Ventura County
Watershed Protection District

Ventura River Levee Evaluation and Rehabilitation

Ventura County, California

Alternatives Report

Draft-Final
April 2012

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Prepared for:

Ventura County
Watershed Protection District

Prepared by:

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EXECUTIVE SUMMARY

The Ventura River Levee (VR-1) is located in the city of San Buenaventura in Ventura County, California. The approximately 2.65-mile-long levee system extends along the eastern bank of the Ventura River from the Pacific Ocean (downstream limit) to the confluence with the Cañada de San Joaquin, where it extends east along the southern bank of the Cañada de San Joaquin for approximately 1,000 feet before it terminates into high grounds (upstream limit). The levee system consists of embankment levees, side slope protection (riverside) consisting of loose or grouted riprap, concrete floodwalls, side-drainage penetrations, and a stop-log structure at a bike trail crossing. The levee system is intended to protect existing residential, commercial, industrial, and potentially developable properties in low-lying areas within the base flood floodplain of the Ventura River Watershed.

In order to remediate the VR-1 system for compliance with the Federal Emergency Management Agency (FEMA) levee certification guidelines, the Ventura County Watershed Protection District (VCWPD) is pursuing a partnership with the U.S. Army Corps of Engineers (Corps). The purpose of this study is to evaluate the existing conditions of the VR-1 system and explore various design alternatives to remediate the current levee deficiencies. The study included reviewing the results of previous hydrology studies, performing hydraulic and scour analyses, and performing risk and uncertainty analysis. Feasibility-level design drawings were prepared to show the layout of the design alternatives. For all of the alternatives, cost estimates were prepared for comparison purpose only.

Two recent field inspections of VR-1 have been conducted: one by Tetra Tech and AMEC in December 2008, as part of the FEMA levee certification process and another by Fugro West in May 2010, as part of the Corps' Periodic Inspection. Remediation of the deficiencies found during the field inspections has been considered as part of each design alternative and included in the cost estimates.

The hydraulic analyses performed for this study included a determination of hydraulic parameters under existing conditions, a freeboard analysis, a scour analysis, a sediment transport analysis, and a risk and uncertainty analysis. The results of these analyses indicate that some areas of the levee have insufficient freeboard under existing conditions. The follow-up risk and uncertainty analysis determined the minimum proposed top of levee elevations necessary to provide the freeboard required by FEMA while also satisfying the Corp's risk and uncertainty requirements. As determined by the scour analysis, VR-1 would experience potential scour ranging from 5 to 21 feet below the 1947 thalweg elevation, which is as much as 8 feet below the existing toedown elevation along portions of the levee. It was determined that without design improvement, the existing protection of the levee embankment could be undermined and may result in levee failure. Incorporation of the results of the sediment transport study performed by the U.S. Bureau of Reclamation into the sediment transport analysis resulted in the finding that the removal of Matilija Dam would not significantly affect the freeboard conditions of VR-1.

Four feasibility-level design alternatives were developed to remediate the current design deficiencies:

- Alternative 1 – Grouted Riprap Toedown Extension
- Alternative 2 – Reinforced Concrete Lining
- Alternative 3 – Sheet Pile
- Alternative 4 – Grade Control Structures

These alternatives are designed to improve the existing protection of the levee embankment to the potential scour limit. All four design alternatives include common measures to remediate other levee deficiencies indicated by the hydraulic analyses (increase in top of levee elevation) and determined during the inspections (for example, sediment removal and vegetation removal).

On the basis of the estimated construction cost for each of the alternatives and their project effectiveness, Alternative 1 (Grouted Riprap Toedown Extension) is recommended as the preferred alternative for remediating the deficiencies and improving VR-1 to comply with the FEMA levee certification requirements.

The estimated construction cost for Alternative 2 (Reinforced Concrete Lining) is 2 percent less than that of Alternative 1. However, because the regulatory agencies typically perceive riprap material as more environmentally friendly than reinforced concrete surfaces, the grouted riprap protection is recommended. Furthermore, grouted riprap is the material that makes up the existing levee embankment protection.

Alternative 3 (Sheet Pile) would be the most expensive solution, costing 30 to 40 percent more than the other three alternatives.

Although Alternative 4 (Grade Control Structures) would be the least expensive of the four alternatives, it should be noted that the cost estimate used for this comparison does not include the environmental mitigation that would likely be necessary. Contrary to the other three alternatives, which would be constructed in the vicinity of the levee, Alternative 4 would require construction activities such as excavation and backfill across the river streambed, likely disturbing environmentally sensitive and critical areas and habitats in the process. Furthermore, the design of the grade control structure may need to incorporate a fish passage feature in order to provide continuous and safe passage for the existing species of fish.

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1. INTRODUCTION

The Ventura River Levee (VR-1) is located in the city of San Buenaventura in Ventura County, California. The approximately 2.65-mile-long levee system extends along the eastern bank of the Ventura River from the Pacific Ocean (downstream limit) to the confluence with the Cañada de San Joaquin, where it extends east along the southern bank of the Cañada de San Joaquin (Figure 1.1). The levee then extends for approximately 1,000 feet before it terminates into high grounds (upstream limit). Because the original levee in the vicinity of the confluence was buried underneath the State Route 33 (SR 33) embankment, the flow from the Cañada de San Joaquin is conveyed to the Ventura River through a double reinforced concrete box culvert measuring 10 feet wide by 8 feet high.

The levee system consists of embankment levees, side slope protection (riverside) consisting of loose or grouted riprap, concrete floodwalls, side-drainage penetrations, and a stop-log structure at a bike trail crossing. The levee system is intended to protect existing residential, commercial, industrial, and potentially developable properties in low-lying areas within the base flood floodplain of the Ventura River Watershed.

1.1 Purpose and Scope of Work

In order to remediate the VR-1 system for compliance with Federal Emergency Management Agency (FEMA) levee certification guidelines, the Ventura County Watershed Protection District (VCWPD) is pursuing a partnership with the U.S. Army Corps of Engineers (Corps). The initial efforts of the partnership include performing various studies and preparing the required documents.

The purpose of this study is to evaluate the existing conditions of the VR-1 system, explore various design alternatives for remediating the current levee deficiencies, and recommend a preferred alternative. The study included a review of the results of hydrologic studies and the performance of hydraulic and scour analyses, and a risk and uncertainty analysis. In addition, feasibility-level design drawings were prepared to show the layout of the design alternatives. A cost estimate was prepared for each alternative, for comparison purposes only. At the end of this report, a preferred design alternative will be recommended, based on the findings of this study.

Documentation of the independent technical review for this report is provided in Appendix A.

1.2 Project Authority

The VR-1 system was authorized by the Flood Control Act approved December 22, 1944, Public Law 534, 78th Congress, Chapter 665, 2nd Session (H.R. 4485), substantially in accordance with the recommendations of the Chief of Engineers in House Document No. 322, 77th Congress, 1st Session. The levee project was locally authorized by the City Council of the City of Ventura on September 8, 1947. In a resolution dated September 30, 1947, the Ventura County Flood Control District (now the Ventura County Watershed Protection District [VCWPD]) assumed the responsibilities for the operation and maintenance of the levee (USACE 1963).

Figure 1.1 – Location Map for VR-1 System

1.3 History of VR-1 System

The design and construction of the VR-1 system was completed by the Corps in December 1948. The levee protects the western portion of the city of Ventura and the suburban area immediately north of the city from a design flood of 150,000 cubic feet per second (cfs). This is the maximum peak design flow that was estimated to occur as a result of the more severe regional storm coupled with conditions fairly conductive to runoff.

Major improvements and modifications to the VR-1 system since its original completion in 1948 are summarized as follows:

- SR 33 was constructed on the landside of VR-1 and across the levee near the upstream end of VR-1.
- A railroad penetration was converted to a bike path crossing, which was retrofitted by the VCWPD in January 2010.
- A concrete curb wall was added to the top of the levee, beginning at the Southern Pacific Railroad (SPRR) bridge and extending upstream for approximately 0.45 mile. This wall was apparently constructed because the railroad removed one of its bridge openings, which constricted the flow conveyance area and caused higher water-surface elevations in the area.
- At several locations along VR-1, adjacent property owners constructed buildings and retaining walls on the landside of the levee and also excavated into or next to the levee.
- Several local drainage penetrations were installed through the embankment of VR-1. The most notable of the penetrations are the New Dent Drain (90-inch-diameter reinforced-concrete pipe [RCP]), the Ramona Street Drain (72-inch-diameter RCP), and the Mission Street Drain (56-inch-diameter RCP).

Additional information on improvements and modifications to VR-1 is provided in the periodic inspection report (Fugro 2011).

1.4 Survey Mapping

The existing topographic mapping of the project area was provided by the VCWPD in November/December 2010. The mapping was generated from a VCWPD cross-sectional survey along the VR-1 system at 100-foot intervals, with each surveyed cross section extending 150 and 100 feet from the levee survey control line in the riverside and the landside directions, respectively, resulting in a 250-foot-wide cross section.

Additional topographic information from a 2005 Light Detection and Ranging (LiDAR) survey, also provided by the VCWPD, was incorporated into the existing topographic mapping to capture areas beyond the limits of the 2010 survey mapping and into the floodplain of the Ventura River where a series of grade control structures have been proposed as one of the design alternatives.

The horizontal control of the topographic mapping is based on the North American Datum of 1983 (NAD 83), and the vertical control is based on the North American Vertical Datum of 1988 (NAVD 88).

2. PREVIOUS LEVEE EVALUATIONS

Two levee evaluations that included field inspections of the VR-1 system have been conducted previously: one by Tetra Tech and AMEC in December 2008 as part of the FEMA levee certification process and the other by Fugro West in May 2010 as part of the Corps' Periodic Inspection of the levee system. Observations and findings of both field inspections are summarized in the following subsections.

2.1 FEMA Levee Certification Evaluation Report

The following text summarizes the field observations and findings for VR-1 during the FEMA levee certification process (Tetra Tech and AMEC 2009):

- The 1949 as-built plans for VR-1 reveal that a minimum of 8 feet of toedown was provided below the channel thalweg when the levee was initially constructed. Over the last 60 years, the Ventura River has degraded along VR-1 to a point where currently, there is minimal to no toedown protection.
- Approximately 1.4 miles of the Ventura River thalweg along VR-1, from Station 64+00 to Station 138+50, is either below or very close to the existing levee toedown. There are no geological features, such as bedrock, or manmade feature, such as rock groins, that would prevent the thalweg of the river from migrating toward the levee and undermining the toedown.
- From about levee Station 119+00 to Station 124+00, the river channel along VR-1 has eroded near the levee structure.
- From Station 39+80 to Station 46+24, modifications to the VR-1 landside slope, such as undercutting and construction of retaining structures, have been performed over time that are considered to have a potential negative impact upon the stability of the slope.
- At Station 35+33, the adjacent landside slope along VR-1 has been subjected to heavy erosion. Some areas on the embankment slope have ungrouted riprap that cannot be observed because it is either missing or buried by soil/debris.
- The maintenance road is failing near VR-1 Station 121+00
- There are concerns about the adequacy of the riprap revetment protecting VR-1 related to undermining of the levee toe and the potential for direct, high-angled flow impingement to occur at unpredictable future locations.

2.2 Periodic Inspection Report

During the 2010 field inspection, primary deficiencies related to the levee embankments, floodwalls, and interior drainage systems were noted (Fugro 2011).

2.2.1 Levee Embankments

- Significant vegetation growth, particularly trees and bushes greater than 2 inches in diameter, was observed on both the riverside and landside of the levee within the vegetation-free zone. The vegetation threatens the operation and integrity of the levee.

- Several unpermitted encroachments were observed within the easement areas that are likely to adversely affect the integrity of the levee. Encroachments that will require permitting include: seven non-Corps-built culverts and side-drainage structures; two segments of floodwalls; the U.S. Highway 101 and SR 33 crossings; an industrial development near upstream end of the levee; concrete k-rails; and utilities.

- Erosion zones were observed on both the riverside and landside levee slopes, and the levee integrity may be threatened. Erosion zones consist of undercutting of the revetment and deterioration of access ramps on the riverward side.

- Areas of minor to significant riprap displacement and stone degradation were observed along the levee; they may pose a threat to the integrity of the levee in the event of a flood. For example, there was no riprap observed along the entire riverside of multiple access ramps. Localized areas were observed along the levee where the riprap has degraded or deteriorated into 2- to 12-inch fragments. Other areas of displacement appear to be the result of human interference where the stone has been moved for the purpose of creating levee access.

2.2.2 Floodwalls

- Floodwalls not shown on the as-built plans that will require permitting include the approximately 550-foot-long Floodwall No. 1 and the approximately 1,050-foot-long Floodwall No.2, which are both located between the SPRR (main line) and the Main Street bridge crossings.

- Active erosion and scouring were observed beneath Floodwall No.1, which may lead to structural instabilities before the next inspection.

2.2.3 Interior Drainage System

- A total of eight Corps-built and seven non-Corps-built, unpermitted culverts and side-drainage structures were observed. The VCWPD has provided as-built plans (Ventura County Flood Control District 1985) only for the New Dent Drain at Station 124+89. Information regarding the design and construction of the remaining six unpermitted culverts and side-drainage structures was not included in the documents that were reviewed.

- Several of the side-drainage structures contain debris and heavy sediment that has impaired the channel flow capacity and has blocked more than 10 percent of the culvert opening at the outfalls.

- A dirt access road, slurry sack headwalls, and underdrains are unpermitted encroachments between the side-drainage structures and the riverbed. While these unpermitted features may enhance operations, maintenance, and emergency access within the riverbed, in some cases, they appear to inhibit adequate drainage from the structures.

- Unpermitted 3-foot-long by 2-foot-wide catch basins with metal grates were observed within 15 feet of the toe on the landward side across from four side-drainage structure outfalls. It was not possible to confirm in the field whether these catch basins are modified inlets at ponding areas for the side-drainage structures. The size and capacity of each catch basin is unknown.

- Significant damage and obstructions were observed at the outlet of the abandoned 30-inch-diameter corrugated metal pipe (CMP) drain at Station 14+10. In addition, information regarding the interior condition of the pipes (obtained via video camera or visual inspection methods) was not provided.

- The slide gate at the inlet for the abandoned 30-inch-diameter CMP drain at Station 14+10 is heavily corroded and inoperable.

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3. HYDROLOGY AND HYDRAULICS

3.1 Hydrology Evaluation

The current hydrology was reviewed and is documented in Appendix B*;* however, no separate hydrologic evaluation was performed for this study. Information on peak discharge along the Ventura River, provided in the current FEMA Floodplain Insurance Study (FIS), was used for the hydraulic analyses.

3.2 Hydraulic Evaluation

The hydraulic evaluation of the VR-1 system included a determination of hydraulic parameters under existing conditions, a freeboard analysis, a scour analysis, a sediment transport analysis, and a risk and uncertainty analysis. The process used for each analysis and the findings of each analysis are documented in Appendix C. The following subsections summarize the hydraulic analyses of the VR-1 system.

3.2.1 Review of Previous Hydraulic Studies

Documentation for the four previous studies of the VR-1 system was reviewed and is summarized in Section 2 of Appendix C: the *Preliminary Examination and Survey of Ventura River* (USACE 1941), the definitive project report (USACE 1947), FEMA's FIS report (FEMA 2010) on which the hydrology information and hydraulic model for this project are based, and the *Matilija Dam Ecosystem Restoration Feasibility* Study (USBR 2004a).

3.2.2 FEMA Flood Insurance Study HEC-RAS Model

The existing Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic model from the FEMA FIS was reviewed and adjusted to set up a "baseline" HEC-RAS model to simulate existing hydraulic conditions for this study (see Appendix C, Section 3). The changes in water-surface elevations due to the adjustments were less than 6 inches at bridges, located downstream of the Main Street bridge. No significant differences were observed upstream of the bridge. The adjustments to the FEMA FIS model included the following:

- Incorporation of the recent cross-sectional survey (November/December 2010) of VR-1
- Change in starting water-surface elevation: use of mean higher high water-surface (MHHW) elevation at National Oceanic and Atmospheric Administration (NOAA) Santa Barbara Station (No. 9411340)
- Revised top elevations of two segments of existing floodwalls upstream of the SPRR bridge
- Adjustment in bridge openings and culvert sizes to account for debris loading conditions per the Corps' requirements (USACE 2004)

The water-surface elevations along VR-1 resulting from the project baseline model are presented in Table 3.1. It should be noted that the HEC-RAS stations for the hydraulic study are different from the actual levee stations, which generally follow the design alignment in the as-built plans.

Table 3.1 – Water-surface Elevations from the Project Baseline Hydraulic Model

Approximate Levee Station	HEC-RAS Station	Channel Thalweg (feet)	Computed WSE [1] (feet)	Top of Levee Elevation (feet)	Computed Freeboard (feet)	FEMA-Required Freeboard (feet)
End of Levee at Approximately Levee Station 149+22.88						
149+15.14	16+95.32	106.94	109.19	120.4	11.21	3.5[2]
Crossing in OST Yard						
148+82.01	16+50.47	106.28	108.89	119.15	10.26	3[2]
148+34.80	16+05.52	105.64	108.8	117.88	9.08	3[2]
Building over Channel						
145+74.67	13+40.21	101.05	107.00	114.35	7.35	3[2]
143+95.45	11+73.49	99.04	107.00	111.65	4.65	3[2]
Crossing in OST Yard						
142+98.93	10+82.10	98.44	107.00	111.03	4.03	3[2]
142+04.16	9+99.46	97.81	107.00	108.49	1.49[5]	3
140+17.38	8+49.36	97.58	107.00	108.12	1.12[5]	3[2]
Crossing in OST Yard						
139+74.04	8+14.85	96.96	107.00	107.91	0.91[5]	3[2]
Ojai Trail Bike Path						
139+12.19	7+75.05	97.68	106.59	107.98	1.39[5]	3[2]
Confluence of Cañada de San Joaquin and Ventura River						
137+93.73	130+21.47	74.05	88.77	107.52	18.75	3
136+70.09	128+77.79	73.25	86.07	107.5	21.43	3
133+76.91	125+97.31	71.15	83.54	104.81	21.27	3
131+26.07	123+40.06	70.09	81.3	100.52	19.22	3
125+39.64	117+27.16	62.75	76.71	96.48	19.77	3
120+30.35	112+51.45	59.23	73.03	92.13	19.1	3
115+74.55	107+31.75	58.28	69.83	88.6	18.77	3
111+68.84	101+56.63	51.14	68.42	86.15	17.73	3
106+21.28	96+36.13	46.46	67.64	82.55	14.91	3
101+51.86	91+88.07	43.6	62.19	79.4	17.21	3
96+73.53	86+86.77	41.59	59.31	76.08	16.77	3
91+69.01	81+75.15	38.25	54.76	71.99	17.23	3
86+66.14	76+71.02	38.02	53.62	67.76	14.14	3
81+92.17	71+78.09	31.85	52.49	63.85	11.36	3

Approximate Levee Station	HEC-RAS Station	Channel Thalweg (feet)	Computed WSE [1] (feet)	Top of Levee Elevation (feet)	Computed Freeboard (feet)	FEMA-Required Freeboard (feet)
76+97.11	66+72.70	29.76	47.42	60.1	12.68	3
72+41.97	61+69.65	24.75	46.26	56.93	10.67	3
67+16.18	56+54.25	22.57	44.63	51.9	7.27	3
62+02.33	51+44.70	19.79	42.02	47.93	5.91	3
56+70.27	46+36.19	19.19	38.29	43.91	5.62	3
52+03.73	41+35.26	18.68	34.76	39.42	4.66	3
47+57.50	36+21.49	17.30	31.00	36.51	5.51	3
43+09.86	31+12.68	12.87	27.96	33.63	5.67	3
39+12.75	28+69.57	11.51	27.8	34.12	6.32	4
Main Street Bridge						
38+31.16	27+33.19	10.77	26.38	30.63	4.25	4
35+75.06	24+96.20	9.62	25.92	29.89[3]	3.97	3
31+04.66	20+56.05	5.17	25.81	29.72[3]	3.91[5]	4
Highway 101 Bridge						
26+77.53	16+51.52	5.34	22.2	25.87[3]	3.67[5]	4
22+06.03	10+71.01	3.02	22.23	25.00[3]	2.77[5]	4
Southern Pacific Railroad Bridge						
20+54.54	6+94.09	2.92	13.24	19.94	6.70	4
16+14.47	3+56.51	2.74	11.35	18.26	6.91	3
13+75.34	1+62.99	2.22	10.26	17.31	7.05	3
11+97.27	0+43.85	2.33	9.31[4]	16.86	7.55	3.5

1. WSE = Water-surface Elevation
2. Crossings (culverts) in the Cañada de San Joaquin have limited capacity and were inundated by the 100-year flood. Therefore, no additional freeboard is required within 100 feet of the structures on either side.
3. Top of floodwall elevations.
4. Starting water-surface elevation was set to 5.30 feet but defaulted to critical flow depth
5. Computed freeboard is less than FEMA-required freeboard at this station.

3.2.3 Scour Analysis

An alluvial channel system such as Ventura River is very dynamic due to changes in sediment transport, river geomorphology, human-induced effects, and other factors. Empirical equations were developed to co-relate the channel hydraulics and channel materials in estimating the potential scour depth (see Appendix C, Section 4).

HEC-RAS Model for Scour Analysis

Assuming that an alluvial channel would not experience supercritical flow conditions for any significant length of time, the critical flow condition should be the worst-case scenario in estimating the potential scour depth. Therefore, the baseline HEC-RAS hydraulic model for this project (Section 3.2.2) was modified for use in the scour analysis by adjusting the Manning's *n* values along the channel in order to simulate the critical flow condition.

Scour Calculations

VR-1 was divided into four hydraulically similar segments for the scour calculations (Table 3.2).

Table 3.2 – Segments of VR-1 for Scour Calculations

	HEC-RAS Station	
Segment No.	**From**	**To**
1	0+43.85	27+33.19
2	28+69.57	41+35.26
3	46+36.19	96+36.13
4	101+56.63	130+21.47

Over time, VR-1 would experience erosion mechanisms of flow both on a short-term (scour) basis and a long-term (degradation) basis. Scour components include general scour, bedform scour, and bend scour. However, because of the large sediment particles in the VR-1 reach, dunes are not likely to form. Therefore, bedform scour was assumed to be 0.0 foot and was not considered further in this study.

Long-term streambed degradation was also considered. This erosion mechanism takes place as a result of disruption in system sediment continuity. Disruptions include the construction of dams and other sediment impoundments, watershed urbanization, and confinement of flood flows as a consequence of levee construction. Therefore, inclusion of long-term streambed degradation in estimating potential scour limits is valid only in the absence of the Matilija Dam removal plan.

The total scour depths due to the erosion mechanisms of the flow along the VR-1 system are summarized in Table 3.3. For Segments 3 and 4, the total scour is mostly affected by bend scour, which takes place as high-velocity flow along multiple threads of low-flow channels in the floodplain strikes channel banks or levees at a large enough angle. For Segments 1 and 2, the presence of several bridge crossings and the influence of the Pacific Ocean would provide relatively fixed locations and stable conditions for the low-flow channels, reducing the potential for significant bend scour. The total scour depth, or potential scour limit, varies from 5 to 21 feet below the 1947 thalweg along VR-1.

Table 3.3 – Total Scour Depths Calculated for VR-1

Analysis Methodology	Scour Depth (feet)			
	Segment 1	Segment 2	Segment 3	Segment 4
Single-event or bend scour[1]	5	6	18	12
Long-term streambed degradation[2]	NA	1	3	7
Total scour[3]	**5**	**7**	**21**	**19**

1. Single-event scour is based on the average value of all methods listed in Table 15 of Appendix C, except that a minimum single-event scour of 5 feet is applied as a factor of safety to account for non-uniform flow distribution (Segments 1 and 2).
2. Based on 50 percent of the long-term degradation that would occur without the removal of Matilija Dam.
3. Sum of bend scour + long-term streambed degradation (measured from the 1947 thalweg).

NA = not applicable

3.2.4 Sediment Transport Analysis

The sediment analysis included as part of the U.S. Bureau of Reclamation (USBR) study (USBR 2004b) was reviewed and is summarized in Section 5 of Appendix C. The study analyzed a "no action" alternative and seven additional alternatives related to the future Matilija Dam removal and their impacts on the sediment transport conditions of the Ventura River. The results of the study showed that when conditions resulting from the various alternatives were simulated for 50 years, the deposition upstream of the Main Street bridge crossing would be as much 3.6 feet**,** whereas there would be no deposition downstream of the bridge after the dam is removed.

For the current study, the deposition values from the USBR's sediment transport study were incorporated into the HEC-RAS model to analyze the change in freeboard conditions. The results indicate that deposition due to the dam removal would not result in significant changes in water-surface elevations (Appendix C, Table 22). Additionally, the freeboard currently available in this area is 4.66 to 21.43 feet; therefore, such a minor change in water-surface elevations is not likely to jeopardize compliance with the FEMA freeboard requirements.

3.2.5 Risk and Uncertainty Analysis

An assessment of the probability of capacity exceedance and an uncertainty analysis of levee containment are both required by the Corps for all new and existing levees (Appendix C, Section 6). The analysis was performed according to the procedures described in Engineer Manual 1100-2-1619 (USACE 1996) and Engineer Regulation 1105-2-101, (USACE 2006).

Engineer Circular 1110-2-6067 (USACE 2010b) requires that a levee or an incised channel have at least a 90 percent assurance of excluding the 100-year flood for all reaches of the system or have at least a 95 percent assurance of at least 2 feet of freeboard above the 100-year flood. The currently available freeboard and the conditional non-exceedance probability at critical sections along VR-1 under existing conditions are presented in Tables 3.4 and 3.5, respectively.

Table 3.4 – Available Freeboard under Existing Conditions

Critical Section (HEC-RAS Station)	Reach	Existing Top of Levee (feet)	Available Freeboard (feet)	FEMA-Required Freeboard (feet)
10+71.01	Between SPRR and Main Street	25.00[1]	2.77	4[2]
16+51.52		25.87[1]	3.67	4[3]
20+56.05		29.72[1]	3.91	4[4]
31+12.68	Upstream of Main Street	33.63	4.09	3
7+75.05	Upstream of SR 33 in Cañada de San Joaquin	107.98	1.39	3
8+14.85		107.91	0.91	3
8+49.36		108.12	1.12	3
9+99.46		108.49	1.49	3

1. Top of floodwall elevation.
2. Upstream of SPRR bridge.
3. Downstream of Highway 101 bridge.
4. Upstream of Highway 101 bridge.

Table 3.5 – Conditional Non-Exceedance Probability under Existing Conditions

Critical Section (HEC-RAS Stations)	Conditional Non-Exceedance Probability by Flood Frequency					
	10%	4%	2%	1%	0.4%	0.2%
	10-year	25-year	50-year	100-year	250-year	500-year
10+71.01	0.9897	0.9702	0.9536	0.9404	0.9267	0.9179
16+51.52	0.9981	0.9943	0.9911	0.9886	0.9860	0.9844
20+56.05	0.9977	0.9935	0.9906	0.9882	0.9857	0.9842
31+12.68	0.9997	0.9990	0.9985	0.9981	0.9978	0.9975
7+75.05	0.9999	0.9460	0.9046	0.7614	0.6252	0.5523
8+14.85	0.9997	0.9185	0.8598	0.6761	0.5094	0.4225
8+49.36	0.9998	0.9311	0.8803	0.7146	0.5608	0.4793
9+99.46	0.9999	0.9504	0.9117	0.7798	0.6541	0.5846

The results indicate that under existing conditions, the assurances for the levee along the Cañada de San Joaquin are insufficient. Also, with the assurance of less than 95 percent for a 100-year flood condition, the cross section immediately upstream of the SPRR bridge does not have enough freeboard, considering it needs an additional freeboard of 1 foot to account for the effects of the bridge.

The levee would need to be raised where the available freeboard or the combination of freeboard and assurance does not meet the Corps' requirements. Below are the proposed minimum top of levee elevations that are required to meet the freeboard requirements and the Corps' risk and uncertainty requirements (Table 3.6). Although the critical sections between SPRR and Main Street do not have the 4 feet of FEMA-required freeboard, because their assurance is more than 95 percent as shown in Table 3.7, the required total freeboard in this reach will be 2 feet plus an additional 1 foot of freeboard, totaling 3 feet, rather than 4 feet.

Table 3.6 – Available Freeboard under Proposed Conditions

Critical Section (HEC-RAS Stations)	Reach	Proposed Top of Levee (feet)	Available Freeboard (feet)	FEMA-Required Freeboard (feet)
Station 10+71.01	Between SPRR and Main Street	25.23	3.00	4[1]
Station 16+51.52		25.87[2]	3.67	4[3]
Station 20+56.05		29.72[2]	3.91	4[4]
Station 31+12.68	Upstream of Main Street	33.63	4.09	3
Station 7+75.05	Upstream of SR 33 in Cañada de San Joaquin	109.59	3.00	3
Station 8+14.85		110.00	3.00	3
Station 8+49.36		110.00	3.00	3
Station 9+99.46		110.00	3.00	3

1. Upstream of SPRR bridge.
2. Unchanged.
3. Downstream of Highway 101 bridge; no change in top of levee elevation.
4. Upstream of Highway 101 bridge.

Table 3.7 – Conditional Non-Exceedance Probability under Proposed Conditions

Critical Section (HEC-RAS Stations)	Conditional Non-Exceedance Probability by Event					
	10%	4%	2%	1%	0.4%	0.2%
Station 10+71.01	0.9934	0.9808	0.9701	0.9618	0.9532	0.9474
Station 16+51.52	0.9981	0.9943	0.9911	0.9886	0.9860	0.9844
Station 20+56.05	0.9977	0.9935	0.9906	0.9882	0.9857	0.9842
Station 31+12.68	0.9997	0.9990	0.9985	0.9981	0.9978	0.9975
Station 7+75.05	1.0000	0.9935	0.9873	0.9626	0.9374	0.9228
Station 8+14.85	1.0000	0.9931	0.9864	0.9609	0.9347	0.9194
Station 8+49.36	1.0000	0.9929	0.9862	0.9604	0.9348	0.9197
Station 9+99.46	1.0000	0.9931	0.9863	0.9605	0.9351	0.9199

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4. EVALUATION OF ALTERNATIVES

As described in Section 3.2.3, scouring and degradation of the channel streambed pose a major potential threat to the life and effectiveness of the VR-1 system. The Ventura River has been experiencing channel degradation within the study reach and would experience total scour depths of 5 to 21 feet below the 1947 thalweg during the 100-year flood events (Table 3.3). Channel degradation and scouring at the levee toe would undermine the existing protection of the levee toe and may result in failure of the levee system unless some form of design remediation or improvement is provided to the existing levee. As shown on the levee profiles included in Sheets 9 and 10 of the feasibility-level plans for the design alternatives (Appendix D), future elevations of the channel streambed, which would be lowered by channel scour and are represented by “potential scour limit” on the profiles, are much lower than the current toedown elevations of the existing toe protection in many areas. It is apparent that without some form of design remediation or improvement to the existing levee, the channel degradation would eventually expose the existing toedown protection and potentially undermining the levee.

To provide protection against long-term channel degradation and scouring, four feasibility-level design alternatives were explored and are graphically shown in the alternatives plans (Appendix D). The alternatives plans also include other design improvements that may be necessary to address the current levee deficiencies identified in the Periodic Inspection report (Fugro 2011) and to comply with the FEMA levee certification guidelines.

4.1 Formulation of Alternatives

All four of the alternatives would protect the existing levee embankment in place while providing additional design improvements and scour protection. As shown on the levee profiles (Appendix D, Sheets 9 and 10), the potential scour limit is lower than the existing toedown elevation upstream of the Simpson Drain penetration near Levee Station 56+00. Therefore, the scour protection design improvement would be provided only upstream of Levee Station 56+00.

The alternatives are as follows:

- Alternative 1 (Grouted Riprap Toedown Extension)
- Alternative 2 (Reinforced Concrete Lining)
- Alternative 3 (Sheet Pile)
- Alternative 4 (Grade Control Structures)

4.2 Alternative 1 (Grouted Riprap Toedown Extension)

Alternative 1 consists of the construction of 3-foot-thick grouted riprap toe protection on the riverside of the levee that would extend from the toedown of the existing riprap protection down to the potential scour limit (Figure 4.1). This toe protection would also include 2.5 feet of overlap with the existing protection at the top of the extension. It would require excavation to the potential scour limit and backfilling of the existing grade along the toe of VR-1. An 8-foot-wide bench would be provided at the bottom of the excavation for construction access.

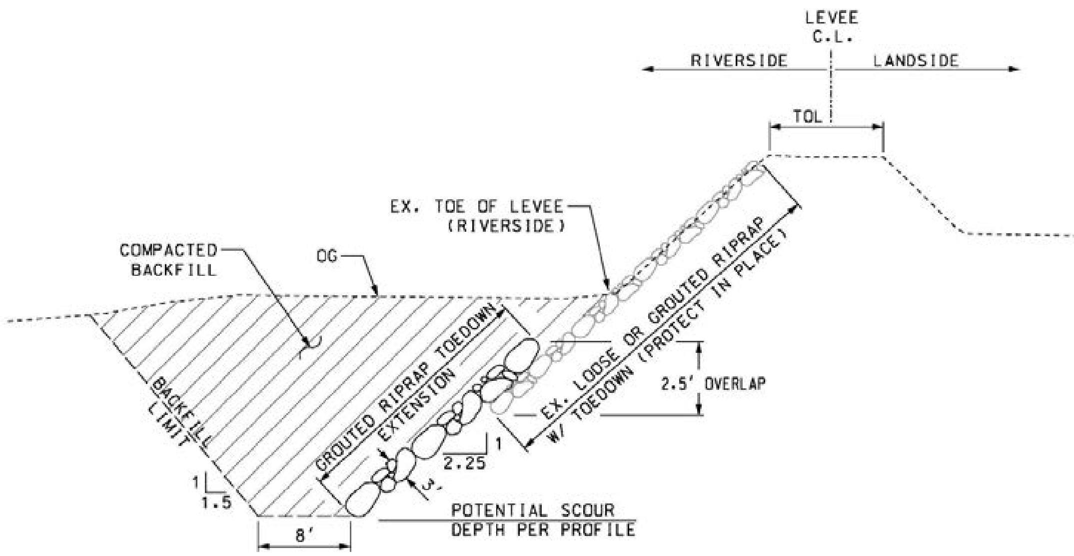


Figure 4.1 – Typical Section (Alternative 1)

4.2.1 Riprap Sizing

Based on the CHANLPRO computer program developed by the Corps (USACE 1998), the required "ungrouted" riprap stone size and its placement thickness for the levee protection were evaluated for the hydraulic conditions of the Ventura River (Table 4.1). The outputs of the CHANLPRO computer program are included in Appendix

Table 4.1– Computed Maximum Riprap Size and Thickness

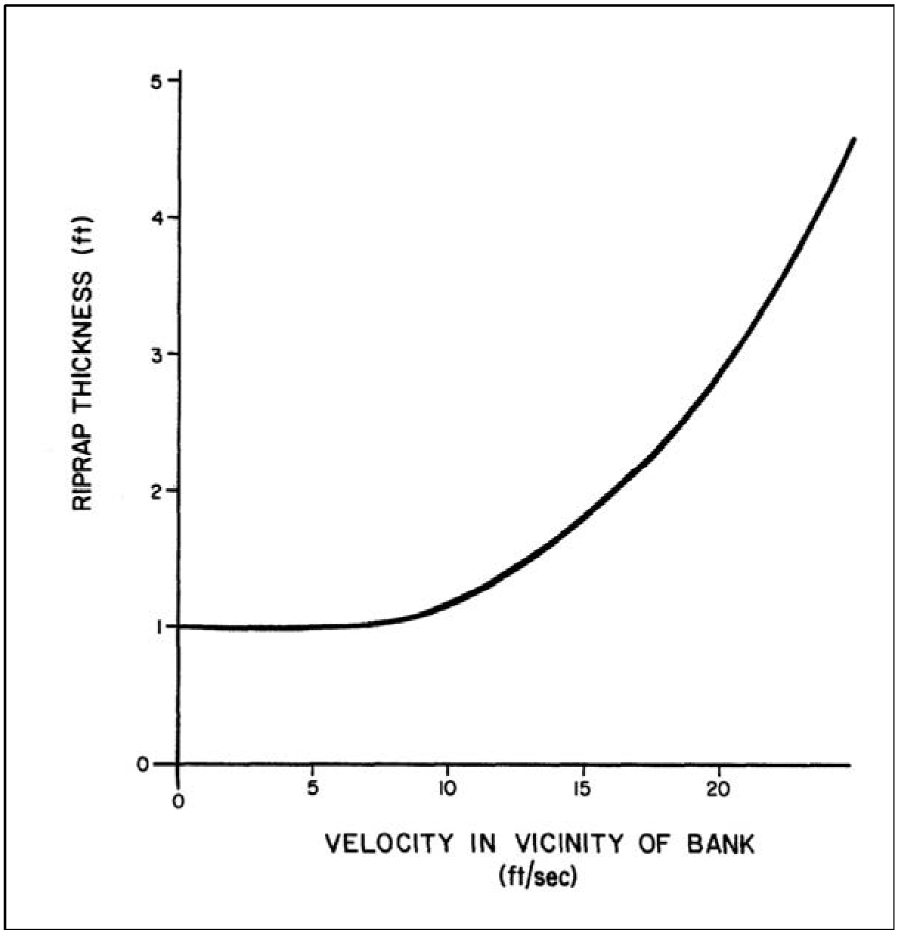
Reach No. [1]	Levee Station	Max. Flow Depth (feet)	Max. Flow Velocity (feet/second)	Maximum Size/Thickness (inches)	
				Straight Reach	Bend Reach [2]
1	0+44 to 27+33	12.77	11.33	21/21	NA[3]
2	28+70 to 41+35	14.46	13.21	27/27	33/33
3	46+36 to 96+36	17.91	18.85	54/78	NA
4	101+57 to 130+21	12.42	19.18	NA	NA

1. Reach number corresponds to the segment number in Table 3.2, which represents a river reach with hydraulically similar characteristics.
2. A center line bend radius of 1,200 feet was assumed.

NA = no stable gradation available

No stable gradation of ungrouted riprap was found by the CHANLPRO computer program for the straight reach condition of Reach 4 and for the bend reach conditions of Reaches 1, 3, and 4 (Table 4.1). Considering that the new protection would be required upstream of Levee Station 56+00 and in view of the impracticality of placing a 78-inch-thick protection (Reach 3, straight reach condition), ungrouted, or loose, riprap was not selected for the riprap toedown extension material.

"Grouted" riprap material was also considered and analyzed. The relationship between the flow velocity and the required grouted riprap thickness is shown in Figure 4.2. The grouted riprap thickness would be approximately 33 inches for the maximum flow velocities of Reaches 3 and 4 (18.85 and 19.18 feet per second, respectively). For the design purpose, the grouted riprap placement thickness of 36 inches, or 3 feet, was selected for this study.



Source: FHWA 1989, Figure 57.

Figure 4.2 – Required Grouted Riprap Thickness as a Function of Flow Velocity

4.3 Alternative 2 (Reinforced Concrete Lining)

Alternative 2 consists of the construction of a 10-inch-thick reinforced-concrete lining toe protection on the riverside of the levee that would extend from the toedown of the existing riprap protection down to the potential scour limit (Figure 4.3). This toe protection would also include 2.5 feet of overlap with the existing protection at the top of the extension. It would require excavation to the potential scour limit at a slope of 1.5(H):1(V) and backfilling of the existing grade along the toe of VR-1. Because reinforced concrete can be placed on a steeper slope than riprap placement, the new concrete lining below the bottom of the existing protection would be constructed in slope of 1.5(H):1(V). This steeper slope would minimize disturbance of the existing floodplain because the backfill limit would be closer to the levee toe. An 8-foot-wide bench would be provided at the bottom of the excavation for construction access.

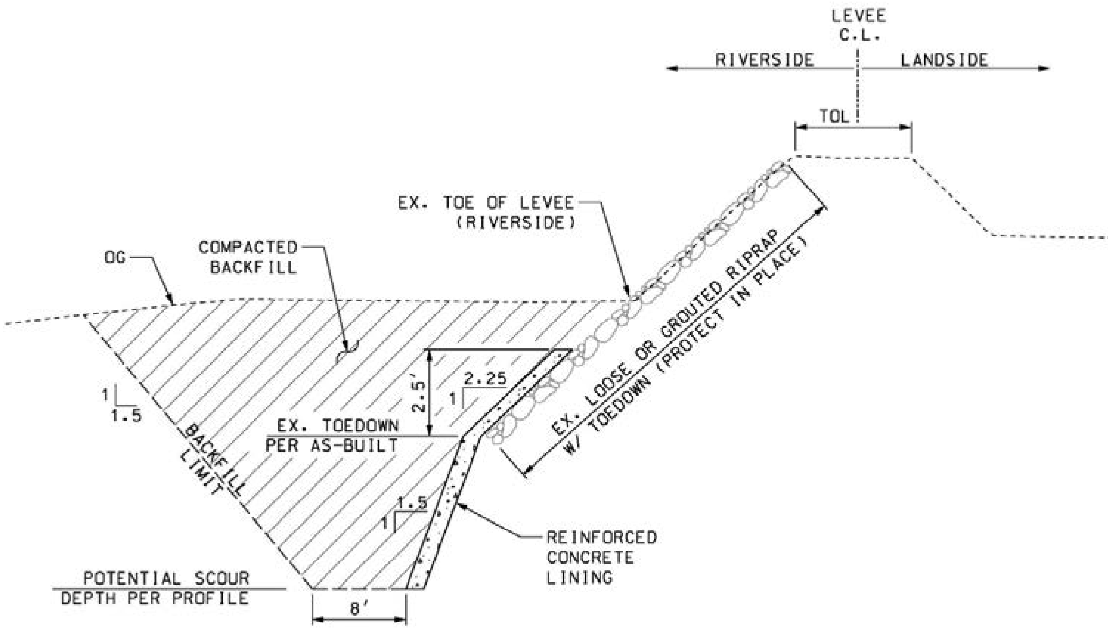


Figure 4.3 – Typical Section (Alternative 2)

4.4 Alternative 3 (Sheet Pile)

Alternative 3 consists of the installation of sheet piles along the riverside levee toe and in front of the existing protection (Figure 4.4). The sheet piles would begin 2.5 feet above the existing toedown elevation and extend beyond the potential scour limit. The total height of each sheet pile would be estimated using approximately three times the height of the earth it needs to retain, or three times the height of the potentially exposed levee toe between the existing toedown elevation and the scour limit. The triangular space between the sheet pile and the existing protection would be filled with loose riprap to prevent eddy current from forming in the area when the area is exposed to the flow during channel scour. This toe protection would also require excavation to the existing toedown elevation and backfilling of the existing grade along the toe of VR-1. Because sheet piles are driven into the ground from above, excavation down to the potential scour depth would be unnecessary. Less excavation would minimize disturbance of the existing floodplain because the backfill limit would be closer to the levee toe. An 8-foot-wide bench would be provided at the bottom of excavation for construction access.

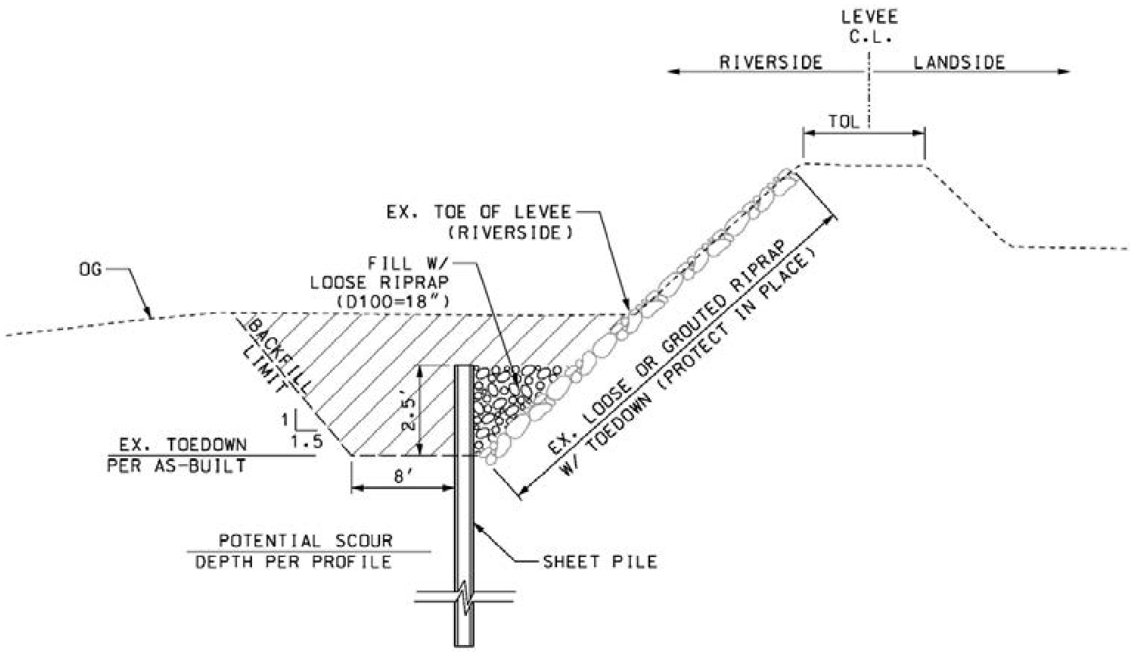


Figure 4.4 – Typical Section (Alternative 3)

4.5 Alternative 4 (Grade Control Structures)

Alternative 4 includes the construction of a series of grade control structures along the river streambed, with each structure extending from one river bank to the other. For this study, grouted riprap was considered as a material for the grade control structure to withstand the erosive force of the river during the design flood. However the suitability of different material such as soil cement or reinforced concrete should be further evaluated in the construction design phase to select the most effective and economical design material for this alternative.

A typical section of the grade control structure is shown in Figure 4.5. Toedown elevations of the grade control structure were evaluated both upstream and downstream of the structure. Because the toedown needs to account for the plunging effect of river flow as it passes over the 3-foot drop of the structure, the toedown elevations are lower than the potential scour limits considered for the other alternatives, which would be constructed along the levee toe. The structure would require a low-flow notch in approximately the same location as the existing low flow, but away from the toes of both river banks to avoid the impingement of low flow on the levee. An 8-foot-wide bench would be provided at the bottom of excavation for construction access.

Alternative 4 also includes the construction of levee toe protection where the grade control structure meets the existing embankment. The toedown protection would consist of the same type of grouted riprap toedown extension as that used for Alternative 1. However, because this toe protection is not designed for a long-term channel degradation of the river but for local scour of the river due to the grade control structures during the flood event, the toedown elevations of this toe protection should be the same as the toedown elevations of the structure. The limits of the new toe protections would be determined by the expected distances of the local scour effects caused by the grade control structures (Figure 4.5).

The total area of disturbances resulting from this alternative is estimated to be less than the disturbance areas resulting from the other alternatives. However, because the grade control structures would be constructed across the river floodplain, the magnitude of adverse impacts on the existing environment may be greater than that associated with the other alternatives.

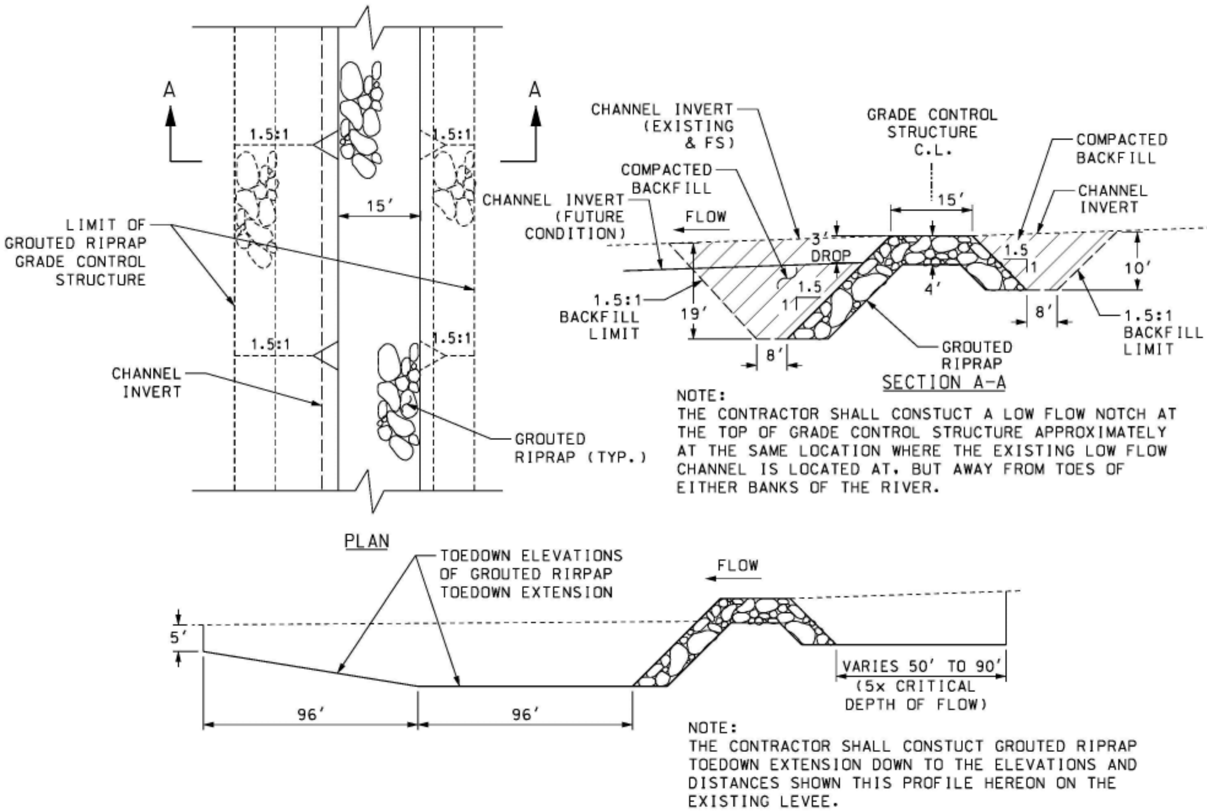


Figure 4.5 – Typical Section (Alternative 4)

4.5.1 Toedown Extensions

A grade control structure has toedown extensions both upstream and downstream of the structure. While both extensions provide protection of the structure against loss of soil by high-velocity flows, the design of the downstream extension is essential to the life of the structure because the plunging flow would create a deeper hole downstream. This scouring of the channel bottom immediately downstream of the structure is usually independent of the bank scour estimated in Section 3.2.3.

The depth of the downstream toedown extension is calculated by the following equation:

$$Z_s = 0.581(\mathrm{q})^{0.667}\left(\frac{h}{Y}\right)^{\mathrm{a}}\left(1-\frac{h}{\mathrm{Y}}\right)^{-0.118} \qquad \text{(Equation 4.1)}$$

where:

Z_s = depth of local scour due to submerged drop, in feet, measured below the streambed face downstream of the drop
q = discharge per unit width of the channel bottom, in cfs/foot
h = drop height, in feet
Y = downstream depth of flow, in feet/foot

Based on Equation 4.1, the depth of local scour, or the minimum depth of the downstream toedown extension, was calculated (Table 4.2). For this feasibility-level design, the toedown depth of 16', which is measured from 'future' channel invert elevation, was used for all grade control structures.

Table 4.2 – Minimum Depth of Downstream Toedown Extension of Grade Control Structure

Levee Station	q (cfs/foot)	Y (feet)	h (feet)	Z_S (feet)
77+00	388.52	17.58	3	15.3
94+00	342.24	15.50	3	14.9
108+50	293.34	19.21	3	12.2
113+50	291.92	15.34	3	13.4
122+75	245.54	12.93	3	12.9

4.6 Use of Soil Cement as Toe Protection Material

Although not selected as one of the four design alternatives, use of soil cement as levee toe protection material was analyzed. Soil cement production usually involves blending on-site material with cement material until the required material strength is achieved. If the available on-site material does not meet the gradation requirements, new soil material that meets the requirements should be imported to the project site, which would significantly increase the construction cost relative to the cost of using on-site material.

Based on a review of the test pit logs and the results of the gradation sieve analyses presented on the as-built plans (USACE 1963), the upper alluvial sediments within the Ventura River floodplain are composed predominantly of coarse gravel and sands containing numerous cobbles and boulders. The gradation analyses of these sediments indicated that approximately 60 to 80 percent of the test pit materials were retained on the No. 4 sieve, with maximum particle sizes of 18 to 36 inches. These materials also had fines contents (passing No. 200 sieve) of less than 5 percent. In a few of the test pits, fairly thin layers of clayey silt and silty clay were encountered, but they did not appear to be continuous throughout the area.

For the soil component of soil cement used in levees, the Corps recommends a maximum particle size of 2 inches, no more than 45 percent retained on a No. 4 sieve, and a percentage of material that passes through a No. 200 sieve ranging from 5 to 35 percent (Engineer Manual 1110-2-1913 [USACE 2000]). When gradation curves generated from the test pit logs, included in the as-built plans, were overlaid on a grain size distribution graph (Appendix E), a comparison of these requirements to the test pits log curves indicates that most of the available borrow material within the river floodplain would not be suitable for use in soil cement production in its existing condition. In order to meet the Corps' criteria, the material should be either imported from off-site borrow sites or extensively screened (likely resulting in 30 to 40 percent loss of usable material) and blended with finer material (either imported or derived from localized deposits of silt and clays encountered in a few of the test pits). This level of screening and blending would require a large-scale processing facility, likely along the floodplain of the Ventura River, and may not be cost-effective or environmentally desirable.

4.7 Increase in Elevations of Existing Top of Levee

In the areas of VR-1 where the available freeboard under the existing conditions does not meet the FEMA freeboard requirement, the existing top of levee elevations should be raised accordingly. Based on the hydraulic analysis (Section 3.2.2), the existing top of levee embankment elevations along the 550-foot-long segment of VR-1 upstream of the SPRR bridge (Station 21+22.5) do not meet the FEMA freeboard requirements. A levee segment along an approximately 300-foot-long reach of the Cañada de San Joaquin upstream of the confluence also lacks sufficient freeboard. In these areas with conditions of insufficient freeboard, the existing top of levee should be raise to the proposed elevations in Table 3.6.

For the segment upstream of the SPRR bridge, the existing concrete curb/wall, constructed along the top of levee embankment, neither provides the required additional freeboard nor appears to be constructed per the Corps' design criteria. The lack of freeboard in this area is likely due to a constriction of flow caused by the modification to the SPRR bridge and the subsequent increase in water-surface elevations relative to the as-built conditions. A new reinforced-concrete floodwall should not only structurally replace the existing structure with the Corps-compliance structure but also be designed with increased height.

For the segment along the Cañada de San Joaquin, a reinforced concrete floodwall or structural fill as appropriate should be added to the top of the existing levee for additional heights of 1.51 to 2.09 feet to meet the freeboard requirements. Additionally the existing stop-log structure should be removed and replaced with a new stop-log structure to facilitate the additional height.

4.8 Remediation for Levee Deficiencies

In addition to remediation of the long-term effects of channel degradation on VR-1, the levee deficiencies identified during the Periodic Inspection should also be remediated during the implementation of the selected alternative. These deficiencies, which are organized into 16 groups (Table 4.3), need to be repaired or remediated for compliance with the Corps' regulations and design criteria and the FEMA certification guidelines. It should be noted that many of the repairs listed in Table 4.3 can be made as part of the VCWPD's routine maintenance activities and do not necessarily have to be implemented in conjunction with any of the design alternatives. These deficiencies and general directions for repairs are shown on the alternatives plans (Appendix D).

Table 4.3 – Levee Deficiencies Identified during Periodic Inspection

No.	Deficiency	Recommended Action
1	Unpermitted Encroachments: Metal storages, concrete k-rail, private retaining walls along landside levee toe	Remove unpermitted encroachment
2	Sediment deposition along riverside levee toe sometimes covering riprap protection	Remove sediment deposition
3	Existing vegetation within the Corps' no vegetation zone	Remove vegetation within 15' from riverside and landside toes
4	Displaced riprap	Restore displaced riprap placement
5	Existing structure not designed per the Corps' design criteria. New floodwall needs to be higher than the height of the existing structure.	Remove ex. concrete curb and construct new reinforced concrete floodwall
6	Unmaintained existing concrete structures	Repair deteriorating surfaces or joints of concrete structures
7	Animal burrows	Remove animal burrows by applying compacted fill
8	Surficial erosion on top or side slopes of levee	Repair levee embankment erosion
9	Unmaintained existing storm drain systems	Restore existing storm drain system by removing sediment, repairing gate assembly, and grading adjacent areas for positive drainage
10	Existing incised channel may impinge on existing levee toe	Fill in incised channel near riverside toe of levee
11	Maintenance ramps with steep sideslopes	Regrade sideslopes of maintenance ramps to be flatter than 2:1 and place riprap
12	Reinforced concrete floodwalls with inadequate freeboard	Construct new reinforced concrete floodwall
13	New stop-log structure needed to accommodate new floodwalls on top of levee	Replace existing 20'stop-log structure with new to meet higher TOL
14	Scour along levee embankment toe	Repair levee embankment to the as-built conditions
15	General maintenance of structures needed	Perform general maintenance of structure to ensure operable conditions
16	Unpermitted features on the levee	Prepare application for permit for unpermitted features on the levee and coordinate with USACE for review and approval

4.8.1 Removal of Unpermitted Encroachment

Some of the unpermitted encroachments such as k-rails or metal storages can simply be moved off site or moved to another location. However, removal or relocation of some encroachments such as the roadway embankment for Highway 33 is impractical and may require further study and analysis to determine whether the encroachment can be approved and permitted by the Corps.

4.8.2 Floodwalls

There are two segments of existing floodwalls just upstream of the SPRR bridge: a lower segment (Levee Station 21+22.5 to 26+90) and a upper segment (Levee Station 27+30 to 37+60). The lower segment of floodwall neither provides adequate freeboard nor appears to be constructed per the Corps' design criteria. This segment of floodwall in its entirety should be replaced with a new reinforced-concrete structure that has higher top of wall elevations, as described in Section 4.7.

The upper segment appears in good condition and provides adequate freeboard although it may need minor general maintenance. It is unclear who owns and maintains this floodwall and there is no as-built plan available for this structure, which is a FEMA levee certification requirement. The VCWPD will need to prepare as-built plans and take over ownership and maintenance of this floodwall to ensure FEMA levee certification. For this feasibility-level study, it was assumed that this upstream segment of floodwall would not be replaced and protected in place, for cost estimating purposes.

4.8.3 Stop-Log Structure

The existing stop-log structure does not provide adequate freeboard and has questionable seepage measures to meet the Corps' design criteria. The stop-log structure including the base, side retaining walls, and aluminum stop-logs should be replaced with a new facility with a height to match the floodwall elevations, as described in Section 4.7.

4.8.4 Permits for Existing Levee Features

The Periodic Inspection performed by Fugro West found that many of the existing features on the levee, including, but not limited to, storm drain penetrations, roadway signs, fence, and utilities, neither are shown on the as-built plans nor appear to have been permitted by proper agencies (Fugro 2011). As recommended in the periodic inspection report, these features should be reviewed by the Corps and approved before the levee certification process. Existing features that cannot be permitted or approved should be removed and disposed of off site.

4.9 Geotechnical Design Considerations

No geotechnical boring or analysis was performed for this study. The future planning and construction-phase design would require geotechnical analysis of the stability, settlement, seismic conditions, seepage control, and foundation and embankment fill of VR-1 to finalize the design details of the preferred conceptual design alternative resulting from this study and further evaluate whether the levee is experiencing other design deficiencies that were not found during the periodic inspection.

4.10 Environmental Considerations

No environmental analysis was performed for this study. The future planning phase would require an environmental analysis of the design alternatives to finalize the design details of the preferred conceptual design alternative resulting from this study and further evaluate environmental restoration and mitigation costs.

4.11 Economic Considerations

No economic analysis was performed for this study. The future planning phase would require an economic analysis of the benefits and costs of the preferred conceptual design alternative resulting from this study to establish a federal interest.

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5. COST ESTIMATES

For each alternative, a "rough order-of-magnitude" cost estimate was developed for comparison purposes only and should not be used for budgetary purposes. A detailed engineer's estimate for construction cost would need to be prepared on the basis of the construction-level design in the future. These cost estimates, which are based on the typical sections shown in Section 4, assume uniform subsurface conditions throughout the project limits, a uniform application of the typical section for the project, with only minor adjustments for different reaches. The subsurface conditions used for this study are based on test pit logs provided in the as-built plans, and an updated geotechnical exploration may alter the quantities shown in the cost estimates. Restoration and mitigation costs for any environmentally sensitive areas within floodplain of the Ventura River that are disturbed by the construction activities are not included in the cost estimates, because an estimation of this particular cost would involve input from environmental agencies and consultation with a biologist which are not part of this study. Additionally, any fees or permits required for construction or maintenance activities and real estate requirements for each alternative are not included.

Detailed information on the quantity calculations is provided in Appendix F.

5.1 Alternative 1 (Grouted Riprap Toedown Extension)

The estimated construction cost of Alternative 1 is $25,593,400.

Table 5.1 – Cost Estimate for Alternative 1 (Grouted Riprap Toedown Extension)

	Contract Items	Unit	Quantity	Unit Cost	Total Cost
1	Mobilization	LS	1	$760,000.00	$760,000
2	Clearing and Grubbing	Acre	22.86	$4,000.00	$91,440
3	Riprap Protection w/Toedown (Sta. 56+00 to 133+00)	LF	7,700	$1,808.73	$13,927,240
3.1	*Grouted Riprap*	*CY*	*30,216*	*$135.00*	*$4,079,160*
3.2	*Excavation*	*CY*	*630,613*	*$8.00*	*$5,044,904*
3.3	*Compacted Backfill*	*CY*	*600,397*	*$ 8.00*	*$4,803,176*
4	Removal of Unpermitted Encroachment	LS	1	$20,000.00	$20,000
5	Sediment Removal	SY	4,600	$3.00	$13,800
6	Vegetation Removal	LS	1	$200,000.00	$200,000
7	Restoration of Displaced Existing Riprap	CY	1,570	$80.00	$125,600
8	Floodwall – Ventura River (Including Removal of Existing Concrete Curb)	LF	561.5	$520.00	$291,980
9	Floodwall – Cañada de San Joaquin	LF	285.0	$480.00	$136,800
10	Restoration of Existing Storm Drain System	LS	1	$39,000.00	$39,000
11	Animal Burrow Removal	LS	1	$10,000.00	$10,000
12	Levee Embankment Surface Erosion Repair	SY	270	$7.50	$2,025

	Table 5.1 – Cost Estimate for Alternative 1 (Grouted Riprap Toedown Extension)				
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
13	Removal of Incised Channel near Riverside Toe	LF	850	$30.00	$25,500
14	Regrading of Existing Access Ramps	EA	3	$5,000.00	$15,000
15	Stop-log Structure Replacement	EA	1	$75,000.00	$75,000
16	Repair of Levee Embankment to As-Built Condition (Including Removal of Private Retaining Wall)	LF	310	$ 140.00	$43,400
17	Permit Application for Unpermitted Existing Features	LS	1	$100,000.00	$100,000
				Subtotal:	$15,876,785
				Planning, Engineering, &Design (@ 12%)	$1,905,214
				Construction Management (@ 12%)	$1,905,214
				Subtotal:	$19,687,213
				Contingencies (@ 30%)	$5,906,164
				Subtotal	$25,593,377
				Grand Total:	**$25,593,400**

5.2 Alternative 2 (Reinforced-Concrete Lining)

The estimated construction cost of Alternative 2 is approximately $25,131,600.

	Table 5.2 – Cost Estimate for Alternative 2 (Reinforced-Concrete Lining)				
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
1	Mobilization	LS	1	$740,000.00	$740,000
2	Clearing and Grubbing	Acre	20.25	$4,000.00	$81,000
3.1	Concrete Lining (Sta. 56+00 to 133+00)	LF	7,700	$1,775.48	$13,671,224
3.1.1	*Reinforced-Concrete Lining*	*CY*	*8,031*	*$800.00*	*$6,424,800*
3.1.2	*Excavation*	*CY*	*456,917*	*$8.00*	*$3,655,336*
3.1.3	*Compacted Backfill*	*CY*	*448,886*	*$8.00*	*$3,591,088*
4	Removal of Unpermitted Encroachment	LS	1	$20,000.00	$20,000
5	Sediment Removal	SY	4,600	$3.00	$13,800
6	Vegetation Removal	LS	1	$200,000.00	$200,000
7	Restoration of Displaced Existing Riprap	CY	1,570	$80.00	$125,600
8	Floodwall – Ventura River (Including Removal of Existing Concrete Curb)	LF	561.5	$520.00	$291,980
9	Floodwall – Cañada de San Joaquin	LF	285.0	$480.00	$136,800

Table 5.2 – Cost Estimate for Alternative 2 (Reinforced-Concrete Lining)					
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
10	Restoration of Existing Storm Drain System	LS	1	$39,000.00	$39,000
11	Animal Burrow Removal	LS	1	$10,000.00	$10,000
12	Levee Embankment Surface Erosion Repair	SY	270	$7.50	$2,025
13	Removal of Incised Channel near Riverside Toe	LF	850	$30.00	$25,500
14	Regrading of Existing Access Ramps	EA	3	$5,000.00	$15,000
15	Stop-Log Structure Replacement	EA	1	$75,000.00	$75,000
16	Repair of Levee Embankment to As-Built Condition (Including Removal of Private Retaining Wall)	LF	310	$140.00	$43,400
17	Permit Application for Unpermitted Existing Features	LS	1	$100,000.00	$100,000
				Subtotal:	$15,590,329
				Planning, Engineering, &Design (@ 12%)	$1,870,840
				Construction Management (@ 12%)	$1,870,840
				Subtotal:	$19,332,008
				Contingencies (@ 30%)	$5,799,602
				Subtotal:	$25,131,611
				Grand Total:	**$25,131,600**

5.3 Alternative 3 (Sheet Pile)

The estimated construction cost of Alternative 3 is $34,942,500.

Table 5.3 – Cost Estimate for Alternative 3 (Sheet Pile)					
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
1	Mobilization	LS	1	$1,230,000.00	$1,230,000
2	Clearing and Grubbing	Acre	12.55	$4,000.00	$50,200
3	Sheet Pile (Sta. 11+00 to 133+00)	LF	7,700	$2,532.23	$19,498,206
3.1	*Sheet Pile*	*SF*	*350,250*	*$45.00*	*$15,761,250*
3.2	*Loose Riprap*	*CY*	*1,996*	*$80.00*	*$159,704*
3.3	*Excavation*	*CY*	*224,576*	*$8.00*	*$1,796,611*
3.4	*Compacted Backfill*	*CY*	*222,580*	*$8.00*	*$1,780,641*
4	Removal of Unpermitted Encroachment	LS	1	$20,000.00	$20,000
5	Sediment Removal	SY	4,600	$3.00	$13,800

Table 5.3 – Cost Estimate for Alternative 3 (Sheet Pile)					
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
6	Vegetation Removal	LS	1	$200,000.00	$200,000
7	Restoration of Displaced Existing Riprap	CY	1,570	$80.00	$125,600
8	Floodwall – Ventura River (Including Removal of Existing Concrete Curb)	LF	561.5	$520.00	$291,980
9	Floodwall – Cañada de San Joaquin	LF	285.0	$480.00	$136,800
10	Restoration of Existing Storm Drain System	LS	1	$39,000.00	$39,000
11	Animal Burrow Removal	LS	1	$10,000.00	$10,000
12	Levee Embankment Surface Erosion Repair	SY	270	$7.50	$2,025
13	Removal of Incised Channel near Riverside Toe	LF	850	$30.00	$25,500
14	Regrading of Existing Access Ramps	EA	3	$5,000.00	$15,000
15	Stop-Log Structure Replacement	EA	1	$75,000.00	$75,000
16	Repair of Levee Embankment to As-Built Condition (Including Removal of Private Retaining Wall)	LF	310	$140.00	$43,400
17	Permit Application for Unpermitted Existing Features	LS	1	$100,000.00	$100,000
				Subtotal:	$21,676,511
				Planning, Engineering, &Design (@ 12%)	$2,601,181
				Construction Management (@ 12%)	$2,601,181
				Subtotal:	$34,942,535
				Contingencies (@ 30%)	$8,063,662
				Subtotal:	$34,942,535
				Grand Total:	**$34,942,500**

5.4 Alternative 4 (Grade Control Structures)

The estimated construction cost of Alternative 4 is $26,599,800.

Table 5.4 – Cost Estimate for Alternative 4 (Grade Control Structures)					
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
1	Mobilization	LS	1	$790,000.00	$ 790,000
2	Clearing and Grubbing	Acre	14.69	$4,000.00	$58,760
3.1	Grade Control Structures – Structure	EA	5	$1,668,480.20	$8,342,401
3.1.1	*Grouted Riprap*	*CY*	*40,543*	*$135.00*	*$5,473,305*
3.1.2	*Excavation*	*CY*	*199,590*	*$8.00*	*$1,596,720*
3.1.3	*Compacted Backfill*	*CY*	*159,047*	*$8.00*	*$1,272,376*

Table 5.4 – Cost Estimate for Alternative 4 (Grade Control Structures)					
	Contract Items	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
3.2	Grade Control Structures – Embankment Slope Protection	EA	5	$1,242,376.00	$6,211,880
3.2.1	*Grouted Riprap*	*CY*	*6,097*	*$135.00*	*$823,095*
3.2.2	*Excavation*	*CY*	*123,138*	*$20.00*	*$2,462,760*
3.2.3	*Compacted Backfill*	*CY*	*117,041*	*$25.00*	*$2,926,025*
4	Removal of Unpermitted Encroachment	LS	1	$20,000.00	$20,000
5	Sediment Removal	SY	4,600	$3.00	$13,800
6	Vegetation Removal	LS	1	$200,000.00	$200,000
7	Restoration of Displaced Existing Riprap	CY	1,570	$80.00	$125,600
8	Floodwall – Ventura River (Including Removal of Existing Concrete Curb)	LF	561.5	$520.00	$291,980
9	Floodwall – Cañada de San Joaquin	LF	285.0	$480.00	$136,800
10	Restoration of Existing Storm Drain System	LS	1	$39,000.00	$39,000
11	Animal Burrow Removal	LS	1	$10,000.00	$10,000
12	Levee Embankment Surface Erosion Repair	SY	270	$7.50	$2,025
13	Removal of Incised Channel near Riverside Toe	LF	850	$30.00	$25,500
14	Regrading of Existing Access Ramps	EA	3	$5,000.00	$15,000
15	Stop-Log Structure Replacement	EA	1	$75,000.00	$75,000
16	Repair of Levee Embankment to As-Built Condition (Including Removal of Private Retaining Wall)	LF	310	$140.00	$43,400
17	Permit Application for Unpermitted Existing Features	LS	1	$100,000.00	$100,000
				Subtotal:	$16,501,146
				Planning, Engineering, &Design (@ 12%)	$1,980,138
				Construction Management (@ 12%)	$1,980,138
				Subtotal:	$20,461,421
				Contingencies (@ 30%)	$6,138,426
				Subtotal:	$26,599,847
				Grand Total:	**$26,599,800**

5.5 Summary of Construction Costs

The estimated total construction cost for each design alternative is provided in Table 5.5.

Table 5.5 – Estimated Construction Cost for Each Alternative

Alternative	Construction Cost
1	$25,593,400
2	$25,131,600
3	$34,942,500
4	$26,599,800

6. CONCLUSIONS AND RECOMMENDATION

In addition to the deficiencies identified during the previous field investigations, the hydraulic, scour, and risk and uncertainty analyses indicated that the VR-1 system would be subjected to channel scour during the 100-year flood event, which would adversely affect the integrity of existing levee structures if no remediation or improvement is provided to the levee. In order to protect against the potential scour depth of up to 21 feet below the 1947 thalweg, four design alternatives were evaluated.

All four design alternatives would also include the common remediation measures for addressing the design deficiencies that were identified during the field investigation, such as levee encroachments, surficial erosion, and needed rehabilitation of existing structures.

Based on a comparison of the construction cost and project effectiveness of each of the alternatives, Alternative 1 (Grouted Riprap Toedown Extension) is recommended as the preferred alternative to remediate and improve VR-1 for compliance with the FEMA levee certification requirements.

The construction cost for Alternative 2 (Concrete Lining) would be 2 percent less than that of Alternative 1. However, because riprap material is typically perceived by the regulatory agencies as more environmentally friendly than reinforced-concrete surfaces, the grouted riprap protection is recommended. Additionally, grouted riprap is the same material as the existing levee embankment protection.

Alternative 3 (Sheet Pile) would be the most expensive solution, costing 30 to 40 percent more than other alternatives.

Although Alternative 4 (Grade Control Structures) would be the least expensive of the four alternatives, the cost estimate for this study does not include the environmental mitigation that would likely be necessary. Compared to other three alternatives, which would be constructed in the vicinity of the levee, Alternative 4 would require construction activities such as excavation and backfill across the river streambed, likely disturbing environmentally sensitive and critical areas and habitats in the process. In addition, the design of the grade control structure may need to incorporate a fish passage feature in order to provide continuous and safe passage for existing species of fish.

It should be noted that this study was based on the assumption that Matilija Dam would remain in place. This assumption was a conservative approach to the design because the planned removal of the dam is likely to supply more sediment to the downstream reaches and may result in sediment deposition in some areas of the VR-1 reach, making the impacts of potential streambed scour on the levee foundation less severe.

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