Marin County Flood Control and Water Conservation District

Gallinas Levee Upgrade Project
Flood Barrier Study

FINAL DRAFT Technical Memorandum

June 2020

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Appendix A Projected Sea Level Rise (in feet) for San Francisco

1. Introduction

1.1 Authorization

The Marin County Flood Control and Water Conservation District (District) has retained GHD Inc. (GHD) to prepare an alternatives screening and development study of a flood barrier wall along the South Fork Gallinas Creek at the Santa Venetia neighborhood in unincorporated San Rafael, CA.

1.2 Scope and Purpose of Work

The scope of the study is to develop design criteria for three alternatives to replace a timber-reinforced flood barrier by incrementally moving the project design and engineering forward to describe and accommodate risk factors that influence the project and ultimately to facilitate the development of construction plans and specifications. These factors include levee crest elevation, structural stability, and construction cost. The flood barrier is within the District's Zone 7 and extends approximately 7,200 linear feet behind private residences and properties adjacent to the South Fork Gallinas Creek, from Pump Station 5 to the Meadow Drive Bridge. In previous studies this has been referred to as Reach 2. Reach 1 continues further north as an earthen levee bordering the Santa Venetia Marsh Preserve to Pump Station 4. It does not use a timber-reinforced flood barrier and is not within the scope of this report. See Figure 1-1 for overall plan view of the existing timber-reinforced flood barrier alignment.

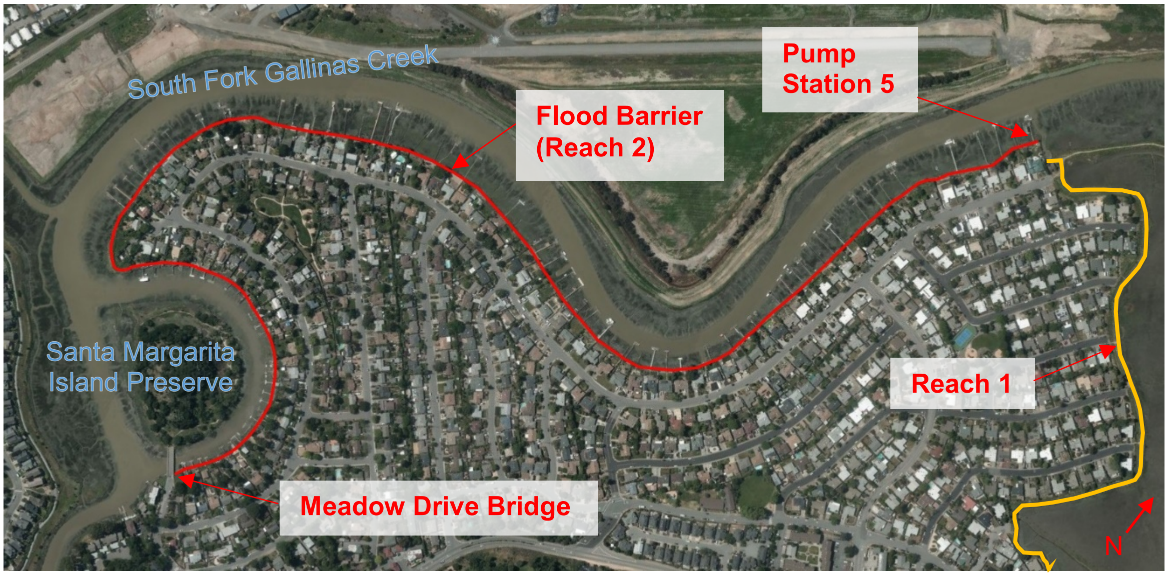

Figure 1-1: Plan View of Flood Barrier

The Santa Venetia neighborhood experienced tidal flooding in 1982 and 1983, and the District subsequently installed the existing flood barrier which consists of timber-reinforced berm (TRB) atop a pre-existing earthen levee. Elevations in this report are typically based on the North American Vertical Datum of 1988 (NAVD88). Various portions of this report will reference National Geodetic Vertical Datum of 1929 (NGVD29) and will be noted as such. The existing top of TRB elevation ranges from elevations 7.2 feet to 15.8 feet, with an average elevation of approximately 10 feet. The average top of earthen levee elevation in Reach 1 is approximately 10.9 feet.

The US Army Corps of Engineers (USACE) studied the system for possible upgrades under the Continuing Authorities Program and determined a viable levee project could not be designed and built to their standards here. That process, however, provided a good set of reports on existing hydrology and geotechnical conditions. The District has since applied for and been awarded a $2,982,753 grant from the Federal Emergency Management Agency (FEMA) through the Hazard Mitigation Grant Program (HMGP). The grant requires a minimum of $1,000,000 local match from the District, so the available total project budget from the grant for design, permitting, and construction is approximately $4,000,000.

Based on the past FEMA and USACE studies, the combination of sea level rise and subsidence of the levee increases the risk of damage to the TRB and overtopping during high tides and/or major flood events. As much of the existing TRB has been deteriorating, it poses a reliability concern to the effectiveness of flood risk management to the area. The District has been maintaining the TRB and repairing or replacing the timber elements at individual properties or segments of the TRB as needed and within available Zone 7 funds. These repairs or replacements do not aim to increase the height of the TRB beyond its original design elevation, which had been approximately 10 feet in NAVD88.

The objective of this study is to evaluate design alternatives for a flood barrier upgrade to replace the existing TRB that can protect residences and properties against a 1% chance flood event with a minimum service life of 30 years. This study builds on previous studies of the area conducted by Zone 7 and the County. The criteria for the alternatives include minimal maintenance requirements and need to be within $3,500,000 construction budget for the entire length of the existing TRB, based on available funding from FEMA HMGP plus local grant-matching funds for this project.

2. Basis of Alternatives Evaluation

2.1 Geotechnical Considerations

The Santa Venetia neighborhood was originally a tidal marshland that was reclaimed by placing fill for urban development. The residential area in the neighborhood was constructed over time since the 1940s, and the neighborhood was protected on three sides along the creek by earthen levees. The subsurface of the neighborhood and the earthen levees lie on top of a thick layer of bay mud, which is comprised of soft, compressible sediments.

While the existing levee has experienced significant settlement since its construction (Kleinfelder 2013), the District's monitoring data of the levee elevation shows that there is still ongoing settlement. It is anticipated that there will be approximately 3 to 4 inches of settlement per every 10 years for several decades under the existing condition (Kleinfelder 2018). With potential new additional loading from some of the possible flood barrier improvement alternatives, there may be additional settlement in the future. In addition, the bay mud exhibits significant potential for lateral spreading and liquefaction during seismic events. There are reports of seepage through the existing TRB at various residential properties, but they are mostly localized at those specific locations. The analysis by Kleinfelder 2013 concluded that the existing condition exhibits a low probability of failure due to seepage eroding away levee material. The sections on the floodwall design alternatives will discuss in detail the structural design to resist sliding, overturning, and seepage.

2.2 Target Level of Flood Protection

The overall goal of the project is to provide 100-year level of tidal flood protection for 30 years (assumed to be approximately 2050, to be in line with available sea level rise guidance planning data increments). In order to determine the top of barrier design elevation, previously modeled 100-year water surface elevations were referenced. The FEMA grant requires that the design also allow for sea level rise and potential settlement over the planned project life, however it is up to the local community's engineers to determine these projections. This section summarizes the sources of estimates for these three elements: the 100-year water surface elevation, sea level rise projection, and settlement over the planned project life.

FEMA defines the 100-year Stillwater Base Flood Elevation as 9.8 feet in the 2017 Flood Insurance Study (FEMA, 2017) for Marin County, at Station B19 as shown in Figure 2-1. The estimate is mainly based on coastal influence, under the 1% chance still water level estimated from the San Francisco Bay Area Coastal Study. Comparatively, the 100-year water surface elevation presented on Page 8 of the Las Gallinas Creek Hydrologic, Hydraulic and Coastal analysis (USACE 2013) was 6.4 feet NVGD29, or approximately 9.1 feet NAVD88. The estimate is based on a coincident frequency analysis to account for the combined probability between coastal water surface elevation and watershed flow, to set the 1% probability water surface elevation.

At the time the existing TRB was being constructed in 1983 the recorded high tides in the preceding year peaked at 8.7 feet (at the San Francisco Gauge). Since the TRB was constructed the tide level never exceed 8.7 feet, and therefore the TRB has never been tested against the design tide height to which it was constructed to respond. The nearest tide height it has experienced is 8.42 (1998) which is less than the 10-year tide, at 8.5 feet, in FEMA's 2017 flood insurance study.

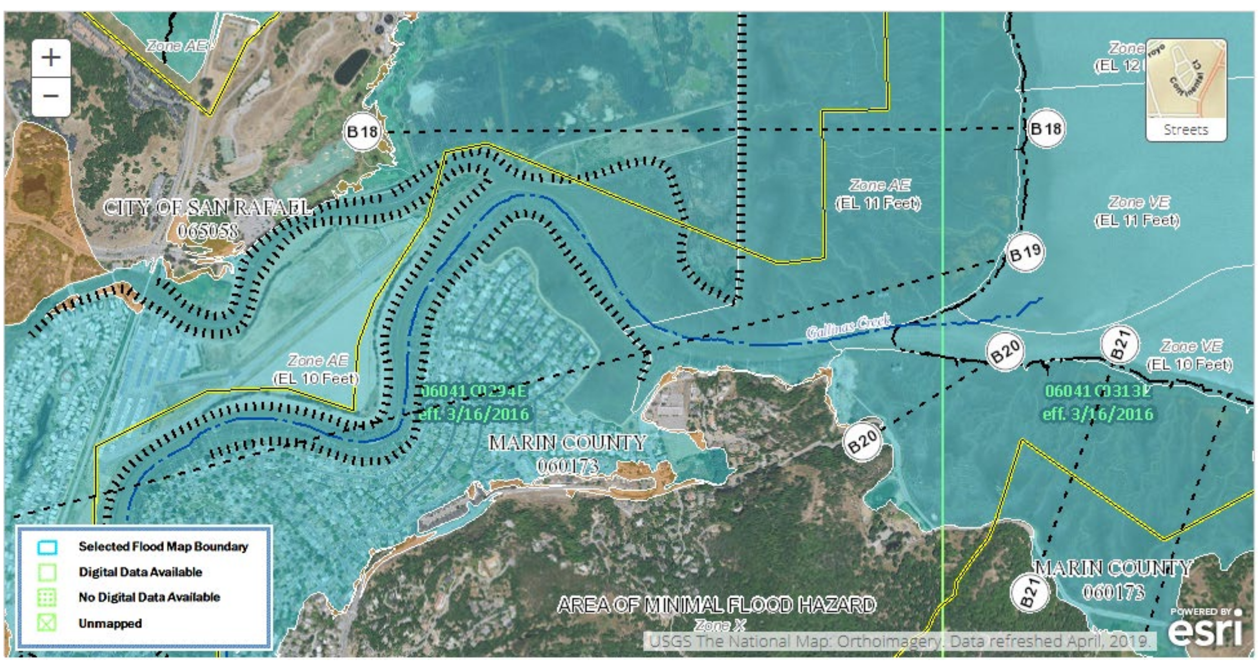

Figure 2-1: FEMA FIS Mapping (FEMA 2016)

The Sea Level Rise (SLR) projections have been estimated by a number of different agencies with the most recent estimates provided by the California Ocean Protection Council (OPC 2018). The State of California Sea Level Rise Guidance Document (OPC 2018, Table 1) provides a range of probabilistic SLR projections for the San Francisco Bay Area. The Likely Range High Emission estimates with 66% probability ranged from 0.6 and 1.1 feet by 2050, corresponding approximately with the anticipated 30 years project life for the new flood barrier anticipated construction completion between years 2020 and 2023. The OPC further estimates that there is a 5% probability that SLR will meet or exceed 1.4 feet by 2050, and 0.5% probability that SLR will meet or exceed 1.9 feet by 2050, which could be considered to represent the upper bound of reasonable SLR rates to consider in project planning. OPC 2018 Table 1 is attached in this technical memorandum in Appendix A for reference.

A land settlement estimate range was provided from an analysis completed by Kleinfelder in 2018 (Kleinfelder, 2018) which considered observed elevation changes at points in Santa Venetia tracked between 1990 and 2012. The analysis projected a settlement range of 3 to 4 inches per every 10 years for the next several decades.

Based on the sum of 100-year stillwater elevation, settlement estimate, and SLR projection, the design criteria may be based on the following range of values (rounded up to the nearest 0.1 feet):

100-year Water Surface Elevation (NAVD88)		2050 Projected Sea Level Rise from OPC (published 2018)		Land Subsidence Estimates from 1990-2012 data by Kleinfelder (2018)	
USACE 2013	FEMA 2016	Low-end 66% Probability	1 in 200 Chance	Low	High
9.1	9.8	0.6	1.9	0.8	1

Table 2-1: Summary of Range of Elevation Design Criteria Factors

Selecting values from Table 2-1 results in a range of 10.45 to 12.7 feet NAVD88 as potential target design elevations that would meet the overall objective of providing 100-year flood protection over a 30-year design life. The alternatives analysis in this study is based on two different flood barrier elevation design criteria: 11 feet and 12.5 feet.

The 11-foot elevation alternative considers the following components:

- The USACE 100-year flood elevation (9.1 feet NAVD88)
- The median value of OPC 2018 66% probability for SLR (0.9 feet)
- The high end of the settlement projection range (1 foot)

The 12.5-foot elevation alternative considers the following components:

- The FEMA 100-year flood elevation (9.8 feet)
- The median between OPC 2018 5% probability and 0.5% probability SLR, which corresponds to the County of Marin's 2017 BayWAVE Vulnerability Analysis SLR estimate (1.7 feet)
- The high end of the settlement projection range (1 foot)

2.3 Existing Timber Reinforced Berm

Along Vendola Drive in the Santa Venetia neighborhood, there are approximately 120 private residences that abut Gallinas Creek with an earthen levee along the rear property lines, and most also have a timber reinforced berm (TRB) on top of the levee. It is a simple but effective method to use two parallel timber retaining walls approximately 2.5 feet apart and filled with soil to provide the structural strength, forming a narrow berm to protect against flood waters. The compacted soil berms works as a barrier to tidal flooding but its effectiveness is decreased as the soil loosens. The faces of the berm consist of horizontal redwood planks stacked vertically, and redwood posts outboard of the berm to provide lateral stability and to maintain the geometry of the soil. The TRB varies in height up to approximately 4 feet, with an average height of 2 feet. Over time, portions of the original timber boards and posts have deteriorated due to a number of environmental factors and some are no longer functional to effectively holding the soil berm between the planks. Figure 2-2 shows an example of deterioration, where the posts have rotated out of position and pulled away from the planks.

Figure 2-2: Deteriorated Timber Reinforced Berm

Figure 2-3 shows an example of a location where the original post has rotted away to the finished grade, and a replacement post was attached like a spur to improve the service life of the wall. In this example, the replacement post is already exhibiting evidence of rotation, and is no longer supporting the planks. The adjacent post the right side of the photo is showing signs of distress and significant section loss. Signs of distress may include fractured or deflected members. Section loss occurs when the cross sectional area of a member is reduced due to decay or infestation, which can result in a significant reduction of bending capacity. It can be exterior loss, where it can be observed that the timber member has deteriorated from its original dimension and shape, or interior loss, such as when insects or fungus burrow into the wood and damage from the inside.

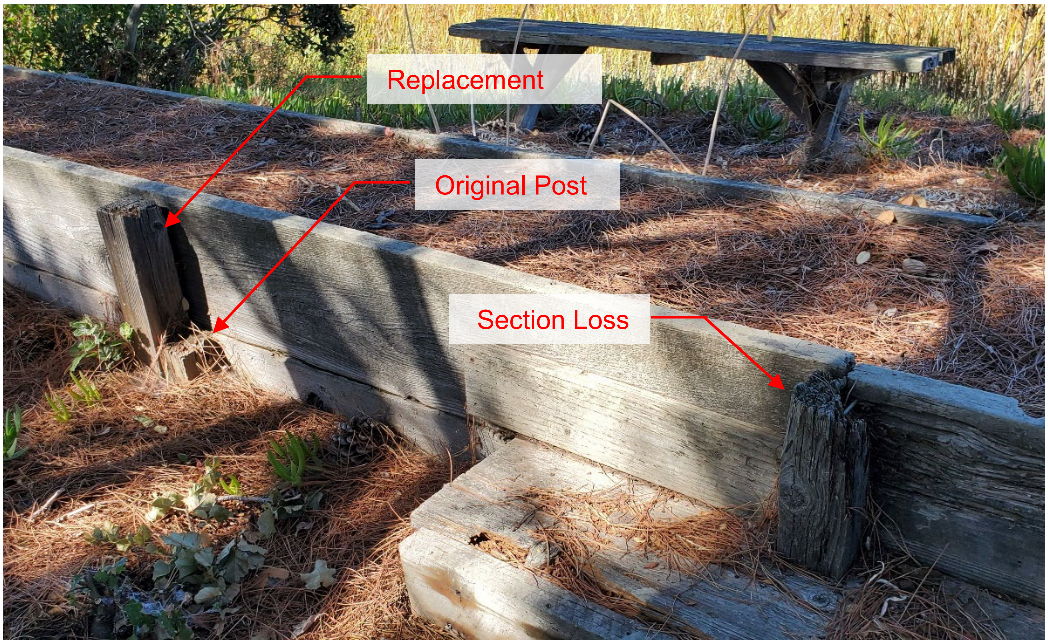

Figure 2-3: Repaired Timber Post

Additionally, portions of the TRB are overgrown with shrubs, trees, and other flora near or within the TRB which can adversely affect the TRB's performance. In some cases the planks do not extend below grade or are minimally embedded to protect against roots and burrowing animals, which may contribute to soil loss and wood rot. See Figure 2-4 and Figure 2-5 for examples.

Figure 2-4: Overgrown Flora Within and Near TRB

Figure 2-5: Loss of Soil Within TRB and Timber Deterioration

As the timber reinforcement deteriorates and shifts out of position, it exposes the soil berm within the TRB. The unprotected soil berm may slough off and loosen the soil berm strength. Roots from vegetation along with burrowing animals further loosen the soil berm, creating voids in the soil. This degrades the functionality of the TRB and increases the risk of water seeping through which my further degrade the TRB system.

As a part of the ongoing operation and maintenance effort, the District has been repairing or replacing portions of the deteriorated TRB with new timbers, with similar design and height to the original 1983 barrier. These renewed sections tend to use thicker timber posts and planks, along with tie wires working as tension ties to hold the parallel walls in place. While these repairs do not increase the flood protection level in terms of height, the repairs improve the service life and condition of that particular section of the existing barrier. In the last 15 years approximately half of the properties with TRBs have had the barrier in the back of the property repaired or replaced, but the maintenance budget was not budgeted for systematic TRB repair, so it can no longer keep pace with the needs over time. See Figure 2-6 for an image of a replacement wall under construction.

Figure 2-6: New TRB Section Under Construction

2.4 Design Criteria

The existing geotechnical reports are high-level planning guides not tailored for detailed design. During the engineering design phase, a detailed geotechnical report would be required that list the geotechnical parameters along the alignment of the TRB. To obtain accurate site-specific soil conditions, a geotechnical engineer would drill several exploratory bores along the project location for analysis and produce a geotechnical report specific to the selected alternative that includes lateral soil loads such as active pressure (the pressure against the wall to produce an overturning force), passive pressure (the resisting pressure on the opposite side of the wall), and seismic loads (the inertia of a column of soil thrusting against the wall to produce an overturning force). Additionally, this geotechnical report will investigate liquefaction and seepage and what controls may be implemented to mitigate those risks. Typically, these soil loads are conservative values and include a minimum 1.5 factor of safety.

After the design alternative is selected, the selected design concept will be evaluated based on the current California Building Code (CBC) and American Society of Civil Engineers Minimum Design Loads (ASCE 7) in conjunction with the revised geotechnical report that has recommendations specific to the selected alternative. The structural design will be consistent with professional standard of care and standard practices. Structures designed per the building code and applicable standards have inherent safety factors built in to the load combinations, along with a minimum factor of safety of 1.5 on out-of-plane overturning or sliding during static conditions. Load combinations that include seismic loads are considered transient loads, and are designed with a minimum 1.1 factor of safety. The walls will be designed for the worst case loading scenario.

For planning purposes, this report utilizes a typical design for each of the alternatives in standard soil conditions based on the building codes and factor of safety.

2.5 Site Constraints

The lack of accessibility for construction presents a significant impediment to inspecting and upgrading the existing flood barrier, and constrains the possible design alternatives that can be considered. There are narrow corridors to access the flood barrier from the street in between the houses (Figure 2-7). The District has access and operation easement to access the existing TRBs via the private residential properties.. From the creek side, access corridors are severely limited due to the salt marsh habitat with the potential to support endangered species between the existing TRB and the creek channel (Figure 2-8).

Figure 2-7: Isometric View of the Site (Source: Google Earth)

Figure 2-8: Vegetation at Bank of South Fork Gallinas Creek

To support the construction work required to upgrade the flood barrier, including raising the height of the berm, there will be a significant amount of construction material and debris to be hauled in and out. Construction material delivery and stockpile may need to be staged on the street, and then carted by hand or small motorized equipment to the site. It would not be possible to bring larger equipment such as excavators or dump trucks onto the site due to the limited width in the access path between houses and backyards, and to minimize temporary construction disruptions to the properties. This constraint plays a major role in the consideration of the constructability, viability, and cost of the flood barrier design alternatives.

3. Flood Barrier Alternatives

3.1 General Description

GHD performed a Light Detection and Ranging (LIDAR) survey at the vicinity of the project site which included the TRB. LIDAR is a remote sensing method that emits pulsed laser outward, an adjacent sensor records the reflected light to measure distance. When combined with positional information, the data collected from this survey was used to create a three-dimensional point cloud. Cross sections were then developed at approximately every 10 feet along the existing TRB alignment, to map the elevations of the toe and top of the existing TRB at both the creek and land sides. The data was compared against the target TRB design elevations of 11 feet (EL11) and 12.5 feet (EL12.5). This data set establishes a preliminary summary of the required TRB heights along the existing TRB alignment, to within an acceptable level of accuracy for this study. Figure 3-1 plots a linear footage summary of the design TRB height. In Figure 3-1, the X-axis shows the number of feet between the toe of berm at the canal side and the target TRB design elevations of EL11 and EL12.5, in one-foot increments The Y-axis shows the total linear feet for each TRB design height increment. All data is based on cross sections of the LIDAR survey and may require additional targeted surveying at locations where the wall exceeds 6 ft high. It is likely that these locations are localized low points and not indicative of the actual wall height.

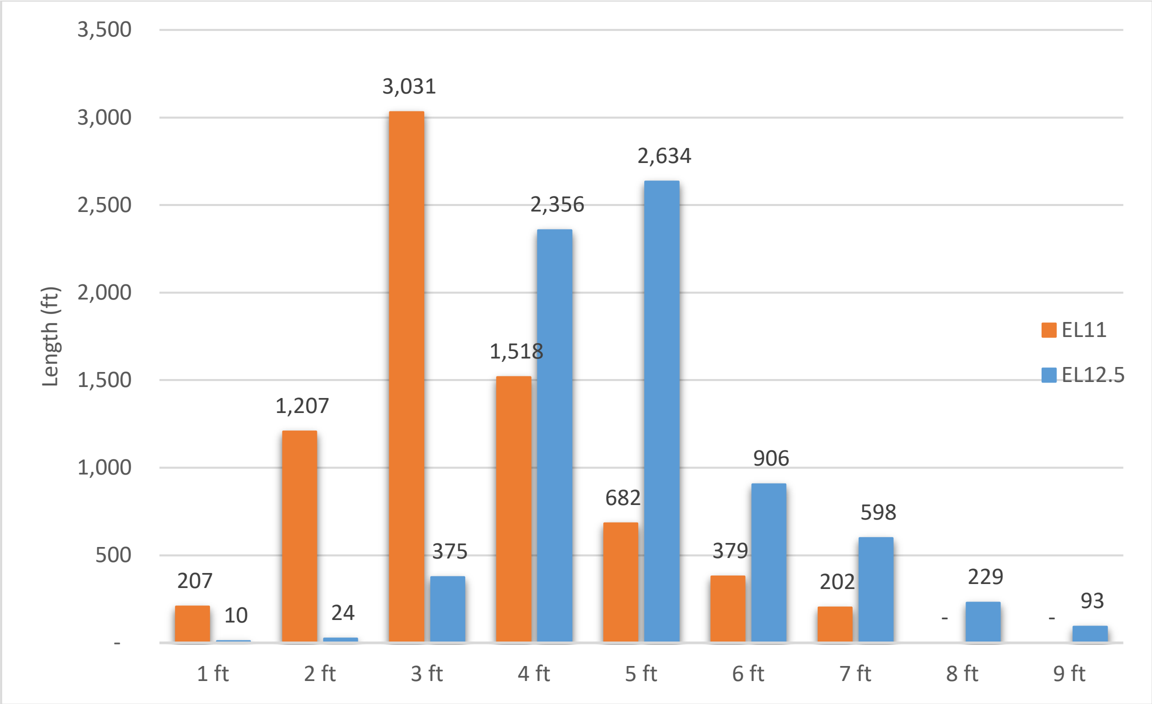

Figure 3-1: Graph of Lengths of Wall Per Wall Height Increment

The following sub-sections describe the alternative designs that were considered as viable alternates to replace the existing TRB, and their estimated cost breakdown per wall height increment. The study included the following three alternatives:

Alternative 1: Timber Reinforced Berm

Alternative 2: Mechanically Stabilized Earth

Alternative 3: Sheet Pile

Note that during the alternative development and formulation, other options such as flood break wall with movable panels or removable stop log floodwall were considered. While some of these options may have lower construction cost, less permanent intrusion at the residential properties, more straightforward access to the creek, and ease of construction considering the access limitation to the floodwall alignment, these options typically require active management, and the reliability is a concern since if some part of the system were to malfunction or was not raised in time for a flood event, it would create a vulnerability to the neighborhood with potential flooding via the weak points. Several technical studies conducted by FEMA after the Hurricanes Harvey and Irma showed that flood damage reduction systems that require active management are very vulnerable to the proper timing for activation Therefore, these options are not considered in detail in this alternative evaluation. In addition, raising the height of the underlying earthen levee with “new” earthen levee is not being evaluated as this requires heavy equipment and a much larger construction area and footprint.

The cost estimates for the alternatives are planning level engineering estimate of probable cost. They are limited to the wall construction and excludes additional studies such geotechnical investigation or surveying.

3.2 Alternative 1: Timber-Reinforced Berm

This alternative is to improve upon the existing TRB design to increase its durability and strength. As the timber deteriorates, the current replacement TRB appears to use larger timber boards and posts, along with steel tie rods to tie the two parallel walls together. While this does improve upon the original design, in order to achieve a longer lifespan, the timber components can be replaced with marine-grade pressure treated lumber. There are various treatment levels depending on the severity of the environment. For this alternative, a heavier-duty treatment level of 0.60 pcf of Chromated Copper Arsenate (CCA) preservative was assumed, which is recommended for salt-water splash, and continuous ground contact. This is approximately equivalent to American Wood Protection Association (AWPA) use category UC4C (ground contact, extreme duty).

The two parallel timber walls would be connected together with polyester reinforcement panels, typically known as geogrid. Typically, the geogrid is used to stabilize earthen embankments, in this alternative design concept the geogrid is applied within the TRB as a tension tie. The geogrid tension ties reduce the active pressure that produces an overturning moment by utilizing the active load that is acting on the opposing wall. This creates a stable structure and can reduced post embedment. The geogrid is not susceptible to corrosion as steel tie rods. Additionally, it can act as a barrier to discourage animals from tunneling in the TRB, it helps maintain the stability of the compacted soil contained inside the TRB as an effective flood barrier. For the purposes of cost estimating, a standard design based on the average height was used with two layers of geogrid. The posts are assumed to be embedded approximately 5 feet into the native soil to adequately resist out-of-plane overturning or sliding. Shorter walls may require shallower post embedment and taller walls may require concrete piers; these details will be developed during the design phase.

See Figure 3-2 for a cross section design concept sketch. See Figure 3-3 for the existing steel tieback system and Figure 3-4 for a polyester reinforcement option.

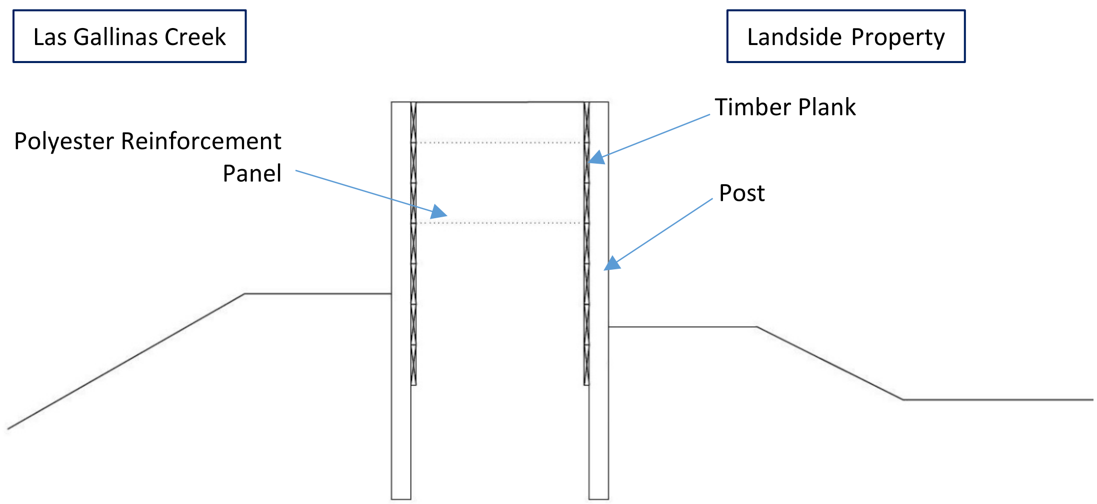

Figure 3-2: Timber Reinforced Berm Cross Section

Figure 3-3: Steel Tieback

Figure 3-4: Polyester Panels (Geogrid)

While the pressure treated lumber will significantly improve the longevity and condition of the TRB, manufacturers of the pressure treated lumber cannot provide a 30-year service life warranty. This is because the various processes applied to the treated lumber penetrate the surface by a couple millimeters and act strictly as a deterrent against marine borers and other insects – it does not provide waterproofing protection to the treated lumber. If exposed cuts and drilled holes are not treated properly, this creates an opening for deterioration. The District would be required to perform periodic inspection and maintenance, to ensure or extend the longevity of the structure.

There are products that provide a coating to the exterior surface of timber products to fully protect against water and marine borers. For example, a two-part epoxy can be applied at the factory and comes with a 50-year warranty. However, it currently costs over six times more than the pressure treated lumber. Since it is unlikely to be able to meet the available project budget, it is not being considered as a viable alternative.

A second option is to use plastic lumber in lieu of natural wood boards. Manufacturers typically guarantee plastic lumber with a service life greater than 30 years and have been used with great success in harsh chemical or marine environments. They are produced in similar shapes as natural wood and are installed with similar tools and techniques. The disadvantage of plastic lumber is that it has less strength when compared against the same size natural lumber. Therefore, the plastic lumber boards cannot span as far as natural lumber, and support posts must be placed with smaller spacing intervals in order to provide support to the board installation.

For either materials, the advantages of a TRB is the ease of construction due to the simple logistic to manually transport the materials to the construction site. All boards can be cut to shape on-site and it is scalable to allow future expansion. Additional boards and posts may be stacked above the existing TRB to elevate the berm height as necessary. For improved protection against seepage and burrowing animals, the concept design for this alternative extends the boards to be embedded 2 feet into the existing earthen levee. This is only designed to mitigate risk of undercutting, but cannot completely eliminate it. Further site-specific investigation and protective measures may be necessary during design at specific properties that exhibit substantial seepage.

Access between the creek side and land side were not considered in the cost estimate. Depending on the height of the TRB, freestanding stairs may be constructed parallel or perpendicular to the TRB. These stairs should not use the timber or plastic lumber as support, but may be attached for stability. It should be attached in such a way that can be easily removed during maintenance of the TRB.

The cost estimate is broken up into two options. Alternative 1A is the pressure treated timber reinforced berm. It includes 2-in x 12-in nominal boards at 8 feet long and 2 feet embedment, along with 4-in x 4-in nominal posts at 4 feet center-to-center, with a single or double mat of polyester geogrid depending on the height of the wall. See Figure 3-5 for the cost estimate breakdown for Option 1A. The X-axis shows the height of the wall in one-foot increments, and the Y-axis shows the estimated cost for both target elevations EL11 and EL12.5.

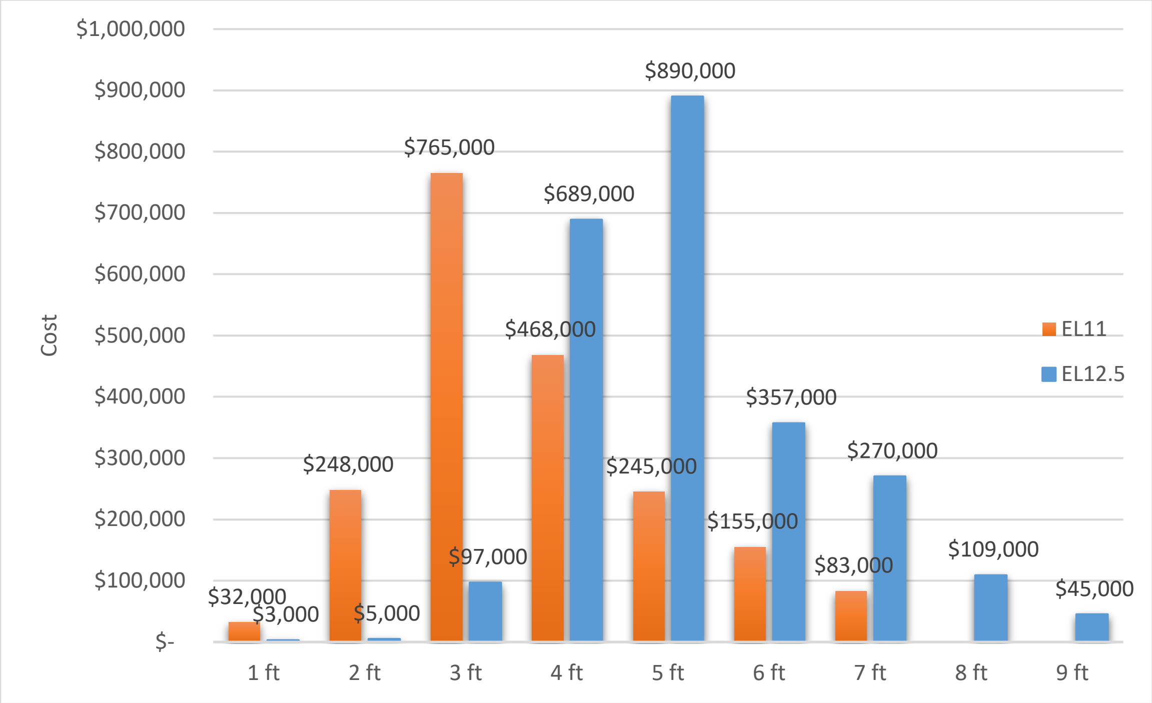

Figure 3-5: Option 1A Cost Estimate Breakdown

Alternative 1B is the plastic lumber-reinforced berm. It includes 2-in x 6-in nominal boards similar in shape to natural wood and 2 feet embedment, along with 4-in x 4-in nominal posts at 2 feet center-to-center, with a single or double mat of polyester geogrid depending on the height of the wall. There are other types of plastic lumber which are extruded structural shapes to permit longer spans between support posts, and they can be considered during project design if this design alternative is selected. See Figure 3-6 for the cost estimate breakdown for Option 1B. The X-axis shows the height of the wall in one-foot increments, and the Y-axis shows the estimated cost for both target elevations EL11 and EL12.5. Table 3.1 lists the total estimate for each alternative.

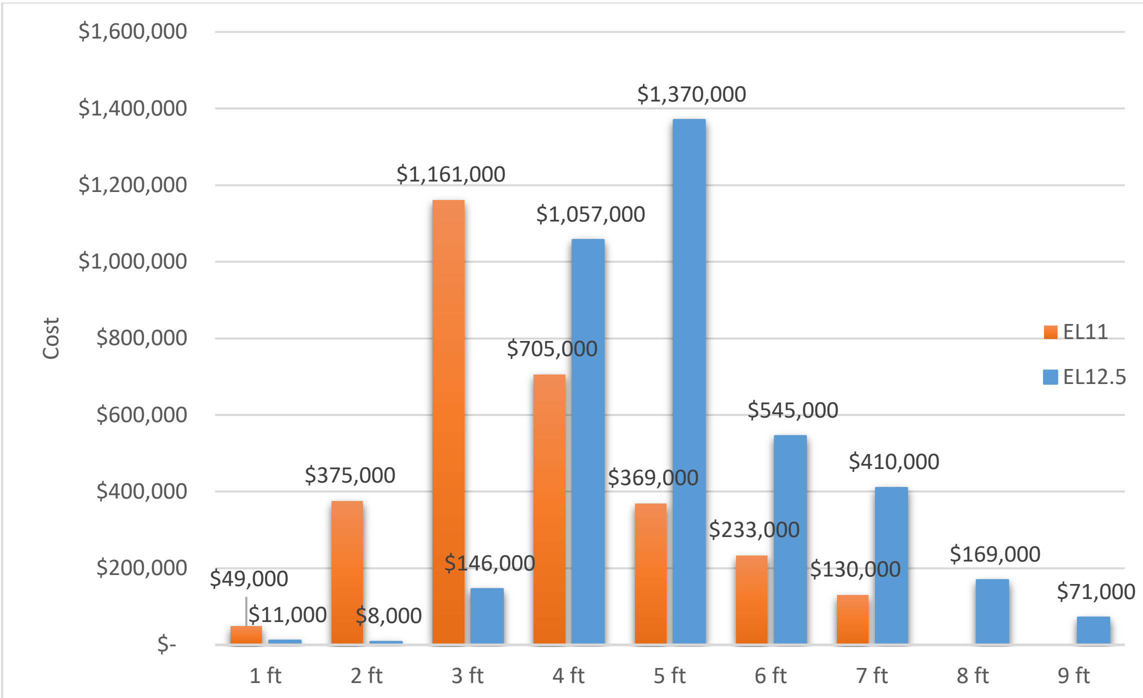

Figure 3-6: Option 1B Cost Estimate Breakdown

The cost estimates in these alternatives are derived from RSMeans for San Rafael 2019 for labor and equipment, and cost estimates on the materials from the manufacturer. It includes 25% overhead and 30% contingency. The overhead includes profit, permitting, and mobilization. RSMeans is a nationally recognized database of localized construction costs for cost estimating.

3.3 Alternative 2: Mechanically Stabilized Earth

Mechanically stabilized earth (MSE) walls utilize precast concrete blocks as the face of the retaining wall, and a geogrid tieback system to engage the soil and provide support against lateral out-of-plane forces. A variation to this system is a gravity wall, which uses self-weight to resist lateral forces, but was not considered due to access restrictions to transport large heavy blocks. See Figure 3-7 for a cross section view of a mechanically stabilized earth wall.

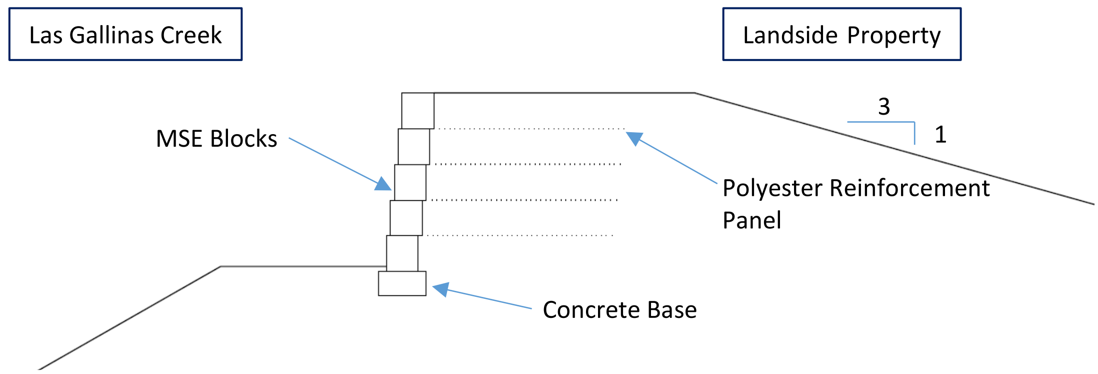

Figure 3-7: Mechanically Stabilized Earth Wall Cross Section

MSE walls can be found in all applications that require a retaining wall, including waterways. The blocks are placed on a small concrete foundation and embedded approximately 2 feet to mitigate soil erosion. The blocks and backfill are installed in layers with a final layer of topping block. See Figure 3-8 for a sample block, and Figure 3-9 for an example of an MSE block wall used as a creek liner.

Figure 3-8: Sample MSE Block

Figure 3-9: Creek Liner Using MSE Block Wall

The advantage of an MSE wall is the durability and ease of maintenance. The materials used generally do not deteriorate nor are susceptible to attacks by marine borers. It can act as a physical barrier against burrowing animals to protect the face of the berm. Additionally, by its very nature of blocks, it is easily scalable to add more courses of blocks to raise the height of the wall. The battered (angled) shape of the front face in addition to the geogrid greatly improves the resistance against out-of-plane overturning or sliding. As the active pressure acts upon the blocks, the geogrid engages a block of backfill soil to act as an anchor. It is a very effective design with minimal footing.

The disadvantage of an MSE wall is the amount of backfill required which would affect grading and landscaping of the residential properties, along with the additional loads that may increase settlement. The fill should be not be placed near homes where the settlement may adversely affect existing foundations. This alternative would be best suited for the properties that have an existing earthen berm with a raised back yard, or for properties that homeowners desire to import their own fill to raise the back yards. The MSE wall builds up the berm and protects the berm along the creek-side.

For stability and improved protection against seepage or burrowing animals, the foundation is embedded 2 feet into the levee. Additionally, the backfill at the landside greatly improves against the risk of undercutting. Further site-specific investigation and protective measures may be necessary during design at specific properties that exhibit substantial seepage.

Access between the creek side and land side were not considered in the cost estimate. Due to the backfill on the land side, there only needs to be one set of stairs at the creek side or a ramp from the dock to the top of the MSE wall. The stairs or ramp should be a separate structure with independent foundation without anchoring to the MSE blocks.

The cost estimate assumes a 2 feet embedment and a fill behind the MSE wall at a 3:1 slope. See Figure 3-10 for the cost estimate breakdown for Option 2. The X-axis shows the height of the wall in one-foot increments, and the Y-axis shows the estimated cost for both target elevations EL11 and EL12.5. Table 3.1 listed the total estimate for each alternative.

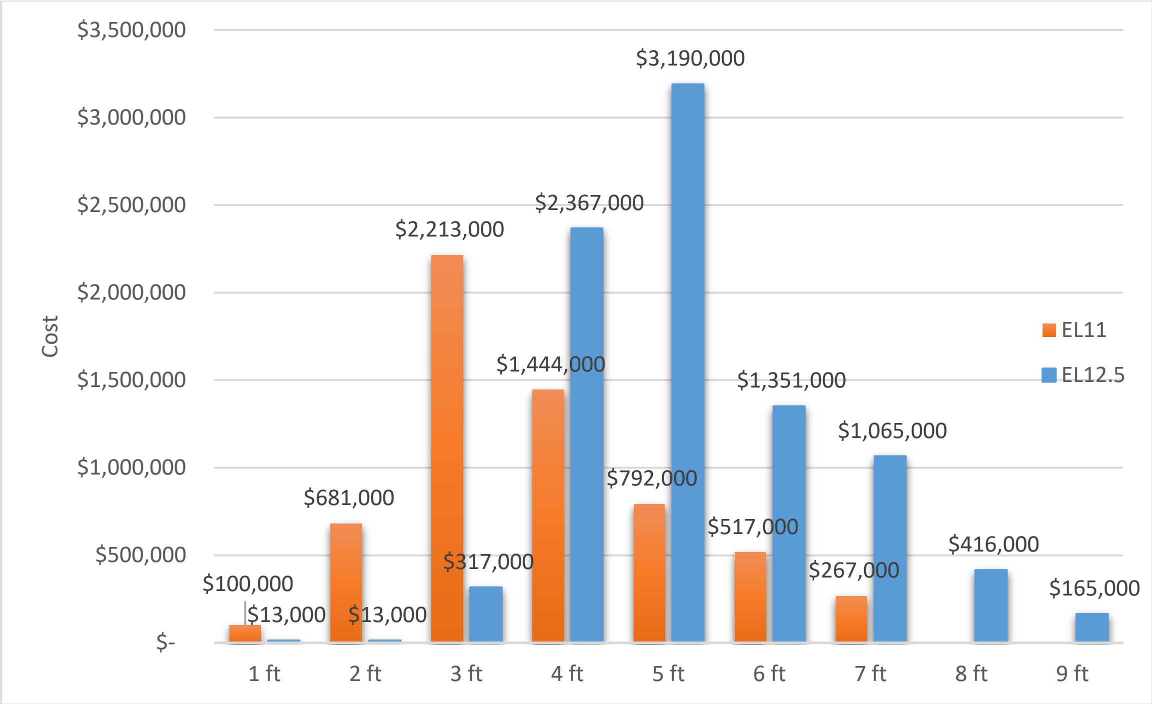

Figure 3-10: Option 2 Cost Estimate Breakdown

The cost estimates in this alternative is derived from RSMeans for San Rafael 2019 for labor and equipment, and cost estimates on the materials from the manufacturer. It includes 25% overhead and 30% contingency. The overhead includes profit, permitting, and mobilization. RSMeans is a nationally recognized database of localized construction costs for cost estimating.

3.4 Alternative 3: Sheet Piles

Sheet piles are sections of material with interlocking edges that are driven into the ground to provide earth retention. They can be metal, vinyl, or fiber reinforced plastic (FRP), each with advantages and disadvantages depending on the site conditions. These sheet piles typically exhibit a deformed shape to enhance structural rigidity and utilize the embedment depth to provide resistance against overturning. See Figure 3-11 for a cross section view of a typical sheet pile wall.

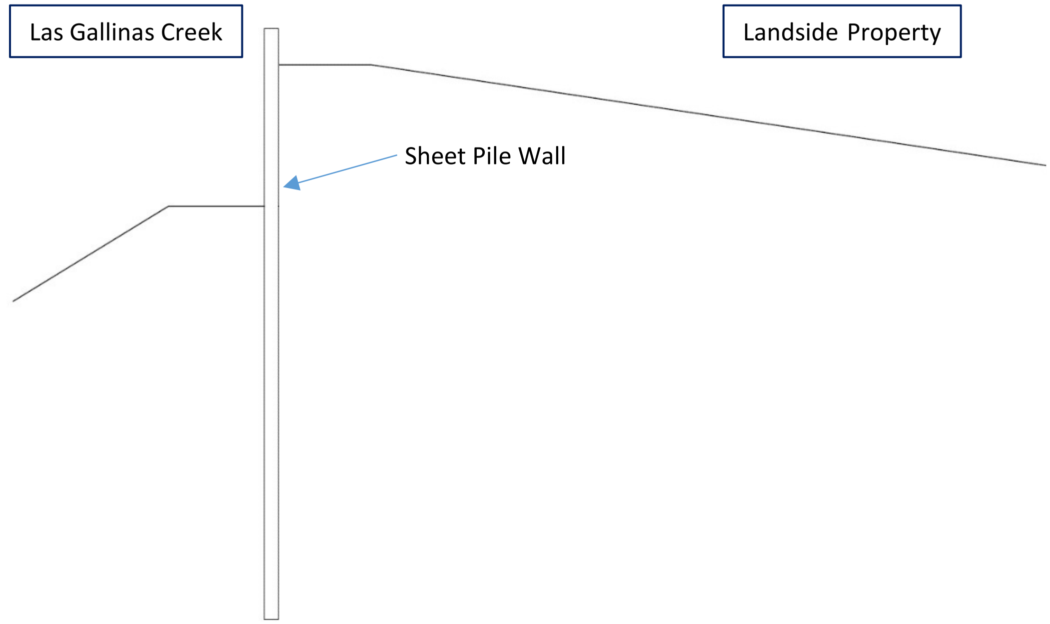

Figure 3-11: Sheet Pile Wall Cross Section

The primary advantage of sheet piles over the other alternatives is that sheet piles are sturdier, and they require a much smaller footprint. Sheet piles have long been used as seawalls and other water barriers with great success. Additionally, the embedment depth creates an impermeable barrier to burrowing animals and protection against seepage, due to the typical minimum 10-feet embedment depth requirement. It requires a deeper embedment than the other alternatives in order to utilize passive pressure from the creek side to offset the active pressure on the land side. This embedment is required to design a stable wall that can resist out-of-plane overturning. The disadvantages of sheet piles are that they are much more expensive, and it is cost prohibitive to retrofit it and add additional height in the future. See Figure 3-12 for an example sheet pile flood wall.

Figure 3-12: Sheet Pile Flood Wall

Typically sheet piles are driven using vibratory hammers or impact hammers mounted on an excavator, but the location of the project precludes the use of excavators due to access restrictions. For these applications, there is a method called a silent piler that uses hydraulics to push the sheet pile into the ground, and then traverses along the previously installed sheet piles to install the next panel in place. See Figure 3-13 for an example of a silent piler.

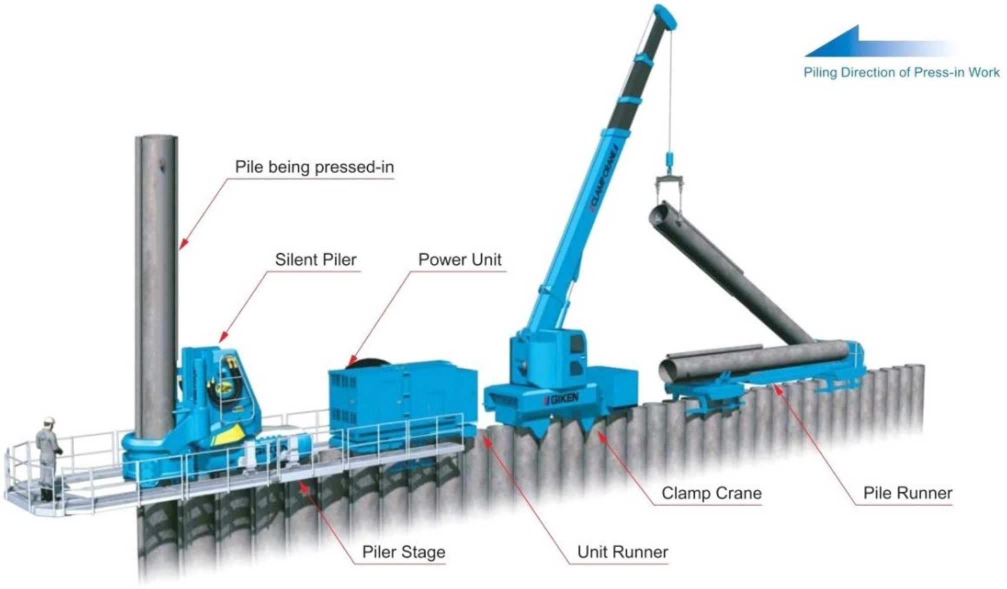

Figure 3-13: Silent Piler

The silent piler would be a well-suited application due to the limited access to the site and is much less intrusive than hammers. However, silent pilers are limited to steel sheet piles. Additionally, due to the way the silent piler traverses the previously installed sheet piles, it is not possible to skip locations – the entire length of the flood barrier must be sheet piles. It also has limitations in the angle of rotation along the alignment and cannot make tight turns.

Vinyl sheet piles were considered as a possible alternative to steel sheet piles. While it has less strength than steel sheet piles, it has been used very successfully in seawall projects around the world. It has an excellent lifespan, greater than 50 years, and is generally less expensive and easier to handle due to its light weight compared to the other sheet piles alternatives. In addition, it is possible to place the vinyl sheet piles with much lighter equipment than what is required for steel sheet piles. Instead of using heavy equipment to hammer or drive the sheet piles, waterjets would be used to loosen the media, and allow the panels to be placed by hand.

The drawback of using waterjets is the amount of water required, and the collection of waterjets discharge as wastewater. It would be cost prohibitive for the contractor to bring water to the site, and collect waterjets discharge into holding tanks for treatment and discharge. The simplest method is for the contractor to pump water from the creek and release the waterjets discharge back into the creek. However, because this would affect the sensitive aquatic habitat, environmental regulatory agencies permitting the project would require extensive and expensive treatment and testing of the waterjets discharge, considered as wastewater. For this reason, this alternative is not viable and is not considered further in this study.

Access between the creek side and land side were not considered in the cost estimate. Due to the backfill on the land side, there stairs on the land side should be much smaller than the creek side. The stairs should not be attached to the sheet pile in order to protect the coating and reduce the risk of contact between dissimilar metals that leads to accelerated corrosion.

The cost estimate assumes the soil is appropriate for hydraulically installed steel sheet piles. See Figure 3-14 for the cost estimate breakdown for Option 3. The X-axis shows the height of the wall in one-foot increments, and the Y-axis shows the estimated cost for both target elevations EL11 and EL12.5. Table 3.1 listed the total estimate for each alternative.

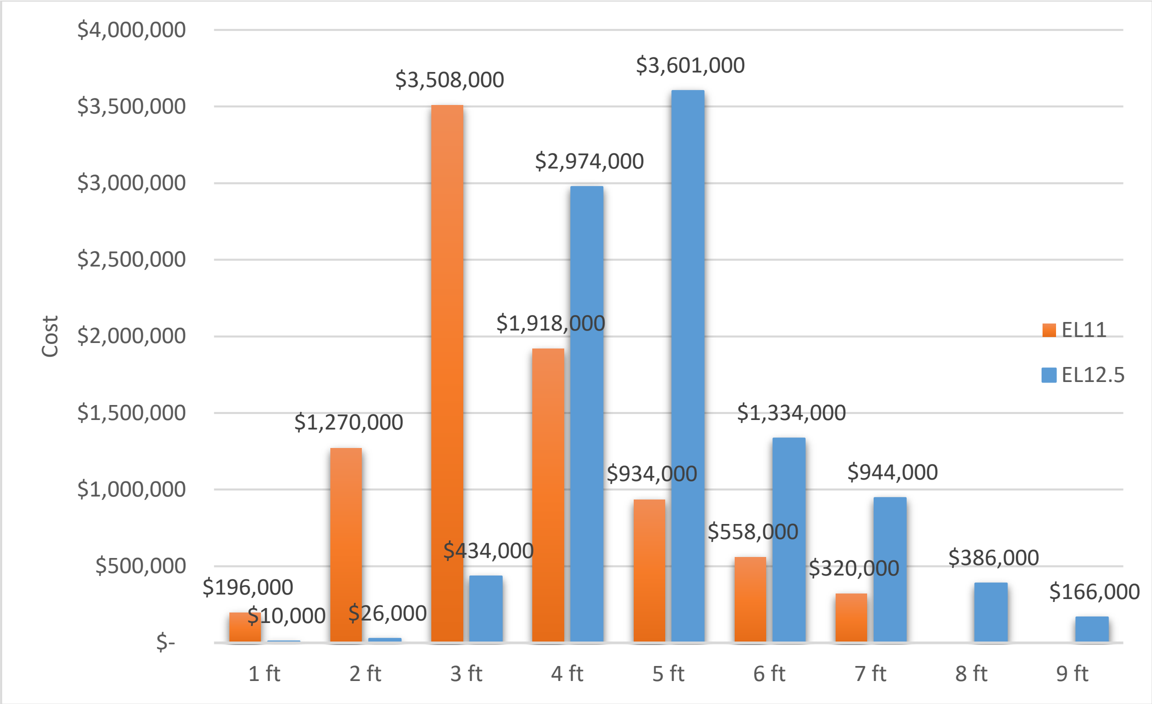

Figure 3-14: Option 3 Cost Estimate Breakdown

The cost estimates in this alternative are derived from a contractor that specializes in silent pilers. Their estimated material and labor costs were escalated to current rates. It includes 25% overhead and 30% contingency. The overhead includes profit, permitting, and mobilization.

3.5 Summary

To facilitate direct comparison, all cost estimates are based on the full 7,200 feet length of the existing TRB flood barrier replacement. Based on survey information, it would be most likely that certain properties would greatly benefit from one alternate over another. The TRB and MSE wall in Alternatives 1A, 1B, and 2 may be interchanged or combined depending on the existing site condition, though the sheet piles in Alternate 3 cannot be discontinuous so it will be less likely to be applicable to individual properties. See Table 3-1 for a summary of cost estimate for all the design alternatives.

Table 3-1: Summary of Cost Estimate

Alternate	Elevation 11 Feet Cost (Total)	Elevation 12.5 Feet Cost (Total)
1A: TRB (Pressure Treated)	$2,000,000	$2,500,000
1B: TRB (Plastic Lumber)	$3,100,000	$3,800,000
2: MSE Blocks	$6,100,000	$8,900,000
3: Sheet Pile	$8,800,000	$9,900,000

4. Recommendations

4.1 General

Table 4-1 summarizes the alternatives and which goals are satisfied. The project guidelines establish a maximum available budget of $3.5M, with a minimum 30-year service life, and future expandability that permit modifications to increase flood protection level without demolishing what was already constructed.

Table 4-1: Summary of Alternatives and Goals

Alternative	Elevation	Budget	Service Life	Expandability
1A: TRB (Pressure Treated)	11 ft	X		X
	12.5 ft	X		X
1B: TRB (Plastic Lumber)	11 ft	X	X	X
	12.5 ft		X	X
2: MSE Blocks	11 ft		X	X
	12.5 ft		X	X
3: Sheet Pile	11 ft		X	
	12.5 ft		X	

We recommend Alternative 1A at Elevation 12.5 or Alternative 1B at Elevation 11 as feasible implementation options. Alternative 1A provides the maximum flood level protection, and Alternative 1B provides maximum reliability. Both alternatives are within the $3.5M available project budget and are suitable for future expansion. Because FEMA requires a long-term solution, meeting the service life criteria is critical to utilizing the FEMA HMGP grant in support of this project, and only Alternative 1B meets both the budget and service life constraints associated. Additionally, the average top of berm in Reach 1 is 10.9 feet, which closely matches the top of berm elevation for Alternative 1B. Therefore, this study recommend Alternative 1B as the preferred option for the TRB improvements.

4.2 Environmental Permitting

The following proposed regulatory requirements are based on the conceptual project alternatives presented above. Additional research and coordination would be required during the design as details of the project become finalized.

4.2.1 Army Corps of Engineers (USACE)

Background

The Army Corps of Engineers (USACE) has permitting authority over activities affecting waters of the United States. Under Section 10 of the Rivers and Harbors Act and Section 404 of the Clean

Water Act, the USACE has authority over all waters including wetlands that have sufficient nexus to interstate commerce (e.g., navigable waters and their tributaries, such as Gallinas Creek). If jurisdictional waters (i.e., below the ordinary high water mark [OHWM]) or wetlands are impacted during construction or operation of the project, then a Corps Section 404 permit would be required. An aquatic resources delineation may be required to determine if wetlands or waters would be impacted by the project. Depending on the extent of the activity, the project could require an Individual Permit or a Nationwide Permit.

Applicability

The project would replace the deteriorating TRB with one of the above-listed alternatives. It is assumed that under any of the alternative scenarios some areas would require work below OHWM. Therefore, waters protected by Section 404 would be affected. Based on the nature of the project, it appears the project could receive coverage under Nationwide Permit 3-Maintenance as it would be replacing an existing structure. However, if once the design has progressed and the proposed alignment was confined to areas above the OHWM and any vegetated wetlands, a USACE Permit may not be required.

If a USACE permit is required, then Section 7 consultation under the Endangered Species Act may be necessary and the permit application would provide a federal nexus. Alternative 1 (Timber Reinforced Berm) and Alternative 2 (Mechanically Stabilized Earth) are less likely to result in adverse effects on ESA-listed species; however installation of Alternative 3 (Sheet Piles), would be more likely to result in consultation with the United States Fish and Wildlife Service and National Marine Fisheries Service.

Federal ESA-listed species known to occur within one mile of the project site include Salt Marsh Harvest Mouse, Ridgway's Rail, and Longfin Smelt (federal candidate). Verifying Ridgway's Rail presence or absence may require protocol surveys conducted from January through March and/or seasonal avoidance.

Application Process

If a Section 404 Permit is required, the process would include preparation and submittal of the Application for Department of the Army Permit Form including the following information:

- Project description and site plan
- Wetland delineation
- Quantification of temporary and permanent impacts and proposed mitigation
- Documentation of no effect on ESA-listed species and avoidance/minimization measures, or preparation of Biological Assessment to support Section 7 consultation (most likely for Alternative 3)

Fees

The USACE does not charge other government entities fees.

4.2.2 Regional Water Quality Control Board (RWQCB)

Background

While Section 401 Water Quality Certifications are required when the activity results in fill or discharge directly below the OHWL of waters of the United States, any activity that results or may result in a discharge that directly or indirectly impacts waters of the State or the beneficial uses of those waters are subject to Waste Discharge Reporting (WDR) under California's Porter-Cologne Water Quality Control Act (Porter-Cologne). In practice, State waters typically include impacts to a stream channel up to the top of bank, and associated riparian areas.

Applicability

All three of the alternatives presented are anticipated to replace an existing TRB in proximity to a Section 10/Section 404 water and associated bank requiring a 401 Water Quality Certification.

Application Process

Prepare and submit a 401 certification/waiver of WDRs application form, including the following information:

- Project description and site plan
- CEQA document
- Quantification of temporary and permanent impacts and proposed mitigation
- Biological study describing potential impacts to habitat types
- Payment of fees

Fees

The RWQCB fee varies depending on the size of the discharge. Based on the FY 2019/2020 calculator, fill and excavation discharges are calculated at a rate of $17,372/acre, minus the application fee. Additional charges include an annual active discharge fee, and an annual post discharge monitoring fee.

4.2.3 California Department of Fish and Wildlife (CDFW)

Background

Fish and Game Code section 1602 requires notification to the CDFW prior to commencing any activity that may: 1) substantially divert or obstruct the natural flow of any river, stream or lake; 2) substantially change or use any material from the bed, channel or bank of any river, stream, or lake; or 3) deposit debris, waste or other materials that could pass into any river, stream or lake. If the project alters the existing streambed or banks of Gallinas Creek, including removing or impacting riparian vegetation, a Lake and Streambed Alteration Agreement would be required.

Several CDFW-designated species of special concern (SSC) are known to be present within one mile of the project site, including California Black Rail, San Pablo Song Sparrow, Burrowing Owl, and Western Pond Turtle. In addition to being addressed under section 1602, this species may require CEQA analysis and avoidance or mitigation measures depending on their proximity to the work area.

Applicability

All three of the presented alternatives are anticipated to impact the bank of Gallinas Creek. CDFW would likely take jurisdiction, as the replacement of the TRB would take partially within the creek bank (berm).

Application Process

The project would require submittal of a Notification of Alteration of Streambed to the CDFW. The notification application would include the following:

- Notification of lake or streambed alteration form.
- CEQA document and record of CEQA filing fee if applicable
- Project description and drawings
- Estimated number and type of trees to be removed, if any (all trees greater than 2 inches in diameter at breast height)
- Biological study describing potential impacts to special-status species and habitat types
- Payment of fees

Fees

Fees for Standard Agreements (five years or less) are determined based on project cost. Project cost is limited to that portion of the project that is within CDFW's jurisdiction. Fees range as follows:

- $609.25 if the project costs less than $5,000.
- $764.50 if the project costs from $5,000 to less than $10,000.
- $1,526.00 if the project costs from $10,000 to less than $25,000.
- $2,290.50 if the project costs from $25,000 to less than $100,000.
- $3,361.50 if the project costs from $100,000 to less than $200,000.
- $4,559.25 if the project costs from $200,000 to less than $350,000.
- $5,430.50 if the project costs $350,000 or more.

4.3 Next Steps

The next step in this process is to investigate the site in detail. This includes environmental permitting, biological studies, detailed surveying, and geotechnical investigation. The environmental permitting and biological studies is required for approval by the various agencies and stakeholders that have an interest in Gallinas Creek. The LIDAR scan that was performed shows the site in general, but detailed surveying would be required to augment the scan by adding in additional information such as trees, obstructions, or confirm specific locations and elevations of various surface features that would affect the site specific improvement design. The geotechnical investigation is required to analyze the site along the alignment and provide soil parameters.

The outcome of the various investigations would guide the final design and alignment. For example, the environmental permitting and detailed survey may uncover that the alignment at certain locations may need to be shifted to avoid contact with the creek and minimize permitting requirements.

The design of a structure is typically an iterative process, where the site parameters that define the structural design often needs to be refined during the course of engineering design process. In this project with over 7,200 linear feet of TRB to design, there will likely be a standard design that may be utilized for a large section. Then at each property or segment along the flood barrier alignment, refinement will be made to tailor the site specific conditions, and fine tune the design to be compatible to the adjacent residential properties. A collaborative design process with local residents and property owners is important to develop and implement a success TRB improvement project.

5. References

1. Geotechnical Data Report, Las Gallinas Levee System by Kleinfelder, July 3, 2013
2. Las Gallinas Creek Hydrologic, Hydraulic and Coastal (HH&C) by U.S. Army Corps of Engineers, December 2013
3. Geotechnical Alternatives Analysis, Las Gallinas Levee System by Kleinfelder, January 15, 2014
4. Flood Insurance Study, Marin County, California, and Incorporated Areas, by Federal Emergency Management Agency, August 2017
5. Timber-Reinforced Berm Improvement Project Basis for Conceptual Design Memo, by Kleinfelder, May 24, 2018
6. State of California Sea-Level Rise Guidance, 2018 Update by California Natural Resources Agency, California Ocean Protection Council, March 14, 2018
7. State of California Sea-Level Rise Guidance, California Ocean Protection Council, 2018 Update

Appendix A

Projected Sea-Level Rise (in feet) for San Francisco

Source:

State of California Sea Level Rise Guidance 2018 Update by California Ocean Protection Council

TABLE 1: Projected Sea-Level Rise (in feet) for San Francisco

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…		5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 -	0.5	0.6	0.8	1.0
	2040	0.6	0.5 -	0.8	1.0	1.3	1.8
	2050	0.9	0.6 -	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6 -	1.3	1.6	2.4	
High emissions	2060	1.1	0.8 -	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8 -	1.5	1.9	3.1	
High emissions	2070	1.4	1.0 -	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9 -	1.8	2.3	3.9	
High emissions	2080	1.7	1.2 -	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0 -	2.1	2.8	4.7	
High emissions	2090	2.1	1.4 -	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0 -	2.4	3.2	5.7	
High emissions	2100	2.5	1.6 -	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2 -	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9 -	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2 -	2.8	3.9	7.4	
High emissions	2120	3	2.2 -	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3 -	3.1	4.4	8.5	
High emissions	2130	3.3	2.4 -	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3 -	3.4	4.9	9.7	
High emissions	2140	3.7	2.6 -	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3 -	3.8	5.5	11.0	
High emissions	2150	4.1	2.8 -	5.8	5.7	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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Document Status

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