GEOTECHNICAL ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

January 15, 2014

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January 15, 2014
Project No. 96670

Mr. Neal Conatser
Marin County Department of Public Works
3501 Civic Center Drive, Room 304
San Rafael, CA 94903

Subject: **Geotechnical Alternatives Analysis Report**
Las Gallinas Levee System
San Rafael, California

Dear Mr. Conatser:

Kleinfelder is pleased to present the attached geotechnical alternatives analysis report for the Las Gallinas Levee System (LGLS) for your review and comment.

The purpose of this report is to provide a preliminary assessment of potential improvement alternatives for the LGLS.

Kleinfelder appreciates the opportunity to work with you on this project. If you have any questions regarding the contents of this report or if we may be of further assistance, please contact the undersigned.

Respectfully submitted,

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this Geotechnical Alternatives Analysis (AA) Report is to present to the Marin County Flood Control and Water Conservation District (District) a screening level assessment of potential improvement alternatives for the Las Gallinas Levee System (LGLS). This report will include summarizing current knowledge of the project, providing requirements for Federal Emergency Management Agency (FEMA) accreditation and assisting in evaluating possible federal interest to aid in developing a federal improvement project.

Based on the results of our geotechnical investigation (Kleinfelder 2013), we have concluded the existing levee does not meet minimum criteria set forth by the United States Army Corps of Engineers (USACE) for seepage and slope stability. These criteria were established based on guidance from the following documents, and are referred to as 'USACE standards' throughout this report:

- EM 1110-2-1913 Design and Construction of Levees
- EM 1110-2-1619 Risk-Based Analysis for Flood Damage Reduction Studies
- ETL 1110-2-547 Introduction to Probability and Reliability Methods for Use in Geotechnical Engineering
- ETL1110-2-556 Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies
- ETL 1110-2-561 Reliability Analysis and Risk Assessment for Seepage and Slope Stability Failure Modes for Embankment Dams
- EC 1110-2-6067 USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation

The entire levee system as evaluated does not provide sufficient freeboard height for the minimum design water surface elevation (WSE) (see Section 3.4 for further discussion of minimum design WSE under the Year 0 condition). To address levee height deficiencies, proposed improvement alternatives include sheetpile floodwalls, concrete floodwalls, reconstructed levee, raising existing levee, and modifications to the existing redwood box that was installed to provide additional freeboard following flooding in 1982 and 1983. The levels of protection that each of these alternatives provides and the ability of these alternatives to be used to obtain FEMA accreditation under a 100-year flood event are provided in this report. Should federal participation be pursued, ongoing interaction with USACE will be required to refine alternatives and determine the level of federal interest in developing formal designs and constructing a project.

1.2 PROJECT LOCATION AND DESCRIPTION

The LGLS, as defined for the purposes of this study, includes levees along the southern and eastern bank of the south fork of Las Gallinas Creek. LGLS partially surrounds the community of Santa Venetia located north and east of the city of San Rafael in eastern Marin County, California. A site vicinity map is shown on Plate 1-1. A copy of the FEMA flood zone map for Santa Venetia is shown on Plate 1-2.

1.2.1 Location and alignment of Reach 1 / Reach 2

As shown on Plate 1-1, stationing begins with Station 0+00 at the eastern end of the levee system near E. Vendola Drive near Pump Station #4 and increases westward to Station 32+00 near Pump Station #5 at the northeastern end of Vendola Drive. The levee then extends to the southwest along Las Gallinas Creek to Station 108+00 at the southwestern end of Vendola Drive.

LGLS is divided into two reaches for purposes of the geotechnical evaluation described in our 2013 geotechnical investigation report (Kleinfelder, 2013). The stationing limits for LGLS Reaches 1 and 2 are summarized in Table 1.1.

Table 1.1 – Summary of LGLS Reaches

Reach	Station
1	Station 0+00 to Station 32+00
2	Station 32+00 to Station 108+00

The Santa Venetia Marsh Preserve pathway traverses the levee crown over the length of the levee in Reach 1. In Reach 2, the levee extends along the outside edge of existing residences' backyards along Vendola Drive. To increase the level of flood protection, a redwood box floodwall structure was constructed along the top of the majority of the existing levee within Reach 2. The redwood boxes are about 2.5 to 3.2 feet wide, measured perpendicular to levee crest, and rise about 1 to 2 feet above the earthen levee crown.

Per USACE criteria, the levees in Reach 1 are classified as coastal levees, and the levees in Reach 2 are classified as riverine levees. Details regarding this classification and associated wave run-up calculations and freeboard requirements are discussed in Kleinfelder's 2013 geotechnical report (Kleinfelder 2013.)

1.3 PREVIOUS STUDIES AND REPORTS USED FOR THIS REPORT

Kleinfelder has completed previous studies and analyses of LGLS and has reviewed the following documents:

- J. Warren Nute, Civil and Sanitary Engineers (J Warren Nute 1971), "Marin County Flood Control and Water Conservation District – Zone 7, Marin County, California, Long Range Plan for Drainage and Flood Control," May 24, 1971.
- Kleinfelder, Inc. (Kleinfelder 2013), "Geotechnical Data Report, Las Gallinas Levee System, San Rafael, California," July 3, 2013.
- Miller Pacific Engineering Group (Miller Pacific 2009), "Geotechnical Investigation, Marin County Flood Control, Zone 7 Pump Station #2, Vendola Drive, San Rafael, California," June 23, 2009.
- Wood Rodgers (Wood Rodgers 2013), "County of Marin, Las Gallinas Levee, Evaluation Study, Santa Venetia, CA, Marin County – Proposed Interim Design Water Surface and Top of Levee Elevation Based Upon Previous Hydraulic Studies," June 3, 2013.
- Kleinfelder, Inc. (Kleinfelder 2006a), "Geotechnical Investigation, Pump Plant No. 1, San Rafael, Marin County, California," February 1, 2006.
- US Army Corps of Engineers (1990), Fluvial and Tidal Flooding Analysis, Section 205, Reconnaissance Study, Las Gallinas Creek, Marin County, California, August 10, 1990.

- US Army Corps of Engineers (2006), "Site Observations to Las Gallinas Levee System, Las Gallinas Flood Control Project, Novato, Marin County, California," prepared by Christopher Wang and Eskender Said, January 2006.
- US Army Corps of Engineers, San Francisco District (USACE-SPN), 2012. Las Gallinas Creek H&H and Coastal Analysis. Prepared by Noble Consultants, Inc. April 20, 2012.
- US Army Corps of Engineers, San Francisco District (USACE-SPN), 2013. Las Gallinas Creek, Downstream Boundary Condition Analysis, February, 2013.

2. CURRENT LEVEE SYSTEM

2.1 HISTORY OF LEVEE CONSTRUCTION

The LGLS was initially constructed by placing fill on tidal marshland. The original real estate developer who envisioned the Santa Venetia development, Mabry McMahon, took ownership of the Las Gallinas area in the early 1900's. In 1914, under Mr. McMahon's supervision, the community was originally developed by placement of six to eight feet of fill and construction of three miles of canals and six miles of levees faced with concrete walls. Due to economic difficulties, McMahon's envisioned development was not completed at that time, and the property was ultimately turned over to other developers in 1939. Additional fill was placed in the 1950s as part of the Santa Venetia residential development, and the final phase of residential development and associated filling was completed by 1970 (J. Warren Nute, 1971.)

The development, containing approximately 800 residences, was protected along its northern, western, and eastern boundaries by approximately two miles of earthen levee. The original levee boundary to the east of Santa Venetia is known as the outer Santa Venetia marsh levee. The easternmost area of originally proposed development was not ultimately developed, and in the late 1970's or early 1980's the inner Santa Venetia Marsh levee was constructed in conjunction with creation of the Santa Venetia Marsh Preserve. As part of this project, the outer Santa Venetia Marsh levee was breached and the inner levee became the eastern boundary of the LGLS. Following high water events in1982 and 1983 resulting from historic high tides (El. 6.03, NGVD 1929 datum), local overtopping of the Reach 2 levee occurred and a timber reinforced berm, i.e. redwood box, was constructed in Reach 2 to raise the levee height to provide protection from future high water events.

The levee under consideration begins at high ground at the original, pre-development shoreline adjacent to San Pablo Bay, extends northwest along the border of Santa Venetia marsh, then parallels the right bank of the South Fork of Las Gallinas Creek for about one mile, then extends southeast to the southern end of Santa Margarita Island. Other levees that continue to the southeast of Santa Margarita Island are not within Flood Control District Zone 7 and are, therefore, not considered within the scope of this report.

Based on the results of our subsurface investigation (Kleinfelder 2013), the levee lies on a foundation consisting of marsh deposits and a thick sequence (up to approximately 65 feet in depth) of soft, compressible bay sediments (locally referred to as Bay Mud), which has consolidated significantly since the levee's initial construction. The Marin County Flood Control and Water Conservation District (District) has monitored settlement points within the Santa Venetia area periodically since 1962 and have repaired failing sections of the redwood box wall to prolong the life of the facility. The results of the monitoring indicate that cumulative settlement of up to approximately two feet has occurred beneath the levees and the areas protected by the levees. The average rate of settlement in the 1960s and 1970s was approximately six inches every ten years. A slight decrease is evident in the settlement rate over time; the average rate of settlement from the period 1990 to 2012 is approximately three to five inches every ten years.

2.2 PAST PERFORMANCE

Periodic levee overtopping has occurred in the LGLS area since its construction in the early- to mid-1900s. Extensive flooding in the 1940s and 1950s led to the creation of Zone 7 of the District. Further flooding was recorded in 1969, 1982, and 1983. During the January 1982 event, 50 homes were flooded. In January 1983, 160 homes were flooded, and in December 1983, 100 homes were flooded (Wood Rodgers, 2013.)

In late 2008 the District distributed a survey to residents of the Santa Venetia area whose homes are situated along the levee. The survey included questions regarding observed seepage and settlement, existing drainage improvements at the residents' properties, burrowing animals, vegetation, and sedimentation along the Las Gallinas Creek channel. The results of the survey were presented in our 2013 geotechnical investigation report. No overtopping has been reported since 1983, though many homeowners report drainage, ponding, and possible seepage through the levee in their backyards.

2.3 PAST MAINTENANCE AND IMPROVEMENTS

Previous mitigation measures implemented along Reaches 1 and 2 after flooding events have included the following:

- Increase in levee height by placing fill on top of existing levee along Reach 1 (1983).
- Increase in levee height by the construction of redwood box along top of existing levee along Reach 2 as a temporary mitigation measure (1983). Further details about the redwood box are included in Section 2.3.1, below.
- Installation of drainage systems, sump pumps, or other water mitigation measures installed by individual homeowners on their properties.

2.3.1 Redwood Box

In 1983, in response to flooding resulting from extreme tidal events, a redwood box-type temporary floodwall was installed atop about 5,549 lineal feet of the levee in Reach 2 (Wood Rodgers, 2008). The redwood boxes are about 2.5 to 3.2 feet wide, measured perpendicular to levee crest, and generally rise about 1 to 2-1/2 feet above the earthen levee crown. These redwood box structures were intended to raise the level of protection for the areas landside of the Reach 2 levees, and have provided some protection during high water events since their installation. These previously-constructed temporary levee improvements have been in place for almost 30 years and show signs of distress. It is our understanding that the District inspects, repairs, and replaces these redwood boxes on an ongoing basis, with an average of about two to three properties maintained each year.

We note that redwood boxes were constructed to increase freeboard along the levee and provide additional protection. However, they are not considered robust enough to qualify as providing the type of protection, nor should they be considered an "engineered" element that would meet USACE or FEMA criteria when the levee system is being considered for accreditation. Specifically, the redwood boxes do not meet USACE or FEMA criteria for height, stability, seepage protection or flood fighting / maintenance access.

2.4 GEOMETRY

The LGLS is 10,800 feet long and between 2 and 6 feet high, with an average height of 5 feet between the top of the levee and the landside toe in Reach 1, and 2 to 3 feet between the top of the redwood box portion of the levee and the landside toe in Reach 2. Representative cross-sections at two locations along the LGLS are shown on Plates 2-1 and 2-2.

Ground surveys were conducted at selected cross section locations by Wood Rodgers in 2008. Additional survey data (for the top of the levee only) was collected in 2006 and 2008 by the District and provided to us by the District in 2013. Based on survey data, approximate levee elevations and geometry are presented below.

2.4.1 Reach 1

Crown elevations vary between approximately +7.8 and +9.4 feet (NVGD29), landside toe elevations range from approximately +0.5 to +3.0 feet (NGVD29), the levee crown width (for the earthen portion of the levee) varies from about 1.5 feet to 10 feet with average widths of 8 feet, and the earthen levee landside slope inclinations are approximately 2 horizontal (H) to 1 vertical (V) in Reach 1. Waterside toe elevations range from approximately +3.4 to +4.5 feet (NGVD29) in both Reaches 1 and 2.

2.4.2 Reach 2

Crown elevations generally vary between approximately +5.4 and +8.0 feet (NGVD29) (for the earthen portion of the levee), with slightly higher crown elevations (+8.0 to 9.4 feet) in the south portion of Reach 2 from Stations 103+00 to 108+00. Landside toe elevations range from approximately +4.3 to +6.5 feet (NGVD29), the levee crown width (for the earthen portion of the levee) varies from about 1.5 feet to 10 feet with average widths of 3 feet, the earthen levee landside slope inclinations are between approximately 6H:1V and 9H:1V, and the earthen levee waterside slope inclinations are between approximately 1.5H:1V and 3H:1V in Reach 2. Elevations for the top of the redwood box vary between approximately +7.4 and +8.7 feet (NVGD29). The redwood boxes are about 2.5 to 3.2 feet wide, measured perpendicular to levee crest, and rise about 1 to 2-1/2 feet above the earthen levee crown.

A summary of the elevations at the levee crest and landside toe at cross section locations surveyed by Wood Rodgers in 2008 are presented in Table 2.1.

Table 2.1 – Summary of Las Gallinas Levee Elevations

Reach	Station	Centerline Elevation of Earthen Levee[1,2]	Redwood Box Elevation[1]	Landside Toe Elevation[1]
1	4+00	8.4	N/A	2.9
1	18+00	8.2	N/A	1.9
2	36+00	6.7	7.5	4.5
2	55+50	5.5	7.4	4.3
2	79+50	7.7	8.7	6.2

Notes:

1. Elevations presented are NGVD29
2. In Reach 2, centerline elevations are referenced to the landside levee toe below the redwood box.

2.5 ACCESS

The County of Marin owns the land upon which Reach 1 is situated. Access to the levee system along Reach 1 is through Santa Venetia Marsh Preserve pathway along the levee crest, and is generally acceptable for levee inspection and construction of mitigation alternatives within the existing levee footprint.

Within Reach 2 there are no County/District rights-of-way other than at the existing pump stations. Access along Reach 2 is limited, as no roads or pathways exist along or beside the levee, and fencing is present between properties that extend up to and in some cases across the levee. In addition, on many properties wooden pathways and/or footbridges extend over the levee with pathway/bridge supports penetrating the levee.

2.6 PROJECT FEATURES (PUMP STATIONS, DITCHES, ETC.)

Within the LGLS there are five pump stations and one drainage ditch adjacent to the levee toe. The five pump stations are located as shown in Table 2.2.

Table 2.2 – Pump Station Locations

Name	Approximate Levee Station
Pump Station #1	52+50
Pump Station #2	61+00
Pump Station #3	88+00
Pump Station #4	0+00
Pump Station #5	32+00

Estancia Ditch parallels the levee toe in Reach 1 between pump stations 4 and 5. The ditch is approximately 2 to 5 feet wide and 1 to 2 feet deep.

Interior drainage landward of the levee is accomplished through overland flow to a piped storm drain system, the Castro and Mabry Ditches and several smaller channels. The Castro and Mabry Ditches are located southwest and northeast, respectively, of Mabry Way and drain to the storm drain system. The storm drain system drains to one of five pump stations.

3. EXISTING LEVEE CONDITIONS

3.1 SURFACE CONDITIONS

Approximate levee height, slopes, and geometry in Reaches 1 and 2 are discussed above in Section 2.4.

3.1.1 Reach 1

The surface condition of the levee in Reach 1 is generally a gravel roadway and serves the public as a well-used walking trail. The slopes of the levee in Reach 1 are well maintained, with short grass and wetlands vegetation growing on the slopes. Vehicle access is possible along the levee crest for the entire reach.

Reach 1 (Stations 0+00 to 32+00) extends from the intersection of the levee with E. Vendola Drive northwest toward Pump Station #5. A ditch, referred to as Estancia Ditch, extends on the landside toe from Pump Station No. 5 to approximately the intersection of the levee with the end of Palmera Way. Seepage has been observed in the landside ditch in the vicinity of the end of Descanso Way and the end of Estancia Way, as documented by the District in early 2009.

During our site reconnaissance we did not observe open burrows or other penetrations within Reach 1. However, based on information provided by the District, we understand that many animal burrows in Reach 1 have been filled with grout over the last two years. Documentation provided by the District indicates that pump station drainage outfalls and a Las Gallinas Valley Sanitary District force main are the only known existing penetrations extending through or beneath the levee.

3.1.2 Reach 2

Access to the levees in Reach 2 is limited due to the development of private residences in the area. Many homeowners have added stairs, boat ramps, fencing, and outbuildings on the slopes of the levee; planted vegetation in the redwood boxes; and otherwise modified the original levee geometry and character. Residences are within 20 to 100 feet of the levee in many locations, and vehicular access along the levee is not currently possible.

Approximately 80 percent of the levee within this reach has been modified by installing redwood box improvements to raise their crest elevation (Note: there are no redwood boxes along Reach 1). The redwood boxes measure approximately 2.5 to 3.2 feet in width and 1 to 2-1/2 feet in height and have been backfilled with a mixture of gravel, sand, silt, and clay soils.

Documentation provided by the District indicates that pump station drainage outfalls and a Las Gallinas Valley Sanitary District force main are the only known existing penetrations extending through or beneath the levee.

We noted burrows throughout Reach 2. These burrows could have been caused by either gophers, squirrels, or some other burrowing mammal. Trees have also penetrated the levee, and the slopes are significantly vegetated with plants and occasional trees.

The waterside and landside slopes of the levees in Reach 2 are over-steepened and exhibit localized slumping.

Wet areas and ponded water have been observed along the landside of the levee by local residents and by Kleinfelder personnel during site reconnaissance on October 21, 2008. Residents' reports of ponded water are largely described as occurring during or after large storm events.

3.2 SUBSURFACE CONDITIONS

In general, the subsurface conditions consist of levee fill material overlying soft Young Bay Mud and other alluvial deposits consisting of varying thicknesses of clay, silt, sand, and gravel layers. Detailed subsurface conditions along the two reaches are described below and detailed in our 2013 geotechnical investigation report (Kleinfelder 2013).

3.2.1 Reach 1

Based on the soils encountered in Kleinfelder's subsurface exploration programs, the levee fill in Reach 1 is between about 7.5 and 14 feet thick and generally consists of layers of medium stiff to hard clay and silt with up to about 30 percent sand and layers of loose to very dense sand

and gravel with clay. Underlying the levee embankment fill is 40 to 45 feet of soft, compressible Young Bay Mud. Underlying the Young Bay Mud is stiff clay and dense sand to the depths explored. Groundwater was observed at depths of 4.5 to 7.5 feet below the existing ground surface at the location explored.

3.2.2 Reach 2

Based on the soils encountered in Kleinfelder's subsurface exploration programs, the levee fill in Reach 2 is between about 5 and 17 feet thick and generally consists of layers of soft to stiff lean clay and silt with up to about 30 percent sand and layers of very loose to medium dense sands and gravels with clay. Underlying the levee embankment fill is between 45 and 50 feet of Young Bay Mud. Underlying the Young Bay Mud is stiff clay and dense sand to the depths explored. Groundwater was observed at depths ranging from 2.0 to 5.5 feet below existing ground surface (bgs) at the time of drilling.

3.3 FINDINGS OF HYDRAULIC ASSESSMENT (H&H)

The United States Army Corps of Engineers (USACE) recently developed WSEs based on current hydraulic and hydrologic (H&H) modeling. Discussions on their use in our engineering analyses are provided in our geotechnical report (Kleinfelder 2013). Values provided by USACE (USACE-SPN, 2012) indicate that 100-year WSEs near Station 80+75 range from about Elevation 6.4 to 8.5 feet (NGVD29 datum). This range represents model results from four different rates of sea level rise, from zero rise (present WSE) to about 2 feet of sea level rise (NRC Curve III).

Tables 3.1a and 3.1b summarizes minimum required crest elevations for both Reach 1 and Reach 2 that will meet a 100-year level of protection and allow FEMA accreditation under the lower end (zero sea level rise, Year 0 condition) and upper end (NRC Curve III sea level rise) sea level rise scenarios. Details on these elevations are presented in Kleinfelder's 2013 geotechnical investigation report. The minimum required crest elevations shown in Table 3.1a are based on a stillwater tide elevation of about 6.4 feet (USACE-SPN 2013), while the minimum required crest elevations shown in Table 3.1b are based on a stillwater tide elevation of about 8.5 feet (USACE-SPN 2013). Achieving these crest elevations will generally require an increase above the existing height of one to four feet.

Table 3.1a – Minimum Required Crest Elevations – Year 0 Condition (No Sea Level Rise)

Reach	Stillwater Tide Elevation (feet, NGVD29)	Maximum Wave Runup (feet)	Freeboard (feet)	Total Crest Elevation (feet, NGVD29)
1	6.4	2.6	N/A	9.0
2	6.4	N/A[1]	2	8.4

Notes:
1. Non-tidal/wave run-up reach

Table 3.1b – Minimum Required Crest Elevations – NRC Curve III Condition (50-Year Sea Level Rise)

Reach	Stillwater Tide Elevation (feet, NGVD29)	Maximum Wave Runup (feet)	Freeboard (feet)	Total Crest Elevation (feet, NGVD29)
1	8.5	2.6	N/A	11.1
2	8.5	N/A[1]	2	10.5

Notes:
1. Non-tidal/wave run-up reach

3.4 FINDINGS OF GEOTECHNICAL ASSESSMENT

A Geotechnical Data Report dated July 3, 2013 was previously submitted to the District. That report presented the findings of Kleinfelder's recent investigation and previous investigations by others. The primary purpose of the investigation was to evaluate the current conditions of the LGLS and to perform a Fragility Analysis that could be used by the District to evaluate options for potential remedial alternatives needed to obtain FEMA accreditation of the levee system and by the U.S. Army Corps of Engineers to perform a preliminary flood damage analysis.

Seepage, stability, and fragility analyses were performed for an index point along Reach 2 based on available geotechnical and survey data, discussions with USACE, and indications of prior ponding during field reconnaissance. Because the Reach 2 levees present a more considerable potential for failure due to their height, construction, and variable engineering quality, and because overtopping of the Reach 1 or Reach 2 levees would result in inundation of the same areas, fragility analyses were performed only for an index point in Reach 2. Fragility analyses were not performed for Reach 1 levees.

The analyses presented in our 2013 GDR report are based on six different WSEs at Station 55+50 (601 Vendola Drive). The lowest WSE approximately corresponds to the elevation of the waterside levee toe (4.3 ft.), the intermediate WSEs approximately correspond to the top of the earthen levee / bottom of the redwood box (6.0 ft.), and the highest WSE approximately corresponds to the top of the redwood box (7.4 ft.). In order to produce smooth fragility curves, a minimum of six points or water level elevations were used to produce the curves. Water surface elevations of +5, +5.5, 6, and 6.6 ft [between the maximum and minimum levels] were used in the analyses. Additional information can be found in the Geotechnical Data Report dated July 3, 2013.

3.4.1 Seepage

In general, levees constructed on low permeability foundation soil (silt and clay) underlain by a higher permeability layer (sand and gravel) may be susceptible to piping and landside failure due to underseepage during high water elevations. Under these conditions, seepage travels horizontally under the levee through the pervious layers with relatively little head loss. At the landside levee toe, seepage is driven vertically upward through the low-permeability foundation (blanket) layer due to the relatively higher total head at the bottom of the blanket. Failure can occur by either uplift of the blanket materials (if the blanket materials are nearly impervious and do not have enough weight to resist the upward pressure head), or by piping (if the blanket consists of low- to non-plastic erodible soils).

The risk of uncontrolled underseepage that could lead to failure of a levee increases as the vertical seepage gradient across the landside blanket layer increases. It is customary (EM-1110-2-1913, USACE 2000) to calculate the exit gradient as an average vertical gradient through the blanket layer as the head loss through the blanket divided by the thickness of the blanket layer. As the actual gradient is the head loss through the blanket layer divided by the actual length of the flowline, which is a longer distance than the vertical thickness, the vertical gradient is conservative.

Seepage analyses were performed for the index point selected. The index point was selected based on the available information including topographic survey and subsurface data. The analytical index point (Sta. 55+00) is located downstream of where the H&H analysis was performed (i.e., Sta 85+00) and the water surface information was adjusted as necessary.

Simplified subsurface stratigraphies were developed based on our current geotechnical investigations. Details of our analyses are presented in our geotechnical report (Kleinfelder 2013).

The results of our seepage analyses indicate that the calculated gradients range from 0 to 0.55 at a point approximately 20 feet from the landside levee crest hinge point depending on the water surface elevation and blanket thickness analyzed. According to USACE criteria (USACE 2000), the gradient at this location must be ≤ 0.5. Gradients of 0.5 or higher could lead to piping or internal erosion of the levees, which could ultimately lead to progressive failure of the levees during high water events.

3.4.2 Stability

Stability analyses were performed on the same index point as the seepage analyses. In general, slope stability is sensitive to changes in strength parameters, phi (the soil's angle of internal friction) and c (cohesion) of the Mohr-Coulomb soil model and the unit weight of the soil.

The cases analyzed for stability risk analyses considered long-term (drained) conditions with steady state seepage along the landside slope of the levee, as per USACE methodology (ETL 1110-2-556). Other conditions typically analyzed for the design and construction of levees including end-of-construction, rapid drawdown, and earthquake conditions, were not considered in the fragility analyses as these are not part of the USACE methodology. Note that all slope stability analyses for all cases will need to be analyzed during final design of any pursued improvement alternative.

The phreatic surface was developed for the steady state condition using the finite element program SEEP/W. The limit equilibrium computer program SLOPE/W was used to perform the stability analyses. Pore pressure distributions from the SEEP/W models were imported into the SLOPE/W models and served as the steady state seepage basis for the limit equilibrium analysis. Circular failure surfaces initiating through the embankment were assumed to be the dominant method of failure and both shallow and deep-seated rotational failures through the embankment and foundation soils were analyzed.

The analyses consisted of performing a search routine to identify the critical failure surface using Spencer's Method. The results of our stability analyses show calculated factors of safety for the conditions analyzed.

3.4.3 Fragility curves

As a condition for potential USACE funding, fragility curves were developed for this project and are detailed in our geotechnical report (Kleinfelder 2013). The total conditional probability of failure as a function of WSE has been developed by combining the probability of failure for three main failure modes; seepage, slope stability, and judgment, and are referred to as the fragility curves. The results of the Fragility Analysis are shown on Plate 3-1. The primary drivers for the steepness of the combined fragility curve are the judgment factors, such as the likelihood of failure due to erosion, animal burrows, or degradation of the redwood box over time. These judgment factors are primary drivers because in Kleinfelder's opinion, they provide a higher contribution to the risk of failure at higher water surface elevations.

3.4.4 Areas Requiring Remediation

The results of our geotechnical analyses for seepage and slope stability, combined with the fragility analyses performed, indicate that the majority of the LGLS is deficient in freeboard, slope stability, under seepage, and/or judgment factors such as the condition of the existing redwood box or the potential for waterside erosion during high water events. There is also the potential for through seepage issues depending on levee stratigraphy. In general, the existing levee (especially in Reach 2) is not up to current USACE standards, including EM 1110-2-1913 Design and Construction of Levees.

Potential remedial measures to correct these deficiencies are presented in subsequent sections of this report.

4. IMPROVEMENT GOALS

The majority of the existing levees within the LGLS (both Reach 1 and Reach 2) are currently deficient in providing the level of protection necessary to prevent damages from a 100-year flood event. Deficiencies described previously include freeboard, slope stability and seepage. Additional deficiencies of the current LGLS include encroachments onto the LGLS from adjacent home/landowners, lack of easements and access for District personnel to maintain the levees, non-standard levee construction, animal burrows within and man-made penetrations (e.g. post-supported wooden walkways) into the levee. These elements described above impact the performance of the levee.

In order to provide a reasonable level of protection, it is important that some level of improvement be implemented for the LGLS. The improvements would strengthen the existing levee system and provide a higher, more reliable level of flood protection. Absent high tides and heavy rains, the risk of potential damage by not improving the LGLS is probably low; however, winter storms coupled with high tides could overtop the existing levee/redwood box system leading to significant damage to adjacent properties and/or localized potential failure of the system.

Conventional measures are available to correct deficiencies identified in the LGLS. For purposes of simplicity, we have limited the measures discussed to those that would generally be practical and feasible to construct given the location, though some may not be cost-effective. Implementation of improvement measures will be constrained predominantly by access limitations in Reach 2 related to the presence of the marsh/wetlands on the water side and private residences on the landside and the current lack of easements and right-of-way to construct alternatives. Implementation of improvement measures in Reach 1 is less constrained due to the County's ownership and access to the existing levee footprint, though any improvement measures that increase the levee footprint will require additional right-of-way.

The goals that proposed improvement measures will need to address include:

- Level of Protection (including freeboard)
- Soundness of the improvement measure

- Access to the improvements
- FEMA accreditation (although this report also provides second tier goals that do not include FEMA accreditation because they may not meet all the required criteria)

The level of protection for the LGLS would be improved by measures that raise the current crest elevation to provide adequate freeboard and/or enhance the overall integrity of the levee prism. Such improvement alternatives include:

- Sheetpile or floodwall to increase freeboard
- Reconstruct levee with flatter slopes and higher crest elevation
- Raise levee in place with existing slope and crest width

The level of protection is the highest if the improvement alternative meets the freeboard requirement discussed in Section 3.3. The level of protection decreases as the elevation of the improvement alternative decreases below the required freeboard elevation.

The soundness of the LGLS, or the integrity of the improvement alternative, increases as measures to strengthen the levee prism or increase its resistance to seepage are implemented. To maximize the soundness of the LGLS, the improvements should be designed and constructed to meet USACE standards and criteria.

While the levees in Reach 1 are accessible for intermittent observation and maintenance along the crest road, the levees in Reach 2 require direct coordination with property owners for any access and there is no feasible equipment access along the Reach 2 levees. The goal for implementation of any alternative will be to provide means for periodic inspection and maintenance and ability for crew to access the area for flood fight. The greatest level of access will be to allow unobstructed passage of maintenance vehicles along the entire length of LGLS, which will require that easements be obtained from property owners adjacent to the levee.

FEMA accreditation requires meeting the minimum USACE criteria to demonstrate the levee system will protect the adjacent area from flooding. To achieve/maintain accreditation it must be demonstrated that the levee slopes are properly constructed, that adequate freeboard is provided, and that the levee won't settle beyond a point where freeboard is reduced below a safe level. Once the levee system is accredited, the system must be maintained so that the conditions required for accreditation continue to be met.

5. ALTERNATIVE DEVELOPMENT

5.1 ALTERNATIVES CONSIDERED

This section describes general design alternatives which could improve the predicted performance of the levee system with respect to increasing freeboard, stability, and resistance to steady-state seepage.

The choices of remediation alternatives for consideration are influenced by the design WSE, adjacent land use, environmental constraints, construction schedule, and long-term maintenance capability. The alternatives considered for this study and discussed in this section include:

- Single Sheetpile
- Floodwalls
- Earthen Levee
- Redwood Boxes

Plates 5-1 through 5-7 present the landside impacts, i.e. real estate takes, for the range of remedial alternatives.

Alternatives that were briefly assessed, but were ultimately not considered for this project, are discussed in Section 5.2.

5.1.1 Single Sheetpile

Sheetpiles are thin steel elements with interlocking edges that are driven through the levee to a specified depth to provide a barrier to seepage through or beneath the levee and as retaining structures for water or soil for this application. Sheetpiles would be generally installed at a height that provides a level of protection consistent with the required freeboard. Sheetpiles are typically driven using a vibratory or impact hammer suspended from a truck- or track-mounted crane. The size of the crane that is needed is a function of the length of the sheetpiles and the depths to which they need to be driven. Depending on the corrosivity of the subsurface materials, all or some portion of the sheets would need to be coated, or additional thickness provided, to account for material loss through corrosion. The sheetpile would typically be located between the existing waterside toe and crest hinge. However, given the sensitive nature of the marsh and wetland environment, the sheetpile may need to be located along the levee crest hinge. To provide a reduced above-ground sheet pile wall height to address potential aesthetic concerns, a buttress may also be constructed landside of the sheetpile. Plates 5-8 and 5-9 present typical sheetpile layouts with and without a buttress, respectively.

Along Reach 1, given the design WSE of 9.0 ft and the typical existing ground surface elevation of 3.4 feet to 4.5 feet, the height of the sheetpile above existing ground at the levee crest will be approximately 2 to 3 feet. Along Reach 2, with the average existing ground surface of El. 3.4 to 4.5, the height will be approximately 3.4 to 5.1 feet, depending on location. The sheetpile will need to be driven approximately 15 to 20 feet below ground surface, according to preliminary modeling analysis, in order to provide the support against overturning design WSE. This sheetpile will terminate within the Bay Mud. Given the weight of typical sheetpiles, we do not anticipate that installation of sheetpiles will contribute to additional settlement of the levees over time. If the buttress is constructed landside of the sheetpile, it may contribute to additional settlement in the underlying soft, compressible soils.

5.1.2 Floodwalls

Floodwalls are a structural element constructed near the top of the levee and should be placed at a height that provides a level of protection consistent with the required freeboard. Typically constructed of reinforced concrete, the floodwall requires a substantial foundation to provide adequate resistance from overturning forces from floodwaters. A floodwall of this type may be more feasible where the required freeboard is greater than 3 feet due to aesthetics, the cost of steel and other structural considerations. Plate 5-10 presents a cross section of a typical floodwall.

A floodwall would be approximately 2.6 to 2.9 feet in height along Reach 1 and 2.8 to 5.1 feet in height along Reach 2. A floodwall can be supported on shallow spread footings (as a T- or L-wall) that extend approximately 24 to 30 inches below the ground surface. This type of wall would not mitigate seepage issues; however, seepage issues could be addressed if the floodwall was constructed as an I-wall and in conjunction with sheetpiles.

5.1.3 Earthen Levee

Over time, the earthen levee has been compromised by erosion, high water levels, homeowner activities including penetration of the existing levee, or the presence of animal burrows. As such, a rebuilt earthen levee would be required to provide proper protection. The existing levee would be removed to the original ground surface, a new foundation prepared, and the levee re-constructed using a combination of existing and imported soil. Any existing homeowner improvements/encroachments would be either temporarily or permanently removed. Minimum levee dimensions and slopes are presented on Table 5.1. Plate 5-11 presents a cross-section of a reconstructed earthen levee.

Table 5.1 – Minimum Levee Dimensions and Slopes

Dimension	Criteria
Levee Crown Width	10 to 12 feet [1]
Landside Levee Slope	Equal to or flatter than 3H:1V [2]
Waterside Levee Slope	Equal to or flatter than 3H:1V

Notes:

1. Per USACE EM1110-2-1913. Additional width may be required based on maintenance, operations and flood fighting constraints. Minimum 20 ft. according to California Code of Regulation (CCR Title 23).
2. Criteria outlined in SPK EDG-03 referenced above for levees without documentation of historical performance.

5.1.4 Redwood Box

The redwood boxes are quasi-floodwall protective measures that have been implemented along Reach 2 of LGLS. Reconstruction of the redwood boxes are considered as a lower cost improvement alternative. Currently, redwood boxes are present as a quasi-floodwall over approximately 80 percent of the existing Reach 2 levee. A redwood box is a considered alternative for areas where the freeboard deficiency is small (i.e., less than 2 feet). Implementation of redwood boxes would most likely require on-going repair or replacement of existing and new redwood box systems as the service life of the wood material used is relatively limited and/or short. A cross section of an existing redwood box on the levee crest is shown on Plates 5-8 to 5-11.

Compared to the floodwalls discussed in Sections 5.1.1 and 5.1.2, the redwood boxes would most likely not have enough permanence to be considered a viable engineered alternative. Depending on the required elevation needed for protection it may be impractical to construct the boxes to the height/width needed. While this alternative could maintain the existing level of protection, it may not be adequate for attaining FEMA accreditation.

5.2 ALTERNATIVES NOT CONSIDERED

In addition to the alternatives discussed above, other alternatives were also noted but not considered further for this report due a general/overall lack of feasibility based on access, cost, real estate impacts, or other considerations. Implementation of these discounted alternatives would not provide an increased level of protection that would justify the higher cost associated with each. These alternatives are discussed below.

A double sheetpile installation was removed from consideration based on the anticipated construction impacts. Because of the relatively low anticipated height required, a double sheetpile installation would not be necessary.

A cutoff wall using slurry trench method would provide a positive cut-off for seepage. However, this alternative requires significant room for the physical plant needed for construction. Due to the location of the levee between the marsh and the adjacent homes, it would be impractical to construct a slurry cutoff wall without significant property-related costs and potential environmental impacts.

Deep soil mixing was discounted for reasons similar to that for slurry walls.

6. DESIGN CRITERIA

The criteria used for assessing and designing the various alternatives are described in detail in this section. The areas of concern for which criteria have been provided include:

- Water Surface Elevation (WSE)
- Under and Through Seepage
- Slope Stability (Static)
- Settlement
- Wave Loading
- Access
- Alignment with respect to sensitive wetlands

Seismic stability is not considered a major element of concern as the probability of the 100-year flood occurring at the same time as the design earthquake is low. While FEMA does not have its own requirement, reliance on USACE criteria requires that levee slopes be evaluated for liquefaction and deformation. However, seismic stability of the LGLS is important in order to anticipate the magnitude of repair required if a design seismic event occurs. The assumption is the levee would be substantially or completely repaired prior to periods of high tides or the start of the subsequent rainy season.

6.1 WATER SURFACES AS BASED ON HYDROLOGY & HYDRAULICS (0.01 EXCEEDANCE PROBABILITY = 100-YEAR WSE)

The 100-year WSE used for design was based on the hydraulics and hydrology analyses performed by USACE for an index point at Station 80+75 in Reach 2. The same analyses were considered applicable to Reach 1, as Reach 1 is hydraulically connected and adjacent to Reach 2. The results of the USACE analyses generated four different WSEs based on existing and future environmental considerations. Where applicable the design WSE takes into account potential sea level rise and wave run-up.

Hydrologic Year 0 (present): The WSE for present conditions is El. 6.4 ft.

Hydrologic Year 50 (historic sea level rise): The WSE for this condition is El. 6.9 ft.

Hydrologic Year 50 (NRC Curve I): The WSE for this condition is El. 7.2 ft.

Hydrologic Year 50 (NRC Curve III): The WSE for this condition is El. 8.5 ft.

6.2 SEEPAGE

6.2.1 Underseepage

Levees constructed on low permeability foundation soil (silt and clay) underlain by a higher permeability layer (sand and gravel), such as those found along the LGLS, are susceptible to piping and landside failure due to underseepage during creek stages with high water levels. Under these conditions, seepage travels horizontally under the levee through the pervious layers with relatively little pressure (piezometric head) loss. At the landside levee toe, seepage is driven vertically upward through the low permeability foundation (blanket) layer due to the pressure at the bottom of the blanket. Failure can occur by either uplift of the blanket materials (e.g. if the blanket materials are nearly impervious and do not have enough weight to resist the upward pressure) or by piping (e.g. if the blanket consists of low- to non-plastic erodible soils). Either condition can develop with as little as one order of magnitude difference between the vertical hydraulic conductivity of the blanket layer and the horizontal hydraulic conductivity of the underlying pervious layer.

The risk of uncontrolled underseepage that could lead to failure of a levee increases as the vertical seepage gradient across the landside blanket layer increases. It is customary to calculate the exit gradient (e.g. average vertical gradient) through the blanket layer as the head loss through the blanket divided by the blanket layer thickness (USACE 2000). This is referred to as “the blanket layer method”. Gradient contours can also be plotted directly by many finite element method (FEM) programs either as individual “x” (horizontal) and “y” (vertical) components or as resultant vectors. The FEM generated gradient contours can be used to identify local maximum gradients and potential boil locations. The USACE blanket layer theory was used for estimating average underseepage exit gradients.

The USACE design criteria for underseepage exit gradients are summarized in Table 6.1.

Table 6.1 – Allowable Exit Gradients for 100-year WSEs (USACE)

Location	Allowable Exit Gradient [1]
Landside toe of levee	≤ 0.5
Bottom of empty ditch at landside toe [2]	≤ 0.5
Bottom of empty ditch 150 feet landward of toe [2]	≤ 0.8
Ditch between landside toe and 150 feet landward of toe [2]	Interpolate between 0.5 & 0.8

Notes:
1. Allowable exit gradients are only applicable for 100-year WSEs. Assumes a minimum saturated soil unit weight = 112 pounds per cubic foot (pcf).
2. Reference USACE EM 1110-2-1913, Section 8-16, "Ditches Landside of Levee".

6.2.2 Through Seepage

Seepage through a levee embankment having a permeable core can occur during periods of high water. Depending on the duration of the high water stage and the hydraulic conductivity of the levee materials, seepage may exit on the landside slope of the levee (i.e. through seepage). There are three potential through seepage related impacts on levee performance, which are:

- Piping (or transport by water flow) of fine-grained, erodible materials from within the levee embankment;
- Concentrated seepage conditions through more permeable layers within the levee embankment; and
- Increased seepage pressures resulting in reduced slope stability of the landside slope.

6.3 SLOPE STABILITY

The USACE identifies four types of design conditions that require evaluation of slope stability. This information is provided here as an indication of the level of design analyses that would be needed for future repairs. The minimum factors of safety (FOSs) for these loading conditions are summarized in Table 6.2. These four conditions are:

Case I: End of Construction - This case addresses slope stability at the end of construction of the adjacent levee and requires a minimum FOS of 1.3. This case would be most critical for low permeability levee embankment and foundation soils that have low undrained strength prior to consolidation under the new embankment loads. Excess pore pressures would be present because the low permeability soil has not had time to drain since being loaded.

Case II: Sudden Drawdown - This case represents the condition where the high water levels saturate a portion of the waterside embankment, and then the flood stage drops at a faster rate than the soil can drain. This case requires a minimum FOS of 1.0 for a short-duration flood stage and 1.2 for a long-duration flood stage.

Case III: Steady-State Seepage from Full Flood Stage - This condition occurs when the water level remains at or near flood stage (WSE at top of levee) for an extended period of time. This condition fully saturates the levee embankment soils, and a steady-state seepage phreatic surface develops. This case requires a minimum FOS of 1.4.

Case IV: Earthquake – The seismic analysis represents a screening analysis not addressed in detail in the USACE manual (EM-1110-2-1913). For the LGLS, the water levels to be evaluated would need to take into account high tide events during the summer, as well as water levels from rainfall events coupled with high tides and/or wave run-up during the winter to assess the susceptibility of the levees to large deformations during the design seismic event.

Table 6.2 – Minimum Required Slope Stability Factors of Safety

Case	Minimum FOS[1]
Case I – End of Construction	1.3
Case II – Sudden Drawdown	1.0 to 1.2
Case III – Steady-State Seepage	1.4
Case IV – Earthquake	Check for liquefaction and deformation

Note:
1. FOS criteria from USACE EM 1110-2-1913.

For this alternatives analysis, our evaluations were based on the results of the slope stability analyses performed for the Fragility Analysis, which only considered Case III as the existing condition per USACE analysis requirements. For a WSE at the top of the redwood box (El. 7.4) and the range of conditions analyzed in the Fragility Analysis, the calculated factors of safety ranged from 1.22 to 4.11. Detailed discussions of Fragility Analysis are presented in Kleinfelder's GDR.

6.4 SETTLEMENT

The LGLS is still undergoing consolidation settlement as a result of the placement of fill above weak, compressible soils. The design implication of this condition is that future remedial activities should take into account the ongoing settlement and provide additional freeboard to account for future settlement over a certain period, or provide a means to maintain freeboard at an acceptable level. Information on past settlement of the LGLS can be obtained in Kleinfelder's geotechnical investigation (Kleinfelder 2013).

6.5 WAVE LOADING

Portions of the LGLS facing the bay can be exposed to wave run-up. The San Pablo Bay front levee system blocks the bay waves being propagated to the project site from most directions. As a result, only the lower portion of the Las Gallinas levee system, from approximately Stations 0+00 to 30+00 (within Reach 1), is exposed to wave action within a narrow band of directions. The wave action on the upper portion of the Las Gallinas levee system, which is upstream of the Santa Venetia Marsh from Stations 30+00 to 108+00 (a small portion of Reach 1 and the entirety of Reach 2), is negligible (USACE-SPN 2012).

For simplicity, we have applied the wave run-up freeboard criteria to the entirety of Reach 1, extending from Station 0+00 to Station 32+00. Consequently, in Reach 1, the maximum wave run-up would be 2.6 feet (See Kleinfelder's 2013 geotechnical report for additional information). The remainder of LGLS in Reach 2 is not subject to any significant wave action, and no wave run-up freeboard criteria apply. Therefore, in Reach 2, total freeboard would be two feet above the stillwater tide elevation based on the guidelines in CFR Chapter 44, Section 65.10, as previously stated.

6.6 ACCESS

Reach 1 is accessible for maintenance and possible future construction either along the top of the levee or along key points on the landside toe. However, within Reach 2, access to the existing levee is complicated by the presence of the residences and the condition of the levee.

Fencing, stairways to waterside docks, and other obstructions prevent all vehicle access along Reach 2 for periodic maintenance or flood-fight. Any remedial activities will require a temporary construction easement, and permanent rights-of-way for future maintenance access after construction are a requirement for FEMA accreditation. For this study, the criteria used for access is a 10-ft wide road, landward of the improvement in order for periodic maintenance and, if needed, flood fighting activities (USACE 2000).

6.7 ENVIRONMENTALLY SENSITIVE WETLANDS

Environmentally sensitive wetlands are present on the waterside slopes and in the waterside channels in both Reach 1 and Reach 2. For the purposes of this study, we have considered the Estancia Ditch on the landside in Reach 1 to be a tidal wetland, though delineation of any tidal wetlands in this area would need to be provided by regulatory agencies. These wetlands contain vegetation and habitat that are protected under both state and federal statutes, and any impact to these wetlands would require significant environmental assessment and mitigation banking to offset habitat reduction. Because there are significant costs associated with assessing and mitigating impacts to wetlands along the waterside slopes, all alternatives analyzed for this report extend toward the landside from the waterside hinge point, thereby confining potential impacts to environmentally sensitive wetlands to only the Estancia Ditch in Reach 1.

7. LEVELS OF IMPROVEMENT (TIERS)

A typical goal for levee improvement projects is to obtain FEMA accreditation. Construction of an accredited levee may not always be obtainable, however, due to a variety of factors including, for example, project infeasibility (e.g., lack of available easements, construction access constraints, environmental constraints, etc.), insufficient funding, or a lack of community support. Therefore, for this Alternative Analyses, we have examined other, lower levels of protection that may be obtainable, but do not meet all goals described in Section 4. Besides full FEMA accreditation, which we are identifying as a "Tier 1" level of improvement, we have presented three alternate tiers. The four tier levels of available improvement are:

Tier 1: FEMA accreditation: Under Tier 1, the improvements will be designed and constructed in accordance with USACE standards and to meet FEMA National Flood Insurance Program (NFIP) accreditation eligibility requirements.

Tier 2: Improved protection without FEMA accreditation: Under Tier 2, the improvements are constructed in a sound method, but not to the level of protection stipulated by USACE for FEMA accreditation. Examples of a Tier 2 improvement would include rebuilding the existing levees along Reach 2, but not to USACE standards, (such as insufficient crest elevation, insufficient freeboard, lack of full-width maintenance and access roads, insufficient width, and/or oversteepened slopes). For this tier, FEMA will not likely accredit the levee system as the protection will not meet USACE standards, but USACE input could be provided and the improvements could be applicable to the USACE Rehabilitation and Inspection Program (RIP).

Tier 3: Minimum level of additional protection: This level of improvement would be a less costly approach for mitigating the levee system, but would provide a level of protection less than Tier 2. Examples of Tier 3 could include rebuilding levees within an even smaller footprint than the repairs proposed under Tier 2, e.g. 10-foot wide maintenance roads would not be constructed, nor would narrower required access corridors for periodic inspection and maintenance. Although Tier 3 would provide additional protection, FEMA/USACE would not be engaged in the design and construction process and therefore, will not provide approval as any alternatives proposed would be well below the USACE's standards. Tier 3 would likely not be applicable to the RIP.

Tier 4: Maintenance with incremental improvement over time: Tier 4 level of improvement assumes annually and/or periodically maintaining or improving the redwood boxes, providing vermin control and grouting their burrows. Redwood box maintenance or improvements would include replacement of degraded wood box materials or replacement and/or recompaction of fill materials inside the redwood boxes. Tier 4 improvements would marginally improve the quality and durability of the levees and redwood boxes currently in place, which would reduce the risk for failure by judgment related failure mechanisms such as erosion of the levee through rodent burrows or damage or undermining of the redwood boxes. However, Tier 4 improvements are not anticipated to raise the overall height of the protection by any considerable margin and the risk of overtopping, underseepage or slope stability failure would still remain.

8. DESCRIPTION OF IMPROVEMENT ALTERNATIVES

In this section, the improvement alternatives introduced in Section 5 are described in greater detail. The improvement alternatives discussed include:

- Sheetpiles
- Floodwalls
- Reconstructed Levee
- Raising of Existing Levee
- Redwood Box

The discussion of each improvement alternative will include a general description of the alternative, methods and equipment for installation, access constraints, ability for the alternative to resist overturning during high water event, and its applicability to Tiers 1 through 4, as presented in Section 7.

8.1 SHEETPILES

Driven sheetpiles are a feasible alternative to provide additional freeboard protection, thus reducing the potential for over-topping during high water events. Sheetpiles also provide additional relief for areas where through or under-seepage could affect levee or foundation integrity. The sheetpiles would be driven near the existing waterside hinge (the edge of the levee crest closest to the water) with their tops at an elevation above the existing levee crest depending on the design water surface elevation. For a design acceptable to USACE and FEMA, an access road landward of the sheetpile would be constructed.

8.1.1 Description of types (steel, vinyl)

Applicable types of sheet piles include steel or vinyl. Steel sheetpiles would be considered the norm, but below grade vinyl sheetpiles have also been used on several projects in the San Francisco Bay Area to provide protection against seepage. We note, however, that USACE technical guidance (USACE 2003) recommends against use of vinyl sheet piles for above-grade floodwalls because of concerns regarding durability, damages from impact, excessive heat and vandalism, and fatigue. Vinyl sheetpiles should therefore only be used for seepage cutoff beneath concrete floodwalls.

Steel sheetpiles are rolled steel members with interlocking joints along their edges. Vinyl sheet piles are made of polyvinyl chloride (PVC). Sheet piling is produced in straight web, arch web, and Z sections in a graduated series of weights joined by interlocks to form a continuous cutoff wall to reduce underseepage and through seepage beneath levees.

The efficiency of sheet piling cutoff walls is dependent upon proper penetration into an impervious stratum and the condition of the sheeting elements after driving. The efficiency of the sheet piling will be reduced if sheet piling encounters dense sands/gravels or cobbles which may tear the sheeting or damage the interlocks. Installation of vinyl sheetpiles can be affected by underlying dense strata.

Sheet piling is not entirely watertight due to leakage at the interlocks; but its installation can significantly reduce the possibility of piping of sand strata through the foundation. Predrilling to design depth at interlock locations and backfilling with slurry bentonite can be performed to reduce leakage.

8.1.2 Methods and equipment

Sheetpiles are typically installed by driving them into the ground using a vibratory or impact hammer suspended from a crane. Depending on the length of the sheets and the size of the hammer needed to drive them, the cranes can be large. The cranes can be either track-mounted or rubber tire. An area wider than the existing levee would be required to allow the crane to sit level. Depending on how this alternative might be implemented, construction or construction staging could occur on either the waterside of the existing levee, or landside of the existing levee, within existing homeowners' backyards. We expect that working on the waterside of the existing levee could be more costly due to the costs associated with mitigating wetland impacts and securing required permits.

Some limited access sheet pile installation equipment, such as rail-mounted or self-supporting sheet pile driving rigs, may be available for consideration for this alternative. Further cost analysis and discussions with limited access contractors should be undertaken during the design phase.

8.1.3 Access constraints

Access for sheetpile installation would be constrained by the proximity of the wetlands on the waterside and residences and other improvements on the landside. Sheetpile installation would result in significant, though temporary, disturbance through the entire levee corridor due to vibration and noise impacts during sheetpile driving. Given that most, if not all, property owners have fencing to separate lots and homes from adjacent lots and homes, the fencing and any existing improvements across the existing levee would need to be removed in order for sheetpile installation to occur, and some improvements may need to be permanently removed where they directly interfere with the proposed sheetpile alignment.

8.1.4 Stability/overturning concerns due to high water events

The process used to design the sheetpile installation should mitigate potential problems due to stability or overturning during high water events. The required embedment of the sheetpiles will be a function of the forces trying to push the sheets over and the ability of the soil into which they are driven to resist those forces. Since the sheetpiles will derive most of their resistance within the underlying soft Bay Mud, embedment is likely to be at least twice the height above grade. In addition, the embedment needs to be sufficient to prevent formation of a gap at the levee surface that could introduce full hydrostatic pressure against the wall and in the levee, which could result in failure of the system. Given that the sheetpile will need to be between 0.5 and 5.6 feet above existing top of levee, we anticipate the sheetpile will be driven about 15 to 25 feet below ground surface and will be supported by the relatively weak, compressible Bay Mud. These considerations would apply for sheetpile or I-wall installation.

8.1.5 Applicability to Tiers 1 through 4

Sheetpiles would be most applicable to Tiers 1 and 2; they would not be implemented if only Tiers 3 or 4 were being considered as it would not be cost-effective to install sheetpiles to an elevation less than the design WSE (including freeboard) or to an embedment depth less than described above. In our opinion, other less cost options could be implemented, i.e. improved/upgraded redwood box.

8.2 FLOODWALLS

Floodwalls, similar to sheetpiles, are essentially a retaining wall designed to provide adequate freeboard during high water events. Floodwalls are generally constructed of reinforced concrete. Sheetpiles would be used in conjunction with floodwalls to provide a cutoff to through or under seepage.

8.2.1 Description of types

Floodwall types can be gravity, cantilever, buttress or counterfort. Based on space limitations for this site we expect that the floodwalls would be a cantilever-type, potentially with soil buttresses on the landward side to assist in preventing overturning of the floodwall during high water levels.

8.2.2 Methods and equipment

A concrete floodwall at this location would most likely be constructed at the original ground level due to the irregular nature of the existing levee cross-section. Construction would use conventional excavation equipment such as bulldozers, backhoes, and possibly scrapers.

8.2.3 Access constraints

Access for concrete floodwall construction would be constrained by the proximity of the wetlands on the waterside and residences and other improvements on the landside, though to a lesser extent than for sheetpile installation. Concrete floodwall construction could require disturbance or removal of the majority of the existing levee.

8.2.4 Settlement concerns

Concrete floodwalls would be subject to the on-going long-term settlement occurring in this area. Floodwall design would need to take into account future settlement by incorporating additional height in the design or providing a mechanism to raise the top of the floodwall in the future.

8.2.5 Stability, overturning

Concrete floodwalls would achieve stability and resistance to overturning through the size and depth of the wall footing. To resist sliding, the wall footing may require a key. The size of the footing will also be a function of the allowable bearing capacity of the soil on which it is founded. If sufficient bearing is not available, a deep foundation may be required.

8.2.6 Applicability to Tiers 1 through 4

Concrete floodwalls would be most applicable to Tiers 1 and 2. Concrete floodwalls, as such, may also be applicable for Tier 3 if only a short section of levee required a limited increase in freeboard.

8.3 RECONSTRUCTED LEVEE

Reconstructing the existing earth levee would involve complete removal of the existing levee to original ground and rebuilding it to current USACE standards. This would require preparation of the foundation and reconstructing the levee using existing soil and imported soil to account for the wider, taller designed levee.

A subset of this alternative is raising the existing levee. This alternative would only be feasible for Reach 1 where the levee appears to have been previously engineered. Presently side slopes on Reach 1 are steeper and crest heights lower than current USACE standards.

8.3.1 Geometry required

A reconstructed levee would have a wider section, with 3H:1V side slopes. Additional height would be required to achieve the freeboard necessary to obtain FEMA accreditation.

8.3.2 Additional footprint required

Because of the added height and flatter slopes, the footprint of the levee would become wider than the footprint of the existing levee. This widening would result in encroachments into the adjacent backyards of residences. The additional width required could be on the order of 20 to 25 feet or more, depending on local variations in the original ground elevation and the existing levee width. We have assumed that any encroachment would be onto the adjacent residences and not onto the adjacent wetlands due to the impact to wetlands and habitat.

8.3.3 Settlement issues and required additional surcharge

Reconstructing the levee to a higher final height will surcharge the underlying compressible soils on which it is founded, resulting in additional settlement being generated with time. The amount of new settlement will be a function of the thickness of the Bay Mud beneath the levee at a given location and the height of the original levee. Design of a reconstructed levee will need to account for the future settlement with additional freeboard, or, alternatively, the levee will need to be constructed in a way that will allow future embankment fill to be placed and compacted to maintain freeboard.

8.3.4 Import of select engineered fill

For the construction of a reconstructed levee along the LGLS, soil will be required to be imported onto the site since the existing levee section does not provide the quantity of material necessary for levee reconstruction. A source or sources of potential imported fill will need to be identified and characterized. No sources have been identified as part of this study. We have assumed the soil would be brought to the site in 18-wheel trucks.

Soils placed and compacted onsite for levee construction should be placed in accordance with USACE requirements. Compaction requirements of the levee fill should be at least 95 percent relative compaction based on ASTM D1557.

8.3.5 Applicability to Tiers 1 through 4

Reconstructing the existing levee would primarily be applicable to Tiers 1 and 2. It could also have applicability to Tier 3 if limited areas of the existing levee were in need of reconstruction to maintain the current level of protection.

8.4 REPLACEMENT/IMPROVEMENT OF REDWOOD BOXES

For this alternative the existing redwood boxes would be modified to improve their function. Modifications could range from replacing deteriorated existing boards and refilling the boxes to reconstructing the boxes on the levee crest. The extent of the work under this alternative would be a function of the degree of improvement desired.

8.4.1 Recommended geometry

In our opinion, given the nature of the existing redwood boxes, modifying the boxes would have a limited effect on the overall level of protection and would be more applicable to maintaining the current level of protection. We would expect the geometry of modified boxes to be similar to the current redwood box geometry, on the order of 1 to 2-1/2 feet high and 2-1/2 to 3 feet wide. Some redwood boxes that are currently less than 2-1/2 feet high could feasibly be raised above existing heights. The recommended maximum redwood box height (as measured from the top of the earthen embankment) is 2-1/2 feet. If the redwood boxes are maintained and repaired, including replacing deteriorating redwood beams, removing vegetation around the boxes, and grouting animal burrows within the levee prism, the likelihood of failure due to judgment related factors (vegetation, deterioration of the redwood box material, etc.) will be reduced.

8.4.2 Material Types

Material types suitable for use in replacement or improvement of the redwood boxes could include natural and manufactured materials, such as redwood, pressure-treated lumber or Trex or other manufactured “wood”.

8.4.3 Limitations and life cycle

This alternative would be limited to locations not needing more than about 2-1/2 feet of protection above the elevation of the existing earthen embankment. The goal of maintaining and modifying the redwood boxes should be to raise the overall level of protection to one consistent top-of-box elevation. Given the current earthen embankment and redwood box geometry, the maximum top-of-box elevation is likely on the order of about 8 to 8.5 feet, which would provide adequate protection and partial to full freeboard only for the lower design WSEs, such as the zero sea level rise (current 100-year WSE) scenario. The existing earthen embankment may require isolated improvements to provide a suitable foundation for the redwood boxes. Above an exposed redwood box height of 2-1/2 feet, design of the boxes could be problematic from a structural standpoint. This alternative only provides additional freeboard and does nothing for overall levee stability or seepage mitigation. The lifecycle of the wooden framework would also be short, similar to the current redwood boxes. They would require frequent inspection and maintenance in order to maintain adequate protection.

8.4.4 Overturning/sliding concerns

The boxes could be subject to overturning or sliding if the supporting posts are not strong enough or deep enough to resist the applied water loads.

8.4.5 Settlement concerns

The redwood boxes would continue to undergo settlement as the levee continues to settle. If the elevation of the boxes is raised, the incremental load would generate additional settlement, although the magnitude should be small.

8.4.6 Applicability to Tiers 1 through 4

Replacement or improvement of the redwood boxes would be applicable primarily to Tiers 3 and 4, but not necessarily in that order. This alternative is not viable for Tier 1 and may have limited viability for Tier 2, depending on the acceptance of this alternative with the USACE.

8.5 MATRIX TABLE (SUMMARIZES ALTERNATIVES)

The applicability of the various remedial alternatives to addressing the deficiencies identified is shown in Table 8.1.

Table 8.1 – Summary of Deficiencies and Mitigation Alternatives

Levee Reach	Deficiency	Mitigation Alternative			
		Sheetpiles with or without buttress	Concrete Floodwall[1]	Reconstructed Levee[2]	Maintain and Replace/Improve Redwood Box
1	Freeboard	Yes	Yes	Yes	Yes
	Seepage	Yes	No	No	No
2	Freeboard	Yes	Yes	Yes	Yes
	Seepage	Yes	No	No	No

Notes:

1. Used in conjunction with sheetpiles, concrete floodwall would provide seepage mitigation.
2. Reconstructed Levee Alternative includes raising existing levee along Reach 2 and possibly raising existing levee along Reach 1 depending on the design WSE used.

9. IMPROVEMENT ALTERNATIVES

9.1 SELECTED ALTERNATIVES

Based on the results of our engineering analyses of the alternatives considered for the improvement of the LGLS during a 100-yr flood event (either the current 100-year WSE with no sea level rise, or the 100-year WSE with NRC Curve III 50-year sea level rise), we have concluded that sheetpiles, floodwalls, and a reconstructed levee are all technically feasible for use for all tier levels, as discussed in Section 7. The remaining alternative, raising existing levee and redwood boxes, does not follow USACE guidelines and therefore, should only be considered technically feasible under Tiers 2 through 4 conditions. Table 9.1 presents the summary of the selected alternatives for each tier.

Table 9.1 – Summary of Alternatives Appropriate for Each Tier Level

Alternative	Tier 1	Tier 2	Tier 3	Tier 4
Sheetpile	X	X		
Floodwall	X	X		
Reconstructed Levee	X	X		
Raising Existing Levee			X	
Redwood Box			X	X

Rough order of magnitude (ROM) costs associated with the various alternatives are discussed in Section 9.2.

The remainder of this section discusses the geotechnical feasibility of each alternative for the various tiers.

9.1.1 Tier 1 – Recommendations and discussion

For Tier 1, improvement alternatives need to meet the design and construction standards in USACE EM 1110-2-1913 in order to qualify for accreditation by FEMA for the NFIP as noted in 44 CFR 65.10. Of the alternatives considered, sheetpile, floodwall, and reconstructed levee are all geotechnically feasible.

9.1.2 Tier 2 – Recommendations and discussion

For Tier 2, improvement alternatives are not designed to meet the design and construction standards in USACE EM 1110-2-1913 in order to qualify for accreditation by FEMA for the NFIP, as noted in 44 CFR 65.10, in their entirety, although input into the design process from USACE will be requested. This tier provides improved protection, but without FEMA accreditation. Depending on the extent of the repair or improvement, the work may fall under the purview of the RIP. Of the alternatives considered, sheetpile, floodwall, and reconstructed levee are all feasible. We believe that not constructing these improvements to meet all applicable USACE standards, including the lack of access roads for periodic maintenance or flood fight, would designate these improvements as Tier 2.

9.1.3 Tier 3 – Recommendations and discussion

For Tier 3, improvement alternatives are proposed as the minimum level of additional protection, e.g. meet at least the design WSE without freeboard, but will not meet in their entirety the design and construction standards in USACE EM 1110-2-1913 in order to qualify for accreditation by FEMA for the NFIP as noted in 44 CFR 65.10. Tier 3 provides improved protection, but is not as significant an improvement as provided with Tier 2, and they are unlikely to fall within the span of the RIP. Of the alternatives considered, raising existing levee and maintaining redwood boxes can both be considered as feasible. Sheetpile, floodwalls, and reconstructed levees, if implemented, will either result in Tier 1 or Tier 2 level of improvements.

9.1.4 Tier 4 – Recommendations and discussion

For Tier 4, improvement alternatives are proposed as maintenance of existing structures which are performed to provide incremental improvement over time. Of the alternatives considered, maintaining redwood boxes is considered feasible. Any other alternatives considered as discussed in this section should only be considered for the other three tiers. Examples of Tier 4 improvement would consist of maintaining or improving the redwood boxes, providing rodent control, and grouting rodent burrows, which is similar to the level of maintenance currently provided.

9.2 COST ANALYSIS SUMMARY

In addition to assessing the geotechnical feasibility of these improvement alternatives, cost is a significant criterion for determining an alternative's overall feasibility. We performed a rough order of magnitude (ROM) cost analysis of each alternative listed above. Our analysis included assessing the impact of the following on the various alternatives:

- Real estate acquisition
- Imported fill material and other construction material
- Environmental Banking in Reach 1 (using approximate costs for non-tidal wetlands bank – further analysis required to determine the feasibility and cost of wetland banking)
- Permitting, environmental assessments, and design
- Construction Management
- Contingencies

These cost factors are discussed in detail below and summarized in Tables 9.2 and 9.3. Table 9.2 presents costs for providing protection against a lower 100-year WSE with no sea level rise (6.4 feet). Table 9.3 presents costs for providing protection against a higher 100-year WSE with NRC Curve III 50-year sea level rise (8.5 feet).

At the time of this report, it is our understanding that the lower level of protection (against the no sea level rise condition) is the minimum requirement for FEMA accreditation. The level of effort and cost required for design, permitting, site access, mobilization/demobilization, and other cost elements apply to all levels of protection. For all alternatives (except for the earthen embankment alternative, which requires increased footprint for increased level of protection) the overall project cost is only marginally increased by raising the level of protection.

The following factors are beyond the scope of this preliminary alternatives analysis report and are not considered in our cost analysis:

- Post-NEPA planning (monitoring and mitigation of environmental impacts following project construction)
- Additional geotechnical investigations and design required to develop alternatives

Appendix A provides a detailed analysis of the cost breakdown for each alternative analyzed.

Table 9.2 – Summary of Remedial Cost Alternatives – 100-Year WSE, No Sea Level Rise

Alternative	Reach 1 (1)				Reach 2				Total Cost (millions)
	Construction	Real Estate	PED/CM (2)	Contingency	Construction	Real Estate	PED/CM (2)	Contingency	
Reconstruct and Raise Levee	$4,574,132	$16,746,000	$1,486,593	$3,649,076	$1,980,000	$42,852,000	$643,500	$7,276,080	$79.2
Single Sheetpile, Maintenance Road w 3' tall soil buttress	$1,136,000	$0	$369,200	$240,832	$3,739,600	$15,180,000	$1,215,370	$3,221,595	$25.1
Single Sheetpile, Maintenance Road/No Buttress					$3,531,600	$11,484,000	$1,147,770	$2,586,139	$20.5
Single Sheetpile, No Maintenance Road					$3,453,600	$8,712,000	$1,122,420	$2,126,083	$17.2
Concrete Floodwall	$2,144,000	$0	$696,800	$454,528	$9,022,000	$11,484,000	$2,429,700	$3,422,352	$29.7
Maintain Redwood Boxes for next 50 years.	Not applicable. No Redwood Boxes in Reach 1.				$500,000	$0	$0	$0	$0.5

(1) Sheet pile costs in Reach 1 are all based on the "Single Sheetpile, Maintenance Road with Soil Buttress" alternative. The existing access road/embankment in Reach 1 would be left in place to act as a buttress, and sheet piles would be installed along the waterside hinge point of the crest. This Reach 1 sheet pile configuration would be paired with any of the three sheet pile configurations in Reach 2 for overall project protection and costing.

(2) PED/CM = Permitting, Engineering and Design and Construction Management.

Note: The following factors are beyond the scope of this preliminary alternatives analysis report and are not considered in our cost analysis:

- Post-NEPA planning
- Additional geotechnical investigations and design required to develop alternatives

Table 9.3 – Summary of Remedial Cost Alternatives – 100-Year WSE, NRC Curve III Sea Level Rise

Alternative	Reach 1 (1)				Reach 2				Total Cost (millions)
	Construction	Real Estate	PED/CM (2)	Contingency	Construction	Real Estate	PED/CM (2)	Contingency	
Reconstruct and Raise Levee	$4,782,132	$19,818,000	$1,554,193	$4,184,692	$2,526,000	$61,284,000	$820,950	$10,340,952	$105.3
Single Sheetpile, Maintenance Road w 3' tall soil buttress	$1,236,800	$0	$401,960	$262,202	$3,979,000	$15,180,000	$1,293,175	$3,272,348	$25.6
Single Sheetpile, Maintenance Road/No Buttress					$3,771,000	$11,484,000	$1,225,575	$2,636,892	$21.0
Single Sheetpile, No Maintenance Road					$3,693,000	$8,712,000	$1,200,225	$2,176,836	$17.7
Concrete Floodwall	$2,816,000	$0	$915,200	$596,992	$9,022,000	$11,484,000	$2,948,400	$3,760,704	$31.5
Maintain Redwood Boxes for next 50 years.	Not applicable. No Redwood Boxes in Reach 1.				$500,000	$0	$0	$0	$0.5

(1) Sheet pile costs in Reach 1 are all based on the "Single Sheetpile, Maintenance Road with Soil Buttress" alternative. The existing access road/embankment in Reach 1 would be left in place to act as a buttress, and sheet piles would be installed along the waterside hinge point of the crest. This Reach 1 sheet pile configuration would be paired with any of the three sheet pile configurations in Reach 2 for overall project protection and costing.

(2) PED/CM = Permitting, Engineering and Design and Construction Management.

Note: The following factors are beyond the scope of this preliminary alternatives analysis report and are not considered in our cost analysis:

- Post-NEPA planning
- Additional geotechnical investigations and design required to develop alternatives

9.2.1 Real estate acquisition

The majority of the alternatives will have either a temporary and/or permanent encroachment onto adjacent homeowner property. We anticipate that all real estate adjacent to the levee will be impacted. As shown in Plates 5-1 to 5-7, reconstructing the levee in accordance with USACE standards will have the greatest impact to permanent encroachment, with encroachment ranging from 50 to 55 feet from the existing landside levee toe. Both sheetpile and floodwall alternatives show encroachments of up to 15 to 20 feet from the existing landside levee toe in order to provide an easement for a 10-foot wide access/maintenance road.

Unit costs for real estate acquisition were previously provided by the District. Based on discussions with the District, real estate acquisition costs are divided into two categories: costs for fully impacted homes and partially impacted homes. Fully impacted homes are classified as those homes located within 6 feet of the proposed mitigation alternative footprint, or for which the mitigation footprint encroaches onto the existing homeowners' residences and structures. Partially impacted homes are located greater than 6 feet from the proposed mitigation alternative footprint, though the mitigation footprint still impacts the homeowners' backyards and non-living areas. Real estate acquisition costs were estimated by the District's Real Estate division and include permanent and temporary easement costs, acquisition of fully impacted homes, homeowner relocation and inconvenience during construction, administrative and legal costs, and contingencies. Significant additional costs would be incurred if an alternative is developed that encroaches into the wetlands.

Continued maintenance of the existing redwood boxes along Reach 2 will not have an impact as no improvement other than the annual maintenance and repair of the redwood boxes are being considered. In order to qualify for the USACE RIP, the District may want to consider obtaining permanent easements to allow for maintenance of the existing redwood box.

9.2.2 Imported fill material

The majority of imported fill material will be for the reconstruction of the levees and, to a lesser extent, the access road. This study did not research locations of available fill material as a construction date is not known. For costing, we have assumed $26/cubic yard (cy), but recognize that the actual cost will depend on the schedule for improvement construction, distance travel from source material to project site, and availability of material at the time of construction. Import material costs shown on Appendix A include transportation of materials from off-site location, placement, and compaction.

Sheet pile ($15/sf) and floodwall ($100/sf) costs include materials, installation, and equipment/crew. The cost of sheet pile, levee reconstruction, and floodwalls were determined from discussions with local contractors and suppliers of materials.

For the redwood box alternative, the cost included a yearly maintenance budget to inspect the entire alignment and provide repairs, including box replacement, as needed. We have assumed a yearly budget in today's dollars between $10k and $20k. Based on recent County repair costs, we estimate that between 150 and 300 feet per year could be fully replaced. We have assumed a 50 year period as most structures are designed for a 50 year design life. A 5 percent annual escalation of yearly cost is included in the cost analysis as shown on Appendix A.

9.2.3 Environmental banking

A ditch present along the landside toe of the existing levee (a.k.a. Estancia Ditch) is considered a tidal wetland due to the presence of tidal vegetation. As such, any alternative that impacts the ditch will need to include cost associated with providing habitat elsewhere via mitigation/environmental banking at an assumed ration of 3:1 (i.e. for every acre impacted, three acres of equivalent or better wetlands located offsite will need to be purchased and maintained in perpetuity). For this study, we have assumed Burdell Mitigation Bank as the area for the wetland banking purchase. It should be noted that at the writing of this report, there are no tidal wetland banks available. We have used costs for non-tidal wetland banks. Further research into the viability and cost of tidal wetland mitigation banking would be undertaken during the design phase as necessary.

For the remainder of the site, we have not considered environmental banking will be necessary as all alternatives will be placed landward of the waterside levee crest hinge point. If through the current process alternatives are added that result in construction activities on the waterside of the levee, consideration will need to be given to the associated impacts of encroachment into the adjacent wetlands.

10. RECOMMENDATIONS FOR FURTHER STUDIES

This report was prepared to provide a screening level assessment of alternatives to improve the performance of the LGLS during a 100-yr flood event. This assessment considered 100-year flood events under the Year 0 (no sea level rise) scenario and the Year 50 (NRC Curve III sea level rise) scenario. Additional discussions between the District and USACE would be required in order to develop a short list of viable alternatives for further analysis, cost refinement, and design. Ultimately, total project costs will include environmental planning and permitting, engineering design, including investigations, preparation of plans and specifications, and construction, including construction oversight.

Final design of the accepted improvement alternative(s) will be required prior to preparing construction plans and specifications for this site. Final design will include additional geotechnical field exploration (e.g. borings, CPTs, exploratory test pits, and/or geophysical and land surveys), laboratory testing, and engineering analyses. For conformance to the current USACE standards for levee construction, an exploration point should occur at the crest, landside toe, and approximately 200 feet landward of the landside toe along the levee's alignment at intervals between 200 and 1,000 feet, depending on the encountered site and subsurface conditions, in order to adequately assess the subsurface condition at the site. The data obtained in the field and laboratory should be used to perform final design analyses, including slope stability and seepage analyses.

11. LIMITATIONS

Recommendations contained in this report are based on our field observations, subsurface explorations completed by Kleinfelder and others, laboratory tests, and our present knowledge of the existing levee conditions. It is possible that soil conditions could vary between or beyond the points explored.

We have prepared this report in substantial accordance with the generally accepted geotechnical engineering practice as it exists in the site area at the time of our study. No other warranty, express or implied, is made.

This report may be used only by the client and their representatives, and only for the purposes stated, within a reasonable time from its issuance. Land use, site conditions (both on site and off site), or other factors may change over time, and additional work may be required with the passage of time. Any party other than the client who wishes to use this report shall notify Kleinfelder of such intended use. Based on the intended use of the report, Kleinfelder may require that additional work be performed and that an updated report be issued. Non-compliance with any of these requirements by the client or anyone else will release Kleinfelder from any liability resulting from the use of this report by any unauthorized party.

Construction safety is the sole responsibility of the contractor, who is also solely responsible for the means, methods, and sequencing of construction operations. We are providing the information below solely as a service to our client. Under no circumstances should the information provided herein be interpreted to mean that Kleinfelder is assuming responsibility for construction site safety; such responsibility is not being implied and should not be inferred. All information given below should be confirmed or modified by the contractor's "competent person" in charge of excavation safety based on the actual field conditions encountered during construction.

12. REFERENCES

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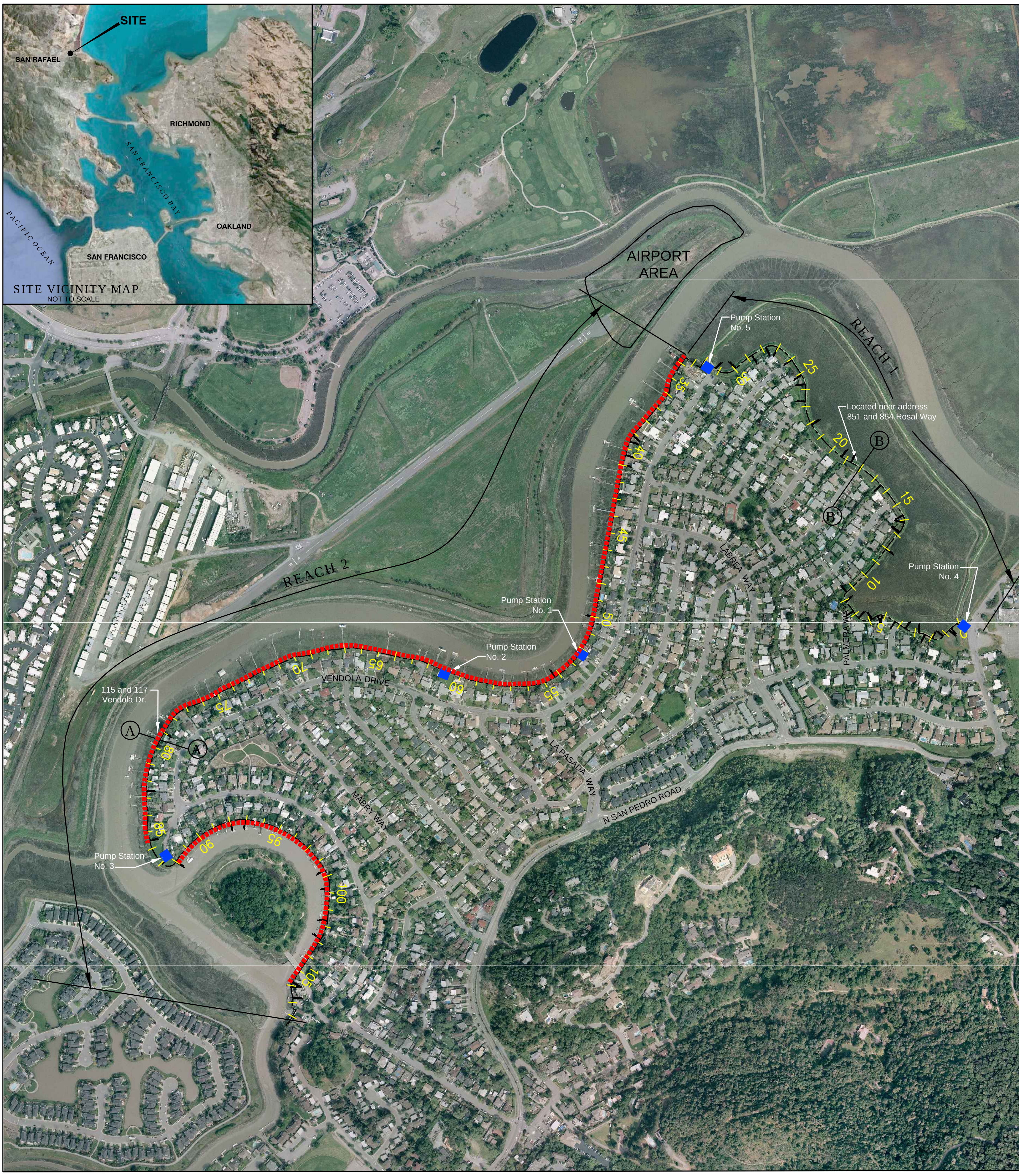
PLATES



LEGEND

(A)—	PROFILE SECTION
85	STATIONING
	REDWOOD BOX
	PUMP STATION

N

500 250 0 500

APPROXIMATE SCALE (feet)

BASE MAP: GOOGLE EARTH PRO 2010

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FILE NAME:	SitePlan-Plate 1-1_R1.DWG

SITE AND BORING LOCATION PLAN

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

1-1

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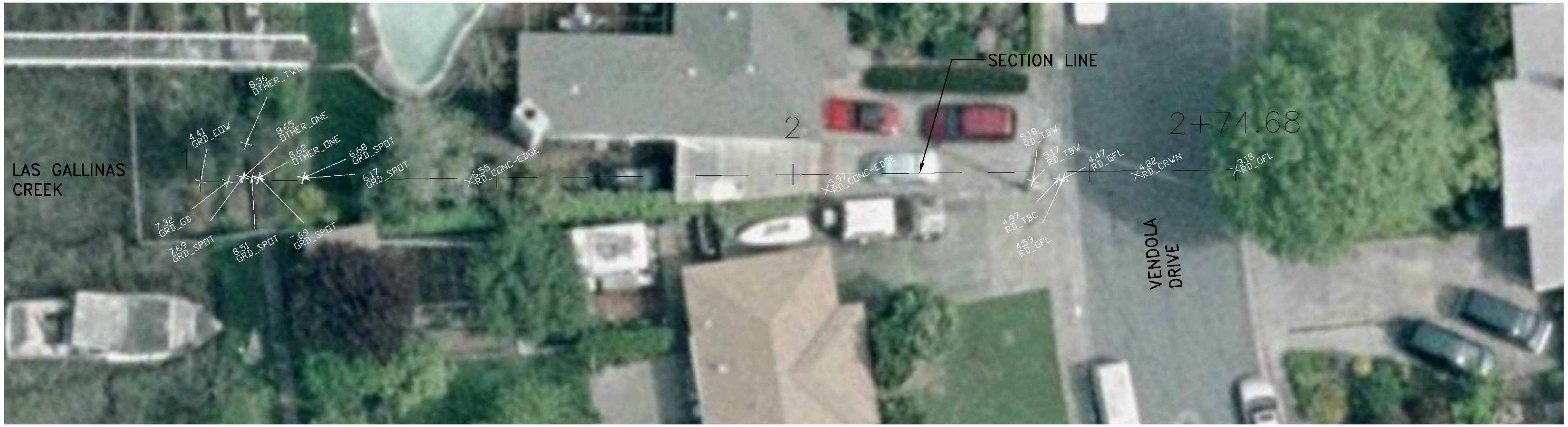

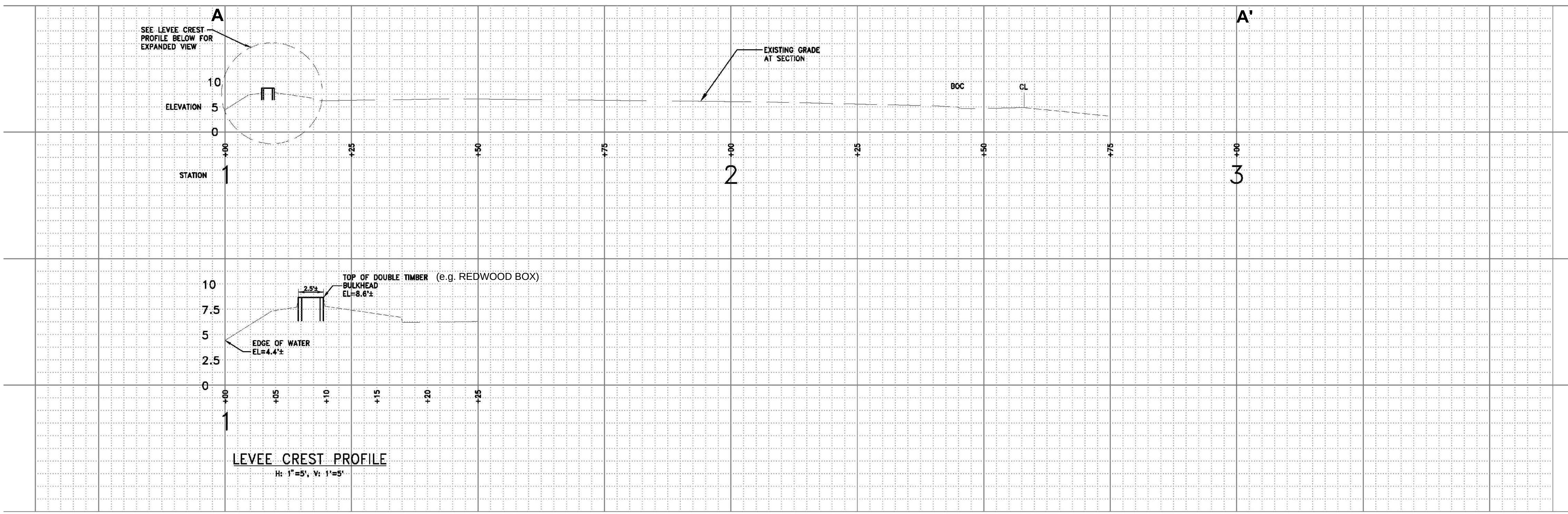

REFERENCE: Wood Rodgers, Levee Evaluation drawing, dated December 2008

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APPROXIMATE SCALE (feet)

NOTE: Reduced scale to fit 11" x17" format.

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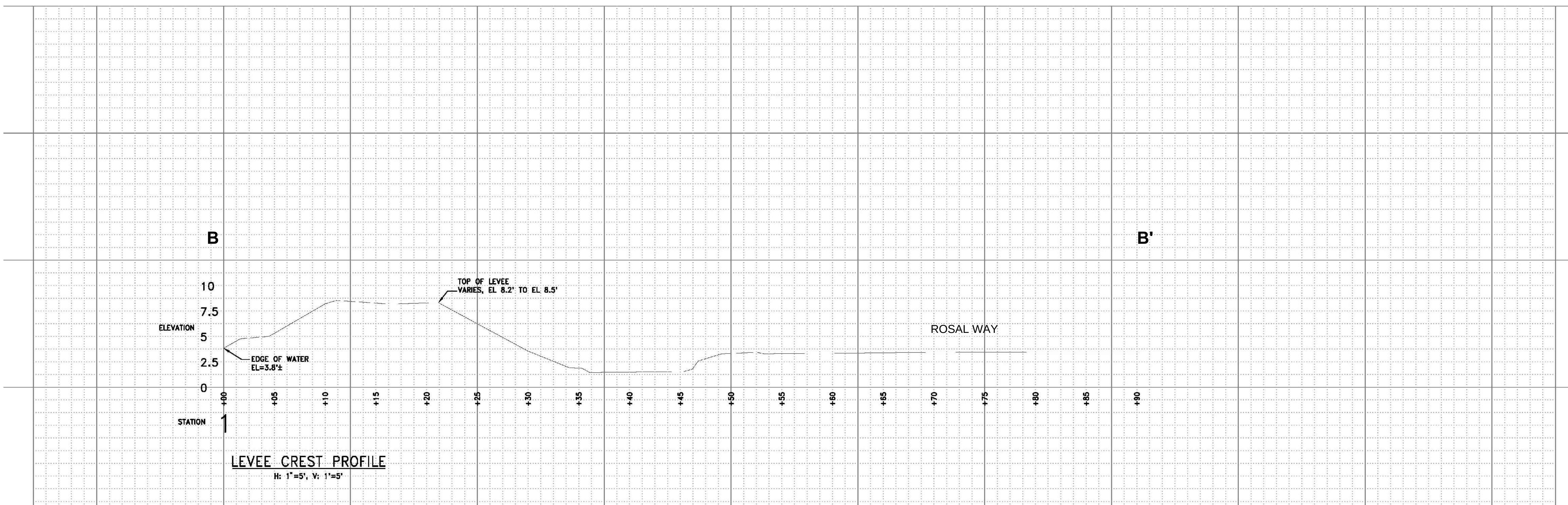
CROSS SECTION A-A'
117 VENDOLA DRIVE

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

2-1



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APPROXIMATE SCALE (feet)

NOTE: Reduced scale to fit 11" x17" format.

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CROSS SECTION B-B'
851 ROSAL WAY

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE
2-2

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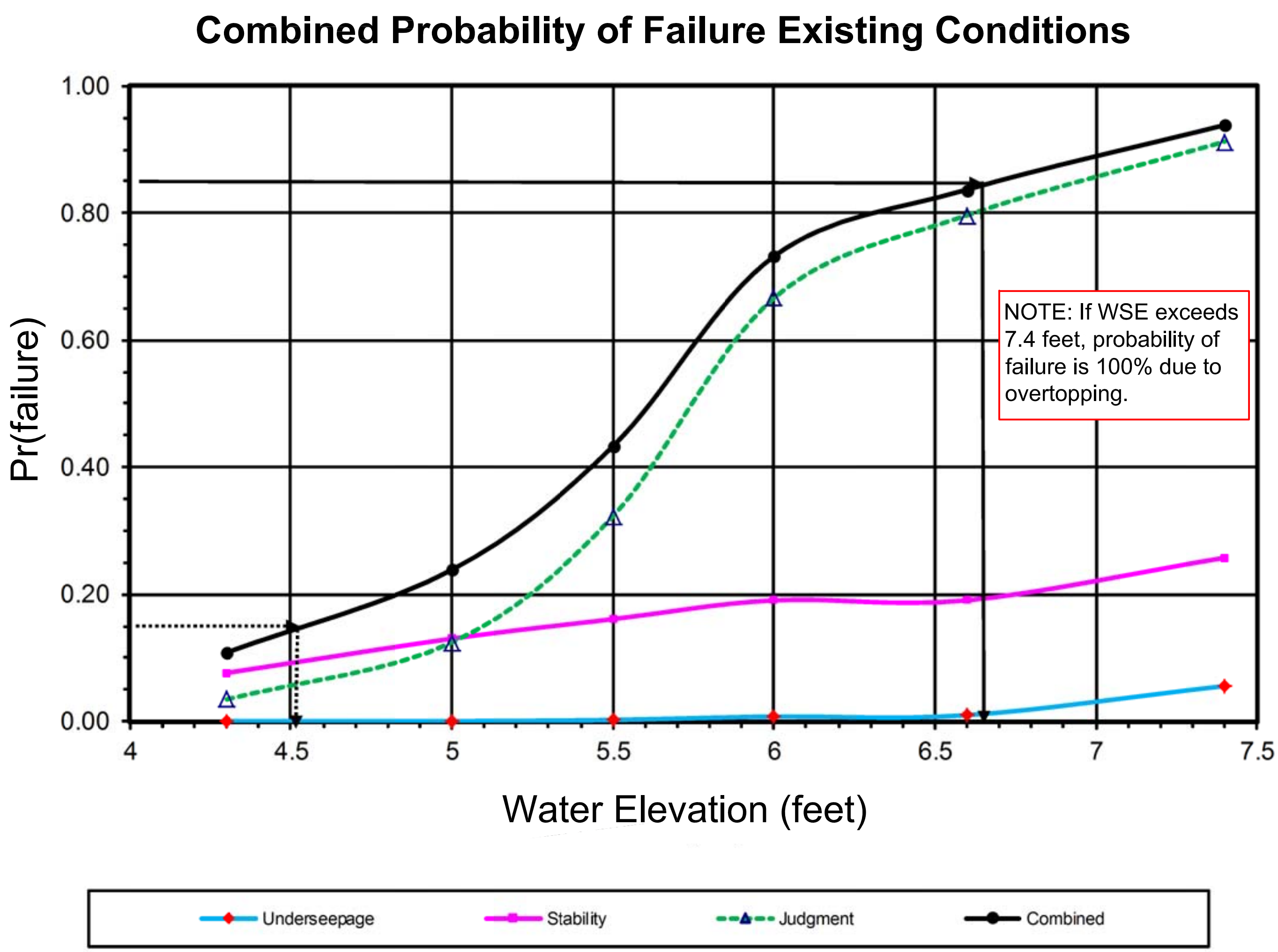

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COMBINED PROBABILITY OF FAILURE EXISTING CONDITIONS

ALTERNATIVE ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

3-1

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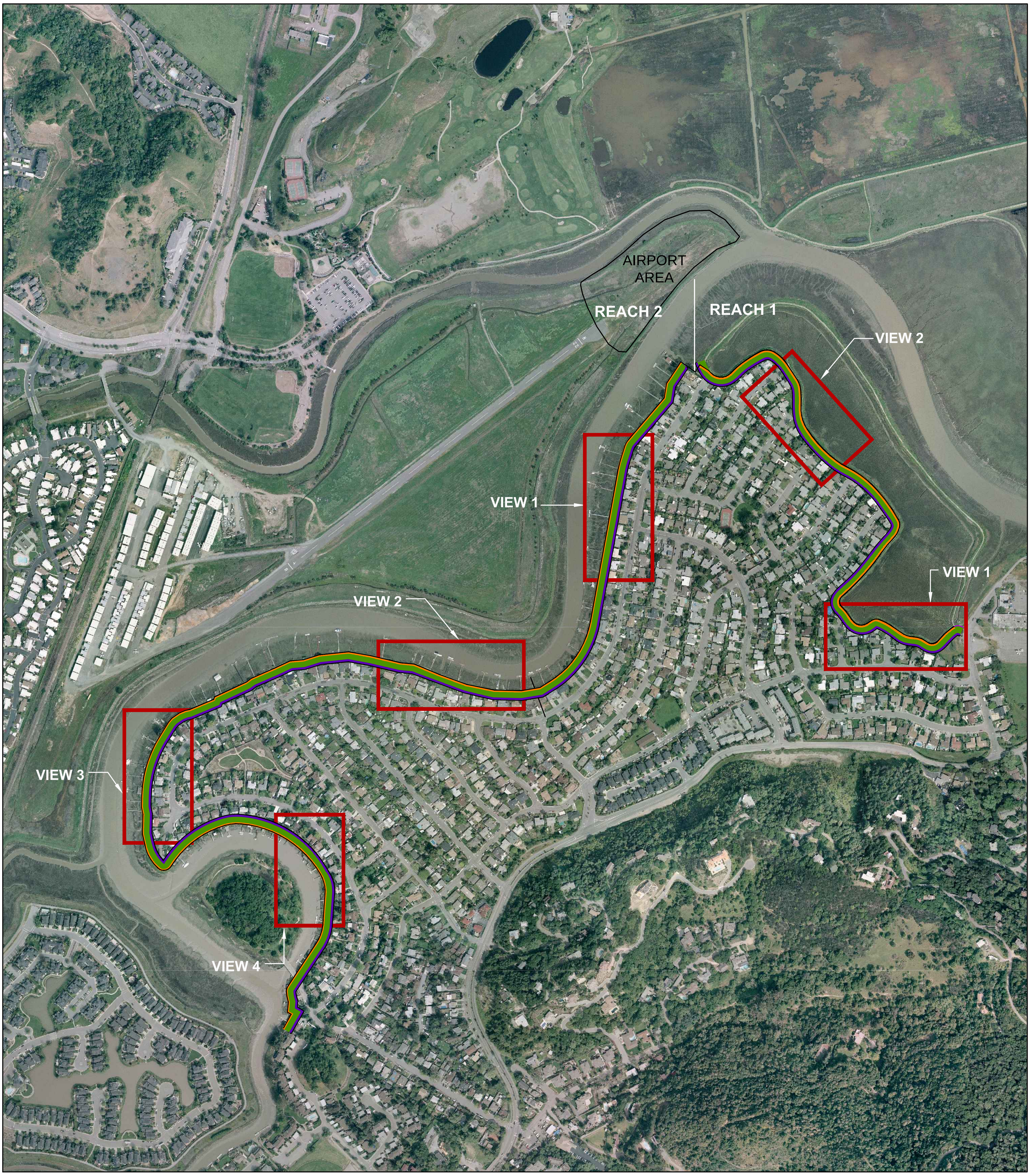

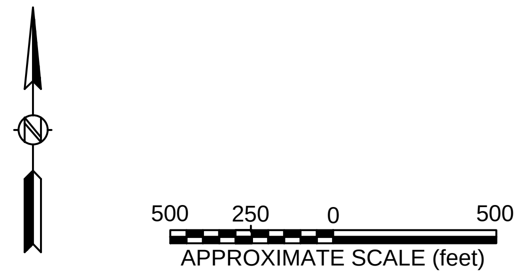

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DRAWN BY:	AG
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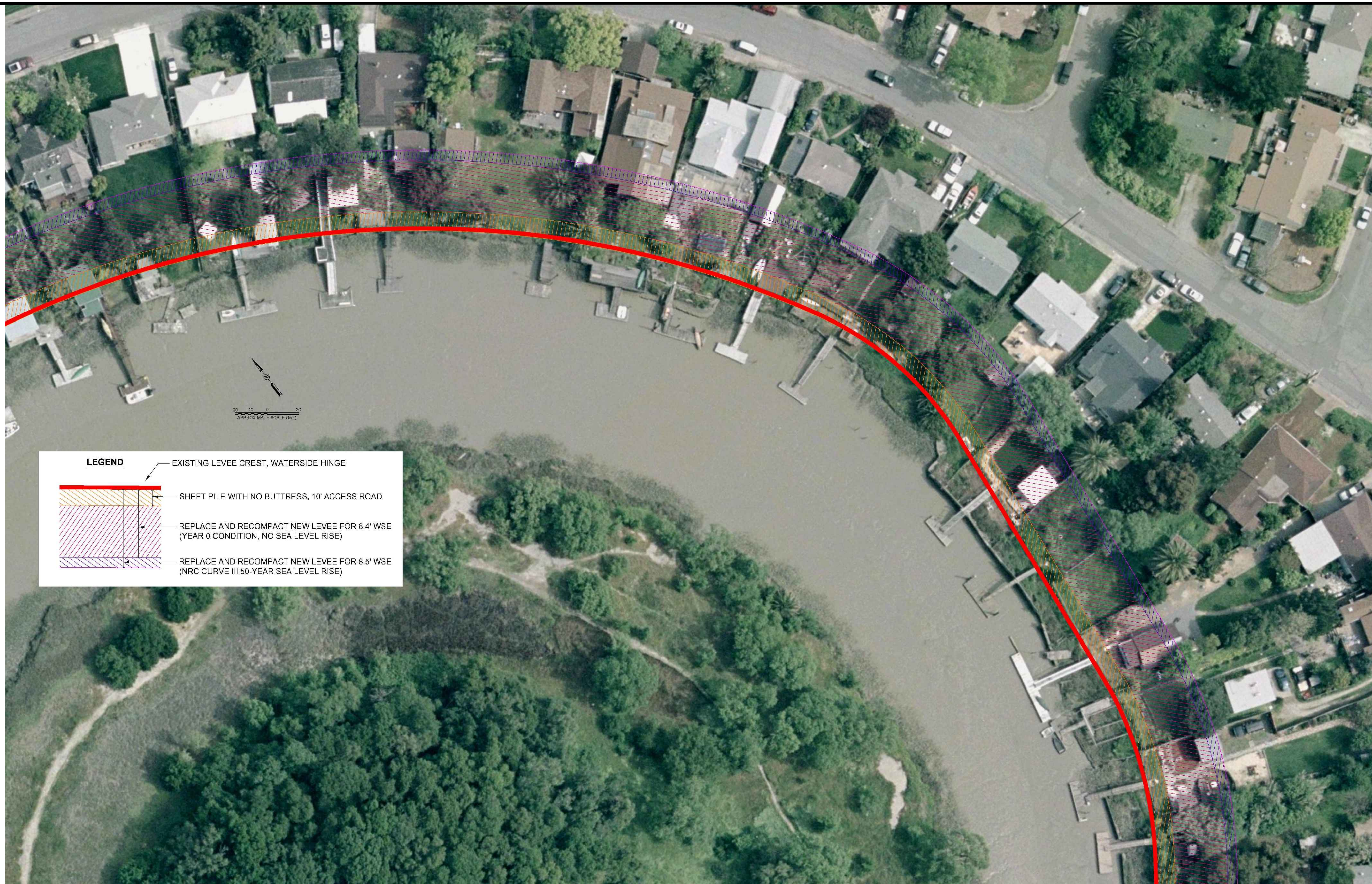
FILE NAME:	P_5-1_Rev-Buffers.dwg

ALTERNATIVE FOOTPRINTS

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE
5-1



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FILE NAME: SiteViews_1-6_R1.dwg	

REACH 2 - VIEW 1

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE
5-2

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FILE NAME: SiteViews_1-6_R1.dwg	

REACH 2 - VIEW 2

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

5-3

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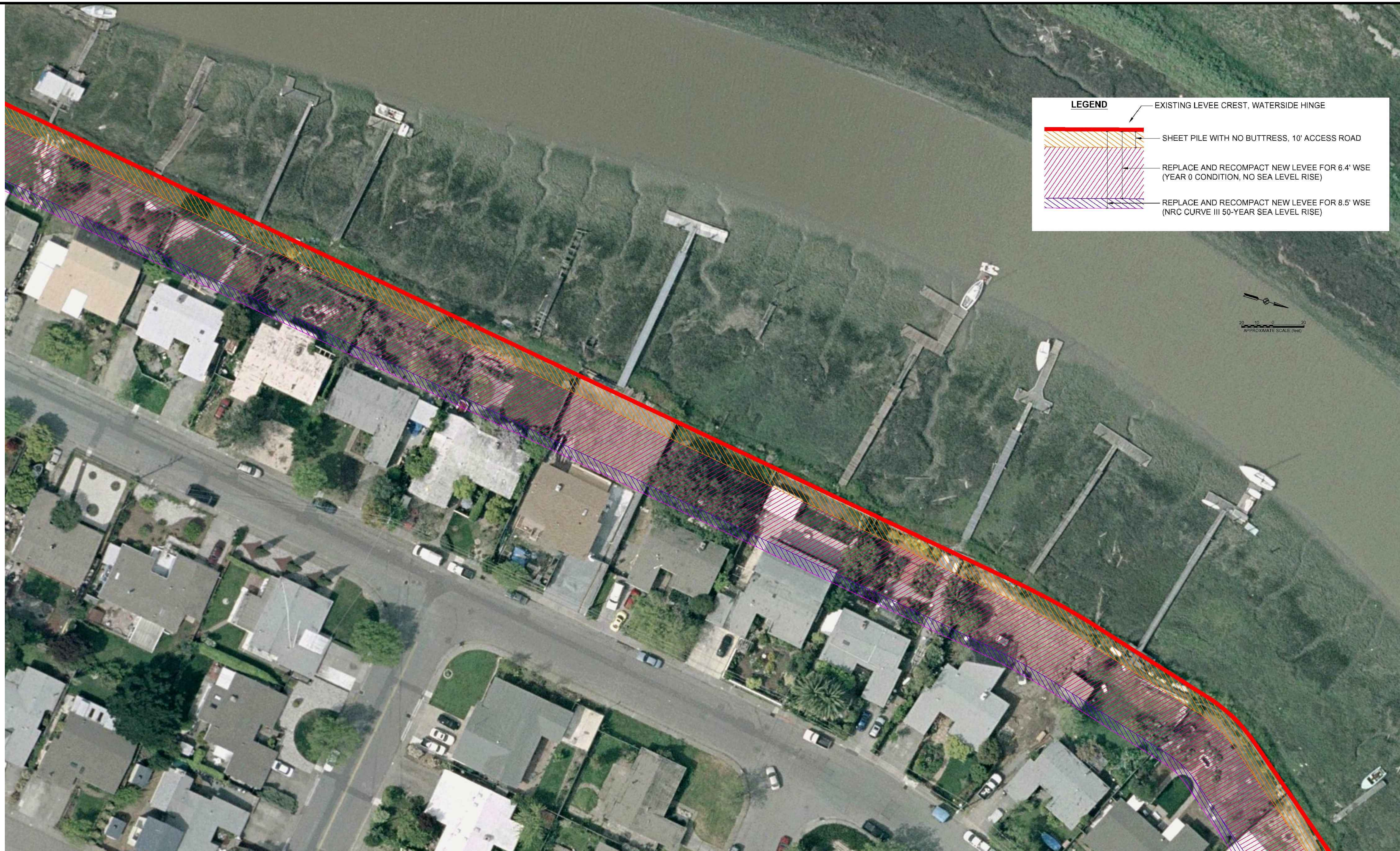
FILE NAME:	SiteViews_1-6_R1.dwg

REACH 2 - VIEW 3

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE
5-4



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REACH 2 - VIEW 4

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

5-5

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DRAWN BY:	AG
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FILE NAME:	SiteViews_1-6_R1.dwg

REACH 1 - VIEW 5

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

5-6

OAKLAND, CA

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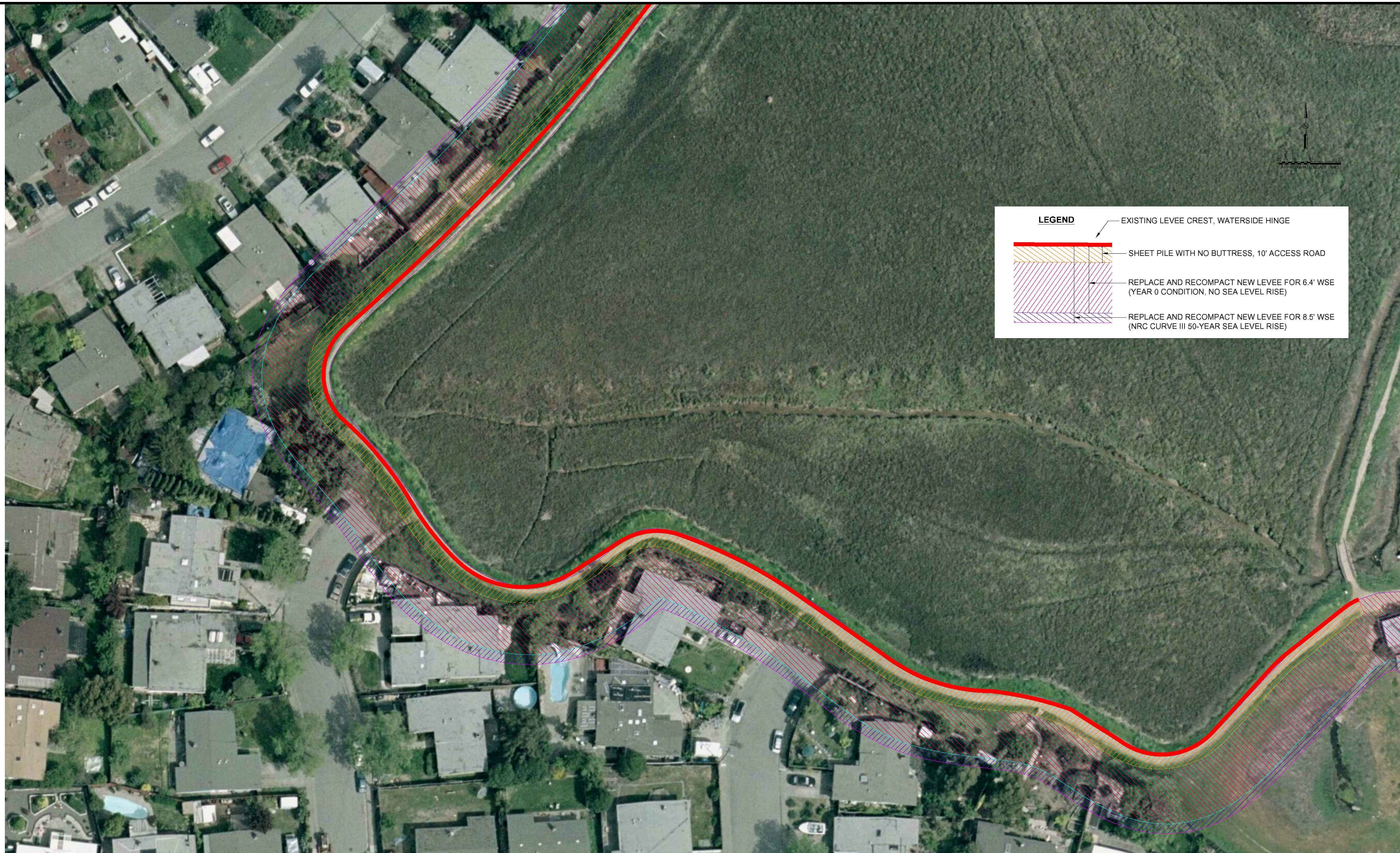

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DRAWN BY:	AG
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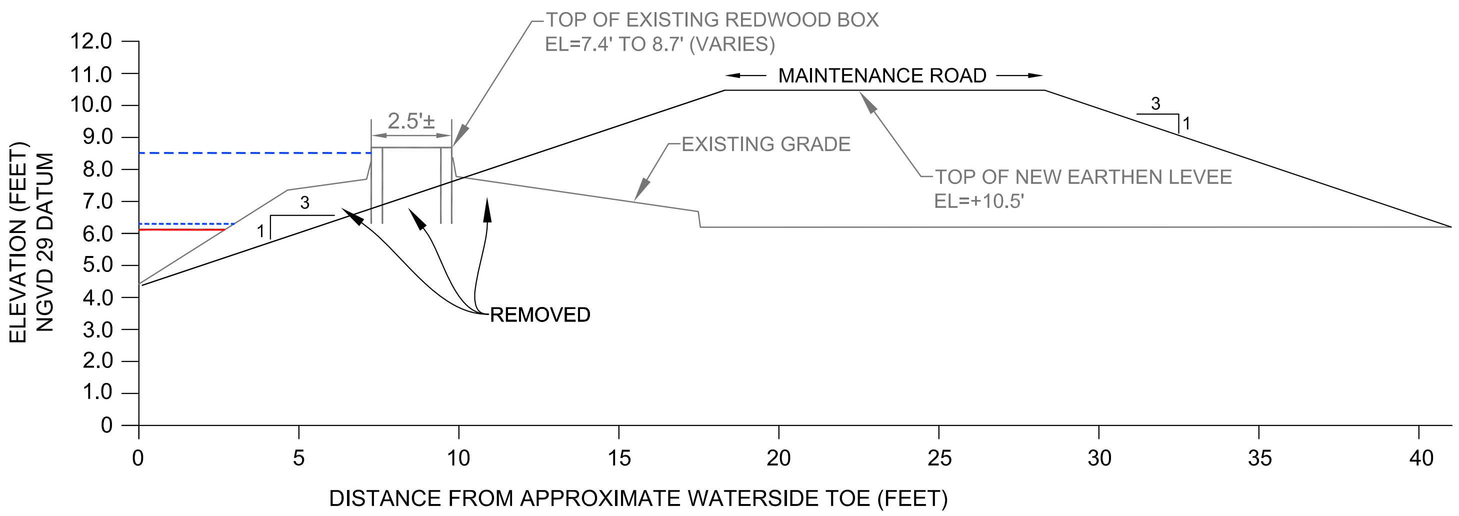
FILE NAME:	SiteViews_1-6_R1.dwg

REACH 1 - VIEW 6

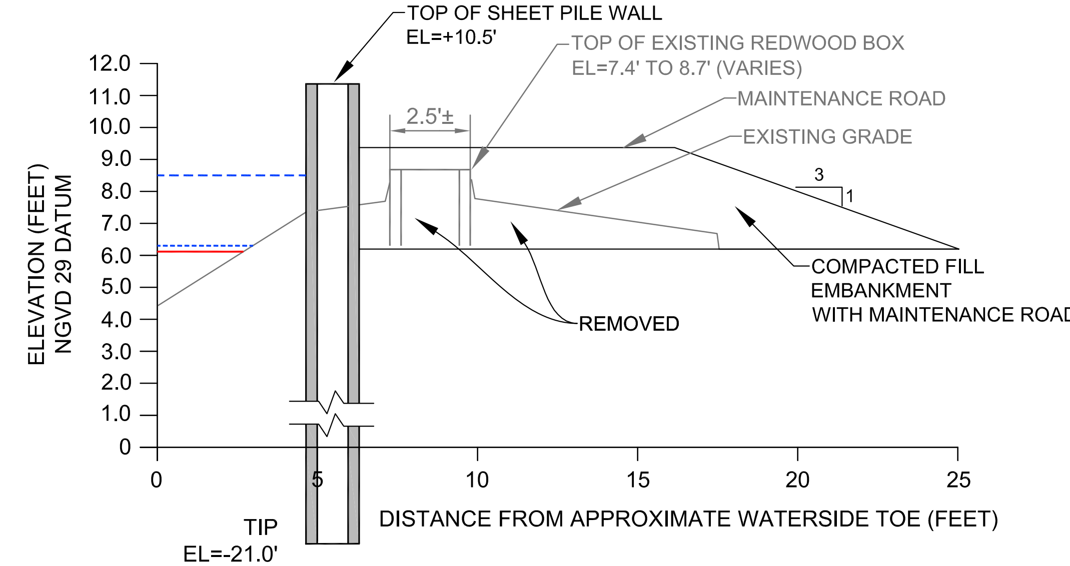
ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE

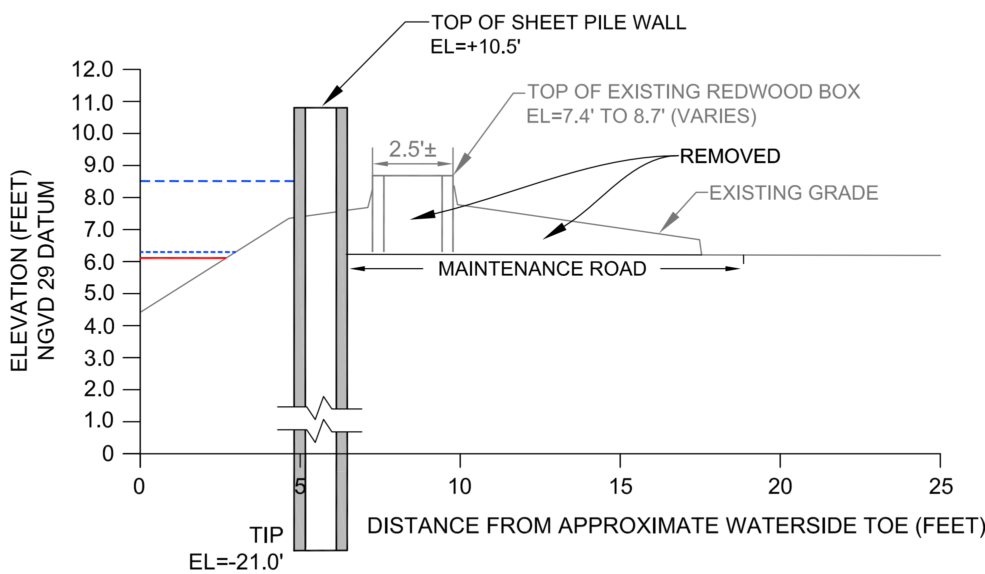
5-7



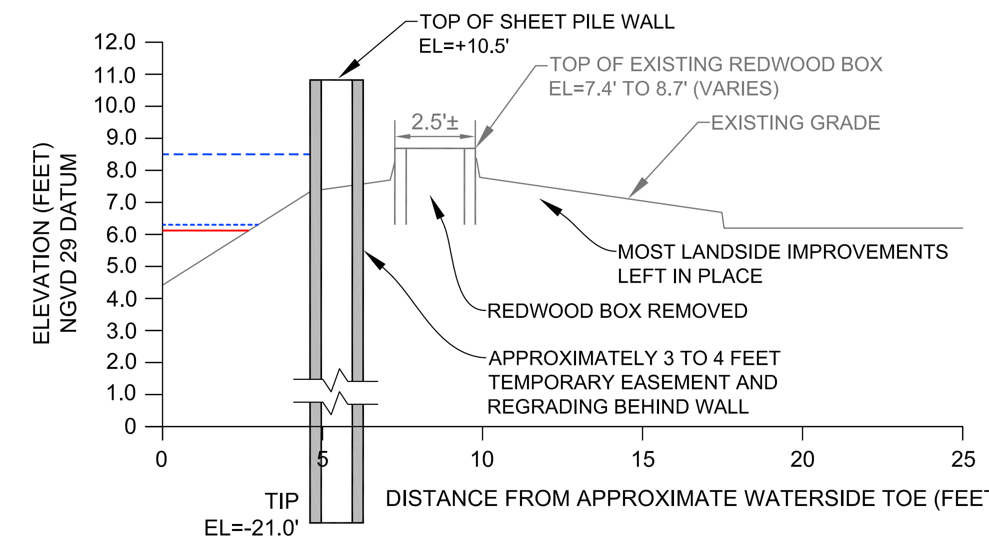
NEW EARTHEN LEVEE



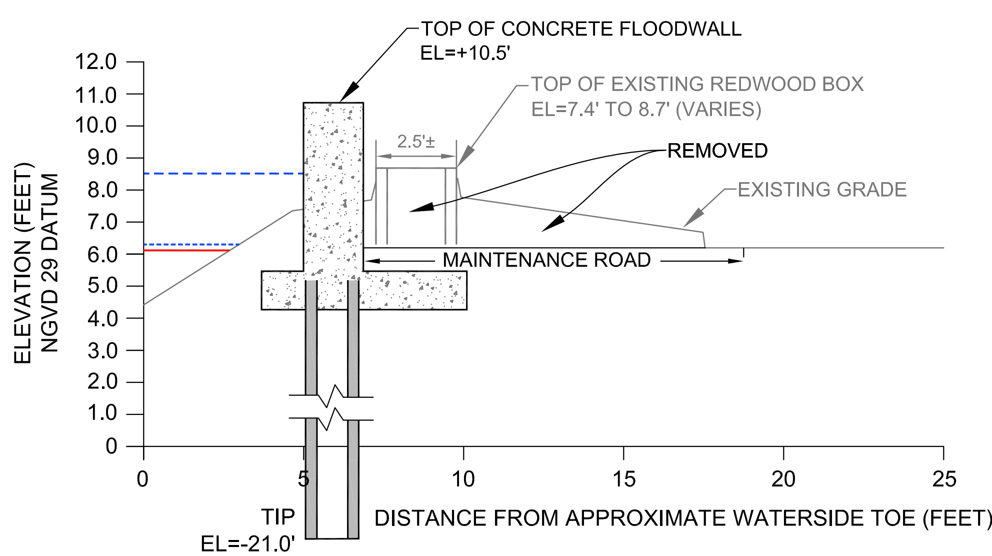
SHEET PILE WALL WITH SOIL BUTTRESS AND MAINTENANCE ROAD



SHEET PILE WALL, NO SOIL BUTTRESS, WITH MAINTENANCE ROAD



SHEET PILE WALL, NO SOIL BUTTRESS, NO MAINTENANCE ROAD



CONCRETE FLOOD WALL WITH MAINTENANCE ROAD

LEGEND

- 8.5 FT: 100-YEAR WSE, NRC CURVE III, YEAR 2061
- 6.4 FT: 100-YEAR WSE, NO SEA LEVEL RISE, YEAR 2011
- 6.03 FT: RECORD HIGH TIDE AT SF GAUGE, YEAR 1983

NOTE:
MITIGATION GEOMETRIES SHOWN ARE DESIGNED TO PROVIDE PROTECTION AGAINST THE 100-YEAR WSE, NRC CURVE III. IF A LOWER DESIGN WSE IS SELECTED (SUCH AS THE "NO SEA LEVEL RISE" WSE) ALL MITIGATION GEOMETRIES WOULD BE LOWERED ACCORDINGLY.

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FILE NAME:	LeveeCrestProfile.dwg

MITIGATION ALTERNATIVES
REACH 2, NRC CURVE III WSE

ALTERNATIVES ANALYSIS
LAS GALLINAS LEVEE SYSTEM
SAN RAFAEL, CALIFORNIA

PLATE
5-8

APPENDIX A

COST ANALYSIS – DETAILED

Reach 1
Station 0+00 to 32+00
Las Gallinas Conceptual Levee Evaluation
Santa Venetia, Marin County, California

	Unit Costs
Steel Sheetpile Cost per Sq Ft =	$15
Concrete floodwall Cost per Sq Ft =	$100
Fill Placement and Compaction per cubic yard =	$26
Burdell Mitigation Bank (non-tidal wetlands) per 0.1 acre	$79,500
Assumed mitigation cost per 0.1 acre for tidal wetlands = 3x non-tidal cost	$238,500
Width of tidal wetlands (Estancia ditch), feet	20

Total Project Costs: Reach 1 - 100-Year WSE, No Sea Level Rise

	Construction Costs													Project Administration		Real Estate	Contingency	Total Cost		
Description of Alternative	**Water Level Elevation[1]** (ft)	**Length of Mitigation Alternative** (ft)	**Height of Mitigation Alternative[2]** Elevation at Top (ft)	**Concrete Floodwall** Elevation at Bottom (ft)	**Sheetpile[3]** Elevation at Bottom (ft)	**Cost of Sheetpile / Floodwall**	**Plan Footprint of Mitigation** (sf) per lineal foot	**Environmental Banking Area** acres	**Environmental Banking Cost**	**Fill Quantity** (cubic yards)	**Fill Cost**	**Mobilization / Demobilization of Equipment**	**Total Construction Costs**	**Construction Management** (12.5% of all construction costs)	**Permitting, Engineering and Design** (20% of all construction costs)	**Real Estate Costs** (see separate table)	**Overall Project Contingency** (16% of all costs)	**Total Cost**	**Rounded Total Cost**	**Meets USACE/FEMA Criteria for Accreditation?**
Reconstruct and Raise Levee	6.4	3,200	9	NA	NA	0	40	1.47	$3,504,132	40,000	$1,040,000	$30,000	$4,574,132	$571,767	$914,826	$16,746,000	$3,649,076	$26,455,801	$26,500,000	Yes
Single Sheetpile, Maintenance Road w/soil buttress (existing levee section acts as buttress)	6.4	3,200	9	NA	-12	$1,008,000	0	0	$0	3,000	$78,000	$50,000	$1,136,000	$142,000	$227,200	$0	$240,832	$1,746,032	$1,700,000	Yes
Concrete Floodwall	6.4	3,200	9	8	-12	$2,016,000	0	0	$0	3,000	$78,000	$50,000	$2,144,000	$268,000	$428,800	$0	$454,528	$3,295,328	$3,300,000	Yes

All elevations are in NGVD29 Datum.
1. Based on Year 0 (no sea level rise) scenario.
2. Top elevation = Water Level Elevation + 2.6 feet wave run-up in Reach 1.
3. Sheet piles required under concrete floodwalls to control for seepage.

Real Estate Costs: Reach 1 - 100-Year WSE, No Sea Level Rise

	Homes Fully Impacted							Homes Partially Impacted								
Description of Alternative	**Number of Homes Fully Impacted** (Requiring full take)	**Cost per home for full acquisition**	**Cost per home for relocation**	**Cost per home for RE administration**	**Cost per home for RE contingency** (20%)	**Total parcel cost per full acquisition**	**Total cost for all full acquisitions**	**Number of Homes Partially Impacted** (Requiring easement)	**Width of easement** (ft)	**Cost per home for easement** ($50/sq ft x easement width x average 70 ft parcel width)	**Cost per home for inconvenience during construction**	**Cost per home for RE administration**	**Cost per home for RE contingency** (20%)	**Total parcel cost per partial acquisition**	**Total cost for all partial acquisitions**	**Total Real Estate Cost**
Reconstruct and Raise Levee	14	$ 750,000	$ 50,000	$ 25,000	$165,000	$ 990,000	$ 13,860,000	13	40	$ 140,000	$ 20,000	$ 25,000	$ 37,000	$ 222,000	$ 2,886,000	$ 16,746,000
Single Sheetpile, Maintenance Road w/soil buttress (existing levee section acts as buttress)	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Concrete Floodwall	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Reach 2
Station 32+00 to 108+00
Las Gallinas Conceptual Levee Evaluation
Santa Venetia, Marin County, California

	Unit Costs
Steel Sheetpile Cost per Sq Ft =	$15
Concrete floodwall Cost per Sq Ft =	$100
Fill Placement and Compaction per cubic yard =	$26

Total Project Costs: Reach 2 - 100-Year WSE, No Sea Level Rise

	Construction Costs													Project Administration		Real Estate	Contingency	Total Cost		
Description of Alternative	Water Level Elevation[1] (ft)	Length of Mitigation Alternative (ft)	Height of Mitigation Alternative[2] Elevation at Top (ft)	Concrete Floodwall Elevation at Bottom (ft)	Sheetpile[3] Elevation at Bottom (ft)	Cost of Sheetpile / Floodwall	Plan Footprint of Mitigation (sf) per lineal foot	Environmental Banking Area acres	Environmental Banking Cost	Fill Quantity (cubic yards)	Fill Cost	Mobilization / Demobilization of Equipment	Total Construction Costs	Construction Management (12.5% of all construction costs)	Permitting, Engineering and Design (20% of all construction costs)	Real Estate Costs (see separate table)	Overall Project Contingency (16% of all costs)	Total Cost	Rounded Total Cost	Meets USACE/FEMA Criteria for Accreditation?
Reconstruct and Raise Levee	6.4	7,600	8.4	NA	NA	0	40	0	$0	75,000	$1,950,000	$30,000	$1,980,000	$247,500	$396,000	$42,852,000	$7,276,080	$52,751,580	$52,800,000	Yes
Single Sheetpile, Maintenance Road w 3' tall soil buttress	6.4	7,600	8.4	NA	-21	$3,351,600	18	0	$0	13,000	$338,000	$50,000	$3,739,600	$467,450	$747,920	$15,180,000	$3,221,595	$23,356,565	$23,400,000	Yes
Single Sheetpile, Maintenance Road/No Buttress	6.4	7,600	8.4	NA	-21	$3,351,600	12	0	$0	5,000	$130,000	$50,000	$3,531,600	$441,450	$706,320	$11,484,000	$2,586,139	$18,749,509	$18,700,000	Yes
Single Sheetpile, No Maintenance Road	6.4	7,600	8.4	NA	-21	$3,351,600	12	0	$0	2,000	$52,000	$50,000	$3,453,600	$431,700	$690,720	$8,712,000	$2,126,083	$15,414,103	$15,400,000	No
Concrete Floodwall	6.4	7,600	8.4	5	-21	$7,296,000	12	0	$0	5,000	$130,000	$50,000	$7,476,000	$934,500	$1,495,200	$11,484,000	$3,422,352	$24,812,052	$24,800,000	Yes
Maintain Redwood Boxes for next 50 years.	Varies	7,600	NA	NA	NA	$0	0	0	$0	0	$0	$0	$0	$0	$0	$0	$0	$0	$0	No

All elevations are in NGVD29 Datum.
1. Based on Year 0 (no sea level rise) scenario.
2. Top elevation = Water Level Elevation + 2.0 feet freeboard in Reach 2.
3. Sheet piles required under concrete floodwalls to control for seepage.

Real Estate Costs: Reach 2 - 100-Year WSE, No Sea Level Rise

	Homes Fully Impacted						Homes Partially Impacted								
Description of Alternative	Number of Homes Fully Impacted (Requiring full take)	Cost per home for full acquisition	Cost per home for relocation	Cost per home for RE administration	Cost per home for RE contingency (20%)	Total parcel cost per full acquisition	Total cost for all full acquisitions	Number of Homes Partially Impacted (Requiring easement)	Width of easement (ft)	Cost per home for easement ($50/sq ft x easement width x average 70 ft parcel width)	Cost per home for inconvenience during construction	Cost per home for RE administration	Cost per home for RE contingency (20%)	Total parcel cost per partial acquisition	Total cost for all partial acquisitions	Total Real Estate Cost
Reconstruct and Raise Levee	24	$ 750,000	$ 50,000	$ 25,000	$165,000	$ 990,000	$ 23,760,000	86	40	$ 140,000	$ 20,000	$ 25,000	$ 37,000	$ 222,000	$ 19,092,000	$ 42,852,000
Single Sheetpile, Maintenance Road w 3' tall soil buttress	0	N/A	N/A	N/A	N/A	N/A	N/A	110	20	$ 70,000	$ 20,000	$ 25,000	$ 23,000	$ 138,000	$ 15,180,000	$ 15,180,000
Single Sheetpile, Maintenance Road/No Buttress	0	N/A	N/A	N/A	N/A	N/A	N/A	110	12	$ 42,000	$ 20,000	$ 25,000	$ 17,400	$ 104,400	$ 11,484,000	$ 11,484,000
Single Sheetpile, No Maintenance Road	0	N/A	N/A	N/A	N/A	N/A	N/A	110	6	$ 21,000	$ 20,000	$ 25,000	$ 13,200	$ 79,200	$ 8,712,000	$ 8,712,000
Concrete Floodwall	0	N/A	N/A	N/A	N/A	N/A	N/A	110	12	$ 42,000	$ 20,000	$ 25,000	$ 17,400	$ 104,400	$ 11,484,000	$ 11,484,000
Maintain Redwood Boxes for next 50 years.	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	0	0	0	0	0	0	0

Reach 1
Station 0+00 to 32+00
Las Gallinas Conceptual Levee Evaluation
Santa Venetia, Marin County, California

	Unit Costs
Steel Sheetpile Cost per Sq Ft =	$15
Concrete floodwall Cost per Sq Ft =	$100
Fill Placement and Compaction per cubic yard =	$26
Burdell Mitigation Bank (non-tidal wetlands) per 0.1 acre	$79,500
Assumed mitigation cost per 0.1 acre for tidal wetlands = 3x non-tidal cost	$238,500
Width of tidal wetlands (Estancia ditch), feet	20

Total Project Costs: Reach 1 - 100-Year WSE, NRC Curve III Sea Level Rise

	Construction Costs													Project Administration		Real Estate	Contingency	Total Cost		
Description of Alternative	**Water Level Elevation[1]** (ft)	**Length of Mitigation Alternative** (ft)	**Height of Mitigation Alternative[2]** Elevation at Top (ft)	**Concrete Floodwall** Elevation at Bottom (ft)	**Sheetpile[3]** Elevation at Bottom (ft)	**Cost of Sheetpile / Floodwall**	**Plan Footprint of Mitigation** (sf) per lineal foot	**Environmental Banking Area** acres	**Environmental Banking Cost**	**Fill Quantity** (cubic yards)	**Fill Cost**	**Mobilization / Demobilization of Equipment**	**Total Construction Costs**	**Construction Management** (12.5% of all construction costs)	**Permitting, Engineering and Design** (20% of all construction costs)	**Real Estate Costs** (see separate table)	**Overall Project Contingency** (16% of all costs)	**Total Cost**	**Rounded Total Cost**	**Meets USACE/FEMA Criteria for Accreditation?**
Reconstruct and Raise Levee	8.5	3,200	11.1	NA	NA	0	40	1.47	$3,504,132	48,000	$1,248,000	$30,000	$4,782,132	$597,767	$956,426	$19,818,000	$4,184,692	$30,339,017	$30,300,000	Yes
Single Sheetpile, Maintenance Road w/soil buttress (existing levee section acts as buttress)	8.5	3,200	11.1	NA	-12	$1,108,800	0	0	$0	3,000	$78,000	$50,000	$1,236,800	$154,600	$247,360	$0	$262,202	$1,900,962	$1,900,000	Yes
Concrete Floodwall	8.5	3,200	11.1	8	-12	$2,688,000	0	0	$0	3,000	$78,000	$50,000	$2,816,000	$352,000	$563,200	$0	$596,992	$4,328,192	$4,300,000	Yes

All elevations are in NGVD29 Datum.
1. Based on NRC Curve III scenario.
2. Top elevation = Water Level Elevation + 2.6 feet wave run-up in Reach 1.
3. Sheet piles required under concrete floodwalls to control for seepage.

Real Estate Costs: Reach 1 - 100-Year WSE, NRC Curve III Sea Level Rise

	Homes Fully Impacted							Homes Partially Impacted								
Description of Alternative	**Number of Homes Fully Impacted** (Requiring full take)	**Cost per home for full acquisition**	**Cost per home for relocation**	**Cost per home for RE administration**	**Cost per home for RE contingency** (20%)	**Total parcel cost per full acquisition**	**Total cost for all full acquisitions**	**Number of Homes Partially Impacted** (Requiring easement)	**Width of easement** (ft)	**Cost per home for easement** ($50/sq ft x easement width x average 70 ft parcel width)	**Cost per home for inconvenience during construction**	**Cost per home for RE administration**	**Cost per home for RE contingency** (20%)	**Total parcel cost per partial acquisition**	**Total cost for all partial acquisitions**	**Total Real Estate Cost**
Reconstruct and Raise Levee	18	$ 750,000	$ 50,000	$ 25,000	$165,000	$ 990,000	$ 17,820,000	9	40	$ 140,000	$ 20,000	$ 25,000	$ 37,000	$ 222,000	$ 1,998,000	$ 19,818,000
Single Sheetpile, Maintenance Road w/soil buttress (existing levee section acts as buttress)	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Concrete Floodwall	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Reach 2
Station 32+00 to 108+00
Las Gallinas Conceptual Levee Evaluation
Santa Venetia, Marin County, California

	Unit Costs
Steel Sheetpile Cost per Sq Ft =	$15
Concrete floodwall Cost per Sq Ft =	$100
Fill Placement and Compaction per cubic yard =	$26

Total Project Costs: Reach 2 - 100-Year WSE, NRC Curve III Sea Level Rise

	Construction Costs													Project Administration		Real Estate	Contingency	Total Cost		
Description of Alternative	Water Level Elevation[1] (ft)	Length of Mitigation Alternative (ft)	Height of Mitigation Alternative[2] Elevation at Top (ft)	Concrete Floodwall Elevation at Bottom (ft)	Sheetpile[3] Elevation at Bottom (ft)	Cost of Sheetpile / Floodwall	Plan Footprint of Mitigation (sf) per lineal foot	Environmental Banking Area acres	Environmental Banking Cost	Fill Quantity (cubic yards)	Fill Cost	Mobilization / Demobilization of Equipment	Total Construction Costs	Construction Management (12.5% of all construction costs)	Permitting, Engineering and Design (20% of all construction costs)	Real Estate Costs (see separate table)	Overall Project Contingency (16% of all costs)	Total Cost	Rounded Total Cost	Meets USACE/FEMA Criteria for Accreditation?
Reconstruct and Raise Levee	8.5	7,600	10.5	NA	NA	0	40	0	$0	96,000	$2,496,000	$30,000	$2,526,000	$315,750	$505,200	$61,284,000	$10,340,952	$74,971,902	$75,000,000	Yes
Single Sheetpile, Maintenance Road w 3' tall soil buttress	8.5	7,600	10.5	NA	-21	$3,591,000	18	0	$0	13,000	$338,000	$50,000	$3,979,000	$497,375	$795,800	$15,180,000	$3,272,348	$23,724,523	$23,700,000	Yes
Single Sheetpile, Maintenance Road/No Buttress	8.5	7,600	10.5	NA	-21	$3,591,000	12	0	$0	5,000	$130,000	$50,000	$3,771,000	$471,375	$754,200	$11,484,000	$2,636,892	$19,117,467	$19,100,000	Yes
Single Sheetpile, No Maintenance Road	8.5	7,600	10.5	NA	-21	$3,591,000	12	0	$0	2,000	$52,000	$50,000	$3,693,000	$461,625	$738,600	$8,712,000	$2,176,836	$15,782,061	$15,800,000	No
Concrete Floodwall	8.5	7,600	10.5	5	-21	$8,892,000	12	0	$0	5,000	$130,000	$50,000	$9,072,000	$1,134,000	$1,814,400	$11,484,000	$3,760,704	$27,265,104	$27,300,000	Yes
Maintain Redwood Boxes for next 50 years.	Varies	7,600	NA	NA	NA	$0	0	0	$0	0	$0	$0	$0	$0	$0	$0	$0	$0	$0	No

All elevations are in NGVD29 Datum.
1. Based on NRC Curve III scenario.
2. Top elevation = Water Level Elevation + 2.0 feet freeboard in Reach 2.
3. Sheet piles required under concrete floodwalls to control for seepage.

Real Estate Costs: Reach 2 - 100-Year WSE, NRC Curve III Sea Level Rise

	Homes Fully Impacted							Homes Partially Impacted									
Description of Alternative	Number of Homes Fully Impacted (Requiring full take)	Cost per home for full acquisition	Cost per home for relocation	Cost per home for RE administration	Cost per home for RE contingency (20%)	Total parcel cost per full acquisition	Total cost for all full acquisitions	Number of Homes Partially Impacted (Requiring easement)	Width of easement (ft)	Cost per home for easement ($50/sq ft x easement width x average 70 ft parcel width)	Cost per home for inconvenience during construction	Cost per home for RE administration	Cost per home for RE contingency (20%)	Total parcel cost per partial acquisition	Total cost for all partial acquisitions	Total Real Estate Cost
Reconstruct and Raise Levee	48	$ 750,000	$ 50,000	$ 25,000	$165,000	$ 990,000	$ 47,520,000	62	40	$ 140,000	$ 20,000	$ 25,000	$ 37,000	$ 222,000	$ 13,764,000	$ 61,284,000
Single Sheetpile, Maintenance Road w 3' tall soil buttress	0	N/A	N/A	N/A	N/A	N/A	N/A	110	20	$ 70,000	$ 20,000	$ 25,000	$ 23,000	$ 138,000	$ 15,180,000	$ 15,180,000
Single Sheetpile, Maintenance Road/No Buttress	0	N/A	N/A	N/A	N/A	N/A	N/A	110	12	$ 42,000	$ 20,000	$ 25,000	$ 17,400	$ 104,400	$ 11,484,000	$ 11,484,000
Single Sheetpile, No Maintenance Road	0	N/A	N/A	N/A	N/A	N/A	N/A	110	6	$ 21,000	$ 20,000	$ 25,000	$ 13,200	$ 79,200	$ 8,712,000	$ 8,712,000
Concrete Floodwall	0	N/A	N/A	N/A	N/A	N/A	N/A	110	12	$ 42,000	$ 20,000	$ 25,000	$ 17,400	$ 104,400	$ 11,484,000	$ 11,484,000
Maintain Redwood Boxes for next 50 years.	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	0	0	0	0	0	0	0