San Francisquito Creek Flood Reduction

Alternatives Analysis

Prepared for | **SAN FRANCISQUITO CREEK JOINT POWERS AUTHORITY**

Prepared by | **PWA** Philip Williams & Associates, Ltd.

with H.T. Harvey and Associates

July 17, 2009

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1. INTRODUCTION

The San Francisquito Creek Joint Powers Authority (JPA), a coalition of cities, regional flood control districts, and other parties with a vested interest in flood management and environmental preservation of the creek, contracted with Philip Williams and Associates, Ltd. (PWA) and H.T. Harvey and Associates (HTH) to evaluate flood management strategies in the upper and lower portions of the San Francisquito Creek watershed. The project is divided into two distinct components, each with specific objectives: to reduce out of bank flooding in the lower reach of the creek downstream of the Highway 101 crossing (the Downstream Project) and to reduce peak flow rates in the creek through flood water detention in the upper portion of the watershed (the Upstream Project). PWA's scope of work included evaluating potential alternatives for hydraulic and flood reduction performance, and developing a conceptual design and opinion of probable cost for each alternative. This phase of the project did not include evaluating land use, permitting, land ownership, detailed environmental assessment, or jurisdictional or other possible constraints.

PWA used a HEC-RAS hydraulic model to develop flood management alternatives in the most downstream reach of the creek and a combination of geospatial analysis and HEC-HMS hydrologic modeling to identify possible detention sites in the upper watershed. HT Harvey and Associates provided input on the biological implications of the Downstream Project. This report describes the development, analysis, and interpretation of the Downstream and Upstream Project alternatives.

1.1 PURPOSE

The purpose of this project is to develop and test alternatives that, once implemented, would reduce flood hazards in the highly urbanized portions of the San Francisquito Creek watershed, which includes the cities of East Palo Alto, Palo Alto, and Menlo Park. The JPA, formed in 1999 following the devastating floods of February 1998, serves as a vehicle for the local communities and Stanford University to develop cooperative and integrated strategies to flood management throughout the watershed. The JPA is working as the local sponsor with the United States Army Corps of Engineers (USACE) to initiate a long-term and large scale, comprehensive flood management plan. The alternatives analyzed in this report are potential early implementation projects that would serve as the first steps in the larger JPA-USACE cooperative management plan.

1.2 REPORT ORGANIZATION

This report is organized as follows:

Chapter 2 – Describes the alternatives analysis for the Downstream Project, including the HEC-RAS modeling and an opinion of probable costs.

Chapter 3 – Describes the screening analysis used to develop alternatives for the Upstream Project, including HEC-HMS modeling, geospatial analysis and an opinion of probable costs.

Appendix A – Documents HTH's biotic opportunities and constraints summary for the Downstream Project.

1.3 REPORT SUMMARY

PWA developed conceptual-level flood management alternatives for the downstream reach and upper watershed of San Francisquito Creek and tested the performance of these alternatives relative to existing conditions using modeling software and geospatial analysis. This project is divided into two separate components referred to as the Downstream Project and the Upstream Project.

For the Downstream Project, PWA developed two alternatives that use a combination of channel terrace lowering, levee setbacks, floodwalls and a bypass channel to reduce fluvial flood levels in the reach of San Francisquito Creek downstream of Highway 101. Alternative 1 maintains the existing channel corridor downstream of Highway 101 and Alternative 2 includes an expanded corridor. A third alternative was developed that diverts a significant portion of flow through a large bypass channel bisecting the Palo Alto Municipal Golf Course. The alternatives were compared with existing conditions using a hydraulic model and were found to significantly reduce water levels during the moderate flood event that occurred in February 2000 compared to existing conditions. Additionally, modeling results indicate that the alternative designs result in water levels for the February 1998 floods that are contained within the channel. For the 100-year design storm, model results indicate that Alternatives 2 and 3 contained water levels within the channel based on existing levee heights, without consideration of freeboard requirements. Based on an opinion of probable costs, the costs of the first two alternatives were similar to each other, but the cost of the third alternative (golf course bypass) was significantly higher due to the large levees required.

Floodplain detention opportunities were identified in the upper part of the San Francisquito Creek watershed for the Upstream Project. PWA developed the flow reduction criteria for this analysis and used hydrologic (rainfall-runoff) modeling to identify locations in the watershed where detention basins could significantly reduce flows to meet the established criteria. We then estimated the storage volume required. Geospatial tools were then used to identify specific locations within the target watershed area with the potential to provide the required flood storage. Three possible "offline" (separate from the stream channel) detention sites were identified. For each site, conceptual grading plans were developed, the percent reduction of the 100-year runoff events was estimated, and an opinion of probable costs was developed.

2. DOWNSTREAM PROJECT

The goal of the Downstream Project is to reduce the frequency of out-of-bank flooding in the reach of San Francisquito Creek between Highway 101 and San Francisco Bay (the Bay). Three conceptual-level alternatives were developed to address the flood management objectives of the JPA, which, in addition to reducing flooding for flows up to the 100-year fluvial event, include developing a design that would be compatible with potential future projects in other locations of the watershed, minimize impacts to infrastructure, and result in a net habitat and ecological benefit. (The 100-year event is the flood event that has a 1% chance of occurring in any given year.) The main tool used to compare the alternatives performance relative to existing conditions was a HEC-RAS hydraulic model. Figure 1 shows the creek channel stations referenced in this report and depict the creek's location relative to East Palo Alto, Palo Alto, and Menlo Park.

In this description of our analysis of the downstream portion of San Francisquito Creek, the upper reach refers to the portion of the creek between Highway 101 and the large bend in the channel near the baseball fields and the Palo Alto Municipal Golf Course (Station 7762 to Station 6009). The middle reach refers to the portion of the creek downstream of this bend and upstream of the Friendship Bridge (Station 5807 to Station 3003), and the lower reach refers to the portion of the creek between Friendship Bridge and San Francisco Bay (Station 2967 to Station 0). All references to the left or right side of the creek are made facing downstream. Station numbers refer to the distance, in feet along the channel centerline, upstream from San Francisco Bay.

Based on the HEC-RAS model results, the upper reach, especially immediately downstream of the Highway 101, is the portion of San Francisquito Creek most prone to levee overtopping. This results from the constricted, narrow channel width in this reach. This reach is also constrained by surrounding infrastructure and therefore the options for increasing channel capacity here are more limited. Due to these constraints, lowering water levels in this reach was a particular focus in developing alternatives for the downstream project.

2.1 DESIGN CRITERIA

The downstream project alternatives were developed with the primary goal of reducing peak water levels lower below existing left and right levee crest elevations downstream of the Highway 101 Bridge during a 100-year fluvial flood event. The design flow rates at various flow change locations in the channel were defined based on the Santa Clara Valley Water District's (SCVWD) San Francisquito Creek Hydrology Report (2007). Creek cross-sectional topographic data, including levee crest elevations, were obtained from the HEC-RAS model provided by the USACE (see Section 2.4.1 for further discussion).

This analysis focused on hydraulic conditions in San Francisquito Creek downstream of the Highway 101 crossing. Additionally, this analysis assumed that all upstream flows reach the channel at Highway 101 (i.e. no flow is lost from out-of-bank flooding at channel constrictions in the upper reaches) and that no new flow reduction activities, such as detention storage in the upper watershed, have occurred relative to current conditions. Because the existing hydraulic model was designed to simulate lower flows only, the 100-year flood event was not analyzed for existing conditions and only for the alternative designs (this is further described in Section 2.4.1).

FIGURE 1 | **DOWNSTREAM PROJECT SITE MAP**

2.2 FORMULATION OF PROJECT ALTERNATIVES

Project alternatives for the downstream reach of San Francisquito Creek evaluated in this study were developed from previously-identified concepts to meet flood management objectives within the infrastructure and habitat constraints of the site. To lower peak water levels during floods relative to existing conditions, the alternative designs increase channel conveyance through a combination of terrace excavation in the existing channel, levee removal and levee setbacks, flood wall construction, and construction of new bypass channels. These elements are described in further detail below.

Levee Lowering at Faber Tract

All alternatives include lowering the levee on the north side of the lower reach of the creek and establishing a more active hydraulic connection between San Francisquito Creek and the Faber Tract wetland, a portion of the Palo Alto Baylands Nature Preserve. The Faber Tract, owned by the City of Palo Alto, is a tidal marsh that was diked and isolated from the tidal action beginning the in 1930's. The outboard levees were breached in 1971, making the site one of the earliest tidal marsh restoration projects in San Francisco Bay. Due to the original breach location, the borrow ditch along the northern side forms the main drainage element of the marsh. Consequently, most of the marsh's secondary slough channels drain from south to north, and the southern portion of the Faber Tract, which is adjacent to San Francisquito Creek, has a less-developed slough channel network as compared to the northern portion.

Each alternative includes lowering this levee to the elevation of the adjacent marsh plain, which is typically assumed to be equal to the elevation of mean higher high water (MHHW). (MHHW was assumed to be equal to 7.1 feet NAVD for this analysis based on Noble, 2009.) From a flood management perspective, lowering the lower reach's northern levee would greatly increase the available flow conveyance area during fluvial flood events by allowing flood waters to spread out over the Faber Tract.

Terrace Excavation

Terrace lowering, common to all alternatives, involves excavating the existing earthen terraces immediately adjacent to the main channel of the creek to marshplain elevation (MHHW). Currently, the creek channel cross-section is such that either the main channel is confined by the existing levees or, in locations with an existing floodplain terrace, the terrace is perched several feet above marsh elevation (see Figure 5 through Figure 9). This floodplain terrace is dominated by non-native ruderal plant species and is of lower habitat quality than that proposed by the alternatives: a marsh dominated by native tidal salt and brackish marsh species (Apendix A). Lowering the existing floodplain elevation by several feet will increase the flow conveyance area in the channel, reducing peak water levels in San Francisquito Creek

Levee Setback

Levee setbacks involve moving a portion of levee away from the creek to increase the width and flow conveyance area of the channel. At locations where levees are set back, the main low-flow channel would not be modified, but the marshplain terraces would be widened to accommodate the additional width. In the middle reach, there are opportunities to shift the left and right levees away from the channel without significantly impacting existing infrastructure on adjacent land owned by the City of Palo Alto. In the upper reach, there is less opportunity for levee setbacks because of the location of adjacent infrastructure.

Flood walls

Floodwalls would be used in those locations that are very constrained in width to provide additional channel cross-sectional area and capacity by replacing the existing trapezoidal channel configuration with a rectangular cross-section. At locations where the levees are not set back, the existing levee top and outboard slope would remain in place and the inboard slope adjacent to the channel would be replaced with a vertical retaining wall. Where the alternatives include levee setbacks, the new levees would include a vertical wall on the inboard side, a levee crest at the same elevation as the existing levee at that location, and an outboard levee side sloping toward the outboard ground elevation. Some locations may require a vertical outboard levee side to minimize the footprint of the levee and to allow for the maximum channel increase without affecting the surrounding infrastructure. All of these configurations are referred to as "floodwalls" in this report, and each could be configured to accommodate trails and/or access roads adjacent to the channel.

Bypass channels

Bypass channels allow a portion of the main channel flow to be diverted either around a structure or around an entire reach of the creek. For Alternatives 1 and 2, bypass channels divert water around the Friendship Bridge over the northwest corner of the Palo Alto Municipal Golf Course. Alternative 3 includes a bypass channel through the middle of the golf course. The bypass channel in Alternative 1 is elevated above the channel and would only be activated at higher flows, while the elevation of the bypass channels in Alternatives 2 and 3 bypass channels would be at MHHW, allowing the exchange of water between the creek channel and the Bay during all flows.

2.3 | PROJECT ALTERNATIVES

This section describes the three alternatives evaluated for the downstream project. Plan views of Alternatives 1, 2, and 3 are shown in Figure 2, Figure 3, and Figure 4, respectively. Cross section views of the alternatives are shown in Figure 5 through Figure 11. Left and right bank are referenced facing downstream.

2.3.1 | ALTERNATIVE 1

Alternative 1 includes a reach of flood walls downstream of US 101, lowered terraces in the middle and upper reaches, levee setbacks in the middle reach, and an overflow bypass channel adjacent to the Friendship Bridge. A plan view of the conceptual alternative can be seen in Figure 2.

The elevation of the marshplain terraces would intersect the main low-flow channel of the creek at approximately MHHW and would extend outward from the channel at this elevation to the toe of the levees. In the middle reach, the levees would extend upward from the channel at a slope of 2:1 (horizontal to vertical). In the upper reach, the levees would extend vertically from the marshplain terrace to the existing levee tops. Vertical floodwalls are required to maximize the flow conveyance in the upper reach.

The height of the levees on the left and right sides of the channel in the upper reach would not be modified under Alternative 1 (or either of the other two alternatives). In the middle reach, the levee heights would not be adjusted, except at locations where the left levee, which is adjacent to homes in East Palo Alto, is found to be lower than the right levee, which is adjacent to the Palo Alto Municipal Golf Course. The relative heights of the levees would be adjusted to ensure that during extreme flood events, flooding would occur preferentially into the golf course, rather than East Palo Alto.

For Alternative 1, the levees would not be set back in the upper reach, but would be set back from the main channel in the middle reach to increase conveyance area. The distance that the right and left levees are shifted varies from location to location, depending on what is adjacent to the outboard side of the existing levees. The proposed alignment for the left and right levees can be seen in Figure 2.

On the left (west) side of the channel, the levee would be shifted to be parallel to the backyard fence line of the homes on Jasmine Way and Camellia Drive in East Palo Alto. The City of Palo Alto owns the land between these homes and the outboard side of the left levee, which consists of open grassland and fill of unknown origin. The creek meanders slightly through this reach and at the location where it is furthest from the homeowner's fence line, the levee would be set back by approximately 175' to the west. This width is available at the upstream and downstream ends of the middle reach. Near the center of the middle reach around Station 4800, where the existing levee abuts the fence line, the left levee would remain in its current location.

The right levee in the middle reach would be shifted eastward toward the Palo Alto Municipal Golf Course. The amount of setback would vary, depending on the distance between the existing levee and the golf course greens. The low-lying areas between the existing outboard levee slope and the golf course are degraded, non-tidal seasonal wetlands, some of which remain wet from artificial irrigation from the golf course (HT Harvey, 2009). These areas would either be converted to tidal marsh as part of the in-channel marshplain terrace or be converted to upland habitat on the levee. Levee setback distances range from 25' in the narrowest location and 125' at the widest location.

The final element of the Alternative 1 design is an overflow bypass terrace running along the right side of the channel at the Friendship Bridge (see Figure 2). This overflow channel provides a wider flow area by allowing high flows to circumvent the constricted portion of the channel at the bridge. The terrace would be at an elevation of 9.8' NAVD, which is slightly less than 3' above the proposed marshplain terraces adjacent to the channel and potentially elevated enough to allow for the bypass channel to be incorporated into the existing golf course. The terrace would remain dry during normal flow events, but would get activated during fluvial flows higher than approximately a 7-year event (based on SCVWD, 2007) or during tides greater than approximately a 10-year event (PWA, 2006).

At the upstream and downstream edges of the terrace, an access ramp would allow access to the approach of the Friendship Bridge. The bridge, its abutment and the high portion of the levee where the bridge connects to the existing levee road would not be modified except for armoring to prevent scour in high flow events. The overflow terrace access roads would be at an elevation of 9.8' NAVD over the course of the bypass channel and would ramp up to the existing Friendship Bridge approach. On the outboard side of the bypass terrace, a levee would be constructed at an elevation approximately equal to the existing right levee to protect the main portion of the golf course from flooding. This levee would tie into Alternative 1's proposed right levee upstream near Station 3800 and downstream near Station 2400.

FIGURE 2 | **ALTERNATIVE 1, CONCEPTUAL LAYOUT**

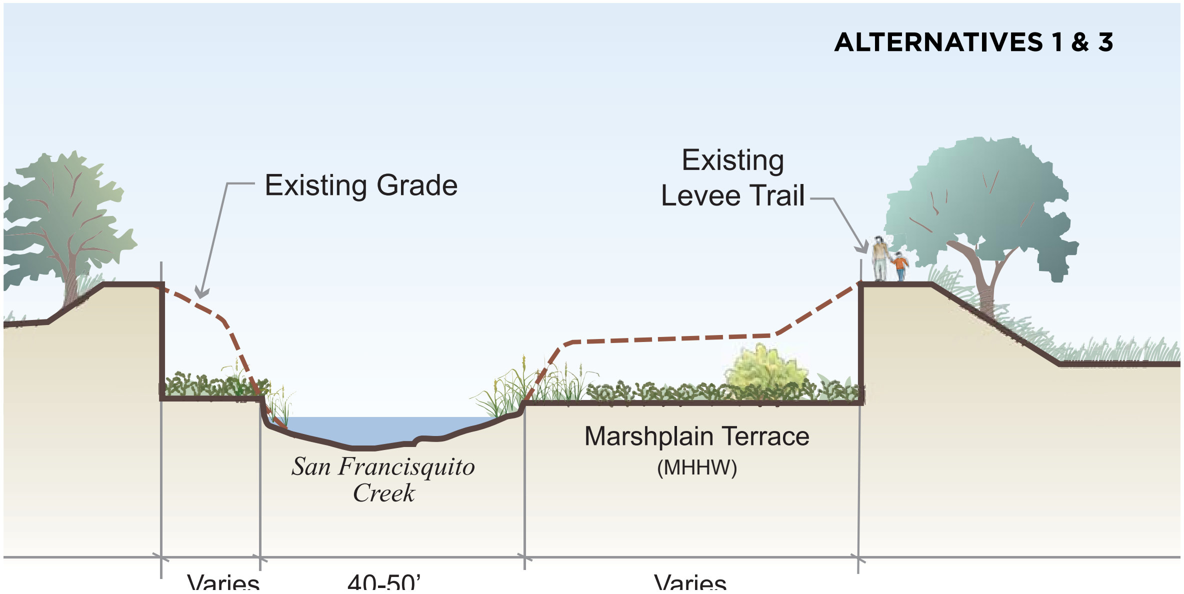
- Cross Sections
- Levee Lowering
- Overflow Bypass Bridge Access
- Levee Top
- Levee Footprint
- Overflow Bypass Terrace
- Marshplain Terrace

N

0 375 750 1,500 Feet

FIGURE 3 | **ALTERNATIVE 2, CONCEPTUAL LAYOUT**

FIGURE 4 | **ALTERNATIVE 3, CONCEPTUAL LAYOUT**



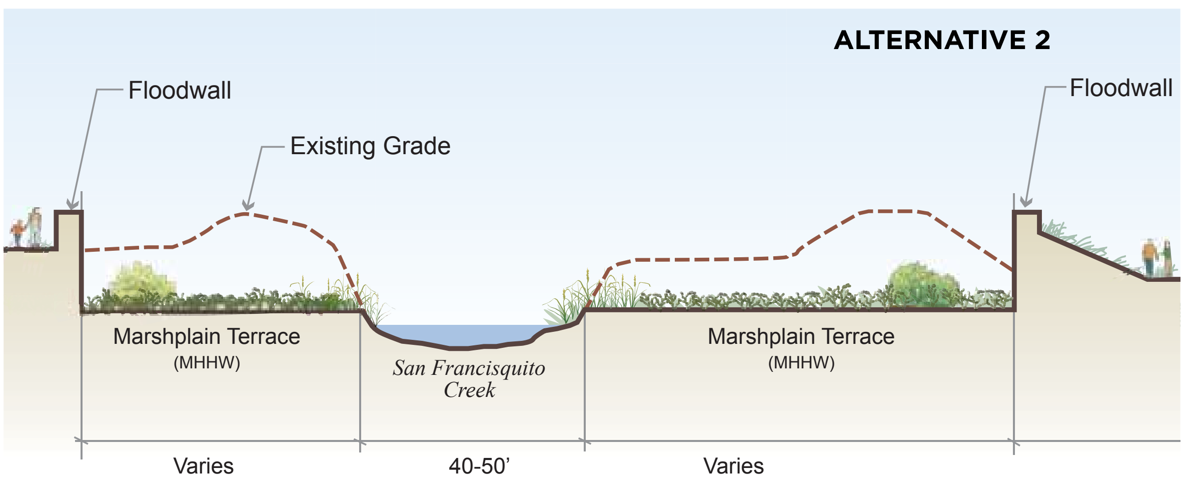
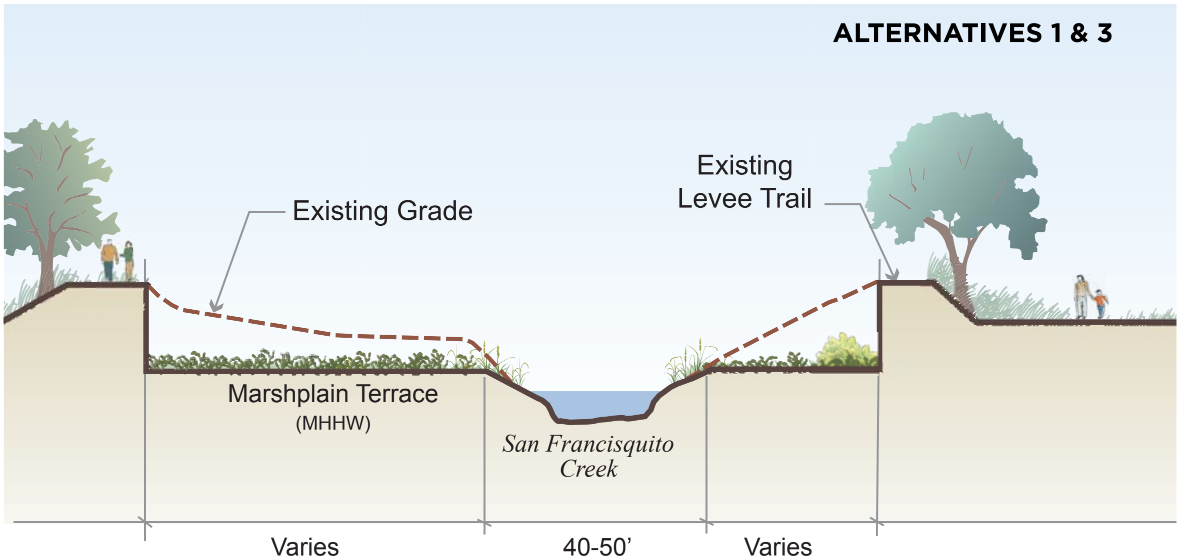


FIGURE 5 | **CROSS SECTION A, VIEW LOOKING DOWNTREAM**



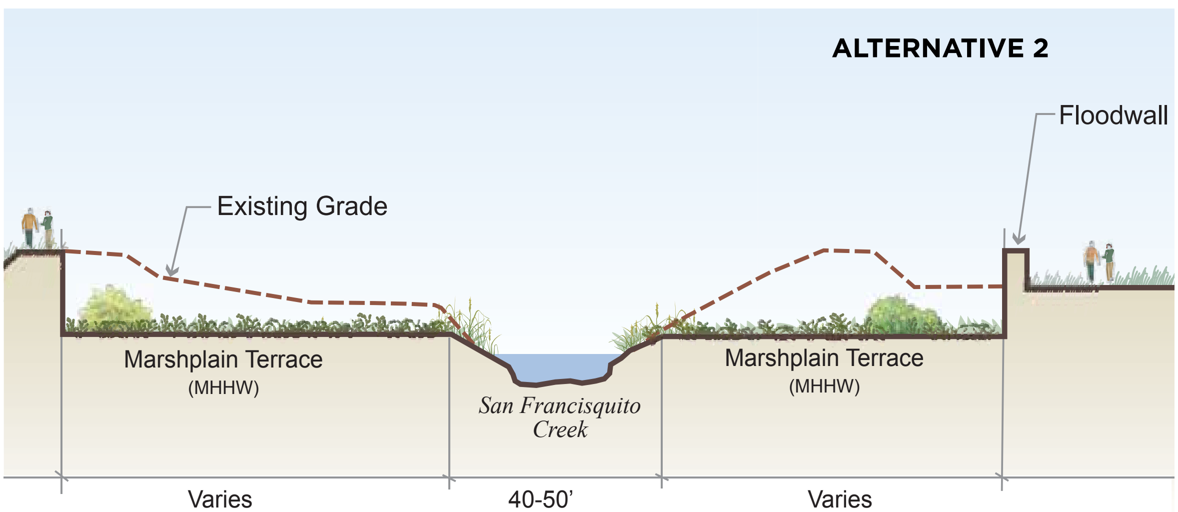


FIGURE 6 | **CROSS SECTION B, VIEW LOOKING DOWNTREAM**

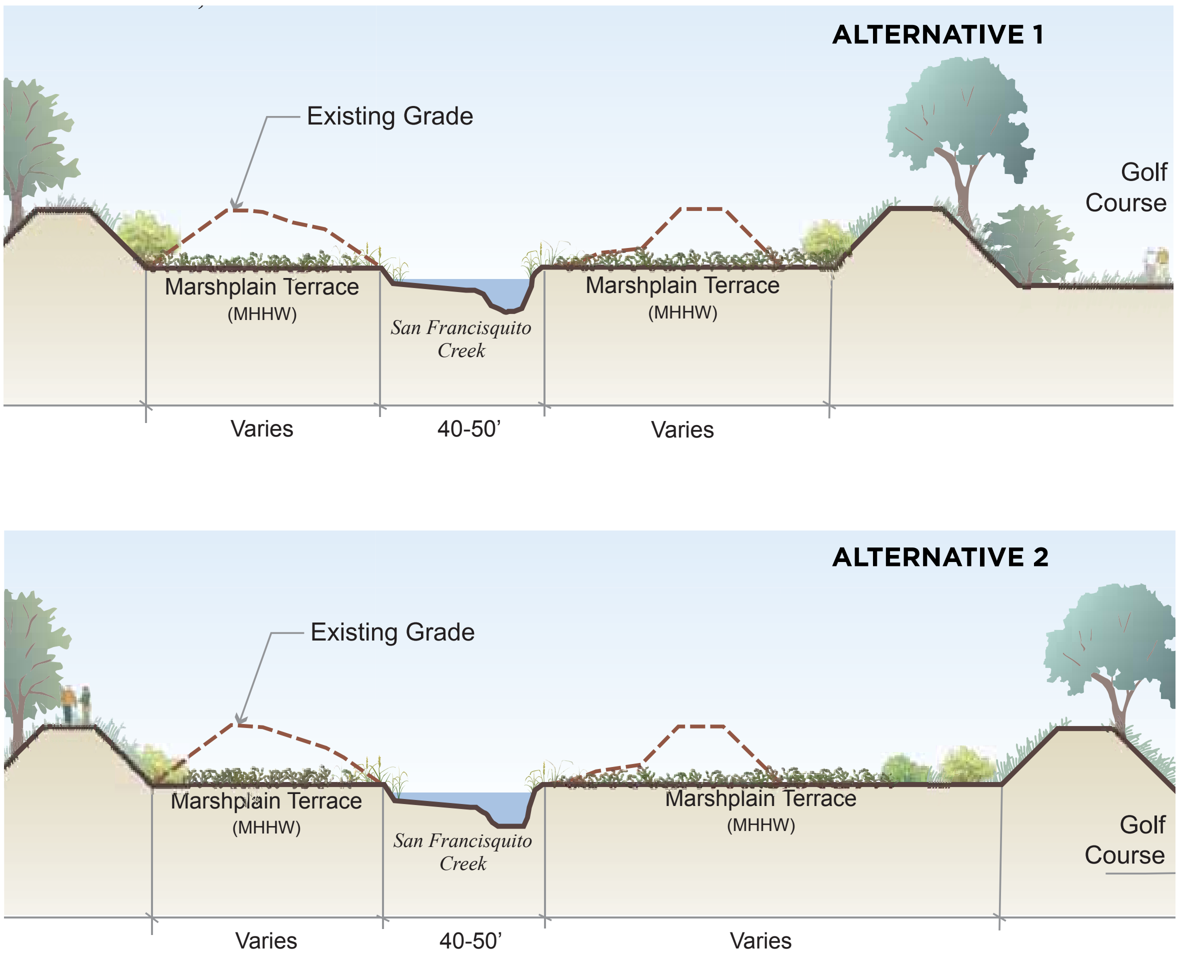


FIGURE 7 | **CROSS SECTION C, VIEW LOOKING DOWNTREAM**

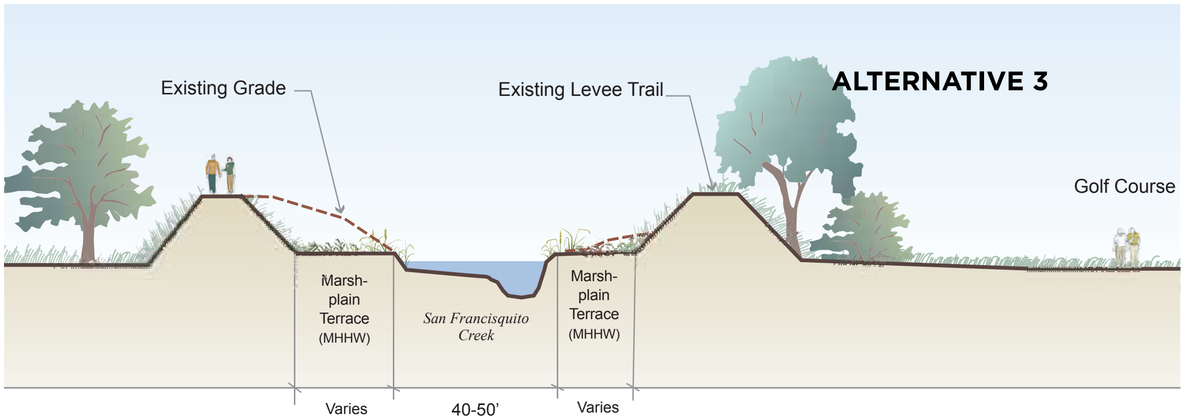


FIGURE 8 | **CROSS SECTION C, VIEW LOOKING DOWNTREAM**

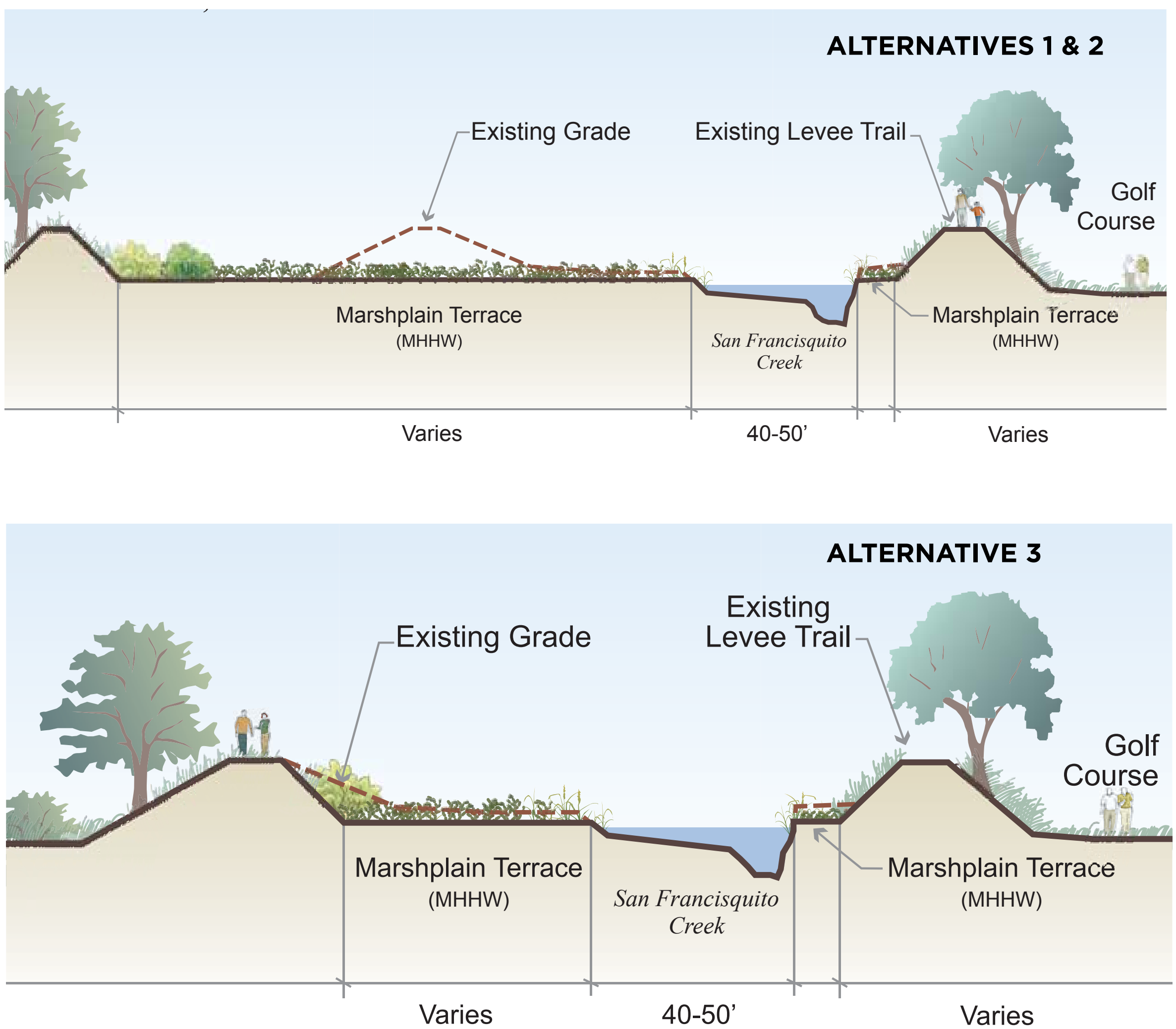


FIGURE 9 | **CROSS SECTION D, VIEW LOOKING DOWNTREAM**

2.3.2 | ALTERNATIVE 2

Alternative 2 is similar to Alternative 1, but modified to further reduce peak flood water levels relative to existing conditions. This alternative includes levee setbacks in the upper reach, increased levee setbacks in the middle reach, and an overflow terrace at a marsh elevation. A plan view of Alternative 2 can be seen in Figure 3.

To maximize flow conveyance in the upper reach, the channel would be widened to include any available open space on the outboard sides of the left and right levees. This includes the crescent-shaped parcel, owned by the SCVWD, on the left bank where Verbena Drive dead ends and a sliver of land that is parallel to Daphne Way near the beginning of the middle reach. On the right bank, the channel would be widened by 30 feet beginning at San Francisquito Creek Pump Station in Palo Alto and ending near the basketball court next to the International School. Downstream of this, the right levee would be shifted back by 50 feet, through the reach adjacent to the post office parking lot and the baseball field overflow parking lot. Similar to Alternative 1, the interior sides of the left and right levees would be vertical and the marshplain terraces in the channel would extend from the low-flow channel to the edge of the floodwalls.

In the middle reach, the left levee alignment for Alternative 2 would be the same as the left levee for Alternative 1. The right levee, however, would extend further east between Stations 5206 and 4606 by approximately 45 feet. This may require a minor realignment of one of the holes at the golf course.

Adjacent to the Friendship Bridge, Alternative 2's overflow terrace would have the same footprint and a similar design to Alternative 1's overflow terrace, but would be graded to an elevation equal to MHHW (7.1 feet NAVD). This would create a continuous tidal marsh beginning in the downstream reach, surrounding the Friendship Bridge's right approach, and extending upstream along the creek's right bank to Highway 101. The bypass terrace would be inundated during spring tides and most moderate fluvial flow events. Vehicle access would be limited to the levee on the right side of the bypass, but pedestrians would be able to access the Friendship Bridge by means of a boardwalk second bridge span over the marshplain bypass terrace (see Figure 3). The boardwalk would most likely not survive a large flood event and have to be replaced periodically.

2.3.3 | ALTERNATIVE 3

Alternative 3 includes in-channel marshplain terraces and a large bypass channel extending across the center of the golf course. It does not include levee setbacks in either the middle or upper reaches. A plan view of Alternative 3 can be seen in Figure 4.

Alternative 3 has the same terracing and vertical flood wall alignment as Alternative 1 in the upper reach. In the middle reach, Alternative 3 includes marshplain terraces excavated in the existing channel, but without realigning the existing levee layout. The existing levee crests would not be modified (except at locations where the East Palo Alto levees are lower than the Palo Alto golf course levees) and the inboard levee sides would be re-graded to be at 2:1 slopes.

The primary feature of Alternative 3 is a large bypass channel extending from south to north through the center of the golf course. This bypass reach would intersect the existing channel at Station 5604 and reconnect with the main channel near the airport runway at Station 1401. During both normal daily flows and fluvial flood events, a portion of upstream flows would be diverted through the bypass channel, therefore significantly reducing water levels in the middle reach.

The bypass reach would be designed with a low-flow channel, floodplain terraces at marshplain elevation, and levees on the right and left sides, with a total width between levees equal to 300 feet. The size of the low-flow channel was designed using empirical hydraulic geometry relationships that were developed for tidal marshes in San Francisco Bay (Williams and Others, 2002). The depth and top width of the low-flow channel, calculated from the total marsh area in the bypass reach, would be 6.5' and 30', respectively. The low-flow channel is the channel below the marsh elevation of MHHW and was assumed to be parabolic in shape. Marshplain terraces would extend from the right and left channel banks for a distance of approximately 115' on each side, until intersecting with the toes of the levees. Inboard levee sides would be at 2:1 slopes. Levee crests were assumed to be comparable in elevation to the levee crest elevations in the main channel at parallel locations. The outboard levee sides slope very gradually downward at a 2% grade to the existing golf course elevations so that the levees could be integrated into the golf course and would not be too steep for playing. Because the golf course is at a fairly low elevation (approximately 4 ft NAVD) relative to the proposed bypass channel levee tops, the overall footprint of these levees are much larger than the existing and proposed main channel levees.

2.4 | HYDRAULIC MODELING

PWA used hydraulic modeling software to compare the flood management benefits of each of the three alternatives relative to existing conditions and each other. This section describes the existing conditions hydraulic model and its adaptation to represent the alternative conditions.

2.4.1 | EXISTING CONDITIONS MODEL

A hydraulic model representing the existing conditions of San Francisquito Creek was obtained from Noble Consultants, Inc. (Noble) on March 12th, 2009. Noble constructed the one-dimensional, steady-state HEC-RAS model for the USACE to evaluate the flow capacities of the existing channel and the major bridges on the creek (Noble, 2009). We focused our hydraulic analysis entirely on the reach of San Francisquito Creek downstream of Highway 101 and did not review the model upstream of this location.

Geometric Data

The Existing Conditions model extends from the mouth of the creek at the Bay to approximately one mile upstream of Highway 280. Channel geometry was developed from a digital terrain model based on a combination of cross section survey data and LiDAR data. Bridge data was derived from field surveys (Noble, 2009).

Cross sections in the reach downstream of Highway 101 are spaced approximately every

200' and are clipped at the highest points on the left and right levees. Because of this clipping, the model represents hydraulic conditions in the active flow channel only and does not accurately simulate flow conditions when water levels are higher than the left or right levees. During levee-overtopping flood conditions, water would spill over the levees and leave the channel, thus reducing the flow and limiting actual peak water surface elevations in the main channel. Because the cross sections did not extend beyond the levee tops, the model predicts water surface elevations in the channel to extend unrealistically above the levee tops at high flows, as if a vertical wall existed at the edge of the cross section. The Noble model was not designed to simulate out-of-channel flow conditions for large flood events. Model results for conditions that cause levee overtopping were therefore not considered accurate and not reported in this study.

Boundary Conditions

The Existing Conditions model was run under steady-state conditions (i.e. non-varying boundary conditions) with the downstream boundary representing a fixed water level in the Bay and the upstream boundary representing runoff from the upper watershed. Flow changes are also specified along the channel and represent locations where significant flow additions occur, such as at tributary junctions. The peak discharge at Highway 101 during the February 2000 storm event was 4,010 cfs and the water level in the Bay was 7.3' NAVD88 (Noble, 2009). Based interpolation from published values for the 5-year and 10-year events, the February 2000 event represents approximately a 7-year flood event at Highway 101 (SCVWD, 2007). Higher flows were not modeled in the Existing Conditions model due to the levee overtopping issues discussed above.

Channel Roughness and Model Calibration

The existing conditions model was calibrated to a flood event that occurred on February 13th, 2000, as it represents a flood event with high in-channel flows and no levee overtopping in the lower reach. Noble calibrated the Existing Conditions model by adjusting channel and bank roughness values using flow data and high water marks from the February 2000 flood event (Noble, 2009). A high water mark was available at the Highway 101 Bridge. Noble's model showed good correlation between simulated and measured water levels at this location, indicating that the calibrated roughness values in the lower reach were likely representative of existing conditions during moderate flood events. (HEC-RAS calculates water levels from downstream to upstream during sub-critical flow and therefore simulated water levels at Highway 101 are directly influenced by simulated water levels in the lower reach.) Manning's n values for the channel and banks were typically 0.035 and 0.050 in the entire downstream reach, respectively. PWA did not adjust these roughness values in the Existing Conditions model.

Vertical Datum

The Existing Conditions model used in this study was in English units in the North American Vertical Datum of 1988 (NAVD88). In developing the model, Noble converted any values from the NGVD29 datum to NAVD88 with a conversion factor of 2.75 feet (0' NGVD = +2.75' NAVD), which is the accepted conversion value used in Santa Clara County and for the South San Francisco Bay Shoreline Study (Noble, 2009). The datum was not changed and all values reported are in NAVD88.

2.4.2 | ALTERNATIVE CONDITIONS MODELS

The Existing Conditions model was adapted to create three new hydraulic models that reflect the geometric conditions of each of the three alternatives by changing channel cross section geometries and reach layouts.

Geometric Data

In the upper reach, Alternatives 1 and 3 have the same geometry; the geometry of Alternative 2 is similar, but includes additional levee setbacks. Above an elevation of 7.1' in the low flow channel, marshplain terraces extend to the toe of the right and left levees. Levee sides extend vertically from the existing crest elevation to the marshplain terraces. The Alternatives 1 and 3 geometries maintain the existing elevations of the levee crests. At the locations where Alternatives 1 and 2 call for levee setbacks, the levee crest was shifted horizontally but the elevation was not changed (see Figure 5 and Figure 6). At Stations 6613 and 6411, the low flow channels were enlarged between the edges of the low flow channel and its intersection with the design marshplain terrace.

In the reach between Station 5807 and the Friendship Bridge, the width between the left and right levees differed between the three alternatives, but the approach for updating cross sections was similar for each alternative. In locations with existing floodplain terraces or where the alternative design includes a levee setback, ground levels were set at marshplain elevation from the edge of the main channel to the toe of the levee. The width of this marshplain terraced varied between cross sections and alternatives (see Figure 2 through Figure 4). Levee side slopes extended up to the existing levee crest at a slope of 2:1. The levee tops and main channel below MHHW were not changed from the Existing Conditions model. Figure 6 through Figure 8 conceptually compare existing conditions and the three alternatives at various locations in the middle reach.

For all three alternatives, the left levee in the lower reach was lowered to marshplain elevation to create a hydraulic connection between San Francisquito Creek and the Faber Tract to the north. After lowering the left levee, the left overbank area of each cross section in this reach was widened to reflect the approximate width of the available flow area in the Faber Tract. This area was narrower immediately downstream of the bridge (approximately 250') and wider at the downstream end of the channel near the Bay (approximately 3,000'). The marshplain terrace was set at an average elevation of 7.1', with the top of the bank adjacent to the channel at 7.0' and the furthest outboard marsh location at 7.2' to provide a mild slope for drainage back into the channel. See Figure 11 for a typical cross section in the lower reach.

Each alternative includes bypass channels: an elevated bypass terrace in Alternative 1, a marshplain terrace bypass in Alternative 2, and the golf course bypass channel in Alternative 3. For Alternatives 1 and 2, these bypass channels were reflected in the model geometry by extending the cross sections adjacent to Friendship Bridge to include the bypass channels and the outboard levees. Figure 10 shows these cross sections. For Alternative 3, an additional channel reach was added to the model to represent the bypass reach and was connected to San Francisquito Creek's main channel through junctions in the model's geometry. Cross sections for this bypass channel include the inboard portions of the levees at 2:1 slopes, marshplain terraces at an elevation of MHHW, and a low flow channel that is parabolic in shape with a 30' top width and a depth of 6.5'.

Roughness

The roughness values were not changed from the calibrated values for the channel and bank areas. Roughness values for marsh areas, including in-channel marshplain terraces and the Faber Tract, were assumed to be equal to 0.035. This value was assumed to reasonably represent pickleweed, the low-growing, dominant tidal marsh plant species in the southern portion of the Bay.

Boundary Conditions

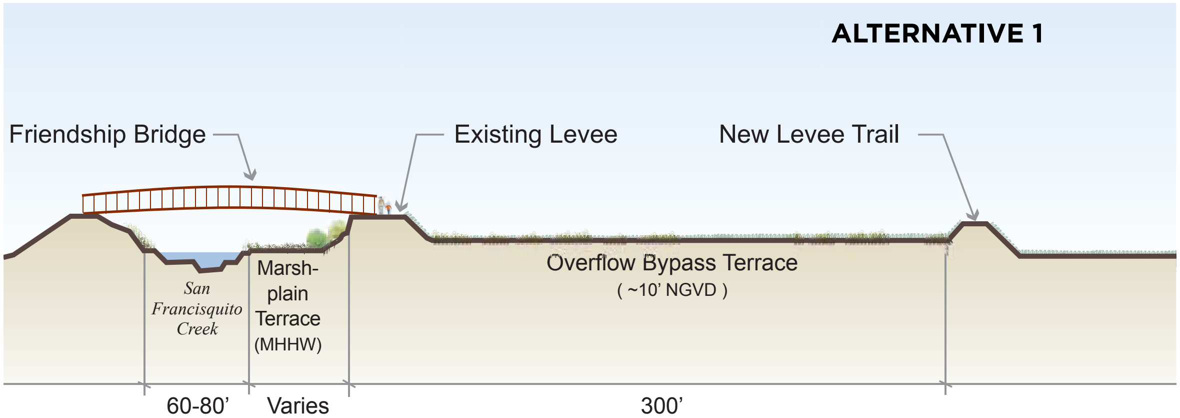
In addition to the February 2000 event modeled for existing conditions, the February 1998 flood and the 100-year fluvial flood events were modeled for the alternative conditions. The flood on February 3rd, 1998 was the most recent event to cause significant out-of-bank flooding on San Francisquito Creek and is a common reference event for stakeholders in the San Francisquito Watershed. It was estimated to be approximately a 45-year event (SCVWD, 2007). The 100-year fluvial event, based on the SCVWD 2007 hydrology analysis, was modeled with MHHW as the downstream boundary to be consistent with the Noble/USACE hydraulic model. Because Alternative 3 had the additional bypass reach in the geometry, the model optimized the relative amounts of flow in the main San Francisquito channel and the bypass channel through the golf course. For each event, upstream flows and downstream water levels are shown in Table 1, including the model-calculated split flow for Alternative 3.

Table 1 shows that for Alternative 3, more water is routed through the bypass channel during the February 1998 event than during the 100-year event, despite there being more total discharge during the 100-year event in the main channel upstream and downstream of the bypass channel connections. Because the higher downstream water level boundary in the February 1998 event results in a higher water level at the downstream connection of the bypass and the main channels, a greater relative flow diversion occurs between the bypass and the main channels. (The model calculates water levels from downstream to upstream, so water level at the downstream end of the flow split determines the flow rate allocated to each channel.)

TABLE 1 | **BOUNDARY CONDITIONS FOR ALTERNATIVE CONDITIONS MODELING**

	All Alternatives			Alternative 3 Only	
Flood Event	**Downstream Water Level**	**Flow at Highway 101**	**Flow at Creek Mouth** (at the Bay)	**Calculated Flow through Bypass**	**Calculated Flow in Middle Reach**
	(ft NAVD)	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**
February 2000	7.3	4,010	4,010	2,187	1,823
February 1998	9.3	7,200	7,200	5,450	3,950
100-year Event	7.1	9,300	9,400[1]	4,161	3,039

1 – A flow increase of 100 cfs is applied at the Friendship Bridge for Alternatives 1, 2, and 3, but the actual total in-channel flow at the bridge is reduced for Alternative 3 due to the bypass channel flow split.



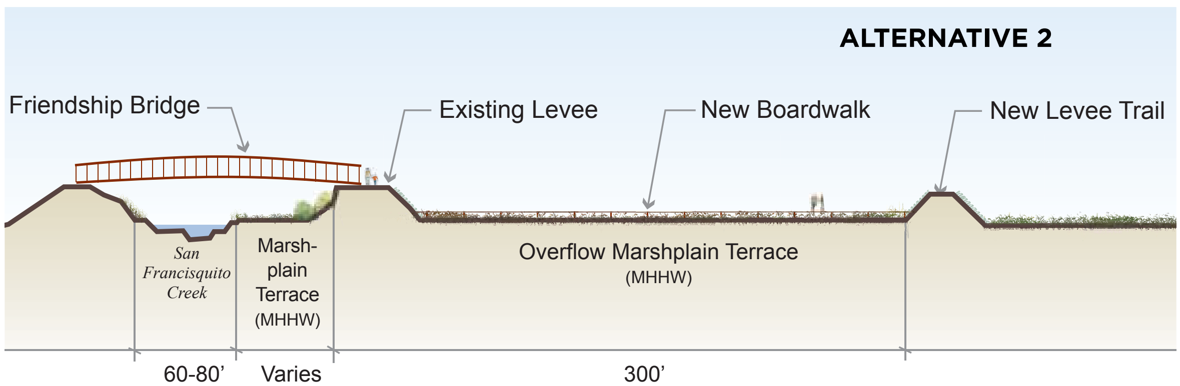


FIGURE 10 | **CROSS SECTION E, VIEW LOOKING DOWNTREAM**

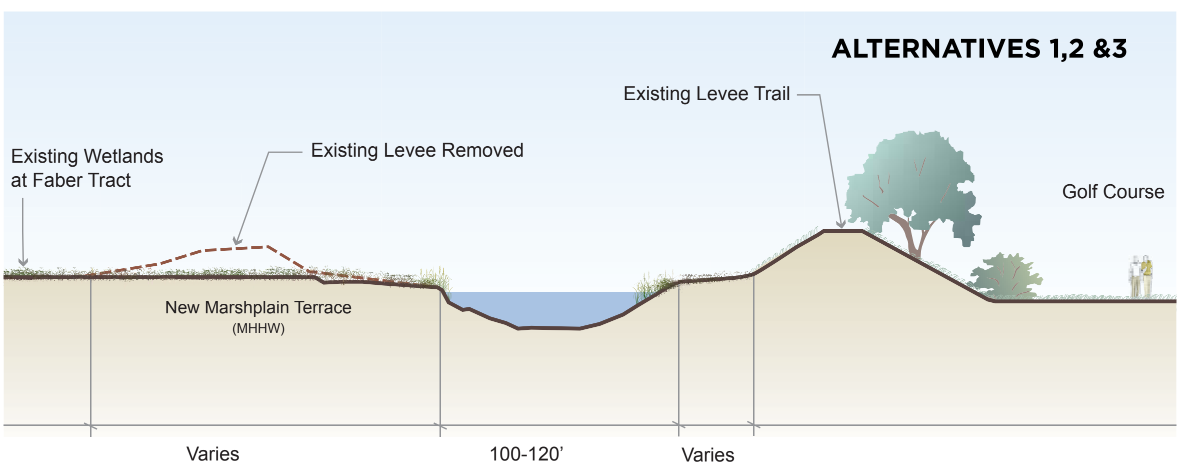
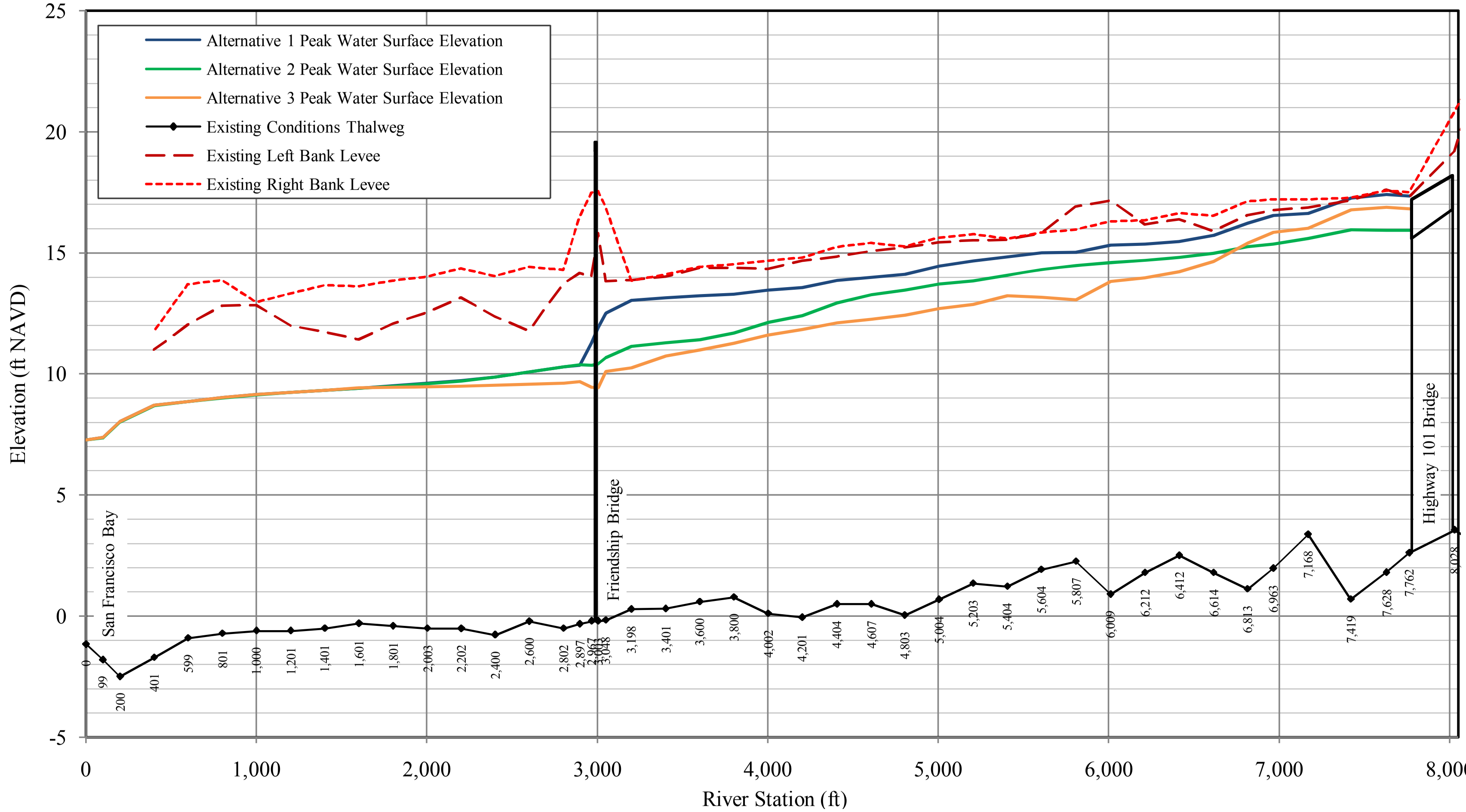


FIGURE 11 | **CROSS SECTION F, VIEW LOOKING DOWNTREAM**

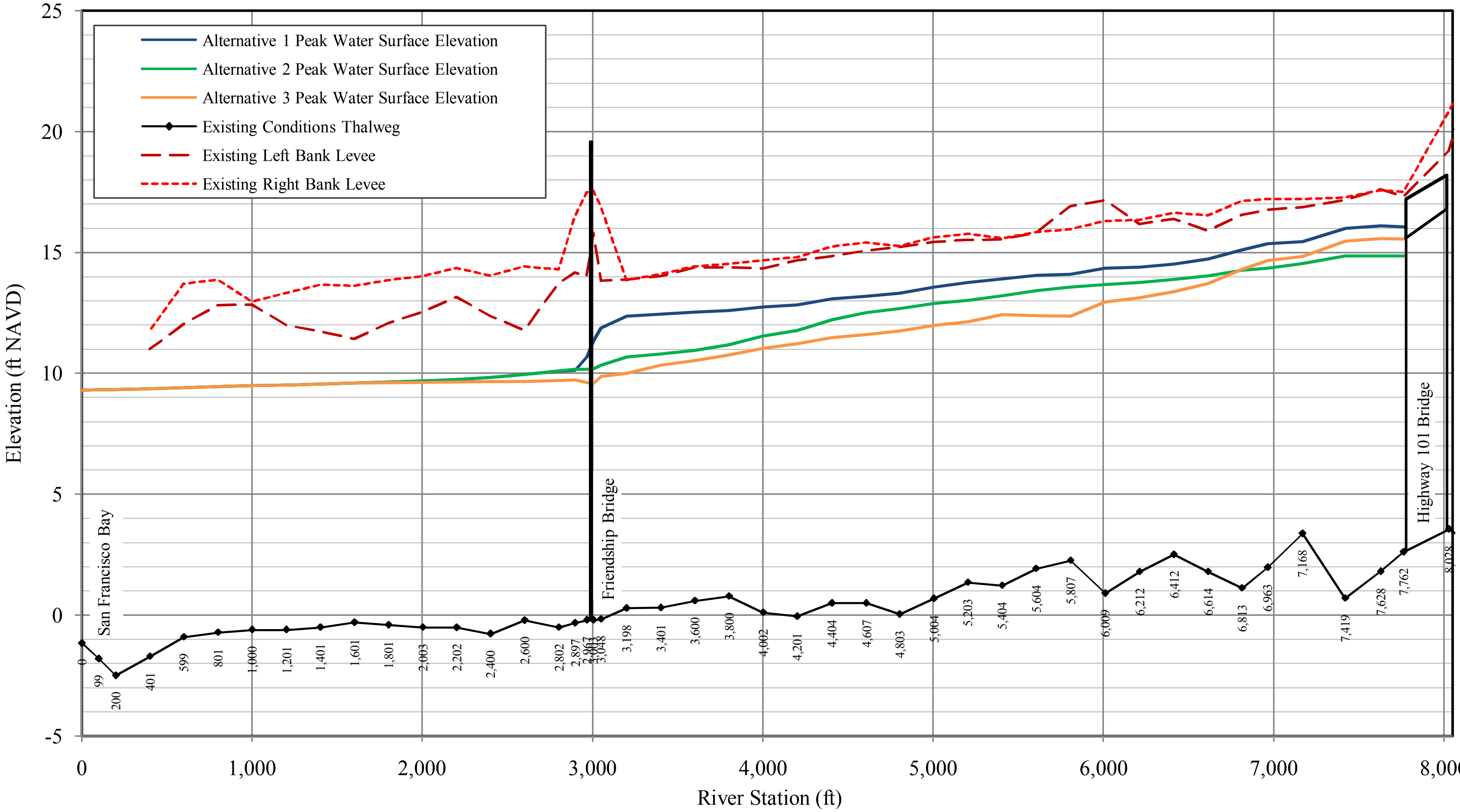
2.5 HYDRAULIC MODELING RESULTS

Figure 12 through Figure 14 show the predicted model peak water surface elevation results for each alternative relative to the thalweg and existing left and right levees. Figure 14 also shows water levels for the existing conditions model for the February 2000 event. The alternatives reduce water levels for the 100-year and February 1998 design events to at or below the levee crests and produced significantly lower water levels for the February 2000 event relative to existing conditions



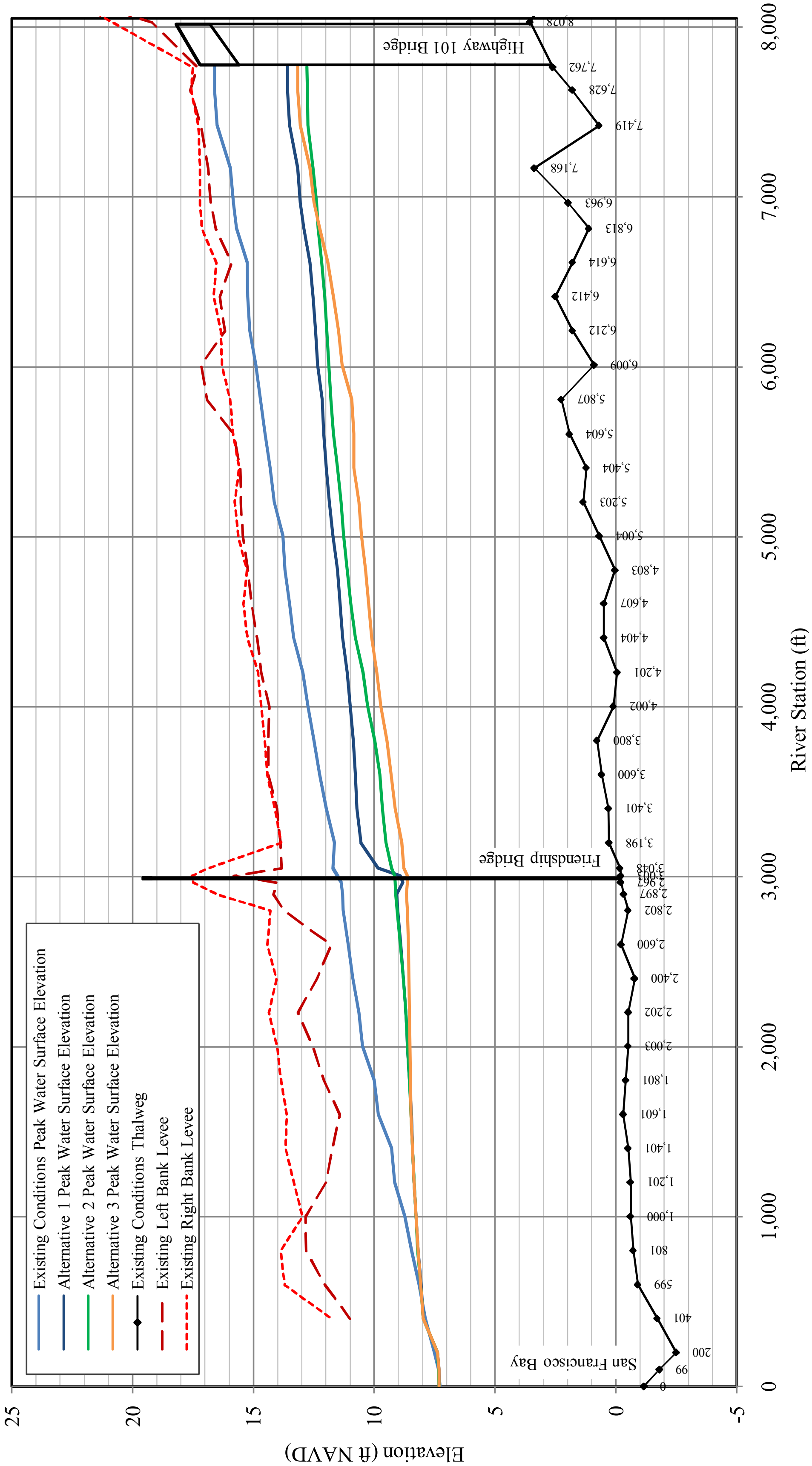
Notes: Peak water surface elevations for the 100-year fluvial flood event discharge of 9,300 at Highway 101 and 9,400 cfs at the Friendship Bridge and a Bay water level equal to 7.1 ft NAVD (MHHW). Existing left bank and right bank levees are referenced to facing downstream.

FIGURE 12 | **DESIGN PEAK WATER SURFACE ELEVATIONS FOR THE 100-YEAR EVENT**



Notes: Peak water surface elevations for February 1998 event where peak flows in San Francisquito Creek were 7,200 cfs and Bay water levels were 9.3 ft NAVD. Existing left bank and right bank levees are referenced to facing downstream

FIGURE 13 | **DESIGN PEAK WATER SURFACE ELEVATIONS FOR THE FEB. 1998 EVENT**



Notes: Peak water surface elevations for February 2000 event where peak flows in San Francisquito Creek were 4,010 cfs and Bay water levels were 7.3 ft NAVD. Existing left bank and right bank levees are referenced to facing downstream.

FIGURE 14 | **DESIGN PEAK WATER SURFACE ELEVATIONS FOR THE FEB. 2000 EVENT**

2.5.1 | EXISTING CONDITIONS

The 100-year and February 1998 flood events were not run with the Existing Conditions model for the reasons previously discussed. For the February 2000 event (about a 7-year flood event), the simulated water surface profile increases steadily from the Bay, remaining lower than the left and right levees at all locations until intersecting with the Highway 101 Bridge deck.

2.5.2 | ALTERNATIVE CONDITIONS

In general, all three alternatives produce similar water surface elevation profiles relative to each other in the lower reach for each of the three flood events simulated using HEC-RAS. Beginning several hundred feet downstream of the Friendship Bridge and extending through the middle reach, Alternative 3 results in water levels lower than the other alternatives due to the significant portion of discharge that gets routed through the golf course bypass channel. (Table 1 shows how much water travels through the golf course bypass relative to the main channel for Alternative 3.) For Alternative 1, an increase in water levels occurs at the Friendship Bridge under all flows, due to a localized channel constriction at the bridge and smaller bypass channel area relative to the other alternatives. Through the middle reach, the alternatives generally run parallel to each other, with Alternative 1 resulting in the highest water levels and Alternative 3 resulting in the lowest water levels. Beginning approximately 1,000' downstream of Highway 101, Alternative 2 results in the lowest water levels because of its larger conveyance area in the upper reach relative to the other alternatives. This occurs for all three flood events analyzed. Table 2 shows water surface elevations at several locations in San Francisquito Creek downstream of Highway 101.

TABLE 2 | **WATER SURFACE ELEVATION RESULTS AT SELECTED LOCATIONS**

		Water Surface Elevation (ft NAVD)			
Flood Event	**Model Run**	**Downstream of Friendship Bridge (2802)**	**Upstream of Friendship Bridge (3198)**	**At Ball Field / Golf Course Bend (5807)**	**Downstream of Highway 101 (7762)**
February 1998	Existing	14.0	14.4	17.9	19.9
	Alternative 1	10.1	12.4	14.1	16.1
	Alternative 2	10.1	10.7	13.6	14.9
	Alternative 3	9.7	10.0	12.4	15.6
February 2000	Alternative 1	9.1	10.6	12.2	13.6
	Alternative 2	9.1	9.5	11.8	12.8
	Alternative 3	8.6	8.9	10.9	13.2
100-year Event	Alternative 1	10.3	13.0	15.0	17.3
	Alternative 2	10.3	11.1	14.5	15.9
	Alternative 3	9.6	10.3	13.1	16.8

2.6 | DOWNSTREAM PROJECT DISCUSSION

To further assess the feasibility and appropriateness of the three Downstream Project alternatives, we developed an opinion of probable costs and a benefits and constraints matrix.

2.6.1 | OPINION OF PROBABLE COSTS

A conceptual-level opinion of probable construction costs was developed to provide additional information for evaluating each alternative. PWA relied on experience with other projects in similar environments and R.S. Means (2009 edition) to estimate unit costs and construction quantities. These cost estimates are considered to be approximately -30% to +50% accurate, and include a 30% contingency to account for project uncertainties. Additionally, these cost estimates include a 10% escalation to account for short term (through 2012) increases in fuel, materials, and labor as a result of inflation or changes in supply and demand. Costs do not include estimated project costs associated with land acquisition, design, permitting, monitoring, and maintenance. These estimates, shown in Table 3, are subject to refinement and revisions as the design is developed in future stages of the project.

TABLE 3 | **OPINION OF PROBABLE COSTS**

	Alternative 1		Alternative 2		Alternative 3	
	Quantity	Cost	Quantity	Cost	Quantity	Cost
Excavation	131 T.C.Y[1]	$2,620,000	142 T.C.Y.	$2,840,000	140 T.C.Y.	$2,800,000
Grading	108 T.C.Y.	$2,160,000	111 T.C.Y.	$2,240,000	830 T.C.Y.	$16,600,000
Flood Wall	1753 L.F.[2]	$654,000	1753 L.F.	$654,000	1753 L.F.	$654,000
Fill Import	-	-	-	-	690 T.C.Y.	$13,800,000
Fill Disposal	23 T.C.Y	$230,000	30 T.C.Y.	$300,000	-	-
Subtotal		$5,664,000		$6,034,000		$33,854,000
Contingency		$1,699,000		$1,810,000		$10,156,000
Escalation		$566,000		$603,000		$3,385,000
TOTAL		$7,929,000		$8,447,000		$47,395,000

1 – T.C.Y. refers to cubic yards, in thousands

2 – L.F. refers to lineal feet

Based on this conceptual-level estimation, Alternatives 1 and 2 are fairly similar in cost, with Alternative 2 approximately 6% greater than Alternative 1. Alternative 3 is much more expensive than the other two alternatives (approximately 6 times greater) due to the extensive volume of grading and fill required for the golf course bypass channel levees.

2.6.2 | CHANNEL SEDIMENTATION AND MAINTENANCE

In addition to conveying excess precipitation as streamflow, San Francisquito Creek also conveys sediment eroded from the upper watershed downstream to San Francisco Bay. A comprehensive sediment study was conducted for the JPA in 2004 (NHC and JSA, 2004) that provides estimated sediment budgets for the watershed. This study suggests that on an average annual basis, about 5,200 to 6,000 cubic yards (cy) of sediment are conveyed to San Francisco Bay, and that deposition in the channel reach from Highway 101 to the Bay has averaged about 1000 cy/year (with about 75% originating in the watershed and 25% coming from the Bay). Sediment production in the watershed is extremely episodic, with most sediment being supplied during the extreme flood events (such as February 1998).

The downstream channel improvements described in Alternatives 1, 2 and 3 will increase the channel flow area between the levees, allowing greater conveyance during large flood events. The ongoing upstream sediment supply and deposition described above will continue, and continuation of the periodic removal of sediment, particularly in the reaches immediately downstream of Highway 101 will be required.

2.6.3 | SEA LEVEL RISE

As a result of global climate change, sea levels around the world are expected to rise. While estimates for the potential range of sea level rise (SLR) vary widely, current “mid-range” estimates are on the order of 1 foot in 50 years scenario, and about 3 feet by 2100. This has implications for the starting water surface level assumed to be occurring in San Francisco Bay at the time a major fluvial flood event occurs. Current practice in flood modeling has been to assume a starting water surface in San Francisco Bay equal to MHHW. SLR would gradually increase the elevation of MHHW, and concurrently, gradually decrease the level of protection provided by the proposed flood reduction improvements.

This problem will be affecting all areas adjacent to the coast and around San Francisco Bay. In planning for any flood management project in the tidal zone, it would be prudent to plan for future SLR. This could be accomplished by over-designing the project (relative to current MHHW) when constructed, or by designing the project to be adapted as SLR occurs. The latter approach would include designing levees and/or floodwalls with an adequate foundation to be raised in the future, and other similar approaches.

2.6.4 | BIOTIC CONSTRAINTS AND OPPORTUNITIES

HT Harvey & Associates reviewed background information and conducted reconnaissance surveys of the project reach to identify the major biotic constraints and opportunities associated with the draft flood reduction alternatives developed by PWA. Their findings are documented in Appendix A and briefly summarized below.

There is also an opportunity to improve tidal marsh habitat quality by incorporating biological considerations into the project design. Such opportunities include 1) the conversion of low quality floodplain terrace habitat (dominated by non-native, perennial pepperweed) to higher quality marshplain habitat dominated by native tidal salt and brackish marsh species, 2) the restoration of high tide refugial habitat for sensitive wildlife species at the ecotone between tidal wetland and upland habitats, and 3) the restoration of fluvial flooding to the Faber Tract. This natural process has been blocked by the levee, and should help restore a sediment source to over time assist the marshplain in responding to sea level rise.

As noted above, the excavation of floodplain terraces within the existing channel and the lowering of the Faber Tract levee would result in a loss of tidal salt and brackish marsh habitat. However, the project can be designed to ensure that this loss is temporary by setting the design elevations and soil preparation techniques to regenerate the physical conditions that will facilitate the natural recolonization of tidal marsh vegetation. In addition, the proposed alternatives would likely both fill a portion of the existing non-tidal seasonal wetland habitat between the Palo Alto Golf Course and the outboard levee slope of San Francisquito Creek. The loss of these non-tidal wetlands could be compensated for by the restoration of high quality tidal marsh habitat within the expanded creek channel and/ or lowered levee along the Faber Tract.

2.6.5 | SUMMARY

Of the three alternatives evaluated for this study, Alternative 2 provides the greatest reduction in peak water levels for the storm events tested. Hydraulic modeling of this alternative indicates that it would contain the 100-year design storm within the channel throughout the study reach. Alternative 3 could provide similar reductions if the bypass channel were combined with the channel modifications assumed for the upper reach under Alternative 2. However, Alternative 3 is significantly more costly than either of the other two alternatives. Alternative 1 reduced water levels significantly; however, model results indicate that the 100-year design storm may not be fully contained at US 101 under this alternative.

3. UPSTREAM PROJECT

The goal of the Upstream Project was to explore flood detention opportunities in the upper portion of the San Francisquito Creek watershed capable of significantly reducing peak flow rates in the creek. A combination of geospatial analysis and HEC-HMS hydrologic modeling was used in the Upstream Project analysis to eliminate unfeasible detention locations. In the remaining areas, three possible detention facility design alternatives were identified.

3.1 | DETENTION SITE SCREENING METHODOLOGY

The detention site screening was accomplished through geospatial analysis and a HEC-HMS hydrologic model. An existing conditions HEC-HMS hydrologic model was created from a HEC-1 model provided by the SCVWD. The results from the HEC-HMS model were used to eliminate locations that would not accomplish target flow reductions. High resolution aerial photos were then used to screen out detention locations based on land use. In a final screening, detention facilities were added to the existing conditions HEC-HMS hydrologic model, and minimum storage volumes were established for identifying suitable detention locations based on topography. The screening process identified a geographic zone that was further evaluated for detention opportunities. Three feasible detention locations were identified. Detention scenarios for these locations were modeled to test their potential for accomplishing the target flow reduction.

3.1.1 | HYDROLOGIC MODEL

A hydrologic model was used to test detention scenarios and quantify potential benefits. Hydrologic models use watershed physical properties and meteorological data to mathematically simulate watershed precipitation-runoff processes over a specified time. HEC-1 and HEC-HMS are both hydrologic modeling software programs written by the USACE's Hydrologic Engineering Center (HEC). An existing conditions HEC-1 model of the San Francisquito Watershed was developed and provided by the SCVWD. PWA imported the HEC-1 model into HEC-HMS to take advantage of the advanced graphical interface and hydrologic engineering capabilities provided in HEC-HMS. The San Francisquito HEC-HMS model was used to simulate existing conditions, and various upstream detention options.

HEC-1 Hydrologic Model

The original existing conditions hydrologic model was developed in the HEC-1 hydrologic model software and provided by the SCVWD on April, 8, 2009. The San Francisquito Creek model was designed to simulate the 100-year 24-hour storm event for the entire San Francisquito watershed. The details of this model (Design Storm Precipitation, Loss Rates, Clark's Synthetic Hydrograph Parameters, Routing Parameters, etc.) are included in the San Francisquito Creek Hydrology Report (SCVWD 2007).

HEC-HMS Hydrologic Model

For the upper watershed detention analysis, the HEC-1 base model provided by the SCVWD was imported into HEC-HMS. HEC-HMS is the successor to HEC-1 and provides a similar variety of options but with an improved graphical interface and more advanced hydrologic engineering capabilities. The parameters in the HEC-HMS model were reviewed and confirmed to match those imported from the HEC-1 model.

3.1.2 | FLOOD-REDUCTION SCREENING CRITERIA

For screening purposes, Middlefield Road Bridge was selected as the watershed location to set the flood-reduction criteria for detention alternatives. The existing conditions Q100 at Middlefield Bridge was estimated by the HEC-HMS model to be approximately 9,200 cfs, while the capacity of Middlefield Bridge is approximately 6,700 cfs. A 27% reduction (2,500 cfs) would be required to decrease the 100-yr event flooding to the capacity of the bridge.

In consultation with JPA staff, a minimum flow reduction of 10% (920 cfs) was selected as the initial screening criterion for detention alternatives, with 27% reduction as the preferred target. Although 27% was identified as the preferred target, an even larger reduction in Q100 would be required to overcome all of the channel conveyance capacity limitations under existing conditions.

3.1.3 | WATERSHED POSITION ANALYSIS

In our initial screening, locations in the watershed where the total Q100 stream discharge was less than the target reduction in Q100 at Middlefield (920 cfs) were eliminated from consideration. The existing conditions HEC-HMS model was used for this portion of the screening process. Working from upstream down, the results for the 100-yr 24hr event at each model node were examined. If a subwatershed or a particular group of subwatersheds yielded peak runoff of less than 920 cfs, they were eliminated from consideration as potential locations for flood detention. Additionally, subwatersheds in the most downstream locations were eliminated based on the level of development in these areas. Figure 15 shows the various subwatersheds that were screened out, leaving the remaining zone as the potential location for flood detention.

3.1.4 | DETENTION VOLUME ESTIMATION

PWA briefly reviewed the potential for three existing facilities within the target watershed area (Lake Lagunita, Felt Lake, and Searsville Reservoir) to provide flood storage. Lake Lagunita has an existing storage capacity of approximately 360 acre-feet. It receives runoff from the surrounding watershed and partially fills during large events. The current diversion used to fill the lake from San Francisquito Creek pumps at a rate of approximately four cfs, whereas the diversion rate that would be required for flood peak reduction would be on the order of 1,100 cfs. Approximately eight 72-inch pipelines 3,000 feet in length would be required to convey this flow rate to Lake Lagunita, rendering this location impractical for flood detention purposes. Felt Lake has an existing storage capacity of approximately 1,000 acre-feet, but diversion challenges very similar to those described for Lake Lagunita make it impractical for flood detention.

Existing Facilities

Searsville Reservoir has a design storage capacity of approximately 1,000 acre-feet, but this capacity has been reduced by about 90% due to sedimentation. Sediment removal could restore some or all of the storage, but significant logistical and engineering challenges to removing sediment at this location (dewatering, transportation, etc.) render this approach impractical as an early implementation project. Theoretically, this location could provide off-line storage in the form of floodplain wetlands or a separate basin if the dam and sediments were removed with this goal in mind. However, off-line detention at this location is also impractical for early implementation.

Because of the logistical and engineering barriers to development of an early implementation flood detention project at the existing facilities, PWA pursued identification of possible sites for new facilities.

Modeling Detention Using HEC-HMS

Assuming a location within the zone identified above, generic flood detention basins were simulated using the hydrologic model to estimate the storage volume needed to reduce the Q100 at Middlefield Bridge by 10%. Separate models were created for in-line detention option (i.e. a dam across the existing creek channel) and off-line detention option (i.e. a basin separated from the stream channel into which water would be diverted from the channel). The in-line detention option was modeled as a reservoir within the identified channel reach. The off-line detention option was modeled as a diversion on the identified channel reach, with the diversion connecting to a reservoir which re-connected back to the channel downstream.

Each reservoir was designed with a elevation-storage function, a circular outlet, and a berm or dam top elevation. The elevation-storage function was estimated from topography located in areas suitable for flood detention using ArcGIS software. The outlet was sized to maximize the flow reduction at Middlefield Bridge.

Detention Volume Results

The results of this analysis showed that an in-line detention facility would require over twice the volume of an off-line detention facility to achieve a comparable level of flood reduction. Storage volume in off-line facilities can be used more efficiently because the basin can be kept empty until the creek reaches flood stage. For screening purposes, the approximate minimum volume needed for a single off-line detention facility to accomplish the desired flood reductions was found to be in the range of approximately 250 acre-feet.

3.1.5 | FEASIBILITY SCREENING

In the final step of screening, suitable detention locations were screened for topographic feasibility. Subwatersheds were removed from consideration that did not have the topography to feasibly accommodate the required storage volume determined from the preliminary detention modeling. Topographic constraints were primarily steep terrain adjacent to the channel which would necessitate excessive earthwork to create detention and/or preclude the diversion of sufficient flow from the channel to a suitable detention location. The remaining areas representing suitable zones for off-line flood detention are shown in Figure 16.

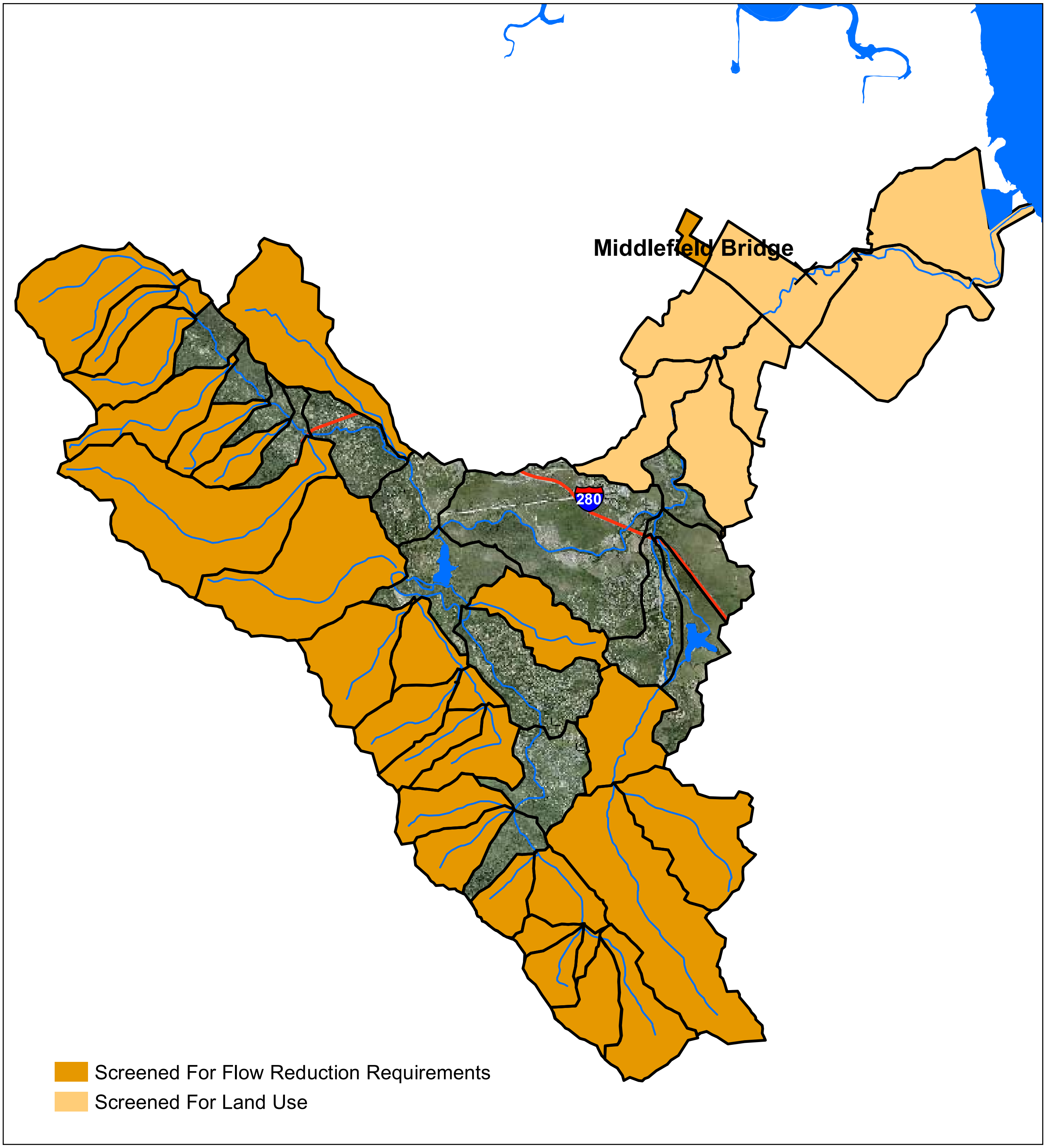


FIGURE 15 | **MINIMUM FLOW REDUCTION AND LAND USE DETENTION LOCATION SCREENING**

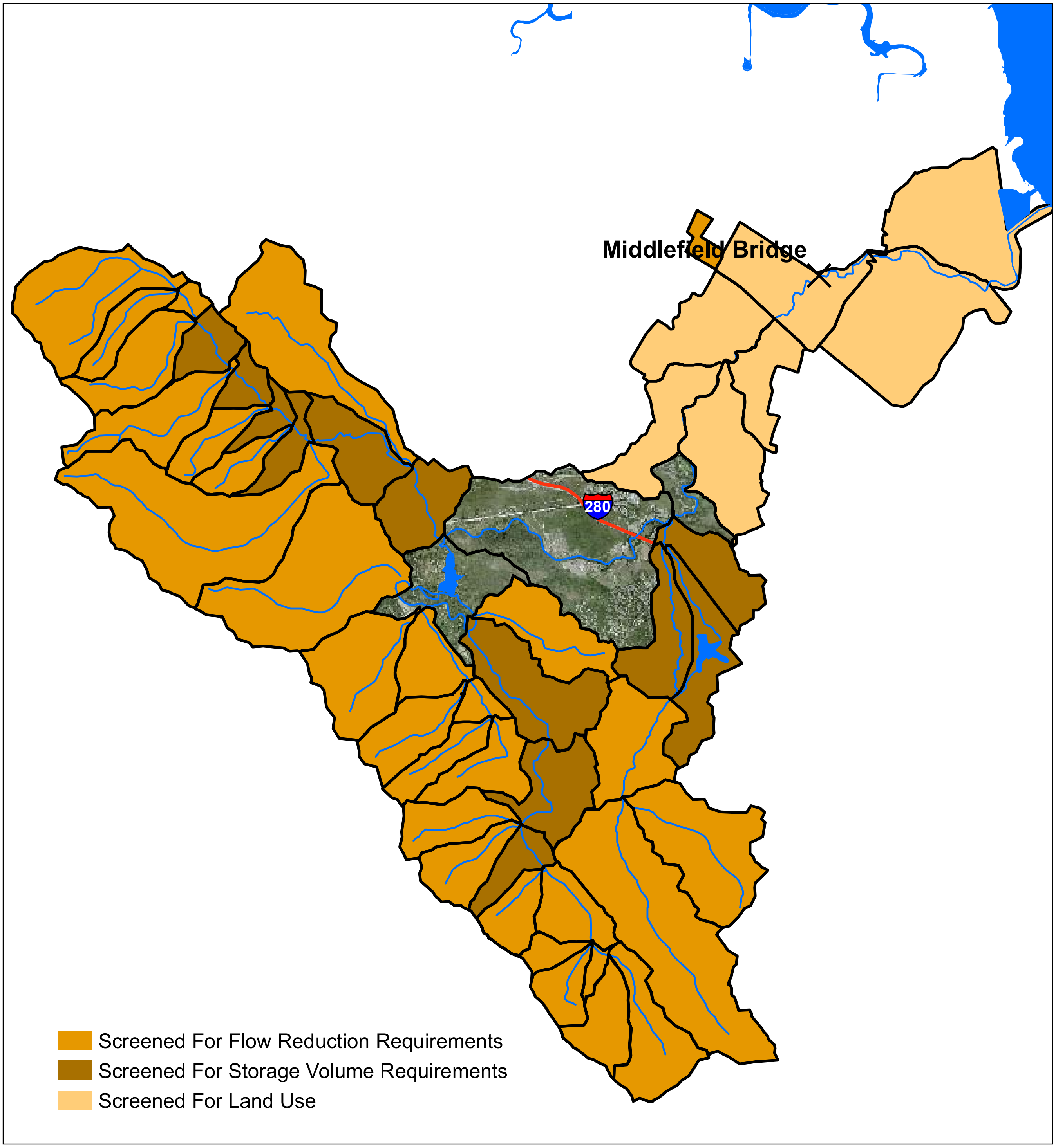


FIGURE 16 | **FINAL SCREENED SUITABLE DETENTION ZONE**

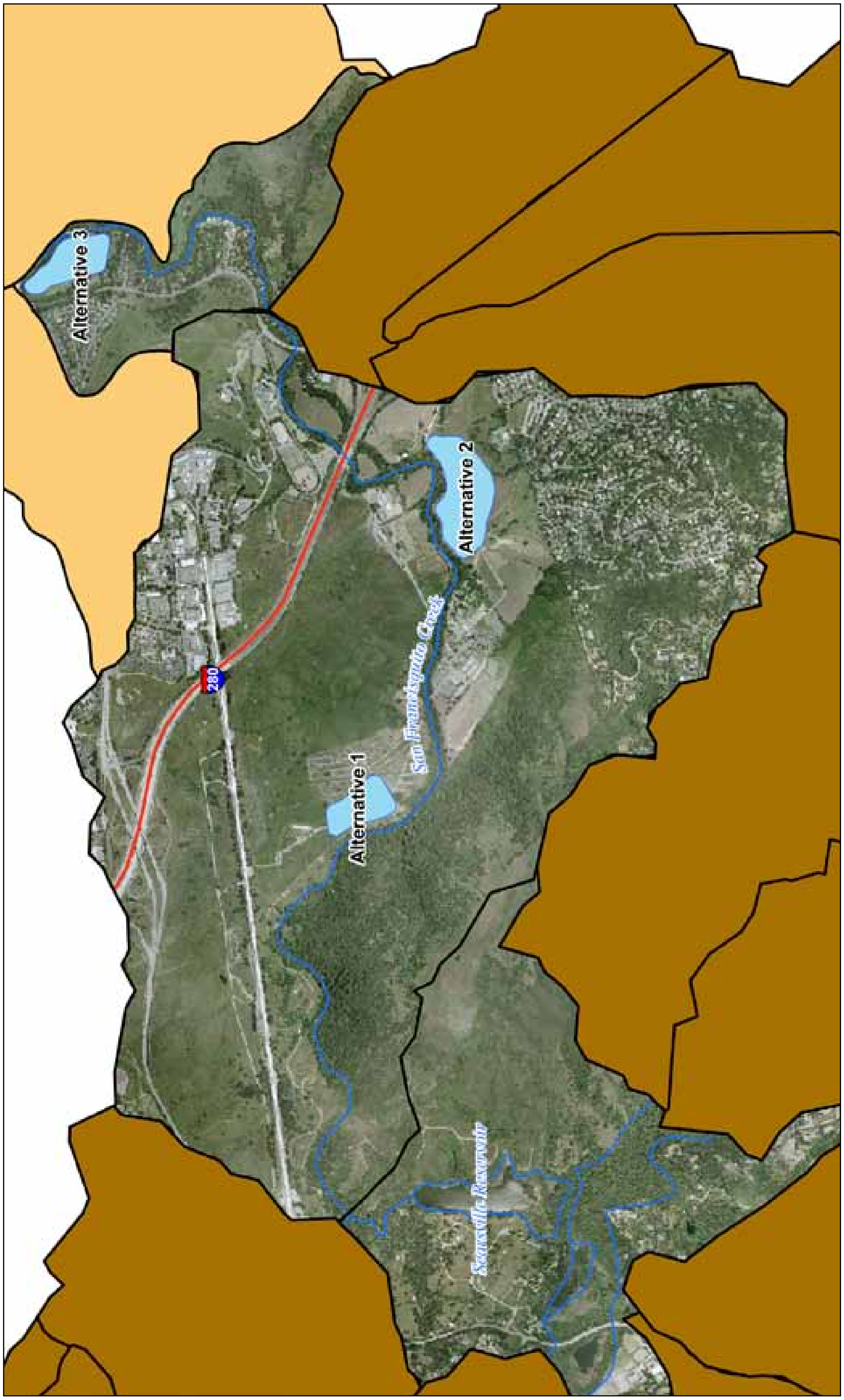


FIGURE 17 | **OVERVIEW OF THREE DETENTION ALTERNATIVES**

3.1.6 | DETENTION FACILITY IDENTIFICATION

In the identified zone, opportunities for detention facilities were explored using a combination of aerial photography and geospatial analysis. Three locations for detention facilities were identified in the suitable flood detention zone, shown in Figure 17 as Alternative 1, Alternative 2, and Alternative 3.

Stage-Storage Analysis

Preliminary stage-storage relationships for Alternatives 1, 2, and 3 were estimated for modeling purposes. First conceptual grading for the three detention facility alternatives was performed using AutoCAD software, assuming excavation of basins with 5:1 side slopes and a flat bottom for the purposes of this evaluation (Figure 18, Figure 19, Figure 20). The basin footprint was determined based on topography, maximizing the use of flatter terrain. From this conceptual grading plan, volumes of each detention facility at various elevations were estimated in ArcGIS software to provide stage-storage relationship to be used in the detention portion of the HEC-HMS model.

Hydrologic Modeling and Results

HEC-HMS hydrologic models were created to test each of the alternatives as well as a combination of the alternatives. For each alternative, the relative location, stage-storage relationship and inflow-diversion relationship were simulated in the model. Outlets were sized to drain detention facilities, restoring flood storage capacity, approximately a day after the flood peak. Models were optimized to fill detention facilities to peak storage. The model results for each alternative and combination is shown below in Table 4.

TABLE 4 | **HEC-HMS HYDROLOGIC MODEL RESULTS**

Alternative	Footprint	Detention Volume	Q100 at Middlefield	Percent Reduction
	(acres)	(acre-feet)	(cfs)	(%)
Alternative 1	12.4	180	8,560	7%
Alternative 2	27.4	440	7,970	14%
Alternative 3	14.4	170	8,570	7%
Combined	54.2	790	7,390	20%

The results of the modeling analysis show that the combined flood peak reduction benefit of the three basins is less than the sum of the flood benefit from each individual basin. This is because once the flood peak is diverted from the channel by the first basin, subsequent diversions are less efficient at reducing peak flows in the channel.

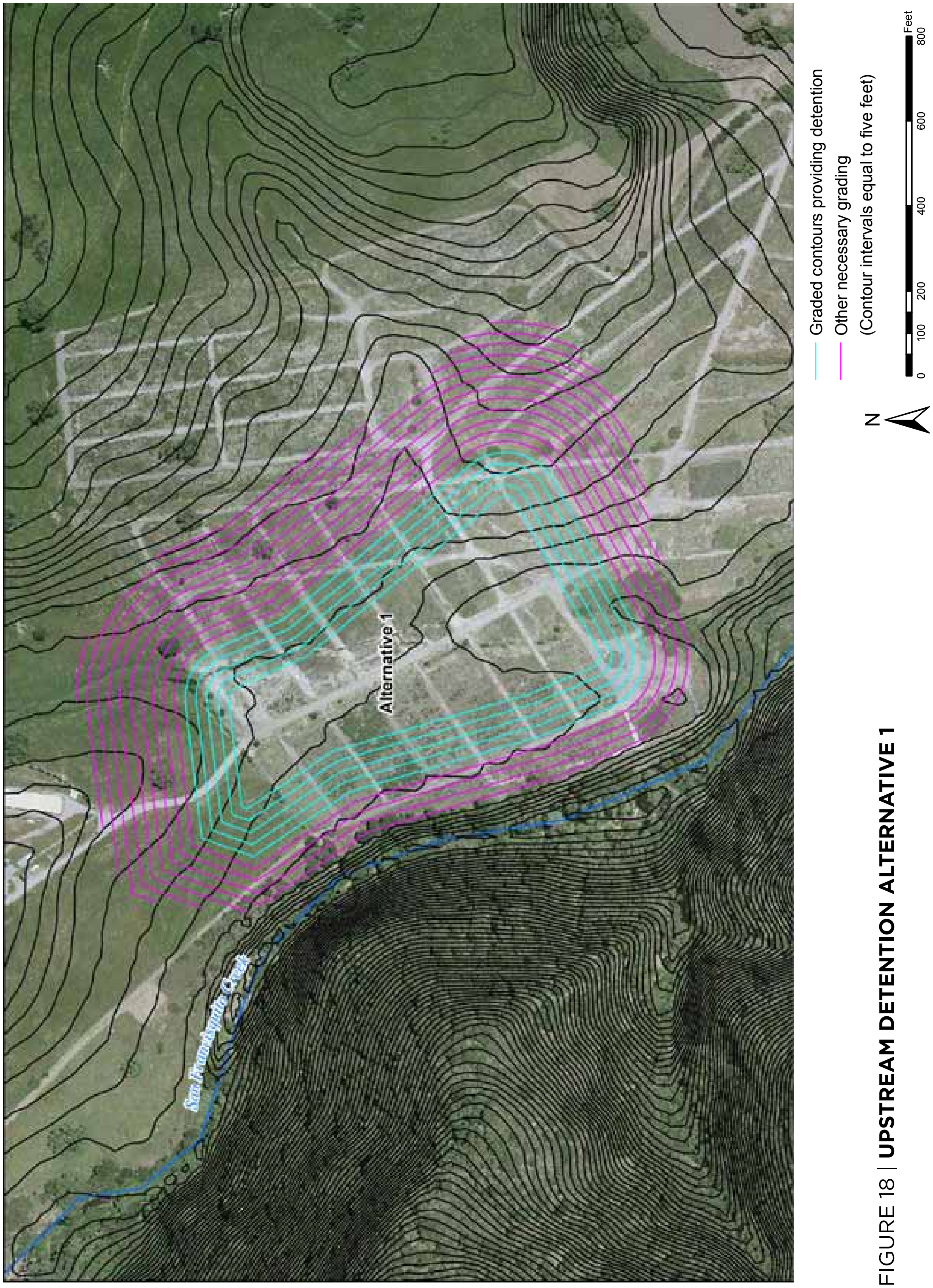


FIGURE 18 | **UPSTREAM DETENTION ALTERNATIVE 1**

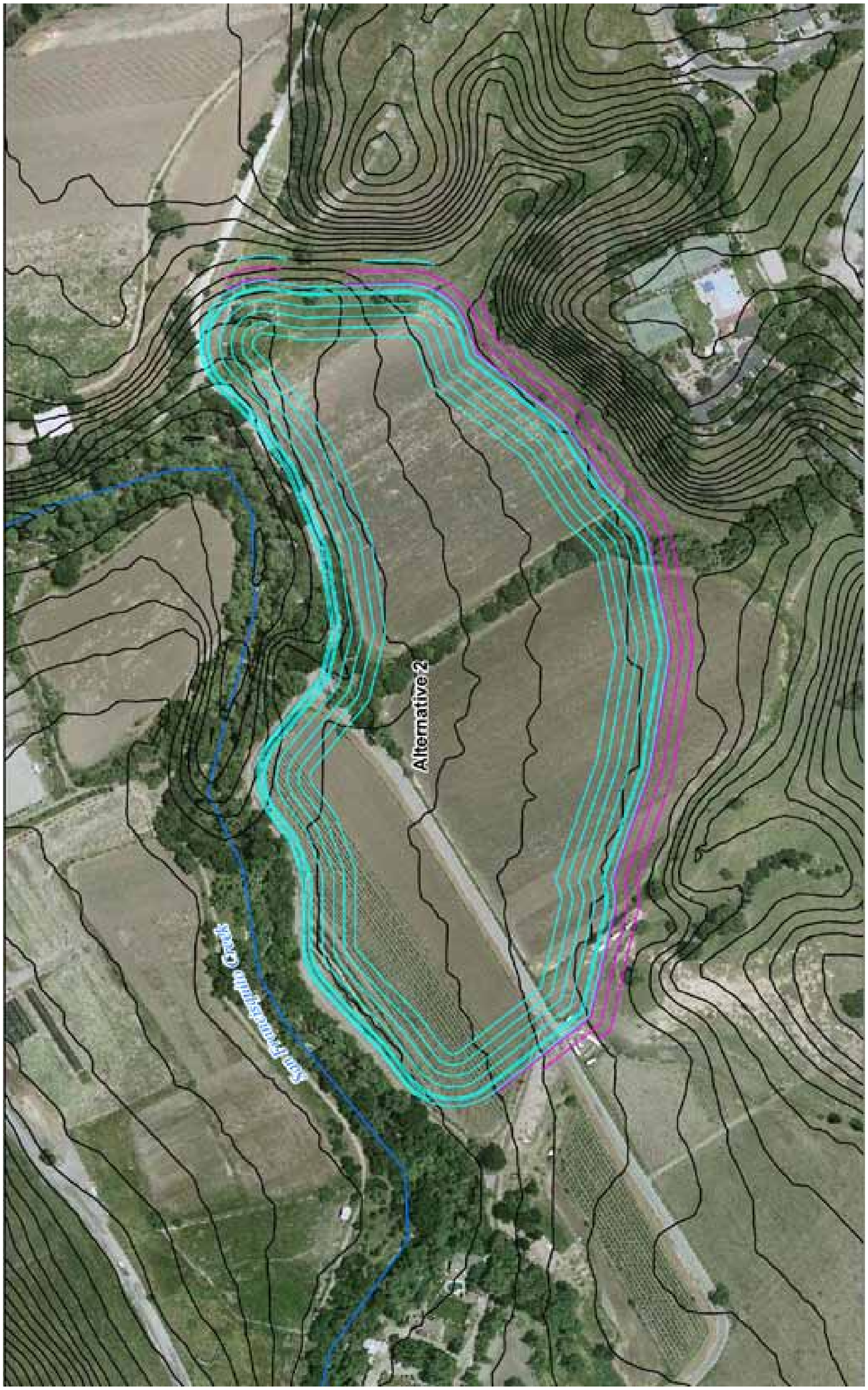


FIGURE 19 | **UPSTREAM DETENTION ALTERNATIVE 2**

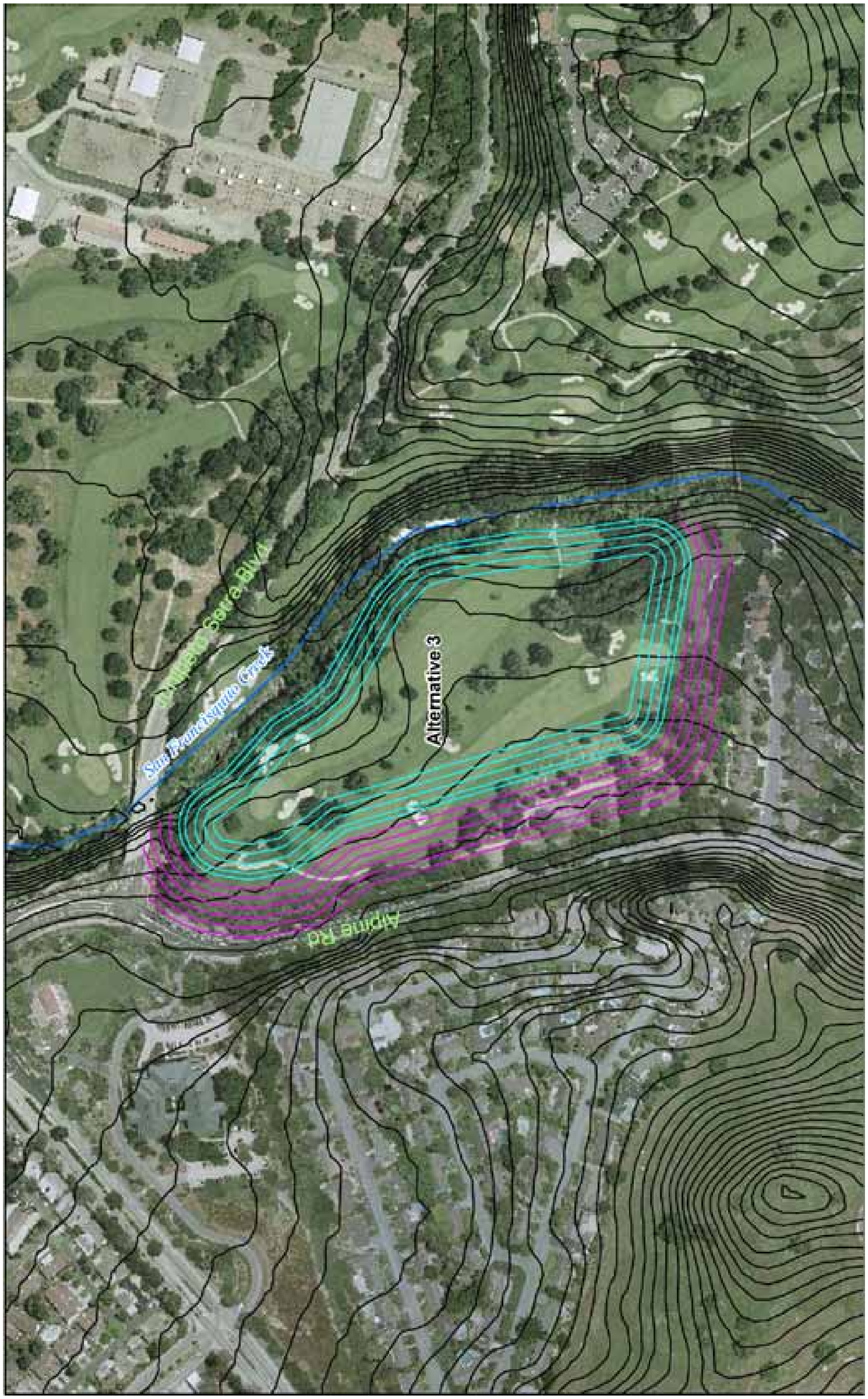


FIGURE 20 | **UPSTREAM DETENTION ALTERNATIVE 3**

3.2 | OPINION OF PROBABLE COSTS

A conceptual-level opinion of probable construction costs was developed to provide additional information for evaluating each alternative. PWA relied on experience with other projects in similar environments to estimate unit costs and construction quantities. These cost estimates are considered to be approximately -30% to +50% accurate, and include a 30% contingency to account for project uncertainties. Additionally, these cost estimates include a 10% escalation to account for short term (through 2012) increases in fuel, materials, and labor as a result of inflation or changes in supply and demand. A unit cost of $20 per yard was assumed for excavation; costs for transportation and disposal are not included. Costs also do not include estimated project costs associated with land acquisition, design, permitting, monitoring, and maintenance. These estimates, shown in Table 5, are subject to refinement and revisions as the design is developed in future stages of the project.

TABLE 5 | **OPINION OF PROBABLE CONSTRUCTION COSTS**

Alternative	Cut Volume	Fill Volume	Opinion of probable Construction Cost	Detention Volume	Relative Cost
	cy	*cy*	*$*	*acre-feet*	*$/acre-ft*
Alternative 1	1,310,000	70,000	$27,600,000	180	$153,000
Alternative 2	1,040,000	10,000	$21,000,000	440	$48,000
Alternative 3	950,000	100	$19,000,000	170	$112,000
TOTAL	*3,300,000*	*80,100*	*$67,600,000*	*790*	*$ 86,000*

3.3 | SUMMARY OF UPSTREAM PROJECT

Among the alternatives evaluated, Alternative 2 provides the greatest reduction in Q100 at Middlefield for the lowest relative cost. The Alternative 2 site provided the largest extent of flat topography, requiring relatively less excavation to provide each unit of storage. As a result, the construction cost per acre-foot of storage is less than half of the other two alternatives. Modeling results indicate that Alternative 2 could reduce Q100 at Middlefield by 14%.

Upstream detention could reduce the scale of downstream improvements needed to contain a 100-year flood event. For example, based on flows estimates reported in SCVWD 2007, a 14% reduction in Q100 at Middlefield would bring the peak flow down to the Q50 level. This suggests that downstream channel improvements designed for Q50, combined with the Alternative 2 detention scenario, could cumulatively contain a 100-year flood event.

The results of the modeling analysis show that the combined flood peak reduction benefit of the three basins is less than the sum of the flood benefit from each individual basin. This is because once the flood peak is diverted from the channel by the first basin, subsequent diversions are less efficient at reducing peak flows in the channel.

The alternatives analysis and opinion of probable cost were developed assuming that 100% of the detention capacity would be accomplished by excavating a basin below the existing ground elevation. Above-ground storage could also be created by building up berms around the basin to increase the storage capacity and allow some re-use of excavated material on-site. However, water would need to be diverted at a point upstream of the basin where the water surface elevation exceeded the elevation of the berm in order to divert water into the basin via gravity. During detailed design development, the design could be optimized to balance above- and below-ground storage capacity based on feasible diversion locations along the creek.

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APPENDICES

29 May 2009

Christie Beeman, P.E.
Philip Williams & Associates
550 Kearny Street #900
San Francisco, CA 94108

Subject: San Francisquito Creek Flood Reduction Alternatives Analysis Project-
Biotic Constraints and Opportunities Assessment (Project # 3029-01)

Dear Christie,

This letter conveys the results of H. T. Harvey & Associate's Biotic Opportunities and Constraints Assessment for the downstream portion of the San Francisquito Creek Flood Reduction Alternatives Analysis Project. The purpose of our assessment was to identify the major biotic constraints and opportunities that will affect project design and permitting for the project reach extending from U.S. Highway 101 to the San Francisco Bay. Such biotic constraints and opportunities may include the presence of potentially regulated habitats, the presence of special-status wildlife species habitat, and habitat restoration opportunities.

Our scope was limited to a reconnaissance-level survey conducted by our restoration ecologists. Field surveys for wildlife and rare plant species were not included. Assessment of the potential for occurrence of rare plants was also not included. Therefore, this letter is not intended to serve as an in-depth assessment of biotic constraints, nor does it assess biotic impacts and mitigation/permitting strategy.

PROJECT UNDERSTANDING

We understand that the project's purpose is to identify feasible alternatives to reduce local and potentially upstream flooding and to compare the benefits and constraints. This effort will lay the groundwork for the San Francisquito Creek Joint Powers Authority to select and design the preferred alternative. We reviewed Philip Williams & Associate's (PWA) draft drawings for the following alternatives:

- Alternative 1: Lower Faber Tract levee, setback existing levees upstream of Faber Tract, excavate marshplain terraces along widened existing channel, create overflow bypass terrace on the south side of the Friendship Bridge.

- Alternative 2: Same as Alternative 1, except slightly wider levee setback on south side and create marshplain bypass terrace in lieu of overflow bypass terrace.

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- Atlternative 3: Same as Alternative 1, except delete overflow bypass terrace and create new bypass channel through Palo Alto Golf Course. The new bypass channel would be fully tidal and would function as a distributary, receiving freshwater flows during all flow events, similar to the existing channel. There would be the potential for the majority of the freshwater flows to shift from the existing channel to the bypass channel over time.

METHODS

H. T. Harvey & Associate's ecologists reviewed the background information provided in the Reference Section below and the draft flood reduction alternative drawings provided by PWA. H. T. Harvey & Associate's restoration ecologists, D. Stephens, B.S. and M. Busnardo, M.S. conducted a reconnaissance survey of the project reach on 23 April 2009. M. Busnardo conducted a subsequent reconnaissance survey on 7 May 2009.

SITE DESCRIPTION

Overview

The project reach is located along the downstream segment of San Francisquito Creek extending approximately 1.4 miles from the U.S. 101 crossing, downstream to the San Francisco Bay. The entire reach is tidal and has been realigned and straightened relative to its historical condition (San Francisco Estuary Institute 2009). Flood control levees are present on both creek banks throughout the reach. Virtually the entire south side of the reach is developed and is bordered by a ball field, the Palo Alto Golf Course, and the Palo Alto Airport. Residential development borders the upstream half of the reach on the north side. Tidal salt marsh habitat is located north of the channel along the downstream half of the reach. This tidal salt marsh habitat includes the approximately 95-acre Faber Tract which was previously diked and then restored to tidal action in 1971 (Palo Alto Times 1971). There is a relatively narrow band of tidal marsh on both sides of the creek mouth that was not previously diked or filled (San Francisco Estuary Institute 2009).

Habitat Mosaic and Plant Species Composition

The San Francisquito Creek channel within the project reach supports a mosaic of open water, tidal marsh, and ruderal upland habitats, and a single small patch of riparian habitat at the upstream end. Tidal marsh habitat generally occurs along the channel in areas below approximately Mean Higher High Water (MHHW). High quality tidal marsh habitat pre-dominates in the channel downstream of the Friendship Bridge (the downstream ~3000 ft). Tidal salt marsh species in this reach include cordgrass (*Spartina foliosa* or *S. foliosa* x *alterniflora*), pickleweed (*Sarcoconia virginica*), gumplant (*Grindelia* sp.), alkali heath (*Frankenia salina*), and saltgrass (*Distichlis spicata*).

The reach extending from the Friendship Bridge upstream to U. S. Highway 101 is a transition zone between tidal salt marsh and tidal brackish marsh habitat and comprises a mosaic of these two habitat types. In contrast to the downstream reach, this reach is infested with a high density of invasive, non-native perennial pepperweed (*Lepidium latifolium*). Perennial pepperweed occurs primarily on elevated floodplain terraces. The floodplain terraces upstream of the Friendship Bridge are generally elevated above MHHW (M. Wickland, pers. comm. 2009) and are dominated by a mixture of perennial pepperweed and non-native grasses. A narrow strip of tidal salt and brackish marsh habitat dominated by primarily native plant species occurs below MHHW along the toe of these elevated floodplain terraces.

A single, linear patch of obligate riparian habitat (i.e. requires access to perennial soil moisture/groundwater) is located approximately 300 ft downstream of U. S. Highway 101, on the southern, inboard levee slope. This patch is dominated by native willow species (*Salix* sp.) and non-native, white cottonwood (*Populus alba*). Relatively low salinity, perennial soil moisture (within the rooting zone) is likely present in this localized area to support this patch of obligate riparian plant species.

Degraded, non-tidal seasonal wetlands occur along the south (golf course) side of the levee from the Friendship Bridge upstream to where the golf course abuts the levee. These are saline wetlands dominated by pickleweed and non-native wetland grasses and forbs.

Land Use History at the Faber Tract

H. Thomas Harvey, Ph.D. consulted for the San Francisco Bay Conservation and Development Commission (BCDC) in the early 1970's on ecological issues related to the Faber Tract. The following is a brief summary of information gathered from his files for that work. The Faber Tract appears to have been diked in the 1930s and apparently used for pasture and hay production. The levee likely eroded sometime between 1961 and 1963 allowing some tidal exchange, but little marsh development. Dredged spoils from the Palo Alto Harbor were then deposited in the Faber Tract between 1968-1969. The BCDC permit for this dredging project required the County of Santa Clara to restore tidal marsh habitat to the Faber Tract (BCDC 1968). The County initially established a hydrologic connection between the Faber Tract and the adjacent tidal marsh to the north via 3 culverts through the levee separating these two tracts. This hydrologic connection was judged by BCDC as insufficient to restore full tidal action and tidal marsh habitat. The BCDC then required that the County breach the outboard levee in the northeast corner of the Faber Tract. The levee was breached in this location on 15 July 1971 (Palo Alto Times 1971), opening the tract to tidal action and forming the current tidal connection between the Faber Tract and the Bay. Aerial photography indicates that the majority of the site was vegetated (with tidal salt marsh vegetation) by 1974.

BIOTIC CONSTRAINTS

Effects on Sensitive Fish and Wildlife Species

Federal and State Endangered/Threatened Species. The tidal marsh and aquatic habitats of the project reach comprise suitable habitat for the following three federally-listed endangered/threatened species which are known to occur on and/or adjacent to the project reach (Figures 1 and 2, and Leidy et al 2005):

- California clapper rail (*Rallus longirostris obsoletus*) (Federal endangered and State endangered/fully protected)
- salt marsh harvest mouse (*Reithrodontomys raviventris*) (Federal endangered and State endangered/ fully protected)
- steelhead (*Oncorhynchus mykiss*) Central California Coast Distinct Population Segment (Federal threatened)
- green sturgeon,(*Acipenser mediorostris*) Southern Distinct Population Segment (Federal threatened)
- longfin smelt (*Spirinchus thaleichthys*) (State threatened)

The first three of these species constitute the project's primary biotic constraint, but the sturgeon and longfin smelt will also need to be addressed. All of the flood reduction alternatives would temporarily impact habitat for these species and would have the potential to take individuals of these species during construction. The excavation of floodplain terrace habitat and lowering of the Faber Tract levee would result in the temporary loss of California clapper rail and salt marsh harvest mouse habitat. Therefore, the project design should incorporate measures to compensate for impacts to habitat for these species and should be designed to maximize long-term habitat benefits. There are more than ample opportunities to design the project to result in net long-term benefits to these species (discussed below).

The proposed alternatives would also have the potential to trap/strand steelhead. However, with input from a fisheries ecologist, each of the alternatives could be designed to avoid this potential impact.

The project would also be required to incorporate measures to minimize short-term, construction impacts to these species. Construction-related measures typically include appropriate construction windows to avoid impacts (e.g. 1 June – 15 October to avoid steelhead migration and avoidance of the clapper rail breeding season) as well as measures like manual removal of vegetation to protect salt marsh harvest mice, biological construction monitoring, and Best Management Practices to protect water quality.

A Section 7 Consultation with the U.S. Fish and Wildlife Service (Service) and National Marine Fisheries Service (NMFS) would be required during the permitting phase for this project. The consultation will likely be "formal", requiring the applicant to prepare a Biological Assessment technical report. This type of consultation typically requires 6-12 months from the time the lead federal agency (likely the U.S. Army Corps of Engineers (Corps)) requests initiation of the consultation with the Service and NMFS. Similarly, the project will need to consult with the California Department of Fish and Game with respect to CESA (California Endangered Species Act), likely to obtain a consistency determination, and to deal with issues regarding California Fully Protected Species. This can be a complex issue since both the California clapper rail and the salt marsh harvest mouse are fully protected.

Other Species of Special Concern. Habitat is present in the project area for several California wildlife species of special concern. These include, and are not limited to, the Alameda Song Sparrow (*Melospiza melodia sinuosa*), the Saltmarsh Common Yellowthroat (*Geothlypis trichas sin vosa*), the salt marsh wandering shrew (*Sorex vagrans halicoetes*), and the Burrowing Owl (*Athene cunicularia*). These species would constrain the project to a lesser degree than the federal/state endangered species discusses above. Potential project impacts and mitigation requirements for species of special concern should be assessed during the CEQA review process.

Temporary Loss of Tidal Marsh Habitat

As noted above, the excavation of floodplain terraces within the existing channel and the lowering of the Faber Tract levee would result in the loss to tidal salt and brackish marsh habitat. However, the project can be designed to ensure that this loss is temporary by setting the design elevations and soil preparation techniques to regenerate the physical conditions that will facilitate the natural recolonization of tidal marsh vegetation. All or at least a portion of these habitats fall within the jurisdiction of the Corps, Regional Water Quality Control Board, and Bay Conservation and Development Commission. Permits would be required from these agencies.

Permanent Loss of Brackish Marsh/Upland Ecotone Habitat

The existing inboard levee slopes are earthen and vegetated throughout the project reach. These slopes, although relatively steep and narrow, do provide refugial habitat for animals residing in the floodplain and marshplain habitats of the channel, to escape spring tide and flood events. The proposed alternatives would convert the inboard levee slopes to floodwalls and retaining walls and thereby result in the permanent loss of this refugial habitat along both sides of the channel in the upstream approximately 1500 ft of the project reach.

Generally, flood walls limit the ability of mammals to escape flooding events, but in this case the upstream reaches are marginal habitat at best for the species of interest in this area (e.g. salt marsh harvest mouse). A more thorough analysis of the trade-offs will be appropriate in the next phase.

Permanent Loss of Riparian Habitat

As noted in the Site Description above, an isolated patch of riparian habitat occurs, along the inboard levee slope, in the upstream segment of the project reach. The project alternatives would remove this habitat and install floodwalls and retaining walls in this location. Given the conversion of earthen inboard levee slopes to walls in the reach where riparian habitat is growing, there appear to be limited opportunities to restore riparian habitat on site to mitigate this impact.

Permanent Loss of Non-Tidal Seasonal Wetland Habitat

As noted in the Site Description above, non-tidal seasonal wetland habitat is present between the Palo Alto Golf Course and the outboard levee slope of San Francisquito Creek. The proposed alternatives would likely both fill a portion of these wetlands (converting them to uplands) and convert a portion of these wetlands to tidal marsh. H. T. Harvey & Associates conducted a wetland delineation on the golf course property including a portion of the area that would be affected by this project (H. T. Harvey & Associates 1994). We determined (and the Corps agreed) that a small portion of the golf course wetlands were Corps jurisdictional, whereas the majority were supported primarily by artificial irrigation. However, this delineation has expired since it is greater than 5 years old and the Corps interpretation of its jurisdiction has continued to evolve. Therefore, a wetland assessment should be conducted to determine if these wetlands meet the current Corps criteria for jurisdictional wetlands. Even if some do not fall within Corps jurisdiction, their loss will still need to be assessed under CEQA.

Additionally, isolated patches of pickleweed are present in this area. Although these patches may be too small and isolated to provide habitat for the salt marsh harvest mouse, this habitat area should be assessed for its potential to support the salt marsh harvest mouse. Earlier work by our staff determined that these areas might function as refugial habitat during high flow events in the creek, but conditions have changed since that assessment.

In our opinion, permanent loss of these non-tidal wetlands could be compensated for by the restoration of high quality tidal marsh habitat within the expanded creek channel and/or lowered levee along the Faber Tract.

Degradation of Water Quality

Alternative 3 has the potential to result in the degradation of water quality within the bypass channel due to potential inputs of pesticides and fertilizers from the golf course. This potential impact and mitigation measures (if needed) should be assessed during the CEQA review process.

BIOTIC OPPORTUNITIES

Increase Tidal Marsh Habitat Quantity and Quality

All of the proposed alternatives would increase the quantity of tidal marsh habitat. For example, Alternative 3 would restore the greatest amount of tidal marsh habitat (greater than 20 acres) by constructing a bypass channel with marshplain terraces through the Palo Alto Golf Course in an area that was historically tidal marsh (SFEI 2009). There is also an opportunity to improve tidal marsh habitat quality by incorporating biological considerations into the project design. Such opportunities include:

1. the conversion of low quality floodplain terrace habitat (dominated by non-native, perennial pepperweed) to higher quality marshplain habitat dominated by native tidal salt and brackish marsh species. This can be accomplished both by increasing the tidal prism, thereby increasing the summertime salinities in the project reach and via the excavation of new marshplains to elevations that will facilitate colonization by tidal salt marsh plant species and deter colonization by ruderal species (e.g. perennial pepperweed).

2. the restoration of high tide refugial habitat for sensitive wildlife species at the ecotone between tidal wetland and upland habitats. This can be accomplished via a combination of grading (e.g. levee lowering and grading of stable inboard levee slopes), topsoil preparation, and active revegetation.

3. the restoration of fluvial flooding to the Faber Tract. This natural process has been blocked by the levee, and should help restore a sediment source to over time assist the marshplain in responding to sea level rise.

Increase Habitat Quantity and Quality for Sensitive Fish and Wildlife Species

The restoration of high quality tidal salt and brackish marsh habitat as described above, would improve habitat conditions for several special-status wildlife species. These species include the federal- and state-endangered California clapper rail and salt marsh harvest mouse, as well as California species of special concern such as the Alameda song sparrow and the salt marsh common yellowthroat. The restoration of tidal marsh habitat would also likely improve habitat conditions for out-migrating juvenile and adult steelhead.

Improve Water Quality

The restoration of additional tidal marsh habitat along the downstream reach of San Francisquito Creek would also likely improve the quality of water entering the Bay by increasing the residence time of flood waters within wetlands, thereby providing improved pollutant filtration prior to Bay discharge.

I hope that this information meets your needs for this phase of the project. Please contact me at 408-448-3222

Max Busnardo, M.S.
Associate Restoration Ecologist

CC:
Dan Stephens and Ron Duke, H. T. Harvey & Associates

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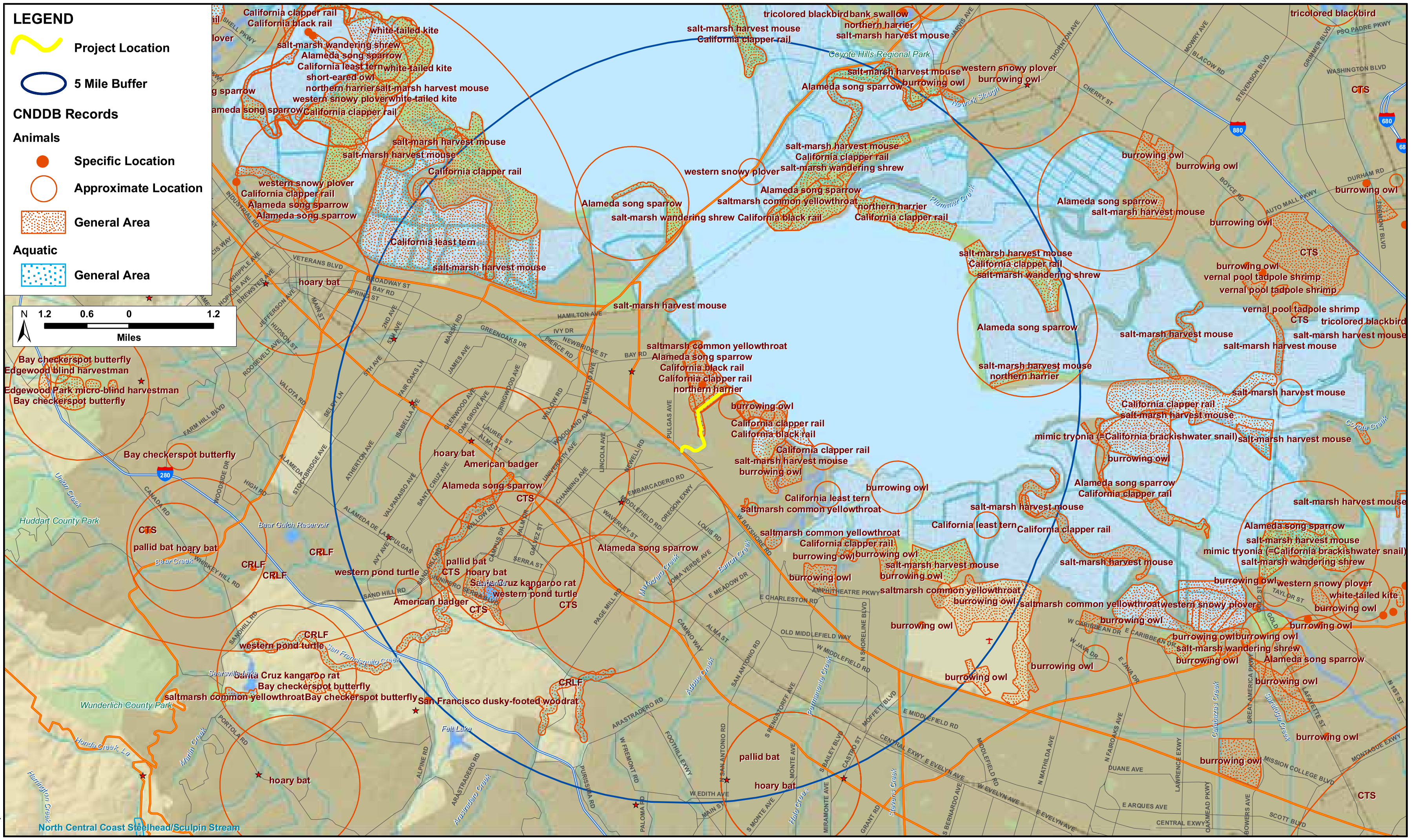

H. T. HARVEY & ASSOCIATES
ECOLOGICAL CONSULTANTS

Figure 1: CNDDB Animal Records
San Francisquito Creek Flood Reduction Alternatives Analysis (3029-01)
May 2009

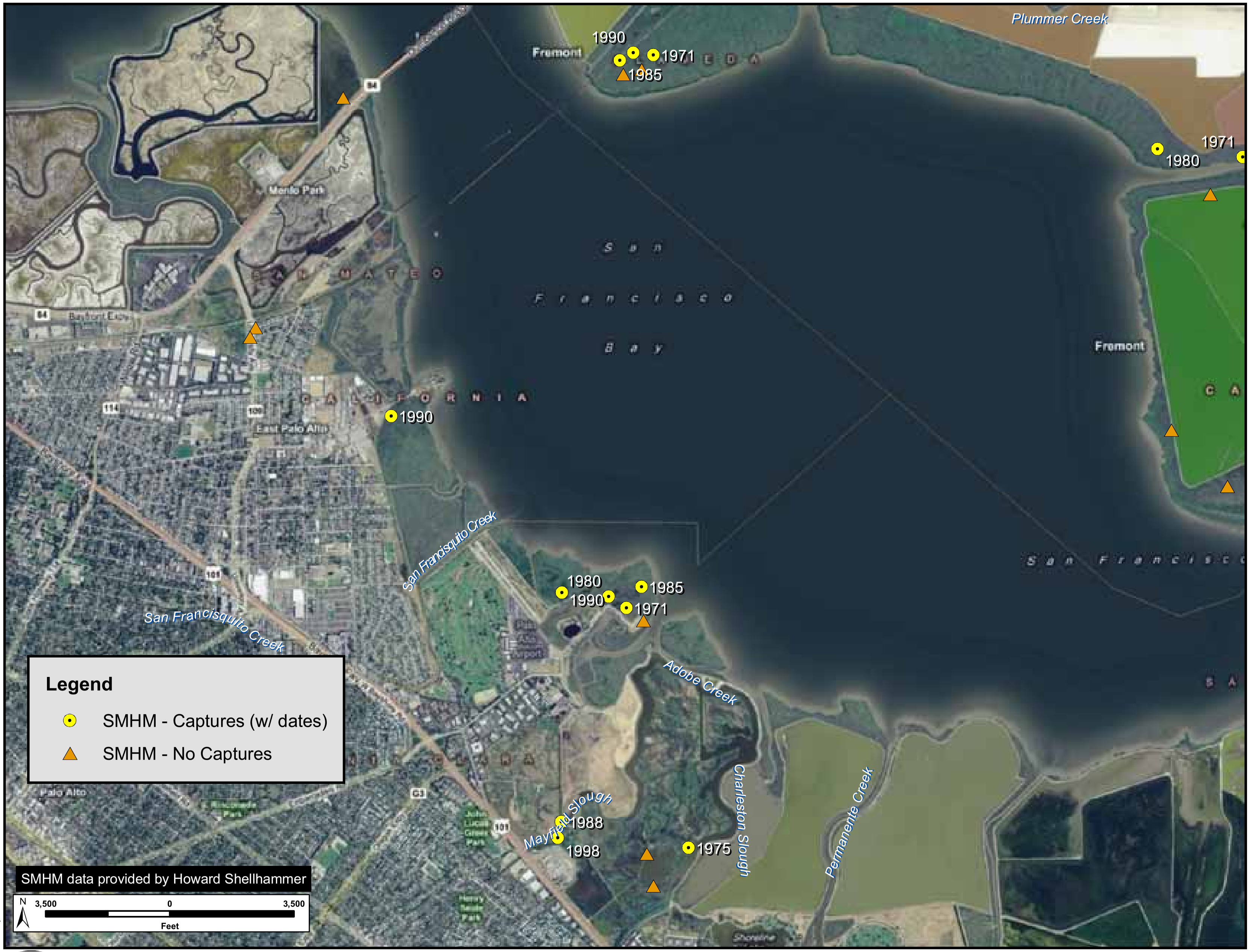

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Figure 2: Salt Marsh Harvest Mouse (SMHM) Trapping Records
San Francisquito Creek Flood Reduction Alternatives Analysis (3029-01)
May 2009