APPENDIX C
ATTACHMENT E

EROSION PROTECTION ANALYSIS

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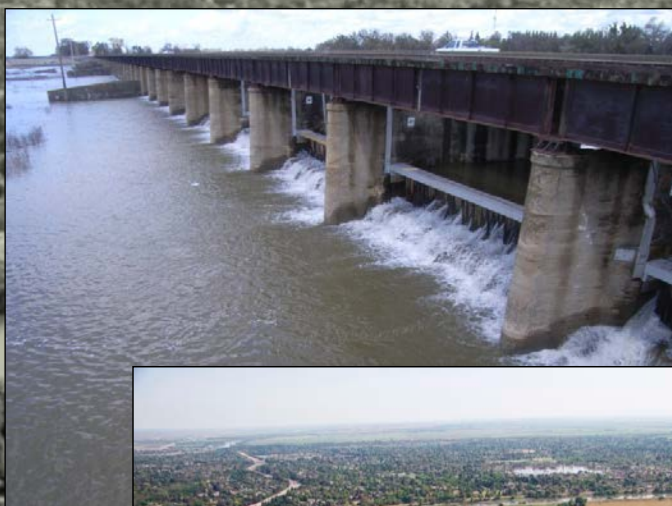
American River Watershed

Common Features
General Reevaluation Report



Attachment E
Draft Erosion Protection Report

February 2015

CENTRAL VALLEY FLOOD PROTECTION BOARD
PUBLIC SAFETY AND FLOOD MANAGEMENT
STATE OF CALIFORNIA

SAFCA
Sacramento
Area Flood
Control
Agency

US Army Corps
of Engineers ®
Sacramento District

Cover Photos courtesy of the Sacramento District:
Sacramento Weir during operation
Sacramento River facing south near the Pocket and Little Pocket neighborhoods
High flows on the American River at the Highway 160 overcrossing
Folsom Dam releasing high flows

AMERICAN RIVER, CALIFORNIA
COMMON FEATURES PROJECT
GENERAL REEVALUATION REPORT

Attachment E
Draft Erosion Protection Report

U.S. Army Corps of Engineers
Sacramento District

February 2015

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American River Watershed Common Features
General Re-Evaluation Report

Erosion Protection Report

Post-ATR Version Dated 8 April 2014

April 2014

On the cover:
Erosion of the left bank and levee of the Lower American River between river miles 4 and 5 resulting from the February 1986 flood.

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ACRONYNMS and ABBREVIATIONS

ACN .... Arcade Creek North
ACS .... Arcade Creek South
ARCF .... American River Common Features
ARCH .... Air Rotary Casing Hammer
ARFCD .... American River Flood Control District
ARFCP .... American River Flood Control Project
ARN .... American River North Basin
ARS .... American River South Basin
ASTM .... American Society of Testing and Materials
ARWI .... American River Watershed Investigation
BGS .... Below Ground Surface
BTA .... Blanket Theory Analysis
CB .... Cement-Bentonite
CFS .... Cubic Feet Per Second
CHP .... California Highway Patrol
COS .... City of Sacramento
CPT .... Cone Penetrometer Test
CW .... Cutoff Wall
CVFPB .... Central Valley Flood Protection Board
CVFPP .... Central Valley Flood Protection Plan
CY .... Cubic Yard(s)
DBH .... Diameter at Breast Height
DCN .... Dry Creek North
DCS .... Dry Creek South
DMM .... Deep Mix Method
DSM .... Deep Soil Mixing
DWR .... Department of Water Resources
DWSC .... Deep Water Ship Channel
EFA .... Erosion Function Apparatus
EIP .... Early Implementation Project
EM .... Engineering Manual
ERU .... Erosionally Resistant Unit
ESP .... Erosion Screening Process
ETL .... Engineering Technical Letter
EVS .... Environmental Visualization System
FEMA .... Federal Emergency Management Agency
FOS .... Factor(s) Of Safety
FOSM .... First Order Second Moment
FT .... Foot/Feet
FT/S .... Feet Per Second
GER .... Geotechnical Engineering Report
GIS .... Geographical Information System
GMS .... Groundwater Modeling Software
GRR .... General Reevaluation Report
H:V .... Horizontal To Vertical Ratio
HTRW .... Hazardous, Toxic, and Radioactive Waste
HQUSACE .... Headquarters U.S. Army Corps Of Engineers
IBC .... International Building Code
IWM .... In-Stream Woody Material
JET .... Jet Erosion Test

K .... Coefficient Of Permeability
KH .... Horizontal Hydraulic Conductivity Under Fully Saturated Conditions
KH/KV .... Ratio Between The Vertical And Horizontal Conductivities; Anisotropic Ratio
KV.......... Vertical Hydraulic Conductivity Under Fully Saturated Conditions
Ky .... Yield Acceleration
LAR .... Lower American River
LiDAR .... Light Detection and Ranging
LM .... Levee Mile
MA .... Maintenance Area
MCDC .... Magpie Creek Diversion Canal
MCY .... Million Cubic Yards
MSWL .... Mean Summer Water Level
MUSYM .... Map Unit Symbol
Mw .... Moment Magnitude
NAD83 .... North American Datum of 1983
NAFCI .... Natomas Area Flood Control Improvement
NALP .... North Area Levee Project
NAT .... Natomas Basin
NAVD88 .... North American Vertical Datum of 1988
NCC .... Natomas Cross Canal
NCEER .... National Center for Earthquake Engineering Research
NCMWC .... Natomas Central Mutual Water Company
NCSS .... National Cooperative Soil Survey
NGA .... Next Generation Attenuation
NGVD29 .... National Geodetic Vertical Datum of 1929
NEMDC .... Natomas East Main Drainage Canal
NLD .... National Levee Database
NLIP .... Natomas Levee Improvement Project
NPACR .... Natomas Post Authorization Change Report
NRCS .... National Resources Conservation Service
NSF .... National Science Foundation
NULE .... Nonurban Levee Evaluations
OCR .... Over-Consolidation Ratio
PACR .... Post Authorization Change Report
PDT .... Project Delivery Team
PED .... Pre-Construction Engineering and Design
PGA .... Peak Ground Acceleration
PGCC .... Pleasant Grove Creek Canal
PGL .... Policy Guidance Letter
Pr(f) .... Probability of Failure
PSHA .... Probabilistic Seismic Hazard Analysis
P1GDR .... Phase 1 Geotechnical Data Report
P1GER .... Phase 1 Geotechnical Engineering Report
QA .... Quality Assurance
QC .... Quality Control
RD .... Reclamation District
RM .... River Mile
SAFCA .... Sacramento Area Flood Control Agency
SB .... Soil-Bentonite
SCB .... Soil-Cement-Bentonite
SGDR .... Supplemental Geotechnical Data Report
SOP .... Standard Operating Procedure
SPT .... Standard Penetration Test

SRBPP .... Sacramento River Bank Protection Project
SRFCP .... Sacramento River Flood Control Project
SRN .... Sacramento River North
SRS .... Sacramento River South
SSURGO .... Soil Survey Geographic Database
SUALRP .... Sacramento Urban Area Levee Reconstruction Project
SWIF .... System-Wide Improvement Framework Policy
TEC .... Topographic Engineering Center
TM .... Technical Memorandum
TRM .... Technical Review Memorandum
ULE .... Urban Levee Evaluations
USACE .... U.S. Army Corps Of Engineers
USDA .... United States Department of Agriculture
USGS .... United States Geological Society
V:H .... Vertical To Horizontal Ratio
¯VS30 .... Velocity Of The Upper 30 Meters
VVR .... Vegetation Variance Request
WRDA .... Water Resources Development Act
WSAFCA .... West Sacramento Area Flood Control Agency
WSE .... water surface elevation

1 INTRODUCTION AND BACKGROUND

1.1 Introduction

The purpose of this attachment is to provide a concise summary of the work performed to date regarding understanding and predicting the stability of the Lower American and Sacramento Rivers with regards to erosion and the capability of the leveed reaches of the mainstem river channels to convey flood releases from Folsom Dam. Additionally, this attachment provides the rationale for the proposed erosion protection features presented in the Engineering Appendix of the American River Common Features GRR Study (ARCF).

This attachment provides further rationale for why the erosion protection features are needed. This is in addition to the American River Common Features General Re-Evaluation Report (ARCF GRR) study efforts to quantify the risk of erosion using levee performance curves (probability of failure) and floodplain delineation (consequence) from a levee break. The levee performance curves are summarized in section 5.4 and are fully described in the ARCF GRR Geotechnical Report (Attachment C). The floodplain delineation is described in the ARCF GRR Hydraulic Report (Attachment B).

1.2 Location

The overall study area for the ARCF GRR Study is illustrated on Figure 1-1 and includes the Sacramento River between Verona and the Freeport Bridge and the American River between Nimbus Dam and the Sacramento River confluence.

In the study area there are additional reaches depicted but not highlighted in Figure 1-1 where erosion concerns have been addressed in one of two ways:

1) The following reaches were analyzed for erosion protection as part of the Natomas Post Authorization Chief's Report of December 2010:

- Sacramento River: Left Bank, From the American Confluence up to the Confluence with the Natomas Cross Canal
- Natomas Cross Canal: Left Bank, Entire reach
- Pleasant Grove Creek Canal: Left Bank, Entire reach
- Natomas East Main Drain Canal: Right Bank, Entire reach,

2) The proposed design in the chief's report and subsequent site specific design refinements are assumed to adequately address erosion concerns on these reaches.

The remaining project reaches in the ARCF Study include:

- Natomas East Main Drain Canal: Left Bank, Entire reach
- Arcade Creek, Left and Right Banks, Entire reach
- Dry Creek, Right Bank, Entire reach
- Robla Creek, Left Bank, Entire reach
- Magpie Creek, Left Bank, Entire reach.

These tributary project reaches are significantly influenced by backwater and, therefore, the erosion concerns in these reaches are not considered as critical to address with a separate analysis given the reduced velocities and erosive forces. In addition, the tributaries on the eastside of Natomas including Dry Creek, Arcade and others do not share the same high risk of erosion in terms of consequence, duration and velocity as on the American and Sacramento Rivers. As discussed in the ARCF Hydraulic Appendix, any features required to address erosion will be part of the site specific design. The cost of these features is likely minimal and will not affect selection of the tentatively selected plan (TSP) nor significantly impact the overall project costs.

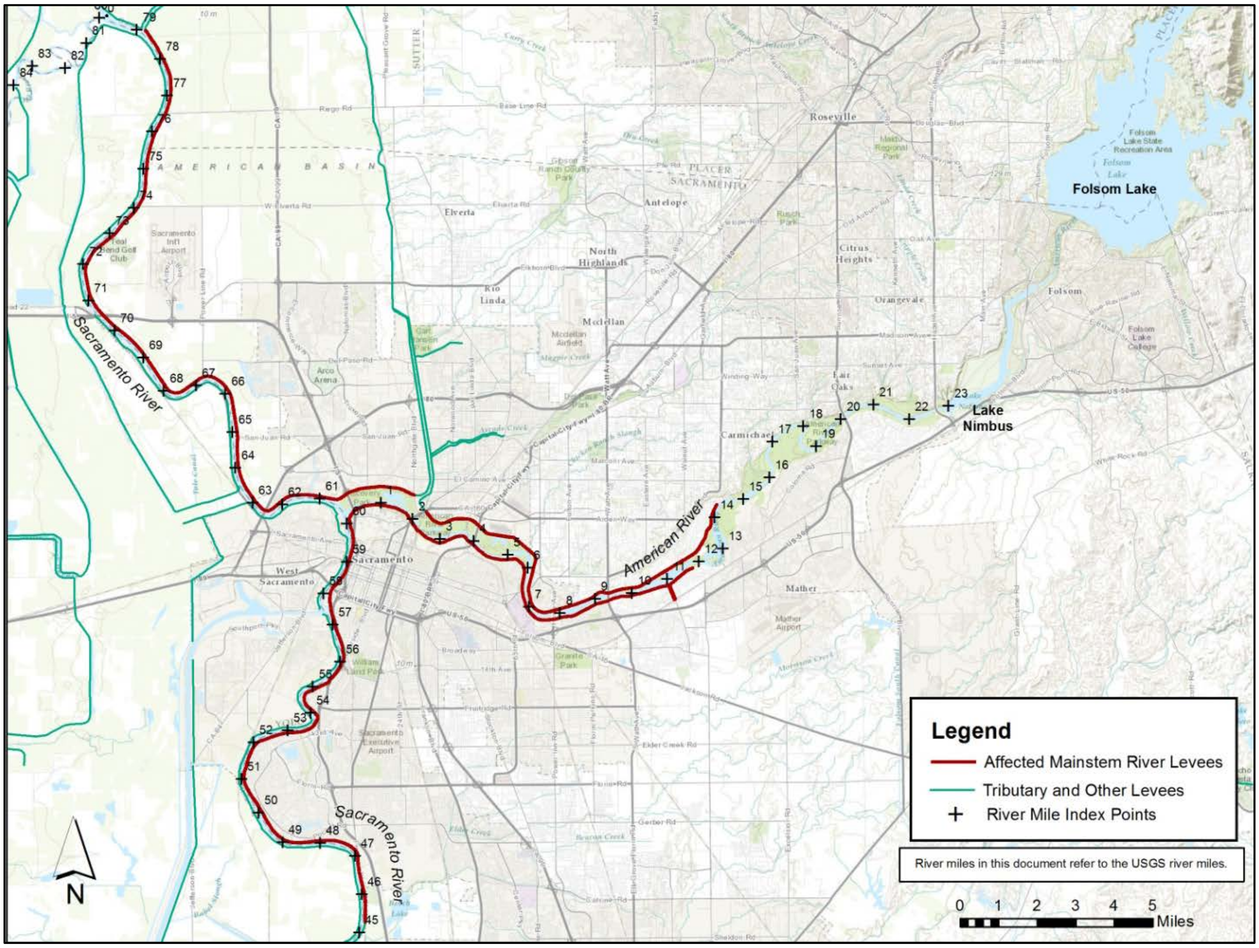

Figure 1-1. ARCF study area and affected mainstem channel levees

The focus areas for this attachment are the leveed reaches of mainstem channels shown in red on Figure 1-1 and specifically include the left levee (i.e. looking downstream) of the Sacramento River and both levees of the American River. The detailed focus area for many of the in depth investigations and analyses is the American River between RM 5 (Paradise Beach) and RM 11 (located above Watt Avenue). The focus areas for the with-project conditions and erosion mitigation features are the American River between RM 0 and 14 and the Sacramento River between the Freeport Bridge (RM 46) and the American River confluence (RM 60.5).

1.3 Background – Lower American River (LAR) Overview

The American River levees were originally intended to convey a release from Folsom Dam of 115,000 cubic feet per second (cfs). During several events since the construction of Folsom Dam, flows have equaled or exceeded the design capacity and caused significant erosion distress. All four significant flood events since the completion of the Federal flood control system in the mid 1950s (1955, 1966, 1986, and 1997) caused considerable damage to the American River levee system due to erosion. The 1986 event had an imminent threat of levee failure. In addition, all four events required extensive repair after the event so the American River levee system could perform for the next major event. The objective release from Folsom Dam is currently under review as part of the Folsom Dam Reoperations Study and the Joint Federal Project is currently constructing improvements to the dam for a release of 160,000 cfs. Based on past performance and recent investigations, erosion is a serious threat to the American River levees that must be addressed.

Figure 1-2 is a typical view of the leveed reach of the Lower American River. This photo is looking upstream in the vicinity of the Guy West pedestrian bridge (RM 7). Figure 1-3 shows a view of an erosion site on the left bank near the lower end of the American River at RM 0.3 in 2008. This site is located just upstream from the Interstate 5 crossing (bridge seen in the background) and is affected by backwater from the Sacramento River.

A recent study (2010) was completed by Ayres Associates for the USACE that further assessed channel stability of the American River. The report included recommendations of short term and long term measures needed to safely convey a discharge (river flow) of 160,000 cfs from Folsom Dam through the Lower American River (LAR), including revetment and grade control.

Following the 2010 report a panel of experts in engineering fields associated with erosion was convened by West Consultants for the USACE due to questions and uncertainties regarding previous design recommendations and the environmental sensitivity of doing extensive erosion work on the American River including grade control. The panel was tasked to consider the adequacy of studies conducted to date, provide recommendations of additional study as appropriate, or recommend moving forward to basis of design and construction. Conclusions and recommendations from this panel led the USACE to pursue additional studies to address if the channel had reached equilibrium in terms of aggradation/degradation, additional refinements to the sediment transport model, further characterization of the geotechnical and geologic characteristics of the watershed, and refinement to the procedure for prioritization of repair sites and the development of erosion protection alternatives. There are a number of past studies that help with understanding erosion issues on the American River. These are summarized below in Section 1.7.

As part of the expanded erosion study, the USACE Project Delivery Team (PDT) found that insufficient geotechnical data were available to adequately support existing and proposed channel stability analysis and potential design recommendations. Specifically, the geotechnical and geologic study focused on characterization of soil properties through exploration and testing, geologic mapping, and 3-dimensional modeling of the subsurface stratigraphy. Additional geotechnical data were generated to characterize the material comprising the existing channel bed between the right and left bank levees of the LAR between River Miles (RM) 5.0 and 11.0. Emphasis was placed on the study reach between RM 5.0 and 11.0 due to substantial increases in velocities and applied shear stresses caused by changes in river geometry, including a narrowing of the channel and two sharp bends (downstream of Watt Avenue and near Paradise Beach, see Figure 1-1).

Figure 1-2. View of Lower American River (looking upstream) at Guy West pedestrian bridge

Figure 1-3. Erosion site on left bank near LAR RM 0.3 (2008)

1.4 Background - Sacramento River Overview

The portion of the Sacramento River in this study has two distinct reaches. The Sacramento River was split at the confluence with the American River for the purposes of this discussion because the conditions of the river change at this location.

Sacramento River – Verona to American River Confluence (RM 79 to RM 61). This reach of the Sacramento River has the levees close to the river and contains the Sacramento Weir which diverts flow into the bypass system. This reach was intentionally designed with the levees close to the banks to help move some of the bed load and debris that remained from the days of hydraulic mining. In addition, USACE was responsible for keeping the river navigable up to the city of Colusa. As a result of this design, much of the reach is protected with rock, especially the outsides of bends. The majority of the rock in this reach consists of cobbles placed prior to the 1960s and some areas with more recent quarry stone. The cobble sites are reaching the end of their design life. Many of the levees are constructed of dredged soils from the bottom of the channel. This reach is also notable because it contains numerous private residences and commercial structures including boat docks on the waterside of the levee. Figure 1-4 shows a section of this reach of the Sacramento River.

Figure 1-4. Typical View of the Sacramento River - Verona to American River Confluence (RM 79 to RM 61)

Sacramento River – Sacramento River South, American River Confluence to Freeport (RM 61 to RM 45). This section of the Sacramento River has tight levees and is tidally influenced. The location of the channel has been relatively stable for the past 150 years (although local scour and erosion can still be an issue). A large percentage of this reach has already been armored with riprap. This area has heavy wave action from recreational boats and wind, and the banks are heavily used by the general public in contrast to the reach discussed above where the banks are heavily occupied by private residences and commercial structures that limits public access along the levees. The general public use in this reach often creates local erosion by walking directly on the levee and banks. Many of the levees are constructed of dredged soils from the bottom of the channel. This reach does not have significant waterside structures such as private and commercial buildings, but has some sections of heavy vegetation and boat docks. Figure 1-5 shows a section of the Sacramento River South study area. The causes of erosion in this reach are boat wake, wind-wave, mass failure, fluvial processes, and public use.

Figure 1-5. Typical View of the Sacramento River Sacramento River South, American River Confluence to Freeport (RM 61 to RM 45)

1.5 Historical Performance

1.5.1 American River

The history of the American River has been significantly impacted by human activity. During the California Gold Rush of 1849 to 1864, the foothills upstream of the river were mined hydraulically, resulting in millions of cubic yards of mining debris being sent down the American River. The hydraulic mining caused approximately 15 to 20 ft of aggradation in the project reach. Dredge mining for gold caused alignment changes to the floodplain and in-channel bars, and significantly altered the topography. Subsequent sand and gravel mining in the river and floodplain resulted in the development of split flow reaches. In 1864, a rechanneling project moved the downstream end of the American River to its present location from an alignment which ran roughly through the Union Pacific rail yard. In the 1950's, the construction of Folsom Dam (RM 30) and Nimbus Dam (RM 23) essentially eliminated the sediment supply from the upper watershed, resulting in the lower reaches of the LAR to become sediment starved causing a lowering of the river channel invert.

Construction of the south levee of the American River started around 1850 and was completed in the 1910's. Construction of the north levee of the American River, located between the Sacramento River and about RM 5 (near Cal Expo), occurred in the 1910's. Construction of the remainder of the north levee, upstream of Cal Expo extending to RM 14, occurred between 1955 and 1957.

In 1955, the American River experienced the flood of record. This is an important flood event in that of the 1 million acre-feet reservoir at Folsom Dam(only 400,000 acre feet is allocated to flood control) was filled in a single event. The peak release from this flood event was 115,000 cfs. Soon after this flood event, the flood magnitude was factored into the hydrology for Folsom Dam operations, which led to the level of protection provided by Folsom Dam being considerably lowered.

Sacramento experienced significant flood events again in 1964, 1986, and 1997. The 1964 flood event was the first time the complete American River levee system was tested with a flow of 115,000 cfs. The 1964 flood event showed considerable stress on the levee system for a flow of 115,000 cfs. An emergency flood-fight along the left bank of the American River near H Street was required to pass the flood event.

The 1986 flood event is significant in that it required a peak release from Folsom Dam of 130,000 cfs in order to avoid a dam failure. The peak flow was passed without a levee failure, but two locations were in the process of failing as flows were receding. Figure 1-6 shows one of the erosion sites located just upstream of the Capital City Freeway. Had the discharge been sustained longer, the levee would have likely failed from erosion.

In 1997, the Sacramento and San Joaquin River systems experienced record flooding and a number of levee breaks. However, in the American River watershed, Folsom Lake experienced a peak inflow of 255,000 cfs and was able to control it to the objective release of 115,000 cfs down the American River, with 28 percent of the flood management storage available at the peak of the storm. Nonetheless, significant erosion occurred at five sites along the American River which required immediate repair following the flood event. These repairs were accomplished under the SRBPP.

All four significant flood events since completion of the federal flood control system in the mid 1950's (1955, 1964, 1986, and 1997) caused considerable damage to the levee system because of erosion. And, all four events required extensive repair after the event so the system was ready for the next major flood event. In addition, erosion also occurred during a flood event in 2006.

Outflow hydrographs (from Folsom Dam) for these flood events are depicted in Figure 1-7 and the approximate durations at various peak flows are listed in Table 1-1.

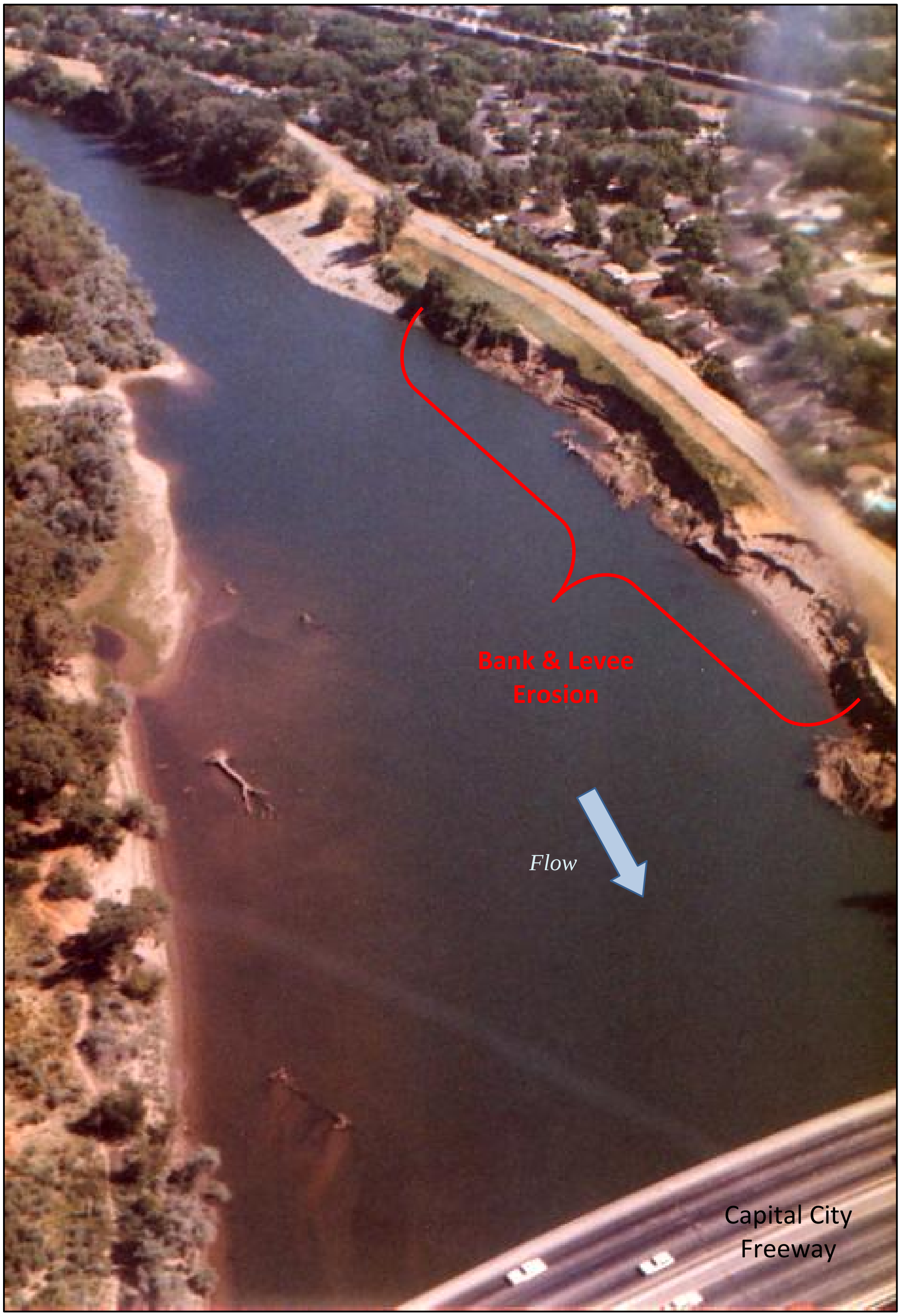

Figure 1-6. Levee erosion from the 1986 flood event (130,000 cfs) on the American River left bank just upstream of the Capital City Freeway (Business 80)

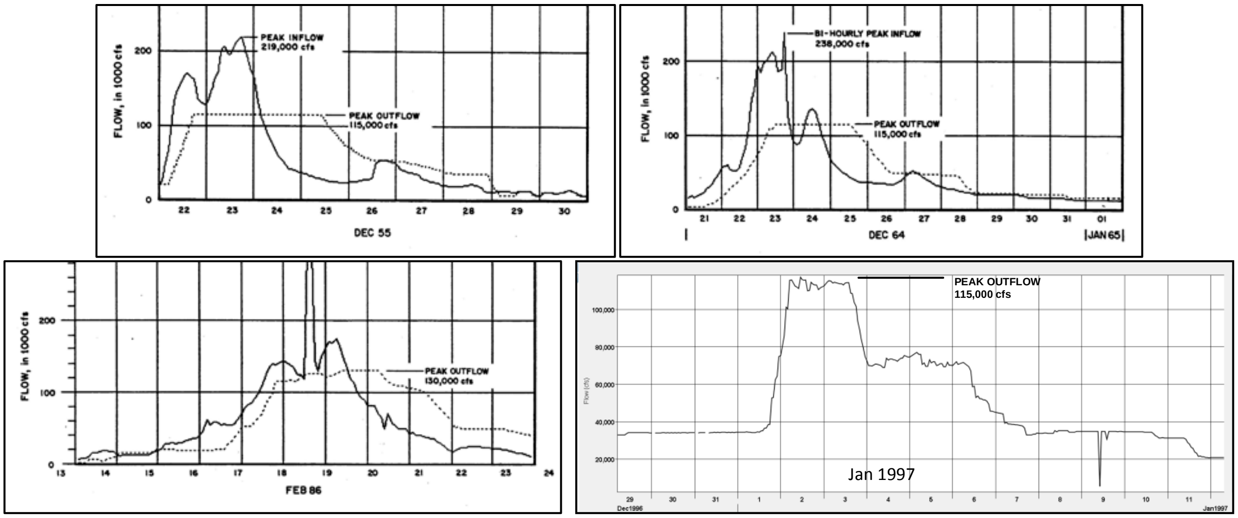

Figure 1-7. Historic outflow hydrographs from Folsom Dam[1]

Table 1-1. Duration of significant historic peak flood events

Flood Event	Approximate Duration (hrs)		
	90,000 cfs	115,000 cfs	> 115,000 cfs
1955	74	64	---
1964	68	48	---
1986	94	64	52
1997	42	33	---

1.5.2 Sacramento River

The history of the Sacramento River has been greatly impacted by the influx of people into the Central Valley. Prior to 1800's the Sacramento River had insufficient capacity to carry the large winter and spring flows, resulting in floodplains that extended for miles beyond the channel banks. The overbank velocities were low and much of the sediment eroded from the mountain and foothill areas would drop out, resulting in floodplain deposition (vertical accretion) and the development of natural levees through the rapid deposition of coarse particles as flow velocities decreased. Hydraulic mining, particularly in the Yuba and Bear Rivers resulted in an excess of sediment load being washed into the Sacramento River and resulted in reduced channel flow and increased flooding in the low elevation areas.

In addition to the hydraulic mining, increased agriculture in the area resulted in land owners building low levees along the river to protect their cultivated fields. The levees were a piecemeal fashion, without coordination between landowners, and led to competition between landowners to continually raise and strengthen their section of the levee to induce flooding on someone else's land.

[1] 1955, 1964, & 1986 events from USACE 1987; the hydrograph for the 1997 event is from CDEC (FOL - Reservoir Outflow)

During the time of hydraulic mining and agricultural development (1850 to 1900), the Sacramento River saw 13 large flood events. The flood of 1862 flooded the city of Sacramento and resulted in loss of life and destruction of property. The levees protecting the city of Sacramento were subsequently raised following this flood. The floods of 1881 resulted in numerous levee breaks on both sides of the Sacramento River, downstream of the city of Sacramento. After the 1800’s, significant floods occurred in 1904, 1907, 1909, and 1928 on the Sacramento River.

Following the floods of the 1800’s and early 1900’s, early planning for the modern Sacramento River flood protection system started and consisted of dams, bypasses, channel widening and deepening, and levee enlargement. Construction of the Sacramento River Flood Control Project began in 1918 and was completed in 1953. The major features that were constructed included levees along the Sacramento River channel, leveed bypasses, and weirs.

The levees along the Sacramento River south of the confluence with the American River were constructed by a private mining and dredging company with the purpose of reclaiming and selling thousands of acres of farmland. The levees were constructed using large “clam shell” dredging machines. The work began in 1912 and was completed by the end of 1915. Based on typical construction schematics shown on basin-wide maps and historical literature, the levees along the Sacramento River were constructed in the following manner:

- A dragline was used to excavate a trench about 6 to 12 feet deep along the centerline of the levee alignment. The trench bottom width ranged from about 12 to 28 feet. The excavated material was deposited along both sides of the trench forming two small containment dikes.

- Hydraulic dredging operations placed material from the adjacent Sacramento River bottom into the excavation area between the dikes. This material consisted predominately of sands.

- The final levee configuration was achieved by covering the dredged sand with the adjacent dike materials. These materials consisted predominately of silt, clay, and fine sand.

It should be noted that because of the construction history outlined above, the upper portion of the semi-pervious blanket beneath the center of the levee has been removed and commonly replaced with sand. Typically, the sand core extends to a greater depth beneath the center of the levee than beneath either of the flanks or the surrounding ground. Most of the levee material was hydraulically dredged from the Sacramento River and piled or pushed into place with no mechanical compaction. Some mechanical shaping of the upper and outer portions of the sand core likely occurred during establishment of the general levee geometry.

The levees along the Sacramento River south of the confluence with the American River were constructed by local interests using clamshell dredges excavating material from the Sacramento River in the early 1900’s. This method of construction usually resulted in a levee constructed on the channel banks with loose, sandy fill material that is deepest below the center of the levee. The materials within the levee embankment are predominantly sands, silty sands, and cohesionless materials. Since the construction of the original levee embankment in the early 1900’s the levee has been remediated and improved several times. Levee remediation and improvements have consisted of embankment reconstruction and or enlargement, floodwalls, waterside rock slope protection, shallow through seepage cutoff wall, deep underseepage cutoff walls, seepage berms, and relief wells.

The 1955 flood was the first test of the new Sacramento River Flood Protection system. At the Sacramento Weir, 30 gates were opened with the peak flow reaching 48,000 cfs sent into the bypass. The peak flow in the Sacramento River at I Street was about 95,000 cfs. During the 1964 flood, the peak flow on the Sacramento River at I Street was about 100,000 cfs, just below the channel capacity of the reach. The flood of 1969 was largely controlled by the reservoirs, flood channels, and bypasses. The flood of 1974 saw a peak of 95,000 cfs at the I Street gage; the Sacramento Weir gates were not opened.

In 1960, Congress authorized the Sacramento River Bank Protection Project for the construction of bank erosion control works and setback levees within the limits of the existing levee system. This project is intended to maintain the integrity of the levee system to continue the degree of protection for which it was designed.

The flood of 1986 had a peak flow of 117,000 cfs at the Freeport gage, just south of the city of Sacramento. The levees on the Sacramento River were severely stressed from high water and seepage. The levees near the Garden Highway required extensive repairs during the flood and nearly failed. The north bank along Arcade Creek was overtopped and 500 homes were inundated.

Since the completion of the Sacramento River Flood Control Project, significant floods have caused considerable erosion related damage to the levee system. Erosion in the Sacramento River has even occurred during lower flow events, as documented by the Sacramento River Bank Protection Project. Numerous emergency bank repairs and repairs done by SRBPP (over 800,000 linear feet) have been constructed in the last 50 years. Erosion continues along the Sacramento River banks and levees and there are currently numerous sites that are in need of repair.

1.6 Monitoring by Corps and CVFPB

USACE and the Central Valley Flood Protection Board (CVFPB) have an ongoing program that identifies critical erosion sites and monitors erosion sites that may become critical. No critical erosion sites were identified during the 2012 reconnaissance by USACE; however, multiple erosion sites were identified on the left bank of the Sacramento River between RM 50.3 to 58.5 (corresponding to approximately MA9 LM 6.0 to COS LM 1.4). Based on the report, some of these sites currently have scattered rock, cobbles or quarry stone at the levee toe and have exhibited no change relative to previous erosion surveys, other than minor new slumping. The erosion mechanisms identified at these sites include wavewash, eddy scour, tree pop-outs, fluvial and whole bank failure.

Two erosion sites were also identified at RM 56.6 and RM 58.5 (corresponding to approximately COS LM 3.5 to LM 1.4), with the erosion mechanisms including fluvial and whole bank failure. These sites reportedly have concrete rubble (does not meet USCAC standards) on the bank and at the toe that is in poor condition; no significant changes in condition have been observed between annual inspections. One erosion site at RM 46.7 (corresponding to MA9 LM 10.0) was recently repaired by the State.

1.7 Stability Investigations

There are a number of studies, investigations, research efforts, and assemblages of expert panels which were focused on quantifying erosion on the Lower American River. These efforts are summarized below. Additional in-depth documentation of these studies is presented in Section 2.3 of the report titled "American River Common Features Project, American River Erosion Advisory Panel Workshop, November 29, 2011 – December 2, 2011, DRAFT Summary of Presentation and Conclusions" by the Sacramento District, U.S. Army Corps of Engineers, dated September 2012.

1.7.1 Prior Studies, Investigations, & Research Efforts

1.7.1.1 Geomorphic Analysis and Bank Protection Alternatives (Water Engineering and Technology, Inc., June 1991)

This study looked at the Sacramento and American Rivers as well as a number of other reaches. The report presents the results of a geomorphic study that was conducted "to determine the dynamics of the studied rivers and sloughs with the objective of developing a geomorphically-based framework upon which bank protection methods could be evaluated and overall protection strategies formulated." The study discussed Lower American River channel aggradation that occurred as a result of hydraulic mining, then degradation that occurred after mining ceased and then much more degradation that has occurred since completion of Folsom Dam in the mid 1950s. The channel incision has slowed down and even stopped in some locations as it reached Pleistocene-age rock outcrops. The study states the river is "sediment hungry" as flow leaves Folsom Dam. The channel degradation creates concerns for both levees and bridges. The levees are at a higher risk of toe scour and the several bridge footings have been exposed as a result of the channel incision.

It is important to note that at the time this report was written, many of the seepage and stability mitigation features had not been constructed along the LAR. In addition, the thinking at that time was that an Auburn Dam would eventually be constructed and that Folsom Dam would limit outflows to 115,000 cfs for events up to the 0.25% (1/400) ACE event.

1.7.1.2 American and Sacramento River, California Project- Geomorphic, Sediment Engineering, and Channel Stability Analyses (Ayres Associates, December 1997)

The purpose of this study was to examine the effects of a potential dry dam (Auburn Dam) including potential modifications to the existing flood control levees along the Lower American River. This included HEC-2 (hydraulic model) and HEC-6 (sediment model) modeling. Output from the HEC-2 model was used to evaluate channel capacity, bed shear stress, work done on the channel banks, and local scour at bridge crossings. Sediment routing was performed for five different scenarios, all using the 100-year flood event. Predicted bed elevation changes within the lower 13 miles of the LAR were all less than 1 foot (either aggradation or degradation). The report concluded that vertical stability along the LAR is not a significant issue. An incipient motion analysis indicated that the bed material is generally immobile at discharges less than 50,000 cfs. A quantitative analysis of the relative effects of the various design scenarios on lateral stability of the channel was conducted using the results from the HEC-2 model and a "weighted average work index" (velocity * bank shear stress * time for various frequency events multiplied by the probability of that event in a year and summed over all events). Rock-based revetments and dikes were recommended as the only forms of bank protection that will insure the integrity of the levees at the majority of the erosion locations.

1.7.1.3 Two-Dimensional Modeling and Analysis of Spawning Bed Mobilization Lower American River (Ayres Associates, October 2001)

The purpose of this report was to examine the possibility of spawning bed mobilization at different flow values on the LAR. A two dimensional model was developed to examine the velocities of different potential flow scenarios. The largest tested flow for the study was 115,000 cfs. The study confirmed the 50,000 cfs as the break point for incipient motion as determined in the previous report. The results indicate that there will be some movement of the spawning material especially above Goethe Park in the upper part of the study reach. The movement of the material largely depends on how long the high flows last. The model is a good indicator of whether movement will occur, but it does not show how far the motion will carry the material or where it is likely to end up.

1.7.1.4 Lower American River, Erosion Susceptibility Analysis For infrequent Flood Events (Ayres Associates, July 2004)

The purpose of this report was to determine the potential for erosion of grass-lined levees and overbanks when flows reached the design flow of 145,000 cfs. This study concluded that the river is degradational under present operating conditions as confirmed by geomorphic principles, by the thalweg profile, and by the field review.

It also concluded that since the channel bed is comprised of erosion resistant material in many locations, the river will tend to erode laterally to satisfy the need for sediment. A field review verified riverbank erosion is occurring even at flows of only 7,000 cfs. The bare soil on these eroded channel banks is increasingly susceptible to future erosion even at lower velocities. The report states a levee failure is possible for at least one location for 145,000 cfs. Additionally, other discharges ranging from 115,000 to 160,000 cfs were investigated and documented in this report.

1.7.1.5 Channel Stability Analysis of the Lower American River, Folsom Dam to the Confluence Sacramento, California (Ayres Associates, January 2010)

The purpose of this study was to assess the long term stability of the LAR for flows up to 160,000 cfs and to identify short and long term measures required to ensure safe and reliable conveyance of these flood flows. This study included a bathymetric survey of the LAR from Nimbus Dam to the confluence with the Sacramento River. The data collection for this survey was completed in August 2006. Ayres performed a field review of the reach (RM 0 to RM 23) of the LAR below Nimbus Dam. Riverbed and riverbank sampling was done for the entire reach and erosion and armored sites were inventoried through the project levee reach (RM 0 to RM 14). The current methods of bank protection include revetments, river cobble revetments, concrete walls, gabions, stone dikes, and concrete rubble. The four primary modes of channel response to the current conditions are channel degradation, increased sinuosity, channel widening, and bed material coarsening. Potential solutions include: revetment, vegetation, grade control, and introducing sediment supply. The only place the HEC-6T model (MBH, 2002) predicted degradation was at Guy West Bridge. In the other reaches, the lateral movement or widening of the channel is expected to occur as the river looks to fill its sediment capacity.

Although each expert provided recommendations that were summarized in the previous chapter of this report, several of the common or related recommendations have been summarized in this section. The consensus was that the current levee system most likely requires repairs to pass the 160,000 cfs release.

The majority of the experts agreed that the location and prioritization of the repairs have not been adequately defined, leading to some of the following observations and recommendations. The status of actions taken or not taken on the recommendations are noted in parentheses below each recommendation:

- Field observations show the bed material is coarsening in the upstream reaches. The coarsening of bed material is not obvious downstream of RM 10, but the pattern of propagation downstream is a logical conclusion.

- The right overbank area between RM 8 and RM 9.5 is also composed of mostly sand and will erode in areas were no armor is available and also where armor is in poor condition. The levee is much closer to the existing riverbank and could be threatened in a single high flow event.

- The river bottom at Guy West Bridge is scoured clean of alluvium. The exposed material in the riverbed consists of clay and has been found to be erodible.

- Based on a discharge of 160,000 cfs and corresponding erosion rates, there is approximately 10 feet of vertical erosion potential into the clay material at Guy West Bridge. The degradation is likely to propagate upstream through the abandoned sewer line and past the Fairbairn water intake structure.

- The river invert immediately upstream of Watt Avenue is also composed of clay. However, river thalweg plots show no change in elevation at that location since 1955.

- The two highest priorities for preventative maintenance at this point in time are to armor the bed at Guy West Bridge and provide bank protection at select locations on the right bank between Howe and Watt.

1.7.2 Expert Panel Consultations and Recent Activities

A series of expert panels were convened on three occasions: 1) October 6-8 & November 16, 2010, 2) November 29 – December 2, 2011, and 3) October 16-17, 2012. Key recommendations and concerns from these panels led to additional investigations and analyses which complimented the studies which were already in progress.

1.7.2.1 Lower American River, Panel of Experts Findings Report (West Consultants, December 2010). [Panel meeting from October 6-8 & November 16, 2010]

A panel of experts was convened to consider the adequacy of what has been done to date and to provide recommendations of additional study as appropriate or to recommend studies completed to date are adequate and can be used as a basis for design and construction. The main conclusions and recommendations include:

- With relatively little effort the existing HEC-6T sediment transport model can be modified to better reflect bed sediment conditions. Results of the model may shed light on vertical stability of the system and could also be used to examine “what-if” scenarios (e.g., stable points such as the gravel plug or clay outcrops are removed). (Status: HEC-6T was modified to reflect improved information on bed sediment conditions. However, what-if scenarios have not been conducted to date.)

- The horizontal and vertical location of the scour resistant clay should be clearly identified and mapped as these materials can impact both vertical and lateral erosion potential of the river. Existing geophysical studies may help with this task and should be identified (see recommendation on consolidating data below). (Status: An initial phase of geologic mapping and 3-dimensional stratigraphic modeling has been completed using existing data as well as data generated for the ARCF GRR study. The level of detail included in the current mapping and modeling is sufficient to support planning level recommendations and conclusions but further refinement could be of benefit depending on the level of certainty required in understanding the locations of this geologic unit).

- Many of the experts viewed the results of the EFA erosion testing program with some doubt or skepticism which points to the need for better characterization of the erodibility of the resistant materials. (Status: Additional EFA as well as JET testing was completed on many samples collected on the channel banks and riverbed. There is a need to study those results, place them in a geologic context, calibrate them based on judgment and any potential scaling effects, and provide guidance on incorporating them into the hydraulic models. This has not been completed).

- Levee slopes previously treated with mixtures of soil and rock be assessed to determine if they meet USACE levee criteria for erosion. Non-standard designs need to be backed up with research or defendable scientific analysis. (Status: The tentatively selected plan assumes that recently constructed bank protection (e.g. “modern” bank protection) is adequately designed for 160,000 cfs. However, this will need to be confirmed in the future, such as during selecting and prioritizing sites).

- Many of the experts agreed that existing data is scattered may not be readily available to professionals studying this reach of river. A centralized database should be created to make past studies accessible. (Status: Much of the data has been centralized on the network).

- Monitoring should continue and possibly be enhanced or extended by various methods. (This has not been completed for this project during the feasibility phase of the study, but should be a component of future efforts).

- Systematic and justifiable criteria for site stabilization will be useful not only for prioritizing work but also to rationalize projects to the public and decision makers. (Status: Criteria for site stabilization and prioritization will need to be completed in the future).

- Written opinions and discussion touched upon the confusing nature and different methodologies employed in gathering bed profiles. Past profiles should be verified and future profiles collected in a consistent and systematic manner. (Status: No plan in place for collecting regular profiles in a consistent manner. This should be addressed as part of future systematic monitoring plan).

1.7.2.2 American River Common Features Project, American River Erosion Advisory Panel Workshop (report dated September 2012). [Panel meeting from November 29 – December 2, 2011]

A new panel of advisors was compiled to evaluate the then current course of study. Some of the recommendations from this panel include:

- The upstream extent of the study area currently is about one mile above Watt Avenue. This boundary should be extended upstream. The purpose of this is that from a sediment transport standpoint, there is still significant quantities of material above the leveed reach of the American River that can be transported through the leveed reach, and this needs to be understand because it will influence how rapidly erosion will occur in the leveed reach. (Status: The study was extended upstream but with lower level of detail. Further investigation would be needed to bring this section of the study up to the same level of detail.)

- The downstream extent of the study area currently is just downstream of H Street/Fair Oaks Boulevard. This boundary should be extended downstream. The purpose of this is that significant erosion has not only occurred in the current study reach but also downstream of here, most notably near the Capital City Freeway. (Status: The study was extended downstream but with lower level of detail. Further investigation would be needed to bring this section of the study up to the same level of detail.)

- There is a considerable amount of data available with regards to historic borings and characterizations of materials. A few examples of this include drilling logs for water wells and groundwater models. Research should occur to identify this data and it should be incorporated into the modeling efforts. (Status: This comment was in regard to including the regional geologic model into a more detailed site specific study and to make sure the study is not isolated from the larger regional context. This was addressed through an expansion to the high and low resolution study areas.)

- The extent of the geophysical investigation should be expanded. This expansion should include extending the overall study area in the upstream and downstream direction but also should include collecting cross sections at various locations; all of the geophysical lines collected at the time of the panel have been profiles (running parallel with the river) as opposed to cross sections (running perpendicular to the river). Additionally, geophysics should be validated by comparison to bore hole data. (Status: This has not been completed to date. However, it is not needed for a feasibility decision at this time. However, additional geophysics to refine the estimate of where highly erodible materials are located in profile and cross-section could be helpful information in the future if more refined modeling is desired such as to inform phasing construction using relative risk.)

- Modeling, most specifically the HEC-6T model is not calibrated. To the extent that any modeling can be calibrated, it should be. (Status: Model was verified using available gage data.)

- Soil filled rock mixtures used for bank protection should be closely monitored during and after flood events to assure that their performance meets USACE standards. (Status: At this time, the use of soil filled rock is not specified as part of the tentatively selected plan. Monitored should be considered moving forward.)

- Existing modern bank protection sites need to be analyzed to assure they can withstand a flow of 160,000 cfs. (Note: This recommendation has not been followed to date. The feasibility study assumes that recent erosion protection was designed and constructed adequately to withstand this discharge without the need for additional analysis beyond what was conducted for the design. It has not been verified that each site was designed for 160,000 cfs.)

- Based on input presented to the panel, there is a high degree of variability in the bed materials. Interpretations made of connecting the dots between borings could be erroneous. More borings should be collected to assure continuity of various layers. Additionally, this refinement in detail needs to be accounted for in the stratigraphic model. (Status: This is true of any such geotechnical model. Additional investigation is deferred to future analysis and design efforts).

- Characterization of materials is primarily being completed by the EFA and JET testing. Other methods to characterize engineering properties of geologic materials should be utilized. An example of one would be the NRCS soil/rock erosion model. Additionally, lab test results needs to be correlated to behavior in the field. (Status: The method was not considered practical for use in the feasibility study and therefore was not conducted).

- Because of the large extent of bankline/levee requiring armoring, a site prioritization method needs to be developed so that the sites being the most urgent will be addressed first when construction begins. (Note: This recommendation to develop this site prioritization method has not been completed at this time and will need to be developed in the future.)

1.7.2.3 American River Common Features Project, American River Erosion Analysis, Technical Working Group Meeting (Final Meeting Minutes dated December 2012). [Panel meeting from October 16-17, 2012]

The previous advisory panel reconvened as a follow-on working group meeting to the November-December 2011 workshop. The following recommendations were given as a summary of the findings of the expert panel:

- Need to combine the results of the geophysical data into the stratigraphic mapping to develop a more complete picture. (Status: This was performed to the extent possible given the restrictions of the data and various software programs currently available.)

- Collect additional borings downstream of Paradise Beach down to the Business 80 crossing. Additionally, there is concern regarding erosion and scour in the downstream end of the river for releases made at Folsom for times when the Sacramento River is at a low stage. (This is anticipated to occur during the design and construction phase of the project).

- Conduct an analysis of how the dredge tailings located near RM's 16 – 19.2 act as a sediment supply to the river. (Status: This has been completed and is discussed later in this report).

- Results of the geophysical data need to be combined into the stratigraphic mapping to develop a more complete picture. (Status: This was performed to the extent possible given the restrictions of the data and various software programs currently available.)

- Collect additional borings downstream of Paradise Beach down to the Business 80 crossing. Additionally, there is concern regarding erosion and scour in the downstream end of the river for releases made at Folsom for times when the Sacramento River is at a low stage. (Status: Additional borings are deferred to future analysis and design efforts. No specific action taken to address erosion and scour in the Lower American River when the Sacramento is at a relatively low stage).

- Conduct an analysis of how the dredge tailings located near RM's 16 – 19.2 act as a sediment supply to the river. (Status: This is complete).

Many of the expert and/or advisory panel recommendations were addressed by work performed by the Sacramento District and/or by the District's contractors, or anticipated to be performed as part of the design and construction phases of the project. Most of these recommendations related to geotechnical, geologic, and/or geophysical investigations (refer to Section 1.8). Some of the recommendations were not addressed due to budget and schedule considerations. Some of these recommendations that were not completed are noted above in parentheses. The District envisions that, as appropriate, the remaining work efforts will be addressed in future studies. For example, there is currently an ongoing channel widening threshold analysis to support changing operations at Folsom Dam.

1.8 Geologic and Geotechnical Investigations and Analyses – Lower American River

1.8.1 Soil Boring and Cone Penetration Test Investigations

Subsurface exploration, soil borings and Cone Penetration Tests (CPT), and subsequent laboratory testing were performed in support of the various geologic, geophysical, and geotechnical investigations, mapping, modeling, and analyses associated with studying erosion on the LAR. The subsurface exploration was led by two teams, one using Sacramento District In-House resources and one led by URS Corporation (URS).

The Sacramento District In-House subsurface investigation included drilling a total of 11 vertical soil borings within the American River channel, 29 vertical soil borings on the levee crest and waterside channel bench, and 15 cone penetrometer tests (CPTs) on the waterside channel bench. The URS subsurface investigation included a total of 44 borings, with 24 primary sonic borings and 20 companion air rotary casing hammer (ARCH) borings along the levee crest and waterside bench.

1.8.2 Erosion Rate Testing

The Engineer Research and Development Center (ERDC), Geotechnical Structures Lab (GSL) and Texas A&M University (TAMU) Department of Civil Engineering further assed the erosion resistance of the LAR by performing Jet Erosion Tests (JET) and Erosion Function Apparatus (EFA) testing on undisturbed samples of cohesive materials located near the bed elevation of the LAR (URS, January 2012; USACE-ERDC, May 2013; USACE, February 2012; USACE, June 2013). The tests resulted in determining values of Erodibility Coefficient, K_d, and Critical Stress, τ_C, of the samples. A total of 81 JET tests were performed on 38 samples and 46 EFA tests on 46 samples.

1.8.3 Geophysical Investigations

To characterize the extent and thickness of lithologic units that may have differing scour potential, the United States Geological Survey (USGS) has performed several geoelectrical surveys of the LAR channel and floodplain between RM 5.5 and RM 11.0. Preceding reports document the methods and results of each survey (Asch et al, 2007; Ball and Teeple, 2012; Powers and Burton, 2012). The combined results of these surveys are released in the subject report as digital data in a three-dimensional (3-D) framework that allows geospatial comparison between the geophysical results and available geotechnical and lithologic data. The data resulting from these surveys have been compiled into similar database formats and converted to uniform geospatial datums and projections. These data have been visualized in a digital three-dimensional framework project that can be viewed using freely available software, allowing a comprehensive analysis of the resistivity structure underlying the LAR corridor and assisting in levee system management.

Traditionally, exploration of lithologic and geotechnical properties is accomplished through borehole drilling, where subsurface materials can be directly observed, described, and tested. Extensive drilling has been conducted on the LAR corridor, resulting in high vertical resolution datasets describing the lithology and stiffness of the sediments. While these types of data are invaluable, their inherently one-dimensional nature makes upscaling to a more manageable regional interpretation difficult. Surface geophysical data can provide supporting information about the variability of subsurface physical properties that may be correlated to changes in lithology or scour potential. While borings provide high-resolution data about the vertical distribution of properties, surface geophysical data can provide high-resolution supplemental data about the lateral variations in physical earth properties. Geoelectrical data, in particular, measure the electrical resistivity of the subsurface. The electrical resistivity of a given material is controlled primarily by the water content and quality, and also by the presence of clays or other conductive minerals. Changes in resistivity structure therefore reflect changes in porosity/compaction, lithologic texture, degree of saturation, and groundwater salinity. Geoelectrical methods also facilitate wide-spread data collection while minimizing potential noise presented by the urban environment, something that typically more strongly affects seismic and electromagnetic methods.

1.8.4 Stratigraphic and Geomorphic Mapping

Fugro Consultants developed reconnaissance and detailed surficial geologic maps of the LAR study area and developed conceptual geomorphic and stratigraphic model with the primary purpose of better understanding the stratigraphy exposed in the channel banks and bed of the LAR. The stratigraphic and geomorphic mapping effort was undertaken in direct response to concerns raised in the Lower American River, Panel of Experts Findings Report (West Consultants, December 2010) in regards to location and extents of the erosion resistant unit and better organizing existing geotechnical and geologic data.

Two levels of investigation were performed: (1) detailed mapping (1:2,400 scale [1 inch = 200 feet]) and analysis of the geologic deposits between the levees from RM 5.0 to 11.0, and (2) development of 1:12,000 [1 inch = 1,000 feet] reconnaissance mapping along the channel corridor between RM 0.0 to 5.5 and RM 11.0 to 22.4. The mapping synthesized existing surface and subsurface data including geomorphic/geologic maps, geophysical data, aerial photographs (both historic and recent), and boring logs, to augment the new field mapping and to aid in the interpretation of deposits and the development of the map.

Fieldwork included reconnaissance of the levees, banks, and river channel to map the riverbed and bank materials, surveying the elevation of relevant stratigraphic contacts, and documenting relevant exposures. Stratigraphic analysis of the apparently hard/dense unit specimens included section description, specimen petrography and microscopy, and pedogenic evaluation of the units. Geomorphic analysis included development of three-dimensional surface contour maps of erosion resistant units, and geologic cross sections and longitudinal profiles. The results of this study were used to identify locations requiring further study and investigation, validate the results of the laboratory testing, and were incorporated into the 3-dimensional stratigraphic model of the LAR.

1.8.5 Upstream Sediment Source Reconnaissance

Fugro Consultants conducted geologic field reconnaissance in areas of gold dredge tailings and aggregate quarries along the LAR in the approximate area between Nimbus Dam (RM ~22.4) and the Watt Avenue Bridge (RM ~9.1). This study was designed to directly address the recommendations of an LAR advisory panel convened by the USACE in October 2012. The primary goal of this reconnaissance level study was to estimate, at order-of-magnitude levels, the potential volume of sediment that could be available for river transport to the LAR from gold dredge tailings and former aggregate quarries along the river's floodplain, principally at flood discharge levels (115,000 cfs and above). A secondary goal was to characterize dredge tailings stratigraphy and visually estimate distributions of tailings' grain size distributions. The results of this study provided the initial field-based context for evaluating the significance of gold dredge tailings and former aggregate quarries as input sources to river sediment transport models. It is anticipated that the results of this reconnaissance effort will be incorporated into future hydraulic models and analyses.

1.8.6 3-Dimensional Stratigraphic Model

URS developed a three-dimensional (3D) stratigraphic model of the LAR to describe the stratigraphy and subsurface conditions of the study reach and help evaluate the stratigraphic susceptibility of this reach to erosion. The model encompassed the levees, banks, and channel of the LAR from RM 5.25 to RM 10.2. In late 2011, an initial model was created and served as a precursor and guide for producing the revised and final 3D model. The initial model included stratigraphic interpretation from numerous borings drilled through the levees along the north and south banks of the river. Except at the bridges, the initial model did not include information from borings drilled within the channel or along the inner banks. The final version of the 3D stratigraphic model represented an increase in detail and complexity over the initial version, presented data included from additional borings that were drilled between the levees and incorporated more geologic, geotechnical, and geophysical data than the earlier models. These data were constrained using an understanding of depositional and erosional processes to fit the model to its geologic environment. As a result, the final 3D model contains enhanced information, especially within the area between the levees where young alluvial sediments related to hydraulic mining have been deposited. In addition to showing subsurface alluvial stratigraphy, the final model shows the top of erosionally resistant sediments that are exposed and identified in the channel at several locations.

1.9 Geologic and Geotechnical Investigations and Analyses – Sacramento River

1.9.1 DWR Urban Levee Evaluations

The California Department of Water Resources' (DWR) Department of Flood Management is managing a levee evaluation program to assess the existing conditions of urban levees in California's Central Valley. The Urban Levee Geotechnical Evaluations (ULE) Program evaluates levee systems that are expected to protect communities of more than 10,000 people and includes a study area referred to as the Sacramento River South Study Area. This study area comprises the levees on the east (left) bank of the Sacramento River from the American River to Freeport, and is comparable to the ARCF GRR Sacramento River study area outside of Natomas. The DWR ULE Project consists of a multiphase investigation and evaluation of levee study area. This multiphase approach consists of a Technical Review Memorandum (TRM), Phase I Geotechnical Data Report (GDR), Phase I Geotechnical Evaluation Report (GER), Supplemental GDR, and GER. These phases of the ULE Project collect existing data, generate new geotechnical data, evaluate the levees based on these data, and form recommendations for improvement measures. While the DWR ULE program and ARCF GRR are independent and separate studies, both studies share relatively common approaches and desired outcomes. The data, results, and recommendations generated by each study are reviewed by both DWR and USACE for consistency and share much of the same supporting information without relying on each other as a basis of conclusions or recommendations. In that form, the Erosion Screening Process (ESP) developed by DWR and discussed in summary in this Section was used by the USACE ARCF GRR PDT not as a basis of decision making but as an independent check.

Part of the ULE Project is a three-tiered ESP that was developed to qualitatively analyze the potential for erosion-induced levee breach during a 200-year flood event. Tier 1 analyses included the following tests: historical performance, levee prism geometry, wind fetch length, and soil erodibility. Tier 2 analyses involved evaluating: flow velocity and testing erosion surface adequacy, wind-wave shear and testing erosion surface adequacy, and field reconnaissance. During Tier 3 analysis, a representative cross section was selected for each levee segment based on existing levee geometry and soil erodibility conditions, given that the other properties (i.e., velocity and wind) were generally constant within a segment. Levee segments are assigned one of three erosion risk levels (low erosion risk, medium erosion risk, or high erosion risk) based on Tier 3 erosion analyses results.

During the Tier 1 evaluation the Sacramento River Study Area was subdivided into 22 levee segments, all of which did not meet one or more of the four Tier 1 test criteria and were advanced to Tier 2 for analysis. Of those 22 segments, 20 did not meet Tier 2 analysis criteria and were advanced to Tier 3 for analysis. The 2 segments not advanced to Tier 3 analysis were classified as low erosion risk. Of the segments advanced to Tier 3 analysis, 2 were classified as low, 14 were classified as a medium, and 4 were classified as high erosion risk primarily due to channel velocity, erodible soil, and levee geometry. This report showed that the Sacramento River levees have a medium to high risk of breach due to erosion.

1.9.2 Fugro WLA Surficial Geologic Mapping and Geomorphic Assessment

William Lettis and Associates developed a technical memorandum to present the results of surficial geologic mapping and geomorphic assessment along the Sacramento River (East Side) from the confluence with the American River south to the town of Freeport. The goal was to provide information on the type and distribution of surface and shallow subsurface deposits that underlie the levee for assessing potential levee underseepage, and to develop a conceptual model that allows reasonable stratigraphic interpretations between widely-spaced subsurface explorations. Data on potential geologic and geomorphic controls on levee underseepage were developed primarily to help guide geotechnical explorations, and secondarily to provide a geologic basis for characterization of levee foundation materials. This study involved integration and analysis of aerial photography, topographic, geologic, and soil maps, other historical documents, and review of available geotechnical exploration data and helicopter-based geophysical imaging data. Synthesis of these data allows for assessing the primary geomorphic processes responsible for the distribution of surficial deposits within the project area, and constructing a preliminary conceptual geomorphic model with shallow stratigraphic interpretations.

1.10 Hydraulic and Sedimentation Studies

Based on the expert panel recommendations above in paragraph 1.7.2.1 "Lower American River, Panel of Experts Findings Report (West Consultants, December 2010), new studies were started. These studies include characterizing and mapping the geology and erosion resistance properties as described below in Section 1.8 "Background of Geotechnical Studies Completed to Date." A bank migration analysis was also completed and is discussed below. In addition, the HEC-6T model of the American River was converted from NGVD 29 vertical datum to NAVD 88 vertical datum and updated to include new geologic and sediment data. This effort is ongoing but draft results and report are available. However, this effort has not been reviewed by USACE for quality and therefore the results should be used with caution. These draft results are further discussed below. In addition, the Sacramento River Bank Protection project included a larger scale sediment study of the Sacramento, Feather, and American Rivers along with relevant weirs and inflows/outflows. These studies are also discussed below.

1.10.1 Sacramento River Sediment Study Phase II – Sediment Transport Modeling and Channel Shift Analysis Lower American River. Common Features - Completed tasks.

This task updated previous bank migration analysis by Ayres with current information, reviewed the approach used by Ayres, and summarized findings and implications. This new approach used new LiDAR information to assist with defining the top of bank in GIS, an issue identified during the expert panel review. Previously, Ayres concluded that the Lower American River had not exhibited significant lateral shifting due to natural river processes from 1957 to 1998, and that significant changes in bankline location were the result of sand and gravel mining operations. NHC confirmed Ayres findings of no significant recent bankline migration by using aerial photos combined with survey data from 1998 to 2010 to develop more accurate banklines. NHC noted that significant differences shown in the previous Ayres analysis were the result of Ayres incorrectly identifying the top of bank from aerial images without the aid of relatively accurate topographic data. NHC concludes that there are no actively migrating meander bends on the Lower American River, although large floods have caused significant instream changes between the channel banklines in the past. Annual river surveys show that lateral erosion and bankline shift is occurring on the Lower American River, but on a scale too small to be accurately identified by air photo interpretation. NHC also collected bed material samples along the Lower American River and compared the data with past measurements. While the report notes there is a lot of variability in the data, the range of the data is typical for natural gravel-bed rivers and does not appear to show any obvious trends (coarsening or fining) since 1993.

1.10.2 Sacramento River Sediment Study Phase II – Sediment Transport Modeling and Channel Shift Analysis Lower American River. Common Features Tasks in-progress (June 2013 draft information report).

This information is based on draft results that have not been fully reviewed by USACE and should be viewed with caution as they are subject to change. However, the information is included here as the results seem reasonable and can be informative. NHC updated the Ayres HEC-6T model by converting it NAVD88 vertical datum, by adding more recent surface and sub-surface bed material gradations and gage data, and by incorporating results from geotechnical investigations of erosion resistant material in the bed and banks (see section 1.9.2). The model was calibrated to the 1997 high water marks and to observed vertical channel changes between 1997 and 2006. The calibrated model was run for multiple synthetic hydrologic scenarios designed to mimic short-term and long-term morphological conditions. This does not include a full set of hydrographs over decades of future conditions but uses a series of individual events to approximate short-term and long-term conditions. This hydrologic approach to the sediment modeling is useful for relative comparison purposes and should not be used to estimate actual future conditions. Other studies have found that trends from a single flood event may be opposite of the long-term trend and therefore these results should not be used for estimating long-term aggradation/degradation trends.

NHC conducted HEC-6T sediment modeling for the Sacramento and Lower American rivers (NHC 2012) that included long-term hydrology (1997 - 2008) from actual gage data as well as n-year specific events (e.g. 1/50 ACE, 1/100 ACE). A comparison of the results for the same reach (Sacramento River between the Lower American River confluence and Freeport) shows that the reach is degradational during a specific n-year flood event but aggradational over the long-term. The implication is that using single event hydrology (e.g. the 1/100 ACE event) or hydrology composed of a series of single n-year events (e.g. 1/100 ACE event followed by a 1/200 ACE event) may provide evidence for the opposite trend (degradation) than if a wider range of flows (e.g. 1997 - 2008 "continuous" hydrology) is used for the same reach. So while specific event modeling is likely more conservative for design and cost of erosion counter-measures for this reach, it may not be helpful if long-term trends are needed for other purposes, such as for determining if future sedimentation will bury spawning gravel.

Despite this limitation, the results enhance the understanding of sedimentation trends in the Sacramento River and may still be informative and perhaps conservative relative to feasibility level designs and costs. There is a lot of uncertainty associated with all sediment models as noted in the comment. However, the Sac Bank Sediment Study shows that using event specific hydrology vs. long-term hydrology for the exact same model can lead the model to show opposite trends. Therefore the relative differences may lead to incorrect conclusions even though both models are subject to considerable inaccuracies.

The results from this study (NHC 2013) include:

- Most of the Lower American River is actively degrading and the degradation increases with increasing flood magnitude and is greater in the upstream reaches (particularly above about RM 14).

- Computed maximum channel degradation is 8-10 ft upstream of RM 19, 2-7 ft between RM's 5-19, and less than 1 ft downstream of RM 5. The results from the updated model of the lower American River are generally consistent with the original Ayres (2010) model. However, there is limited geologic information below river mile 5 and above river mile 11.5 and results in these reaches may include some uncertainty.

- Modeling results indicate that for all the flows simulated the shear stress in the reach with locally exposed hard material (between RM 7 and RM 11) is below the critical stress for erosion of moderately resistant materials (clay and cemented sand with silt). Therefore, significant scour below this erosion resistant material/surface is not anticipated. However, this is for general reach wide trends and local erosion such as at bridge piers may occur. Local scour should be further evaluated during future studies.

- The simulations generally indicate a coarsening of the surface bed material due to flood events.

1.11 Levee Screening Tool

As part of the USACE Risk Assessment Framework, the levee segments along the American and Sacramento Rivers were assessed using the Levee Screening Tool, a part of the USACE Levee Safety Program. Through this approach a Levee Safety Action Classification (LSAC) was assigned to the American River North (American River North Bank, NEMDC East Bank, Arcade Creek North and South Bank, and Dry Creek North and South Bank levees) and South (American River South Bank and Sacramento River East Bank levees) Basins by the Levee Senior Oversight Group (LSOG). The USACE Risk Assessment Framework process for assigning LSAC ratings entailed a series of presentations and reviews at the District level (relative risk assessment), consistency level (National QA Cadre), and senior-level (LSOG) for each levee segment. Each segment was evaluated on up to six performance modes depending on the features that were present in the segment. The performance modes were: Embankment and foundation seepage and piping, embankment stability, embankment erosion, closure systems, floodwall stability, and floodwall underseepage and piping. Following the presentation and input from the National QA Cadre and LSOG panels, a final LSAC classification was assigned for each segment. The presentation process encompasses segments within the same levee system and following all presentation and assignment of ratings per segment, an overall LSAC rating was given to the system. The final recommendation was then forwarded to the USACE levee safety officer for approval, action, and dissemination.

The USACE Levee Screening Tool Application Guide and User's Manual: Levee Safety Action Classification (LSAC) provides reference documentation and further details the rating process. The system rating is consistent with the highest risk segment within the levee system. Levee systems were assigned one of five classes which are described below:

- Class I – Very high risk warranting "urgent and compelling" actions to reduce risk,
- Class II – High risk warranting "urgent" actions to reduce risk,
- Class III – Moderate risk warranting "high priority" actions to reduce risk,
- Class IV – Low risk warranting "priority" actions to reduce risk,
- Class V – Normal risk considered tolerable, requiring only that "normal" levee safety activities continue.

The overall system rating assigned to the American River North Basin was an LSAC I. The main contributing factor is embankment erosion on the American River North Levee. This performance mode coupled with the high population at risk, critical infrastructure within the basin, and expected loss of life during a breach contributes heavily to the overall rating.

The overall system rating assigned to the American River South Basin was an LSAC I. The main contributing factors included embankment seepage and stability on the Sacramento River South Levees, and embankment erosion on both the American River South Levee and Sacramento River South Levees. These performance modes, in conjunction with the high population at risk, residential and critical infrastructure, and expected loss of life during a breach contributes to the overall rating.

2 Completed Bank Protection Work

As discussed in Section 1.5, erosion has continued on both the Sacramento and Lower American Rivers and ongoing repairs have been performed to maintain channel integrity (i.e., the ability of the channel to convey the design discharge). Figure 2-1 depicts the modern revetment repair sites (shown in green) and a series of historic revetment sites (shown in orange), many of which consist of cobbles. In the Lower American River, these cobble sites are considered ineffective as erosion protection for large discharges which approach 160,000 cfs. For completeness, revetment segments for both left and right levees on the Sacramento River are included on Figure 2-1 to illustrate the magnitudes of the erosion problem on these mainstem channels and levees. As will be shown in Figure 6-3, the tentatively selected plan is to replace the historic revetment (e.g. cobble) with modern revetment to protect the banks from anticipated future flows.

In general, the repair sites provide insight into the bank protection features proposed for the subject ARCF GRR study. Specifically, as will be presented below in Section 6, the proposed bank protection features use design concepts adopted from several of the existing repair sites along the Lower American and Sacramento Rivers.

Sample repair sites along the Lower American River are illustrated on Figure 2-2 and Figure 2-3. Figure 2-2 shows the left bankline, looking downstream, at the repair site near RM 0.3 in 2010. This is the same erosion site shown in Figure 1-3 located on the left bank of the LAR upstream of the Interstate 5 crossing. Figure 2-3 (2010) is looking downstream at the repair site near RM 4.3 which is the bank and levee erosion site shown in Figure 1-6 located on the left bank upstream of the Capitol City Freeway. Erosion during the 1986 flood event nearly failed the levee at this site. In some cases, the bank repair consists of re-grading the slope and placing riprap with an emphasis on ensuring that the toe rock meets design criteria. In other cases, woody material is placed with the toe rock for fish habitat.

On the Sacramento River located at RM 62.5 (just downstream of the Interstate 80 crossing), Figure 2-4 shows bank erosion on the right bank on the Sacramento River in 2009. The repair for this site is shown in Figure 2-5 which was completed under the SRBPP.

Another Sacramento River erosion site is illustrated in Figure 2-6. Specifically, this photo shows the erosion and slope stability problems along the left bank at RM 53.2 in 2005. The repair for this site is shown in Figure 2-7 which was completed under the SRBPP.

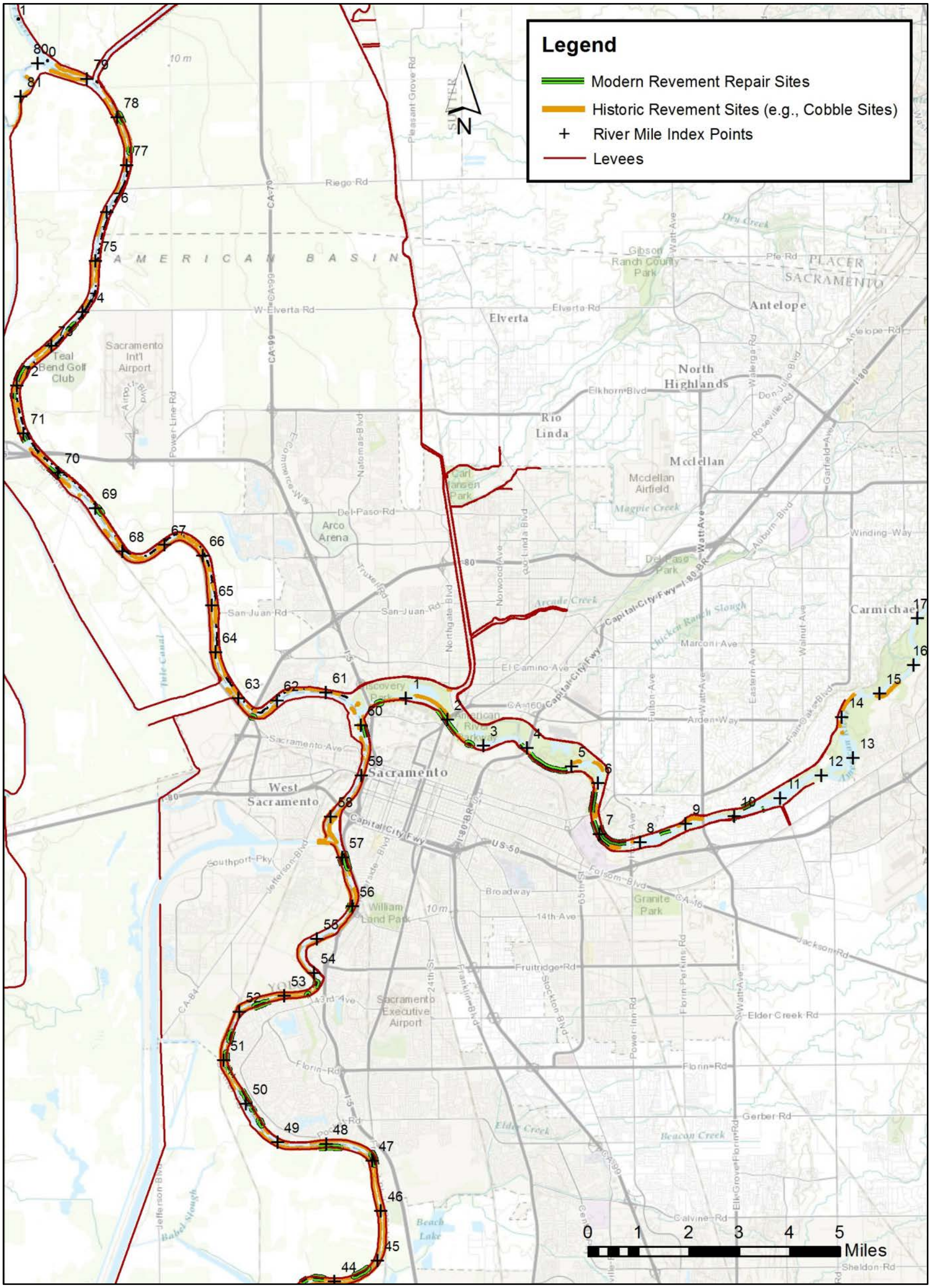

Figure 2-1. Historic and modern revetment sites along the Sacramento and American Rivers

Figure 2-2. View of repair site on the left bankline near LAR RM 0.3 (2009)

Figure 2-3. View of repair site on left bankline near LAR RM 4.3 (2010)

Figure 2-4. Erosion site of the right bank of the Sacramento River at RM 62.5 (2005)

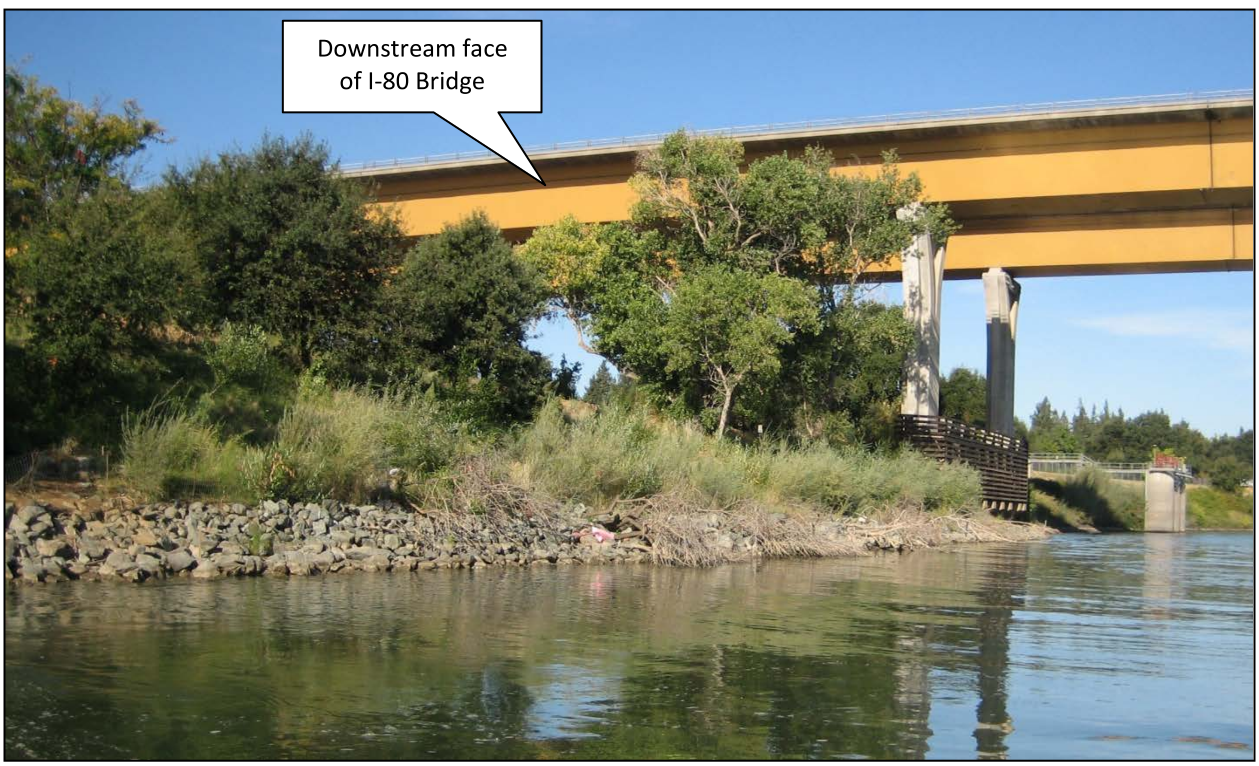

Figure 2-5. Repaired site at Sacramento River right bank RM 62.5 (2009)

Figure 2-6. Erosion site of the left bank of the Sacramento River at RM 53.2 (2005)

Figure 2-7. Repaired site at Sacramento River left bank RM 53.2 (2009)

3 Geologic and Geotechnical Characterization

3.1 Geologic and Geomorphic Mapping and Analyses of the Lower American River

Regional geologic and geomorphic mapping show that the floodplain of the LAR is inset into (topographically lower than) older late Tertiary to Quaternary age alluvial deposits that form steep bluffs along the north (i.e. right) bank of the river from about Folsom Dam downstream to about Watt Avenue. Within the LAR study area, the middle Pliocene to Pleistocene (< 5.3 million to pre-Riverbank age) Fair Oaks, and the Pleistocene (1.8 million to 11,000 years old) Riverbank, and Modesto Formations underlie or are directly adjacent to the LAR. The Fair Oaks formation forms the steep bluffs along the north side of the American River with its contact dipping into the subsurface west of Watt Avenue while the Riverbank and Modesto Formations are expressed as a series of progressively younger and topographically lower alluvial fan deposits that make up most of the surficial geology of the LAR study area. The Riverbank Formation forms several broad, gently sloping alluvial fan surfaces south of the river, and the Modesto Formation forms the terraces closest to the river. To a large extent, the present-day levees along the American River have been constructed on the top of the river’s banks, and overlie geologically young (i.e., late Pleistocene to Holocene), unconsolidated sand and silt-rich floodplain sediments, including post 1850 mining spoils.

Detailed geologic mapping, as well as petrographic and pedogenic analyses, completed during this study demonstrated the presence of two potentially erosion-resistant units within the stratigraphy of the LAR. These were: (1) a moderately cohesive silty and sandy interbed of relatively limited lateral and longitudinal extent within a thicker package of loose Holocene sediments (the “upper” unit); and (2) much thicker, more widespread relatively erosion-resistant deposits associated with the Pleistocene-aged Fair Oaks formation of Shlemon (1967) (the “lower unit”). Figure 3-3 presents a generalized stratigraphic section.

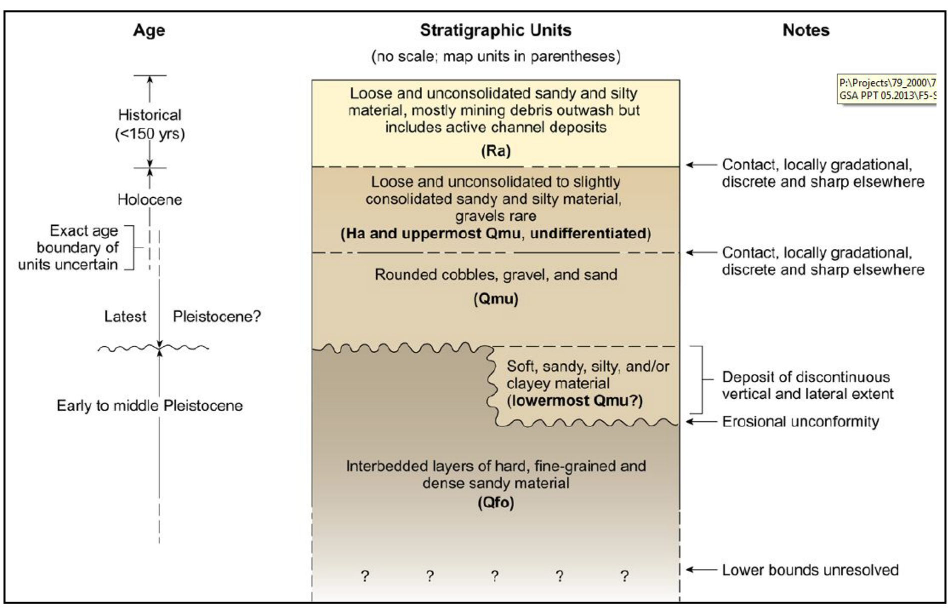

Figure 3-1. Generalized, composite stratigraphic section of the Lower American River

The upper unit was mapped in the banks of the LAR from RM 5.2 to 5.7 and may also exist near the Fairbairn water intake structure near RM 7.2 to 7.3. The upper unit was interpreted to be a geologically young deposit that is only slightly more cohesive than the surrounding early Holocene or the latest Pleistocene upper Modesto Formation sandy and gravelly sediments, and may be only weakly resistant to erosion.

Surficial geologic mapping and synthesis of geotechnical data show that the Plio-Pleistocene age Fair Oaks formation is exposed in the channel bed and banks locally upstream of Watt Avenue (RM 9.0 to 11.0) and intermittently exposed in the channel bed downstream of Watt Avenue to near RM 6.7 (slightly downstream of the Guy West pedestrian bridge). Prominent outcrops upstream of Watt Avenue occur at RM 10.1 and from RM 9.4 to 9.7. Downstream of Watt Avenue, the formation lies mostly below the modern bed elevation of the river and is not readily visible. Generally, a variable thickness of modern and/or upper Modesto Formation-age gravels and cobbles overlie the Fair Oaks formation in this reach. In some locations, the bathymetric data suggest that localized scour has removed most of the overlying gravels and cobbles and the Fair Oaks formation may be present in the channel bed (e.g., RM 8.2–8.3). Downstream of the Howe Avenue Bridge, between approximately RM 6.6– 7.5, bathymetry data show broader areas of scour where the formation is likely more widely exposed in the channel bed or lies concealed beneath a thin cover of active channel gravel only a few feet thick. The unit likely is continuous in the north-south directions beneath the levees, but at elevations below the present day thalweg, and thus the unit provides no bank resistance to lateral erosion and will not contribute to levee stability.

No paleosols containing well-developed, laterally continuous pedogenically-derived, clay-rich hardpans or silica-cemented duripans were observed in the detailed study area. Based on a review of the geotechnical data, inspection of a limited number of boxed core samples collected via sonic drilling in late 2011, examination of in-stream outcrops, and petrographic analysis, the erosionally resistant materials in the detailed study area have undergone only limited pedogenesis. Petrographic study supports field observations that there is little precipitated chemical cement in these sediments and shows the coarser grains to be held together at least partly by minor amounts of clay and fine silt, which occurs as secondary pedogenic coatings on grains and pores in some samples.

Multiple geologic processes likely are responsible for the relatively indurated nature and apparent erosion resistance of the sediments composing the lower unit (i.e., the Fair Oaks formation). The results of this study suggest that silica cementation is not responsible for the relatively high apparent density / hardness of the sediments. Rather, it is more likely that multiple lithification processes, including (but not limited to) partial cementation, compaction, desiccation, and authigenesis (i.e., recrystallization), occurring over geologic time (i.e., 10^5 to 10^6 years) in aggregate, contribute to the induration presently observed. An additional factor contributing to the high apparent density / hardness of these sediments may be the natural angularity of the glacially-derived silt and fine sand component. In our opinion, the relatively old age of the Fair Oaks formation is likely the greatest single factor contributing to the high apparent density / hardness of the sediments that make up the formation. The process of consolidation, acting over hundreds of thousands of years, may result in materials that are sufficiently dense and compact as those observed in the detailed study area.

Although the terminology “erosion resistant” is used to refer to the outcrops of the relatively indurated material in the river channel, the outcrops do erode. Field observations suggest several mechanisms of erosion are currently occurring at both the granular- and outcrop-scale, including tension cracking and block-topple, scour resulting in potholes and development of flutes or grooves, and potentially wet-dry and freeze-thaw cycles.

3.2 3-Dimensional Stratigraphic Model of the Lower American River

The general goal was to develop a 3-dimensional (3D) stratigraphic model of the LAR study reach by incorporating both existing and newly collected geotechnical and geologic data, and utilizing geologic principles to place the stratigraphy into a depositionally based framework. The model was intended to describe the stratigraphy and subsurface conditions of the study reach and help evaluate the stratigraphic susceptibility of this reach to erosion near the levee banks.

URS created a 3D stratigraphic model of the LAR study reach using Environmental Visualization System (EVS) software (version 9.6, developed by C Tech Development Corporation). For the geographic information systems (GIS) component of the task, URS used ESRI's ArcGIS (version 10) to produce ESRI file geodatabases, shapefiles, and GRID geospatial data formats in ArcGIS (version 9.3.1) format, per USACE's specifications. URS used Microsoft Excel and EVS utilities to translate tabular data, comprising the interpretation of the stratigraphic units into EVS input file formats.

Stratigraphy was interpreted through review of the boring logs and surficial outcrops. To create the 3D model, the stratigraphic contacts were manually drawn on 24 hardcopy cross sections approximately perpendicular to the American River channel axis and 12 profiles. The sections and profiles included surface topography and exploratory boring stick logs. The stick logs contain abbreviated boring information, including; USCS soil classification, hammer blowcounts, laboratory fines content, collar elevation, bottom elevation, and offset distance from section or profile line. The sections and profiles were converted to x, y, z tables in Microsoft Excel and imported into the EVS data format.

Seven general stratigraphic units are described below, based upon consolidation of numerous sample descriptions within each layer. The descriptions are necessarily broad because they describe alluvial deposits that have some degree of variability with depth and lateral extent, both parallel and perpendicular to the channel.

- **Fill:** This unit is primarily levee construction soils excavated from nearby channel, composed of mixtures of sand, silt, and clay. Locally, this includes fill placed for roads or other purposes.
- **Post-1850 Alluvium:** This uppermost stratigraphic unit is sandy and crops out mainly between the current channel banks except downstream of the Howe Avenue bridge where it extends to the right edge of the model, beyond the land side toe of the right bank levee. This unit is primarily composed of silty fine sand, fine sandy silt, silt, and clean fine to medium grained micaceous sand. This unit is not defined by exploratory soil boring data primarily because it is located where it was difficult to drill soil borings: on mid-channel bars and along the inner edges of the high-flow channel margins.
- **Silty sand, sandy silt, silt, sand (three SS subunits):** This unit is primarily composed of sand and silty sand with SM and SP-SM classification with lesser amounts of poorly-graded sand (SP) and sandy silt (ML). This unit locally was described as containing thin lenses of clayey gravel (GC) and low-plasticity clay (CL).
- **Sand (three S subunits):** This unit is primarily composed of poorly-graded sand (SP) with slightly lesser amounts of silty sand (SM) and sand with silt (SP-SM). Thin, discontinuous lenses of low-plasticity sandy clay (CL), clayey sand (SC), and gravels (GM to GP) are occasionally present.

- **Silty clay, sandy clay, clay, and silt (five CS subunits):** This unit is primarily composed of low-plasticity clays and silts (CL) and (ML) with varying amounts of sand. Locally. this unit contains thin, discontinuous lenses of gravelly clay to clayey gravel (CL to GC), clayey sand (SC), and silty sand (SM).
- **Boulders, cobbles, gravel with sand (three BCG subunits):** This unit is primarily composed of well-rounded very coarse materials. These materials were difficult to sample, even with the sonic drill rigs because of the hardness of the cobbles and boulders. The boring logs classify these materials primarily as poorly- to well-graded gravels (GP to GW), and silty gravels (GM), with lesser amounts of poorly-graded gravels and silty gravels (GP-GM), and boulder/cobbles. Lenses of other finer grained materials were occasionally present within these coarse layers.
- **Clay (one C subunit):** This unit was only differentiated in two borings on the left bank near LM 9.6. It consists of a 3-to 4-foot-thick layer of fat clay.

The areal distribution and grain size of the alluvial deposits beneath the study reach reflect a complex history of erosion and deposition. There are clayey deposits, bouldery/cobbley deposits, and a variety of sedimentary layers with grain sizes in between. Relatively thin, discrete layers of alluvium can be identified in the boring logs. These layers are not always traceable between exploratory borings that are many hundreds of feet apart and are too thin for resolution of the model, but are important to identify as they relate to depositional and erosional processes. The larger-scale stratigraphic units composed of predominantly similar materials (but containing thin, heterogeneous lenses) can be projected from beneath one levee, across the river, and under the levee on the opposite bank. These larger packages of mostly similar deposits are what make up the units in the 3D model.

Each of the main stratigraphic units except the Post-1850 Alluvium appear to accrete in a downstream direction, where they are then overlain by the next younger unit. There is no unit younger than the Post-1850 Alluvium. This shows that at certain times, deposition of units of differing grain sizes was happening concurrently along the American River. However, the presence of the study area-wide lower clay and silt layer in the model appears to indicate that nearly this entire area was a distal fan environment for an extended period of time earlier in the Pleistocene epoch. The nearly continuous boulder/cobble/gravel layer reflects a period when discharge was sufficiently high that flow velocity and depth created shear stresses capable of transporting these large clasts. This may reflect the influence of climate change at the end of the last glacial period, about 10 to 15 thousand years ago.

The erosionally-resistant surface appears to be relatively continuous across the site and to have a downstream slope that is roughly parallel to but slightly steeper than the alluvial deposits and the modern active channel. The erosionally resistant materials observed exposed in the channel are relatively fine-grained silty sands and sandy silts that are predominantly uncemented. The top of the erosionally-resistant surface appears to have relief that may be the result of several factors. The most likely is the possible erosion that may have occurred in the past before this surface was buried or in modern time once the surface became exposed. This explanation fits areas where the erosionally-resistant boundary cuts sedimentary units (see Figure 3-4). The nearly ubiquitous presence of a coarse boulder/cobble/gravel layer on top of the erosionally-resistant surface would have required high discharge velocities and shear stresses to mobilize, and these forces could have eroded the top of the erosionally resistant surface. Another possible source of the relief visible on the top of the erosionally-resistant surface is due to the limitations of the input data, primarily the dependence on boring log information and the challenge of extrapolating a potential erosionally-resistant surface elevation where little information related to cementation or resistance to erosion is provided.

Figures 3-4 and 3-5 are examples of cross sections generated from the 3D stratigraphic model depicting the layer discussed above. Figure 3-6 provides a graphical legend for stratigraphic units displayed in the cross sections. Figures 3-4 and 3-5 are looking downstream.

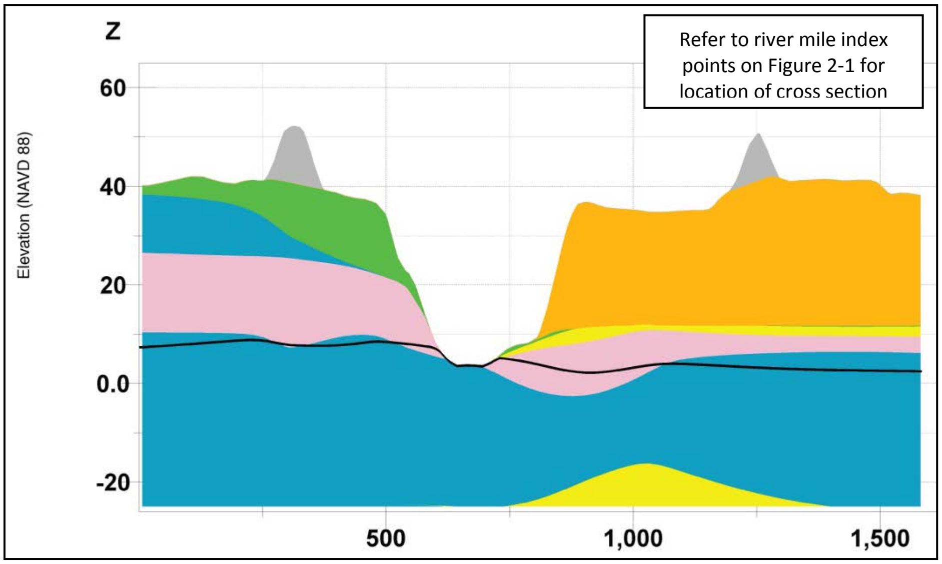

Figure 3-2. 3D Stratigraphic Model Section 11 Near RM 7.2

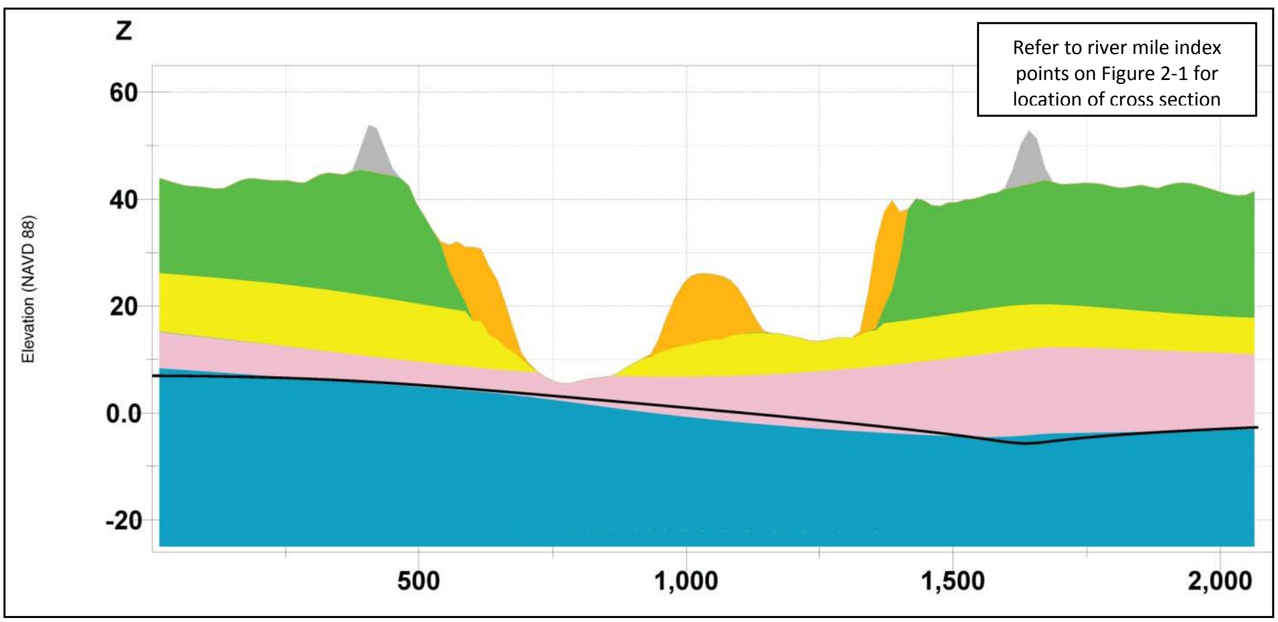

Figure 3-3. 3D Stratigraphic Model Section 15 Near RM 7.9

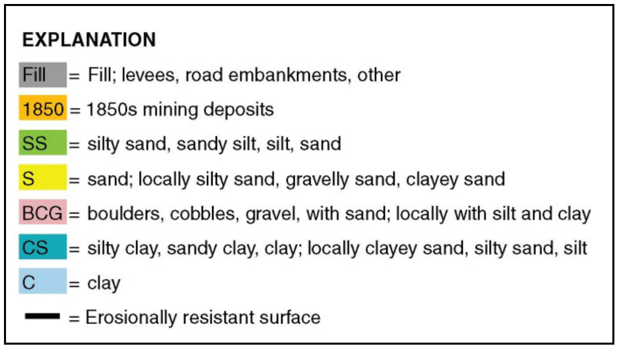

Figure 3-4. 3D Stratigraphic Model Unit Legend

3.3 Sacramento River South Geologic and Geotechnical Characterization

The Sacramento River has irregular sinuosity south of the confluence with the American River, with both large and small radius-of curvature meander bends. The river has, in places, laterally migrated over the past thousands of years, with erosion occurring on the outsides of bends, and deposition of younger sand-rich sediment occurring on the insides of the river bends. Geologically older and erosion-resistant Riverbank Formation is present at the ground surface south and east of the city of Sacramento, and younger alluvium is inset into this formation. Additionally, because of the low topographic position and proximity to the confluence of the two large rivers, the Sacramento area has been subjected to repeated inundation by floodwaters during the past several thousand years. The floodwaters deposit fine sand and silt-rich alluvium along the flanks of the river bank and finer-grained clay and silt are carried in suspension onto the distal floodplain. This hydraulic sorting process creates a ‘natural levee’ landform with a topographic gradient that slopes away from the river. Consequently, the levee is underlain by a variable, relative thick, and relatively young, sandy and silty, unconsolidated alluvial deposits.

South of the confluence of the American River, the Sacramento River demonstrates a complex relationship of fluvial deposits at the surface and beneath the eastern floodplain of the Sacramento River. The surface and subsurface distributions of sandy and clayey deposits are a function of former river positions on the landscape, and present-day geomorphic processes adjacent to the river channel. The levees are underlain entirely by geologically young, unconsolidated, silty and sandy fluvial deposits.

In general, the deposits beneath the eastern floodplain of the Sacramento River consist of three or four fluvial stratums in the following sequence, described from ground surface downward. The top-stratum, consists of very loose and very soft silt, sandy silt, with thin, laterally discontinuous clay and sand lenses. This stratum 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. Beneath the silty top-stratum is a stratum of coarser-grained sediment that ranges in consistency from medium dense fine-to-coarse grained clean sand, sandy silt, and localized occurrences of pebbles, gravels, and cobbles. This stratum is interpreted as latest Pleistocene Modesto Formation (upper member), which was deposited as meander scrolls and channels from lateral migration of river channel(s) across the former valley surface. Underlying this sandy unit is a stratum of gravel that may or may not be the lower member of the Modesto Formation. The gravel is laterally extensive near the American River confluence. In the south part of the study area (Pocket area), this gravel is not present or it exists only in local patches within older channels. Within the Pocket area, a medium stiff to stiff fine-grained (clayey silt, silty clay) stratum, with local gravel patches, discontinuously underlies the more-permeable sands of the second stratum. This fine-grained stratum is distinctly denser than the top-stratum, and may represent lower Modesto Formation flood basin deposits on the earlier valley floor, in former low lying areas adjacent to the river channel. Underlying the upper three unconsolidated sequences is a hard, moderately-cemented silt to siltstone. This unit has been correlated to the upper member of the Riverbank Formation. Thus, the upper member is inset to the lower member of the Riverbank Formation. It is permissibly older, perhaps the latest Pliocene-early Pleistocene Laguna Formation.

4 Hydrology and Hydraulics

4.1 Flow Frequency and Duration

As discussed previously, the American River levee system was originally intended to convey a discharge of 115,000 cfs. When the Joint Federal Project (JFP) is completed at Folsom Dam, in combination with levee repairs currently being completed under the Common Features Project (and other authorities) and the dam 3.5 foot raise, the intent is for the river to be able to convey a discharge of 160,000 cfs, assuming that the levees do not fail from one or more of the potential failure modes (i.e., seepage, stability, insufficient height, or erosion). Please refer to Section 6.5 for a discussion on the feasibility design considerations.

In addition, modifications of Folsom Dam operations will shift the way floods are released into the lower river from Folsom Dam. Specifically, frequent flood events, that is, floods which occur say once in every ten to twenty-five years, will have a larger peak discharge compared to those under current dam operations. Table 4-1 lists a sample of the current and future peak discharges for a range of n-year flood events. This information is taken from the ARCF GRR study to remain consistent. The Folsom Water Control Manual Update will likely update these values as part of their evaluation.

In addition, modifications of Folsom Dam operations will shift the way floods are released into the lower river from Folsom Dam. Specifically, frequent flood events, that is, floods which occur say once in every ten to twenty-five years, will have a larger peak discharge compared to those under current dam operations. Table 4-1 lists a sample of the current and future peak discharges for a range of n-year flood events. These values are from the ARCF GRR study to maintain consistency and it is anticipated that the values will be updated as part of the Folsom Water Control Manual Update evaluation.

Table 4-1. Comparison of peak discharges between with- and without-project conditions

Flood Event	Peak Discharge (cfs)	
	Current Conditions[2]	Future Conditions[3]
50% (1/2) ACE (2-year)	30,200	25,200
10% (1/10) ACE (10-year)	43,100	71,700
4% (1/25) ACE (25-year)	99,700	115,000
2% (1/50) ACE (50-year)	115,000	115,000
1% (1/100) ACE (100-year)	145,000	115,000
0.5% (1/200) ACE (200-year)	320,000	160,000

The important point here is that under future operating conditions to meet the goal of increased flood damage reduction, larger flood flows will need to be conveyed through the American River with greater frequency compared to past operating conditions. These higher flood flows will exert additional pressure on the banklines and levees resulting in greater erosion, sediment transport, and potentially, modest changes to the planform of the low-flow channel.

[2] Draft values based on NA1 HEC-RAS modeling using the American River storm centering.
[3] Draft values based on the American River Common Features "With-Project Condition" HEC-RAS modeling using the American River storm centering and assuming that the dam 3.5' raise is in place.

In addition, durations of the larger peak flows have been tabulated for both the without-project condition (see Table 4-2) and for the with-project condition (see Table 4-3). The values for the without-project condition are of the same order magnitude as the durations listed in Table 1-1 for the significant historic flood events in which significant volumes of channel erosion occurred. However, the with-project durations (Table 4-3) are much greater for the 1 and 0.5% ACE events compared to the without-project values (Table 4-2). Duration of the flow is directly related to the volume of erosion which can occur. The flow durations are a source of uncertainty in the project performance since the channel will be expected to convey large peak flows (i.e., some in excess of historic floods) for durations substantially longer than the durations of historic peak flood flows.

Graphical comparisons of with- and without-project hydrographs are illustrated in Figures 4-1 through 4-3 for selected n-year events. The without-project hydrographs are depicted with blue lines and the with-project hydrographs with red lines.

Table 4-2. Durations of without-project peak discharges for n-year events

Synthetic Flood Event	Approximate Duration (hrs)[4]			
	90,000 cfs	115,000 cfs	>115,000 cfs	160,000 cfs
50% (1/2) ACE	---	---	---	---
10% (1/10) ACE	---	---	---	---
4% (1/25) ACE	23		---	---
2% (1/50) ACE	63	48	---	---
1% (1/100) ACE	120	91	43	---
0.5% (1/200) ACE	135	103	60	29

Table 4-3. Durations of with-project peak discharges for n-year events

Synthetic Flood Event	Approximate Duration (hrs)[5]			
	90,000 cfs	115,000 cfs	>115,000 cfs	160,000 cfs
50% (1/2) ACE	---	---	---	---
10% (1/10) ACE	---	---	---	---
4% (1/25) ACE	50	41	---	---
2% (1/50) ACE	88	74	---	---
1% (1/100) ACE	142	133	---	---
0.5% (1/200) ACE	171	163	55	31

[4] Draft values based on the American River Common Features “Without-Project Condition” HEC-RAS modeling using the American River storm centering.

[5] Draft values based on the American River Common Features “With-Project Condition” HEC-RAS modeling using the American River storm centering and assuming that the 3.5 ft dam raise is in place.

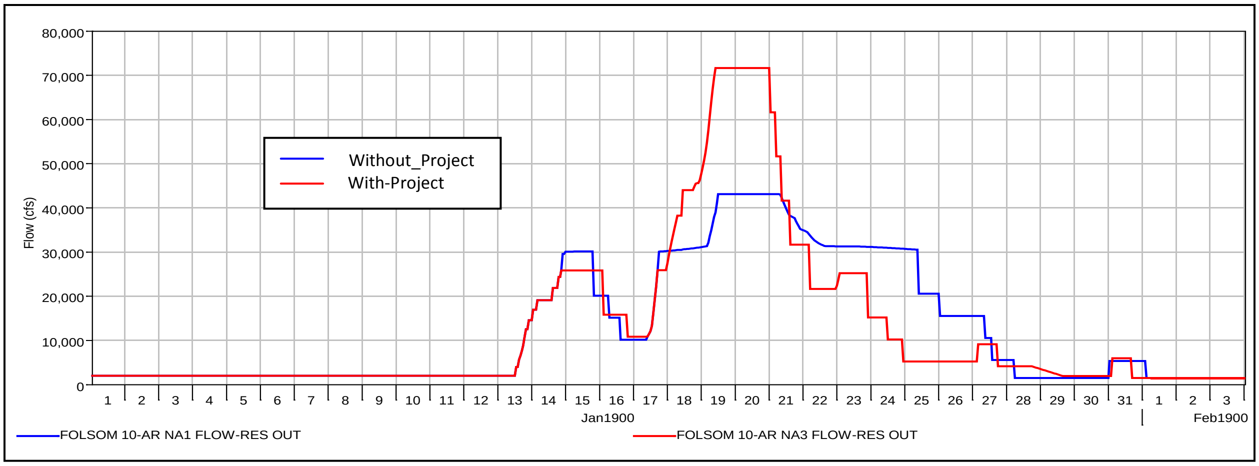

Figure 4-1. With- and without-project hydrographs for the 10% (1/10) ACE event on the LAR

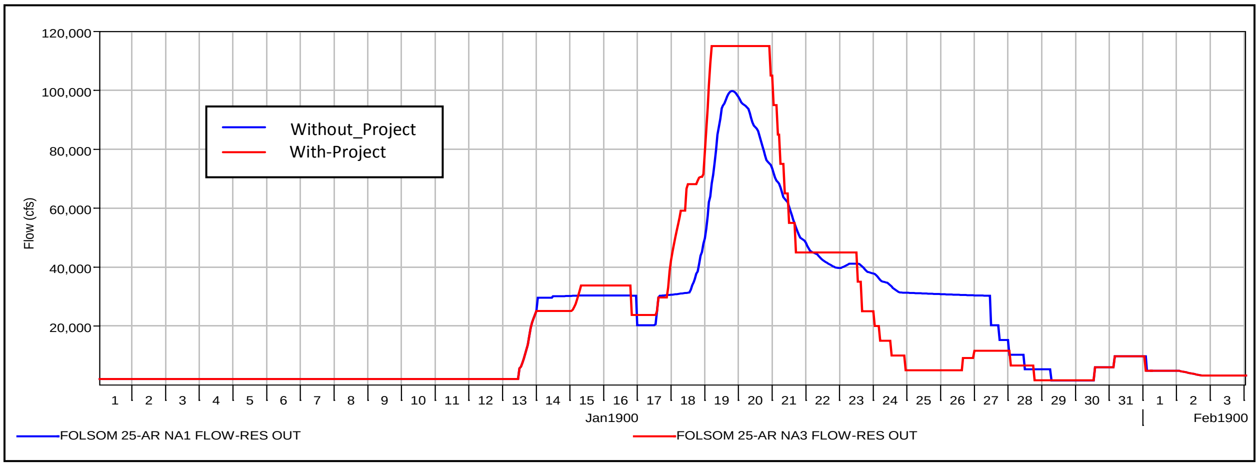

Figure 4-2. With- and without-project hydrographs for the 4% (1/25) ACE event on the LAR

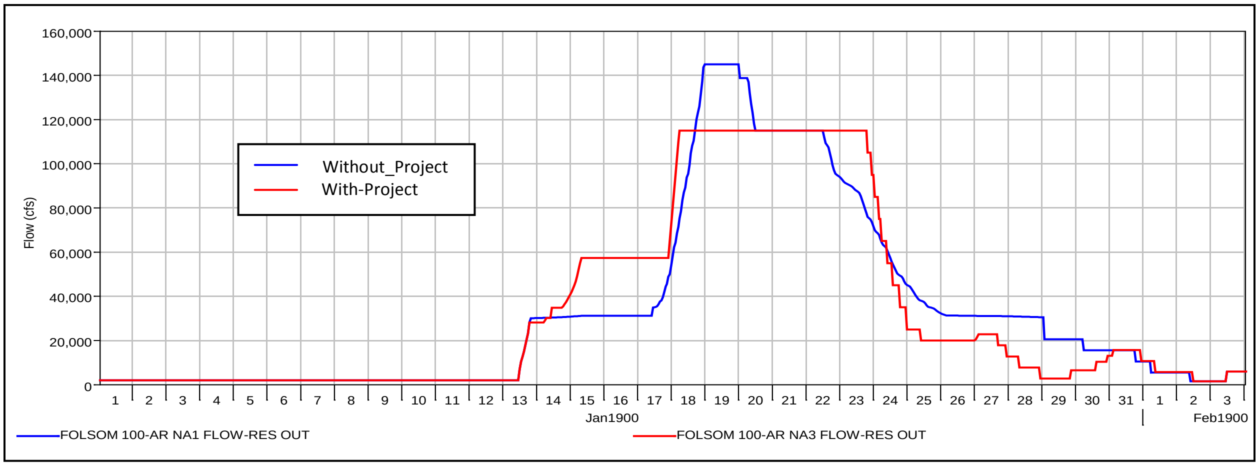

Figure 4-3. With- and without-project hydrographs for the 1% (1/100) ACE event on the LAR

4.2 Hydraulic Modeling Results

With- and without-project hydraulic analyses are presented in the Hydraulic Appendix Executive Report dated May 2013. Technical analyses therein consist of one-dimensional, unsteady HEC-RAS modeling for the channel hydraulics and quasi two-dimensional FLO-2D modeling for the overbank floodplains. Also included are analyses for quantifying uncertainties in the various hydraulic parameters and results. Please refer to that report for details and documentation of those efforts.

In order to get a more detailed estimate of the velocity and shear in the American River upon which the likelihood for erosion may be estimated, Ayres Associates performed two-dimensional modeling of the Lower American River using RMA-2 (Ayres 2004). This analysis was conducted for infrequent flood events specifically consisting of peak flows of 115,000, 130,000, 145,000, and 160,000 cfs. The areal extent of the modeling included the Lower American River between RM 0 and 14 and the Sacramento River approximately between RM 59.2 and 61.4.

Results of the two-dimensional modeling are presented in the report titled “Lower American River, Erosion Susceptibility Analysis for Infrequent Flood Events” dated July 2004 by Ayres Associates. Samples of the results from this analysis are shown in Figures 4-4 and 4-5. Specifically, Figure 4-4 shows the velocities for a discharge of 115,000 cfs which average about 6 to 8 ft/sec in the channel with maximum velocities ranging up to about 12 ft/sec. Figure 4-5 shows the velocities for a discharge of 160,000 cfs which average about 5 to 9 ft/sec in the channel with maximum velocities ranging up to about 13 ft/sec.

Of concern in both of these figures are the proximities of the relatively high velocities to the levees along the Lower American River. Additionally, the range of the computed velocities is of concern since the magnitude of the velocities is great enough to erode many of the relatively fine grained material present in the channel lining. Table 4-4 is an excerpt from Fischenich (2001) which lists the permissible shear and velocity for various materials. A review of this list coupled with the computed 2-D velocities and shears indicates that the large discharge events are capable of eroding the material typically found lining the Lower American River channel.

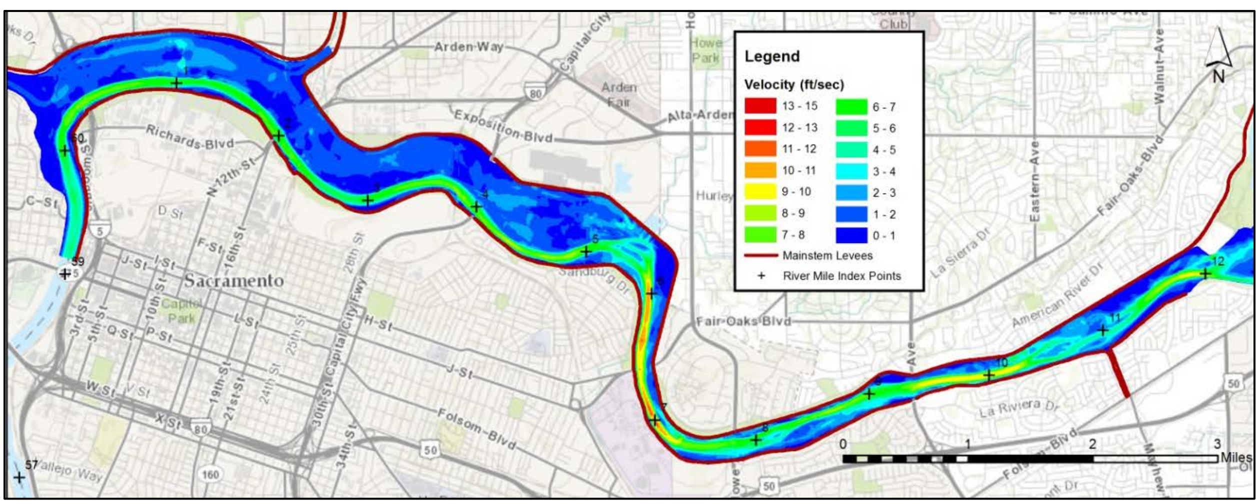

Figure 4-4. Two-dimensional velocities for a discharge of 115,000 cfs in the Lower American River

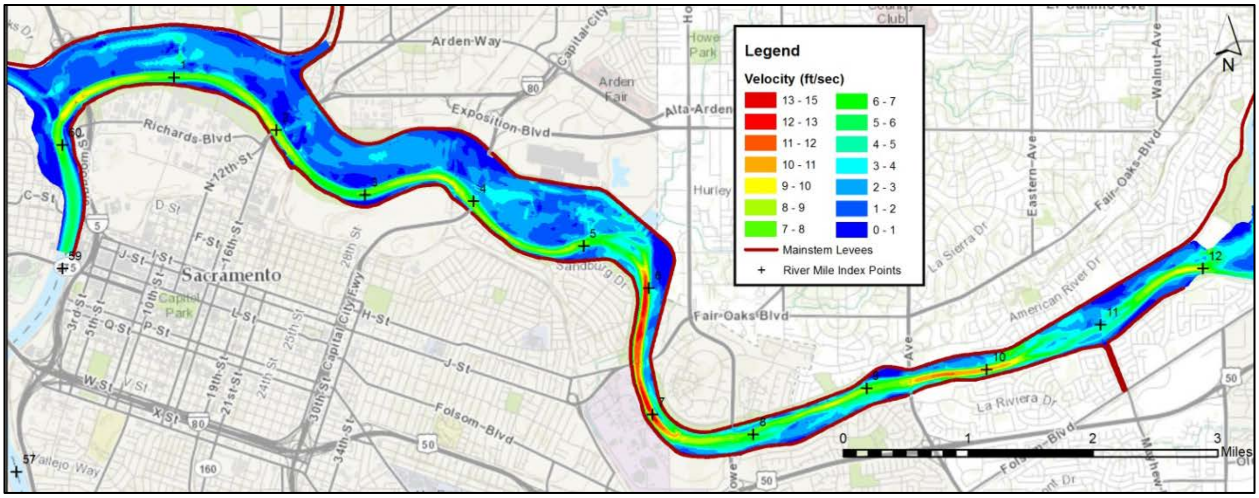

Figure 4-5. Two-dimensional velocities for a discharge of 160,000 cfs in the Lower American River

Table 4-4. Permissible shear and velocity for selected lining materials (Fischenich 2001)

Permissible Shear and Velocity for Selected Lining Materials[1]

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soils	Fine colloidal sand	0.02 - 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 - 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 - 0.05	2	A
	Silty loam (noncolloidal)	0.045 - 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel/Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 - 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 - 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1-0.6	N/A	E, N
	Hardwood tree plantings	0.41-2.5	N/A	E, N
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5	E, H, M
	Straw with net	1.5 – 1.65	1 – 3	E, H, M
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.00	2.5 – 7	E, H, M
Non-Degradable RECPs	Unvegetated	3.00	5 – 7	E, G, M
	Partially established	4.0-6.0	7.5 – 15	E, G, M
	Fully vegetated	8.00	8 – 21	F, L, M
Riprap	6 – in. d_{50}	2.5	5 – 10	H
	9 – in. d_{50}	3.8	7 – 11	H
	12 – in. d_{50}	5.1	10 – 13	H
	18 – in. d_{50}	7.6	12 – 16	H
	24 – in. d_{50}	10.1	14 – 18	E
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O
Hard Surfacing	Gabions	10	14 – 19	D
	Concrete	12.5	>18	H

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

A. Chang, H.H. (1988).
B. Florineth. (1982)
C. Gerstgraser, C. (1998).
D. Goff, K. (1999).
E. Gray, D.H., and Sotir, R.B. (1996).
F. Julien, P.Y. (1995).
G. Kouwen, N.; Li, R. M.; and Simons, D.B., (1980).
H. Norman, J. N. (1975).
I. Schiechtl, H. M. and R. Stern. (1996).
J. Schoklitsch, A. (1937).
K. Sprague, C.J. (1999).
L. Temple, D.M. (1980).
M. TXDOT (1999)
N. Data from Author (2001)
O. USACE (1997).

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5 Channel Stability and Erosion Assessment

Channel stability and erosion are interconnected but the terms “channel stability” and “erosion” need to be discussed for clarity. An unstable channel can be a channel with morphological changes that are so rapid that it generates public concern (ASCE 2008). A more scientific definition of an unstable channel is a channel that has abrupt, episodic, or progressive changes in location, geometry, slope, or planform pattern because of changes in water or sediment inputs or outputs (ASCE 2008). Channel erosion consists of erosion of the bed and banks by flowing water or collapse, slumping, or toppling of large masses of bed and bank material (ASCE 2008). While perhaps not typically considered erosion, slumping and toppling associated with river banks and sometimes in cohesive bed materials is an important consideration.

Channel stability depends on the time and space scale. The entire channel reach may be stable even though there are locations of instability, such as around bridges. Similarly, the channel may appear to be unstable over shorter periods of time but when viewed over a longer time frame the observed instabilities are oscillating around a long-term mean value. This last condition can be considered to be a state of dynamic equilibrium.

Channel stability and erosion of the Lower American River and Sacramento River in the Common Features GRR project area are discussed below in terms of vertical and lateral erosion, including some of the inter-connected nature of vertical and lateral erosion.

5.1 Vertical Erosion

Vertical erosion potential can be demonstrated for the American River by applying a qualitative general relationship originally proposed by Lane in 1955 (Lane 1955):

$$QS \approx Q_s d_s$$

Where:
Q = Water discharge
S = Slope of the channel
Q_s = Sediment discharge
d_s = Sediment diameter

Applying this to the Lower American River, the reduction of available sediment supply from construction of dams and erosion of the mining debris overtime (reduced Q_s), and increasing the magnitude of the lower discharge flood events that move the most sediment (i.e. cause the most erosion) over time corresponds to a coarsening of the river bed (increased sediment size), erosion of the channel (reduced slope), and increased flow depth with unpredictable shifts in channel width (ASCE 2008 page 476).

The evidence shows this expected vertical erosion occurred as anticipated from Lane’s relationship above. According to thalweg profiles compiled by various researchers, the channel of the lower American River degraded by up to 15-30 ft from the early 1900s to the late 1990s (NHC 2012). The reader is referred to NHC 2012 and NHC 2009 for other studies that corroborate this finding. See also Figure 5-1 and Figure 5-2 (Note elevations are in meters). The Sacramento River Bank Protection project’s sediment study indicates the Lower American River has degraded between 1997 and 2008 by an average of 0.67 feet over the lower 3.7 miles. This degrading trend is shown in Figure 5-3 below (NHC 2012) (Note elevations are in meters). A similar degrading trend is also observed further upstream using a different approach. A plot of the changes in rating curve for the Fair Oaks gage on the American river indicates a general trend of erosion from 1986 to 2008 as shown in Figure 5-4 (NHC 2009). This general erosional trend is expected to occur in the future as indicated in Figure 5-5.

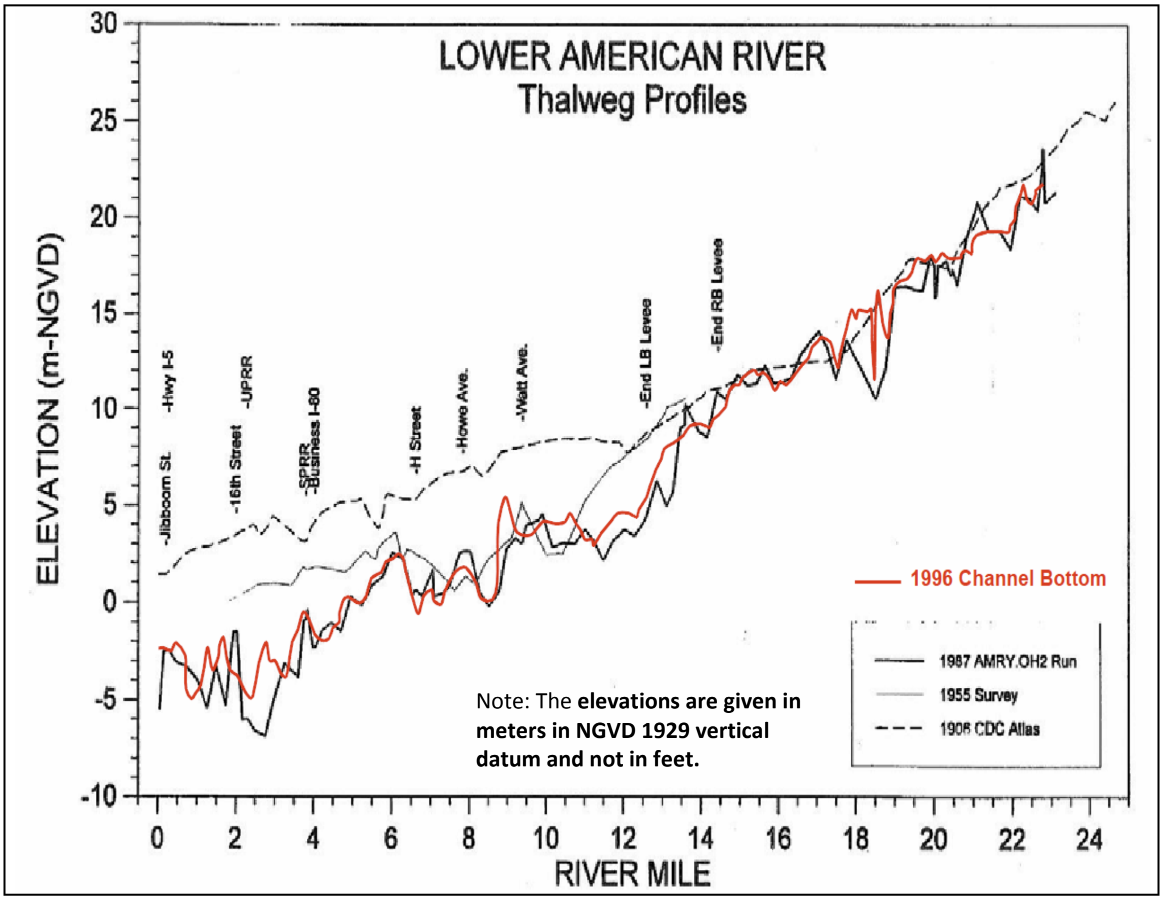

Figure 5-1. Historical profile of the Lower American River showing general degrading trend since 1906 (NHC 2009)

The Sacramento River discharge is also controlled by dams and should experience similar response to construction of dams as the American River. The same studies referenced above corroborate this trend for most of the Sacramento River. However, some reaches are aggrading and others degrading. The Sacramento River between Verona and the Sacramento Weir experienced a slight degradation trend between 1997 and 2008 while the portion from the Sacramento Weir to Freeport experienced aggradation as indicated in Figure 5-6. This may be due to the interaction of the Sacramento and American Rivers. During large flood events on the American River, water flows upstream in the Sacramento River and discharges over the Sacramento Weir. The sediment flowing from the American River and Sacramento River likely deposit in the reach between the Sacramento Weir and Freeport, contributing heavily to the aggradational trend noted between 1997 and 2008. This is a trend that seems likely to continue well into the future if no modifications are made to the system. Long term HEC-6T simulations show this same pattern after 50 and 100 years of simulation as shown in Figure 5-7.

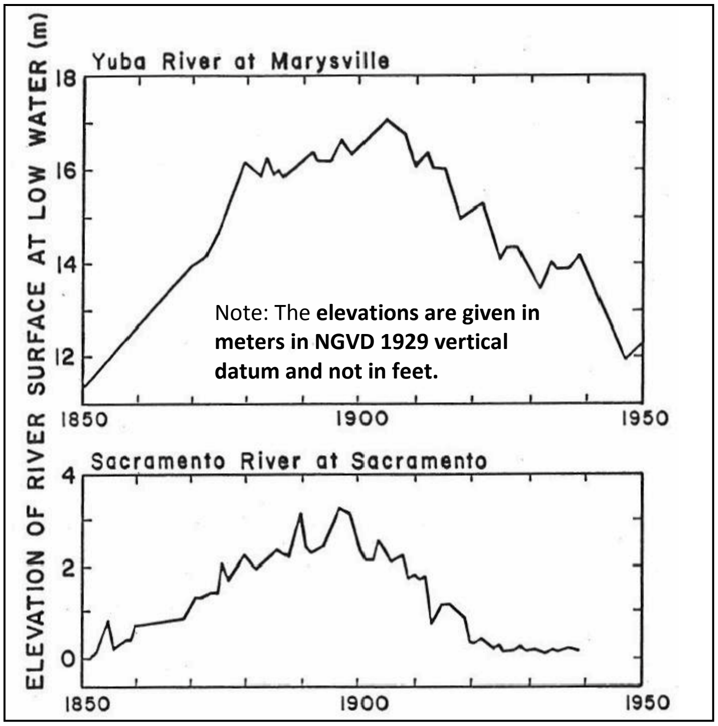

Figure 5-2. Historical water surface elevations on Yuba and Sacramento Rivers showing effects of deposition and erosion of hydraulic mining debris (developed by Meade 1982 from NHC 2009)

It is estimated that between 1 and 2.3 feet of aggradation will occur downstream of the Sacramento weir in the next 50 years. Implications for this aggradation are reduced capacity to pass flood flows. However, event specific simulations show this same reach degrades (0 – 1 ft of degradation estimated) following flood events (Figure 5-8). It is therefore possible that this long term aggradation does not significantly impact channel capacity during flood events as the floods may mobilize this sediment. This information together with estimated relative sea level rise and other pertinent information should be used to inform risk based decisions for both feasibility and design level study phases.

The future trend noted in Figure 5-5 does not include more recent data collected on the erosion resistant formation beneath the American River that could limit future vertical erosion. A more recent update of the model includes this new geotechnical information and draft results are shown below in Figure 5-9. The model used in Figure 5-9 includes the updated geotechnical information but has other differences with the model used in Figure 5-5. The significant differences between the models used for Figure 5-5 and Figure 5-9 are:

- Figure 5-9 model includes the updated geotechnical information while Figure 5-5 model does not
- Figure 5-9 model is based on synthetic event hydrology while Figure 5-5 model is based on actual historical hydrology

- Figure 5-9 model is “fixed” at the downstream boundary by a rating curve while the Figure 5-5 model is allowed to adjust dynamically based on changes to the Sacramento River (i.e. Figure 5-9 is not “linked” to the Sacramento River HEC-6T model while Figure 5-5 is).

Therefore the results depicted in Figure 5-9 cannot be compared directly with those shown in Figure 5-5. The amount of scour seems to be much less than previously predicted, which may be partially explained by model differences noted above. Despite these model differences, the average expected channel erosion for the Lower American River for 50 to 100 years of simulation is about 5 to 7 feet (see in Table 5-1). The results show it is possible the channel will degrade to the erosion resistant material between RM 6.5 and 10 (as shown in Figure 5-9). It is also possible that the bed will erode to the erosion resistant surface for portions of the reach above RM 15 (above where the current federal levees end); especially since the depth of active erosion likely exceeds that observed or predicted by the models. This makes protecting the levee toe critical for flood risk reduction and future degradation upstream of the levees may have detrimental impacts on environmental and recreational interests in that reach.

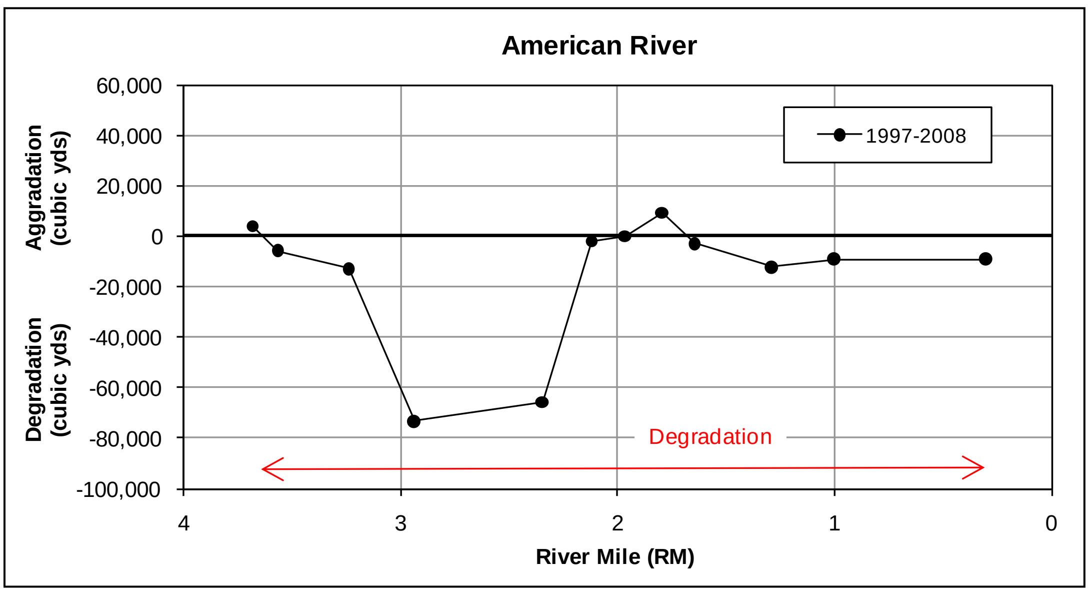

Figure 5-3. Aggradation/degradation trends for lower portion of the American River showing degradation between 1997 and 2008, supporting the trend noted in long-term HEC-6T simulations

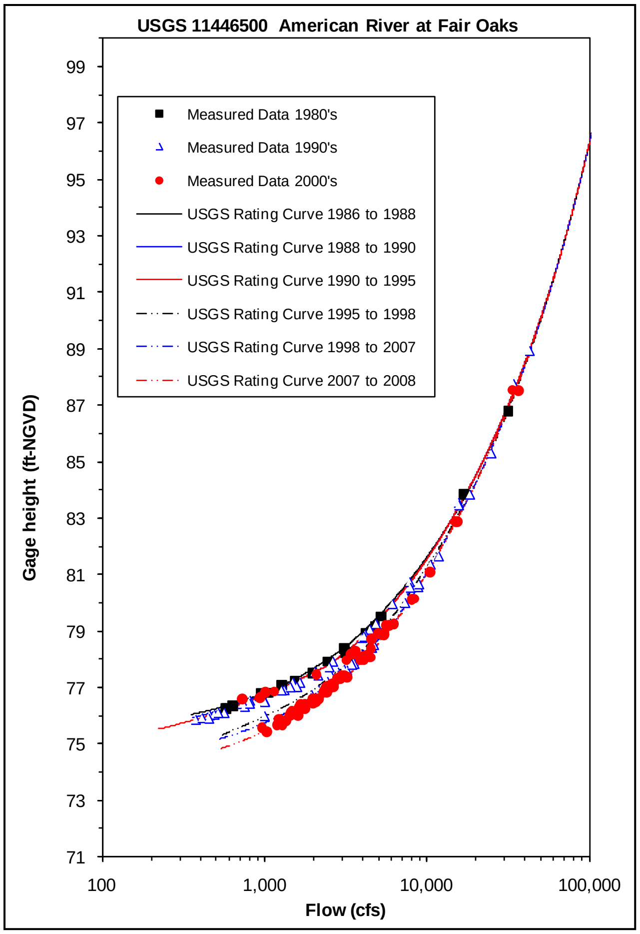

Figure 5-4. Stage versus flow plot of Fair Oaks gage on the American river indicating vertical erosion (reduction of water surface for the same discharge) from 1986 to 2008 (from NHC 2012)

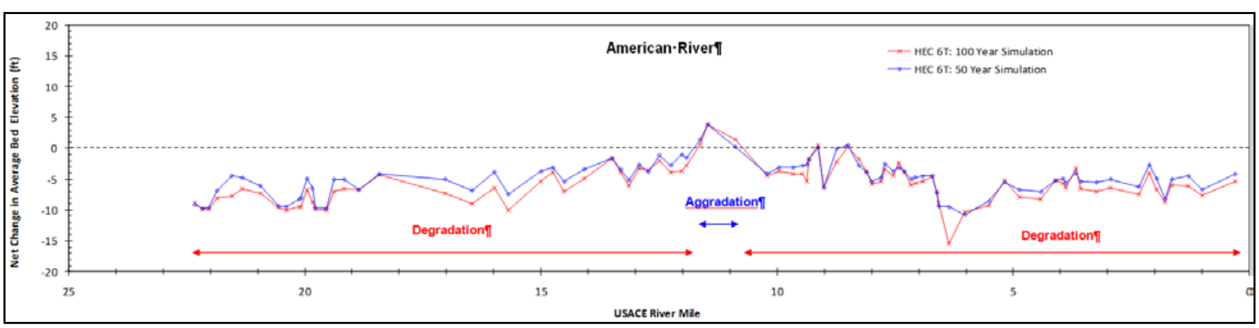

Figure 5-5. Net change in thalweg elevations and section-average bed elevations in American River (long-term simulations)

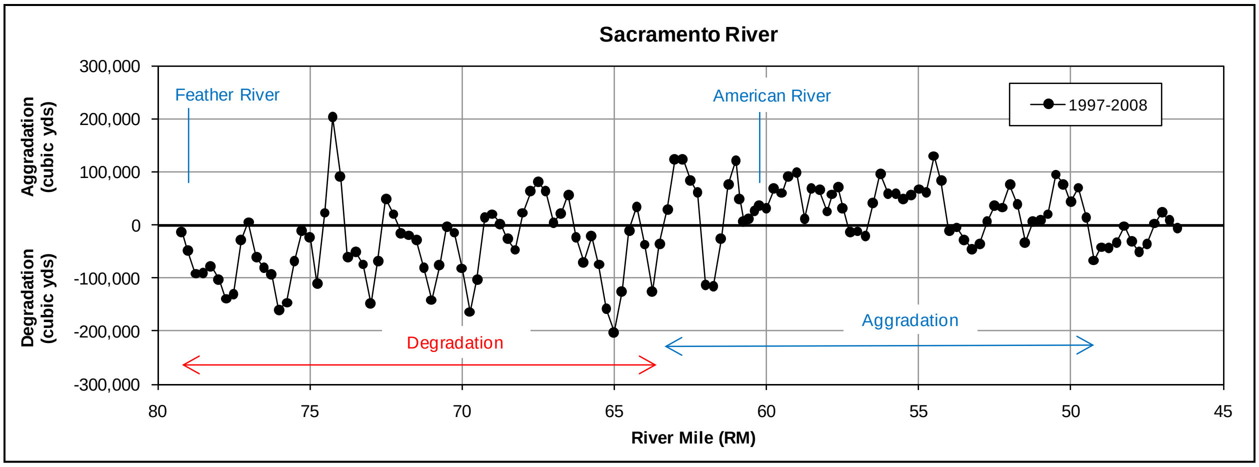

Figure 5-6. Aggradation/degradation trends of a portion of the Sacramento River showing aggradation between the Sacramento Weir and Freeport between 1997 and 2008, supporting the trend noted in long-term HEC-6T simulations

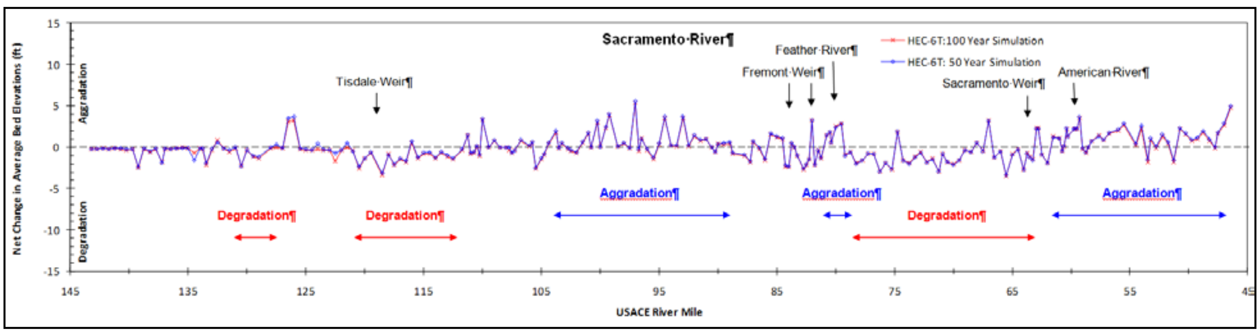

Figure 5-7. Net change in thalweg elevations and section-average bed elevations in Sacramento River (long-term simulations)

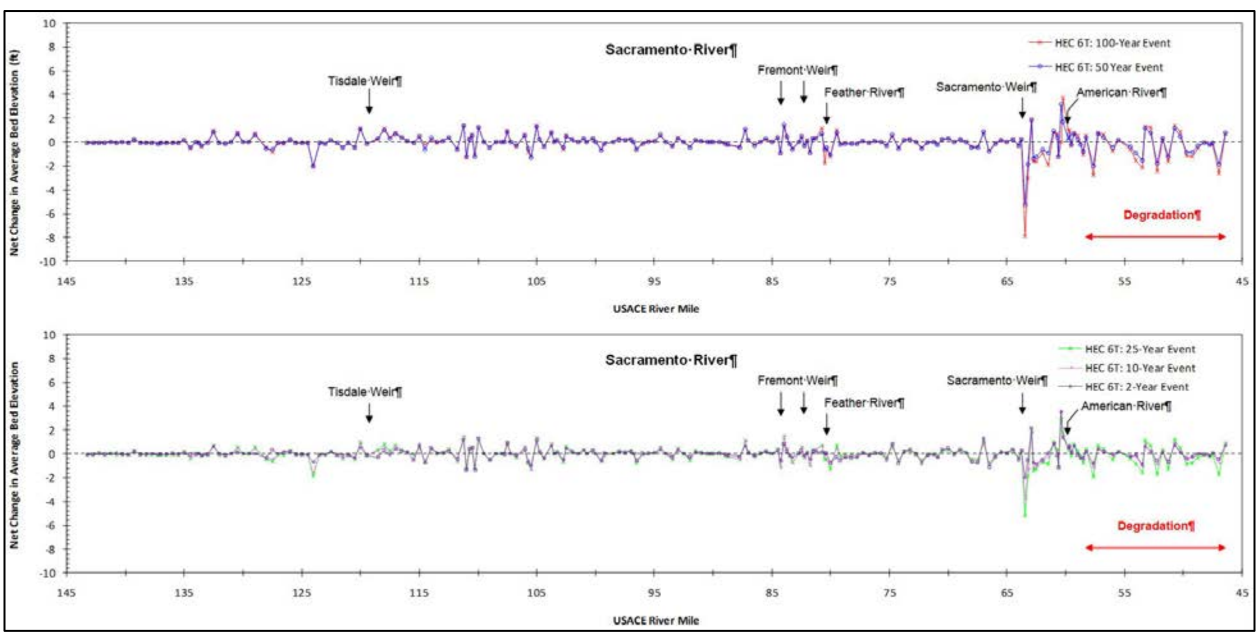

Figure 5-8. Results from single event HEC-6T simulations showing degradation between the Sacramento Weir and Freeport during individual flood events.

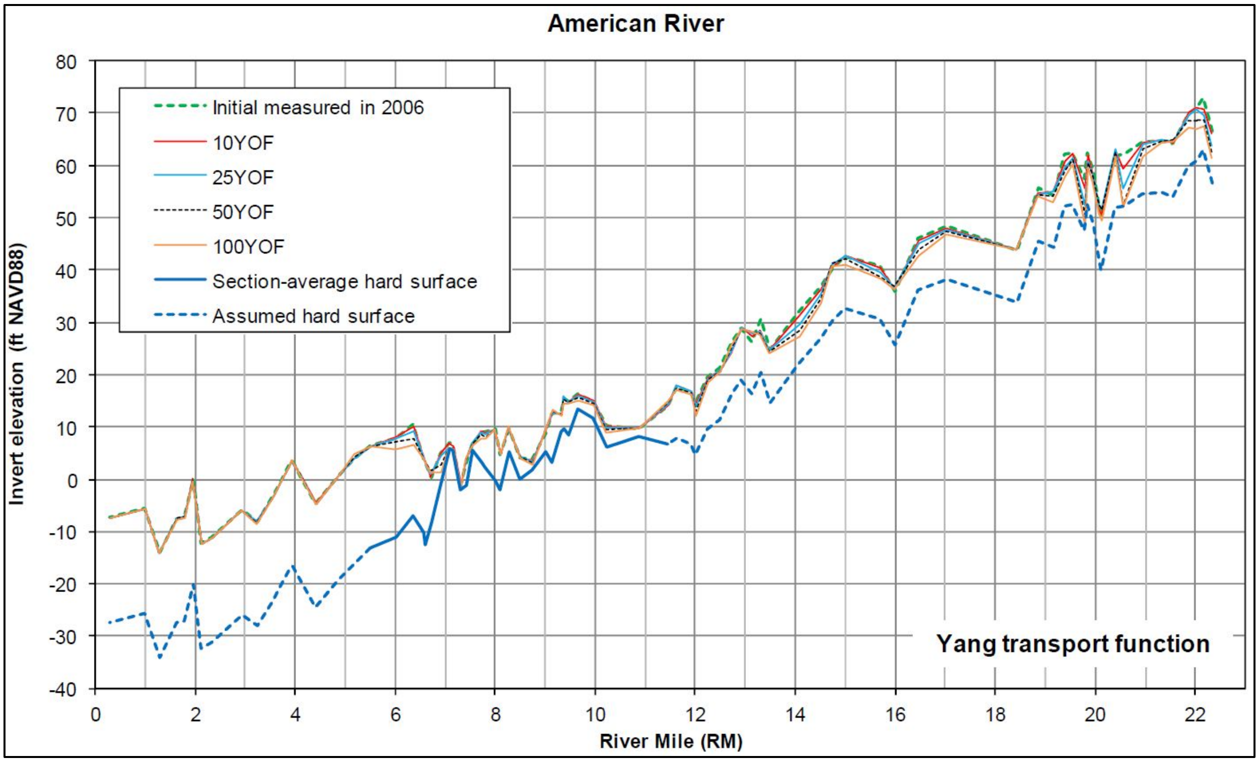

Figure 5-9. Draft results from simulation of a series of high flow flood events showing estimated erosion resistant material (e.g. Section-average hard surface).

Table 5-1. Simulated long-term bed aggradation and degradation for the American River by reach

American River				
River Mile	50-year simulation		100-year simulation	
22-20	-7.48	-7.30	-8.67	-8.48
20-15	-6.99	-5.70	-8.61	-7.21
15-10	-2.88	-2.08	-3.70	-2.72
10-5	-5.50	-4.88	-6.10	-5.57
5-0	-5.35	-5.67	-6.37	-6.79
Average	**-5.39**	**-4.83**	**-6.42**	**-5.84**

5.1.1 HEC-6T Model Sensitivity and Limitations

A series of sensitivity runs was performed for the 50-year period to evaluate effects of changing sediment supply on simulated bed profiles. Model sensitivity to changes in sediment supply was evaluated by increasing and decreasing upstream sediment inflows on the Sacramento, Feather, and American Rivers by 30%. The sensitivity test shows that the simulated hydrological changes generally tend to slightly increase the magnitude of long-term bed adjustments. The American River simulations are not sensitive to the upstream sediment supply because the supply is so small. For the Sacramento River, simulated degradation or aggradation generally increase from 1 to 5 ft, with a prevailing aggrading trend in the lower half of the study reach (less than 1 ft in the lower portion – which is the lower ½ of the reach from Colusa to Freeport).

A series of sensitivity runs was performed for the 50-year period to evaluate effects of climate changes on simulated bed profiles. Model sensitivity to climate changes was simulated by arbitrarily increasing the 30 highest flows in a given year by 1/3 and decreasing the other flows such that the total annual runoff did not change. The effect of future sea level rise on sediment transport conditions was assumed to be insignificant. This assumption is validated by a relative sea level rise analysis conducted for the Sacramento River Bank Protection project. The sensitivity test shows that the simulated hydrological changes generally tend to slightly increase the magnitude of long-term bed adjustments. The overall pattern in long-term evolution of the bed profile, however, does not change significantly. For the Sacramento River, simulated degradation or aggradation generally increase from 1 to 5 ft, with a prevailing aggrading trend in the lower half of the study reach. In general the simulated changes in hydrological conditions appear to have less significant effect on channel evolution trends compared to the simulated changes in sediment inflow. For the American River, bed degradation for the climate change scenario increases by up to 1-4 ft, particularly for the lowermost portion of the study reach.

These results assume that the hydrology, including operation of Folsom Dam, are identical to the years 1997 – 2008 and repeated for the next 50 and 100 years. Actual results will be different due to uncertainty in future hydrology, anticipated changes to operations of Folsom Dam, and uncertainty of sediment and geology conditions. In general, increased discharge from Folsom Dam is expected to exacerbate the amount of aggradation/degradation in the Sacramento and Lower American River. The HEC-6T model developed by the ARCF GRR (e.g. Figure 5-9) used hydrology that is thought to be representative of changes to operations at Folsom Dam.

It is important to consider that HEC-6T does not simulate local scour or local deposition, bank erosion, natural adjustments in channel widths, or lateral movement of the channel. These other factors are important considerations but are not possible to model concurrently at this time. It should be noted that the channel of the lower American River is highly irregular at many locations (especially in braided reaches upstream of RM 8). These irregular reaches may not be adequately represented in the 1-d HEC-6T model. Therefore, results obtained for the irregular reaches may be subject to simulation errors and should be treated with caution. In general, however, degradation predicted by the model for the lower American River (the HEC-6T model developed for the Sac Bank Project, see Figure 5-5) agrees with the stage-discharge records obtained for the American River gage at Fair Oaks which shows ongoing channel degradation. It should be noted that the HEC-6T model was developed and calibrated primarily for long-term simulations with gradually varying flows and gradual bed adjustments and therefore may be inaccurate for flood-event simulations with rapid changes in flows and rapid bed elevation changes. Along with these limitations, natural variability adds uncertainty to the results. Therefore, results obtained from flood event simulations should be regarded as approximate. The results should also be viewed as reasonable approximations of future trends.

The HEC-6T erosion studies do not consider risk to project levees from other sources such as boat wakes, wind waves, local scour at tree roots or fallen trees, etc. The degradation can also undermine bridges and other structures in or crossing the channel. Site-specific analysis is needed during design for structures such as bridge piers to account for local scour and overall erosion.

5.1.2 Grade Control Considerations

Erosion into the cohesive resistant material is affected by water quality, material history such as weathering, and macro-scale properties such as zones of weakness. The modeling indicates that expected erosion into the erosion resistant layer is minimal to none. However, there is spatial variability in the material properties and weak zones within the material that may accelerate the overall erosion of this material due to macro-scale processes such as toppling of weakened exposed blocks. In addition, sediment movement during floods can increase erosion beyond the expected clear-water scour limits since the sediment acts as a “sand-blaster” on the erosion resistant material. Given this uncertainty, it is important to consider the possibility of some scour into this erosion resistant layer during future studies, such as for analysis of bridge piers. The underlying erosion resistant layer likely will erode more slowly than less resistant material, but the ultimate equilibrium depth of scour may not be different from a less erosive resistant layer. However, the time required to erode to the equilibrium depth may exceed the expected life of the project and is not expected to occur under a single event. Therefore, it is reasonable to proceed without structural features at this time. Monitoring of the various sites should be included as part of the Operations, Maintenance, Repair, Replacement and Rehabilitation (OMRRR) effort under the project.

The addition of any grade control features on the American River is not currently part of Alternative 1 or 2, or the recommended plan. While the need for future grade control due to erosion of the erosion resistant layer cannot be ruled out, it is considered a lower risk to not include this feature in the tentatively selected plan. It is expected that any issues with erosion into the erosion resistant material will be noticed during regular infrastructure monitoring and necessary OMRRR actions taken in a timely manner to protect levees and other infrastructure as needed due to the expected relatively slow rate of erosion. As previously mentioned, the analysis does not indicate significant erosion of this layer and so the rate of erosion is likely small enough to allow for timely future remedial action if necessary. The panel experts are in disagreement over the need for grade control, with a majority not recommending any features, and the rest saying that there is not enough information to make a conclusion. In addition, including a grade control structure guarantees financial expenditure to address an issue that may not be needed and will create additional impacts to the channel and environment, such as accelerated local erosion downstream of the structure and reduced ecosystem function (e.g., impaired aquatic organism movement). Therefore, not including grade control in the Alternative 1 or 2, or the recommended plan is considered lower risk than including it in the same plans. Not including the grade control is a residual risk to be addressed at some point in the future.

Overall the Sacramento and American River reaches in the Common Features GRR are in an overall degrading state with the American River expected to degrade much more than the Sacramento River. Grade control is not anticipated to be necessary but the need for this should be monitored as part of routine operation of the constructed project.

5.2 Lateral Erosion

Lateral erosion can be the result of channel planform adjustments, changes to the vertical channel profile, or from localized features such as bridges and pipes in the channel. Lateral erosion from local features needs to be considered during future studies and will not be discussed further in detail. Channel planform adjustments that can cause lateral erosion may include river bends migrating outward toward the banks and/or downstream, braided channels attacking the banks, and channel avulsion during a flood event. Changes to the vertical channel profile include aggradation or degradation in response to river channel changes.

5.2.1 Lateral Erosion Potential from Vertical Erosion

As indicated in Section 5.1, the LAR downstream of Folsom Dam has incised into the sediment deposited from the gold mining of the 1800's. An appropriate conceptual model therefore is the Channel Evolution Model (CEM) shown in Figure 5-10. As the channel incises (stage II), the banks are steepened until the banks fail, widening the channel (stage III). Eventually the erosive shear stresses along the channel are reduced along with the ability of the water to remove the sediment from the failed banks. This leads to accumulation of material within the channel that begins to form a new floodplain but also continues to erode the banks (stage IV). Finally a new stable state of dynamic equilibrium is reached (stage V).

Based on the Channel Evolution Model, it is anticipated that channel widening will occur downstream of Folsom Dam as a result of Folsom Dam construction. This is a simplification of complex local processes but shows the long-term expected response for the Lower American River. Similarly, the degradation of the Sacramento River between Verona and the Sacramento Weir noted in Section 5.1 indicates this reach is at risk of lateral erosion as well.

Historic cross-sections at Hazel Street on the Lower American River (see Figure 5-11) illustrate the general trend of the channel degrading and widening consistent with the channel evolution model. This cross-section appears to show this channel at this location in 1992 was in stage III or IV of the channel evolution model and is not stable. Other historical cross-sections show a similar trend indicating possible channel instability. There could also be local instabilities in these selected cross-sections that are not indicative of the entire reach. However, the overall collective information seems to indicate the Lower American River has been unstable in the past and may be widening or stabilizing (phase III or IV) now and in the future.

While some of the levees may be protected from lateral erosion, the 1986 flood indicates that unprotected levees on the Lower American River are still at risk of failure from lateral erosion (see Figure 1-6).

Similar to the Lower American River, the Channel Evolution Model indicates channel widening potential between Verona and the Sacramento Weir due to degradation. The reach between the Sacramento Weir and Freeport is already relatively confined by levees and it is possible the long-term aggrading trend shown in Figure 5-7 becomes degradational during individual flood events. This is supported by HEC-6T model results that show long-term aggradation for this reach (Figure 5-7) but degradation during an individual flood event (Figure 5-8). The Channel Evolution Model is applicable to long-term trends and not individual flood events. However, it is reasonable to conclude the degradation expected in this reach during a single flood event could destabilize channel banks that exceed a critical height threshold, leading to bank failure and channel widening at least in localized areas. Further, Therefore channel widening could be a possible long-term result for this reach as well due to destabilization of channel banks from degradation during flood events. This observation indicates lateral erosion and channel widening can reasonably be expected for both the Lower American River and Sacramento River within the Common Features GRR project.

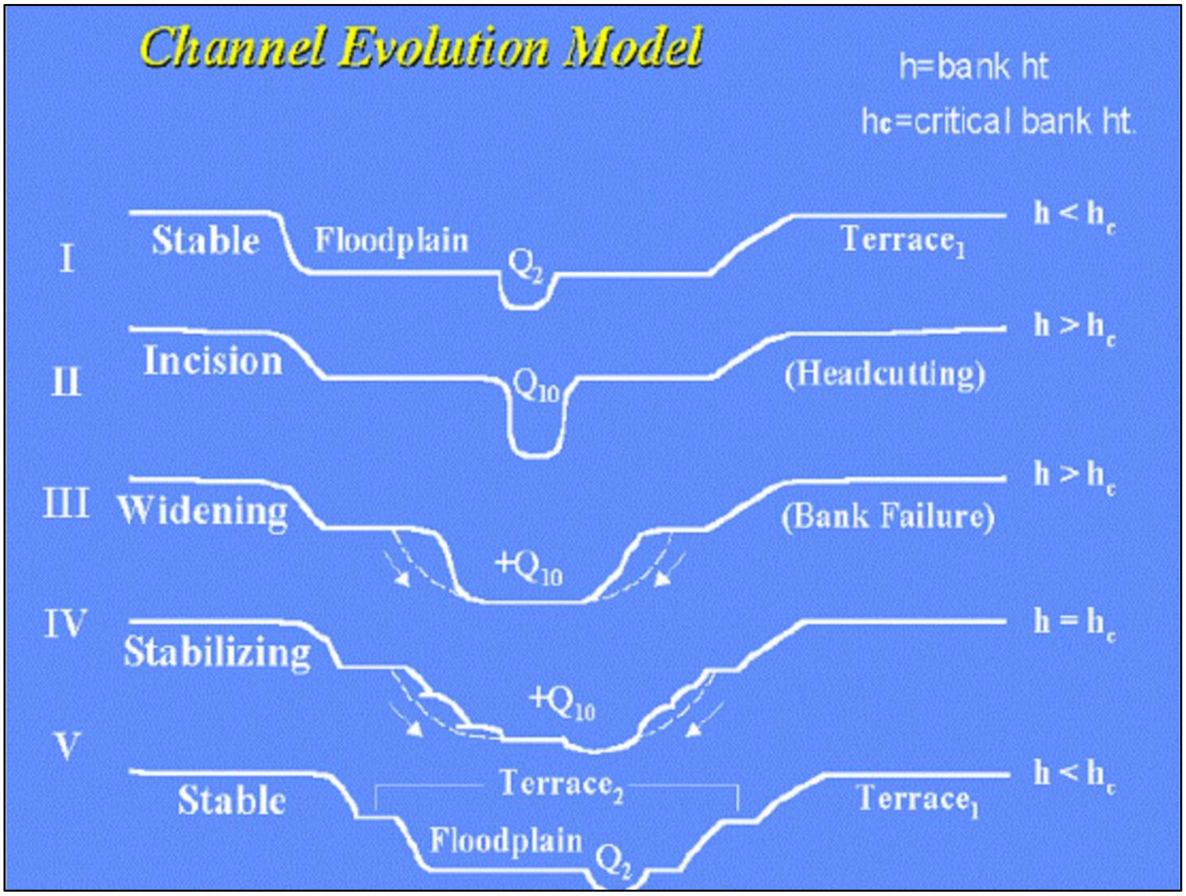

Figure 5-10. Channel Evolution Model describing how a stable channel responds to a disturbance that causes channel incision before reaching a new stable dynamic equilibrium

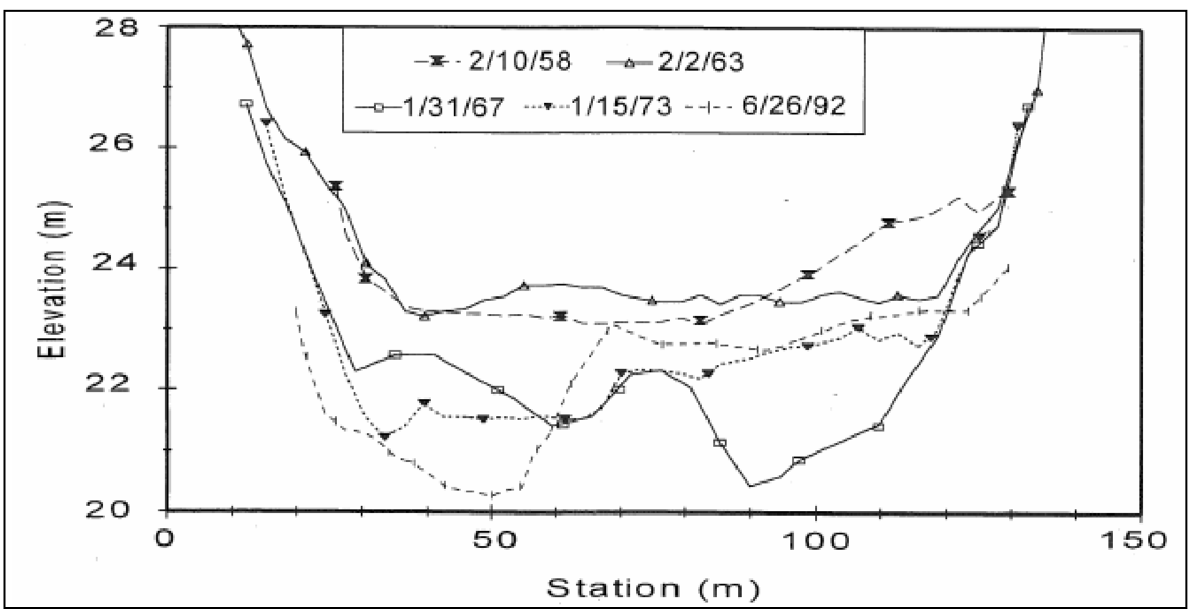

Figure 5-11. Historical erosion at Hazel Street showing vertical and lateral erosion, which shows Channel Evolution Model trends (developed by James 1997 in NHC 2009). Note distances elevations are in meters

This assessment is consistent with the findings of a bankline migration analysis conducted by NHC using historical maps and aerial photography from 1949 to 2005. This analysis shows that the average low flow channel width of the Sacramento River reach between Verona and Freeport increased about 5% to 10% during this time period. Confinement of flows by levees and changes in hydrologic conditions, caused principally by Shasta Dam and the Trinity Diversion, are thought to have contributed to the observed width increase during this time period. Similarly, the analysis of the channel shift maps indicates that there has been about 4% decline in surface area at the 40 largest overbank berm sites in the Sacramento River between Colusa and Freeport. The observed loss of the overbank berms is mostly related to the increase in channel width between 1949 and 2005.

5.2.2 Lateral Erosion Potential from Planform adjustments

Lateral erosion can also occur as a result of natural river channel planform movement such as actively migrating river meanders, braided channels directing flow at the banks, and channel avulsions during flood events. Ayres conducted a bankline shift analysis of the Lower American River from 1957 to 1998 which was updated by NHC in 2010. The NHC analysis indicates that there was no observed bankline shift in the Lower American River between 1998 and 2010. NHC concluded that while there are currently no actively migrating meander bends on the Lower American River, large floods have caused significant instream changes between the channel banklines in the past. It is also noted that lateral erosion and bankline shift is occurring on the Lower American River, but on a scale too small to be accurately identified by air photo interpretation. This is because erosion is often occurring in vertical cutbanks obscured by tree canopy, making them difficult or impossible to see in air photos. In addition, the rate of erosion may not be discernible due to the resolution of the air photos.

NHC also conducted bank migration analysis for the Sacramento River using air photos from 1949 – 2005. Analysis of these maps indicates that significant (>150 ft) river channel shifting has occurred since 1949 over only about 12% of the Sacramento River between Colusa and Freeport. These areas of significant channel shifting are located out of the ARCF GRR study location in areas where one or both levees are set back from the river channel. Lateral channel evolution is limited for the study reach of the Sacramento River from Verona to Freeport because the river channel is closely bordered by revetted levees that limit lateral channel evolution. However, this does not mean that bank erosion is not occurring in this reach. As noted previously the American River is experiencing erosion that is not clearly identifiable from aerial photographs due to steep banks and vegetation obscuring the erosion. This is also likely the case for portions of the Sacramento River between Verona and Freeport as demonstrated in erosion sites along this reach identified during annual reconnaissance surveys of the Sacramento River Bank Protection Project.

5.2.3 USDA BSTEM Analysis

A comprehensive analysis of streambank- and levee-erosion rates over a 48-year period was conducted by USDA-ARS for the Sacramento River Bank Protection Project. The work was conducted along 300 miles (483 km) of the Sacramento River main stem and selected reaches, including the Lower American River. Reconnaissance was conducted by boat and helicopter with fifty sites selected for site-specific intensive analysis. In-situ geotechnical data was collected at these sites including Jet Erosion Tests (JET), borehole shear tests (BST), and soil samples of soil layers for particle size analysis. The percent reach failing along the reaches was estimated using GPS referenced video and a Modified Rapid Geomorphic Assessment.

The 50 intensive sites were analyzed for sediment loading and bank retreat using the Bank Stability and Toe Erosion dynamic model (BSTEM). This model estimates bank retreat and sediment loading by linking hydrology, hydraulics, slope stability failures, erosion from moving water, multiple layers of different soil types, and root reinforcement of the soil. The dynamic version of the model was used that incorporates hydrographic data. Hydrographs from 12 years of record were used (1996 – 2008). BSTEM results were extrapolated to the reach using the estimated percent failure and the results compared to actual gage data of suspended sediment load. This verified the model was producing reasonable results. With this verification of the model, the 12 years of hydrology were repeated 4 times to simulate 48 years of future erosion. This model assumed that the channel is vertically stable which for the purpose of the USDA analysis was found to be an adequate assumption.

The USDA analysis estimated that about 44% of the total suspended sediment load in the Lower American River is from the banks although continued erosion could reduce this to about 20% in about 48 years. The report concludes that it is important that analysis use continuous simulation of streambank processes to predict loadings and rates of lateral retreat to capture the dynamics of erosion processes. The report notes a couple of points:

- Magnitude of lateral retreat are not well correlated with sediment loadings for a site possibly because significant erosion can occur at the toe of a bank without bank retreat at the top of the bank. However, subsequent flows may lead to bank retreat at these over-steepened banks.

- Bank failures are not well correlated with high discharge events because antecedent soil moisture conditions are important and failures often occur on the receding limb of the flood as the confining pressure of the flood water is removed from the relatively saturated and weaker bank.

The study found that in general the portion of the Sacramento River between Verona and Freeport and the Lower American River have between 20% - 40% of the banks failing. One of the highest estimated sediment loadings was found to be near Lower American River USGS RM 16 even though this bank was relatively far from a levee. A relatively moderate sediment loading was found at Lower American River USGS RM 5.5 while a low sediment loading was found at the mouth of the American River. This indicates a general upstream trend of progressively more erosion the closer a location is to Folsom Dam. Of the seven sites analyzed within the Common Features project area on the Sacramento River, 2 had relatively high loadings (between USGS RM 55 – 57), three had relatively moderate loadings (USGS RM 64 – 79), and two had relatively low loadings (USGS RM 48 – 50). The loadings were extrapolated using the percent of the reach failing to estimate the sediment loading from each 2-mile segment of the study area. One site on the Sacramento River between USGS RM 73 and 74 was found to erode such that the river would impinge on the levee within 48 years. However, there could be other sites where this could occur that were not analyzed.

Of the 50 intensive sites analyzed, seven are within the Common Features GRR study area along the Sacramento River and three are located in the Common Features GRR study area along the Lower American River. While this may be appropriate for large scale studies like the Sacramento River Bank Protection Project, it is likely not a large enough sample for more narrowly focused feasibility studies such as the Common Features GRR. Also, no sites were located in the area constricted by levees between RM 5 and 10 on the Lower American River. In addition, the hydrology used for estimating erosion 48 years into the future generally had higher flow rates than long-term averages and therefore may over predict long-term sediment loading and bank retreat. However, the study still provides valuable insight into erosion in the Common Features GRR project area. The estimated percent of total sediment derived from the banks agrees remarkably well with the results from a historic channel shift analysis (NHC 2012). This study by the USDA confirms the results of the Channel Evolution Model and the observations from annual erosion surveys and air photo analysis.

The magnitude of the erosion does not always correlate well with erosion risk to levees. Distance of the levee from the channel as well as geology need to be considered. For example, a levee set back 300 feet from the channel is not in danger from a channel that only moves a maximum of 200 feet. Similarly, A levee could be set back 300 feet but be at risk of erosion failure if the soil between the levee and the river channel is highly erodible. However, a levee with a 30 foot berm may not be at risk if the soil between the levee and the channel is erosion resistant. See Section 5.4 for more on levee risk from erosion. So while the distance of the levee from the channel is important for estimating levee risk from erosion, soil properties also need to be considered.

5.2.4 Channel Stability and Erosion Risk Findings

The channel evolution model, historical data, and modeling of future conditions indicates that the levees of the Lower American River, and to a lesser extent the Sacramento River between Verona and Freeport, are at risk of erosion related failures. According to NHC (NHC 2012), it is appropriate to say that the Sacramento River between Colusa and Freeport is in a state of dynamic equilibrium. However, there are portions of this channel that appear to be actively degrading (NHC 2012). So while these sub-reaches may not be considered stable by themselves, the entire reach as a whole is considered to by dynamically stable. The Sacramento River between Verona and Sacramento Weir is expected to degrade slightly in the future and un-revetted portions of the levees are at risk from erosion. The Sacramento River between Sacramento Weir and Freeport is expected to aggrade overall in the future but may degrade during individual flood events. Potential implication of the simulated long-term changes in bed profiles can be increased stress along the toe of the project levees or overbank berms in the degrading reaches, which may result in increased scour along un-revetted channel sections. In the aggrading reaches, increase in bed elevations may result in higher flood stages, reduced flood conveyance, and possibly increased local bank and levee erosion from flows re-directed to the sides of the channel due to the deposited sediment. Therefore, levees not protected adequately from erosion between the Sacramento Weir and Freeport are at risk from erosion.

In contrast, the American River does not appear to have reached a state of dynamic equilibrium in the leveed portion of the reach based on recent analysis. A relatively erosion resistant layer may limit vertical erosion, leading to increased bank and levee erosion. Therefore, the levees on the Lower American River not protected adequately may be at risk from erosion. The presence of riprap may increase the rate of erosion into the erosion resistant material in the channel bed at some locations. Erosion protection designs will therefore need adequate toe protection to prevent undermining the toe of the erosion protection.

For both the Lower American River and the Sacramento River, infrastructure encroaching in the floodway, such as bridges and pipelines, need to be adequately protected from reasonably anticipated scour during design and construction. This effort is not included in the tentatively selected plan. It is assumed this effort will occur during future analysis and design efforts and likely needs to be coordinated with multiple agencies and infrastructure owners. Civil Design has also determined that the additional cost of the scour and erosion counter measures for the infrastructure is not significant compared to the overall cost of the erosion protection currently included in the tentatively selected plan and is well within the associated cost contingency. The tentatively selected plan also does not include grade control as the consequences of including it are higher than the risk of not including it. However, protecting the levees along Sacramento River and Lower American River from erosion is important to reduce the probability of erosion related levee failure and to improve flood damage risk reduction for the protected areas.

5.3 Other Erosion Sources

Other sources of erosion include wind-wave, boat, vegetation, recreational, and bridge scour. These sources are expected to be minor compared to the fluvial process, but are discussed herein for completeness.

5.3.1 Wind Wave Erosion

The potential for wind waves to overtop and erode flood control features (principally levees) near the City of Sacramento was analyzed and alternatives to reduce risks associated with wind wave erosion developed, including costs (USACE 2010). The analysis is based on coincident 1/200 ACE event water levels and extreme wind events. 34 sites were selected where local wave conditions are expected to be maximized yet representative of nearby levee sections. The analysis follows Engineering Circular 1110-2-6067 and other technical publications related to wind wave analysis. This analysis represents the latest guidelines for wind wave erosion analysis adopted by USACE, Sacramento District. Each site was assigned the highest risk computed for the site for either levee face erosion or overtopping for any wind direction at the site. The risk from this site was then generalized to nearby levee locations with similar wave heights, geometry, and erosion protection.

This report identified those study sites where potential erosion due to wind waves could affect levee performance during a 200-year storm event. The report then presented methods to assess the potential for the waterside levee face to erode and determine if the maximum erosion would encroach on the minimum levee dimensions, and evaluate the potential for levee overtopping to threaten levee stability. Results of the quantitative analysis at each site were interpreted to assign a low, moderate, or high wind wave erosion risk at each site. Because the analysis is conservative and general in nature, it is recommended that detailed wind wave analysis be conducted during future studies at sites that may benefit from reduced repair requirement or the extent of the repair due to wind waves (See USACE 2010 for additional information). The study included reaches that are part of the Natomas PAC.

5.3.2 Boat Wave Erosion

Boat wave erosion has not been accounted for in this analysis because the impact of boat wave erosion in the project area is unlikely to be significant. Only smaller recreational boats operate in the Sacramento and lower American Rivers, and the other project reaches do not have enough consistent depth or width of channel to sustain boat traffic. Any repairs needed from boat waves would likely be addressed as part of standard operation and maintenance of the levees.

5.3.3 Vegetation Erosion (Tree Scour)

The preliminary designs for erosion protection include leaving some of the vegetation in place, an option made possible by a waiver process included in ETL 1110-2-571. A pier scour analysis to represent tree scour (likely using HEC-18) is included in the application for waiver. This effort is considered part of the erosion analysis, and is expected to be performed during future studies.

5.3.4 Recreational Erosion

Local bank and berm erosion due to a combination of recreational activities (e.g., biking, hiking, fishing, etc.) and the corresponding infrastructure features including bike paths and maintenance facilities is expected to be minimal compared to fluvial sources of erosion and should be addressed as part of the normal O&M activities.

5.3.5 Bridge Scour

There are over 15 bridges crossing the channel on multiple reaches in the project area. Bridges along the Sacramento and American rivers will likely need an analysis during design or refinement of the selected alternative to account for bridge scour protection. This effort is considered part of the erosion analysis and is expected to be done as part of future studies.

5.4 Expected Levee Performance

5.4.1 American River

As presented in Section 18 of the ARCF GRR Geotechnical Report (Attachment C), plots depicting the combined probability of poor levee performance (a.k.a. fragility curves) for with- and without-project conditions were developed at a series of index points along the various study watercourses. These curves communicate the cumulative (or combined) probability of levee failure versus the water surface elevation of flow in the river channel. Specific considerations taken into account when these curves are developed include underseepage, through-seepage, slope stability, and engineering judgment. Furthermore, the engineering judgment component consists of considerations for vegetation, animal burrows, encroachments, utilities, and erosion. It should be noted that the erosion component was not estimated based on any analyses, but on the experience of an expert elicitation panel, considering the location of the index points, the conditions of the foundation and levee material, the water velocity at that specific location, and on past history. For more information on the expert elicitation process a summary of the document "Geotechnical Office Report, Geotechnical Expert Elicitation Meeting Minutes," dated July 2009, is available upon request.

The levee performance curves were finalized in 2011 with the judgment curves (erosion as a component) that were developed using an expert elicitation in June 2009. The validity of the erosion component of the performance curves was discussed at the expert panel and project team meetings. It was found that the estimated levee performance captured by the curves was reasonable based on the available data and expertise. In consultation with the project team the decision was made not to develop more rigorous analytical methods to refine the erosion portion of the curve.

Sample fragility curves for the American River at two locations are illustrated for the north levee in Figure 5-12 and for the south levee in Figure 5-13. Inclusion of both the with- and without-project fragility curves in these figures indicates the change, or reduction, in probability of failure due to with-project improvement measures. Both the with- and without-project fragility curves account for the reduction in probability of poor performance due to the cutoff walls constructed as part of the ARCF WRDA 1996-1999 project. Therefore, the combined fragility curve at these two locations represents the judgment curve, of which erosion is the primary contributor to the without-project curve. The with-project curve accounts for residual risk due to vegetation, animal burrows, encroachments, and utilities that may not be addressed by the project alternatives or structural improvements. In both sample figures, the cumulative probability of poor performance, or levee failure, is less than 20 percent for the condition where the water surface elevation is at the top of the levee crest once the project is constructed. Without the project, the cumulative probability of poor performance is greater than 50% and indicates the erosion protection provided by this project is needed to reduce flood damage risk.

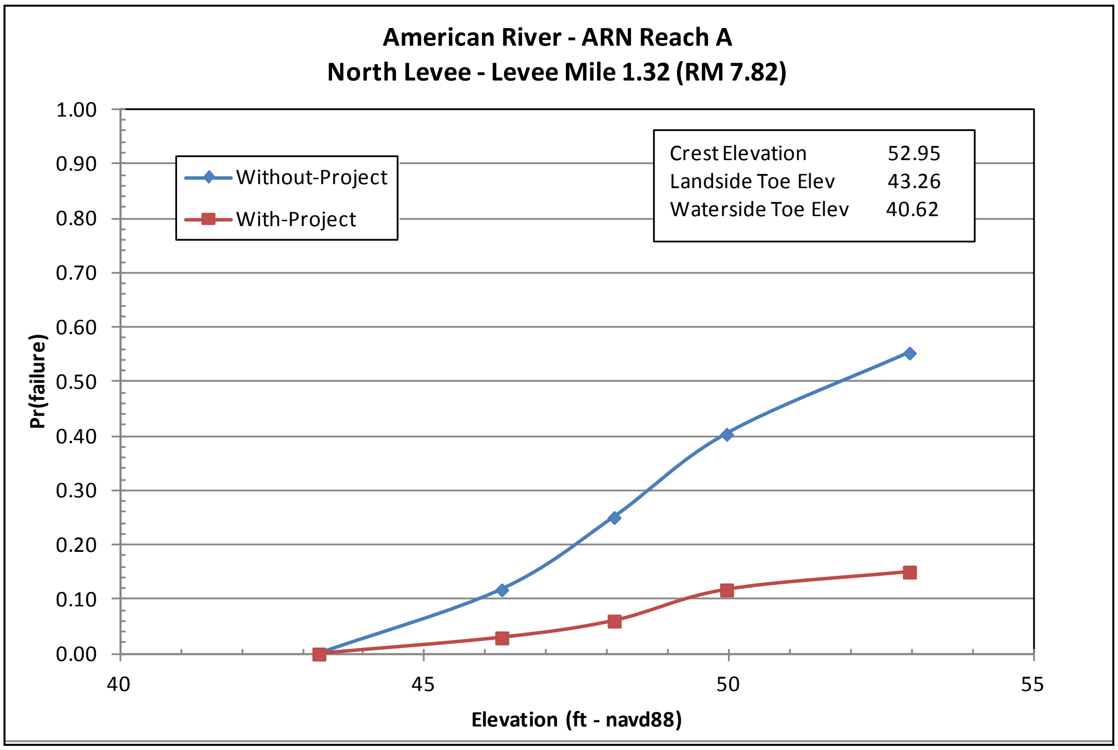

Figure 5-12. "Judgment" component of the levee fragility curves for the American River north levee at RM 7.82

5.4.2 Sacramento River

As discussed above, a series of plots depicting the combined probability of poor performance (a.k.a. fragility curves) for with- and without-project conditions were developed at a series of index points along the various study watercourses. These plots are presented in Section 18 of the ARCF GRR Geotechnical Report (Attachment C). Sample fragility curves for the Sacramento River at one location are illustrated for the east, or left, levee in Figure 5-14. Similar to the above figures for the American River, this figure shows the "judgment" component of the fragility curves. There remains a residual risk due to vegetation, animal burrows, encroachments, and utilities that may not be addressed by the project alternatives or structural improvements. In the sample figure, the cumulative probability of poor performance, or levee failure, is reduced from a little over 20 percent down to less than 10 percent for the condition where the water surface elevation is at the top of the levee crest.

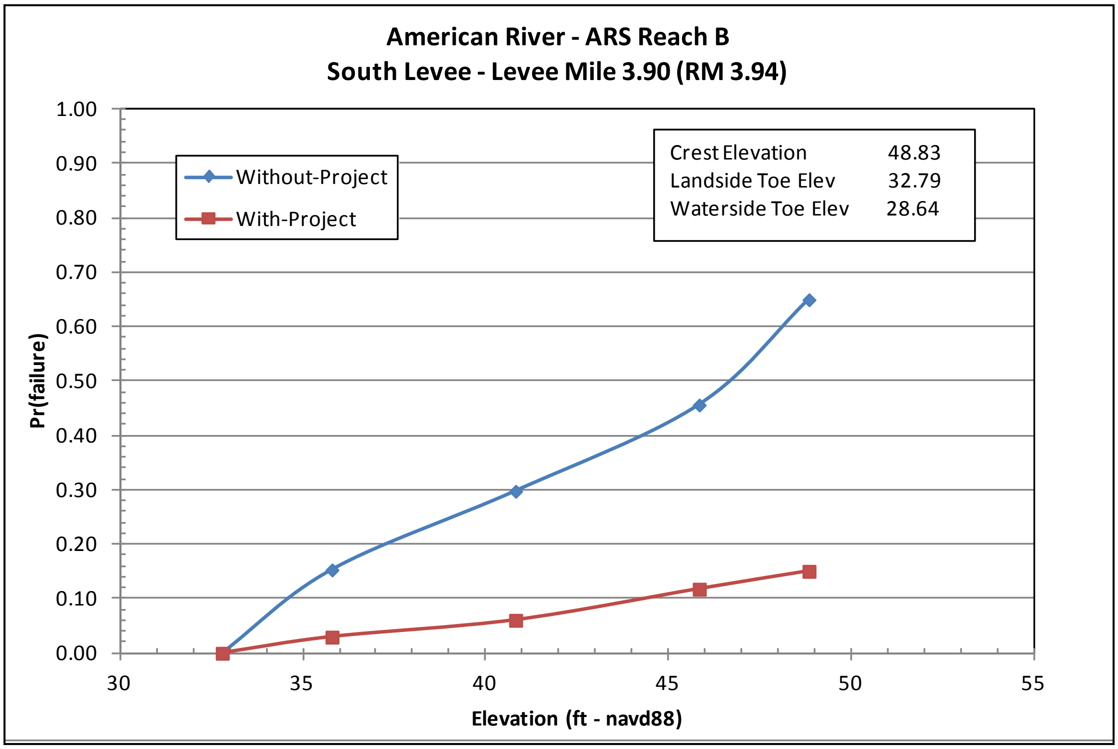

Figure 5-13. "Judgment" component of the levee fragility curves for the American River south levee at RM 3.94

Historic aerial photos in combination with a riprap database showing known riprap locations (as of 2007) was used to develop a rating of relative levee risk from erosion by channel shifting. The results of this effort by NHC (NHC 2012) are shown in Table 5-2 for the portion of the Sacramento River in the ARCF project footprint. This data shows about 18% of the levees in this reach are at higher risk from future erosion from channel shifting. However, this may be overstated as some higher risk sites have since been repaired with large riprap.

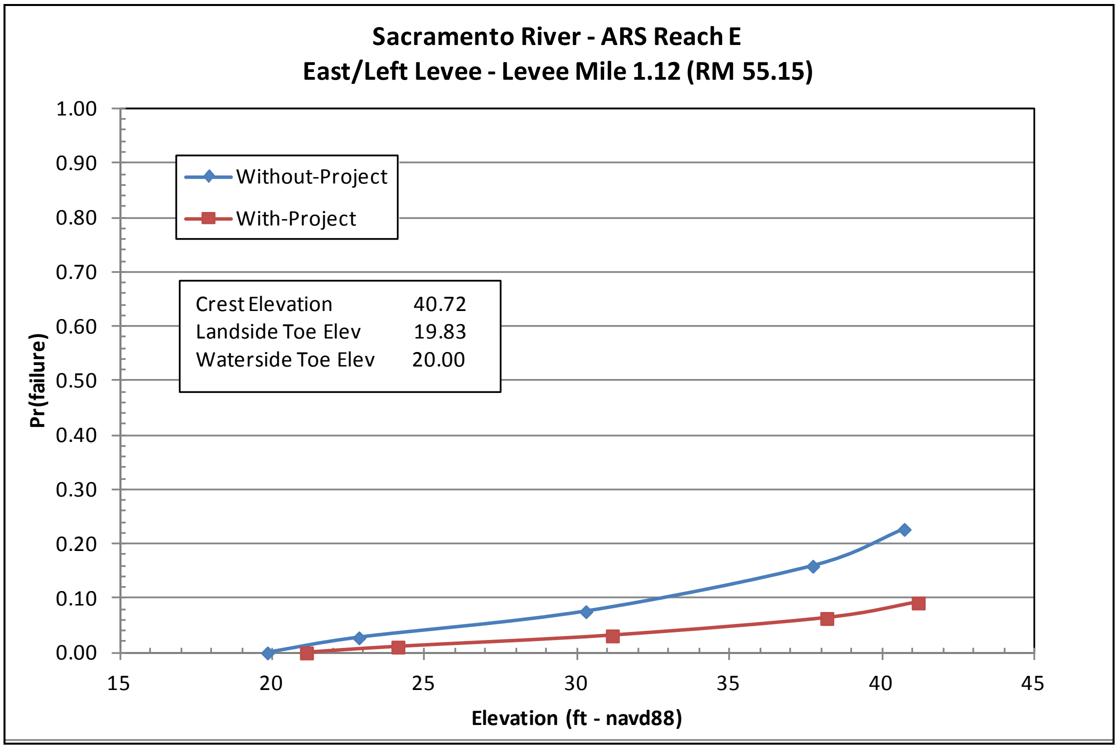

Figure 5-14. "Judgment" component of the levee fragility curves for the Sacramento River east/left levee at RM 55.15

Table 5-2. Levee risk ratings for Sacramento River by reach

Levee risk rating	Feather River to Freeport	
	Cumulative Miles	% total
R1	38.3	55
R2	2.6	4
U1	18.9	27
U2	10.0	14
U3	0.0	0
Total	**69.8**	**100**

Where:
R1 = Revetted bank, lower erosion risk
R2 = Revetted bank, higher erosion risk
U1 = Un-revetted bank, lower erosion risk
U2 = Un-revetted bank, higher erosion risk
U3 = Un-revetted bank, higher erosion risk, higher uncertainty

6 Bank Protection Basis of Design

6.1 General

The erosion protection features to support preliminary cost estimates were developed with input from the PDT with the objective of developing a reasonable cost to support plan selection. The erosion protection features are the same for alternatives 1 and 2. Two methods were used in an attempt to minimize the environmental impact of the features: Bank Protection and Launchable Rock Trench.

While the Bank Protection method is applicable in all areas, the Launchable Rock Trench method is applicable only in areas where there is sufficient bench between the levee toe and river. Both methods have similar rock quantities and costs are roughly equivalent, but the Launchable Rock Trench initially appears to have less environmental impact. For the purposes of the feasibility study, the Launchable Rock Trench was selected as the preferred method when either was technically feasible. It is expected that future studies will take into account many factors including the environmental impact to determine the final design.

The erosion protection was designed to convey the 0.5% ACE (1 in 200) future condition as described in Section 4.

6.2 Bank Protection

The bank protection design concept was adopted from the Lower American River (LAR) Sites I-V which was constructed shortly after the 1998 flood event. The design was developed by Ayres Associates and incorporated a rock protected slope with launchable rock bench. The rock bench has a trapezoidal soil trench “burrito wrapped” in geotextile. The soil trench would house a variety of woody tree species; offer shaded riparian area, and other beneficial habitat. This type of fix has performed well over the last decade and has required very little maintenance.

Several cross sections were analyzed along the American and Sacramento Rivers to develop typical sections that reasonably represented river conditions. For preliminary analysis, two sections were developed and used to develop quantities.

The typical sections were evaluated against project design parameters to ensure they meet minimum criteria. Design criterion was governed by EM 1110-2-1601 “Hydraulic Design of Flood Control Channels” with stone weight data from ETL 1110-2-120. Use of the Engineering Research and Development Center (ERDC) software CHANLPRO was used to develop some example gradations. Table 6-1 is a summary of the design parameters used for multiple cross sections along the American River.

After further evaluation, it was noted that the minimum geometries associated with the design sections resulted in rock quantities that exceeded minimum requirements for launchable rock and mitigation features. Rock gradations were deemed less important for determining costs for this design level. The geometry of the bank protection design (refer to Figures 6-1 and 6-2) yielded sufficient volumes of rock to meet anticipated launchable rock requirements and sufficient mitigation features to offset environmental impacts. The launchable rock volume requirements were determined based on average velocities for above-mentioned typical sections. Site-specific design for erosion protection sites will occur in future studies.

Table 6-1. Summary of the design parameters used along the American River

Description	Typical Section Locations	
	Downstream of Paradise Beach & Upstream of Howe Ave. (Includes all of the Sacramento River)	**Between Howe Ave & Paradise Beach**
Depth of Flow (ft)	37 to 50	47
160k cfs Velocity (ft/s)	7	12
Minimum Rock Thickness (ft)	3	3
Scour Depth => Launch Dist (ft)	10 to 20	10
Design Slopes (upper/lower)	2:1	2:1-3:1
Riparian Bench Slope	10:1	10:1
Minimum Launchable Rock Area per ft (underwater placement) (ft^2)	100 to 200	100

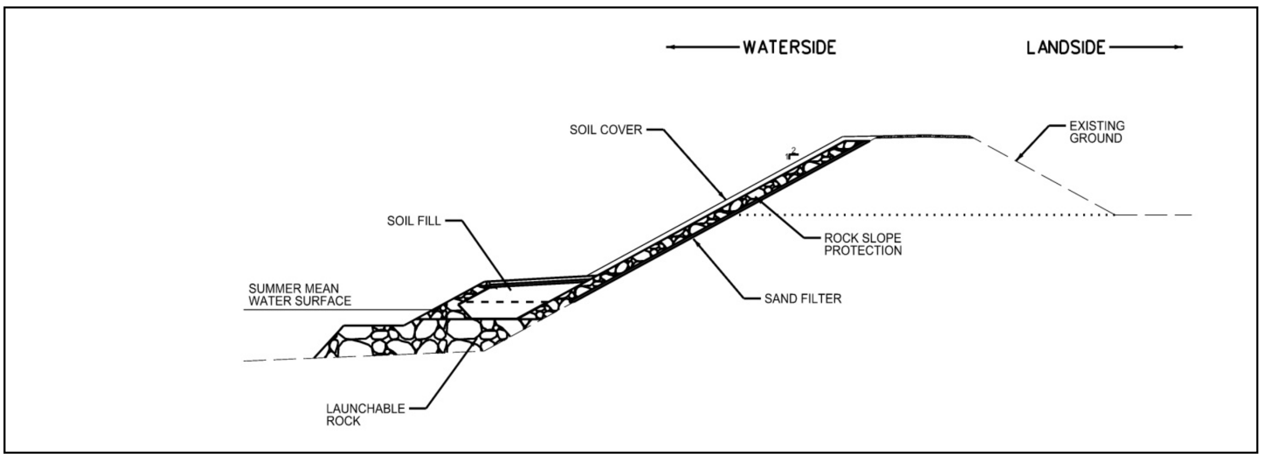

Figure 6-1. Bank protection generic design section and assumptions (insufficient bench)

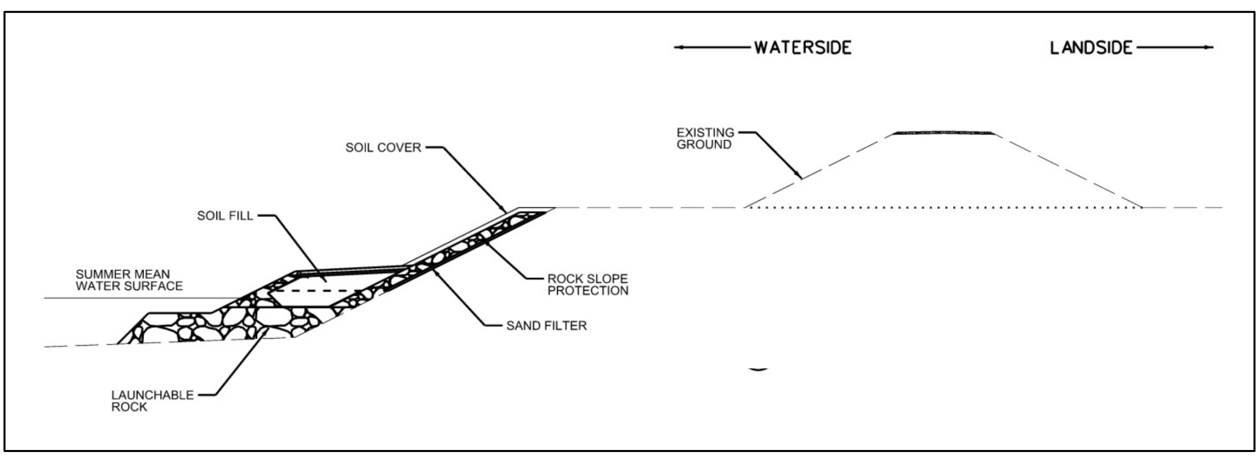

Figure 6-2. Bank protection generic design section and assumptions (sufficient bench)

6.3 Launchable Rock Trench

The rock trench design concept (depicted below in Figure 6-3) comes from the Windrow trenching method of erosion protection widely used along the Mississippi and Missouri Rivers. The trench design was only considered when the width of the existing waterside berm (if any) was enough to accommodate the construction of the trench. This form of passive erosion protection allows the existing berm to erode away naturally and does not require wet work or the disruption of shaded riparian habitat. The design includes trenching waterward of the levee, placing rock, and providing a soil cover for vegetation and other mitigation features.

The rock trench design used many of the same parameters shown under Table 6-1 for bank protection. The placement of the trench invert was a key design parameter and often dictated the required width of the berm. The invert was placed at the Summer Mean Water Surface Elevation (SMWSE) to remove the trench out of the vadose zone and eliminate the need to place rock in the wet. The SMWSE invert also reduced the launching distance and therefore the quantity of rock needed for scour. The reduced launching depth also increased the reliability of the launchable rock trench to launch uniformly and perform as intended. The generic design section and assumptions are shown below prior to any specific section edits.

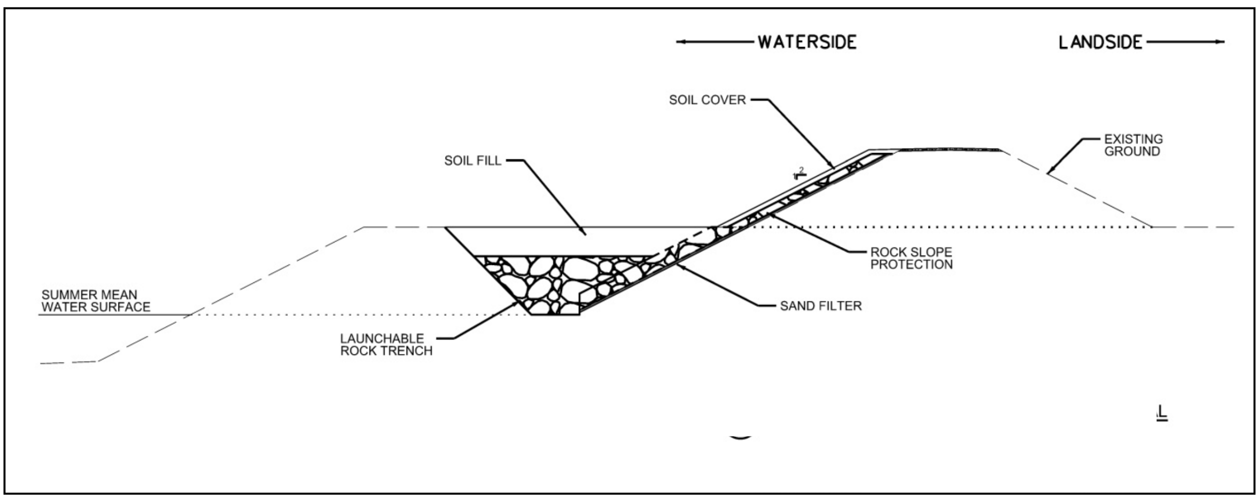

Figure 6-3. Launchable rock trench generic design section and assumptions

The design section would be lowered to the depth of the assumed SMWSE for that location. Rock slope protection was also provided on the waterward slope of the levee and carried all the way to the waterside hinge point. Excavation and fill quantities would vary because of the SMWSE and its relation to the existing elevation of the waterward berm.

It should be noted that the performance of windrow trenches can be compromised in high scour and velocity areas. EM 1110-2-1601 engineering criteria take these into account, however, there’s still a level of risk that cannot be mitigated. In the mentioned conditions, the rock may launch all at one time or non-uniformly in such a way that will provide decreased erosion protection performance. The consequences of this situation are greater than bank protection because the existing bank will have already eroded away back towards the toe of the levee. There will be very little time to flood flight and respond to the eroding site, which could lead to failure or breach of the levee. Conversely, if bank protection fails (undermined, flanked, etc) or stops providing its intended function, there is still bank available to flood fight and prevent the erosion from propagating towards the levee. Both methods offer a proven history of performance, however, the launchable rock trench will inherently have more risk that should be acknowledged by design team, and project sponsors.

6.4 Erosion Protection Footprints

Along the American River, the rationale used to determine where bank protection was required for the feasibility study involved consideration of several factors. The most important factors included: 1) the velocity computed by Ayres' 2-dimensional hydraulic modeling (Ayres 2004) for a discharge of 160,000 cfs, 2) the erodibility of the material near the levee prism, and 3) the past performance of the levee segment with respect to erosion. Figure 6-3 depicts the footprints of the proposed erosion protection for both the Lower American and Sacramento Rivers.

Using the above criteria, bank protection was determined to not be required along two segments of the right bank of the American River. The upstream segment, extending between the upstream end of the levee (~RM 14.4) and RM 10.3 and the downstream segment extending between a point near Cal Expo (RM 5.5) and the confluence with the Sacramento River (RM 0). In addition to following the above criteria, a portion of the upstream segment contains a 4000 foot-long reach wherein the channel includes a wide right overbank consisting of high ground (i.e., the location of a sewage treatment plant) in which the water surface elevation for a discharge of 160,000 cfs does not get near the levee and the levee essentially exists as a "freeboard" levee.

In addition, there are no proposed erosion protection features located along the left levee of the Sacramento River upstream of the American River confluence. The rationale for this approach is the assumption that, as recommended by the 2010 feasibility study for the Natomas PAC, a new levee will be constructed located adjacent to and on the landside of the existing Sacramento River levee (i.e., as a future without-ARCF GRR project condition). Furthermore, it is assumed that with the new proposed levee in place, the new levee template is located sufficiently far enough away from the existing bank that some bank erosion could occur along the entire Sacramento River reach, including into the existing levee prism, without threatening the new levee (e.g., analogous to erosion buffer zone). Nonetheless, O&M of the river bank will still need to occur. These assumptions will need to be verified during site-specific design of the ARCF project to ensure that the subject "new" levee does/or will in fact be constructed and that erosion "buffer" zones are adequate to preclude erosion which could lead to levee failure for flow into the Natomas Basin floodplain.

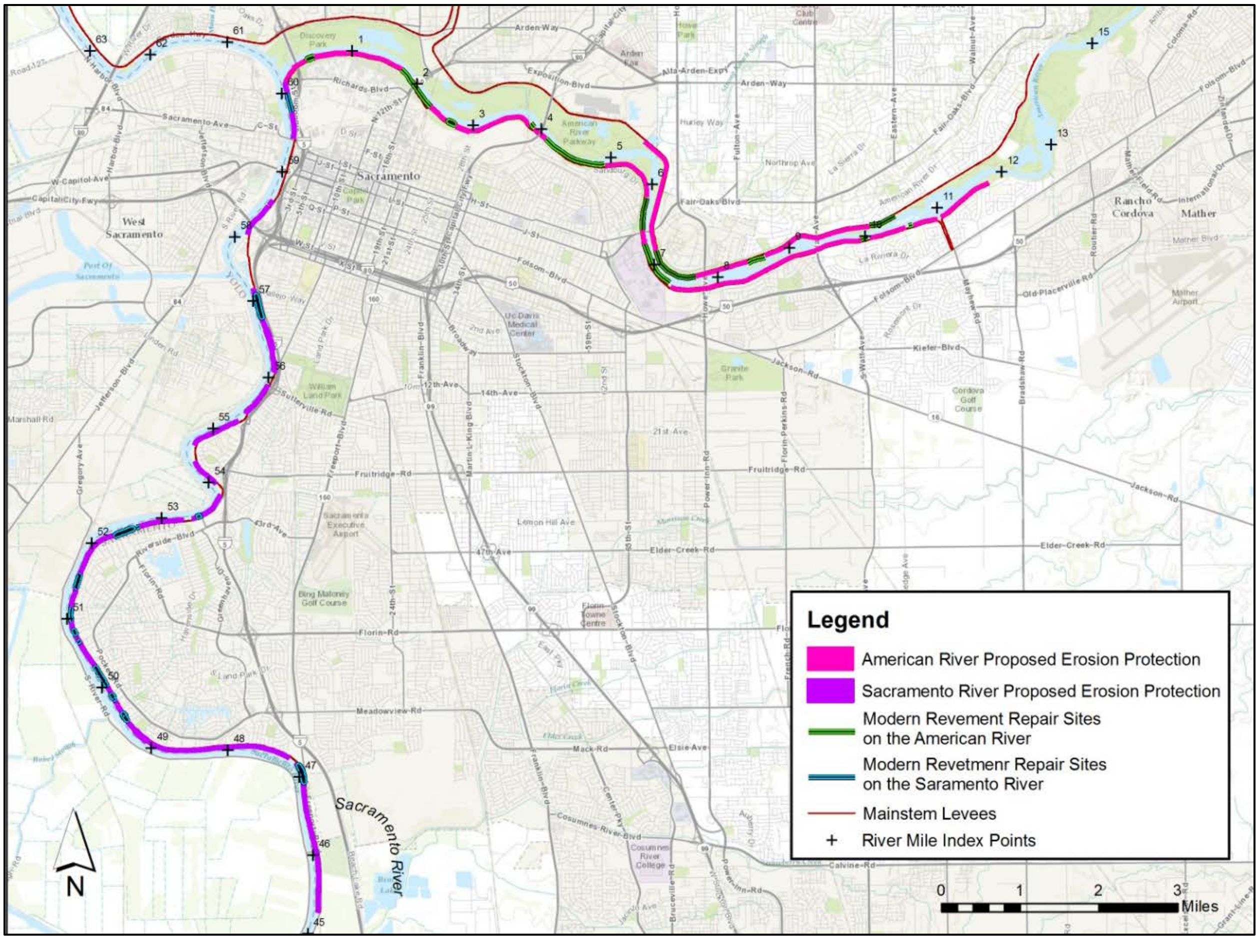

Figure 6-4. Footprints of the proposed erosion protection along the mainstem channels

Table 6-2 lists the cumulative lengths of the existing and proposed erosion protection features along the Lower American River. As illustrated by this table, about 100% of the left bank of the leveed reach will include some form of erosion protection features and about 35% of the right bank of the leveed reach will include erosion protection features.

Table 6-2. Cumulative length of existing and proposed erosion protection features along the Lower American River

	Left Bank		Right Bank	
	Levee Miles	Percent	Levee Miles	Percent
Existing Modern Revetment	3.1	28%	1.3	9%
Proposed Revetment	8.1	72%	3.7	26%
No Protection Proposed	0.0	0%	9.3	65%
Totals	11.2	100%	13.0	100%

Table 6-3 lists the cumulative lengths of the existing and proposed erosion protection features along the left (eastern) bank of the Sacramento River in the GRR study area. As illustrated by this table, about 84% of the left bank will include some form of erosion protection features.

Table 6-3. Cumulative length of existing and proposed erosion protection features along the left (eastern) bank of the Sacramento River

	Left Bank	
	Levee Miles	Percent
Existing Modern Revetment	2.7	18%
Proposed Revetment	9.8	66%
No Protection Proposed	3.3	16%
Totals	14.8	100%

A channel stability analysis (Ayres Associates, 2010) was used to determine areas requiring revetment with the assumption that all areas without modern bank protection will be protected. Modern protection was determined by areas defined as rock riprap with overall condition of good or very good. Additionally, there are some areas of high ground and areas with significant existing berm where protection is not required as shown in Figure 6.3.

6.5 Feasibility Design Considerations

The assumption of the feasibility study is that all modern revetments in the project area are designed to reliably and safely convey the design discharge of 160,000 cfs. The feasibility study assumes older revetments (e.g. “cobblestone” revetments) are unable to reliably and safely convey the design discharge. These historical cobble sites are likely beyond their intended design life and are in varying degrees of disrepair and failure. This leads to the assumption of replacing all historic cobble sites with modern angular bank protection.

However, a few exceptions to replacing the cobble sites exist in areas of lower velocities where the feasibility study assumes new erosion protection is not needed due to the lower velocities. For example, the right bank or “North” levee downstream of RM 5.5 and upstream of RM 10.5 (see Figure 6-3). Portions of the furthest upstream right bank levee are not expected to have water against the levee on the waterside for the design discharge.

These assumptions will need to be checked during implementation using site-specific analysis. Sites needing bank protection will need to be identified, prioritized, and designed for the design discharge during implementation. This may require additional environmental documents as the extent and location of the rock protection could change based on the new analysis and site-specific designs.

The current proposed rock protection locations and rock design for the project is a reasonable approximation of future actions used to estimate a reasonably conservative project cost, associated environmental impacts, and to assist with establishing federal interest. However, site-specific analysis and design needs to occur in the future during implementation and future changes to the location, extent, and design are possible.

While the repairs are expected to be designed and constructed to commonly accepted engineering and construction standards and USACE guidelines for the design discharge, it is expected that continued operations and maintenance will be necessary including:

- Repairing damaged rock protection
- Possibly installing additional rock protection
- Monitoring during floods
- Possible flood fighting

The estimates are reasonably conservative even though uncertainty remains in the location, costs, and environmental impacts of the proposed rock protection. Continued operations and maintenance activities are needed and possibly emergency patrols and emergency response during flood events.

7 Recommendations and Considerations

7.1 Conclusions and Recommendations

This document provides a brief history of erosion along the American and Sacramento Rivers and the nature of the erosion problem given the sediment starved condition of flood flows which occur downstream of the Folsom and Nimbus Dams. A number of investigations have been conducted to quantify the erosion problem. These investigations include 2-D hydraulic analysis and mapping of velocities and shear stresses, 1-D HEC-6T sediment transport analyses, geomorphic analyses, geotechnical and geophysical surveys and investigations, laboratory testing to determine the erodibility of some of the material, and 3-D stratigraphic mapping of the channel materials. These studies were pursued as an extensive attempt at quantifying the erosion problem. The results of these studies are summarized in subsequent subsections.

The studies support the GRR and are primarily focused on providing a reasonably conservative estimate of the project costs, benefits, and environmental impacts. The studies and this document are not site selection, prioritization, or design efforts although they may serve as a useful reference for these future efforts. More detailed site selection, prioritization, and site-specific designs are needed during implementation to more efficiently utilize limited federal funds.

Additional efforts are needed in the future to support implementation. These include but are not limited to:

- Confirm that portions of the levee not included in Figure 6-3 for new bank protection are designed for the 160,000 cfs design discharge on a site-specific basis,
- Develop and implement a site-selection and prioritization process,
- Collect data necessary for site-specific analysis of existing bank protection and design of new bank protection,
- Design the needed rock protection based on site-specific data in accordance with standard engineering practice and USACE guidelines,
- Monitor bank protection performance during and after flood events.

Repair and maintain rock protection as needed on a continual basis to keep the bank protection performance level from deteriorating.

7.1.1 Prototype System Performance

Although analytical analyses can provide a wealth of information regarding expected performance of the river and levee system, the actual performance of the prototype system provides the best insight into the system performance during future large flood events. To that end, significant historical erosion events were identified and the corresponding erosion-based damage discussed. These events indicate that basically all large flood events which have occurred since completion of the Federal flood control system (e.g., the floods of 1955, 1966, 1986, and 1997) have caused considerable damage to the levee system due to erosion. All four of these large events required extensive repair after the event so that the system was ready for the next major flood event.

In the 1986 food event, discharges greater than 115,000 cfs (with a sustained peak flow of 130,000 cfs) were released from Folsom Dam for about 52 hours. Wholesale erosion went undetected during this event at a couple of locations and almost failed the south levee near the Capital City Freeway crossing as illustrated on Figure 1-6. Sacramento was fortunate during this event, for had the discharge been sustained longer, the levee would have likely failed from erosion.

In the Sacramento River system, erosion has even occurred during lower flow events, as documented by the SRBPP. Numerous emergency bank repairs and repairs completed by the SRBPP (over 800,000 linear feet) have been constructed in the last 50 years. Erosion continues along the Sacramento River banks and levees and there are currently numerous sites that are still in need of repair.

7.1.2 Updated Geologic, Geotechnical, and Geophysical Information

Input from subject matter experts was solicited and used to advise on the direction of the study and investigations. Specifically, the experts provided opinions on the current stability of the river channel with regards to erosion and on requirements for additional study, data collection, and analysis. The data collection and analyses focused on improving the geologic and geotechnical characterization of the material properties which comprise the river channel and overbanks.

Data collected as part of this study included soil borings, cone penetrometer tests and geophysics. Samples obtained from the soil borings were testing in geotechnical laboratories for classification properties and erosion rates using JET and EFA testing. The data obtained in the subsurface investigations and laboratory testing were included in geologic mapping and 3-d modeling. Geologic analyses included development of three-dimensional surface contour maps of the erosion resistant unit, and geologic cross sections and longitudinal profiles. The final 3D model contains enhanced information, especially within the area between the levees where young alluvial sediments related to hydraulic mining have been deposited. In addition to showing subsurface alluvial stratigraphy, the final model shows the top of erosionally resistant sediments that are exposed and identified in the channel at several locations.

Field observations suggested that erosion of the exposed erosionally resistant sediment occurs over time at both the granular- and outcrop-scale. However, the mechanisms and time scale associated with that erosion are not well understood and were not studied. Due to the location and properties of the material, the risk posed to the flood control structure from erosion of the erosion resistant sediment were estimated to be low and no further study of its erosion mechanisms or time scale were performed.

Cross sections generated from the 3D stratigraphic are illustrated in Figures 3-4 and 3-5 and indicate that highly erodible mining materials are present in the channel (as berms and channel banks) and, in some cases, underlie the levees. The Lower American River has highly erodible zones which will, in time, erode during high flow events if left unprotected. In some cases, bank and levee failure will result.

Although not conducted as part of the ARCF GRR study, the results and conclusions of the DWR Urban Levee Evaluation circumstantiate the results and conclusions of the analysis performed for the ARCF study and presented herein. Given that the ULE used a different approach and still obtained similar results (i.e., that many of the levees have medium and high erosion risks) significantly adds to the validity of the ARCF conclusions.

7.1.3 Hydrology, Hydraulic, and Sedimentation Impacts

Once the JFP auxiliary spillway is constructed and functioning, new operations criteria are planned which would result in larger flood flows being conveyed through the American River with greater frequency compared to past conditions. These higher flood flows would exert additional pressure on the banklines and levees resulting in greater erosion, sediment transport, and potentially changes to the planform of the low-flow channel. Nonetheless, it is important to note that without inclusion of the proposed erosion protection features, the flood damage reduction benefits intended for the project cannot be fully realized since the lower American River channel will likely not be able to safely convey the new larger discharges and flow restrictions from Folsom would likely be put in place.

Two-dimensional modeling of the Lower American River using RMA-2 was performed to get a more detailed estimate of the velocity and shear in the American River compared to computed one-dimensional values. Results indicate relatively high velocities adjacent to the levees. Additionally, the range of the computed velocities is of concern since the magnitude of the velocities is great enough to erode many of the relatively fine grained material present in the channel lining.

7.1.4 Summary

Given the experience gained by past floods and post-flood repairs and on review and examination of the products of the erosion analyses discussed herein, it is clear that the erosion protection measures proposed by the ARCF GRR must be included along the leveed reaches of the lower American River and along the left bank of the Sacramento River. Failure to include these features will likely result in levee failure leading to catastrophic damages and possibly lives lost. There is a substantial life safety issue related to erosion along the river channels given the magnitude of the flooding coupled with the proximity of densely populated development immediately adjacent to the river channel and levees.

The available information indicates that many of the levee segments without modern bank protection are at risk of erosion related failures along the Sacramento River and Lower American River in the Common Features project study area. The levees therefore need to be protected to provide adequate flood damage risk reduction. Past erosion on the Lower American River (Figure 1-6) indicates that impending erosion failures may be covered by water and may not be observed in time to provide adequate warning to flood fight and/or evacuate residents. This is in contrast to landside seepage or stability related failures that may be more easily visible and allow more time for adequate flood fighting and/or evacuation of residents. The potential for unobserved erosion related failures increases the potential consequences to life and property. A passive approach of fixing erosion damage to levees during or after a flood event is not likely to reduce flood damage risk substantially. A passive approach to erosion is therefore not recommended for this project as the probability of failure and potential consequences of a failure during the design flood event are high. However, an active approach of providing erosion protection as proposed in the tentatively selected plan (TSP) is appropriate and should increase flood damage risk reduction from erosion once constructed.

Future site-specific erosion related data collection, analysis, and design is necessary for implementing the GRR including confirming feasibility assumptions. Future efforts are also needed to monitor the performance of the rock protection and make the necessary repairs to maintain the performance of the bank protection for the life of the project.

7.2 Other Considerations

A number of additional considerations require annotation and will need to be addressed in future studies of the ARCF study in order for the project to be considered "whole" or "complete". These considerations are discussed below.

Given the large increase in the design flow from 115,000 to 160,000 cfs as well as the large increase in discharge for relatively frequent events (discussed above in Section 4.1), the impacts of the project with respect to infrastructure encroaching in the floodway, such as bridges and pipelines, will need to be investigated including features needed for mitigating the impacts. It is unlikely that the subject increase in discharge will not induce a negative impact on the local bridge scour values.

The need for bed or invert protection, at one or more locations, is not a current component of the GRR plan, but has been the focus of discussion by members of the expert panels. The need for bed protection at key locations will need to be monitored in the future as part of project operations.

As discussed above, extensive investigations have been performed to quantify/predict erosion of the lower American River. In some cases, unknowns remain and recommendations are put forth for additional study to potentially fine tune the answer. There is considerable uncertainty related to predicting erosion. It is conceivable that additional investigation may optimistically lead to a reduction in length or volume of the proposed erosion protection features. However, the potential uncertainty in such favorable results may not be worth the impacts to the study schedule or budget.
As depicted in Figure 6-3, a number of existing revetment repair sites will be included as part of the complete erosion protection system. These sites must be assessed in future studies to confirm that these sites are stable, prevent erosion for discharges up to and including 160,000 cfs, and to prioritize sites to be constructed over a period of years.

Given that a primary goal of the ARCF GRR project is to increase the capacity of the American River to 160,000 cfs, the channel stability of downstream receiving channels also needs to be validated. Failure to confirm the downstream channel stability may result in stability problems being moved downstream.

7.3 Qualifications and Limitations

Given that the foundation of this report consists primarily of relevant extracts of other work efforts, coupled with the complexity of river erosion processes, as a standalone work effort the report does not constitute a rigorous analysis quantifying the erosion problem. In some cases, study conclusions on various topics have varied through time. This situation is not of great revelation since the erosion and stability problems have been under study for several years and occasionally new results, based on more detailed information, contradict older conclusions which were frequently based on lesser detailed information. However, the report is sufficient for supporting the proposed erosion protection features and cost estimates consistent with a feasibility study given the new "Smart Planning" paradigm.

It is important to note that there are several limitations in the information in this report and that additional analysis and design will be required in future studies in order to develop a complete and technically workable project.

The threshold analysis, currently ongoing, should produce information relating to how wide the American River channel could get as the availability of bed material available for transport continues to diminish. Additionally, this analysis should also provide valuable insights which will be useful in updating the Folsom Dam Water Control Manual.

The amount of erosion protection is extensive and is not expected to occur at once. During future studies, additional work will be necessary to prioritize sites to be constructed over a period of years.

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