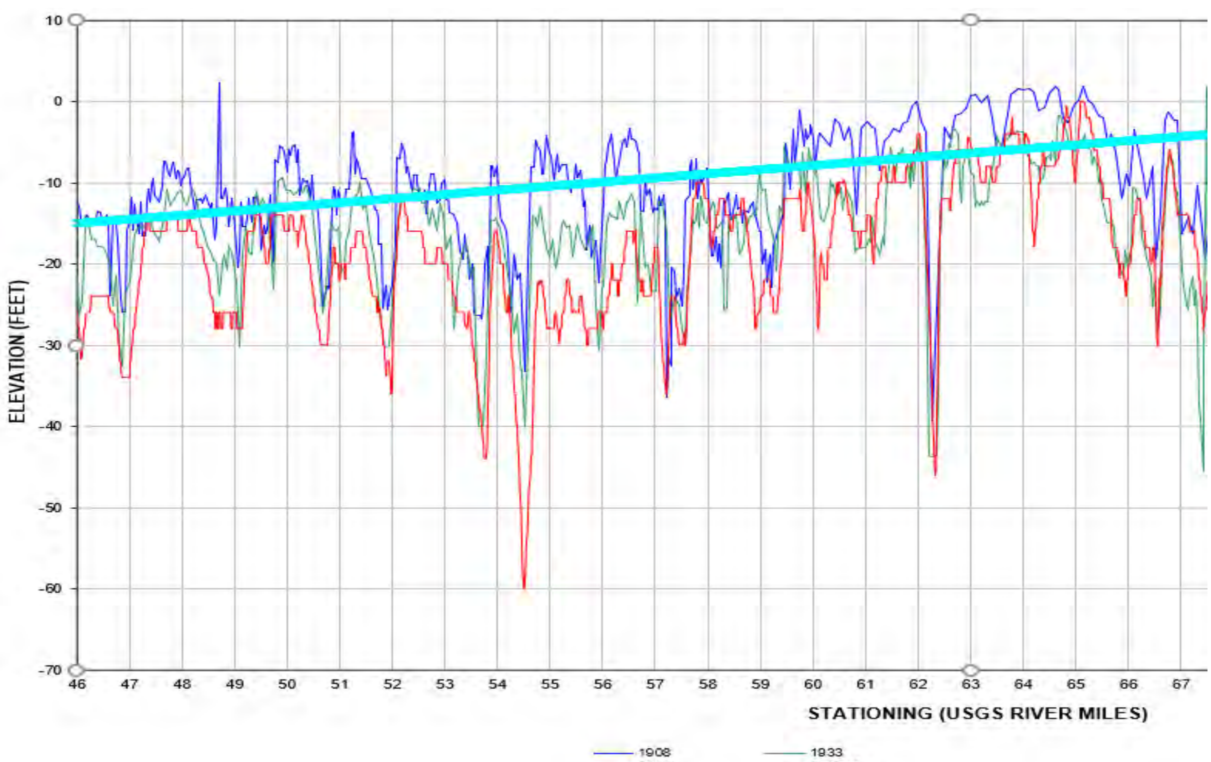

Figure 3-12 From NHC (2006), Thalweg Profiles for Sacramento River 1908 (State of California), 1933 (USACE) and 1997 (USACE) RM 46 Freeport to RM 67 (Note East Side Study Reach is RM 46 to RM 60).

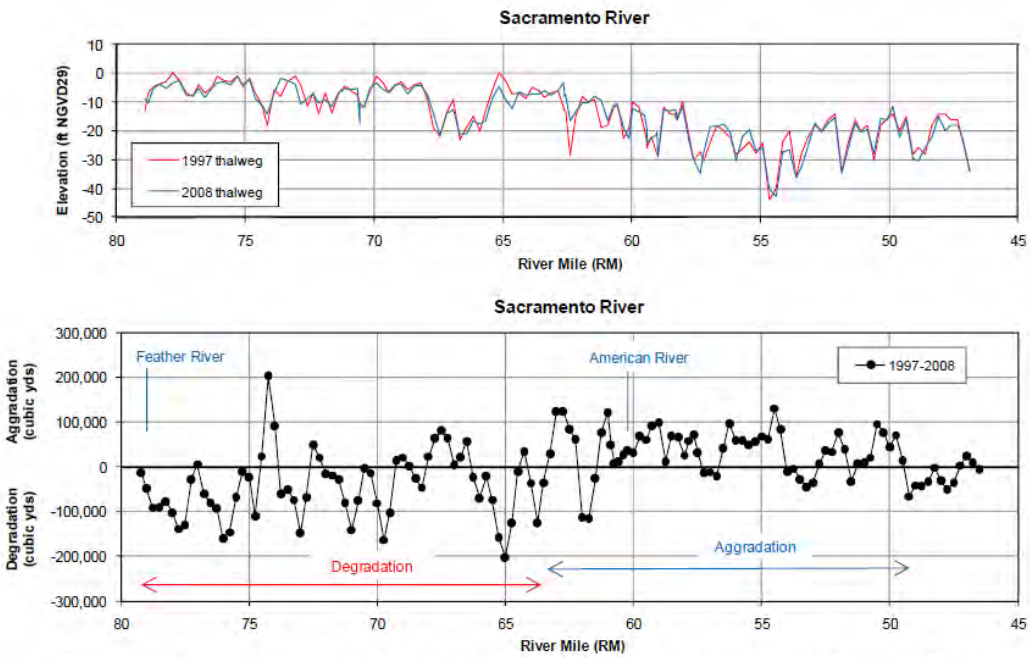

Figure 4.34. Thalweg profiles (top) and aggradation/degradation volumes (bottom) for lower Sacramento River between 1997 and 2008.

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Figure 3-13 From NHC 2012, Changes in Bed Elevations (Top) and Channel Bed Sediment Volumes (Lower Panel) Between 1997 (Post Record January 1997 flood) and 200; Study Reach is RM 46 to 60.

The more significant changes occurred in vertical stability as the channel bed rose up to 10 to 12 feet by 1900 in response to the influx of hydraulic mining sediments, and then fell back to original elevations by the 1950s. Figure 3.12 shows the rise and fall of annual low water elevations at Sacramento. Figure 3.13 shows thalweg profiles for 1908, 1933 and 1997 showing the flushing of hydraulic mining sands that was reportedly complete by the 1950s. A recent comparison of changes in channel bed elevations between 1997 and 2008 (Figure 3-14) from NHC (2012) found localized changes in scour hole depth and movement of sand waves, but no significant changes overall. A more recent comparison of channel bed changes between 2008 and 2018 (maps in Appendix A, CBEC, 2019) also shows little change (most change areas are less than 5 feet which is within the expected variability given a mobile sand bed and sand movement in and out of scour holes).

There are local instances of artificial dredging and filling of the floodplain berm areas within the levees (e.g. Sacramento Marina and Miller Park constructed at RM 58.1 to RM 57 in the 1960s), and construction of various infrastructure such as roads, bridges and water supply intakes (RM 59 and RM 47.2). New and higher levees were built in the 1950s and 1960s to protect new urban areas from Sutterville Road (RM 56) to just upstream of Freeport at RM 46.

The USACE conducted systemwide erosion studies beginning in the late 1980s (WET, 1991) that included analysis of geomorphic processes and channel stability. WET (1991) and NHC (2012) found that the channel bed profile in the study reach was stable, moving 3+ feet of high waves of sand that account for minor fluctuations in year to year bed elevations. However, NHC (2005) recognized a significant potential for local bed scour at six erosion sites in the Pocket area (RM 49.6 to 53.1) during peak flood events 8 to 24 feet below the static bed elevations of - 10.0 to -20.0 feet . At times, the static bed elevation has been as low as - 60.0 feet after the large 115,000 cfs peak 1997 flood (1997 line in Figure 3-14). Channel width has, in general, been found to be stable at the large scale, but chronic and progressive erosion due to long duration flows and fine erodible bank materials will continue to be a challenge for protecting levees. This includes repairing or replacing older structures undermined by erosion or not meeting modern design standards, which includes furnishing enough rock to fill scour holes under peak flow conditions.

To support planning for the SRBPP, an evaluation of current and future sediment transport and channel stability was conducted by NHC for the USACE in 2012 (NHC, 2012).The study examined changes in channel geometry, bed and bank elevation, and channel bank locations from the period of 1950 to 2008. For the study reach RM 60 to RM 46, the NHC (2012) study found the following:

1) Very little bank erosion occurred in the study reach over the studied period (1950-2008). Maximum erosion was 50 feet at one location (RM 56.6) which appears to be related to hydraulic changes due to vegetation clearing and filling at and near Miller Park between 1957 and 1964.
2) Sediment transport modeling was used to project bed elevations over the next 50 to 100 years, and the results indicate only slight degradation occurring in the study reach. These results are attributed to a long term decrease in sediment supply from the Upper Sacramento River and American River. Examination of historical sediment records taken at USGS gaging stations, including two within the study reach (Sacramento River at Sacramento [RM 59.5] and Sacramento River at Freeport [RM 46]), did not indicate any significant trends in sediment transport since the 1960s.
3) A sensitivity analysis of sediment supply was conducted in long term simulations by increasing incoming loads by 30%; this analysis found little change in bed elevations in the study reach RM 60 to RM 46.
4) An increase in peak flows resulting from hydrologic climate change was found not to significantly affect sediment transport or bed elevations in the RM 46 to RM 60 reach.

Future climate change will likely affect river flows and sea level in the study reach. As part of the Central Valley Flood Protection Plan (CVFPP) (DWR, 2017), DWR developed 50 year future projections of hydrologic and hydraulic changes using widely accepted climate and sea level change estimates. Applied specifically to the Sacramento River, it was found that an estimate of 1.8 feet of water surface rise in a projected 200 year peak flood (Figure 3-12) as a result of an increased flow (mainly caused by warmer temperatures, higher snow levels and greater per unit area runoff rates). The effect of sea level rise of 1.8 feet at the mouth of the Sacramento River at Collinsville dissipates to 0.0 foot rise at the American River due to hydraulic controls in confined leveed channels and bypass weirs. Although no specific estimates of climate change effects on bank erosion have been made, it is thought that the frequency and duration of erosive flows will increase (DWR, 2017).

In summary, the Sacramento River channel in the study reach is generally stable at the large scale, but past and ongoing active bank erosion near levees in local reaches requires constant monitoring and repairs. This has resulted in the installation of bank protection structures covering over 80% of the 14.0 mile total bank length in the study reach, of which 13% have modern design standards (USACOE 2015). Repairs of older, damaged structures is commonplace and there are unprotected areas close to or within the levee structural template.. Future climate change estimates indicate hydrologic changes will result in more frequent and longer duration erosive flows, which will increase likelihood of accelerated bank erosion.

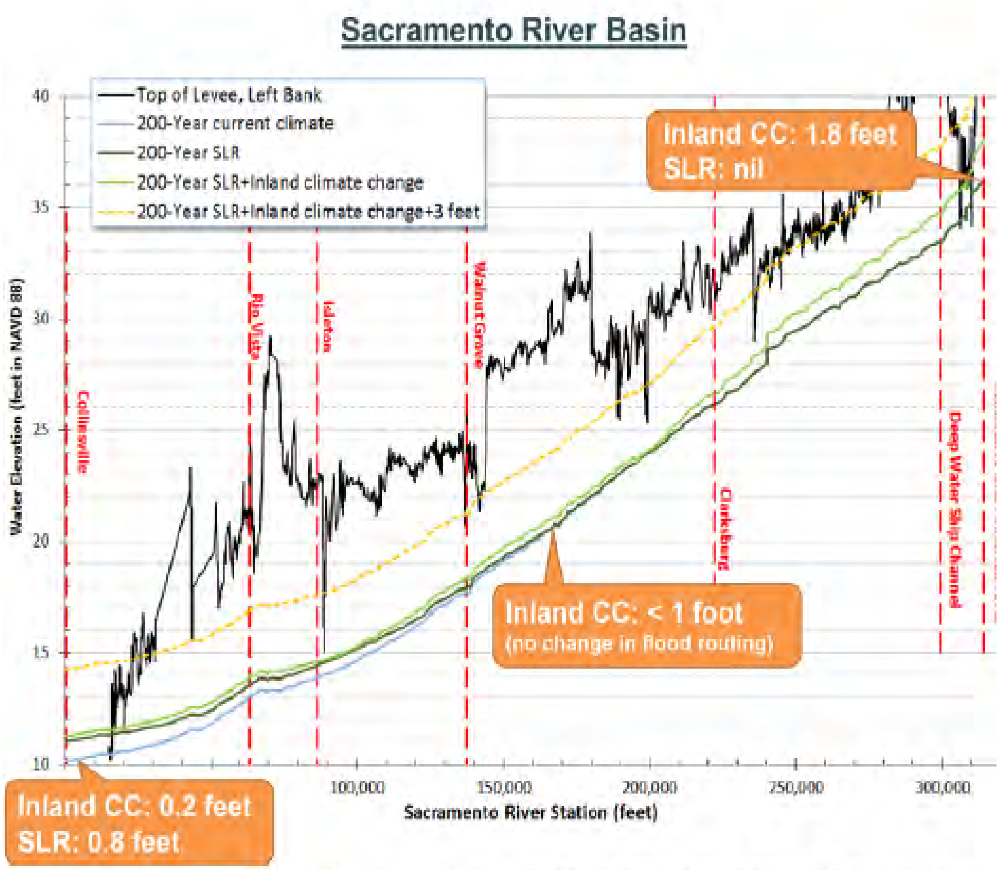


Figure 3-13. Projected Inland Climate Change (CC) and Sea Level Rise (SLR) Response 200-Year Flood for Sacramento River

Figure 3-14 Projected Hydraulic Change Associated with Climate Change in Hydrology and Sea Level Rise in a 200 Year Flood (Source: DWR 2017).

3.8 Present Conditions

The current geomorphic conditions are shown on the surficial geologic maps prepared by Fugro William Lettis & Associates (Fugro WLA 2010) (Figure 3-15), with details of the materials forming the levee foundation and river banks. This study was part of the Urban Levee Evaluation (ULE) (URS 2012) Program that primarily focused on seepage and underflow through levee foundation materials and finding locations that crossed old paleo channels and more permeable pathways. The ULE program examined multiple threats to the study area levee system, including bank erosion. Since the levees are close to the river channel, in many places an extension of the river banks, the subsurface information should approximate channel bank materials.

Figures 3-16 and 3-17 show geologic cross sections taken near I St Bridge at RM 59.5, and along the Pocket area respectively with the following descriptions from Fugro WLA (2010) of subsurface geologic units (note these are more generalized than the surficial map units of Figure 3-15. DWR has not yet contracted work to reconcile the units (Steve Mahnke, DWR, personal communication April, 2019)). The following excerpts from Fugro WLA provide descriptions of stratigraphic "packages" shown in cross sections Figures 3-16 and 3-17.

> *Package 1*
> The upper package, or top-stratum, consists of about 20 to 40 feet of very loose and very soft silt, sandy silt, with thin, laterally discontinuous clay and sand lenses. This stratum, which may act as a seepage blanket layer, was laid down during the Holocene as overbank and flood basin deposits and represents vertical accretion of the natural levee and floodplain surface over the past several thousand years.
>
> *Package 2a and 2b*
> Beneath the silty top-stratum (Package 1) is a package of coarser-grained sediment that ranges in thickness from about 10 feet to more than 80 feet thick. This package consists of medium dense, fine-to-coarse grained clean sand, sandy silt, and localized occurrences of pebbles, gravels, and cobbles. We interpret this permeable stratum as the latest Pleistocene Modesto Formation (upper member), which was deposited as point bars, meander scrolls, and channels from lateral migration of river channel(s) across the former valley floor surface. Underlying this sandy unit is a package of gravel that may or may not be the lower member of the Modesto Formation. The gravel is laterally extensive in the northern part of the map area, and underlies both sides of the Sacramento River near the I Street Bridge (Figure 3-16). The upper part of the gravel package may be gradational into the overlying sand, and thus also be upper Modesto Formation; representing a fining-upward trend. In the south part of the map area (i.e. Pocket area), this gravel is not present or it exists only in local patches within older channels.
>
> *Package 3 (discontinuous)*
> Within the Pocket area, a medium stiff to stiff fine-grained (i.e., clayey silt, silty clay) package, with local gravel patches, discontinuously underlies the more-permeable sands of Package 2. This fine-grained package is distinctly more dense than the top-stratum, and may represent the lower Modesto Formation flood basin deposits on the earlier valley floor, in former low lying areas adjacent to the river channel. This package is not present in the northern part of the study area, and may be a local layer associated with the large meander bend of the Pocket area. Additionally, Package 3 appears to be locally absent at depths near station 1440+00, suggesting deep granular sediments associated with the Holocene meander scroll deposits mapped through in this location (Figure 3-17). Past levee under seepage problems have been documented in this area.

Package 4

> Underlying the entire unconsolidated sequence (i.e. packages 1 through 3) is a hard, moderately-cemented silt to siltstone. The top of silt occurs irregularly between about 50 and 70 feet below mean sea level (). The variable top elevation of this unit probably reflects post-depositional topographic relief. We tentatively correlate this unit to the upper member of the Riverbank Formation, based on limited subsurface data along the back-edge of the modern floodplain, topographic position, and proximity to the surface exposure of the lower member within the map area. Thus, the upper member is inset to (i.e., topographically lower) the lower member of the Riverbank Formation. It is permissibly older, perhaps the latest Pliocene-early Pleistocene Laguna Formation. However, the importance of this unit lies in its hardness, commonly refusing standard penetration test (SPT) advance where encountered. The fine-grained texture and hardness of this unit make it essentially a basal, no-flow boundary beneath the overlying granular sediment. Hardpan horizons are not present in the unconsolidated subsurface stratigraphy suggesting either: (1) burial of the sediments such that soil-forming process cannot occur; or (2) youthful sediments (i.e., entirely Holocene) that have not had sufficient time to develop a moderate or mature soil profile; or both.

Based upon the bathymetry and topography of the channel and potential exposures of surface and subsurface units provided in Fugro WLA (2012), the natural deposits on the east bank of the Sacramento River in the study reach are:

- Modern silty sand and sand on the channel bed currently transported by the Sacramento River ("channel bed material" of Figure 3-16);
- Holocene unconsolidated silty sand from natural levee deposits and silty clay from flood basin deposits (Package 1);
- Late Pleistocene sands and gravel from meandering river deposits (Upper Modesto Formation Package 2a); and
- Early Holocene or older stiff, silty clay basin deposits in the Pocket area to downstream end of study reach (Package 3 in Figure 3-16).

The present bank materials exposed along the channel bed and banks is likely Holocene silty sands, coarser sands at old overflow channel exposures and intermittently more clay rich materials along the Pocket. It is possible that deep scour holes could expose deeper package 2b dense gravel, sand (late Pleistocene Lower Modesto Formation) and/or package 4 dense clay (Pleistocene Upper Riverbank or Laguna Formation), but this would be too deep to affect the erosional stability of banks.

Artificial fill (See Figure 3-16) is associated with raising land in the City of Sacramento and extending levees in the mid to late 1800s from the American River confluence to about Sutterville. Fill was added to levees and banks through the whole study reach in the early 1900s as part of the federal project levees. South of Highway 50 to Freeport, flood protection has been provided by levees alone without extensive fill in floodplain developments, and land surfaces remain low (much of the Pocket area is below 10.0 feet) with levees 20 to 30 feet higher.

Recent natural floodplain deposits of well sorted sand are found along the shorelines throughout the study reach, but most prominently along the Pocket area where remnant floodplain surfaces persist. These appear to be deposited in off channel slackwater areas during larger floods, then eroded in steplike cut banks by subsequent floods (Figure 3-18) and possibly boat and wind waves. Some areas show cycles of burial and exhumation of trees (Figure 3-19).

Plate 1 - Surficial Geologic Map of the East Side of the Sacramento River

This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey topographic base map prepared in 1952 and photo revised in 1973. See accompanying report for complete descriptions of map units, process descriptions and methodology.

Explanation

- Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts within 30' of line shown on map.
- Erosional channel, generally <100 ft in width; likely contains unsorted soil. Dashed where approximate.
- Urban Project Levee
- 1760+00 — Sacramento River Levee stationing provided by URS.
- SR- IV — Geomorphic Reach described in text
- A — A' — Cross Section
- W 1937 — Water; date indicates year of historic dataset.
- C — Canal, circa 1937.
- BP — Borrow pit present in 1937.

Geologic Units

HISTORICAL

- L — Levee (made of artificial fill), circa 1937.
- RR — Railroad embankment (made of artificial fill), circa 1937.
- Rob — Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
- Rcs — Crevasse splay deposits; fine to coarse sand, with lenses of silt and clay deposited from breaching of natural or artifical levees.
- Rdf — Distributary fan deposits; sand, silt and clay.
- Rch 1854 — Channel deposits, as shown on 1854 topographic maps; well sorted sands and fine gravels.
- Rch — Channel deposits; well sorted sands and fine gravels.
  - Rpb — Point bar; well sorted sand with minor amounts of silt and clay.
  - Rb — Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
- Rdc — Distributary channel deposits, trace gravel, sand, silt, and clay; channelized flow conducting sediment to floodplain.
- Ra — Alluvial deposits, undifferentiated; sand, silt, and minor lenses of fine gravel.

HOLOCENE

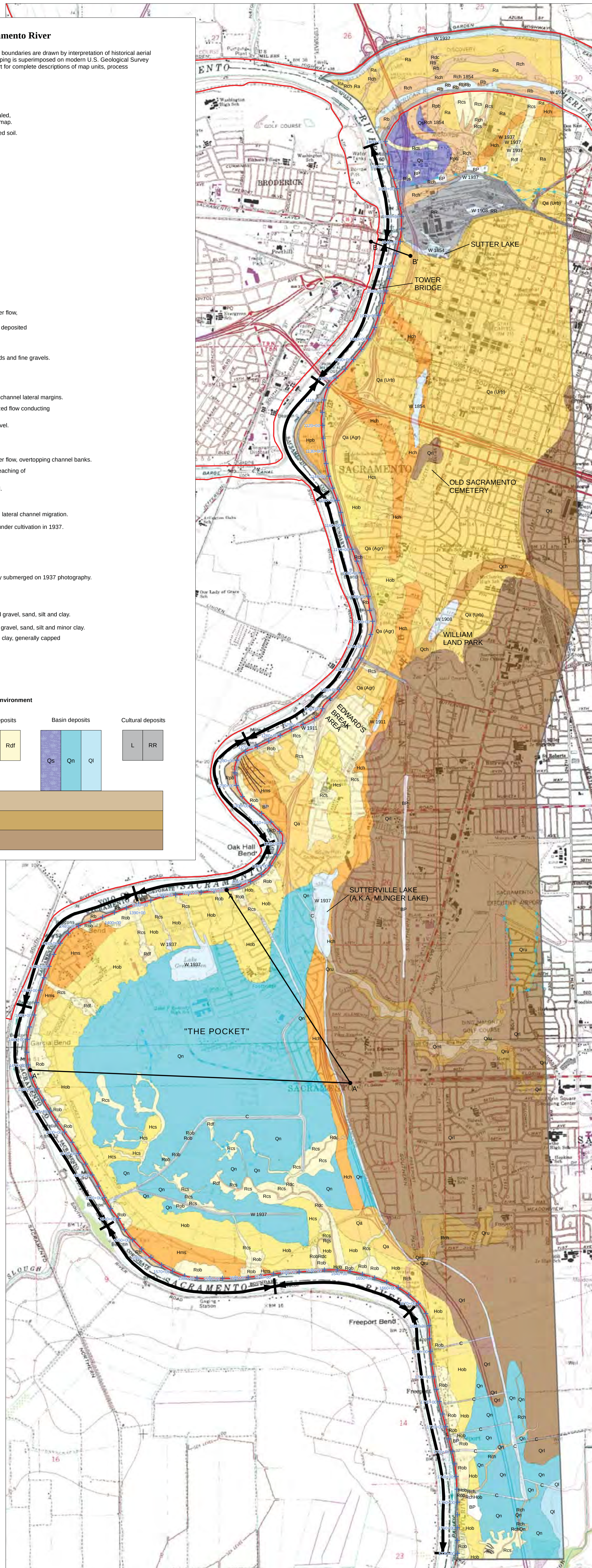
- Hob — Overbank deposits; sand, silt, and clay; deposited during high-stage water flow, overtopping channel banks.
- Hcs — Crevasse splay deposits; fine to coarse sand, with silt deposited from breaching of natural or artifical levees.
- Hch — Channel deposits; sorted sands, silts and scattered gravel; fining upward.
  - Hpb — Point bar; well sorted sand with minor amounts of silt and clay.
  - Hms — Channel meander scroll deposits; interbedded sand, silt and clay from lateral channel migration.
- Qa — Alluvial deposits undifferentiated; sand, silt, and minor lenses of gravel; under cultivation in 1937.
- Qch — Channel deposits; sorted sands and silts; fining upward.
- Ql — Lacustrine deposits; fine sand, silt and clay, under cultivation in 1937.
- Qn — Basin deposits; fine sand, silt and clay, under cultivation in 1937.
- Qs — Marsh deposits; silt and clay, likely organic-rich; perennially or seasonally submerged on 1937 photography.

PLEISTOCENE

- Qml — Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
- Qru — Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
- Qrl — Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally capped by a paleo-soil with strong duripan horizon.

Stratigraphic Correlation Chart

Time / Epoch	Channel deposits	Floodplain and alluvial-fan deposits	Basin deposits	Cultural deposits
Historical	Rch, Rb, Rpb, Rdc	Qa; Ra, Rob, Rcs, Rdf	Qs, Qn, Ql	L, RR
Holocene	Qch; Hch, Hpb, Hms	Hob, Hcs		
Pleistocene	Qml			
	Qru			
	Qrl			



1:20,000

0 — 1 mi

0 — 1 km

N

Map projection: NAD83 UTM Zone 10N

Topo base USGS 7.5' quadrangles:
Sacramento East topographic map, published 1948, revised 1992; map scale 1:24,000, five foot contour interval.
Sacramento West topographic map, published 1948, revised 1992; map scale 1:24,000, five foot contour interval.
Florin topographic map, published 1968, revised 1980; map scale 1:24,000, five foot contour interval.
Clarksburg topographic map, published 1967, revised 1980; map scale 1:24,000, five foot contour interval.

DWR URBAN LEVEE PROJECT
WLA WORK ORDER W08

Surficial Geologic Map of the East Side of the Sacramento River

FUGRO — Fugro William Lettis & Associates, Inc.

Plate 1
REV 1

Geologic Mapping by G. Van Etten and J. Pearce
Digital Cartography by M. Ticci

10/29/2010

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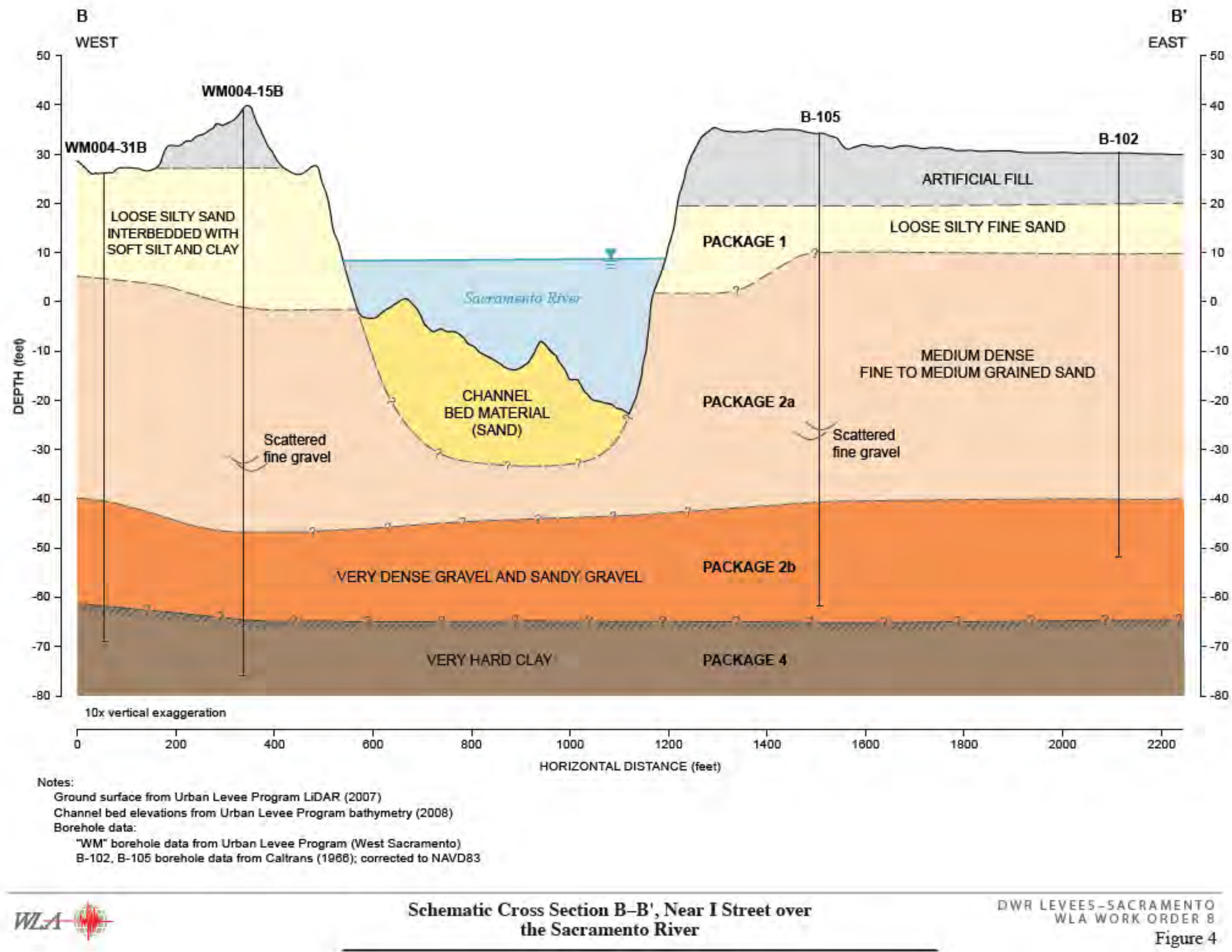


Figure 3-16 Geologic Cross Section at RM 59.5 I St Bridge (Fugro WLA 2012). See Figure 3-15 for Location of Cross Section Line. Note: View is Upstream (North) and the East Bank is on the right side of cross section.

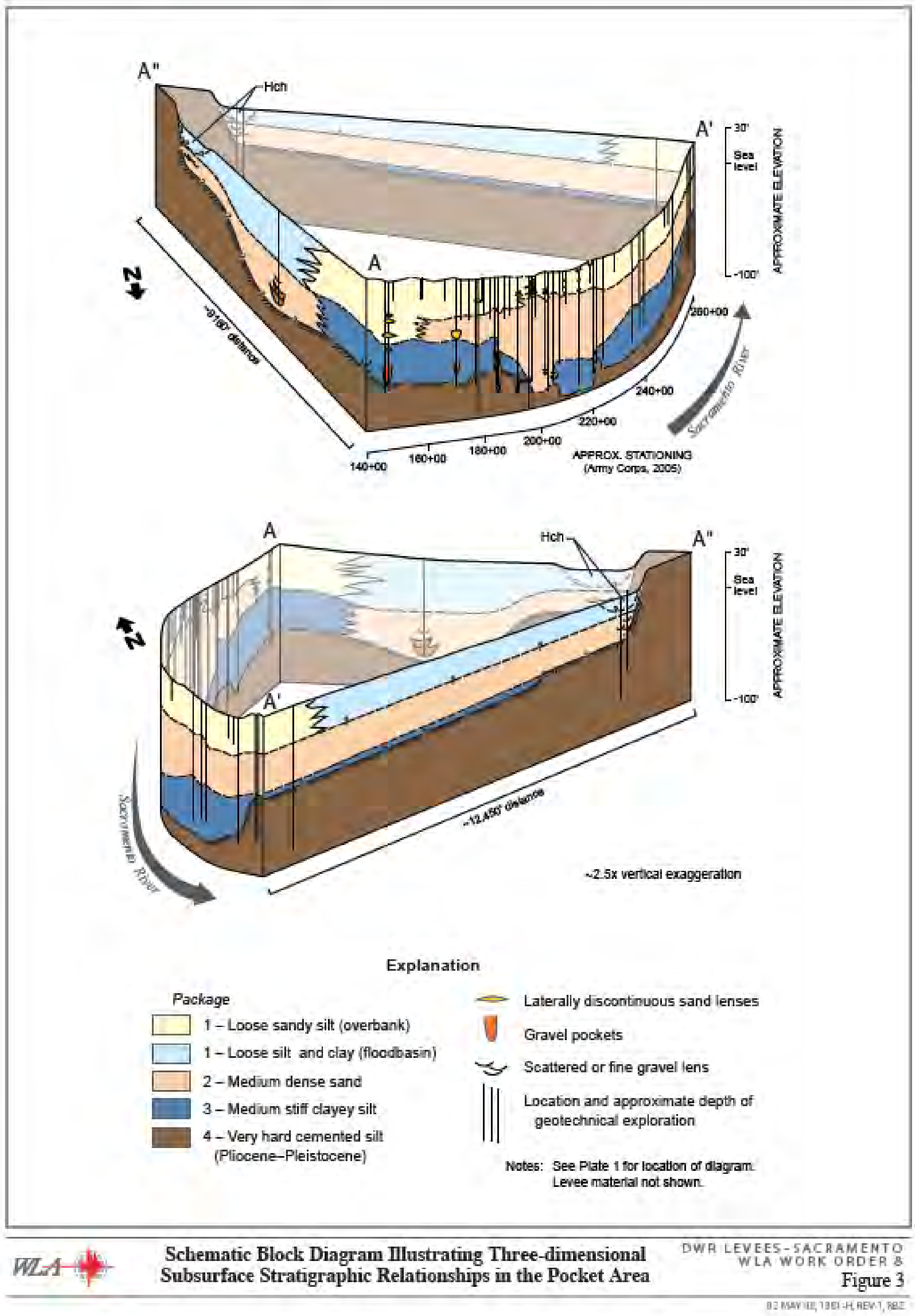


Figure 3-17 Geologic Profiles Along The Pocket Area (Fugro WLA 2012). See Figure 3-5 for Location of Section Lines.

Figure 3-18 Recent Sand Deposits Placed During High Flow Events Then Eroded By Subsequent Flows (RM 58.5 on May 14, 2019 Flow at 30,000 cfs) (Source: NHC 2019).

Figure 3-19 Burial and Exhumation of Cottonwood Trunks at RM 56.5 by Recent Overbank Sand Deposition and Erosion, May 14, 2019 (Flow at 30,000 cfs) (Source: NHC 2019).

3.9 Key Conclusions

A geomorphic assessment of the east bank of the Sacramento River from the American River confluence (RM 60) to Freeport (RM 46) has found a high degree of historical stability in channel pattern and width since the 1850s. Vertical stability underwent dramatic changes as a result of hydraulic mining sediments introduced in the 1860s. This filling or aggradation raised the bed at Sacramento by over 10 feet and, at its peak, to elevations well above and tidal influence. The aggradation began dissipating by the early 1900s and ended in the 1950s with channel bed elevations recovering to pre-1850 levels. Bed elevations are presently stable with year to year fluctuations on the order of several feet, due to sand wave movement and ephemeral scour hole development. Localized erosion has been an ongoing challenge since at least the 1930s, necessitating ongoing efforts of installing bank protection. Since the 1950s, erosion has been managed by close monitoring and piecemeal treatment of damaged banks or revetments. Based upon available evidence described in this report, no long term changes in ongoing geomorphic processes and resultant channel form are anticipated.

The most significant land use changes to the study area have been the construction of levees and the placement of fill close to the channel banks on the general alignment of the original natural levees. In many locations the waterside levee slope coincides with the bank slope and floodplain berms are limited. In some places, these slopes are unprotected or have older and undersized erosion protection materials. Over 80% of the east bank has been hardened due to the increased concentration of hydraulic force caused by levee raising and long periods of flows well above the critical threshold for erosion. The bank protection structures range from modern rip rap revetments (13 percent), to gunite walls, layers of cobble and broken concrete. Widespread erosion and placement of several thousand linear feet of modern rip rap in the mid 2000s, indicate ongoing progressive erosion and the need to closely monitor local reaches. Estimates of future climate change indicate a shift towards greater frequency and duration of potentially erosive flow events over the next 50 years.

Based upon available evidence and recent historical trends, no long term changes in large scale geomorphic processes and channel form are anticipated. However, local erosion is very important to monitor and address in a timely manner.

4 FLOOD EVENT BASED EROSION POTENTIAL BY SEGMENT

4.1 Overview

The purpose of this erosion assessment is to support meeting the American River Common Features GRR goal for the American and Sacramento River levee systems to reliably pass the maximum flood flow release from Folsom Dam of 160,000 cfs, an estimated once in 325 year annual chance of exceedance (1/325). This means identifying the locations where new or upgraded bank protection is needed to withstand the maximum event (115kcfs on Sacramento River) and future flood flows over the next 50 years. To accomplish this, NHC developed a methodology for the Sacramento River east bank levee system using quantitative estimates of erosion coupled with scientific and engineering judgement on the reliability of the existing levee and bank erosion protection system.

The flood event based erosion assessment methodology presented below is designed to test the resistance of the Sacramento River east bank levees to the anticipated erosional forces that could occur in next 50+ years. To accomplish this, 33 segments were discretized over the 14 mile study reach based upon the channel, bank and levee geometries, similar hydraulic conditions, revetment designs (if present), vegetation cover, and the presence or absence of a berm and its width. The end product is an overall erosion potential rating system of low, moderate and high for channel banks and levee waterside face. It was developed by:

1) Calculating the potential extent of scour and lateral erosion and proximity to the levee structural prism.
2) Rating the likelihood of the estimated erosion to occur given the resistance of soil materials, existing revetments and/or vegetation to scour and fluvial erosion.
3) Combine the results with the Section 3 geomorphic analysis conclusions to yield overall erosion potential ratings.

The erosion assessment background information, data, calculation results, and ratings for each segment is provided in Appendix A. This information will be used by the EOE review committee to select segments for new bank protection; the ultimate construction project locations could be whole or parts of segments.

Sacramento Area Flood Control Agency

northwest hydraulic consultants

Legend

● USGS RM

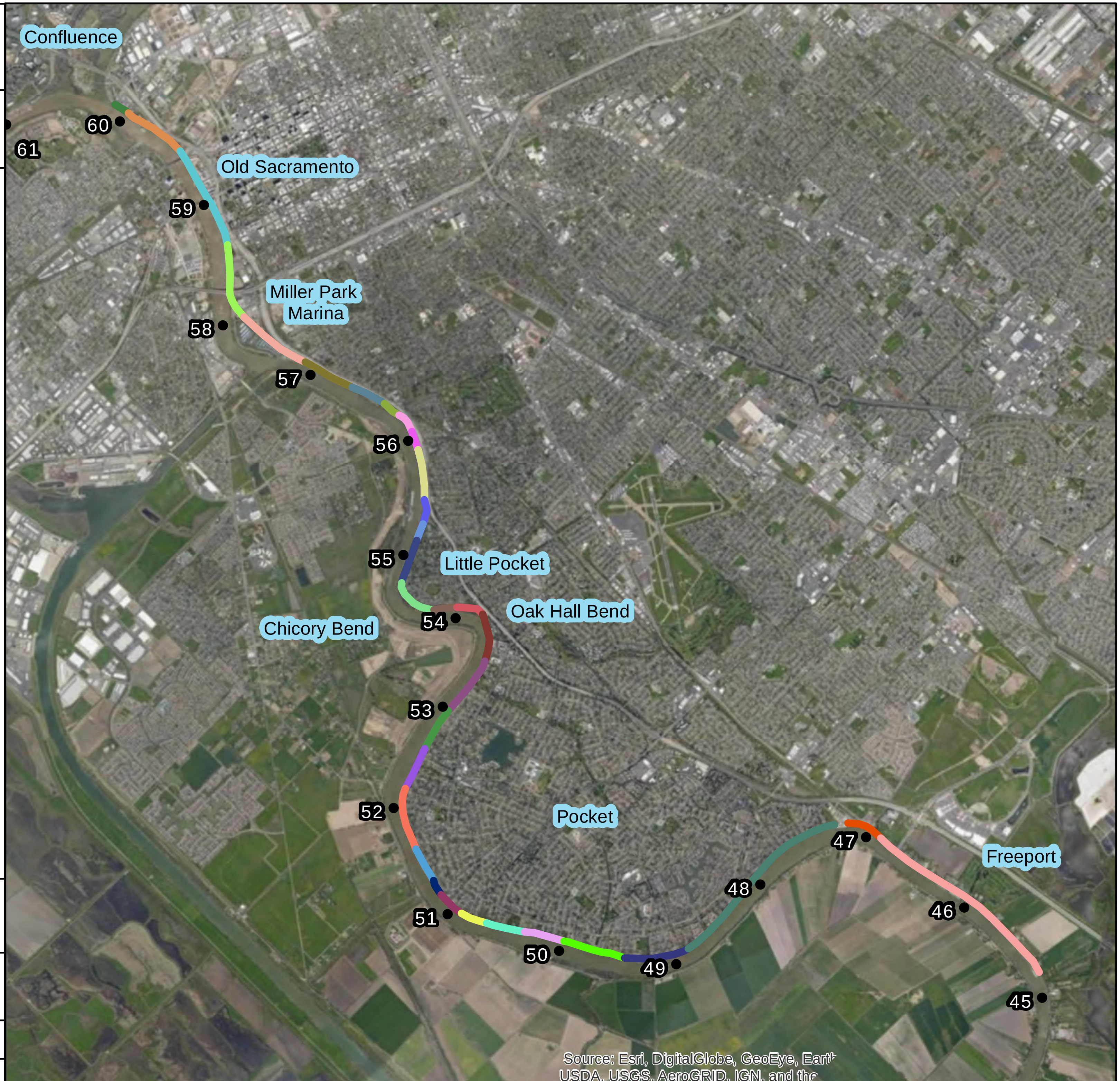
Sac River Segments

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33

Landmark

Scale = 1:90,000

0 5,000 10,000 Feet



Sacramento River Erosion Assessment

Segment Characterization Map

FIGURE 4-1

Job: 5004539	Date: JULY 2019

4.2 Flood Event based Erosion Extents Calculations

The erosion calculations for estimating erosion extents for each segment focused on three primary erosional processes working on channel banks and levees: toe of slope (bank and levee) scour, fluvial erosion and mass slope failure.

4.2.1 Scour at Bank Toe and Levee Toe

Bank erosion often occurs by progressive erosion and undermining of the channel bank toe followed by upper bank mass slope failure during flood conditions. The consequences of scour are an increase in bank height and steepness, which increases the potential for mass slope failure. If slope failure occurs, it can instantly reduce or eliminate the berm (if present), expose unvegetated and/or unrevetted soil to hydraulic forces and expand erosion significantly. Without slope failure, protective vegetation cover and/or revetment on the slope face could withstand toe scour, remain intact and provide resistance to fluvial erosion.

Scour is defined as the temporary lowering of the channel bed and banks during flood conditions due to increasing hydraulic and erosive force. It is an important yet complex process involving hydraulics, channel bed materials, geotechnical materials at depth, sediment transport and location within the river channel planform. Banks on the outside of bends on meandering rivers experience greater force than the inside while straight reaches tend to have hydraulic force evenly distributed across the channel. The depth of scour primarily depends on the hydraulic force working against the resistance of channel bed and bank materials and underlying materials at depth. Alluvial channels, which have self forming boundaries, are prone to expansion in width and depth and channel flow area in order to carry more flow and to reduce velocities. The Sacramento River in the study area is generally stable in width (although progressively eroding) but with a fine grained and erodible sand dominated bed, which favors deepening (scour) over widening. In some cases, scour can be limited by the inflow of sediments from upstream and/or by erosion resistant materials at depth. Scour is a short term peak flood event phenomena (hours or days) in contrast with longer term (years or decades) channel bed degradation or incision due to geomorphic factors.[4]

The flood event based scour used here is referred to as natural or general scour[5] which is what occurs across the channel in response to increases in hydraulic force as flood magnitude increases. The concept of an “equilibrium” or “regime” channel geometry dates back to the 1930s when expansion of agriculture required unlined canals to be dug over long distances within erodible materials. It was found that for a given slope, the channel would adjust its size to a given discharge based upon hydraulic,

[4] The conclusion of Section 3 found that no long term channel change is anticipated in the next 50 years.

[5] There are other types such as local scour associated with natural (e.g. large wood or boulders) or artificial hydraulic structures (bridge abutments and piers, etc). Pier and abutment scour are associated with bridges.

materials and planform factors such as river bends and abrupt expansion or contraction of channel width or depth.

Prediction of scour depths along the channel bed and toe of river banks is a difficult problem. For the Sacramento River, channel width is generally controlled and not subject to great fluctuations. The channel bed however has a highly mobile sand bed which appears as actively moving sand waves. Based upon examination of previous reports and geotechnical data, the erodible, modern unconsolidated in transit sands on the bed range up to 30 – 50 feet thick. Scour deeper than modern sands is possible as underlying older sediments are generally fine, unconsolidated and erodible. Bathymetric measurements taken after the 1997 flood (117,000 cfs at Freeport USGS gage) found scour holes as deep as -60.0 feet below sea level (See Figure 3-12 at RM 54.5). Previous estimates of channel scour depth made by NHC (2005 and 2007) ranged between -10 and – 50 feet.

Similar challenges are found with calculation of scour depth at the toe of levee. Although hydraulic force is less than that in the channel, flow depths over 20 feet are common and levee and foundation materials are fine (silty sands). While adequate grass cover and rip rap can withstand the forces, the actual cover as observed in the field is highly variable and the presence of extensive rip rap along the waterside levee face, even where there is relatively wide berm, attests to the potential hazards.

For this study, methods were used:

1) USACE (1994) EM 1110-2-1601 regime scour method.
2) Blench regime scour equation.

USACE EM – 1110-2-1601 Scour Method

The USACE uses a regime based empirical method that calculates general scour and uses a "scour multiplier" factor to account for channel curvature at bends as follows (using chart in Figure 4-2):

1) The ratio of the centerline radius of the bend measured from aerial photographs and water surface width at the representative segment cross section location from 2018 lidar bathymetry survey was calculated for each discharge (50 kcfs, 100 kcfs, 110 kcfs and 115 kcfs).

2) The mean water depths for the straight channel sections located just upstream of the bends of interest were taken from the HEC RAS model.

3) Scour multipliers were determined using Figure 4-2. The bend-radius-to-channel-width ratio values of step 1 on the x axis are aligned to intersect with the line in the center of Figure 4-2. This yields the y-axis values or scour multiplier from the ratio of maximum water depth in the bend to mean water depth in the straight approach channel ratio (Figure 4-2 Plate B-41). Scour multipliers for the study area range from 2.0 to 3.0.

4) The scour multiplier of step 3 is then multiplied by the mean water depth in the straight approach channel to yield the maximum water depth in the bend. Finally, subtracting the maximum water depths from the water surface elevations gives the peak scour bed elevation at the toe.

This method was used to project the peak flow scour elevation of the waterside levee toe and bank toe for each segment. The EM 1110-2-1601 is a design curve which generally produces conservative results relative to observed data (See line in Figure 4-2 below). This produces a conservative estimate of scour depths. The results are found in Appendix A.

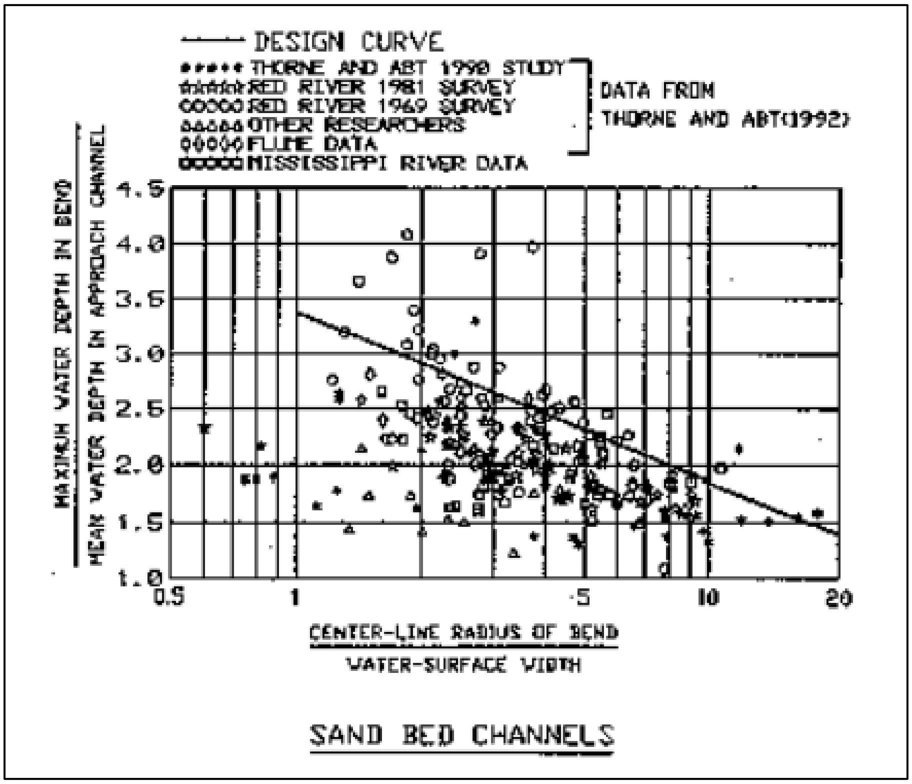


Figure 4-2- Plate B-41: Scour Depth in Bends from USACE (1994).

BLENCH SCOUR REGIME EQUATION

The Blench method as recommended by the US Department of Interior Bureau of Reclamation (1984) uses the following methodology (See Figure 4-3 for accompanying charts).

1) First, the mean discharge intensity (q) is calculated as q = Q/b where q = discharge intensity, Q = flood flow, and b = the average channel width measured from cross sections taken from the 2018 lidar data at a moderate flood stage where most of the hydraulic force is concentrated. This excludes low velocity areas along the fringes of the maximum flood stage.

2) The average flood depth with scour is then calculated as $d = (q^2/F_b)^{1/3}$; where d = average depth, and F_b is the bed factor, and q is from step 1. The bed factor, F_b, is 0.5 for fine sand and 1 for medium sand. For this study, 0.75 was selected.

3) To yield maximum scour depths, the average flood depths from step 2 were multiplied by the zero bed "z-factor" to account for the variation in channel depth expected by location within a river reach. The values vary from 1.00 for the inside of bends, 1.25 for straight reaches to 2.0 for sharp-angled bends.

4) Subtract maximum scour water depth from water surface elevation to yield scour elevation.

and the Blench equation for "zero bed factor":

$$d_{fo} = \frac{q_f^{\ 2/3}}{F_{bo}^{\ 1/3}} \qquad (27)$$

where:

d_{fo} = Depth for zero bed sediment transport, ft (m)
q_f = Design flood discharge per unit width, ft^3/s per ft (m^3/s per m)
F_{bo} = Blench's "zero bed factor" in ft/s^2 (m/s^2) from figure 9

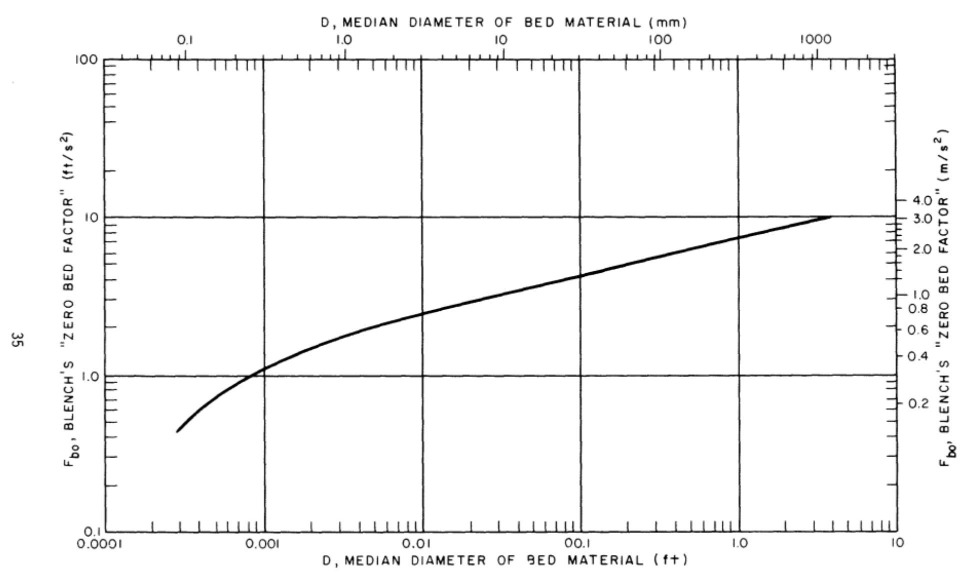


CHART FOR ESTIMATING F_{bo} (AFTER BLENCH)

Figure 9. - Chart for estimating F_{bo} (after Blench, 1969).

Figure 4-3- Figures from US Department of Interior Bureau of Reclamation (1984).

The scour calculation results for the two methods for channels are shown in Figure 4-4 and are summarized in Appendix C. The USACE method usually provides more conservative results but there are wide variations. The Blench equation yielded more consistent results and were used as toe scour values for bank slope stability and erosion extents.

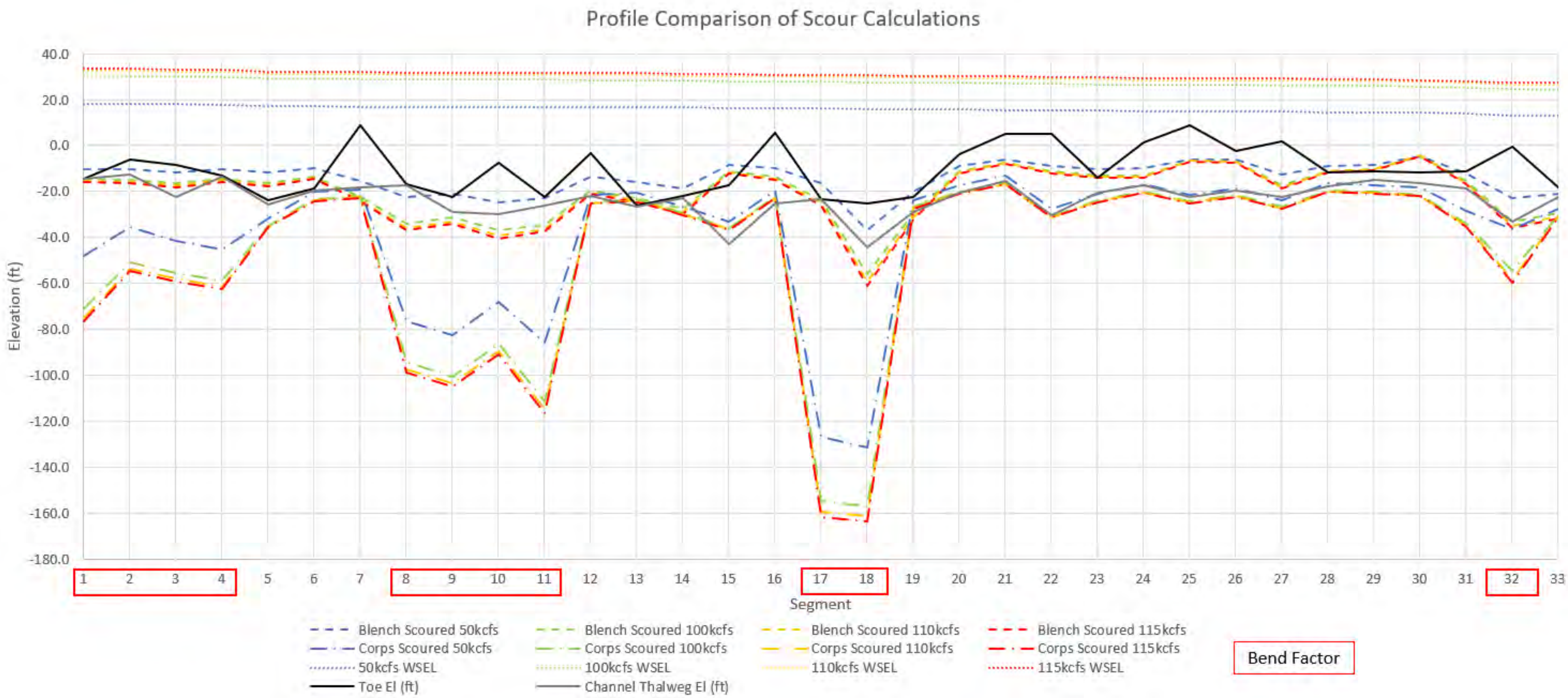


Figure 4-4 – Sacramento River Longitudinal Plot of Channel Bed and Scour Calculations.

4.2.2 Fluvial Erosion

Fluvial erosion refers to the detachment of soil particles away from bank, levee, and/or bed material by the hydraulic force of flow and shear stress. Erosion is a function of the hydraulic shear stress exerted by the flow and the ability of the surface material to resist it. Shear stress is a function of the flow depth and velocity. The ability of the bank to resist erosion is dependent on the bank material, and can be increased with protection provided by vegetation or revetments.

The hydraulic shear stress used here to estimate erosion was computed using output from the HEC RAS model as discussed in Section 2.5. The critical shear strength of the surficial covering of the slope and underlying soil were evaluated independently based on the material type and quality (vegetation cover or rip rap rock size and type).

For the surficial covering, three different types of materials were identified: grass, woody riparian trees and shrubs, and riprap. The predominant material covering the lower third of the slope is used to determine critical shear stress of the surficial covering. Table 4-1 shows the critical shear stress for each material. The reduction of strength is a function of type of vegetation and quality of coverage. The critical shear stress assigned to grass was conservatively estimated for a poor grass after a long flow duration.

Table 4-1. Critical Shear Stresses of Bank Material Coverings.

Material Type	Range of Critical Shear Stresses in Fischenich	Critical Shear Stress used in Erosion Assessment
Grass	1.0 psf -3.7 psf (after 100 hours of exposure to flow)	1.0 psf
Woody Riparian Vegetation	0.41 psf – 2.5 psf	1.5 psf
Riprap		2.5 psf

The critical shear stress for the soil was determined using Fischenich (2001) reporting shear thresholds for various types of materials. Based upon the bank soil type, a general field assessment of cohesiveness (colloidal), field verification of approximate grain size, and a review of blow counts where available in the boring logs, an analog material in Fischenich (2001) was used to identify an approximate critical shear stress for bank and levee material. Critical shear stress and erodibility of material is strongly based on bulk density.

The predominate bank materials along Sacramento River East bank (Table 4-2) are silty sands. Examination of boring logs taken along the levee centerline reveal predominately silty sands (with low blow counts less than 25) with discontinuous lenses of coarser sands, minor gravels. Downstream of the Sutterville area (RM 56), some more resistant clay rich or partially lithified units are found, but silty sands still dominate.

Table 4-2. Critical Shear Stress of Different Bank Materials along east bank Sacramento River.

Soil Type	Critical Shear Stress (psf)	Fishenich (2001) Comparable Material(s)
Silty Sand for Channel banks and bed	0.045	Alluvial silt (non colloidal) (0.045 psf-0.05 psf)
Fill for levees	0.05	Alluvial silt (non colloidal) (0.045 psf-0.05 psf)
Sand (for comparison)	0.04	Sandy loam (non colloidal) (0.03 psf-0.04 psf)

4.2.3 Slope Failure Potential

The potential for slope failure and risk to the levee is based on the steepness of the levee waterside slope and bank slope during non-flood and peak flood periods with scour conditions. Non-cohesive sand and silt sized sediments typically have an angle of repose of about 32 degrees or 1.5 horizontal units to 1 vertical unit (1.5H:1V) slope. Material cohesion by clay content, compaction or other factors allows for steeper slopes but is hard to quantify for non-uniform materials. Figure 4-5 graphically shows the estimated scour adjusted bank and levee slopes with peak flood scour. Bank slope failure potential is rated using the 1.5:1 as a threshold for slope failure with and without the bank toe lowered by scour.

The conceptual drawing in Figure 4-5 shows that the scour adjusted profile for the levee waterside slope shows encroachment into the levee prism, typically a threshold for treatment. The scour adjusted profile for the channel bank does not show encroachment.

4.2.4 Lateral Erosion Extents

The single event lateral erosion extents values represent the length of lateral erosion extent into the bankline and levee waterside face. This method follows closely the approach taken in the DWR Erosion Screening Process (URS 2009) to calculate erosion. The difference between the applied shear stress, τ, and the critical shear stress of the bank soil, τ_c, is multiplied by an erodibility coefficient, *K*, and duration of event, *D (in hours)*, to determine a length of erosion into the bankline or levee waterside face, E_L.

$$E_L = K(\tau - \tau_c)D \qquad \text{(Equation 4)}$$

The DWR ESP methodology (URS 2009) provides a range of erodibility coefficients from literature. These values are provided in Table 4-3 below. The erodibility coefficient is variable with the type of soil and strongly dependent on the bank soil bulk density, and pore water pressure. The most appropriate erodibility coefficient was based upon available data on the bank and levee material types (always silty sand for banks and fill for levees).

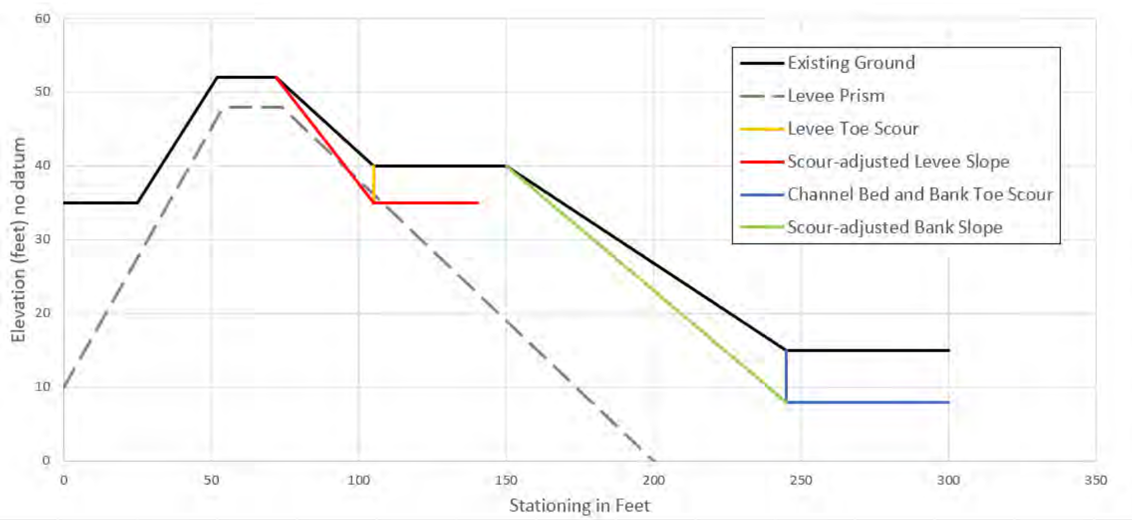


Figure 4-5. Conceptual Figure for Determining Slope of Levee and Bank Surface after Scour has Occurred. (note: the 1.5H:1V threshold is exceeded in some segments under existing conditions without scour).

Table 4-3. Erodibility Coefficients Assigned By Soil Type (URS, 2009).

Material	ASTM Typical Soil Type	Erodibility Coefficient (K) (ft^3/lb-hour)
Very Resistant	Boulders and Cobbles	0.005
Resistant	Gravel (GP-GW)	0.021
Moderately Resistant	Clay (CL, CH, SC, GC) and silt (ML, MH) with liquid limit higher than 35	0.094
Erodible	Sand (SP, SM, and mixtures), clayey silt (CL-ML), and low plasticity silt with liquid limit between 25 and 35 and a plasticity index of 7 or less	0.409 used for low estimated lateral erosion
Very Erodible	Sandy Silt with Liquid Limit 25 or less, and a plasticity index of 4 or less	1.867 used for high estimated lateral erosion

Storm hydrographs for n-year (e.g. n = 1/325, 1/100, etc) storms were provided by the USACE in July 2019 (See Table 2-1). The hours of duration of n-year storms was taken from the HEC-RAS 1D model except for 50,000 cfs which is the projected median number of days with the new Folsom Dam Water Control Manual hydrology.

For channel banks and the levee waterside slope, the single event lateral erosion calculations provide a range of low and high erosion estimates. The low erosion estimate uses the mean channel shear stress from the HEC RAS 1D model output and a low end value of 0.409 erodibility coefficient (Table 4-3) for the expected silty sand soil. The high erosion estimate uses a higher shear stress calculated using the maximum flow depth at the thalweg (deepest part of the channel) and a higher erodibility coefficient of 1.867 for silty sand (Table 4-3).

4.2.5 Eroded Bank and Levee Profiles

Bank and levee profile plots using existing topography and bathymetry were created to analyze the sum of scour and lateral erosion at each segment. The main objective is assess whether the levee structural prism is presently compromised or could be affected by project scour and lateral erosion. These plots were also used to examine whether a slope stability threshold of 1.5H:1V is exceeded under existing or with scour conditions.

A typical cross-section plot for each segment, from the landside levee toe to about the channel centerline, was cut from the 2018/2008 topography/bathymetry data. The minimum levee prism (see Section 1.3 Figure 1-2) aligned with the center line of the levee crown was plotted onto each cross-section. The existing levee and bank slopes were than vertically translated downward to the maximum scour depth (Section 4.3.2), then horizontally translated for the maximum erosion length (Section 4.3.5) and finally compared to the minimum levee template (See Figure 4-6 for example). Events where the extents impinged into the levee prism were identified.

nhc

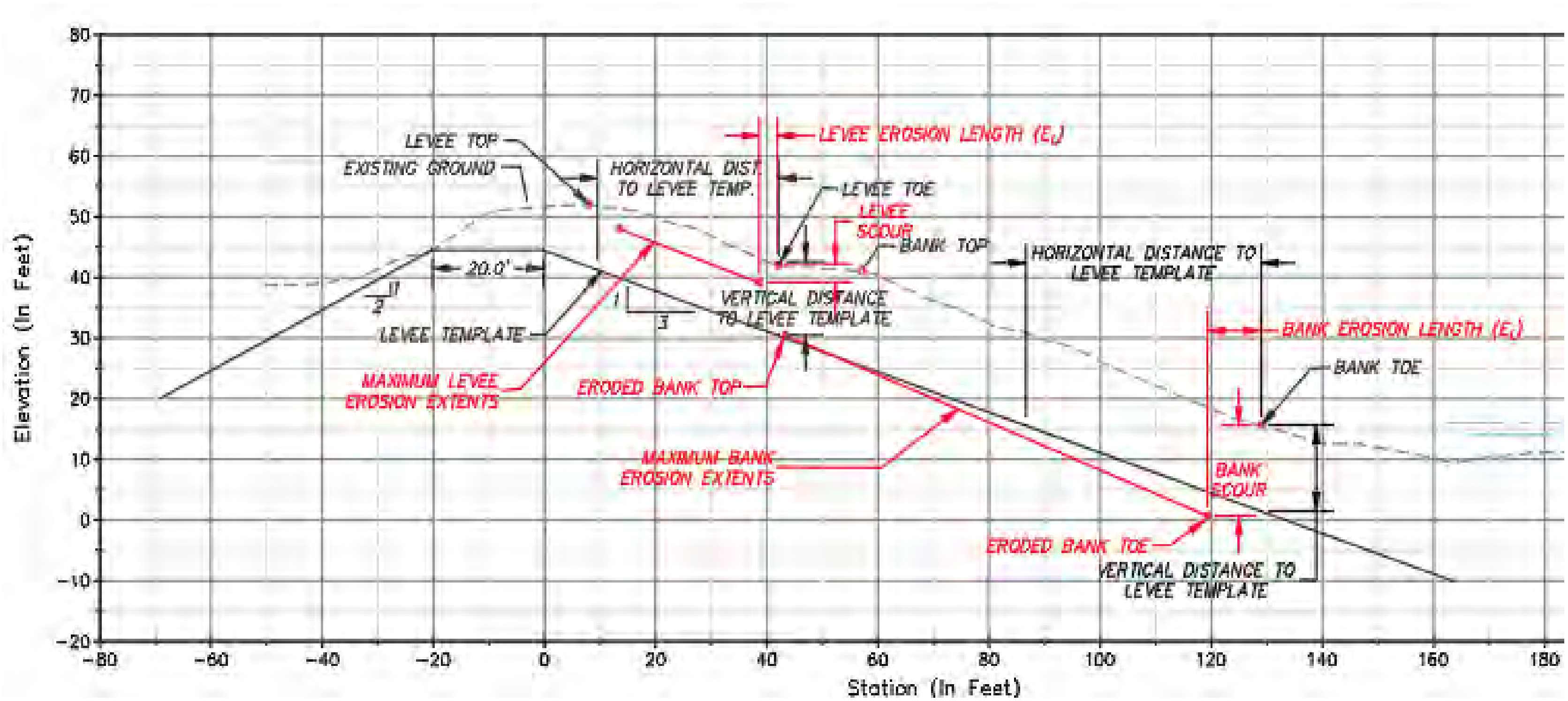


Figure 4-6. Cross-section showing maximum bank erosion extents as computed for a single flow event at the bank and at the levee face. In this example, the bank erosion encroaches into the minimum levee template, but the levee erosion does not.

4.3 Segment Analysis

The segment analysis examines local site factors that influence the likelihood that the computed erosion extents will occur and yields an overall low, moderate or high potential erosion ratings. The projected erosion extents are raw estimates using only materials and hydraulic force factors. In order to account for local site specific conditions that can increase or decrease erosion, each segment was further evaluated by rating four key factors in a stepwise manner:

1) Erodibility of bank and levee materials.
2) Erosion resistance provided by vegetation and protection structures.
3) Slope Failure Susceptibility.
4) Overall erosion potential.

The details and results are provided below.

Step 1: Erodibility: Erodibility qualifies as the ability of the surface flow force to erode the bank/levee material without consideration of the presence or absence of the surficial erosion resistance elements, such as vegetation or riprap. It is qualified based on the estimated shear stress applied by the flow, and the estimated shear strength of the bank/levee materials. Applied shear stress, computed using results of the hydraulic model, can increase locally due to turbulence by presence of hard structures, strong velocity gradients, and/or angular impingement of flow into slope surface (such as on the outside of a bend). Erodibility was qualified as:

- **High:** High erodibility where the applied shear stress exceeds the shear strength of the soil, and entrainment would be expected to occur if no protection is present.
- **Moderate:** Moderate erodibility where the applied shear stress does not exceed the shear strength of the soil, but turbulent conditions that could increase local shear may cause entrainment.
- **Low:** Low erodibility where the applied shear stress does not exceed the shear strength of the soil, and turbulent conditions are not expected to occur.

Step 2: Erosion Resistance: Erosion resistance accounts for the effect of surficial protective cover such as vegetation, rip rap, and/or underlying erosion resistant layers. The erosion resistance at a segment is qualified by the type of material (rock, cobble, etc.), its adequacy to resist erosion, as well as the percent of protective cover and quality of the surficial covering.

The adequacy of the material to resist erosion is determined by using the results from the hydraulic model. For angular rock, the existing rock size is compared to expected stable rock sizes that are calculated with applicable USACE design equations for the given hydraulic conditions. For cobble, the stability is evaluated by comparing the computed applied shear stress to critical shear based on the cobble size. For vegetation, the resistance is a function of the computed applied shear stress, type of vegetation, a critical shear strength assigned to the vegetation type from published values in Fischenich (2001) and field observations.

The quality of the surficial covering is a qualitative assessment of the quality and overage of protective rock and vegetation. Areas of rip rap and cobble armor that are only one rock diameter thick or which does not completely cover the protected area, erode and fail by allowing material to be winnowed underneath or from between individual rocks. Although rock may be unlikely to move, erosion of underlying material may still occur and compromise the armoring and bank/levee face. Similarly, patchy vegetation may have exposed areas that could be eroded and lead to bank failure. Erosion resistance is qualified as:

- **Good:** Good erosion resistance identifies locations where riprap or cobble armor of adequate size and thickness exists to resist expected hydraulic forces and/or where vegetation of adequate type and cover exists to resist expected hydraulic conditions. Erosion, scour or slope failure is not expected to occur.
- **Fair:** Fair erosion resistance identifies locations where hydraulic conditions are equal to or less than the expected critical shear strengths of the existing resistance, but where resistance may be compromised due to inadequate covering. Erosion may occur at locations where fair resistance exists.
- **Poor:** Poor erosion resistance identifies locations where hydraulic conditions exceed the expected critical shear strength of the existing resistant material. Erosion is expected to occur at locations with poor resistance.

Step 3 Overall Slope Failure Susceptibility: Overall slope failure susceptibility qualifies the likelihood of mass failure of the bank and/or levee slope with consideration of toe scour. The overall slope susceptibility is determined by two factors: 1) Step 3A slope failure potential and 2) Step 3B scour resistance.

Step 3A Slope Failure Potential: Slope failure potential refers to the potential for geotechnical mass failure of the bank/levee segment due to over-steepening. Slope failure potential was determined by analyzing slope stability for a bank/levee cross-section with the maximum estimated peak flood flow scour depth at the toe of the bank and/or levee. No adjustments were made for cohesive sediments or vegetation root strength. Slope failure potential is qualified as:

- **High:** High slope failure potential identifies bank/levee segments where scour depths are likely to compromise geotechnical stability of the bank and/or levee slopes. These segments are locations where either the existing slope or potential scour will create a bank slope steeper than 1.5H:1V.
- **Moderate:** Moderate slope failure potential identifies bank/levee segments where scour depths may deteriorate geotechnical stability of the bank and/or levee slopes. These segments are locations where the existing slope has shown indications of stress (tension cracks in soils, etc.) or instability, or where additional loading (such as undercut trees) exist.
- **Low:** Low slope failure potential identifies bank/levee segments where scour is unlikely to deteriorate geotechnical stability of the bank and/or levee slopes. These segments are locations where either the existing slope or potential scour will create a bank slope of 1.5H:1V or flatter, and which do not show indications of stress or additional loading near the top of the bank.

Step 3B Scour Resistance: Scour resistance qualifies the ability of the surficial covering of the bank/levee toes to resist scour. The surficial covering is typically either natural bank material, or bank protection angular quarry rock used as rip rap, cobble, etc. The scour resistance at a segment is qualified on the type of material, the adequacy to resist scour, and the quality of the surficial covering.

The adequacy of the material to resist scour is determined using the results from the hydraulic model. For angular rock, the existing rock size is compared to expected stable rock sizes calculated with applicable USACE design equations for the given hydraulic conditions. For cobble, the stability is evaluated by comparing the computed applied shear stress to critical shear determined based on the cobble size. For natural bank conditions (i.e. sandy and silty soils), the scour resistance is assumed to be minimal unless an erosion resistant layer is mapped along the toe.

The quality of the surficial covering is a qualitative assessment of ground cover. Rip rap and cobble armor, which does not extend below the maximum scour depth or does not have enough volume to fill a scour hole, should not be relied upon to resist scour. Scour resistance is qualified as:

- **Good**: Good scour resistance identifies locations where riprap or cobble armor of adequate size and thickness exists to resist expected hydraulic forces, or where the erosion resistant layer is at the toe of the bank preventing scour.
- **Fair:** Fair scour resistance identifies locations where riprap or cobble armor of adequate size exists, but not keyed into adequate depths or with adequate volume to launch into scour holes. Scour holes may form at these segments under the right conditions.
- **Poor:** Poor scour resistance identifies locations where the toe of the bank and/or levee does not have material of adequate size or volume to resist scour. Scour is likely to occur at these locations.

With consideration of scour and slope stability, the **overall slope failure susceptibility** (Table 4-4) is qualified as:

- **High:** High overall slope susceptibility identifies segments with **High Slope Failure Potential** and either **Fair** or **Poor Scour Resistance.**
- **Moderate:** Moderate overall slope susceptibility identifies segments with **Moderate Slope Failure Potential** and either **Fair or Poor** scour resistance.
- **Low:** Low overall slope susceptibility identifies segments with **Low Slope Failure Potential** and segments with **Good scour resistance.**

Table 4-4. Overall Slope Failure Susceptibility ratings matrix with result in gray cells.

Scour Resistance	Slope Failure Potential		
	Low	Moderate	High
Good	Low	Low	Low
Fair	Low	Moderate	High
Poor	Low	Moderate	High

Step 4: Overall Erosion Potential: The overall erosion potential qualifies the likelihood of the segment to be susceptible to erosion including scour. It couples the erosion potential, erosion resistance, and slope failure susceptibility. If the slope failure susceptibility is moderate or high, the erosion resistance is not considered in the overall erosion potential. Overall erosion susceptibility qualifies as:

- **High Overall Erosion Potential:** segments with either 1) **High Slope-Failure Susceptibility** and **High** or **Moderate Erodibility,** or 2) **Moderate** or **Low Slope-Failure Susceptibility** with **High Erosion Potential** and **Poor** or **Fair Erosion Resistance.**
- **Moderate Overall Erosion Potential:** Moderate overall erosion potential identifies segments with either 1) **Moderate Slope-Failure Susceptibility** and **Moderate Erodibility,** 2) **Moderate Overall Slope-Failure Susceptibility** and **High Erosion Potential** and **Good Erosion** Resistance, or 3) **Low Overall Slope-Failure Susceptibility** with **Moderate Erosion Potential** and **Fair** or **Poor Erosion Resistance.**
- **Low Overall Erosion Potential:** Low overall erosion potential identifies segments with **Low Erodibility.**

Table 4-5 reviews the erosion potential ratings matrix.

4.4 Summary

The detailed data and results of the event based erosion analysis is presented for each segment of the 33 segments in Appendix A and Section 5. Table 4-6 shows overall bank erosion potential and identifies whether the scour alone or maximum combined lateral erosion and scour would impinge into the levee prism. Table 4-7 shows the same information for the overall erosion potential of levees.

Figures 4-4 through 4-7 show the overall levee and bank erosion potential for flows of 50 kcfs, 100 kcfs, 110 kcfs and 115 kcfs. The details and highlights of the ratings and site specific factors is provided in Section 5. 18 of the 33 segments analyzed were rated high for overall bank erosion potential at locations where the levee prism has already been encroached or could be impinged in the near future. Four segments were found to be rated high for erosion potential at the levee and projected to impinge on the levee prism.

Table 4-5. Overall Erosion Potential Rating Determination Matrix. To Obtain Overall Erosion Potential, Read Columns 1 through 4 from Left to Right in Following steps: 1) Find the Appropriate Row for the Erodibility of Bank Materials at a Segment, 2) Select the Appropriate Row for the Erosion Resistance Rating, 3) Select the Appropriate Row Containing the Slope-Failure Susceptibility, then 4) Identify the Overall Erosion Potential.

Erodibility 1	Erosion Resistance 2	Slope-Failure Susceptibility 3	Overall Erosion Potential 4
Low	Good	Low	Low
		Moderate	Low
		High	Low
	Fair	Low	Low
		Moderate	Low
		High	Low
	Poor	Low	Low
		Moderate	Low
		High	Low
Moderate	Good	Low	Low
		Moderate	Moderate
		High	High
	Fair	Low	Moderate
		Moderate	Moderate
		High	High
	Poor	Low	Moderate
		Moderate	Moderate
		High	High
High	Good	Low	Low
		Moderate	Moderate
		High	High
	Fair	Low	High
		Moderate	High
		High	High
	Poor	Low	High
		Moderate	High
		High	High

Table 4-6. Summary of potential for bank erosion and maximum erosion extents relative to minimum levee template.

Segment		50 kcfs		100 kcfs		110 kcfs		115 kcfs	
		Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?
Left Bank	1	High	Yes	High	No	High	No	High	No
	2	High	Yes	High	Yes	High	Yes	High	Yes
	3	Low	Yes	Low	Yes	Low	Yes	Low	Yes
	4	High	Yes	High	Yes	High	Yes	High	Yes
	5	High	No	High	No	High	No	High	No
	6	Low	Yes	Low	Yes	Low	Yes	Low	Yes
	7	High	No	High	No	High	No	High	No
	8	High	Yes	High	No	High	No	High	No
	9	High	Yes	High	No	High	No	High	No
	10	High	Yes	High	Yes	High	Yes	High	Yes
	11	High	Yes	High	Yes	High	Yes	High	Yes
	12	High	No	High	No	High	No	High	No
	13	High	Yes	High	Yes	High	Yes	High	Yes
	14	High	Yes	High	Yes	High	Yes	High	Yes
	15	Low	No	Low	No	Low	No	Low	No
	16	High	Yes	High	Yes	High	Yes	High	Yes
	17	High	No	High	No	High	No	High	No
	18	Low	Yes	High	Yes	High	Yes	High	Yes

Segment	50 kcfs		100 kcfs		110 kcfs		115 kcfs	
	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?
19	High	Yes	High	Yes	High	Yes	High	Yes
20	High	Yes	High	Yes	High	Yes	High	Yes
21	High	Yes	High	Yes	High	Yes	High	Yes
22	High	Yes	High	Yes	High	Yes	High	Yes
23	High	Yes	High	Yes	High	Yes	High	Yes
24	High	Yes	High	Yes	High	Yes	High	Yes
25	High	Yes	High	Yes	High	Yes	High	Yes
26	High	Yes	High	Yes	High	Yes	High	No
27	High	Yes	High	Yes	High	Yes	High	Yes
28	Low	No	Low	No	Low	No	Low	No
29	High	Yes	High	Yes	High	Yes	High	Yes
30	High	No	High	No	High	No	High	No
31	High	Yes	High	Yes	High	Yes	High	Yes
32	Low	No	Low	No	Low	No	Low	No
33	High	Yes	High	Yes	High	Yes	High	Yes

Table 4-7. Summary of potential for levee erosion and maximum erosion extents relative to minimum levee template.

Segment		50 kcfs		100 kcfs		110 kcfs		115 kcfs	
		Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?
Left Bank	**1**	Low	No	Low	No	Low	No	Low	No
	2	Low	No	Low	No	Low	No	Low	No
	3	Low	No	Low	Yes	Low	Yes	Low	Yes
	4	Low	No	Low	No	High	No	High	No
	5	Low	No	Low	No	Low	No	Low	No
	6	Low	No	Low	Yes	Low	Yes	Low	Yes
	7	Low	No	Low	No	Low	No	Low	No
	8	Low	No	Low	No	Low	Yes	Low	Yes
	9	Low	No	Low	Yes	High	Yes	High	Yes
	10	Low	No	High	Yes	High	Yes	High	Yes
	11	Low	No	Low	No	Low	No	Low	No
	12	Low	No	Low	No	Low	No	Low	No
	13	Low	No	Low	No	Low	No	Low	No
	14	Low	No	Low	No	Low	No	Low	No
	15	Low	No	Low	No	Low	No	Low	No
	16	Low	No	Low	No	Low	No	Low	No
	17	Low	No	Low	Yes	Low	Yes	High	Yes
	18	Low	No	Low	No	Low	Yes	High	Yes

Segment	50 kcfs		100 kcfs		110 kcfs		115 kcfs	
	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?	Erosion Potential	Extents Impinge Levee Template?
19	Low	Yes	Low	Yes	Low	Yes	Low	Yes
20	Low	No	Low	No	Low	No	Low	No
21	Low	No	Low	No	Low	No	Low	Yes
22	Low	No	Low	No	Low	No	Low	No
23	Low	No	Low	No	Low	No	Low	No
24	Low	No	Low	Yes	Low	Yes	Low	Yes
25	Low	No	Low	No	Low	No	Low	No
26	Low	Yes	Low	Yes	Low	Yes	Low	Yes
27	Low	No	Low	No	Low	No	Low	No
28	Low	No	Low	No	Low	No	Low	No
29	Low	No	Low	No	Low	No	Low	No
30	Low	No	Low	No	Low	No	Low	No
31	Low	No	Low	No	Low	No	Low	No
32	Low	No	Low	No	Low	No	Low	Yes
33	Low	No	Low	No	Low	No	Low	No

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Legend

- ○ Segment Endpoints - Bank
- ◇ Segment Endpoints - Levee
- ● USGS RM

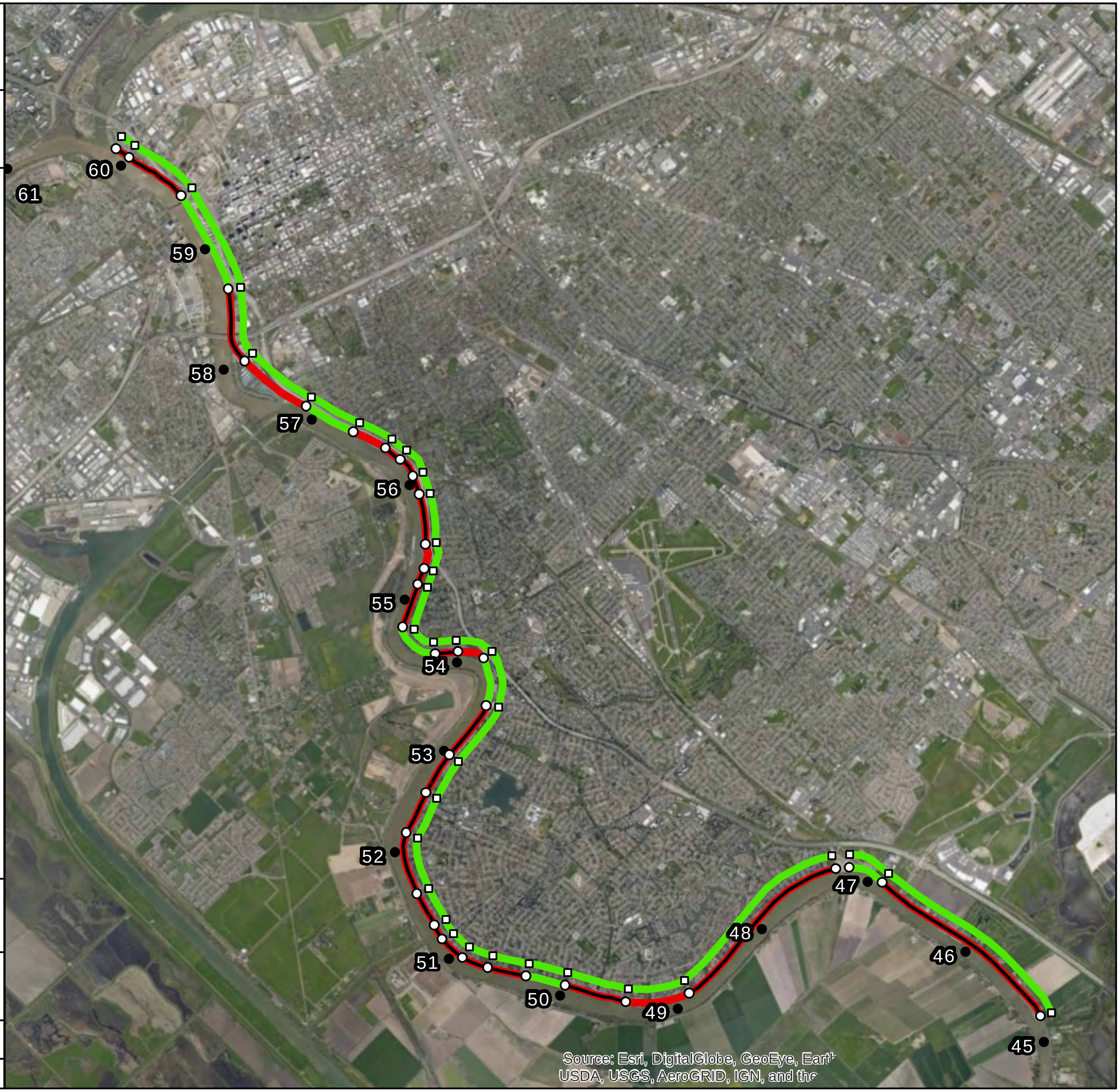
Bank Erosion Potential	Levee Erosion Potential
High	High
Moderate	Moderate
Low	Low

High and Impinging

N

Scale = 1:90,000

0 5,000 10,000 Feet



Sacramento River Erosion Assessment

50 kcfs Erosion Potential

FIGURE 4-4

Job: 5004539	Date: JULY 2019

Sacramento Area Flood Control Agency

northwest hydraulic consultants

Legend

- Segment Endpoints - Bank
- Segment Endpoints - Levee
- USGS RM

Bank Erosion Potential: High, Moderate, Low

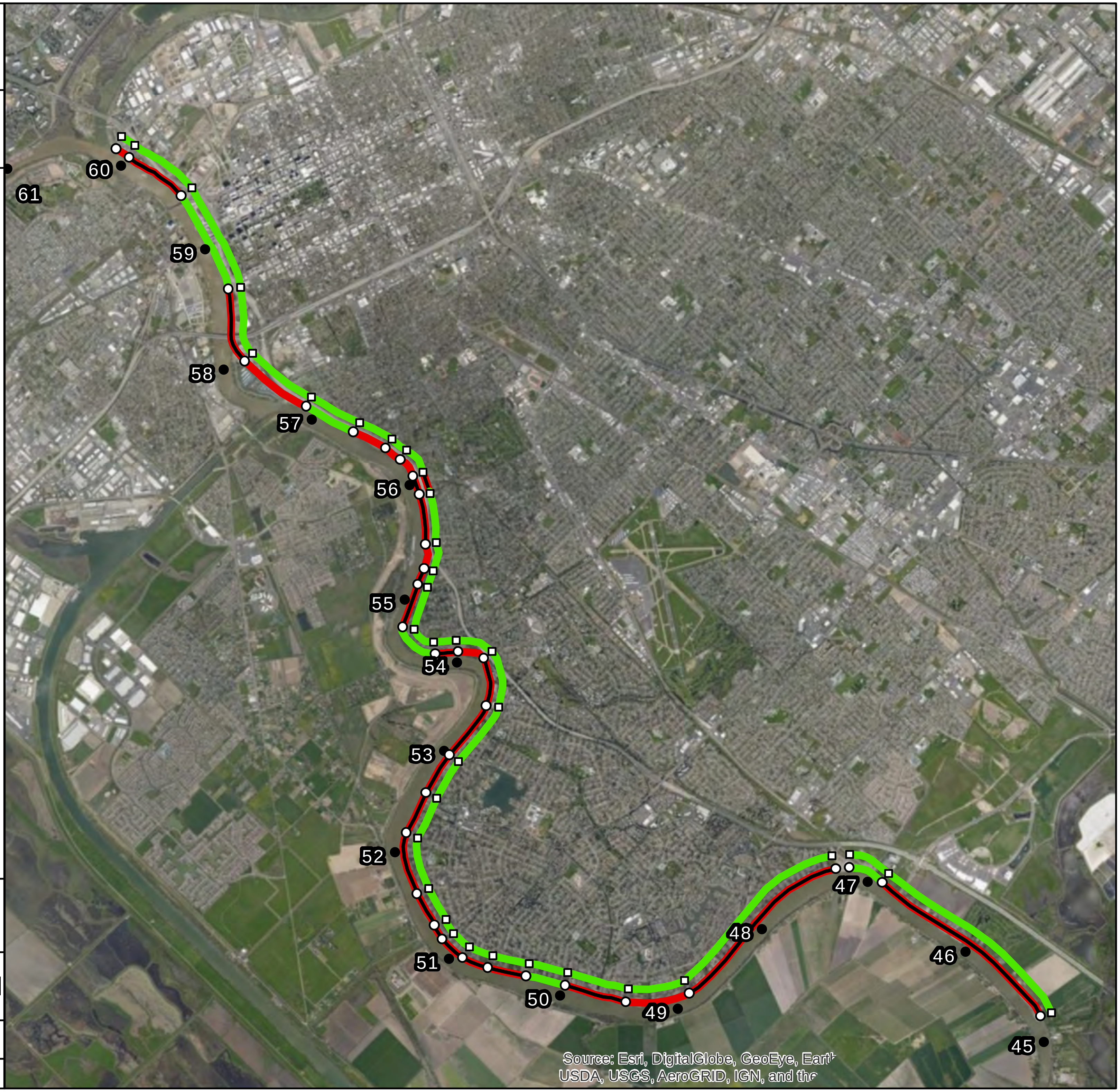
Levee Erosion Potential: High, Moderate, Low

High and Impinging

Scale = 1:90,000

0 5,000 10,000 Feet

N



Sacramento River Erosion Assessment

100 kcfs Erosion Potential

FIGURE 4-5

Job: 5004539 | Date: JULY 2019

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Legend

Segment Endpoints - Bank

Segment Endpoints - Levee

USGS RM

Bank Erosion Potential	Levee Erosion Potential
High	High
Moderate	Moderate
Low	Low

High and Impinging

Scale = 1:90,000

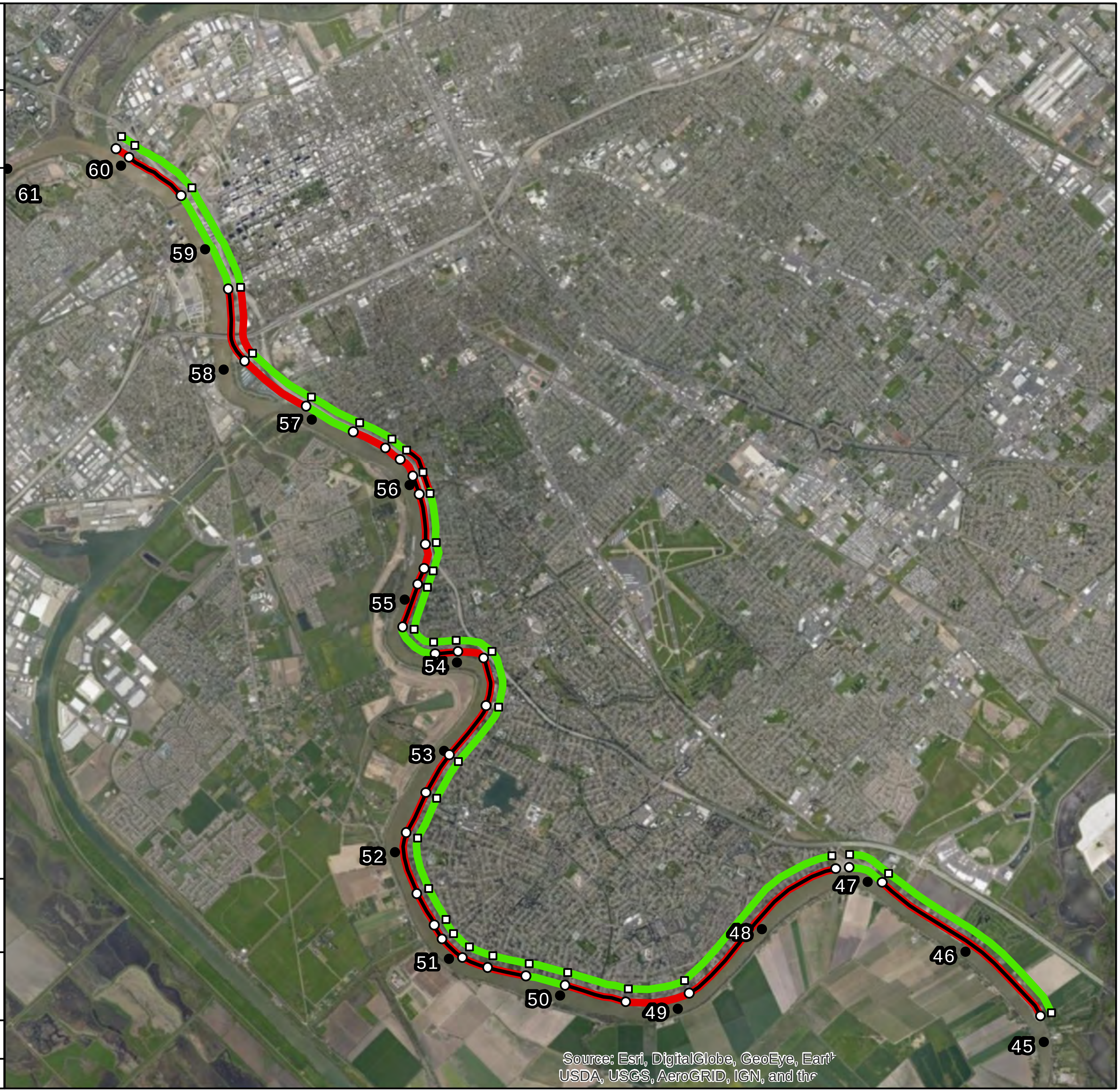
0 5,000 10,000 Feet

Sacramento River Erosion Assessment

110 kcfs Erosion Potential

FIGURE 4-6

Job: 5004539 | Date: JULY 2019



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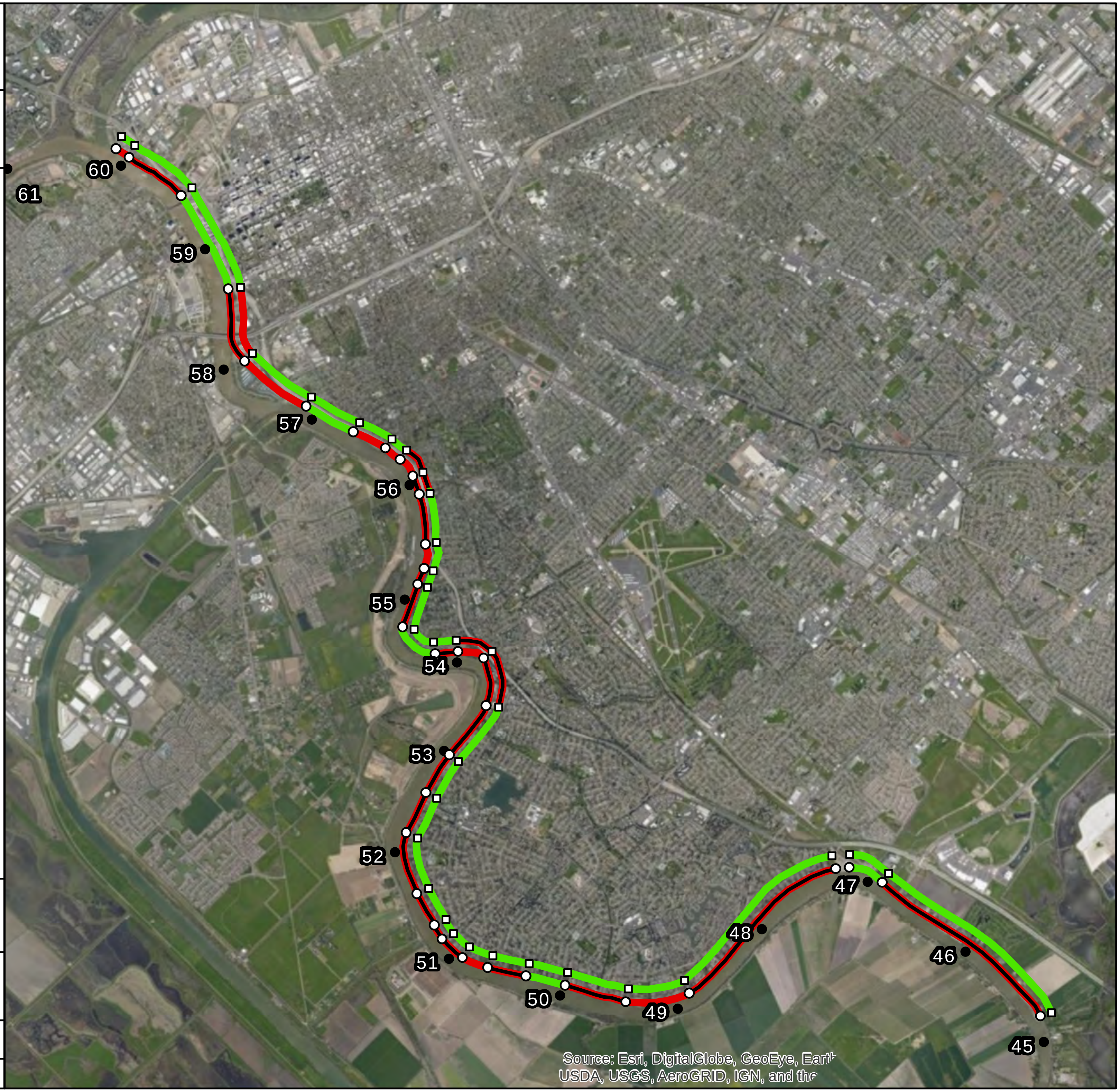
Legend

- Segment Endpoints - Bank
- Segment Endpoints - Levee
- USGS RM

Bank Erosion Potential
- High
- Moderate
- Low

Levee Erosion Potential
- High
- Moderate
- Low

High and Impinging



N

Scale = 1:90,000

0 5,000 10,000 Feet

Sacramento River Erosion Assessment

115 kcfs Erosion Potential

FIGURE 4-7

Job: 5004539	Date: JULY 2019

nhc

5 OVERALL EROSION POTENTIAL

5.1 Overview

Section 5 provides an integrated summary for each of the 33 segments using the results of Section 3 long term geomorphic processes and Section 4 flood event erosion potential calculations and ratings.

The geomorphic analysis built upon existing studies to conclude that channel planform and profile are generally stable and not likely to exhibit dramatic changes into the 50 year future period. Channel widths have been generally stable. However, the history of extensive and ongoing bank protection efforts and field evidence of ongoing erosion indicate that progressive erosion along banks and the waterside levee face will need to be closely managed. There is a high potential for deep channel bed scour during peak flood conditions which was not integrated into older revetment designs. Indications are that future erosion will be local, discontinuous and not a systemwide channel widening event. However, over long reaches bank stability largely depends on the longevity of the root systems of a single, top of bank line of large trees that appear to be in decline due to age and erosion. Little new vegetation recruitment is occurring due to the lack of good soil and hydrologic conditions. Many revetments installed prior to 2000 appear damaged and inadequate. Modern revetments that include a riparian vegetation bench and a large volume of rock have withstood large floods well and were designed to account for channel bed scour and anticipated hydraulic force.

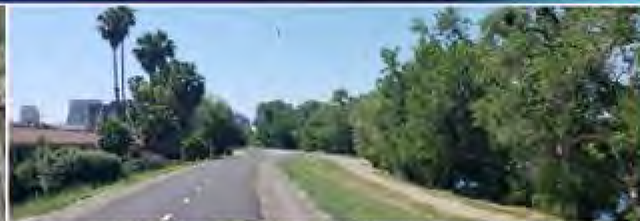
The Section 4 results of scour and erosion extent estimates and the conditions of banks and levees to resist erosion found significant risks to levee stability from ongoing and potential future erosion due to fine bank and levee materials combined with long duration flood events. Eight of the 33 segments analyzed were rated high for overall erosion potential at locations where the levee prism has already been encroached or could be impinged in the near future. Estimates of scour and lateral erosion of the levee toe and face were found to be low in most places, however some levee slopes are at risk and there are multiple locations that have been repaired since 2006.

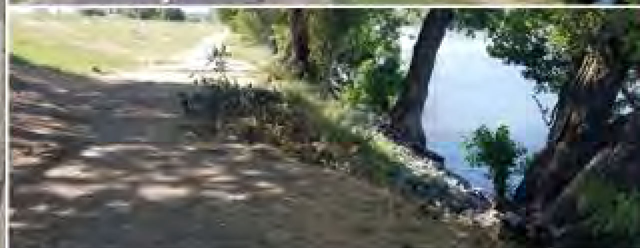
The following is a segment by segment summary of the erosion assessment results. Note that the locations are accurate within 0.01 miles or 50 feet +/-.

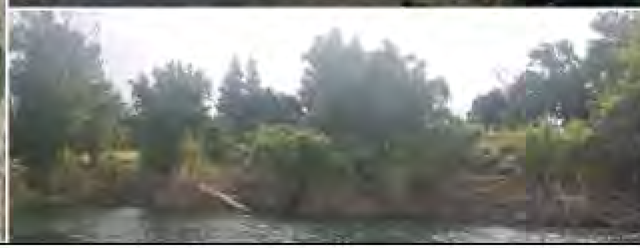
5.2 Segment 1 RM 60.1 to 60.0

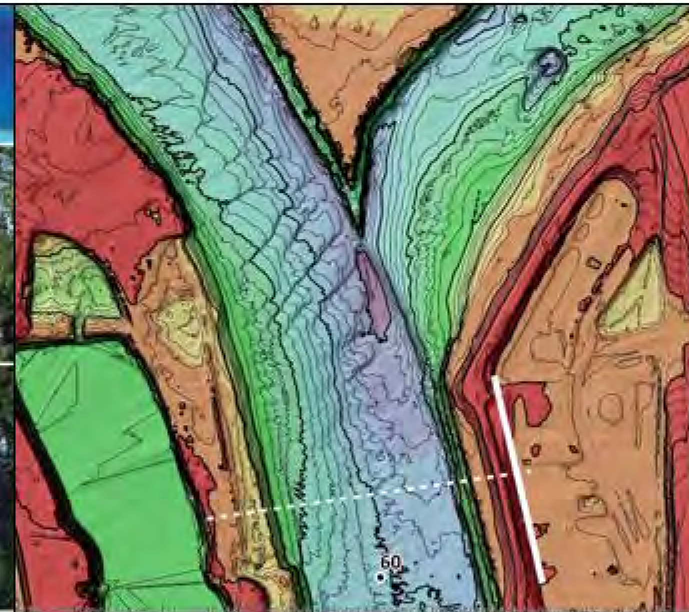
Segment 1 (Figure 5.1) covers 850 feet +/- from the mouth of the American River at Discovery Park to a waterside levee access ramp. This location is on the apex outside bank of a 2.0 mile long bend. The thalweg is along the toe of bank at elevation -10.0 to -15.0 feet . The channel bank height is about 45 feet with roughly a 1.5H:1V slope. The berm is generally 50 feet wide but in spot locations with recent erosion it is less than 10 feet. The berm has a barren access road extending out 10 + feet from the levee toe; other areas of the berm and levee face have adequate grass cover. The bank has sparse to moderate vegetation cover with large trees, mostly older cottonwoods, some shrubs and a mix of 2006-era and older rip rap, cobble and broken concrete. Large tree roots are exposed due to a combination of erosion and foot traffic (the area is heavily traveled and used for recreation and temporary homeless encampments).

Segment 1: RM 60.0 to 60.1





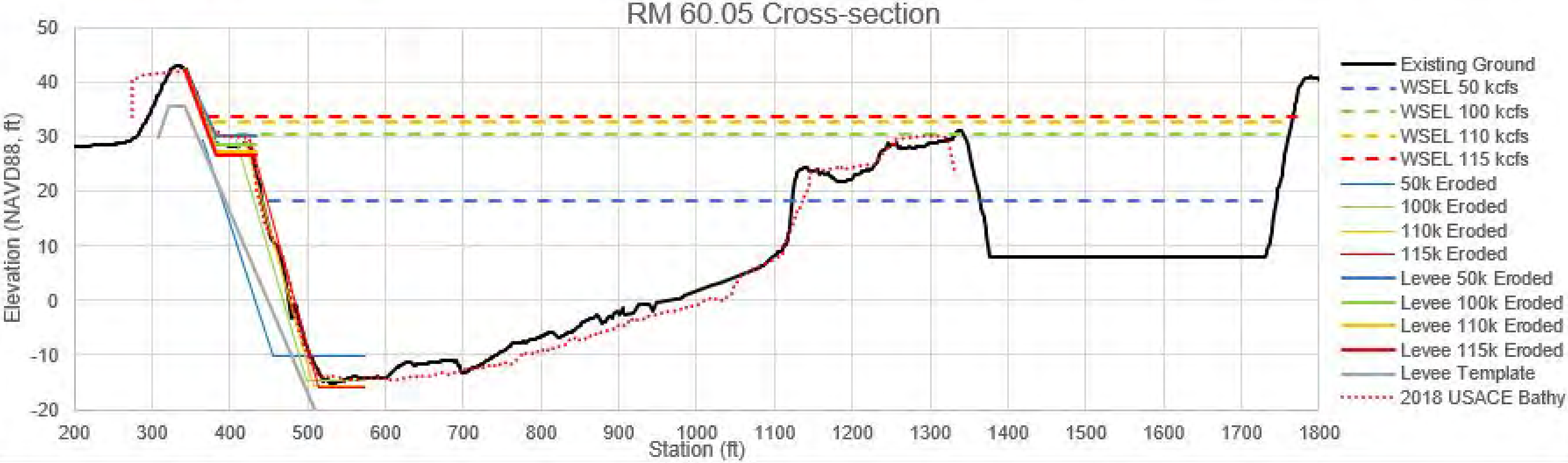




Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.19	3.88	3.98	4.04

Soil Type	Channel bar deposits; fine gravel, sand, and silt.
Bench Width	< 50 ft
Existing Revetment	Sparse concrete, cobble, and rock from 2006 repairs.
Distinction	Start of reach US; Levee moves towards river DS

RM 60.05 Cross-section



Areas of recent erosion and repairs are visible, some may have been mass failures after loss of large tree roots. The condition of cottonwoods indicates that tree failure and bank erosion at those locations will be repaired as they occur. There was no observed recruitment of new seedlings.

The bank experiences shear stresses ranging between 0.14 and 0.18 lbs/ft^2 which is significantly higher than the critical shear for silty sand bank materials (0.045). Although scour is not expected to be high, a high slope failure susceptibility for the existing slope results in overall high ratings for erosion potential in all flows. The lateral erosion extents are outside of the levee prism except for lateral erosion at 50,000 cfs due to the relatively long 288 hour duration flow. Therefore the bank is rated overall high with levee prism encroachment. (note: the scour depth for 50,000 cfs is above the existing toe of bank because the overall channel cross section area and depth is greater than the predicted scour depth; this does not infer bed aggradation. Similar results are found at other segments).

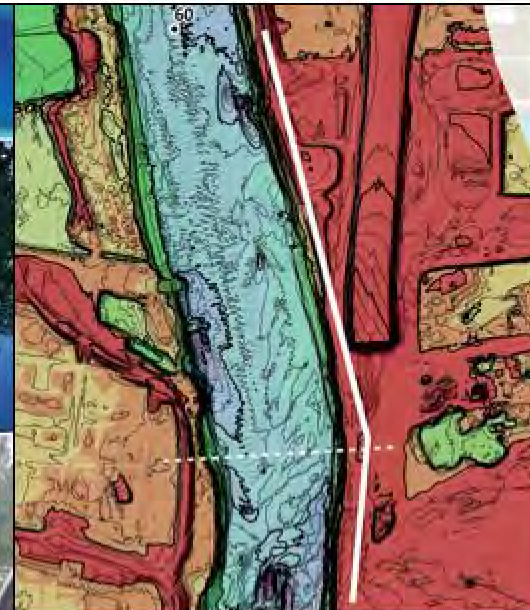
The levee has good grass cover with stable slopes. The shear stresses are very low less than 0.01 lbs/ft^2 over the range of flows, far lower than the critical shear of 0.050 lbs/ft^2 for levee fill. As a result, the levee rates as low overall erosion potential and no encroachment into the levee prism is anticipated.

5.3 Segment 2 (RM 59.4 – 59.5)

Segment 2 is 2,800 feet long with a berm 0 to 50 feet wide and significant old and new infrastructure, including the Sacramento River Water Intake Structure at RM 59.8. The levee structure varies along the segment length. At the upper end of the segment, the levee protects a low floodplain with commercial developments. From RM 59.85 to 59.6, the levee top is adjacent to landside fill at the same elevation, including the Interstate 5 road fill. From RM 59.6 to RM 59.45 the levee top is part of the Jibboom Street and American River Bike Trail fill where the bank is within the area of the new I Street Bridge (RM 59.6) corridor and will be subject to reconstruction. At RM 59.9, a new museum is under construction at the old P G&E gas plant. A new stormwater pumping plant and outfall designed to serve the Railyards Redevelopment Project is to be located along the east side of I-5 at RM 59.6 to 59.5; although no detailed plans are available it is resumed the bank will be reconstructed to accommodate the new outfall.

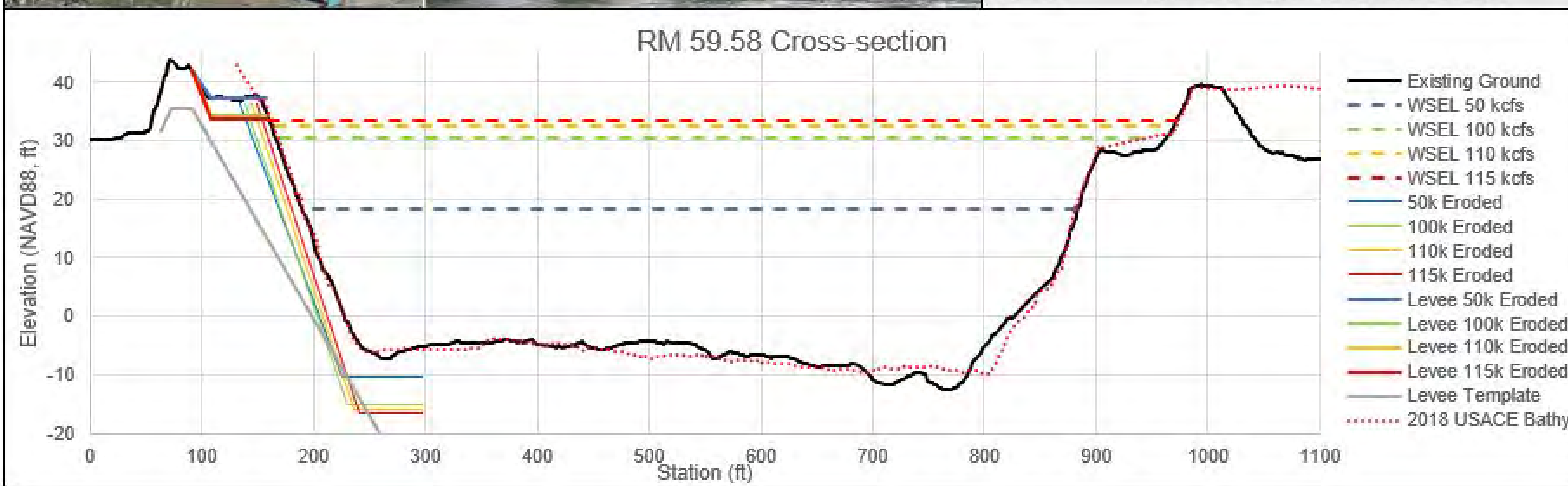
The bank along this section is steep, highly degraded and includes old buildings, pipes, an old water intake structure and a variety of old bank protection, including cobble, rip rap and concrete rubble. The underlying bank soils are silty sands. The vegetation cover is predominately large individual cottonwoods with sparse understory and many barren areas. The channel bed at the toe of the bank is around -8 to -10.0 feet . The LMA (City of Sacramento Public Works Department) reports that maintenance equipment access to the lower part of segment 2 is difficult to none. The downstream end of segment 2 near the I street Bridge is the upstream end of the 1.2 mile long Old Sacramento Floodwall and Promenade.

Segment 2: RM 59.45 to 60.0



Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.00	4.13	4.29	4.39

Soil Type	Marsh deposits; silt and clay, likely organic-rich
Bench Width	< 50 ft
Existing Revetment	Concrete rubble, cobble, and rock from 2006 repairs.
Distinction	Levee moves away from river US; Floodwalls start DS



The bank is steep and over 40 feet high and rates high for erodibility due to silty sand materials and high for slope failure susceptibility. Vegetation cover protection is rated inadequate due to its sparseness and the ongoing undermining of large tree roots systems. The projected scour depths at all flows encroach into the levee prism with lateral erosion extents up to 8 feet. Shear stress ranges from 0.08 lbs/ft^2 for 50 kcfs to 0.17 lbs/ft^2 for 115kcfs which is significantly higher that the 0.045 lbs/ft^2 for the silty sand bank materials. As a result, segment 2 is rated high for overall erosion potential.

The levee sections rate low erosion potential due to low shear stress (0.02 lbs/ft^2) which are exceeded by the 0.050 lbs/ft^2 critical shear of fill.

5.4 Segment 3 (RM 58.65 to 59.45)

Segment 3 has a 1.2 mile long vertical flood/retaining wall which extends from the I Street Bridge to Front Street Park. The floodwall between RM 59.45 at the I street Bridge to 59.0 at Tower Bridge was constructed in the 1910s as part of the Southern Pacific Railroad Warehouse complex and now includes a promenade, two restaurants constructed directly over it and a marina. It is constructed of thick concrete gravity foundation without rebar or foundation pilings. It was reported that improvements were made in the 1990s including installation of structural tie backs at the Restaurant locations. The LMA reports that there have been several repairs made due to cracking and displacement of concrete. One of these repairs appears to be related to the river ward slumping of an old concrete post and beam structure located just upstream of the Tower Bridge. The landside of the flood wall is a few feet lower with fill underlying most of Old Sacramento from the post-1862 flood fill placements. There are openings in the wall for stop log placements in large floods.

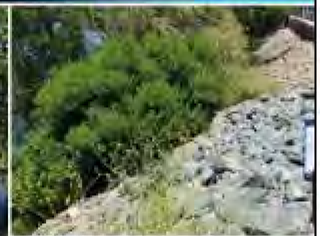
Downstream of the Tower Bridge, a concrete promenade and railroad tracks sit atop a floodwall foundation consists of a combination of new steel sheet piling from RM 59.0 to 58.5 (the site of a reported water main break and erosion in the 1980s) and older floodwall that has rip rap revetment. A set of as built plans are dated 9/15/1997 entitled “Levee Reconstruction (Old Sacramento Floodwall).” These show extensive structural strengthening of the wall using 70 foot long sub horizontal steel rod tie backs from the lower wall waterside face into the fill behind the wall and bolted into buried concrete pad anchors. Near vertical steel expansion rods 25 feet in length were installed to from the top of the wall through unreinforced concrete wall to the existing foundation. The work also shows extensive repairs of cracks.

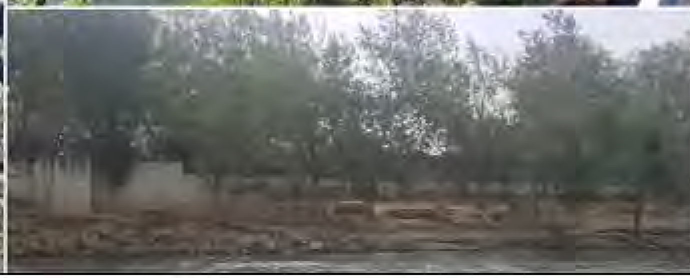
The presence of the stable floodwall results in a low overall erosion potential for bank and levee. Scour and erosion extents impinge on the levee prism.

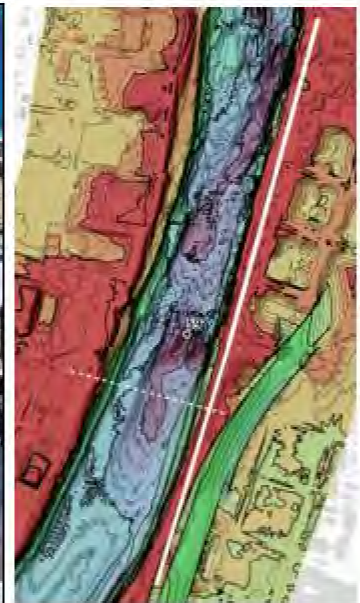
Despite overall low erosion potential ratings, there are several issues that require attention.

1) The old concrete post and beam structure located just upstream of the Tower Bridge should be examined to determine how it is tied into the floodwall and whether it is slumping in the river and pulling the floodwall with it. The possible actions could included modifying or removing the old structure, cutting the structural ties with the floodwall or strengthening the floodwall.

Segment 3: RM 58.65 to 59.45

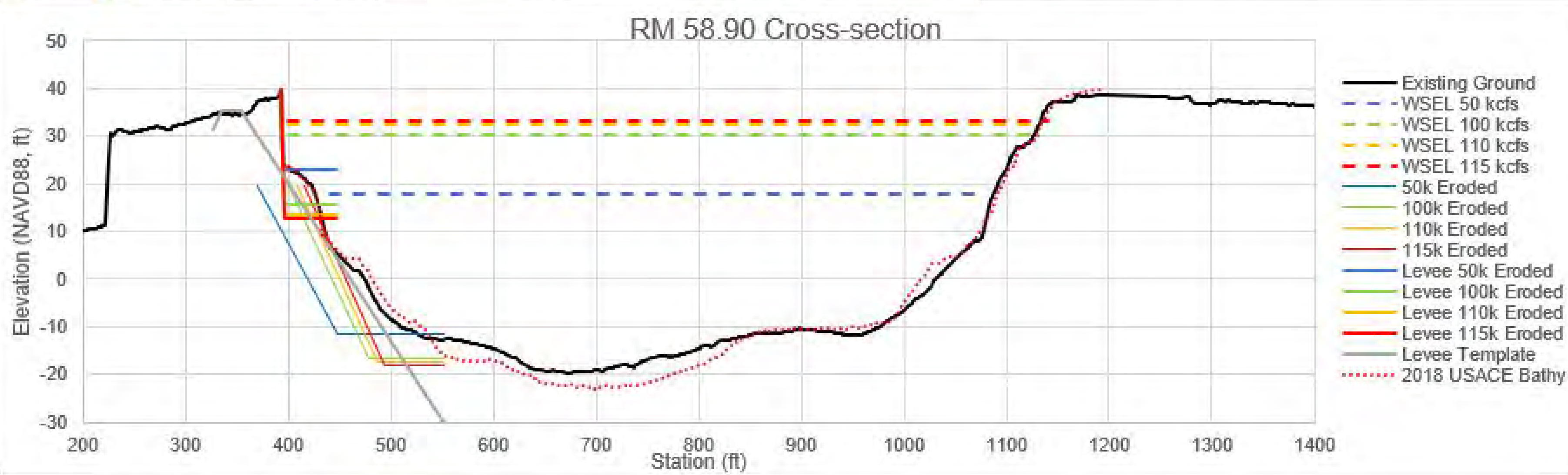






Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.08	3.97	4.11	4.19

Soil Type	Alluvial and channel deposits undifferentiated; sand, silt, and minor lenses of gravel; fining upward.
Bench Width	< 50 ft
Existing Revetment	Floodwalls; retaining walls, rock, cobble, rubble.
Distinction	Start of floodwalls US; End of floodwalls DS.



2) Downstream of the steel sheet pile at RM 58.5, there are placements of rip rap revetments that are not detailed in the reconstruction plans. The plans show only reconstruction of the shoreline to a 2H:1V slope, but nothing regarding rip rap placements. NHC was not able to locate plans or drawings that show the depth of the flood wall foundation and or the extent of the placed rip rap. It is recommended that a search for plans and/or a field investigation be conducted to clarify the rip rap design and function.
3) The LMA (City of Sacramento) has been repairing cracks in the floodwall between Tower Bridge and the downstream restaurant (Crab Shack) at a great frequency in the past. The reasons besides item 1 above, are not readily clear. The maintenance work is keeping up with inspections and repairs, however given the age of the wall it is recommended that a structural assessment be conducted.

5.5 Segment 4 (RM 58 – 58.65)

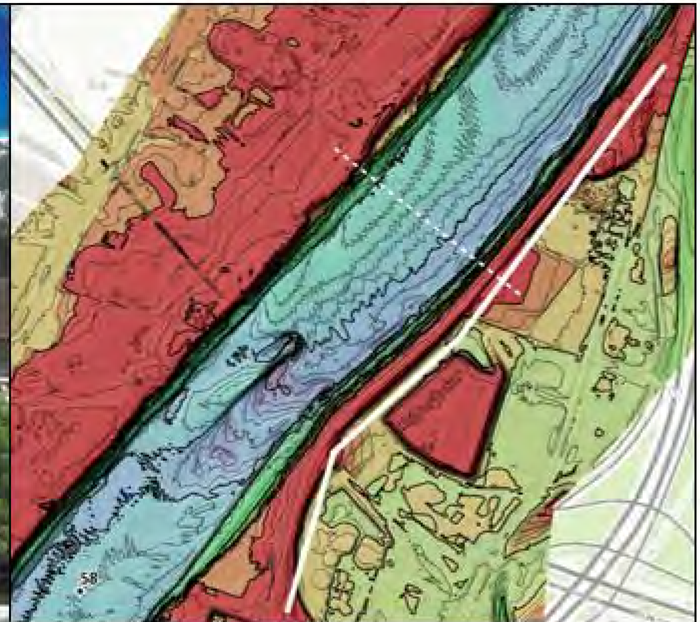
Segment 4 extends for 3,500 feet from the downstream end of the Old Sacramento floodwall to the upstream end of Miller Park. This reach includes the Pioneer Basin stormwater and sewage treatment facility and outfall and the Highway 50 Pioneer Bridge crossing. At RM 58.2, the levee veers southeastward through oil tanks farms and the Broadway road entrance to the Miller Park Marina. The top of levee crown includes the American River Bike Path Trail and two sets of railroad tracks which creates a 40 foot top width double the minimum levee prism of 20 feet. The levee top is around 38 feet while the low floodplain areas landward are around 20 feet .

Overall the bank along segment 4 is in a degraded condition and this makes segment 4 a critical erosion location. There is active, ongoing erosion and critical locations upstream of Highway 50 bridge where there is no berm; the existing steep bank which includes the waterside levee slope is 50 feet high and is already encroached into the levee prism. The channel thalweg at the toe of bank is at elevation – 14 feet.

There are many sections of significant bank erosion. Some of these have been repaired over the past 10 years as they occurred restoring the pre-erosion profile. Other locations have cobble, old rip rap, and concrete and asphalt rubble that has been undermined. Many of the trees have erosion around the roots and many areas are barren. One repair location at RM 58.5 is being outflanked flows that overtop the rip rap and erode the fine materials behind the revetment; black plastic has been placed along this location.

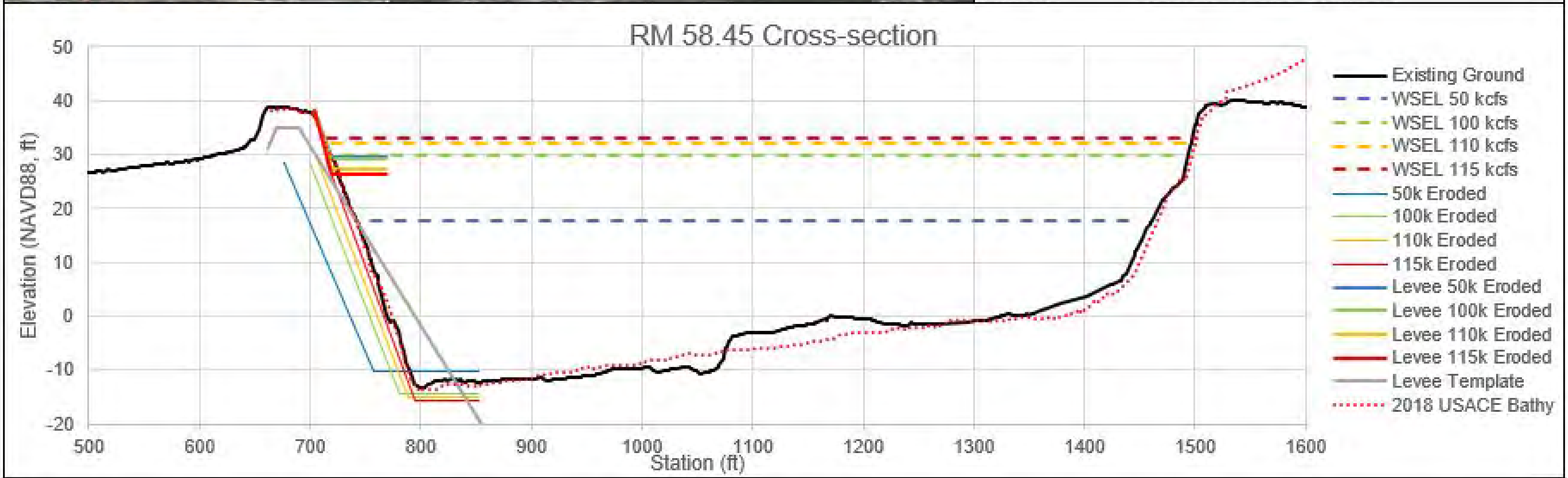
The bank materials are silty sands (critical shear 0.045) and vegetation cover is sparse and absent in many places. Modeled shear stress ranges between 0.10 and 0.17 lbs/ft^2 which exceeds critical shear of bank materials in all flows. Slope failure susceptibility is high due to existing steepness and even with minor scour depth. Vegetation cover protection and existing rip rap are rated inadequate. The levee prism is already encroached and projected scour and lateral erosion progression is farther into the levee. As a result, the segment 4 bank is rated high for overall erosion potential. The consequence of lateral bank erosion on levee stability is high upstream of Highway 50 where active erosion is occurring along an overly steep bank and there is no berm (although the levee crown width is greater than 20 foot

Segment 4: RM 58.0 to 58.65



Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.06	4.04	4.18	4.27

Soil Type	Alluvial and channel deposits undifferentiated; sand, silt, and minor lenses of gravel; fining upward.
Bench Width	50-100 ft
Existing Revetment	Rubble, emergency rock (SCDU-01, -02, -03), Pioneer Reservoir.
Distinction	End of floodwalls US; Marina starts DS.



minimum). The risk to levee decreases as the levee moves hundreds of feet away from the bank downstream of Highway 50, through Broadway and into Miller Park.

The overall erosion potential levee for the levee is rated low due to low shear stress (maximum 0.02 lbs/ft^2 compared to 0.050 lbs/ft^2 critical shear) and predicted scour and lateral erosion extents do not encroach into the levee template. However, since there is no berm upstream of Highway 50, the levee is vulnerable due to bank failure risk, particularly mass failure.

5.6 Segment 5 (RM 57.1 – 58.0)

Segment 5 covers the Miller Park and Marina area where the levee is set back from the Sacramento River shoreline and bank by 600 to 1,200 feet. The levee is aligned adjacent to the paved access road to the boat ramp. The downstream 1,000 feet occurs along the boat launch parking lot. The downstream end berm width is 75 feet wide which transitions into the modern revetment of segment 6.

The overall erosion potential is high for banks due to high shear stress and fine bank materials. For most of the segment the berm width is adequate, however, it is unclear how the last 100 feet, where the berm width is low, ties into the modern revetment of segment 6. The projected scour depths are all above the bank toe indicating that the channel section is sufficiently wide. Bank scour and lateral erosion extents do not encroach into the levee prism except possibly at the aforementioned down stream tie in to segment 6 (RM 57.1).

The levee erosion potential is rated low due to low shear stress (maximum 0.02 lbs/ft^2 versus 0.050 lbs/ft^2 critical shear), adequate cover and slope steepness. However, the LMA reports that there was an emergency repair to the levee recently that was thought to be a beaver lodge and not lateral erosion. The levee also has numerous large trees within the upper slopes.

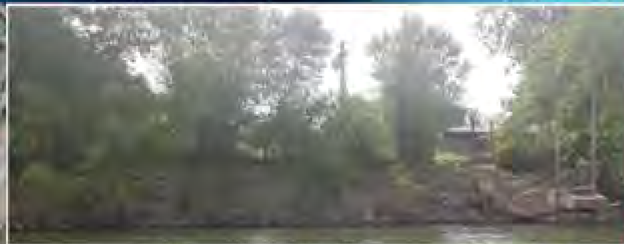
5.7 Segment 6 (RM 56.65 – 57.1)

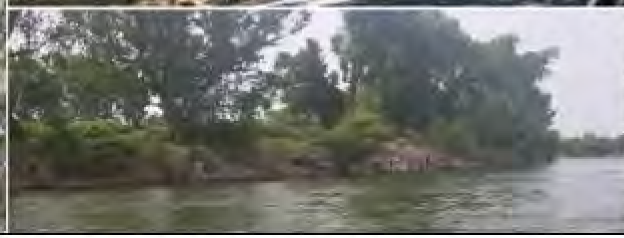
Segment 6 is 2,400 feet long and has a modern bank protection structure built in 2007. The segment is located along a straight reach of the river which has been narrowed by historic levee raising on the west bank in the City of West Sacramento. Examination of historical aerial photographs reveals extensive erosion after construction of the Port of Sacramento Barge Channel and encroachment of the associated levee system in the late 1950s. The reach includes an abandoned sewer outfall and building located at RM 56.63. The levee section is relatively wide (over 40 feet in places) along the entire segment due to the presence of the bike trail and railroad tracks on the crown.

The fine bank materials are well protected by the modern revetment structure. Scour depths for all flows are above the existing bank toe elevation. Lateral erosion extents calculations encroach into the levee prism. The overall bank erosion potential rating is low due to the rip rap protection and adequate rock volume. The riparian plantings placed in the revetment are doing well, although the soil placed over the upper slope rip rap has eroded away (due to poor placement and quality of materials used).

The overall erosion susceptibility of the levee is rated low due to adequate grass cover and below threshold slope gradient, however all scour and lateral erosion extents impinge into the levee prism.

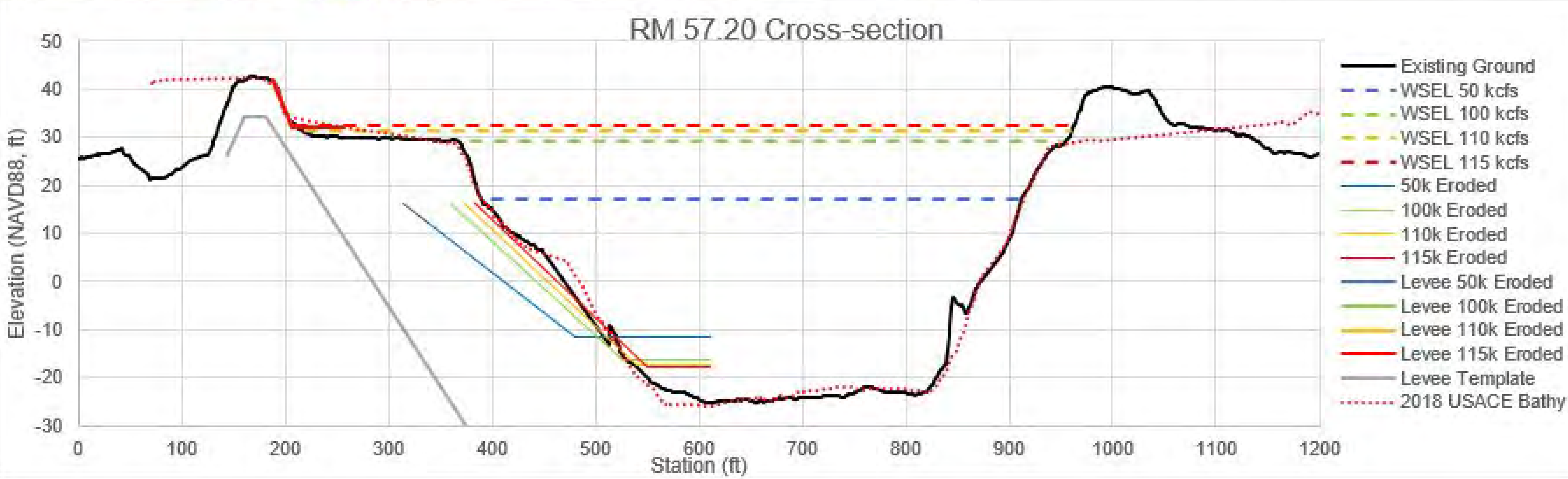
Segment 5: RM 57.1 to 58.0



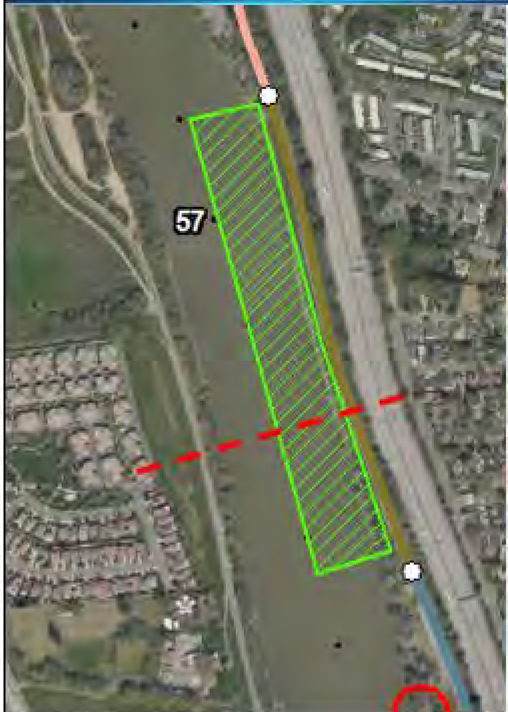


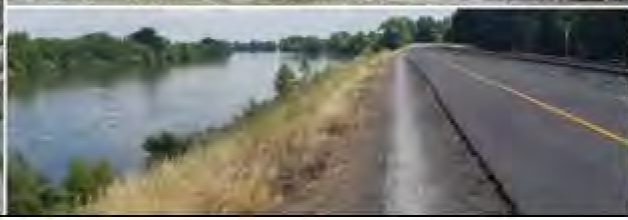
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.28	4.37	4.54	4.62

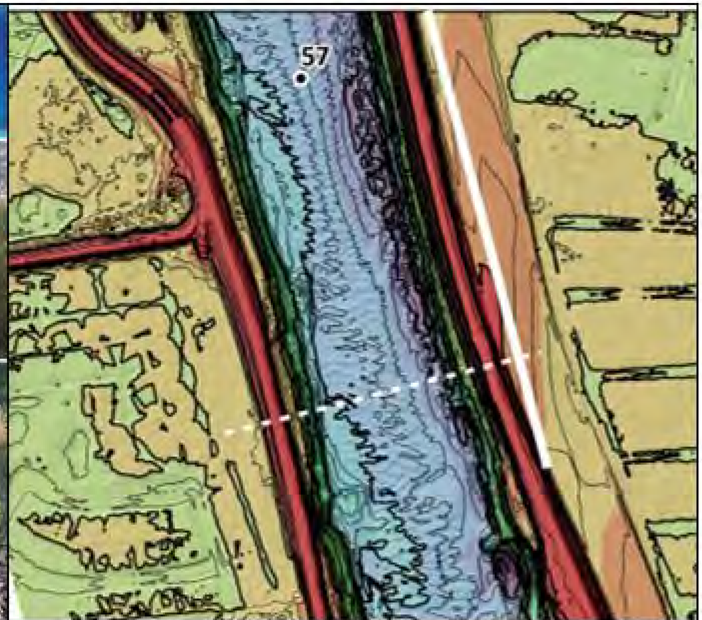
Soil Type	Point bar and channel deposits; well-sorted sand and fine gravels, minor amounts of silt and clay.
Bench Width	50-200 ft
Existing Revetment	Miller Park marina and boat launch, emergency rock (SCDU-04 and -07).
Distinction	Start of marina US; Modern revetment starts DS.



Segment 6: RM 56.65 to 57.1

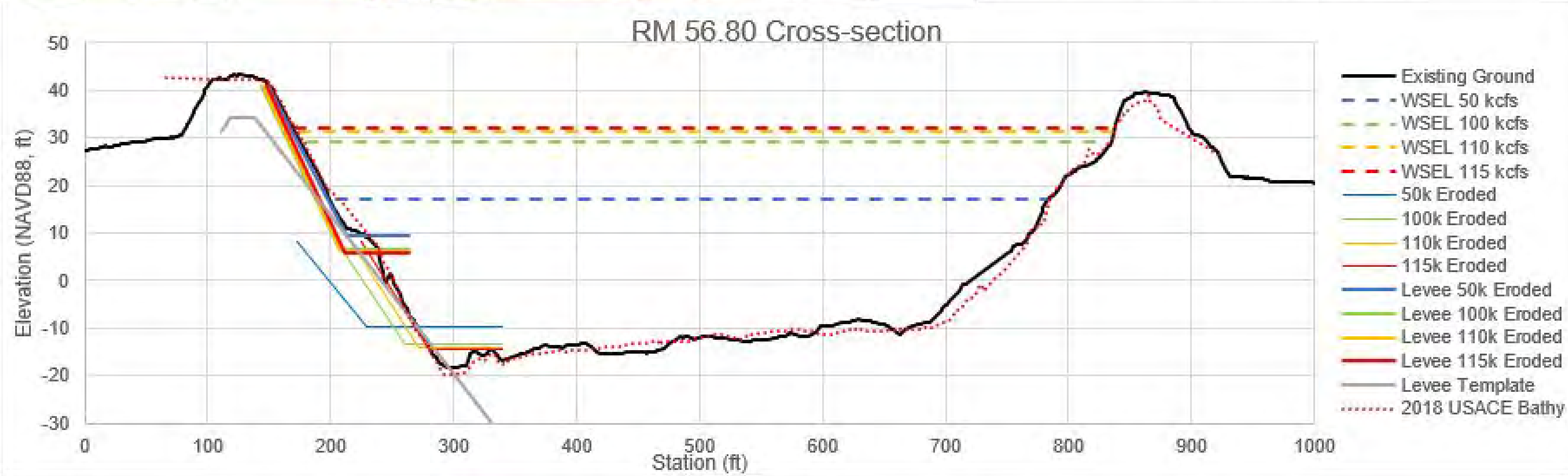






Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.24	4.30	4.45	4.53

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	~25 ft
Existing Revetment	Modern revetment – Site RM 56.7L (2004).
Distinction	Marina US; Modern revetment ends DS.



5.8 Segment 7 (RM 56.35 – 56.65)

Segment 7 is 1,600 feet long with variable berm width (less than 50 feet to 200 feet) and a wide levee crown (40 feet +/-). The berm has large mature trees along the bankline and landward up to a cleared maintenance road at the toe of levee. Many tree trunks show evidence of being buried in fine silty sediments (presumably in larger floods) and exhumed by erosion (in smaller floods) multiple times. The levee toe and waterside face have been repaired with rip rap likely within the last 20 years. There is a long corrugated metal pipe storm drain outfall at RM 56.35.

The upper bank has a 3-5 foot high erosion cut within the root zone of the large trees and is bounded by a gently sloping wave washed shoal of what appear to be recently deposited silty sands. The top of bank has a topographic high suggesting a natural levee formation (i.e. fine sediment deposited in the high roughness boundary at vegetation line). The cut bank appears within the zone of 50,000 cfs which approximates the geomorphic effective discharge[6]; based upon its height and the deposition and erosional processes, the berm appears to be a terrace[7] (rather than geomorphic floodplain[8]).

The bank slope failure susceptibility and erodibility are rated high for all flows. Bank scour depths and erosion extents do not reach the levee prism. The overall bank erosion potential is rated high for all flows.

The levee overall erosion risk is rated low for all flows due to stable slopes and protection by grass cover and rip rap. However, the projected shear stress (0.040 lbs/ft^2) is close to the critical shear for fill (0.050 lbs/ft^2) and the presence of extensive recent rip rap placements indicates erosion in the recent past (2006 era rip rap). The erosion monitored closely and rectified as needed by the LMA.

5.9 Segment 8 (RM 56.2 – 56.35)

Segment 8 is short with a narrow berm (less than 20 feet) that is actively eroding. The bank is unprotected and levee slope has been actively repaired (2006 era rip rap). Vegetation and rock placements are sparse along the steep and eroding bank. The berm is a terrace and is barren due to the maintenance road extending from the levee toe. The bank and levee slope are nearly coincident and about 65 feet above the toe of bank (at – 30 feet).

The overall bank erosion rating is high for all flows due to steep slopes, lack of cover and fine materials. Scour and lateral erosion encroaches into the levee template at all flows. Scour depths, enhanced by the

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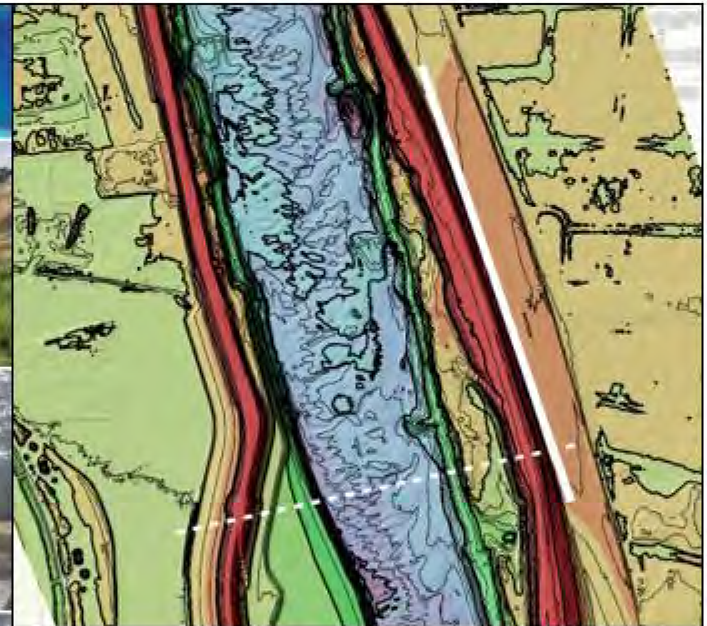
[6] Geomorphic effective discharge or dominant discharge is the flow that does the most work over time. It is thought that the channel morphology (width and depth and pattern as viewed from above) is reflected by the flow that does the most work.

[7] A terrace is a bench that is elevated above the elevation where geomorphic floodplain is forming. Terraces were once at the active floodplain forming level but have since been elevated by channel incision/degradation.

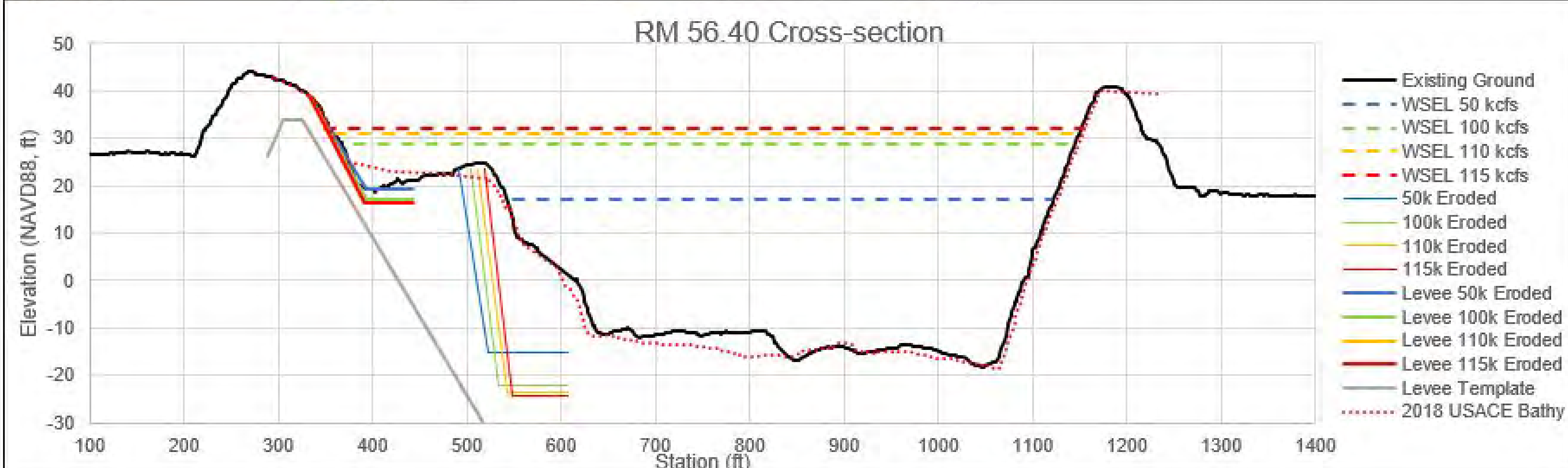
[8] A geomorphic floodplain is defined as a low bench adjacent to the channel that receives fine sediment deposition and is actively forming in the current climate.

Segment 7: RM 56.35 to 56.65

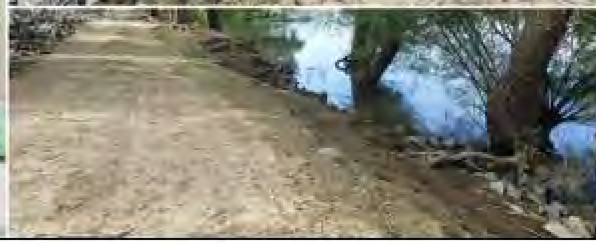


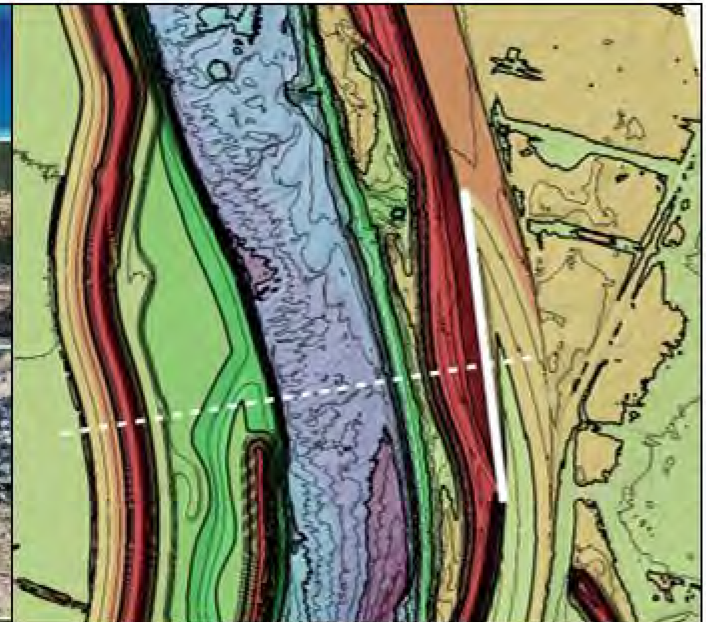
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.23	4.50	4.69	4.79

Soil Type	Channel bar deposits; fine gravel, sand, and silt.
Bench Width	50-175 ft
Existing Revetment	None
Distinction	Modern revetment ends US; Change in berm width DS.



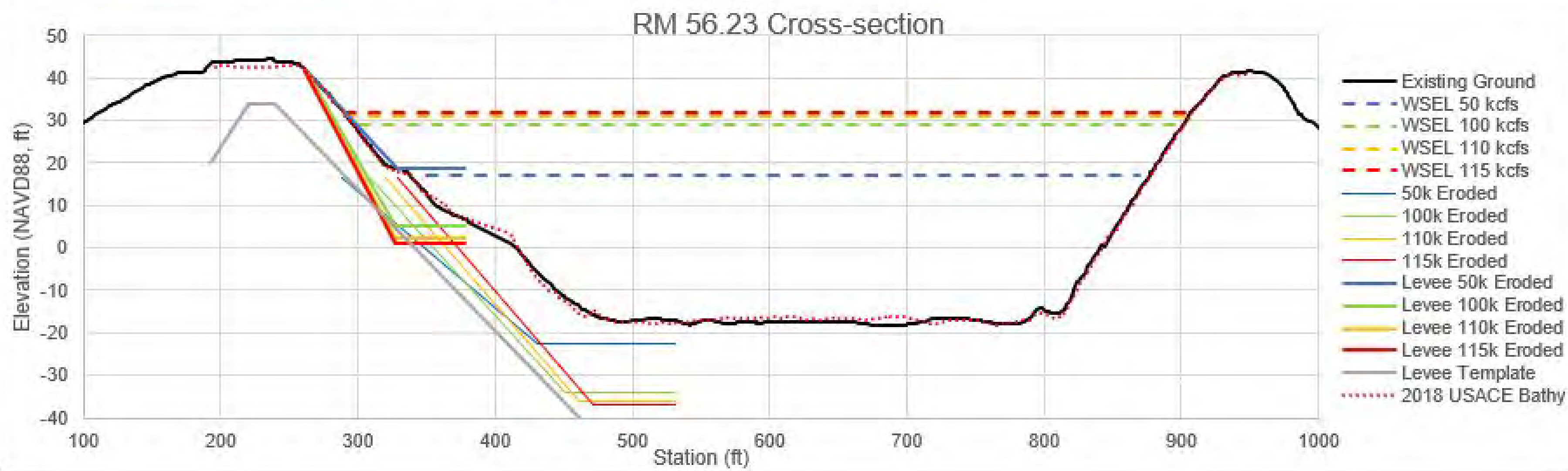
Segment 8: RM 56.2 to 56.35





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.34	4.65	4.85	4.96

Soil Type	Channel bar deposits; fine gravel, sand, and silt.
Bench Width	25-100 ft
Existing Revetment	Rock along levee toe.
Distinction	Change in berm width US; Change in berm width DS.



planform location and the outside of a bend, and lateral erosion impinge into the levee prism. The levee overall erosion potential is rated low, however the projected scour and lateral erosion extents encroach

the levee prism. The presence of extensive rip rap on the levee face and evidence of recent and ongoing erosion suggests that risk may be higher.

The levee section is significantly wider in Segment 8 than most sections, therefore the consequence of lateral erosion for levee risk is lower than other locations.

5.10 Segment 9 (RM 56.07 – 56.2)

Segment 9 has a relatively wide berm (greater than 50 feet) and gently sloping and sparsely vegetated cut bank[9]. The berm has large trees and grass understory. The waterside levee face has many patches of 2006-era rip rap and the lower 200 feet has gunite (concrete) cover which extends into segment 10 downstream (built in the 1920s). The levee section is relatively wide (crown width over 30 feet) and has good grass coverage but there are extensive patches of rip rap repairs on the levee waterside face.

The overall erosion potential for bank erosion is rated high for all flows due lack of adequate cover and protection and erodibility. Scour depths are modest above 50,000 cfs and erosion extents do not encroach into the levee prism.

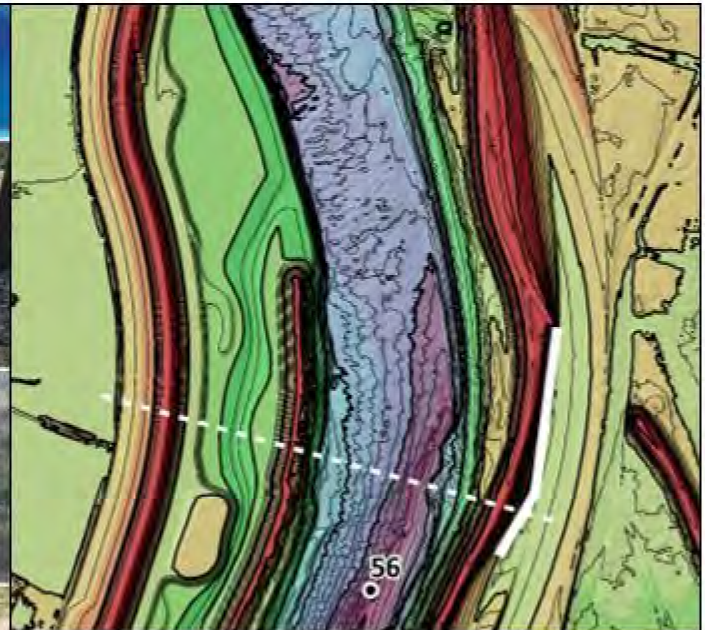
The levee overall erosion rating is high for flows 100,000 cfs and 115,000 scour and lateral erosion at these flows extend into the levee prism. This is the result of high slope failure potential enhanced by scour and its location along the outside of the bend. The projected maximum shear stress at the levee toe is 0.040 lbs/ft^2 which is close to the critical shear of 0.050 lbs/ft^2 and the patches of rip rap repair indicates exceedance of erosion thresholds in the recent past. The downstream 200 feet of levee slope is protected by gunite which has been in place since the 1920s.

5.11 Segment 10 (RM 55.9 – 56.07)

Segment 10 is a 900-foot long reach of gunite (concrete) covered bank and levee slope that extends from below low water level (lower than elevation 0.0 feet) to the top of the levee. This structure was placed in the 1920s and it is reported by LMA personnel that the lower part of the structure when visible at very low flows, has a vertical timber wall. This structure has held up well for nearly 100 years considering it is situated at a narrow channel section at the outside of a tight bend. However, current visual inspection examination of historic aerial photographs and reports from the LMA indicate it has been rapidly decaying over the past 10 years. There are numerous cracks and missing chunks with numerous repairs ranging from more gunite patches to cobble placements.

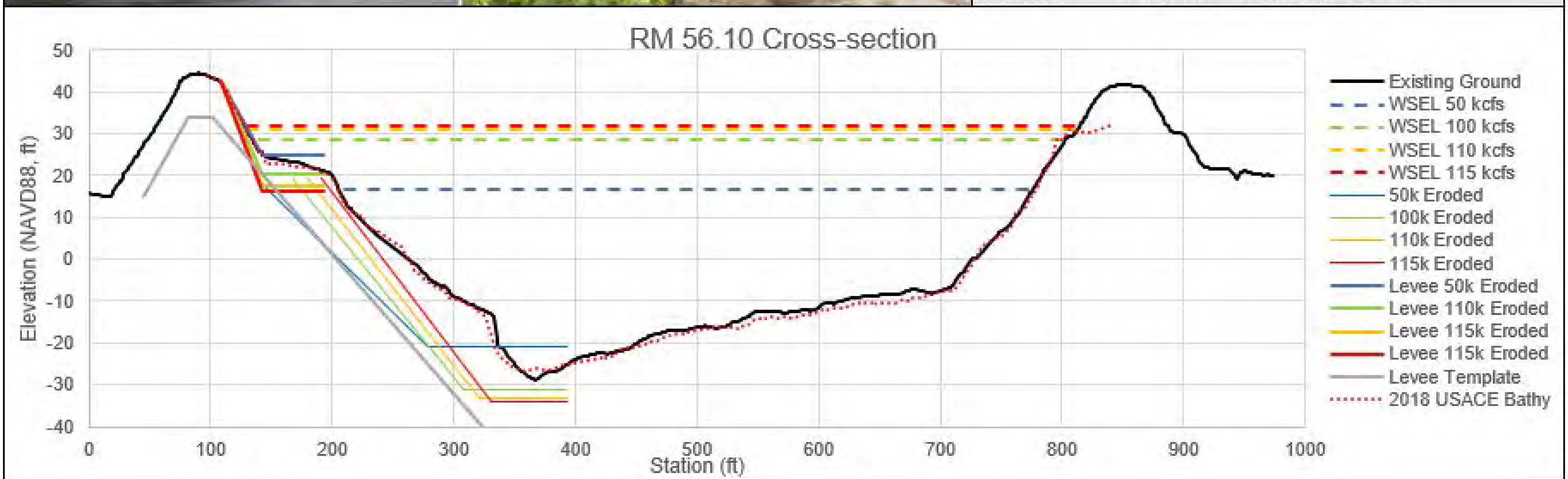
[9] Cut bank is a vertical erosional feature created by erosion along the sides of a channel.

Segment 9: RM 56.07 to 56.2

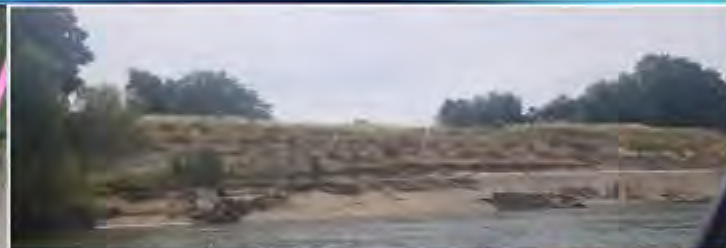


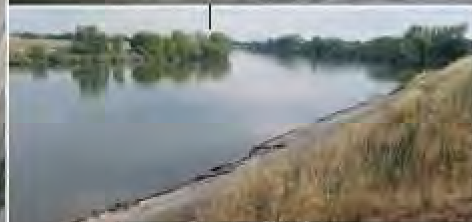
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.37	4.67	4.87	4.98

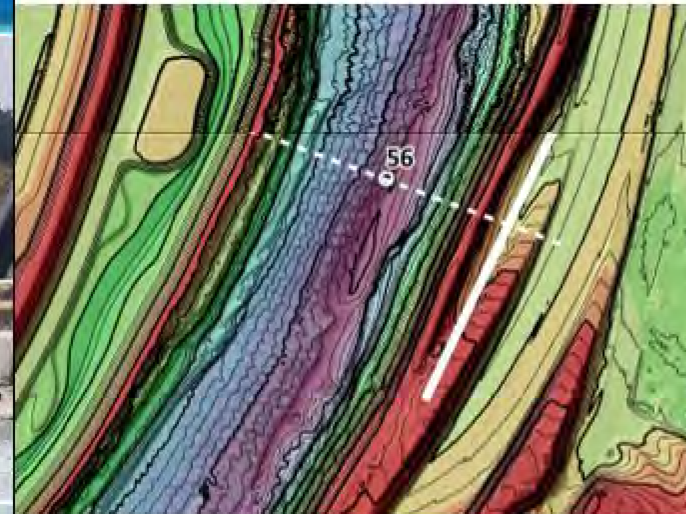
Soil Type	Channel bar and Crevasse splay deposits; fine gravel, fine to coarse sand, with lenses of silt and clay.
Bench Width	50-100 ft
Existing Revetment	Emergency rock along levee toe before gunite.
Distinction	Change in berm width US; Start of gunite DS.



Segment 10: RM 55.9 to 56.07

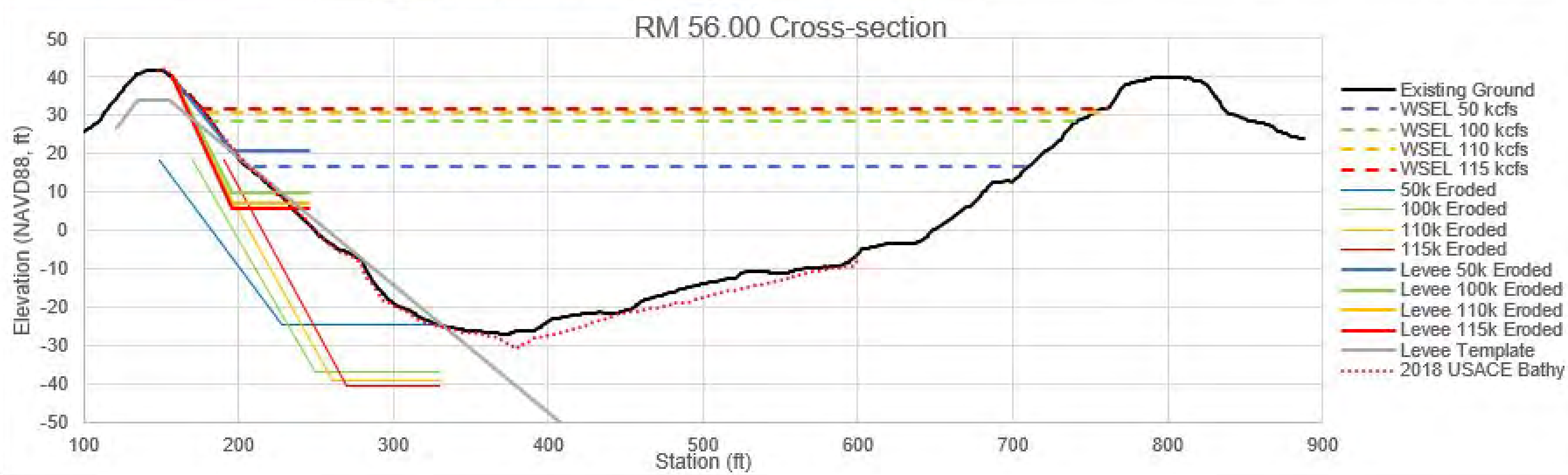






Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.38	4.68	4.87	4.98

Soil Type	Channel bar and Crevasse splay deposits; fine gravel, fine to coarse sand, with lenses of silt and clay.
Bench Width	None
Existing Revetment	Broken gunite and cobble.
Distinction	Change in berm width US; End of gunite DS.



The bank is steep and 65 feet high from thalweg and toe of bank (elevation -25.0 feet) to top of levee (elevation 40 feet). The current bank line encroaches into the levee prism before consideration of estimated scour and lateral erosion. There is no berm and the bank slope coincides with the levee slope.

The bank and levee rates high overall for erosion potential due to enhanced deep scour at outside of bend, oversteepend slopes, and failing protection. The scour and lateral erosion for nearly all flows extend well into the levee prism for both levee and bank. The presence of a scalped slope below elevation -10.0 feet suggests that toe erosion is progressing perhaps into or under the timber wall. The overall slope geometry suggests that mass failure during a large flood is a possibility if toe erosion increases.

5.12 Segment 11 (RM 55.5 – 55.9)

Segment 11 extends from Sutterville Road to the upstream end of the Westin Hotel. The bank and levee slope are coincident as there is no berm and it is located on the outside of the bend. Similar to Segment 10, the levee prism is already encroached, the bank is very steep and it appears that progressive toe erosion is ongoing. The bank levee height is 65 feet from the toe of bank at elevation -25 feet to 40 feet at the levee top. The levee crown is wide. The reach between RM 55.5 and 55.6 show indications of slump failures up to the levee crown as there are tension cracks spot repairs in the bike path asphalt pavement. There appears to be a small slump involving about half of the levee slope just upstream of the marina pier.

The overall bank erosion potential is rated high for all flows above 50,000 cfs due to high slope failure susceptibility. The presence of evidence for recent mass failure / slumping supports the high rating. The projected scour and lateral erosion extends well into the already encroached levee prism.

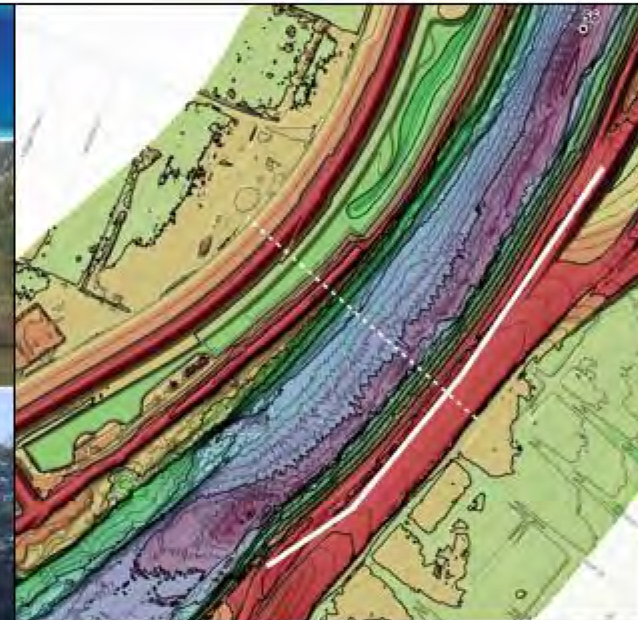
The levee overall erosion rating is low for all flows and scour and lateral erosion is minimal due to very low shear stress (0.02 lbs/ft^2 maximum). However, any failure to the bank could change the levee stability quickly since it appears that potential mass failure plane extends into the levee crown as evidenced by tension cracks in the crown. The levee section in this segment is very wide which could limit the consequences of levee failure.

5.13 Segment 12 (RM 55.3 – 55.5)

Segment 12 is located along the frontage of the Westin Hotel, which is located atop deep fill at the levee top elevation. The frontage has rip rap protection along most of the marina slope, but it is unclear if this was designed to address scour. The building project and rip rap were constructed in 2007.

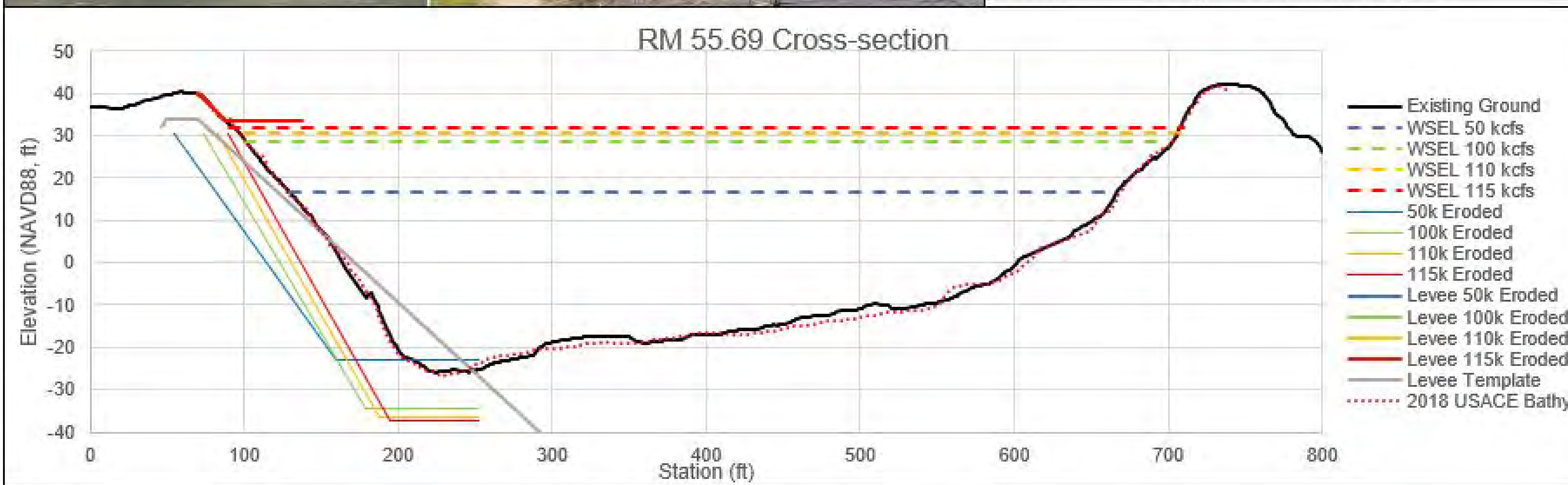
The consequences of erosion are very low due to the depth of fill from the bank to under the hotel property. Any erosion issues would only threaten the hotel parking lot and lawn area. The levee prism is well behind the existing bank, but projected scour and lateral erosion of bank encroach. The bank is rated overall high potential. The levee is rated low. There is no impingement into the levee prism.

Segment 11: RM 55.5 to 55.9

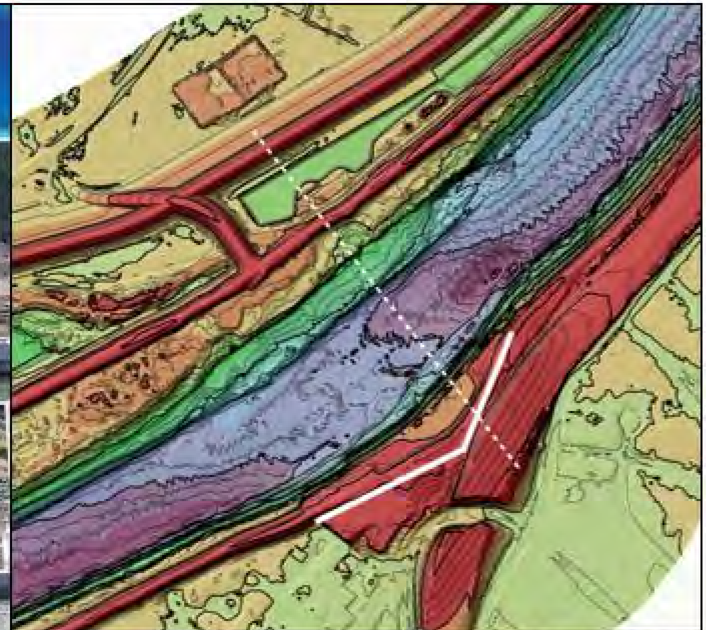


Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	2.94	4.05	4.20	4.29

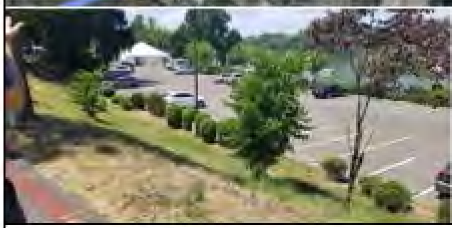
Soil Type	Alluvial deposits undifferentiated; sand, silt, and minor lenses of gravel.
Bench Width	~50 ft
Existing Revetment	Rock along bank.
Distinction	Start of gunite US; Start of hotel parking DS.

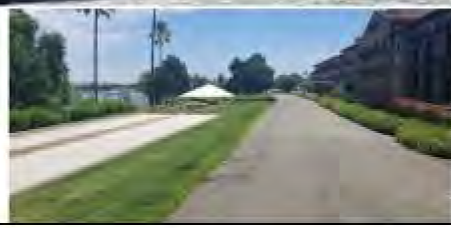


Segment 12: RM 55.3 to 55.5

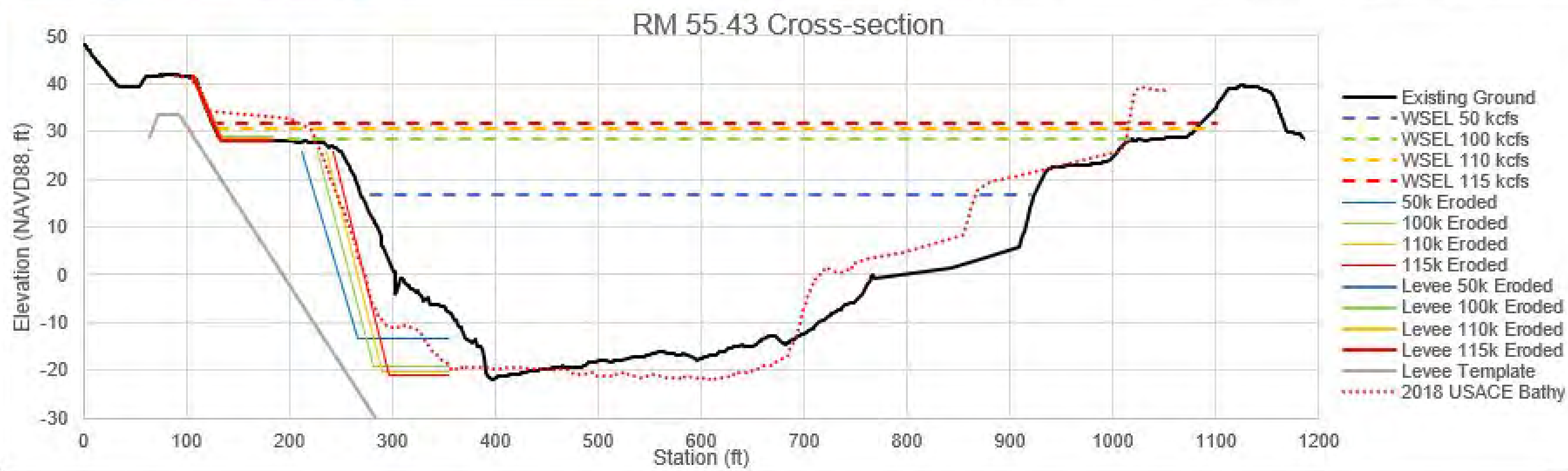


Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.28	4.53	4.69	4.78





Soil Type	Channel bar deposits; fine gravel, sand, and silt.
Bench Width	25-100 ft
Existing Revetment	Parking lot, rock on bank.
Distinction	End of hotel parking US; End of hotel property DS.



5.14 Segment 13 (RM 55.15 – 55.3)

Segment 13 is a recognized erosion location that is currently in design and projected for construction soon with the USACE Sacramento District (Site 55.2). The proposed project will be a modern rip rap design with a soil trench for riparian vegetation.

The overall bank erosion potential is high due to high erodibility, poor cover and an oversteepend slope. The bank scour is low as the channel section is larger than calculations predict. However, lateral erosion extends into the levee prism at all flows (the prism is already encroached). The floodplain behind the levee is low and marks the upstream end of the Little Pocket Reach where homes were built on low floodplain directly up to the landside levee toe. Several lengths of the levee are fenced and gated where private Homeowners Associations are established (HOAs); DWR who maintains the levee has full time access to conduct maintenance and repairs.

The levee is overall bank erosion potential is rated low and scour and lateral erosion extents do not encroach into levee prism.

5.15 Segment 14 (RM 54.75 – 55.15)

Segment 14 is located within a straight reach section with a narrow to no berm, steep slopes and a moderate density and diversity of vegetation. The bank and levee slopes coincide. There are large trees along the bank with undermined roots and some gaps in the bank treeline indicate past tree fall and rip rap repairs. The existing bank is steep and encroached into the levee prism. The thalweg aligned along the toe of bank at elevation - 22.0 feet 65 feet below the top of levee. The levee top elevation is around 42 feet while the floodplain behind the landside levee toe is around 20 feet .

The levee prism is already impinged under existing conditions and is further impinged by scour and lateral erosion. The overall bank erosion potential is rated high for all flows due to the steep slope and high slope failure potential, high erodibility and lack of adequate cover.

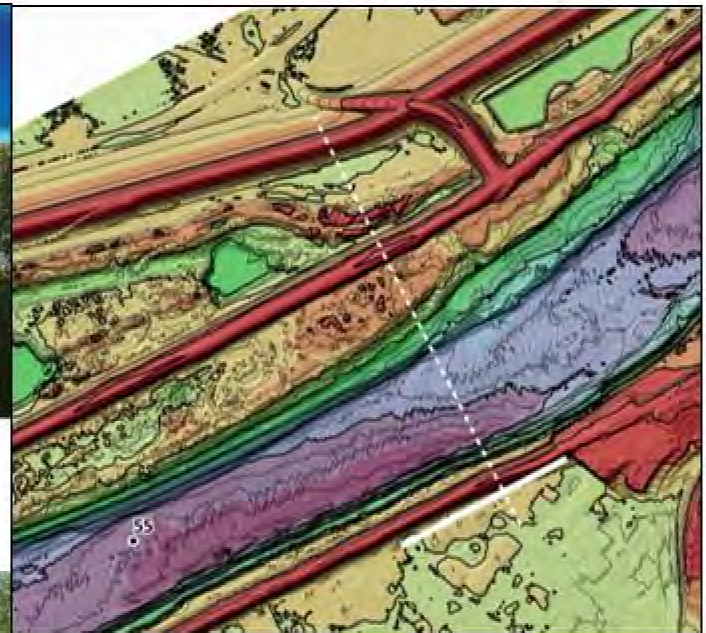
The levee overall erosion potential is low due to low shear stress and adequate grass cover. The levee section at this location is relatively wide.

5.16 Segment 15 (RM 54.2 – 54.75)

Segment 15 is situated on the inside of a bend with a wide point bar and a 100 to 350 foot wide berm separating the levee from the channel bank. The riparian forest is the last remining of the historic floodplain benches that were drawn onto the 1908 maps and is presumed to be a relict of the hydraulic mining era aggradation. The wide berm buffers the levee from lateral bank erosion. The topography in cross section shows natural levee formation at the top of bank.

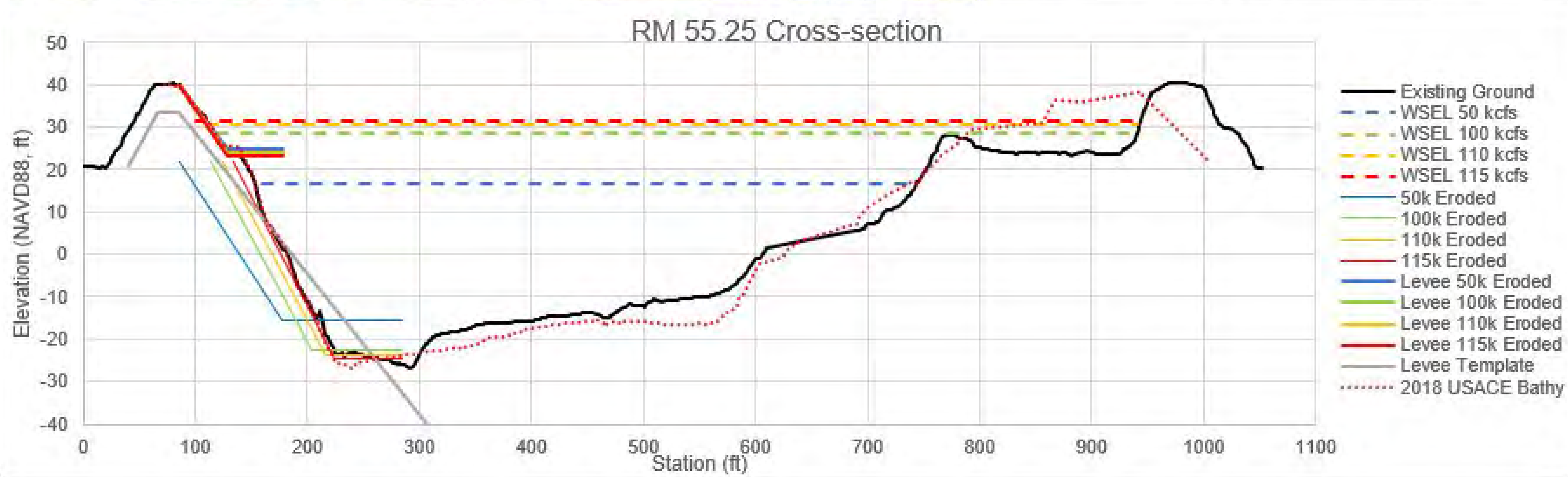
The bank is natural with a erosion cut within the 50,000 cfs stage range. The bank is lined with older large cottonwoods with patches of scrub willow. The thalweg at elevation – 40 feet is aligned along the west bank 300+ feet away from the east bank; as a result the bank is gently sloping and about 65 feet high.

Segment 13: RM 55.15 to 55.3

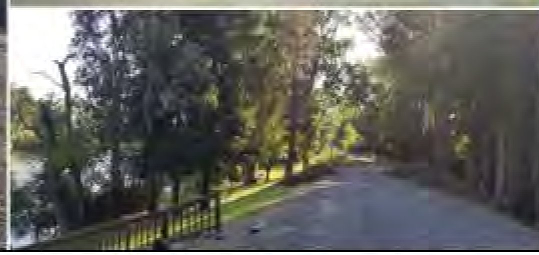


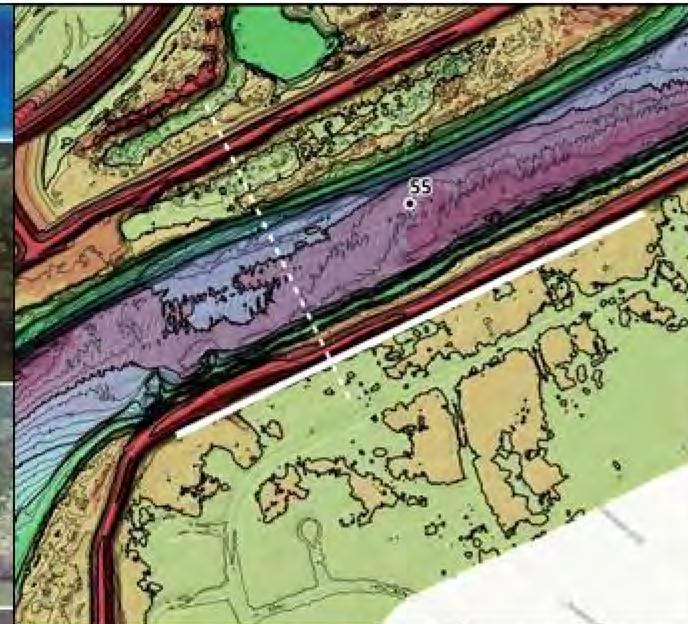
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.21	4.39	4.55	4.64

Soil Type	Crevasse splay deposits; fine to coarse sand, with lenses of silt and clay deposited.
Bench Width	< 50 ft
Existing Revetment	None – Future Site 55.2*
Distinction	End of hotel property US; End of Site 55.2 DS.



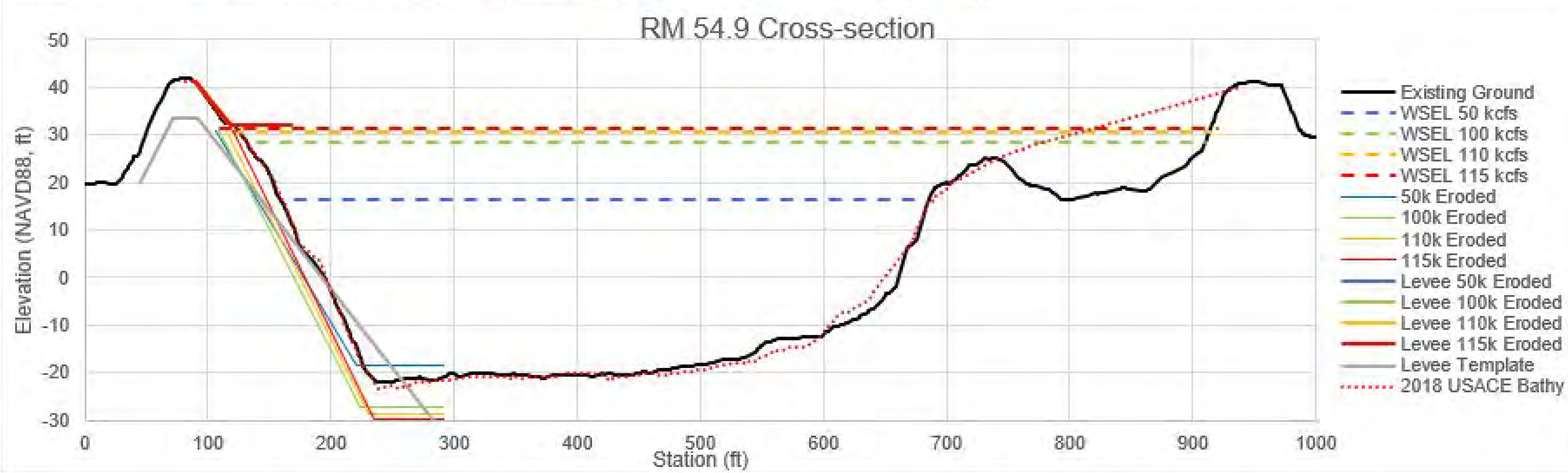
Segment 14: RM 54.75 to 55.15



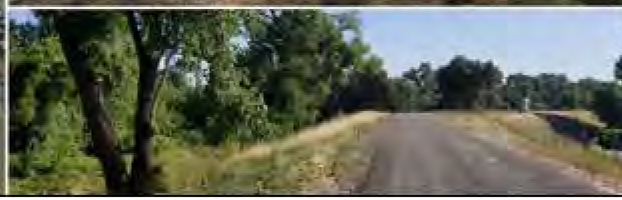


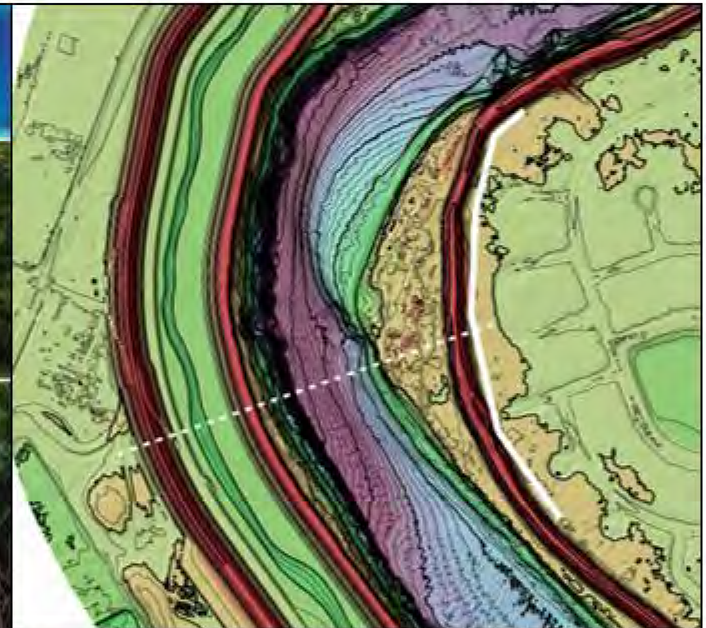
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	2.64	3.82	3.99	4.07

Soil Type	Overbank and alluvial deposits undifferentiated: sand, silt, clay, and minor lenses of gravel.
Bench Width	< 50 ft
Existing Revetment	None
Distinction	Start of Site 55.2 US; Start of Chicory bend DS.



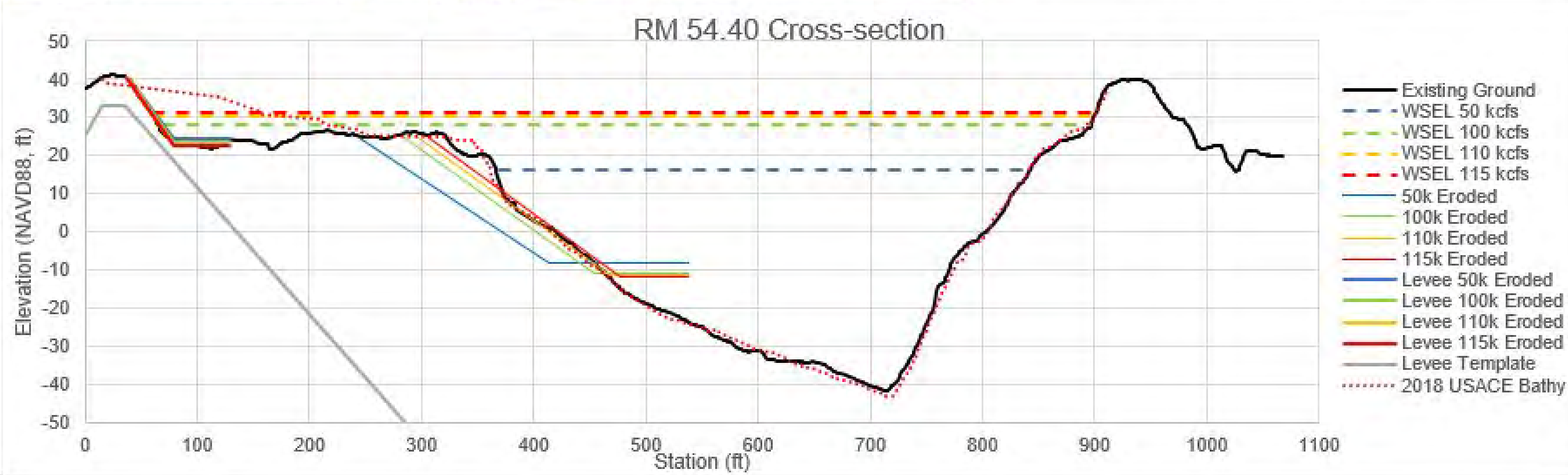
Segment 15: RM 54.2 to 54.75





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.36	4.47	4.63	4.72

Soil Type	Point bar; well sorted sand with minor amounts of silt and clay.
Bench Width	50-350 ft
Existing Revetment	None
Distinction	Start of point bar US; End of point bar DS.



The overall bank erosion potential is rated low due to gentle slope, good cover and good erosion resistance overcoming high erodibility. The scour or lateral erosion extents do not encroach into the levee prism.

The levee toe and face are subject to some erosion as the maximum shear stress of 0.06 lbs/ ft^2 is slightly higher than the critical shear of 0.050 lbs/ft^2. But the projected scour depths and lateral erosion does not encroach into the levee prism. With adequate grass cover, the overall erosion rating for the levee is low.

5.17 Segment 16 (RM 54.0 – 54.2)

Segment 16 is situated along a straight channel segment between bends in the river. The berm width is consistently less than 50 feet. The thalweg is aligned along the opposite bank 400 feet away from the toe of bank which rests at elevation – 25.0 feet. The bank vegetation cover consists of large, mature cottonwoods generally aligned along the top of bank and in a single row. The erosion cut elevation indicates the berm surface is a terrace above the 50,000 cfs effective discharge range. Examination of historic aerial photographs and field conditions indicate that loss of large individual cottonwood trees and their roots systems instantly removes 10-15 feet of berm width and creates a critical condition that the local LMA patches with rip rap. The vegetation free zone from the toe of levee and 12 feet +/- towards the bank is kept clear as a maintenance access. There is a mix of old cobble, concrete rubble and rip rap with patches of 2006 era rip rap where trees were lost.

The channel section is relatively narrow (600 feet +/-) and as a result hydraulic force along the bank is relatively high (maximum 0.22 lbs/ft^2) which exceeds critical shear stress for bank materials. Vegetation cover is rated inadequate and loss of large, single trees removes all protection and usually prompts placement of rip rap to preserve the berm. As a result, the overall erosion potential of the bank is rated high and all projected scour depths encroach into the levee prism. Lateral erosion is additive.

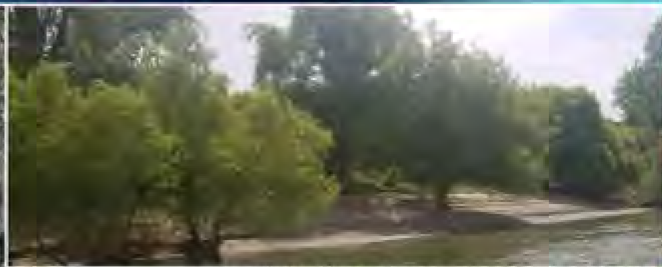
The levee overall erosion potential is rated low due to adequate vegetation cover good slope stability. Projected shear stress for all flows exceeds the critical shear for levee fill at the levee toe but scour and lateral erosion do not encroach into the levee prism.

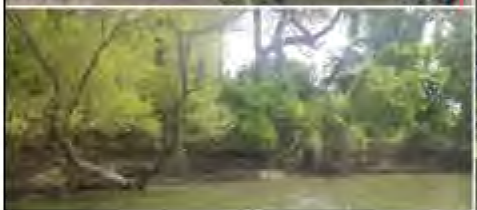
5.18 Segment 17 (RM 53.8 – 54.0)

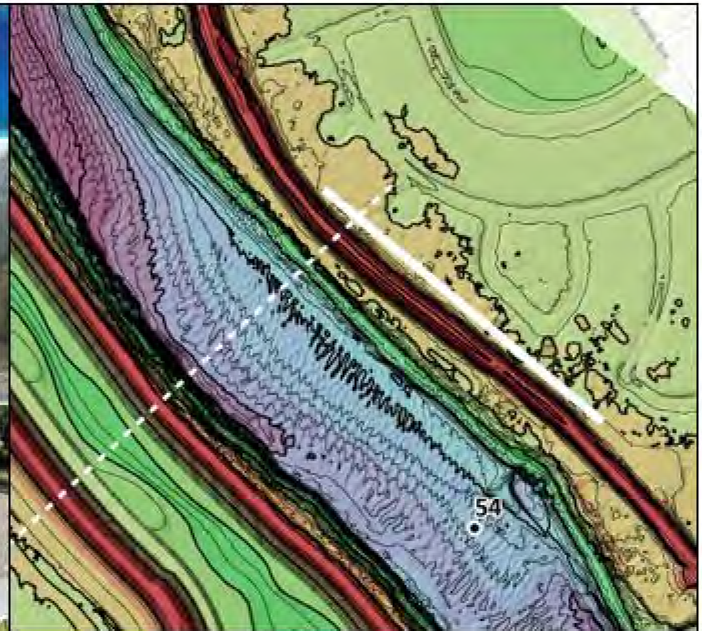
Segment 17 is located just upstream of a sharp bend in the channel. It has a relatively wide berm (100+ feet) and is densely vegetated. There is a stormwater outfall at RM 53.98 that is damaged. The remaining bank has older cobble, rip rap and concrete rubble cover that have partially eroded away. The levee is around elevation 40 feet and the land behind the levee at around 15 feet . The thalweg is aligned along the toe of bank at elevation -23 feet but is over 100 feet from the top of bank.

The bank erosion potential is high due high slope failure susceptibility and mass loading by large trees along top of bank. The projected depth of scour and lateral erosion are well away from the levee prism.

Segment 16: RM 54.0 to 54.2

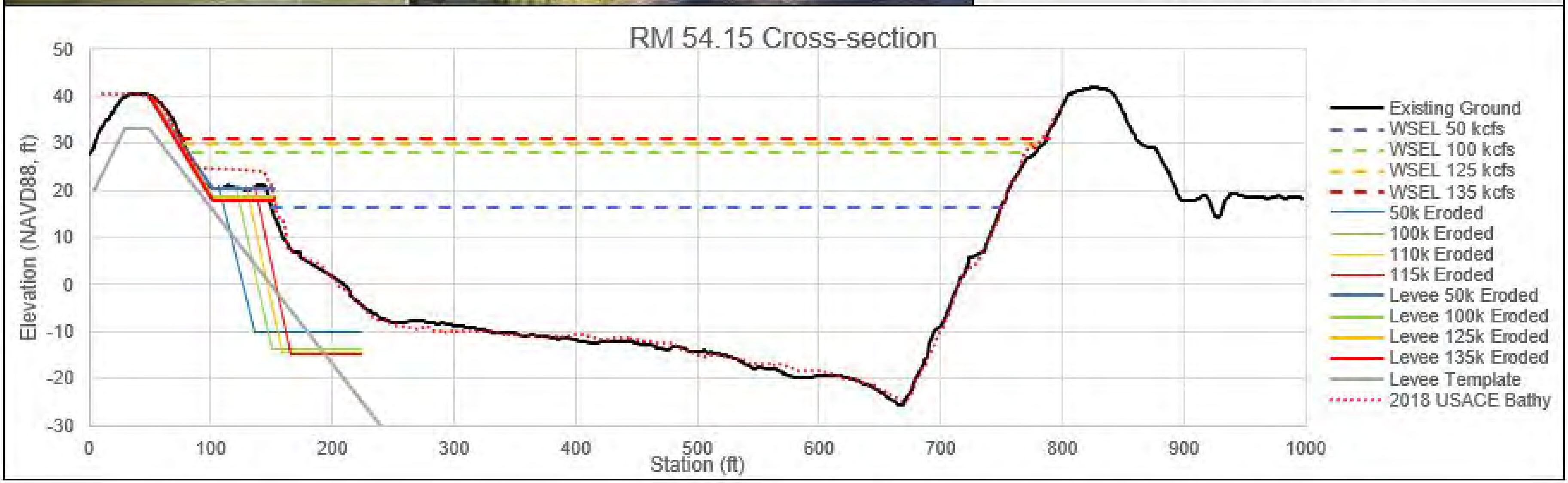




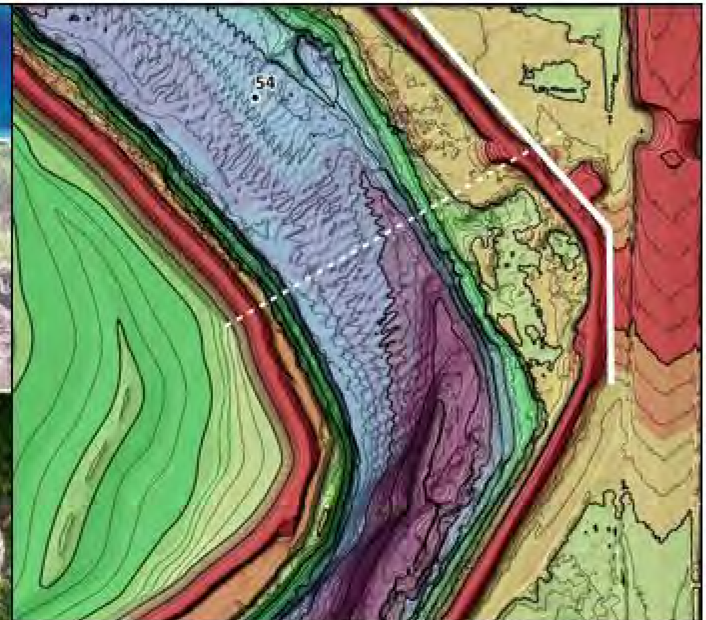


Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.41	4.68	4.86	4.96

Soil Type	Overbank deposits; sand, silt, and clay; deposited during high-stage flows.
Bench Width	50-125 ft
Existing Revetment	None
Distinction	End of point bar US; Start of Oak Hall Bend DS.

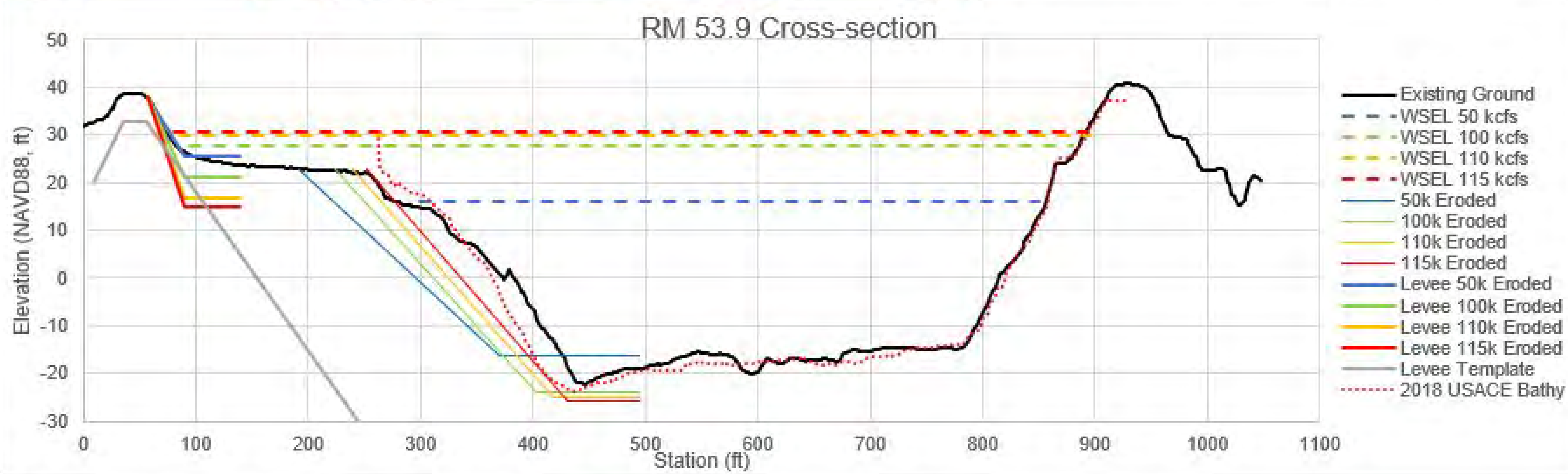


Segment 17: RM 53.81 to 54.0



Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.60	5.12	5.34	5.46

Soil Type	Channel bar and meander scroll deposits; fine gravel, interbedded sand, silt, and clay from lateral channel migration.
Bench Width	100-300 ft
Existing Revetment	Sparse old rock
Distinction	Start of Oak Hall Bend US; End of Oak Hall Bend DS.



The levee erosion potential is low for flows below 100,000 cfs, but high for 115,000 cfs due to scour depth and oversteepening of the levee waterside slope. The projected erosion extents encroach into the levee prism for all flows above 50,000 cfs.

5.19 **Segment 18 (RM 53.5 – 53.8)**

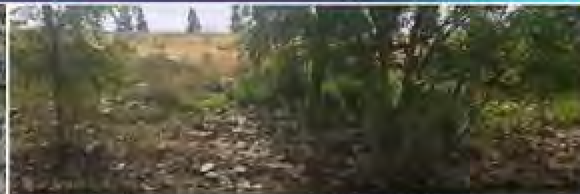
Segment 18 is located along the outer bank of a sharp bend with essentially no berm width (i.e. levee and bank slopes coincide). The thalweg at elevation – 45 feet is aligned along the bank toe. The overall levee and bank height is about 80 feet. The existing bank slope is already encroached into the levee prism and the slope between the levee and shoreline is very steep. Vegetation along the bank slope below the levee toe varies from a continuous line of dense willow scrub (some patches appear to be planted) to patches and individual large trees.

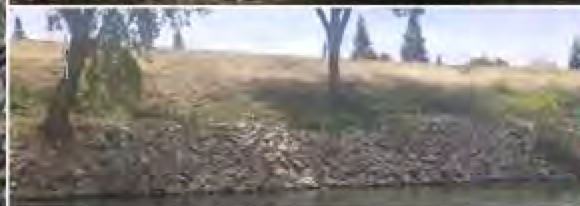
Field inspection from the waterside shows a continuous and large rip rap revetment with the willows and other vegetation growing through. NHC wasn't able to find any documentation, plans or as-builts for this structure and thus is not able to confirm the date of installation nor the below water extent and volume of rock. Examination of aerial photographs show continuous tree cover along the shoreline in 1947 then a barren, continuous revetment in 1957. There appears to have been an upgrade around 1971 when there was construction of residential properties and Interstate 5 just behind the levee. Vegetation grew in after 2006 and there are indications of patches in the upper slope of the revetment which may indicate repair (possibly with plantings). Inspection from the waterside showed several areas where the rock slope rip rap has moved or eroded away. In any case, without as built plans it is unknown how reliable the existing protection will be in future floods. Examination of a cross section at RM 53.8 (See Appendix A) and field inspection of distorted and fallen trees and a break in the shoreline rip rap cover suggests a recent bank slump failure between the 2008 and 2018 bathymetry surveys.

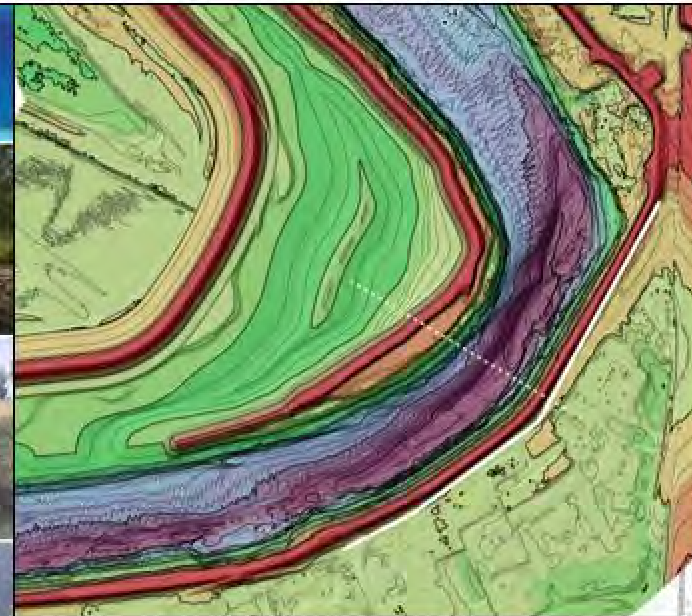
Due to slope failure susceptibility and location along the outside of the bend, the overall erosion potential for the bank is rated high for flows above 50,000 cfs. The overall erosion potential for the levee is high at 115,000 cfs. This is due to deep scour of the bank and levee toe that over steepens slopes. Scour and lateral bank erosion extents are well into the levee prism and the long duration, 50,000 cfs flow lateral bank erosion projection is through the levee.

NOTE: All of the following segments around The Pocket (Segments 19 through 30) have a narrow or absent berm with a single line of large trees (cottonwoods) that are being eroded out leaving gaps where they have fallen. In most gaps, rip rap has been placed to retain berm width and maintenance access along the toe of levee. There are 11 locations of modern rip rap revetment placements dated after 2000 and have as-built plan sets. The modern revetments cover roughly 20 percent of the bankline from RM 47 to 53.5, have a soil trench and riparian plantings and range in length from less than 100 feet to nearly 2,000 feet. One plan set entitled "FEMA Sites" covers 8 sites between RM 49.6 to 53.1 segments 29 to 19. Some of the transitions between the modern soil trench revetments and the adjacent banks are abrupt (i.e. 90 degrees) which forms eddies and in some cases causing some erosion.

Segment 18: RM 53.5 to 53.81

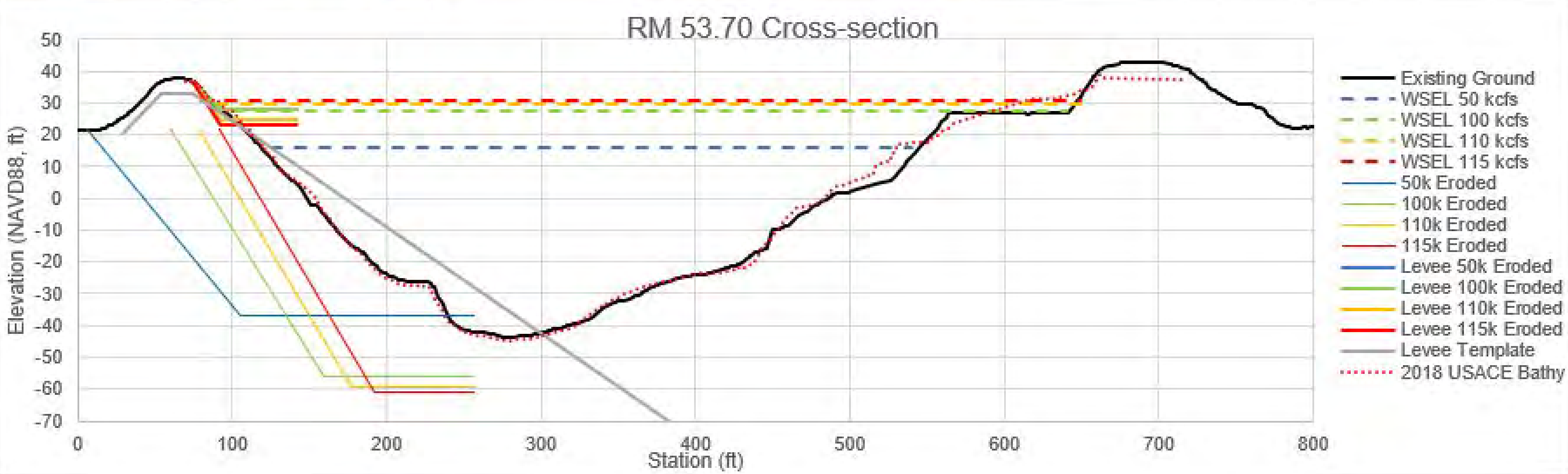






Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.71	5.09	5.29	5.40

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Old rock with planted soil trench – Site RM 53.7L (1970), sparse 2006 rock.
Distinction	End of Oak Hall Bend US; Change in bank protection DS.



5.20 Segment 19 (RM 53.0 – 53.5)

Segment 19 is situated at the downstream end of the sharp bend and the upstream end of The Pocket, a low floodplain area (most below elevation 10 feet) that is densely urbanized. Berm widths between 0 and 50 feet. The thalweg is aligned along the toe of bank at elevation -28 feet. The existing bank slope is steep and already encroached within the levee prism. The bank and berm (where present) vegetation consists of some large trees and a fairly continuous shoreline cover of shrub willows (some appear planted). There is a very short 200 foot long modern revetment at RM 53.47 which appears to have adequate rock volume, but this only covers less than 10% of the segment.

The overall bank erosion potential for all flows is high and scour and lateral erosion encroaches further into the levee prism. Hydraulic force along the bank toe is 0.28 lbs/ft^2 maximum. The levee rating overall is low, however scour and lateral erosion extents at the levee toe encroach into the levee prism at all flows.

5.21 Segment 20 (RM 52.6 – 53.0)

Segment 20 is a continuation of Segment 19 with more exposed older bank protection on the upstream end and a modern revetment at the downstream end. Berms widths are less than 50 feet and 0 feet in several places. The bank vegetation of large tress is fairly continuous and there are numerous 2006-era rip rap repairs where trees have fallen. There are several private piers along the bank. The levee on the opposite west bank was recently set back which could reduce hydraulic force on the east bank.

The bank is steep and there are indications of recent mass failures. The thalweg is aligned along the west (opposite) bank and the toe of bank elevation is – 5 ft. The levee crown at elevation 35 feet is slightly wider than 20 feet minimum prism.

The overall bank erosion potential is rated high for all flows due to high erodibility and inadequate cover. Hydraulic force exceeds the critical shear of 0.045 lbs/ft^2 and scour and lateral bank erosion at all flows encroaches into the levee prism.

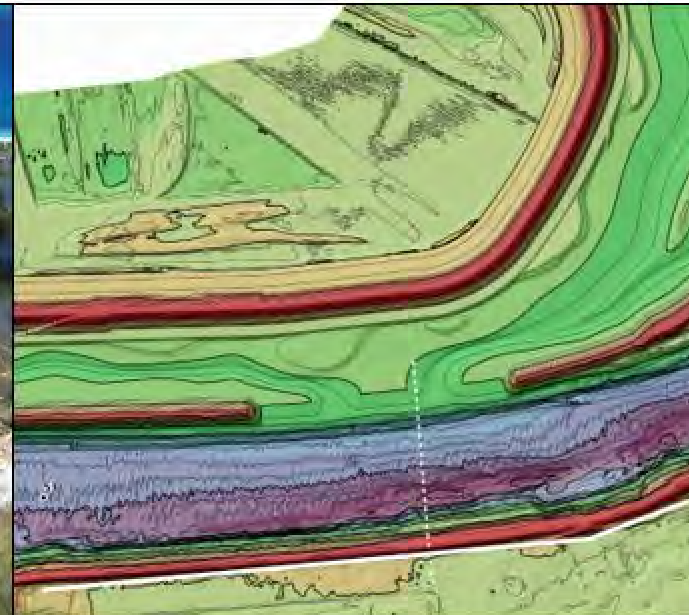
The overall levee erosion potential is rated low for all flows and the scour and lateral erosion extents do not encroach into the levee prism.

5.22 Segment 21 (RM 52.2 – 52.6)

Segment 21 has a narrow to nonexistent berm with 1,200 feet (70 percent of the bankline) of modern revetment and 800 feet of patchy 2006-era repairs. Outside the modern revetment, the bank is very steep and already encroached into the levee prism. The thalweg is aligned along the west bank and the toe of bank is at elevation 5.0 feet and the bank is 40 feet high to the top of the levee.

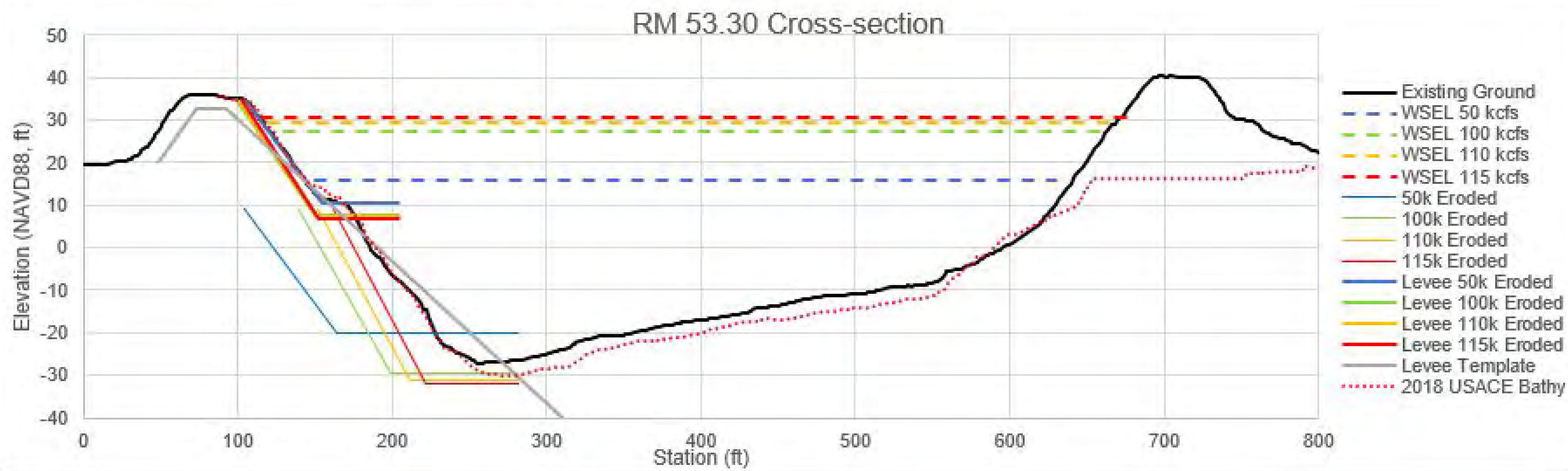
The bank vegetation is generally continuous shrub shoreline cover with patches of large trees and some barren spots.

Segment 19: RM 53.0 to 53.5

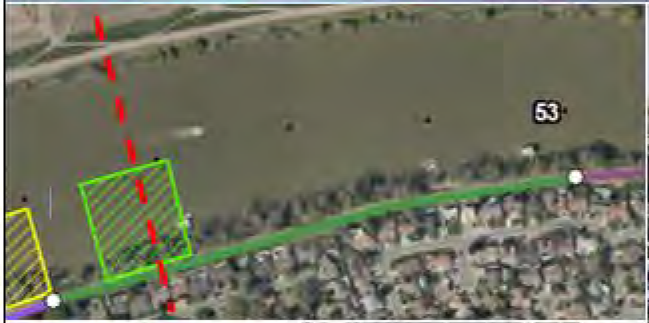


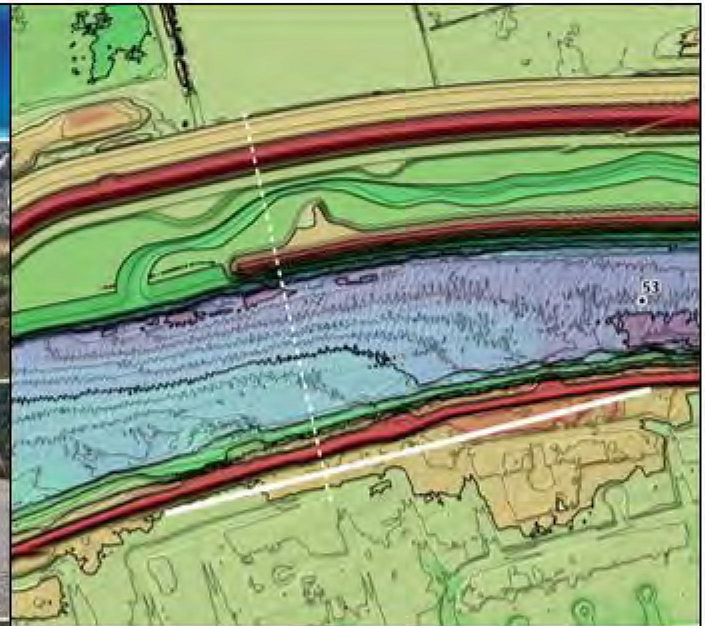
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.28	4.49	4.68	4.77

Soil Type	Overbank and Crevasse splay deposits; sand with lenses of silt and clay
Bench Width	< 50 ft
Existing Revetment	Modern revetment – Site RM 53.1L (2006). Old rock and cobble.
Distinction	Change levee width US; Change in bank protection DS.



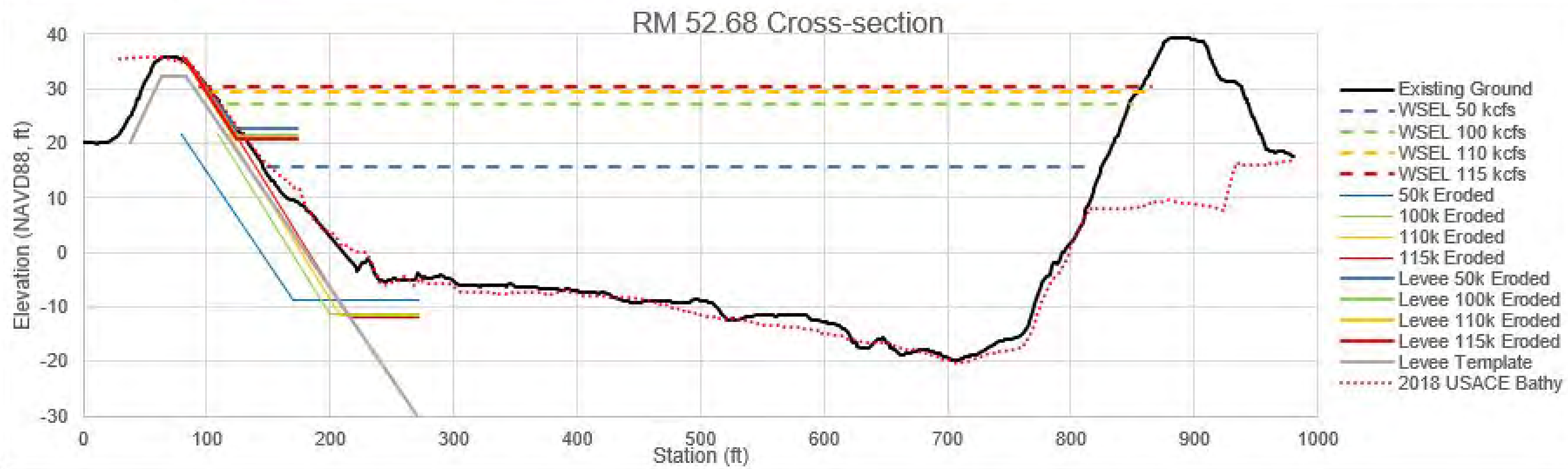
Segment 20: RM 52.6 to 53.0



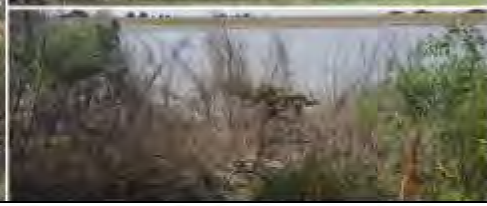


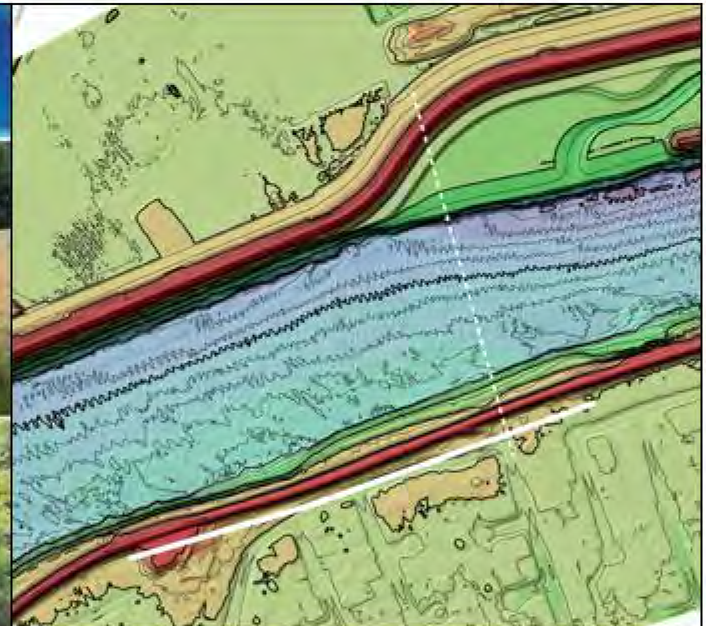
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.11	3.91	4.04	4.11

Soil Type	Overbank and Crevasse splay deposits; sand with lenses of silt and clay.
Bench Width	< 50 ft
Existing Revetment	Modern revetment – Site RM 52.4L (2006). Sparse rock, concrete, rubble mostly around docks.
Distinction	Change in bank protection US; Change in bank protection DS



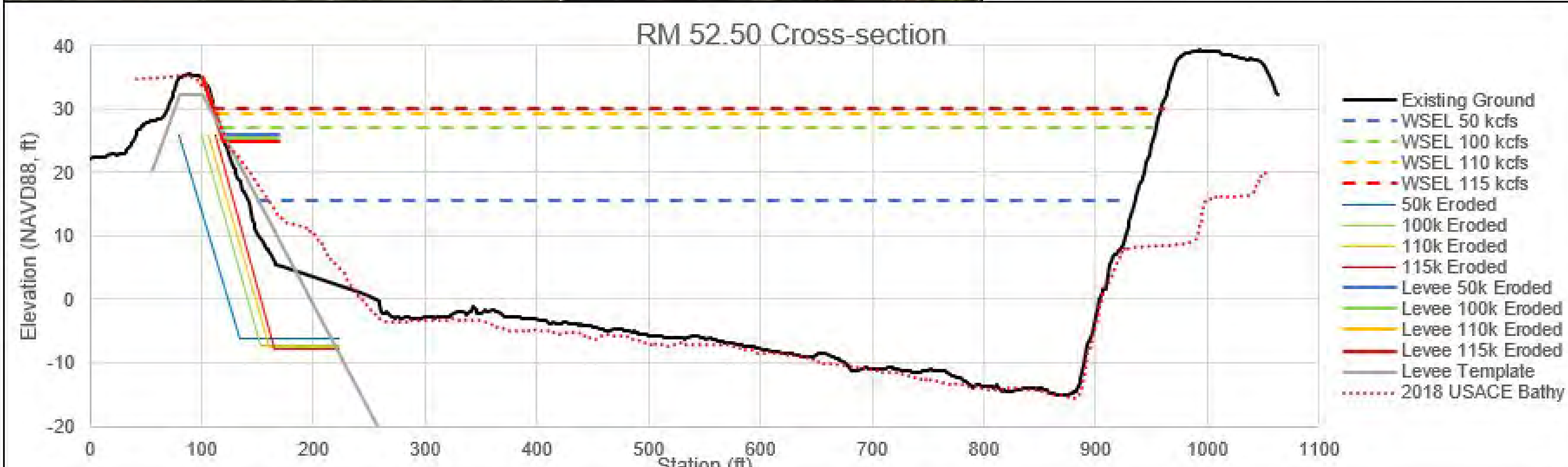
Segment 21: RM 52.2 to 52.6





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.15	4.08	4.21	4.29

Soil Type	Overbank and channel bar deposits; fine gravel, sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Modern revetment – Site RM 52.3L (2009).
Distinction	Change in bank protection US; Change in bank protection DS.



The overall bank erosion potential is rated low for the revetment section (1,200 feet) but the unprotected 800 feet is rated high due to inadequate cover. This yields an overall high erosion potential for the segment all flows. The bank scour and lateral erosion extents encroach into the levee at all flows.

The overall levee erosion ratings are low for all flows and the scour and erosion extents do not impinge into the levee prism.

5.23 Segment 22 RM (51.6 – 52.2)

Segment 22 is located along the inside of a sharp bend that has a relatively narrow 500 foot wide channel section. Berm widths are less than 50 feet and the top of bank erosional cut is relatively high (15+ feet) above the 50,000 cfs level. Bank vegetation is discontinuous predominately large trees with some patches of willow scrub. Tree roots are deeply undermined in places and there are large gaps where large trees have fallen in the past. The toe of bank elevation is – 18 feet and parts of the segment are encroached within the levee prism. There are many patches of bank protection of all types, including fairly extensive 2006 era repairs on bank and levee face.

The overall erosion potential of the bank is rated high for all flows due to steep slopes, erodibility and high slope failure susceptibility. Loss of large trees significantly reduces berm width. Scour and lateral bank erosion for all flows encroaches into the levee prism.

The levee is rated low for overall erosion potential and the projected scour and lateral erosion do not encroach into the levee prism.

5.24 Segment 23 (RM 51.3 – 51.6)

Segment 23 has a continuous berm that is less than 50 feet wide. There is modern revetment from RM 51.4 to 51.6 that was built in 2006. Vegetation cover along the bank is discontinuous with patches of scrub willow where large trees have fallen. Similar to other areas, loss of large trees diminishes berm width to the point of needing repair to maintain the toe of levee access. The thalweg is aligned along the opposite bank. The toe of bank elevation is - 8 feet and the bank toe-to-levee top height is 40 feet.

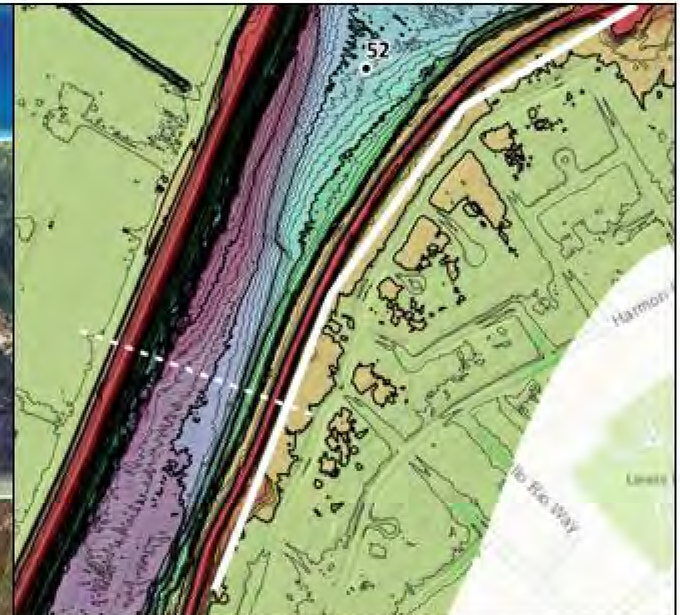
Since the modern revetment only covers a portion of the segment, the segment is rated for the unprotected part. The overall bank erosion potential rating is high for all flows due to high slope failure susceptibility. Scour and lateral erosion extents encroach into levee prism for all flows.

The levee rating is low for all flows primarily due to good vegetation cover, below critical shear stress and low slope failure potential.

5.25 Segment 24 (RM 51.15 – 51.3)

Segment 24 is a short gap between modern revetments. The berm width is less than 50 feet in the upper 100 feet and zero over the remainder. Vegetation is sparse with large widely spaced trees along the section with berm. The section without berm is barren with 2006 era rip rap repair. The existing bank is

Segment 22: RM 51.6 to 52.2



Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.24	4.31	4.46	4.54

Soil Type	Overbank and channel meander scroll deposits: fine gravel, sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Mix of cobble, riprap, broken concrete.
Distinction	Change in bank protection US; Bank protection starts DS.

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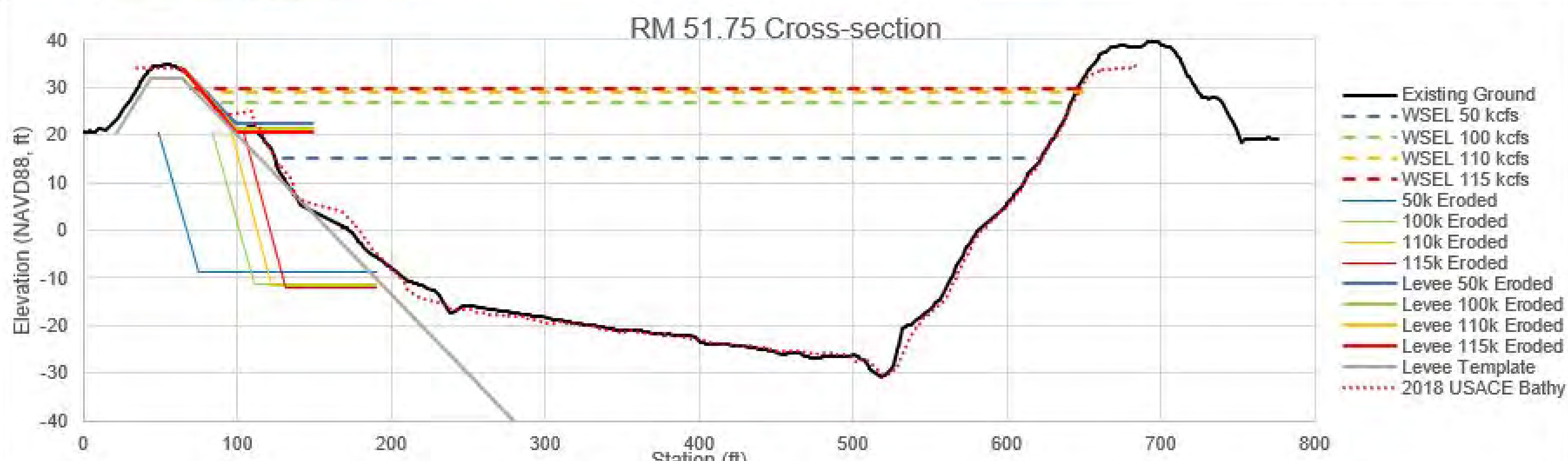
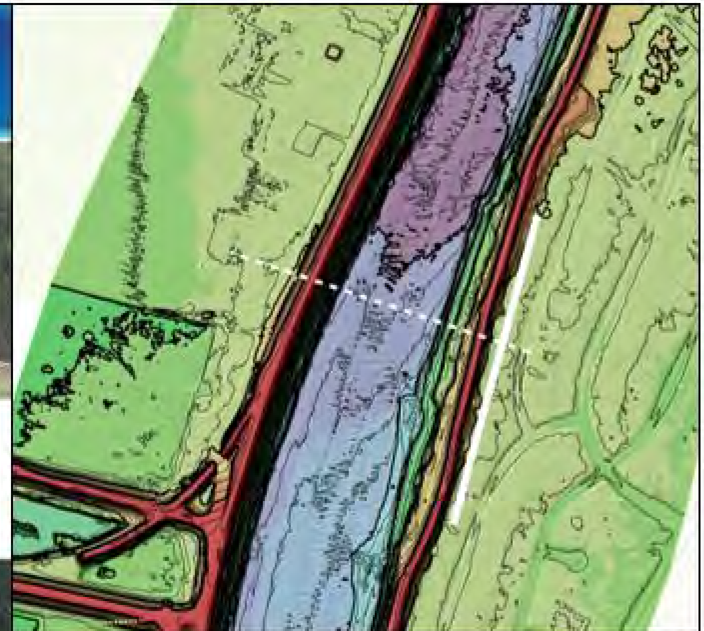
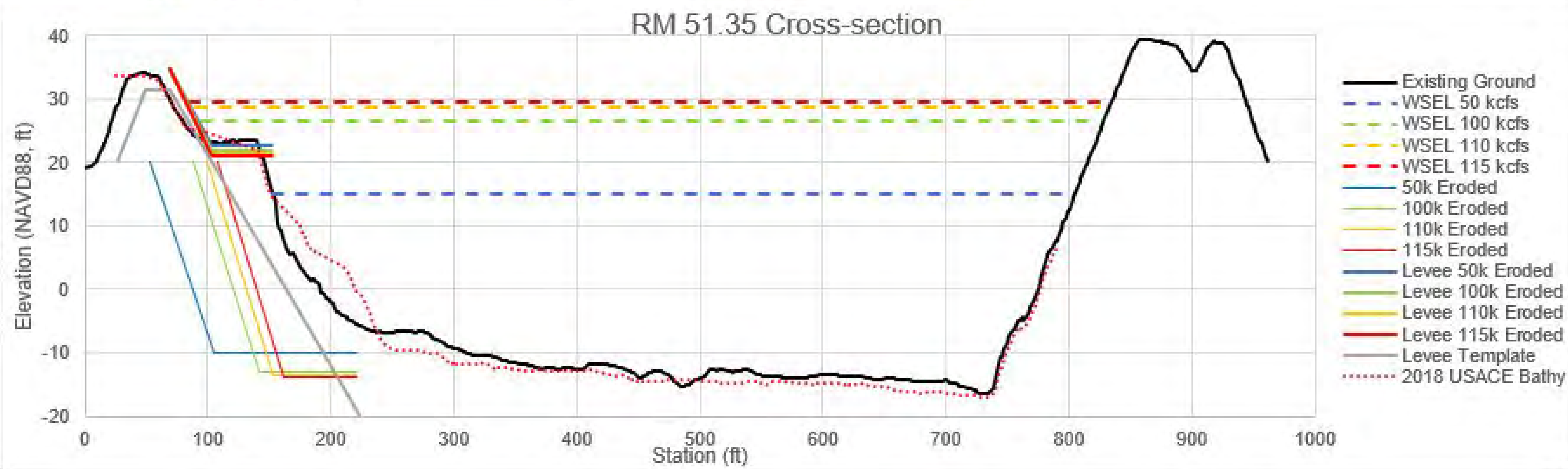


Segment 23: RM 51.3 to 51.6

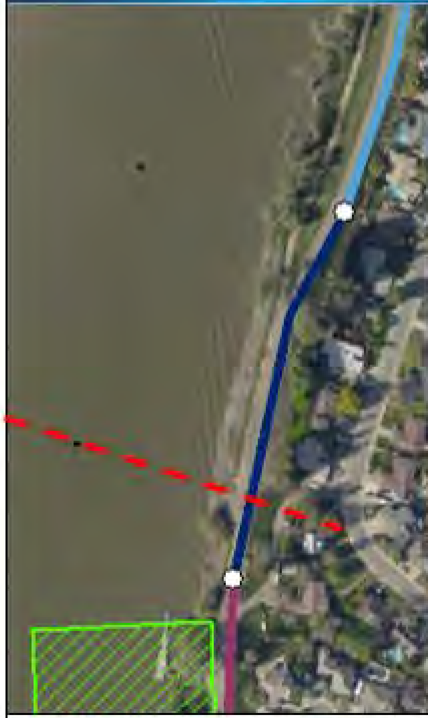


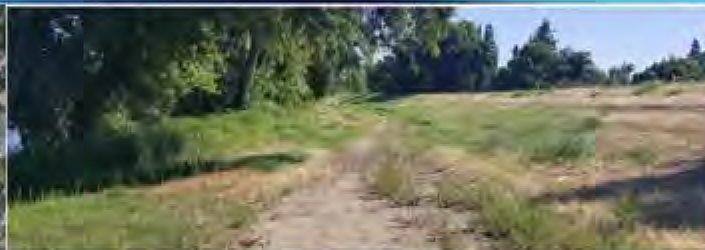
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.22	4.34	4.51	4.60

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	~50 ft
Existing Revetment	Modern revetment – Site RM 51.5L (2006). Mix of cobble, riprap, broken concrete.
Distinction	Bank protection ends US; Change in bench width DS.



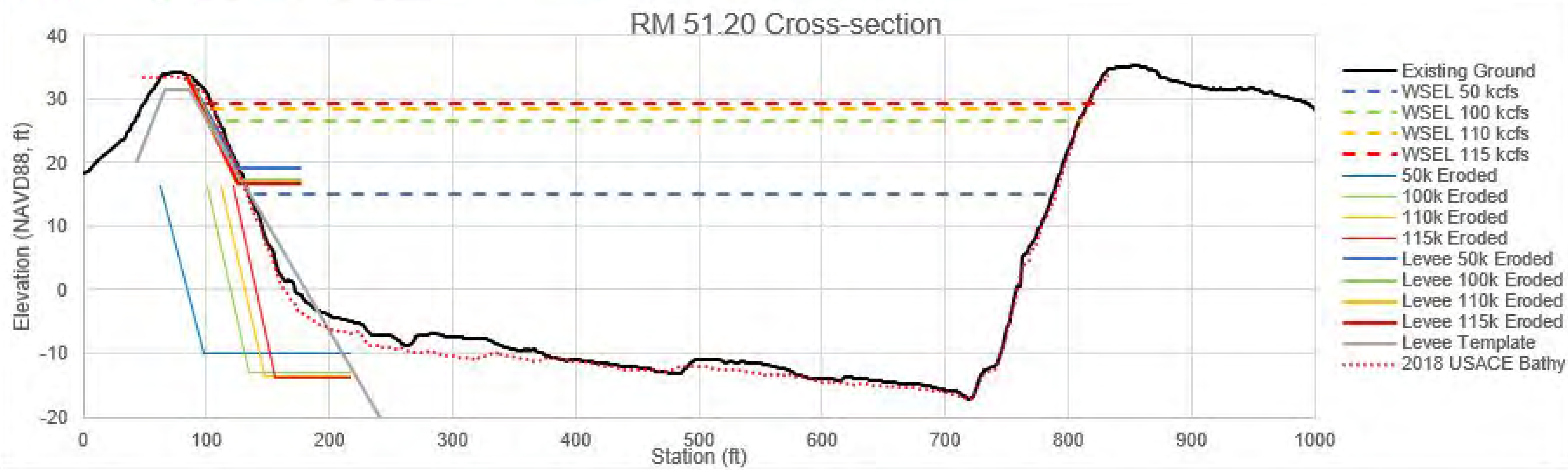
Segment 24: RM 51.15 to 51.3





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.67	4.81	4.98	5.07

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Concrete and rock.
Distinction	Change in bench width US; Change in bench width DS.



encroached with the levee prism and it appears that there has been roughly 10+ feet of progressive erosion of the bank toe between 2008 and 2018 bathymetry surveys.

The overall bank erosion potential is rated high for all flows due to deep scour and high slope failure potential. All projected scour and lateral erosion extents encroach into the levee prism.

The overall levee erosion potential is rated low for all flows due to low slope failure susceptibility. The projected scour and lateral erosion extents into the levee prism in all flows.

5.26 Segment 25 (RM 50.9 - 51.15)

Segment 25 has modern revetment which was installed in 2006 except all but the last 300 feet. The berm width is less that 50 feet and vegetation cover along the bank is continuous shrub willow and large cottonwoods and oaks. There are patches of 2006 era rip rap along the levee toe of slope in places. The bank is relatively steep with toe elevation at 8 feet .

For the modern revetment, the bank erosion hazard rating is low for all flows due to good slope failure susceptibility and good protective cover. However, the unprotected 300 foot long section the overall rating is high and thus high for the segment.

Scour and lateral erosion encroaches into the levee toe in all flows. The modern revetment was found not to have adequate volume for projected scour at all flows.

The overall levee erosion rating is low for all flows and projected scour and lateral erosion does not encroach into levee.

5.27 Segment 26 (RM 50.6 – 50.9)

Segment 26 is located within a relatively narrow and straight reach of the Sacramento River. The berm width is generally 0 feet and there are widely spaced large trees with fairly contiguous willow scrub cover. The levee and bank slopes have many 2006 era rip rap repairs and there are scattered older revetments. The process of large tree loss and spot repair is common. The bank and levee slopes are encroached within the levee prism without projected scour. There are indications of past large mass bank failures in the 2008 and 2018 bathymetric surveys.

The overall bank erosion potential rating is high for all flows due poor cover. The projected scour and lateral erosion extents impinge the levee prism at all flows.

The overall levee erosion potential is low for all flows. The projected scour and lateral erosion extents do encroach into the levee prism.

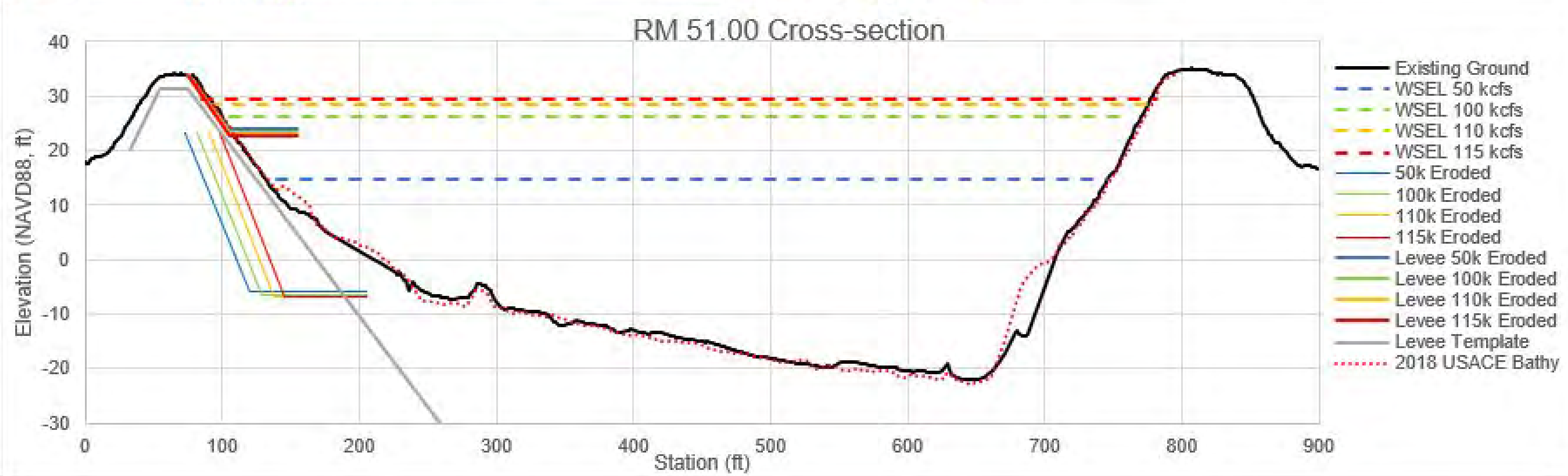
5.28 Segment 27 (RM 50.35 – 50.6)

Segment 27 is a continuation of Segment 26 but with nearly continuous 2006 era rip rap along the lower levee slope and toe and the upper bank. The levee/bank slope is very steep and encroached within the

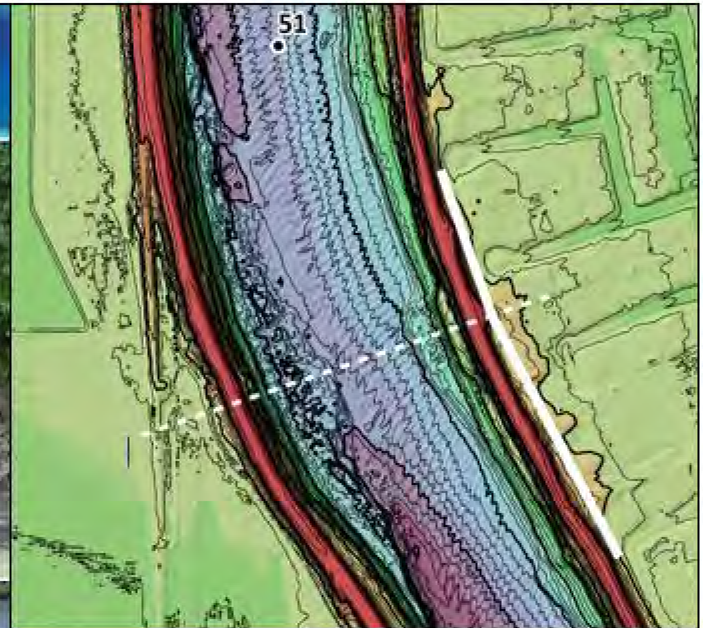
Segment 25: RM 50.9 to 51.15

Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.31	4.73	4.94	5.05

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Modern revetment – Site RM 50.8L (2006). Rock on slope.
Distinction	Change in bench width US; Change in bank protection DS.

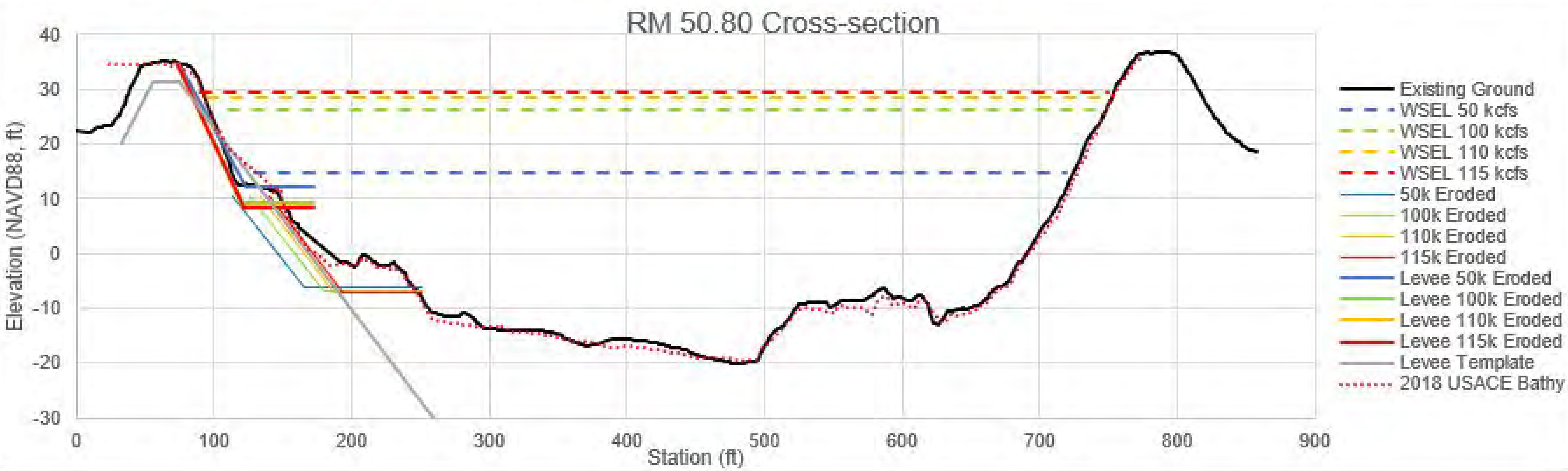


Segment 26: RM 50.66 to 50.9

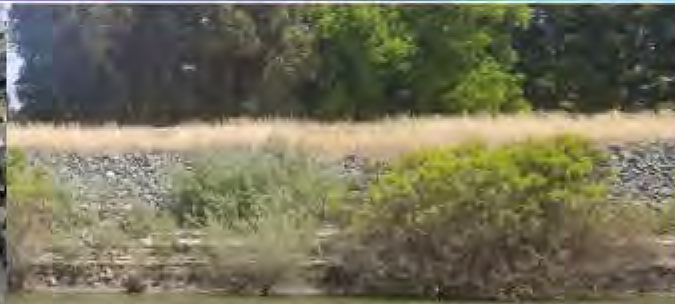


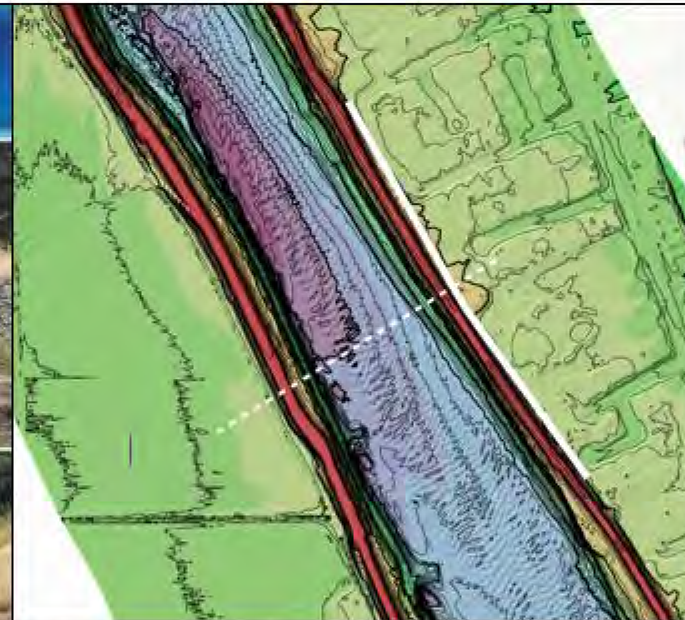
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.11	4.24	4.40	4.50

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Sparse 2006 rock, modern revetment – Site 50.4L (2006)
Distinction	Change in bank protection US; Change in bank protection DS.



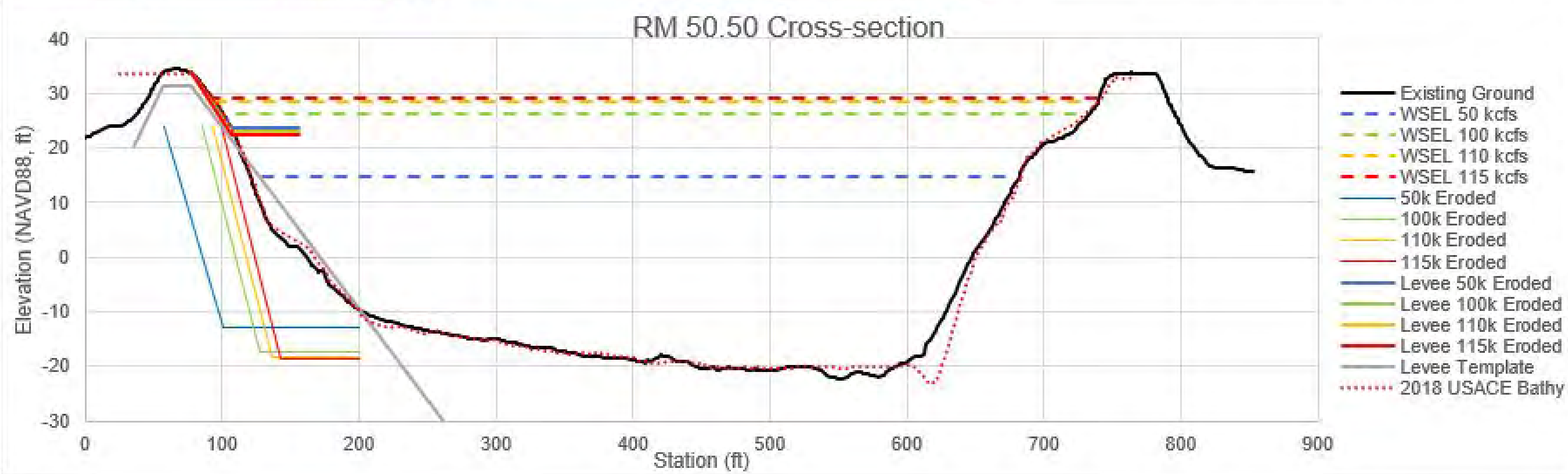
Segment 27: RM 50.32 to 50.66





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	2.99	3.89	4.01	4.08

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Sparse 2006 rock.
Distinction	Change in bank protection US; Change in bench width DS.



levee prism. Scrub vegetation along the shoreline is fairly contiguous. The 2006 era rip rap appears to have been placed in an excess volume so as to launch when the lower bank eroded. None of this rip rap is found along the lower bank shoreline, although there are patches of older repairs in cobble, rubble and rip rap.

The overall bank erosion potential is rated high for all flows due to high slope failure susceptibility. The projected scour and lateral erosion extends farther into the levee prism.

The overall levee erosion rating low for all flows and there is no encroachment into the levee prism although it is close.

5.29 Segment 28 (RM 50.05 – 50.35)

Segment 28 has full coverage of modern rip rap installed in 2007. There is continuous berm less than 50 feet wide. The bank vegetation is a mix of patches of large trees (oaks and cottonwoods) with continuous willow scrub along the shoreline (which is part of the modern revetment soil trench design). The bank is very steep but with the residual berm, it is not encroached into the levee prism. The thalweg is along the bank toe at elevation – 15 feet .

The overall bank erosion potential is rated low for all flows due to the modern revetment and adequate rock volume. The possible exceptions are the transitions at the ends of the modern revetment which tend to be abrupt possibly causing erosion due to eddies. The potential scour and lateral erosion do encroach into the levee template.

The overall levee erosion potential is rated low for all flows and projected scour and lateral erosion do not encroach into the levee prism.

5.30 Segment 29 (RM 49.45 – 50.05)

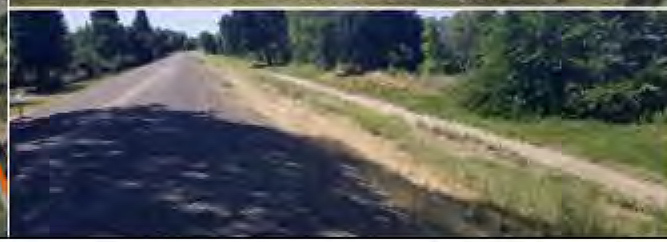
Segment 29 is a rough continuation of Segment 28 with little or no berm. There are two modern revetment sites between RM 49.5 and 49.6, and about 200 feet between RM 49.8 and 49.9. There is a large concrete box stormwater drainage out fall at RM 49.7 with a pump station on the land side of the levee.

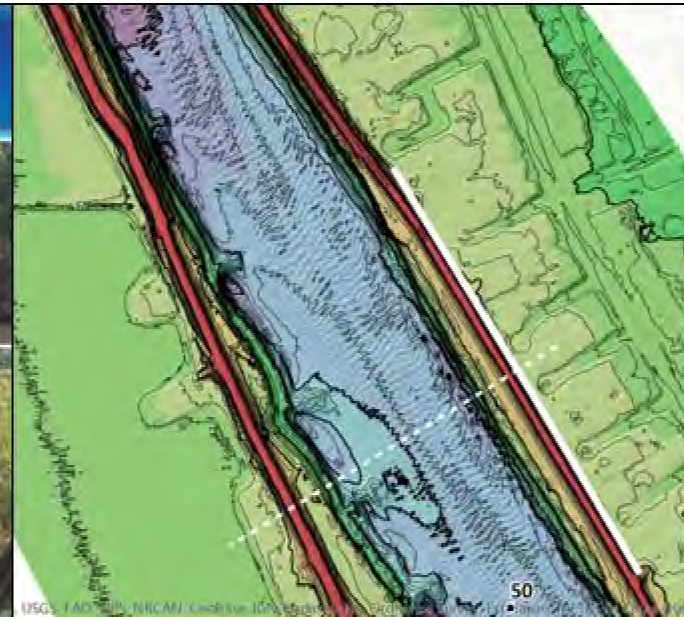
The bank is very steep and already encroached into the levee template. The thalweg is aligned along the toe of bank at elevation -15 feet . The bank height below the 50,000 cfs stage is 30 feet and 50 feet to the top of levee. Bank vegetation cover ranges from dense to barren and includes large oaks, cottonwoods and willow scrub.

The overall bank erosion rating is high for all flows due to high slope failure susceptibility. The projected scour and lateral erosion encroaches further into the levee prism.

The overall rating for the levee is low due to low slope failure susceptibility. The scour and erosion extents at 115,000 cfs encroaches into the levee.

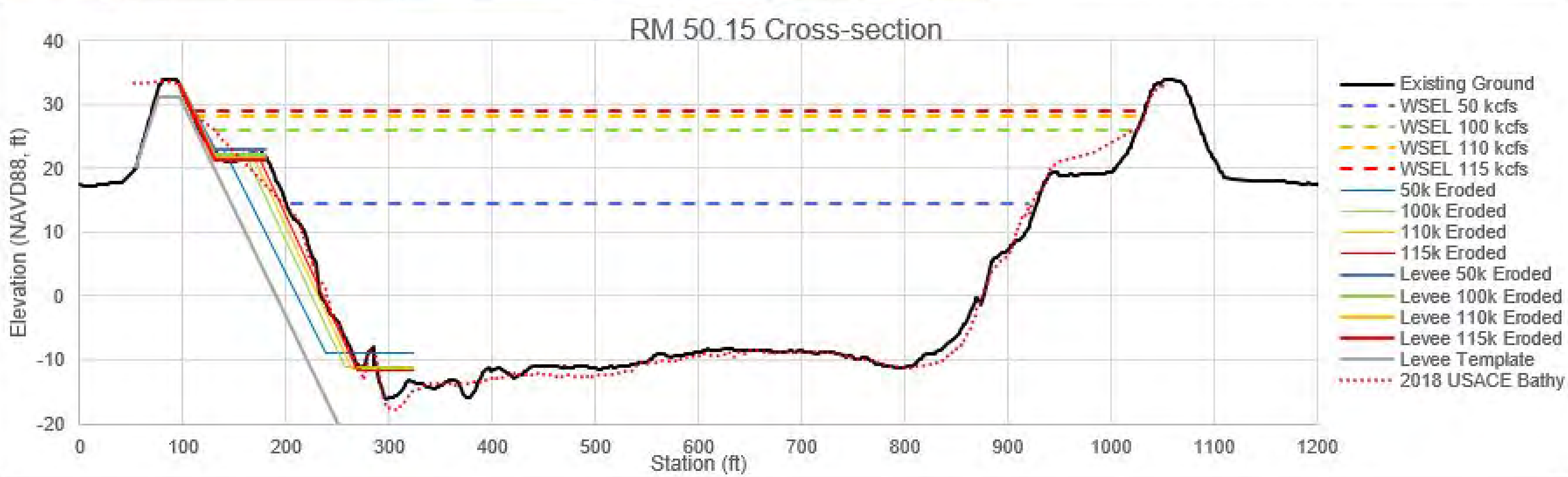
Segment 28: RM 49.98 to 50.32



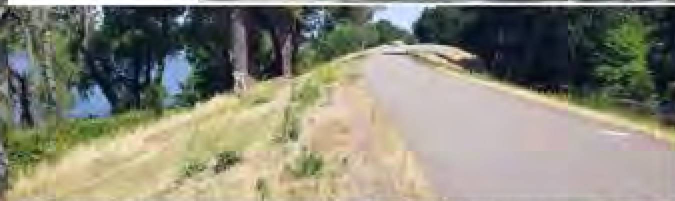


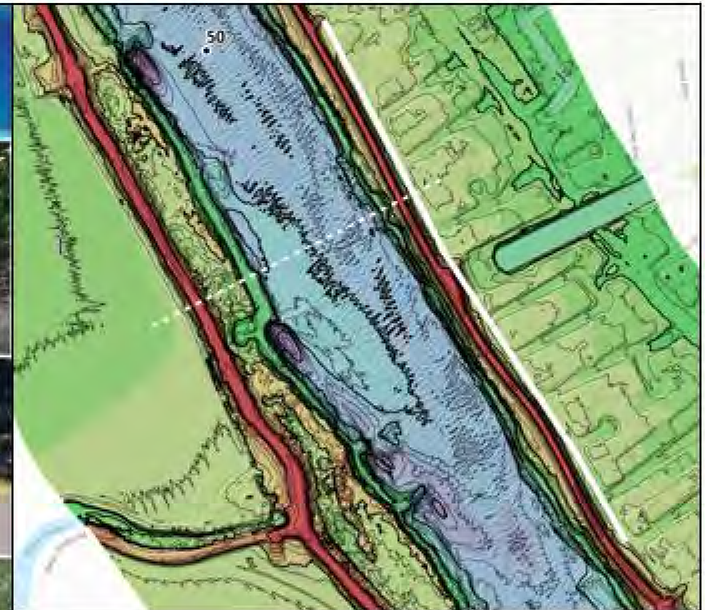
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	2.99	3.87	3.97	4.04

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	~ 50 ft
Existing Revetment	Modern revetment – Site RM 50.2L (2006); Concrete rubble on US end.
Distinction	Start of bank protection US; Bank protection ends DS.



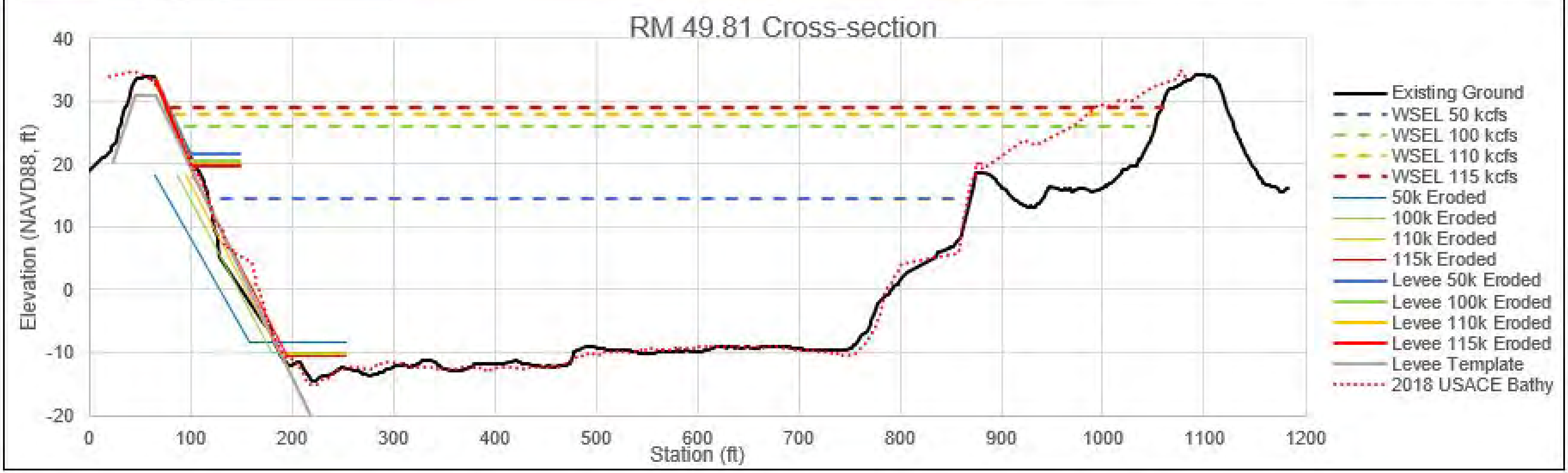
Segment 29: RM 49.45 to 49.98





Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.23	4.24	4.38	4.45

Soil Type	Overbank and Crevasse splay deposits; fine to coarse sand, silt, and clay.
Bench Width	< 100 ft
Existing Revetment	Old cobble and rock, Modern revetments – Sites RM 49.6L (2006), RM 49.7L (2008), and RM 49.9L (2006)
Distinction	Bank protection ends US; Garcia Bend boat launch DS.



5.31 Segment 30 (RM 48.45 – 49.45)

Segment 30 is aligned along the inside of a broad bend and includes the Garcia Park and Boat Launch area. The berm width ranges for zero to over 50 feet in places and the levee section is relatively wide. The overall bank height is over 40 feet from levee top to toe of bank. There is significant land between the bank, levee face and the levee prism.

Bank vegetation is highly variable consisting of patches of large cottonwoods and oaks with a moderate shrub cover. There is a variety of older bank protection including rip rap, cobble and rubble. There are significant patches of 2006 era rip rap along the levee face, toe and where there is no berm on the upper bank. Large trees are found mostly along the top of bank and similar to other locations along The Pocket, single tree fall usually prompts patch repairs. Most of the large trees have undermined roots.

The overall bank erosion susceptibility is high for all flows due to slope failure susceptibility and projected scour and lateral erosion extents do not impinge into the levee prism.

The overall levee erosion susceptibility is low for all flows and the projected scour and lateral erosion does not encroach into the levee prism.

5.32 Segment 31 (RM 47.25 – 48.85)

Segment 31 covers the remaining frontage along The Pocket up to the Freeport Water Intake at RM 47.25. The berm width is less than 50 feet and is zero in many places. The history of this segment includes extensive rip rap installations in the 1970s when development took place and many repairs since. Over the past 20 years +/-, many large trees have been lost and the gaps are filled with rip rap. There are several critical areas where there is old or no bank protection and ongoing erosion is progressing into the narrow berm and towards the levee toe.

The bank is very steep and coincides with the levee slope in many places. The existing bank is encroached into the levee prism in many places.

The overall bank erosion potential rating is high for all flows as a result of oversteepened slopes, moderate shear stress and mass loading of large trees. Projected bank scour is well within the levee template for all flows, lateral erosion extents project further.

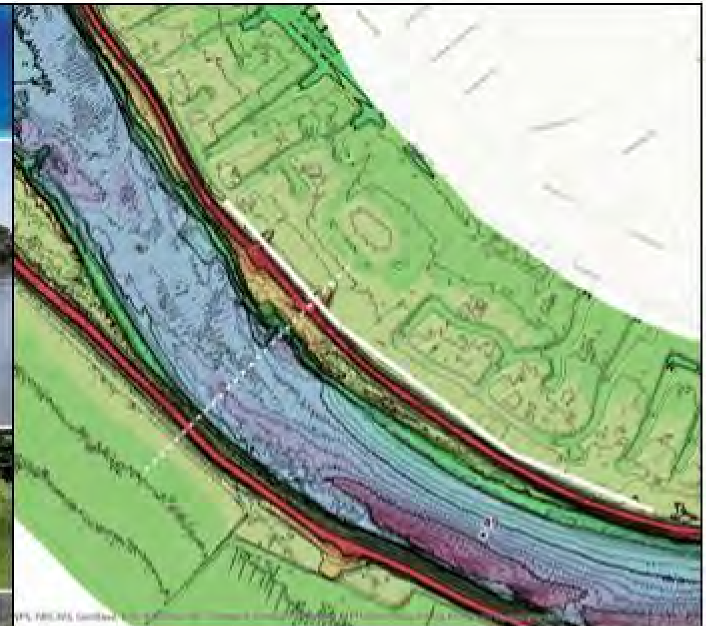
The overall levee erosion rating is low and the projected scour and lateral erosion almost encroaches into the levee template at 115,000 cfs.

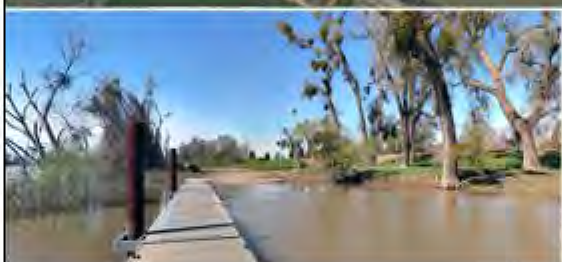
5.33 Segment 32 (RM 46.9 – 47.15)

(note – The Freeport Water Intake at RM 47.2 was not analyzed)

Segment 32 has modern revetment that was installed in the early 2000s. The berm is relatively wide in most places with moderate coverage of large trees. The shoreline vegetation is continuous as a result of the soil trench in the modern revetment and is predominately willow scrub with small trees. The thalweg

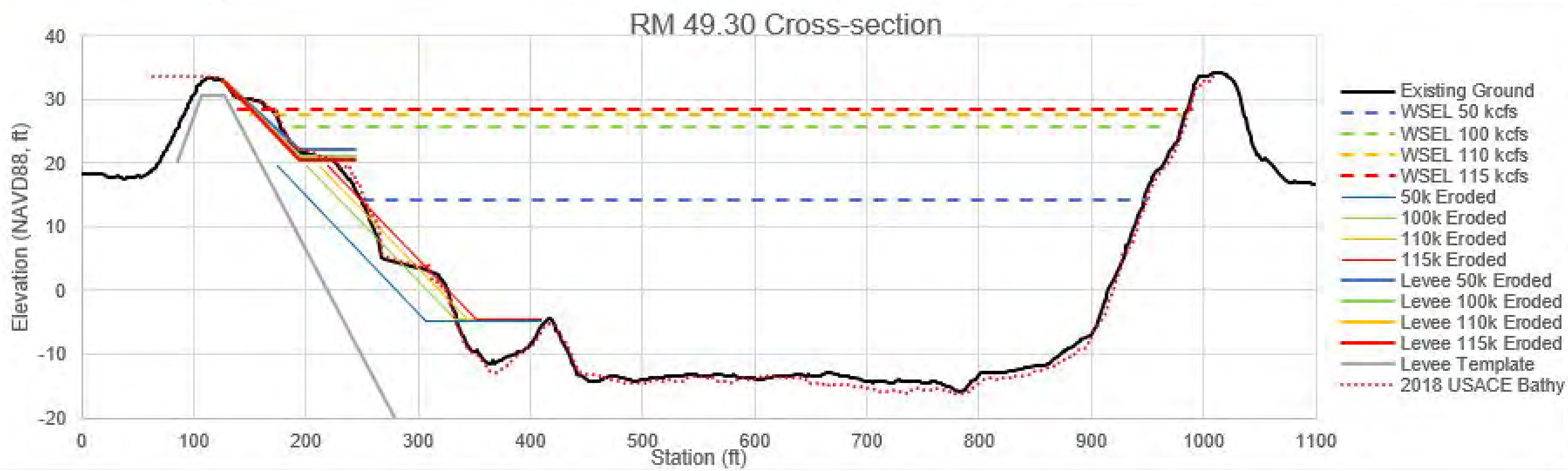
Segment 30: RM 48.85 to 49.45



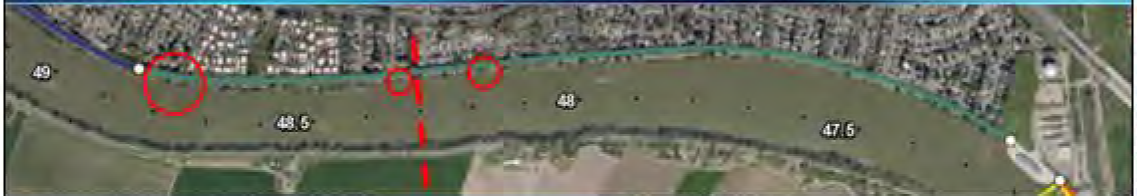


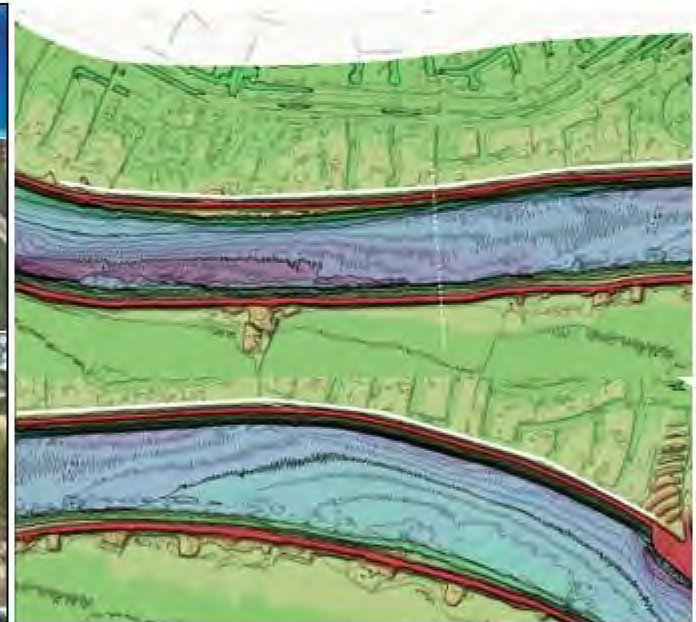
Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.42	4.56	4.72	4.82

Soil Type	Channel bar and meander scroll deposits; fine gravel, sand, silt, and clay.
Bench Width	50-100 ft
Existing Revetment	Old cobble, concrete, rock; boat launch pavement.
Distinction	Boat launch starts US; Change in bench width DS.



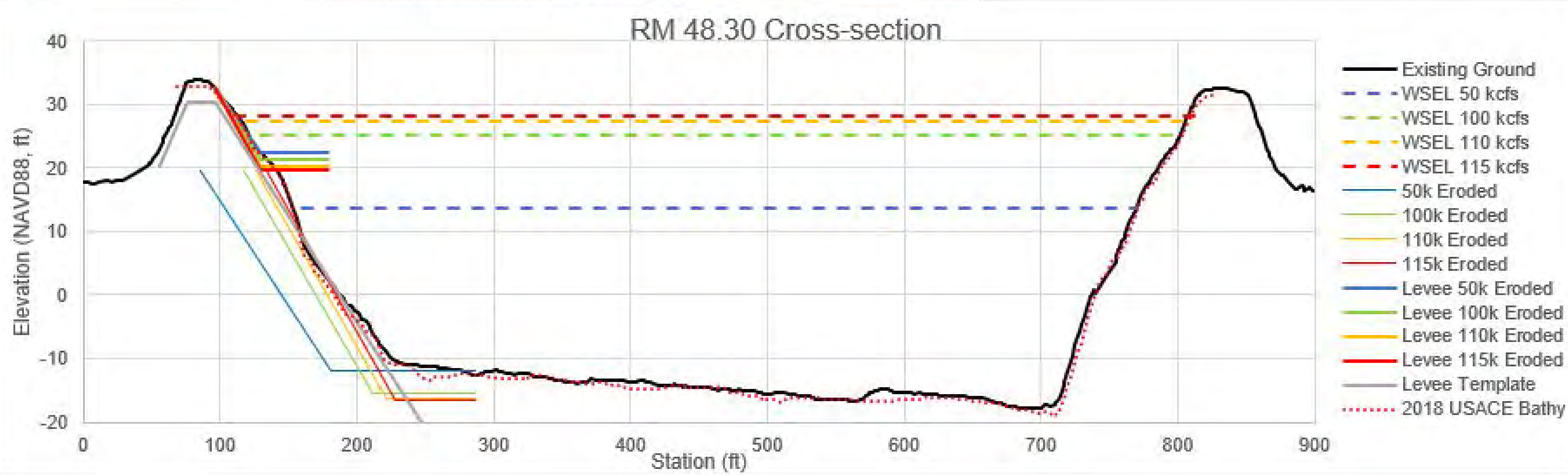
Segment 31: RM 47.25 to 48.85



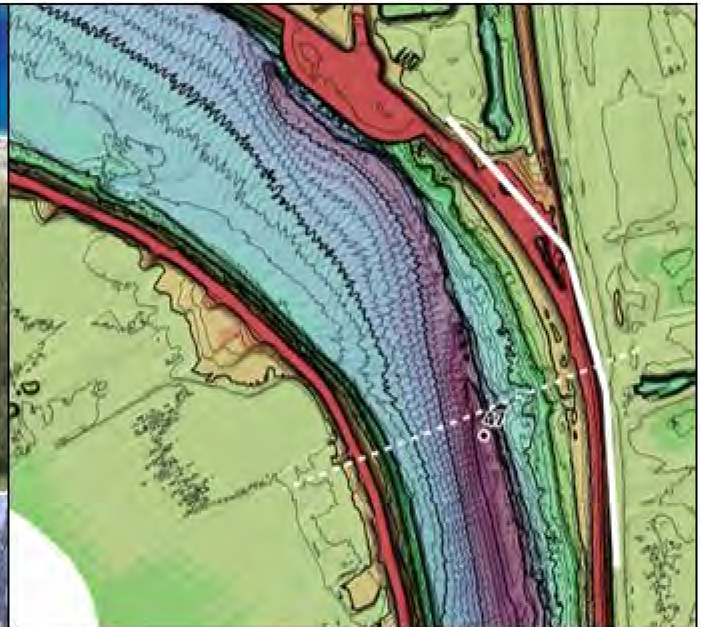


Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.23	4.22	4.37	4.45

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Old cobble, concrete, rock.
Distinction	Change in bench width US; Water intake structure DS.

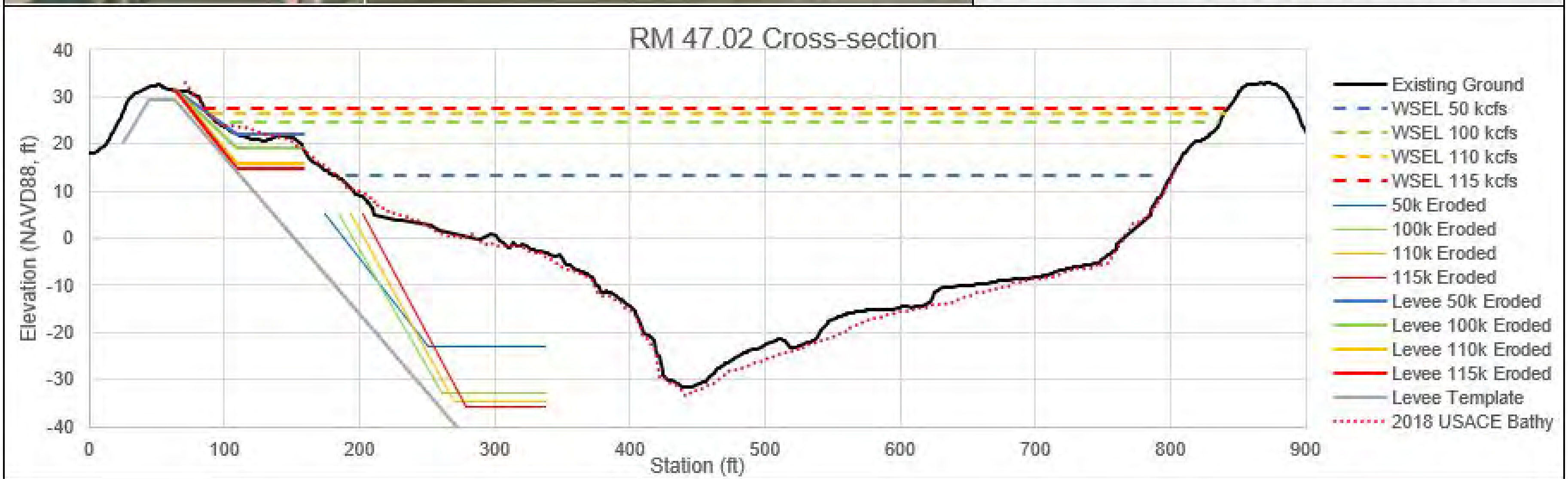


Segment 32: RM 46.9 to 47.15



Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	3.47	4.94	5.16	5.28

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	50-100 ft
Existing Revetment	Modern revetment – Site RM 47.0 (2007)
Distinction	Water intake structure US; Bank protection ends DS.



is at elevation – 30 and is situated in the middle of the channel approximately 100 feet from the toe of the revetment which ends at elevation 0 feet .

The overall bank erosion potential rating is low for all flows due to modern revetment and adequate rock volume. The projected bank scour and lateral erosion depths do not encroach into the levee prism.

The levee erosion potential is low for all flows. Projected scour of up to 7.6 feet at 115,000 cfs, encroach into the levee template.

5.34 Segment 33 (RM 45.2 – 46.9)

Segment 33 is a long straight reach that covers the rural area of Freeport up to the downstream end of the study reach at the Morrison Creek cross levee. This downstream location was selected to assess erosion hazards that could affect the cross levee which protects floodplains to the north; any levee break upstream would allow flow into the urban area of Sacramento. Any break downstream would not significantly affect Sacramento.

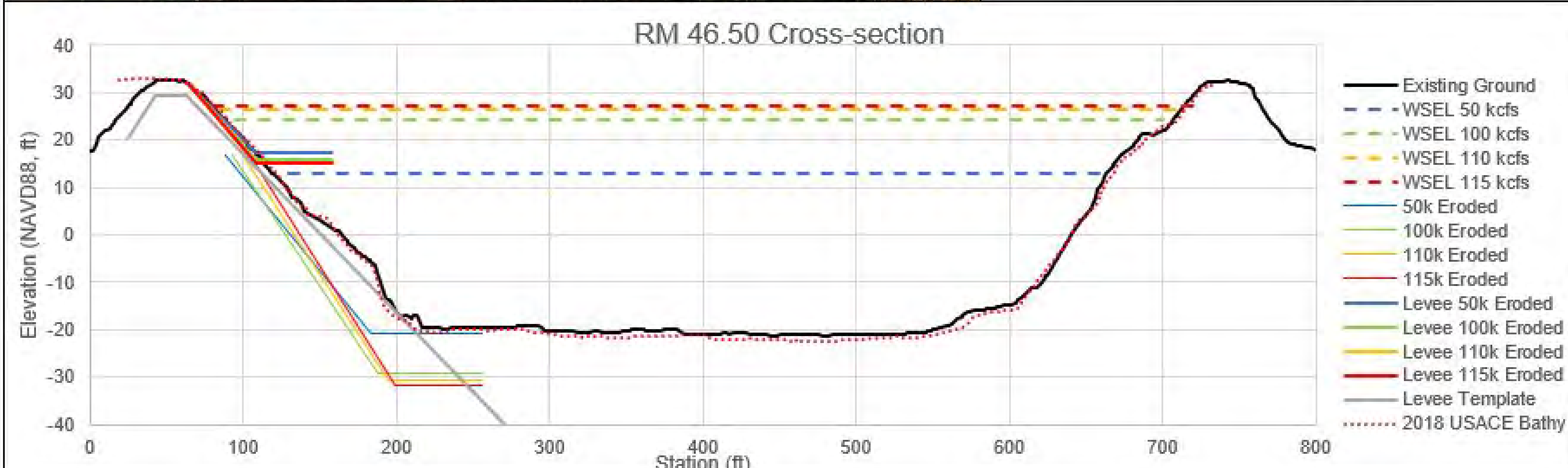
The levee and bank slopes coincide along the entire length of segment 33. There are some locations where the slope touches the levee prism. Most locations show an overly wide levee section. The thalweg is generally along the toe of bank at elevation – 20 feet and the levee top is around 30 to 32 feet . The bank and levee slopes are steep in most cases and there are numerous patches of older rip rap along the shoreline. Vegetation cover is sparse and variable between large trees (mainly oaks) and shrubs and willow scrub along the shoreline.

The overall erosion potential for banks is rated high for all flows. Scour encroaches into the levee prism and lateral erosion extends farther. The levee rates low for overall erosion potential and projected scour and lateral erosion do not extend into the prism.

Segment 33: RM 45.2 to 46.9

Flow	50 kcfs	100 kcfs	110 kcfs	115 kcfs
Avg Vel Chnl (ft/s)	2.75	3.95	4.13	4.22

Soil Type	Overbank deposits; sand, silt, and clay.
Bench Width	< 50 ft
Existing Revetment	Old cobble, rock, bare banks.
Distinction	Bank protection ends US; End of reach DS.



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