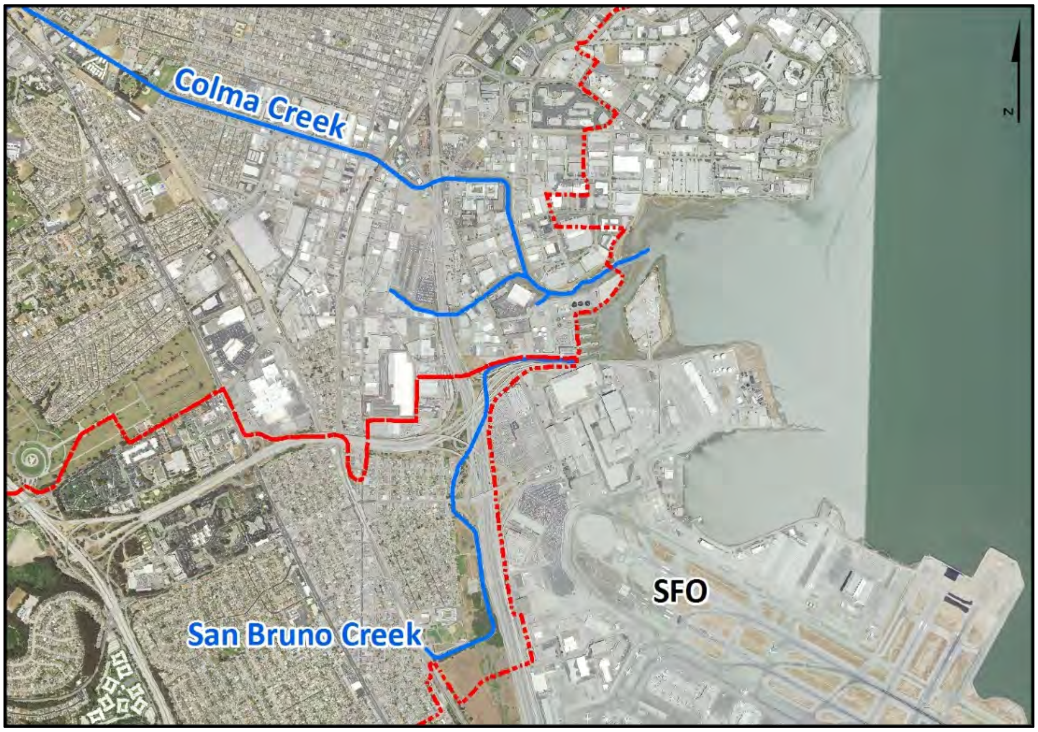
SAN BRUNO CREEK / COLMA CREEK
RESILIENCY STUDY
FINAL REPORT



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Prepared by:

moffatt & nichol + AGS
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EXECUTIVE SUMMARY

E.1 Introduction

San Mateo County has more property at risk from sea level rise than any other county in the Bay Area (Pacific Institute 2012). Of particular concern is the San Francisco International Airport (SFO); as the 7th busiest airport in the nation, SFO is critical to the Bay Area economy. San Bruno Creek and Colma Creek both drain to the San Francisco Bay immediately north of SFO property. Fluvial impacts from the creeks combined with tidal changes due to sea level rise in the vicinity of these creeks' outlets into the Bay pose a flood risk to both SFO and the adjacent communities. This area contains residential neighborhoods that have been subject to severe flooding, habitat for threatened and endangered species, and substantial public infrastructure. In response to this complex problem, the County of San Mateo partnered with SFO and the California Coastal Conservancy to obtain a Climate Ready Grant to prepare a sea level rise vulnerability assessment and adaptation plan for the shoreline area northwest of the airport, where San Bruno and Colma creeks meet the Bay.

The study was intended to complement the Shoreline Protection Study that SFO recently completed to assess the vulnerability of the airport perimeter system and evaluate adaptation options for both 1%-annual-chance floods and sea level rise. The locations of Colma Creek and San Bruno Creek relative to SFO are illustrated in Figure E-1 for reference.

The purpose of the study was to assess the vulnerability of assets within the lower reaches of both creeks to flooding from sea level rise and storms along the Bay shoreline and to develop conceptual adaptation strategies for the Project Area.

The scope of the SFO Colma Creek and San Bruno Creek Resiliency Study was to:

1) Establish an interagency working group focused on the Project Area.
2) Conduct a sea level vulnerability assessment of the Project Area.
3) Develop sea level rise adaptation strategies for the Project Area.

E.2 Setting

The lower reaches of the Colma Creek and San Bruno Creek watershed (Project Area) shown in Figure E-1 are prone to flooding, especially during high Bay water levels. Given the multiple jurisdictions, significant infrastructure, low lying elevations, and valuable habitat that exists in the area, addressing this ongoing flooding is a complex task. Some of the key issues are described below:

E.2.1 Topography

Figure E-1 shows that much of the land surface of the lower watersheds and SFO lies at very low elevations. While most of the region's shorelines have been built up above potential tidal elevations, much of the airport is below +7 ft NAVD88[1], along with a portion of the Belle Air

[1] The North American Vertical Datum of 1988 (NAVD88) is the official vertical datum for the United States National Spatial Reference System, as affirmed by NOAA's National Geodetic Survey (NGS, 2015).

neighborhood in the City of San Bruno. Figure E-1 illustrates the extent of the Creeks' lower watersheds that are within an elevation range encompassing typical tidal elevations up to the 100-year extreme water level in the Bay, and how they would be affected by about 3-ft of potential sea-level rise, which is the most likely value of SLR by 2100 for the region. These areas constitute the most susceptible regions to increased coastal flooding due to sea-level rise, and include the Belle Air neighborhood in San Bruno and the Lindenville and Tanforan neighborhoods in South San Francisco, along with the two wastewater treatment plants operated by SFO and SSF. The "King Tide" referenced in the figure below is the annual high tide water elevation that occurs in the South Bay.

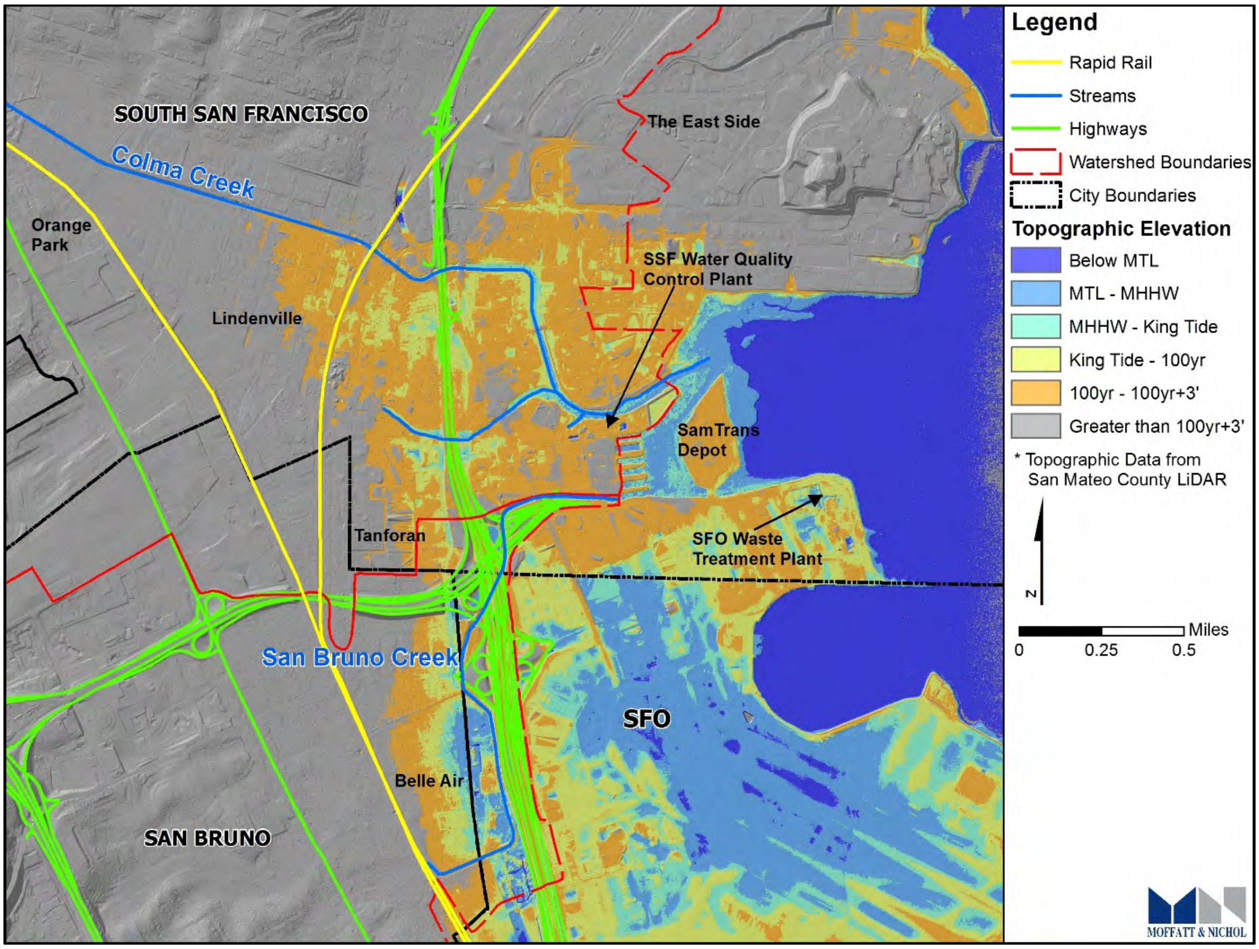

Figure E-1. Topographic Elevations in the Lower Watersheds

E.2.2 Colma Creek Watershed

Colma Creek extends from San Bruno Mountain to its outlet at the San Francisco Bay just north of the San Francisco Airport and south of Point San Bruno. Colma Creek flows through portions of Colma, South San Francisco, San Bruno, and Daly City. The western border of the basin is the San Andreas Fault while the northern edge terminates at the San Bruno Mountain ridge and the south is bounded by Interstate 380. The total drainage area is approximately 15.8 square miles and is mostly developed.

The San Mateo County Flood Control District (SMCFCD) oversees the Colma Creek Flood Control Zone, established in 1964, to alleviate flooding in the City of South San Francisco. The Colma Creek flood control project originally spanned 3 miles from San Francisco Bay up to Mission Road in South San Francisco. There are multiple flood control elements in the Colma Creek watershed:

- The Colma Creek Flood Control Channel, which was improved in 2006 with the construction of a 70-ft wide rectangular concrete channel from Spruce Avenue to San Mateo Avenue near downtown City of South San Francisco.
- Seven pump stations in the lower Colma Creek watershed operated by the City of South San Francisco (SSF) Department of Public Works (DPW). The City's storm drain system, including the seven pump stations, is illustrated on Figure 2-5.
- Navigable Slough, which is a tidal channel that is tributary to Colma Creek, and passes under Hwy-101 and South Airport Blvd. in culverts.

There are multiple critical infrastructure elements that are located within the lower Colma Creek watershed as illustrated in Figures 2-4 through 2-7. . The South San Francisco BART station is located immediately adjacent to the Colma Creek flood control channel, while the San Bruno BART station is located near Navigable Slough and Tanforan. The South San Francisco Caltrain station is also in the lower watershed, roughly 0.5-mile north of the flood control channel and adjacent to Hwy-101.

There are four PG&E electrical substations located in the Colma Creek watershed; two in the vicinity of the flood control channel in the lower watershed. There are two major highways located in the lower Colma Creek watershed within the Caltrans' right of way: U.S. Highway-101 and CA State Route-82.

E.2.3 San Bruno Creek Watershed

San Bruno Channel collects runoff from the City of San Bruno, a drainage area of approximately 4.5 square miles, which lies south of the Colma Creek drainage basin. Most of the San Bruno Creek watershed drains through pipes in the City's storm drain system. The San Bruno Channel outlet to the San Francisco Bay is approximately 1,400 feet to the south of the Colma Creek outlet. The channel exits to Bay through a tide gate structure. The watershed is bounded by the City of South San Francisco and Colma Creek to the north, the City of Millbrae and the South Lomita Canal/Highline Canal to the south, the City of Pacifica and the Coast Range to the west, and the San Francisco International Airport to the east.

The SMCFCD oversees the San Bruno Creek Flood Control Zone, which was established in 1967 to construct flood control and drainage improvements in the lower reach of San Bruno Creek. There are multiple flood control elements in the San Bruno Creek watershed:

- Two pump-stations, Walnut and Angus, which are maintained by the SMCFCD.
- Two open channel sections of San Bruno Creek in the lower portion of the watershed, Cupid Row Canal and North Channel.
- A tide gate structure where the North Channel exits to San Francisco Bay that consists of four, 5-feet diameter circular pipes with flap gates on the downstream side. The tide gate

structure was designed for the 25-year flow based on the 1965 watershed, with a Mean Higher High Water tidal elevation at the site (SMCFCD, 1965).

There are multiple critical infrastructure elements that are located within the lower San Bruno Creek watershed as illustrated in Figures 2-9 through 2-12. These include:

- BART tracks
- Caltrain tracks and station
- PG&E electrical substations
- Caltrans Highways

The BART and Caltrain lines both pass through the lower watershed, and the San Bruno Caltrain station is located near the upstream point of the Cupid Row Canal. There are also two electrical substations located in the lower watershed, between the Caltrain line and Hwy-101.

There are three major highways located in the lower San Bruno Creek watershed within Caltrans' right of way: U.S. Highway-101, CA State Route-82 (also called El Camino Real), and Interstate-380.

E.2.4 FEMA Analyses and Results

The original FIS for South San Francisco was performed in 1980 and covered all significant flooding sources affecting the City. The historical Flood Insurance Rate Maps (FIRMs) for the City are dated September 1981 (FEMA, 2012). There was no previous analysis of flood hazards for the City of San Bruno, and the City had been mapped as Flood Zone D, which represent areas with possible but undetermined flood hazards.

FEMA performed a county-wide Flood Insurance Studies (FIS) for San Mateo County in 2012, which included the cities of San Bruno and South San Francisco. The FEMA Coastal Flood Hazard Studies for San Francisco Bay (BakerAECOM, 2013) were based on a comprehensive study of flood hazards with particular emphasis on coastal flooding hazards at the bay shoreline. The draft flood maps for San Mateo County include revised Flood Hazard Zones for the lower Colma Creek watershed, where the proposed Base Flood Elevation (BFE) propagates up the creek and is able to overtop the flood control channel's banks. These revisions to the Colma Creek system include additional Flood Hazard Zone AE areas on the south side of the channel.

The FEMA Coastal Flood Hazard Study for San Mateo County did not include a riverine component. Therefore, the riverine hydraulics of the Colma Creek flood control channel was not re-assessed. The proposed changes to the Colma Creek system FIRMs extend from the Bay to the Caltrain tracks. The flood hazard zones upstream of the Caltrain tracks (west of the tracks) were carried over from the San Mateo Countywide FIS from 2012.

The Coastal Flood Hazard Study also did not assess riverine flooding within the San Bruno Creek watershed. However, a significant portion of the lower San Bruno Creek watershed, east of the Caltrain tracks, is now shown as Flood Hazard Zone AE with a flood elevation of +10' NAVD on the draft FIRMs. Since no shoreline exists in the immediate vicinity of this interior flood area, which is substantially removed from the source of coastal flooding, it appears that the extent of flooding has been determined by projecting the BFE across any contiguous area(s) that are topographically below the BFE, irrespective of overland flow distance. The draft FEMA FIRM data for the region is illustrated in Figure 2-18.

E.3 Sea Level Rise

Numerous peer-reviewed publications about climate change and sea level rise have been published in recent years, and sea level rise (SLR) projections vary from study to study. A wide variation in projections of global and regional SLR is caused by significant uncertainties in future emissions of greenhouse gases, the effects upon global temperatures, and the effects in turn upon ice sheets and other drivers of the sea level.

This document focused on three governmental reports that describe future scenarios:

- The National Oceanic and Atmospheric Administration (NOAA) Climate Program Office (CPO), *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (2012).
- The National Research Council (NRC), *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* (2012).
- The Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), *State of California Sea-Level Rise Guidance Document* (2013).

In order to plan for future SLR, it is generally not useful to focus on specific dates and the SLR expected on those dates. A better approach is to consider specific increases and to understand the needs for additional flood protection based on those increased levels. This report considered 1-ft, 2-ft, and 3-ft of SLR. Table E-1 shows the range of dates at which these increases are projected to occur, based on the three referenced governmental reports.

Table E-1. Range of Dates at which Specific SLR Values are Anticipated

RSLR Value	Earliest Date	Latest Date
1-ft	2030	2080
2-ft	2050	2125
3-ft	2065	2155

E.4 Hydrologic and Hydraulic Modeling

E.4.1 Hydrologic Modeling of Creeks

A hydrologic analysis using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) was performed to develop recurrence interval design flowrates for the two creek systems. The general methodology for estimating flood-frequency discharges for each of the surface creeks was based on a modified version methodology outlined in the *Santa Clara County Drainage Manual* (SCCDM, 2007).

The Colma Creek HEC-HMS model was calibrated to 33-years of measured flows from the USGS stream gage located at Orange Memorial Park. Table 4-2 summarizes the estimated discharges for return periods of interest at various locations within the lower Colma Creek watershed. The discharge estimates reflect stream routing in Colma Creek but do not reflect flows leaving the channel due to upstream flow constrictions.

The San Bruno Creek HEC-HMS model used the same watersheds as was applied in the recently completed City of San Bruno city-wide Storm Drain Master Plan (GHD, 2014), but applied the SCCDM methodology used in the analysis of Colma Creek. Table 4-3 summarizes estimated discharges for return periods of interest at various locations in San Bruno Creek; the flows do not account for any capacity limited systems upstream and therefore assume that all flows reach the headwaters of Cupid Row Canal and the North Channel.

E.4.2 Hydraulic Modeling of Creeks

This flood risk assessment also included the development of 1-dimensional hydraulic models for each creek in the USACE's Hydrologic Engineering Centers River Analysis System *(*HEC-RAS*)* to determine water surface profiles for each creek under a range of environmental conditions. Both Colma Creek and San Bruno Creek discharge into San Francisco Bay, which is tidally influenced. A range of boundary conditions were applied to the hydraulic model to assess different scenarios of high flood flows with different tidal elevations and sea level rise projections and to facilitate the estimation of frequency of occurrence for high water levels in San Francisco Bay coinciding with high creek discharges.

The Colma Creek HEC-RAS model prepared for this flood risk study was based on a previous model created in 2004 by Schaaf & Wheeler, updated with information field surveyed in November 2011. It extended from the mouth of Colma Creek at San Francisco Bay to just upstream of Spruce Street. The Colma Creek modeling assumed all of the flood flows were kept within the channel, without overbank flooding, to determine the floodwall or levee elevations that would be necessary to contain all the flow within the channel. The HEC-RAS analysis also determined the hydraulic capacity of the flood control channel capacity at various tidal elevations in the Bay; the channel capacity results are presented in Section 4.

The San Bruno Creek HEC-RAS model developed by Schaaf & Wheeler as part of the SFO Shoreline Protection Study (M&N+AGS, 2015) was used as a basis for developing the model for this study. The model extended from the downstream side of the Hwy-101 culverts up to the headwaters of the Cupid Row Canal near Lions Park, using the survey data collected by Meridian Surveying for this study along Cupid Row Canal and the North Channel. The lower reaches of San Bruno Creek has open space areas that contain overbank flooding in surface depressions adjacent to the channel. To track and account for the volumes of flood flows that leave the channel during storm events, these areas of surface depression were added to the San Bruno Creek model as storage areas, which required unsteady flow HEC-RAS simulations. A hydraulic capacity analysis similar to Colma Creek was also performed for San Bruno Creek to assess the channel capacity at various tidal elevations in the Bay. The hydraulic results for San Bruno Creek with various downstream tidal elevations are presented in Section 4.

E.4.3 Risk Assessment (Coincident Frequency)

Flooding results from the combination of high creek discharge and high water levels in San Francisco Bay. There are observed data that justify the expectation that high creek discharges may coincide with high water levels in San Francisco Bay. The winter storms that lead to flooding in the creeks are associated with low barometric pressures, which lead directly to higher tides. However, since the occurrence frequencies of this correlation are uncertain, this study performed a statistical analysis similar to a joint probability analysis for each creek.

The assessment analyzed the correlation between daily discharge in Colma Creek (USGS, 2014) and tidal elevations in San Francisco Bay (NOAA, 2014) over a 20-year joint period of record. Specifically, it considered tidal residuals – the difference between measured and astronomical tides – which capture the meteorological influence. The analysis concluded that higher tidal residuals are associated with relatively high creek daily discharge values. However, there is not a linear correlation between the two. Instead, there is a threshold in the creek daily discharge values at 50 to 100 cfs. If the creek discharge is above the threshold value then higher tidal residuals are observed. However, the tidal residuals do not increase further for extremely high creek discharge values.

There were two main conclusions: (1) There is a threshold in the creek daily discharge value, at 50 to 100 cfs daily mean discharge, above which higher tidal residuals are observed. (2). Once the threshold in the creek daily discharge is reached, further increases in the creek discharge are not associated with further increases in the tidal residuals .

These results supported the conclusion that there is little correlation between the tidal residuals and the creek discharge when the analysis is limited to days with creek discharges above the threshold. However, the tidal residuals on those days are relatively large compared to the data set as a whole and extreme high tidal residuals are always associated with creek discharges above the threshold. Therefore, an appropriate functional form for the conditional relationship between the creek discharge and the tidal residuals is, in effect, a step function: different probability distributions for the tidal elevation are defined for high discharge days (with the Colma Creek daily discharge greater than 100 cfs) and low discharge days (all other days).

The flooding results shown in this report reflect a direct implementation of this statistical relationship for the coincident frequency for high water levels in San Francisco Bay and high creek discharge, which represents a significant improvement over past methodology in the ability to predict the combined recurrence interval of flood elevations in the creeks. Determining the location in each of the creeks where the water surface profile in the channel is independent of the downstream tidal elevation was also critical in defining the extents within the lower watersheds that are susceptible to the effects of future sea-level rise.

E.4.4 Increased Flooding Potential

Colma Creek

In the lowest portion of Colma Creek, downstream of the Utah Avenue Bridge to the creek mouth, the resultant water surface profiles show that flood stages in this area are driven by tidal elevations. This area has improved coastal defenses and the top-of-bank elevations are above the existing 100-yr coincident flood stage. However with future SLR, these levees would be elevation deficient.

The reach of Colma Creek between Utah Avenue and South Airport Boulevard is known to have existing deficiencies, as evidenced by the resultant water surface profiles. San Mateo County is currently in the process of performing engineering studies to raise the southern flood wall in this reach to help mitigate flooding in the commercial district between South Airport Boulevard and the Creek, centered at Wondercolor Lane and at Utah Avenue.

The reach of Colma Creek upstream of Hwy-101, from the Caltrain tracks up to Spruce Avenue, has a channel capacity coinciding with approximately a 10-year flood event for the existing tidal condition without SLR. The effective FEMA FIRMs for South San Francisco shows overbank flooding from the channel between Spruce and the Caltrain tracks, centered on Linden Avenue.

A comparison of 100-yr coincident water surface profiles for Colma Creek for present conditions with future conditions including SLR values of 1-ft, 2-ft, and 3-ft shows that SLR has a significant impact on flood elevations in the creek for the lowest reach downstream of Utah Avenue. In the reach between Utah Avenue and Hwy-101, SLR appears to have a much smaller impact on the water surface profiles. And in the reach upstream of Hwy-101, SLR appears to have only a negligible impact on flood stages in the creek.

San Bruno Creek

Since the lower reaches of San Bruno Creek are protected from storm surge by a set of tide gates, the effects of tides on the water surface profiles is different than for Colma Creek, which is open to the Bay. In lower San Bruno Creek, water levels are influenced by backwater effects from flood flows being trapped upstream of the tide gates during high-tides.

The reach of North Channel downstream of the Hwy-101 culverts is able to contain approximately a 10-year flood event due to a few low-spots on the channel banks. However, the flood elevations in this lower reach are being moderated by the overbank flooding that occurs in the San Bruno Creek system upstream of the Hwy-101 culverts. The majority of this flooding occurs on the west side of Cupid Row Canal, adjacent to the Belle Air neighborhood, and to a lesser degree in the reach of North Channel between San Bruno Avenue and Hwy-101.

The overbank flooding upstream of Hwy-101 and San Bruno Avenue is not the result of those culverts being undersized. The two primary contributing factors to the flooding are the relatively low top-of-bank elevations on the Cupid Row Canal immediately upstream of San Bruno Avenue, and the undersized tide gate structure at the Creek's outlet to the Bay.

The tide gates prevent storm surges and resultant high water levels in the North Channel, but the consequence of SLR is increased backwater effects in the creek due to flood flows being trapped upstream of the tide gates during high-tides, and the entire reach of San Bruno Creek from the tide gates up through Cupid Row Canal being susceptible to impacts from SLR. In particular, the results illustrate that the effects of SLR will be increased frequency of overbank flooding in the Belle Air neighborhood, to the point that it would become about an annual occurrence event.

E.5 Assessment of System Deficiencies

E.5.1 Colma Creek System Vulnerabilities

The Colma Creek system has various locations that are vulnerable to changes in flood stages due to Sea Level Rise (SLR). The locations are listed below.

- Colma Creek Floodwall Elevations- Upstream of Highway-101
- Colma Creek Floodwall Elevations - Highway-101 to Utah Avenue
- Colma Creek Floodwall Elevations - Downstream of Utah Avenue to Creek Mouth
- Navigable Slough – Top of Bank Elevations

E.5.2 San Bruno Creek System Vulnerabilities

The San Bruno Creek system has various locations that are vulnerable to changes in flood stages due to Sea Level Rise (SLR). The locations are listed below.

- San Bruno Creek Tide Gate Structure;
- Belle Air Neighborhood (City of San Bruno);
- Walnut Street and 7th Avenue Neighborhood (City of San Bruno);
- SFO Long-Term Parking Lot.

E.6 Conceptual Adaptation Measures

Potential concept-level adaptation and mitigation measures for the reaches/sections identified as vulnerable to Sea Level Rise, were developed as part of this study and are described below.

Conceptual adaptation measures at Colma Creek include:

- Floodwalls: These would be small profile concrete or other floodwalls at the crest of existing levees. Current land uses preclude the use of set-back levees within the Colma Creek system.
- Colma Creek Tide Gate & Pump Station: A tide gate at the mouth of Colma Creek would prevent storm surges and increasing tidal elevations from propagating up the creek and causing flooding in the reach below Hwy-101. Without additional detention storage, a pump-station would also be required to pass the relatively large discharges in Colma Creek during flood events without causing backwater flooding.
- Channel Deepening: This would include dredging of lower Colma Creek to increase channel capacity. The reach of Colma Creek upstream of Hwy-101 is a concrete lined channel; therefore, channel deepening is not an option.
- Navigable Slough Improvements: The existing south banks of Navigable Slough have low-spots that could contribute to flooding in SSF and San Bruno. Storm surges could be prevented from moving up Navigable Slough by incorporating a flap gate on the existing culvert that passes Navigable Slough underneath South Airport Boulevard.
- Surface Detention: There may be potential for additional storage for flood volumes within both the upper and lower watershed through surface detention basins or underground vaults, to mitigate the existing overbank flooding that is occurring. This would temporarily inundate developed areas, but would be managed based on land uses.
- Regional Tidal-Barrier Structure: A larger regional tidal-barrier structure could be built spanning from the San Mateo County Transit District (SamTrans) peninsula (the leaf) north or west to the Bay Trail and Littlefield/Utah Ave, creating a wetlands basin behind the gates. The benefit of this regional flood mitigation measure would be additional detention and lower backwater levels within both Colma Creek and San Bruno Creek.
- Low Impact Development (LID): This approach should also be applied as part of the overall strategy for addressing fluvial flooding risk by reducing imperviousness within the Colma Creek watershed. Common elements of LID include pervious pavement, cisterns

and rain barrels, and French drain systems for groundwater recharge. The SMCFCD and the cities of South San Francisco and San Bruno are already participants in the San Mateo Countywide Water Pollution Prevention Program, which was mandated by the California Regional Water Quality Control Board Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit that was adopted in 2009.

Conceptual adaptation measures for San Bruno Creek include:

- Pump Station on North Channel: The San Bruno Creek tide gate structure is only sized to convey a 10-yr flow at a MHHW tide. One alternative is to construct a pump station that would carry the excess flows around the tide gate and into the Bay.
- Floodwalls or Set-back levees on North Channel: There are significant crest elevation deficiencies in the lower reach of North Channel, downstream of Hwy-101. Floodwalls or set-back levees could be constructed to prevent flooding from the channel onto SFO property.
- Upgrade the Tide gate Structure: Replacing the tide gate structure with one-size culverts to pass the 100-year storm event at high tides would alleviate flooding of the SFO Long-Term Parking Lot and flooding upstream of Hwy-101 in residential areas of the City of San Bruno. A larger tide gate structure would lower upstream water surface elevations and lessen upstream flooding.
- Surface Detention in Cupid Row Canal: This includes using SFO's open space area on the west side of Hwy-101 for flood retention storage.
- Surface Detention at South Lomita Canal: This includes passing flood flows from Cupid Row Canal, south into the Lomita Channel in Millbrae. The structures that pass the Lomita Channel underneath Hwy-101 have been identified as having additional capacity.
- Surface Detention at SFO Long-Term Parking Lot: This includes using the current SFO Long Term Parking Lot, which is at a relatively low elevation adjacent to the Creek, for additional surface detention storage.
- Surface Detention at Highway 101 & San Bruno Avenue: This includes using the area immediately upstream of the Hwy-101 boxes, in SMCFCD's jurisdiction for additional detention storage. This area has existing low spots that could be used for storage with the addition of set-back levees.
- Upstream Surface Detention: The City of San Bruno Storm Drain Master Plan (SDMP) proposed two possible upstream detention basins within the San Bruno Creek watershed (GHD, 2014). Both detention basins have the potential to mitigate the severity of overbank flooding in Cupid Row Canal and the North Channel.
- Regional Tidal-Barrier Structure: The larger regional tidal-barrier structure alternative described in the Colma Creek section, spanning from the SamTrans peninsula (the leaf) north or west to the Bay Trail and Littlefield/Utah Ave, would also provide the same flood protection benefits for the San Bruno Creek watershed.
- Low-Impact Development: Elements of the Low-Impact Development (LID) approach should also be applied as part of the overall strategy for addressing fluvial flooding risk by reducing imperviousness within the San Bruno Creek watershed.

E.7 FINDINGS AND RECOMMENDATIONS

Based on the data collection, stakeholder outreach and analyses performed for this study, it is apparent that a coordinated approach to addressing basin-wide flooding issues would be very advantageous to the region. There is valuable data related to the drainage system, flood prone areas, design criteria, and potential mitigations that resides with the individual stakeholders, and there is some coordination that occurs but it follows jurisdictional boundaries. Significant findings and potential recommendations for next steps are listed in this section.

E.7.1 Findings

A list of the significant findings of the study is presented here:

- The lower watersheds contain significant public infrastructure.
- The lower watersheds contain valuable habitat for threatened and endangered species.
- Residential neighborhoods in the lower watersheds are susceptible to severe flooding; the San Mateo County Flood Control District, the SSF and San Bruno Public Works Departments, and local residents are all aware of the problem.
- An updated analysis of riverine flooding for the region's Flood Insurance Study has not been performed in 30-years.
- The development within lower watersheds, east of the Caltrain tracks, has been built on reclaimed marshlands which are settling, resulting in the need for protection by levees.
- The existing San Bruno Creek tide gates only has the capacity to pass a 10-yr flowrate, which contributes to backwater flooding within the lower creek system.
- San Mateo County has existing flow gage data on Colma Creek at Orange Park, but this gage should be augmented with additional water-level gages in the lower watersheds to facilitate future engineering studies.
- SLR has a significant impact on flood elevations in Colma Creek downstream of Utah Ave. In the reach between Utah Ave and Hwy-101, SLR appears to have a much smaller impact on the water surface profiles. And in the reach upstream of Hwy-101, SLR appears to have only a negligible impact on flood stages in the creek.
- The high concentration of existing development in the Colma Creek watershed requires a watershed-based approach and prioritization of mitigation based on vulnerabilities.
- SLR will exacerbate backwater flooding in San Bruno Creek, and the entire creek from the tide gates up through Cupid Row Canal is susceptible to impacts from SLR. SLR will increase the frequency of overbank flooding in the Belle Air neighborhood, to the point that it would become about an annual occurrence event.
- Upgrading the San Bruno Creek tide gate structure would have immediate benefit in reducing flood elevations within the lower watershed.

E.7.2 Recommendations

Establish Governance Structure, Collaboration Strategy, and a Regional Working Group

There would be value for the Working Group that was assembled for this study to continue collaborating, as there is no other similar forum. It may be possible to even form a governance structure to facilitate the continued collaboration of all the stakeholders, such as a Regional Watershed Management Working Group to address the complex problems of coastal and fluvial flooding within the watersheds' various jurisdictions, which would be exacerbated by SLR.

Develop Regional Watershed Management Plans

Establishing a vision for the management of the lower watersheds by conducting/developing Regional Watershed Management Plans would benefit the stakeholders. The combined watersheds of Colma Creek and San Bruno Creek pass through multiple jurisdictions, including portions of Colma, South San Francisco, San Bruno, Daly City, and Unincorporated San Mateo County. Since some of the proposed flood mitigation and SLR adaptation strategies focus on implementing design elements throughout the larger watershed areas, such as smaller surface detention basins and LID, developing an overall regional watershed management plan for the combined Colma Creek and San Bruno Creek watersheds would help the jurisdictions plan and prioritize these smaller design elements in a concerted manner.

Conduct Focused Research & Studies

Based on discussions at the Working Group meetings, there would be value in performing focused research and studies to assess the viability of potential adaptation strategies for the region and to evaluate the adaptation strategy criteria for a more refined screening of the alternatives. Examples of these subsequent studies could include:

- Document lessons learned from other regions by reviewing region-wide adaptation studies from neighboring flood control agencies, such as the Santa Clara Valley Water District, the Alameda County Public Works Agency, the Contra Costa County Flood Control District, and the Marin County Flood Control District.
- Perform environmental studies to evaluate potential impacts to Endangered Species Habitat from the adaptation alternatives, such as the viability of storing additional stormwater runoff in the Cupid Row Canal and South Lomita Canal lowlands, which are existing Endangered Species Habitat.
- Conduct Flood Insurance Studies for riverine flooding.
- Perform groundwater percolation tests to assess the viability of various land uses for upstream detention and LID within the watersheds.
- Document the existing land uses and temporary easements within the watersheds.
- Complete an asset inventory for assets susceptible to SLR issues in the watersheds.

Initiate Implementation Plans for Identified Alternatives

The next phase of engineering studies and research for this project should focus on the adaption strategy alternatives which could seemingly be implemented more quickly and efficiently than some of the other more long-term strategies. For example:

- Improvements to Navigable Slough would have immediate benefit to neighborhoods within both SSF and San Bruno.
- One of the two surface detention basins proposed in the recent San Bruno SDMP, Crestmoor Canyon, was recommended as soon as funds are available (GHD, 2014) and would help mitigate the severity of overbank flooding in Cupid Row Canal and the North Channel.
- The existing San Bruno Creek tide gates are not a FEMA certified and accredited structure. Acquiring FEMA accreditation would potentially have benefit to the residential communities in lower San Bruno in regards to FEMA Special Flood Hazard Zones and the need of homeowners to purchase flood insurance.

Develop an Information-Sharing Platform

As part of the cooperative nature of a regional Working Group, information on stormwater infrastructure, natural resources, and other factors affecting how flood control and LID resources are managed should be shared among stakeholders. Increased information sharing will aid in allowing all stakeholders to better manage their aspects of stormwater infrastructure in the area and will help avoid duplication of efforts for new data gathering and data assimilation.

Education/Public Outreach

Some of the recommended adaptation strategies in this study would be greatly facilitated by having a broader level of support and understanding from the public, such as ballot measures for countywide bonds or more stringent requirements for LID techniques. There is a potential benefit to the stakeholders in undertaking efforts to educate the public through outreach programs on the implications of SLR to their communities and the adaptation strategies that have been identified to mitigate for these effects.

Identify Potential Grants and Funding Sources

Given that the benefits of flood and SLR mitigation are region-wide, opportunities for grant funding, assessments, bonds, and levies should be investigated. Potential sources of funding for subsequent studies in the lower Colma Creek and San Bruno Creek watersheds include:

- California Coastal Conservancy Climate Ready Grant Program
- California DWR Integrated Regional Water Management (IRWM) Grant Program
- NOAA NOS Coastal Resiliency Grant Program
- San Mateo Countywide Bonds

Incentivize Basin-Wide LID

Currently, the Municipal Regional NPDES Permit for San Mateo County has a threshold of 5,000 square feet of impervious surface for new development and redevelopment projects to incorporate LID techniques; that threshold could be reduced or eliminated. The cities could also prioritize implementing LID techniques on public lands within their jurisdictions. There may be value to each of the cities within the two watersheds to incentivize the additional use of LID within the watersheds.

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ACRONYMS

AMC	Antecedent Moisture Condition
ART	Adapting to Rising Tides Study
BART	Bay Area Rapid Transit
BCDC	San Francisco Bay Conservation and Development Commission
BFE	Base Flood Elevation
Caltrans	California Department of Transportation
CCSF	City and County of San Francisco
CDEC	California Data Exchange Center
CFS	Cubic Feet per Second
CN	Curve Number
CO-CAT	Coastal and Ocean Working Group of the California Climate Action Team
CPO	Climate Program Office (NOAA)
DEM	Digital Elevation Model
DPW	Department of Public Works
DTL	Diurnal Tide Level
DWR	California Department of Water Resources
ENSO	El Niño South Oscillation
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GEVD	Generalized Extreme Value Distribution
GPM	Gallons per Minute
HEC-HMS	Hydrologic Engineering Centers Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HR	Hour
LID	Low-Impact Development
LiDAR	Light Detection and Ranging
M&N	Moffatt & Nichol
MIN	Minute
MHHW	Mean Higher High Water
MHW	Mean High Water tide
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
MTL	Mean Tide Level
NAVD88	North American Vertical Datum of 1988

NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRCS	Natural Resources Conservation Service
PDF	Probability Density Function
PFDS	Precipitation Frequency Data Server
PG&E	Pacific Gas and Electric Company
RSLR	Relative Sea Level Rise
SamTrans	San Mateo County Transit District
SCCDM	Santa Clara County Drainage Manual
SDMP	Storm Drain Master Plan
SFO	San Francisco International Airport
SLR	Sea Level Rise
SMC	San Mateo County
SMCFCD	San Mateo County Flood Control District
SSF	City of South San Francisco
SWL	Still Water Level
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSE	Water Surface Elevation

1.0 INTRODUCTION

1.1 Background

San Mateo County has more property at risk from sea level rise than any other county in the Bay Area (Pacific Institute 2012). Of particular concern is the San Francisco International Airport (SFO); as the 7th busiest airport in the nation, SFO is critical to the Bay Area economy. San Bruno Creek and Colma Creek both drain to the San Francisco Bay immediately north of SFO property. Fluvial impacts from the creeks combined with tidal changes due to sea level rise in the vicinity of these creeks' outlets into the Bay pose a flood risk to both SFO and the adjacent communities. This area contains residential neighborhoods that have been subject to severe flooding, habitat for threatened and endangered species, and substantial public infrastructure. In response to this complex problem, the County of San Mateo partnered with SFO and the California Coastal Conservancy to obtain a Climate Ready Grant to prepare a sea level rise vulnerability assessment and adaptation plan for the shoreline area northwest of the airport, where San Bruno and Colma creeks meet the Bay.

The study was intended to complement the Shoreline Protection Study that SFO recently completed to assess the vulnerability of the airport perimeter system and evaluate adaptation options for both 1%-annual-chance floods and sea level rise. The locations of Colma Creek and San Bruno Creek relative to SFO are illustrated in Figure 1-1 for reference.

1.2 Purpose

The purpose of the study is to assess the vulnerability of SFO and its neighbors to flooding from sea level rise and storms along the Bay shoreline directly northwest of the airport where San Bruno Creek and Colma Creek meet the Bay (Project Area) and to develop conceptual adaptation strategies for the Project Area.

The primary objectives of the SFO Colma Creek and San Bruno Creek Resiliency Study are 1) to establish an interagency working group focused on the project area, 2) to conduct a sea level vulnerability assessment, and 3) to develop sea level rise adaptation strategies. The following is a description of the approach for each of these objectives:

1) <u>Establish an interagency working group focused on the Project Area.</u> Given the complexity of the Project Area, which contains a number of public infrastructure assets and spans multiple jurisdictions, the establishment of an engaged and effective interagency working group is critical to the success of the project. The working group would consist of representatives from SFO, California Coastal Conservancy, San Mateo County (SMC), City of San Bruno, City of South San Francisco (SSF), San Francisco Bay Conservation and Development Commission (BCDC), Caltrans, Caltrain, SamTrans, Pacific Gas and Electric Company (PG&E) and Bay Area Rapid Transit (BART).

2) <u>Conduct a sea level vulnerability assessment of the Project Area</u>. The SFO Shoreline Protection Feasibility Study, which was completed in April 2015, included a flooding vulnerability analysis of SFO's property and provided an excellent foundation for the conceptual adaptation strategy alternatives developed as part of this study.

The vulnerability assessment was to follow the guidelines set forth in the California Climate Adaptation Planning Guide, consider a range of sea level rise scenarios for the years 2050 and 2100, and build off the lessons learned from BCDC's Adapting to Rising Tides (ART) project. Work included:

a. Gathering hydrology and hydraulics data for both creeks from previous Federal Emergency Management Agency (FEMA) flood insurance studies and performing additional cross section surveys to update this data. Gathering Light Detection and Ranging (LiDAR) topographic data to assess elevations of levees, trails, roadways, and parking lots.

b. Conducting engineering analyses (including estimating the combined effects of storm surges, astronomical tides, and rainfall) to determine flood and storm risks. Coordinating with the Interagency Working Group to select the appropriate sea level rise criteria for analysis of future risks.

c. Developing an existing condition assessment to identify constraints including available versus required freeboard, potential overtopping, existing gaps, potential impacts to existing sensitive habitat, and other design considerations.

d. Performing one-dimensional unsteady state hydraulic modeling to develop flood stages and inundation depths for varying tailwater conditions. Conducting hydrologic modeling for a range of storm events for the present and the future with different sea level rise scenarios including mid-century and end of century.

e. Developing alternative flood protection system improvements to address the identified deficiencies, and analyzing alternatives using multi-objective criteria.

3) Develop sea level rise adaptation strategies for the Project Area. The study was to develop sea level rise adaptation and mitigation strategies for the Project Area. These strategies were to include items such as: improvements to the San Bruno Creek and Colma Creek; tidal land restoration; habitat enhancement; the development of parks, recreation areas and trails; and levee construction. These strategies also considered protection of endangered species and spartina (cordgrass) management.

1.3 Scope

Tasks completed for this study included the following:

- Task 1: The coordination of meetings and facilitation of communication between the cities, the county, public agencies, land owners and others with an interest in the study area were accomplished. These communications were part of the establishment of an interagency working group.
- Task 2: The acquisition and review of existing data on the creeks and channel structures and documentation on sea level rise.
- Task 3: Collect additional survey data necessary for hydraulic model development.
- Task 4: Development of a hydrologic and hydraulic study of the lower Colma and San Bruno Creeks to assess flood risk from high Bay water levels at present and in the future with sea level rise, in combination with high creek discharges.

- Task 5: Identification of reaches/sections of the creeks that are vulnerable to sea level rise, development of potential adaptation measures for these reaches/sections, and recommendations for future studies.

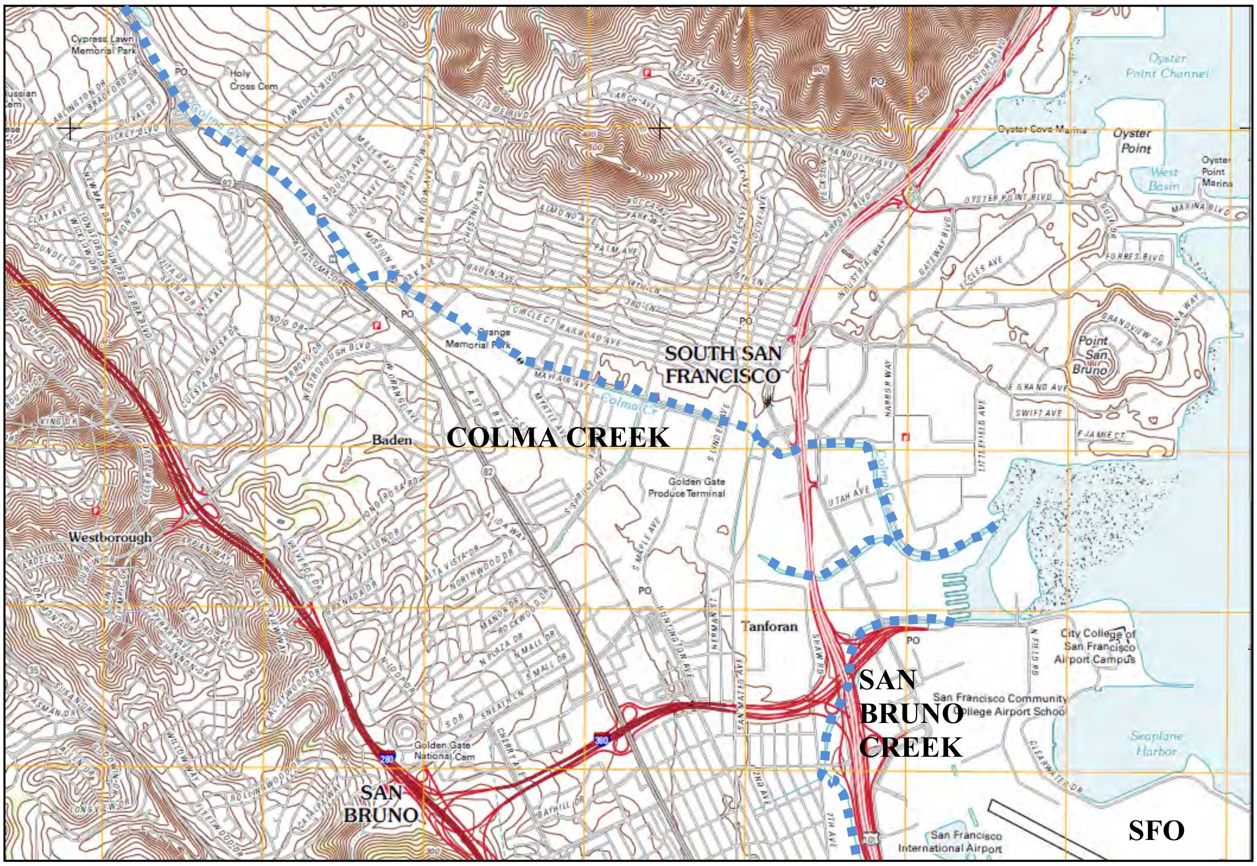

Figure 1-1. Vicinity Map

2.0 SETTING

The lower reaches of the Colma Creek and San Bruno Creek watershed (Project Area), which are shown in Figure 2-1, constitute an extremely complex region. Multiple factors contribute to the complexity of the region. Factors affecting the Project Area are described below.

- The Project Area is under the governing jurisdiction of multiple entities including SFO, SMC, the San Mateo County Flood Control District (SMCFCD), the City of San Bruno, SSF, BCDC, and the California Department of Transportation (Caltrans).
- It includes multiple major property owners including SFO and Caltrans.
- It includes multiple residential neighborhoods.
- It has experienced severe flooding in the past, which has significantly impacted lower income neighborhoods.
- It provides habitat for the California Clapper Rail, San Francisco Garter Snake and the California Red-legged Frog, all of which are federally and state listed endangered species.
- It includes substantial public infrastructure in addition to SFO including two major highways, Caltrain and BART lines and stations, two sanitary sewage treatment plants, several PG&E electrical substations, and multiple storm drains, culverts, flood control channels and pump stations.
- It provides important Bay Trail segments as well as bike paths.

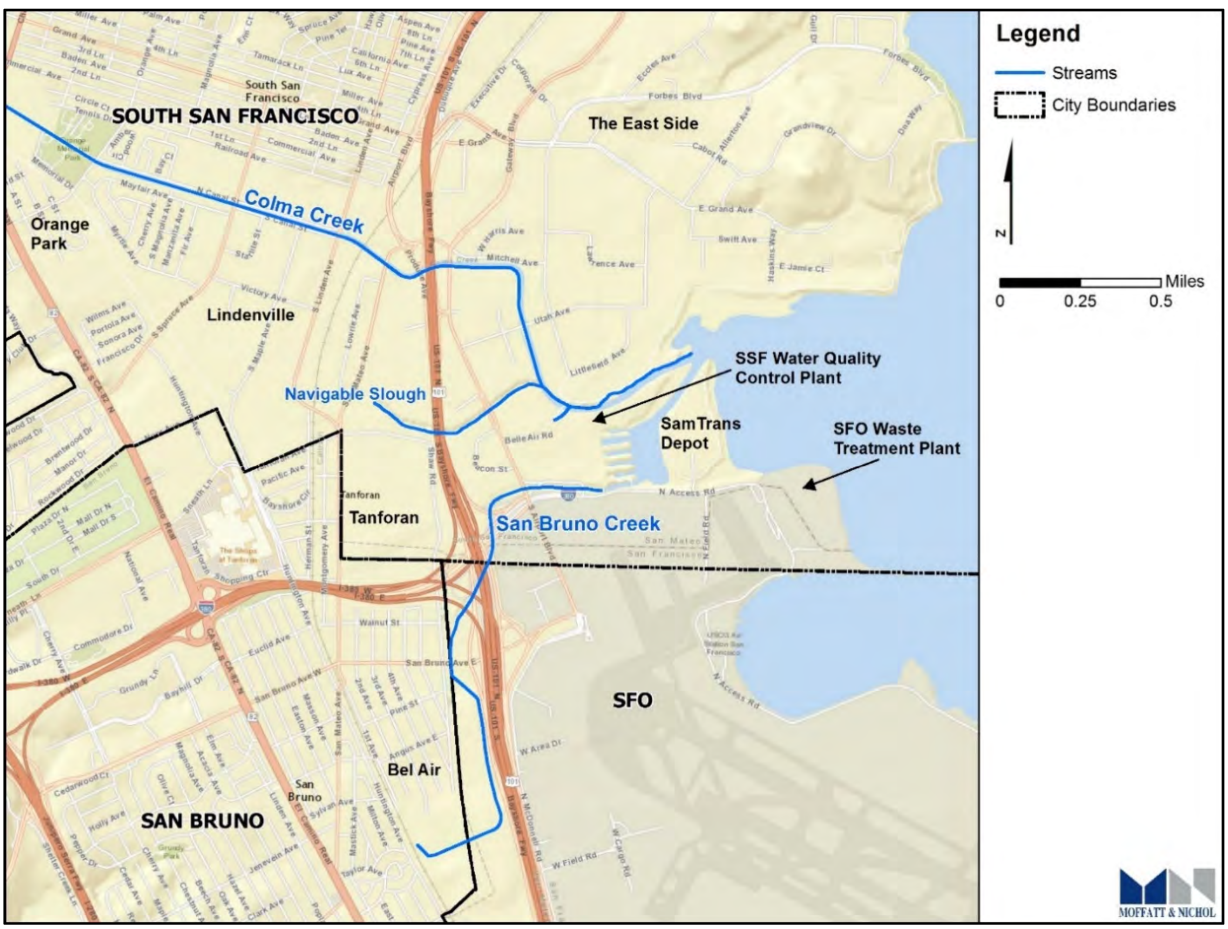

Figure 2-1. Project Area Map of the Lower Watersheds

2.1 Topography

Topographic LiDAR data for the Project Area was provided by multiple sources. The San Mateo County Flood Control District provided a LiDAR digital elevation model (DEM) surface for the entire watershed areas of the two creeks (referenced to NAVD88) with a horizontal resolution of 5 ft. Raw LiDAR files covering the airport and surrounding areas in San Mateo County were also provided by SFO, with the point elevation data referenced to NAVD88. To display the variation in elevations of the study area, the raw LiDAR points were converted to a raster image with a horizontal resolution of 1 m. The LiDAR data for both the County and SFO surfaces was acquired by the USGS during flights in June, 2010. Figure 2-2 shows the elevation data derived from the LiDAR; the two creeks are also highlighted along with the rapid rail lines and highways in the region.

Figure 2-2 shows that much of the land surface of the lower watersheds and SFO lies at very low elevations. While most of the region's shorelines have been built up above potential tidal elevations, much of the airport is below +7 ft NAVD88, along with a portion of the Belle Air neighborhood in the City of San Bruno (presented with light and dark blue colors). Figure 2-2 illustrates the extent of the Creeks' lower watersheds which are within an elevation range from typical tidal elevations up to the 100-year Base Flood Elevation plus 3-ft of potential sea-level rise (presented with yellow and orange colors). These areas constitute the most susceptible regions to increased coastal flooding due to sea-level rise, which includes the Belle Air neighborhood in San Bruno and the Lindenville and Tanforan neighborhoods in South San Francisco, along with the two wastewater treatment plants operated by SFO and SSF.

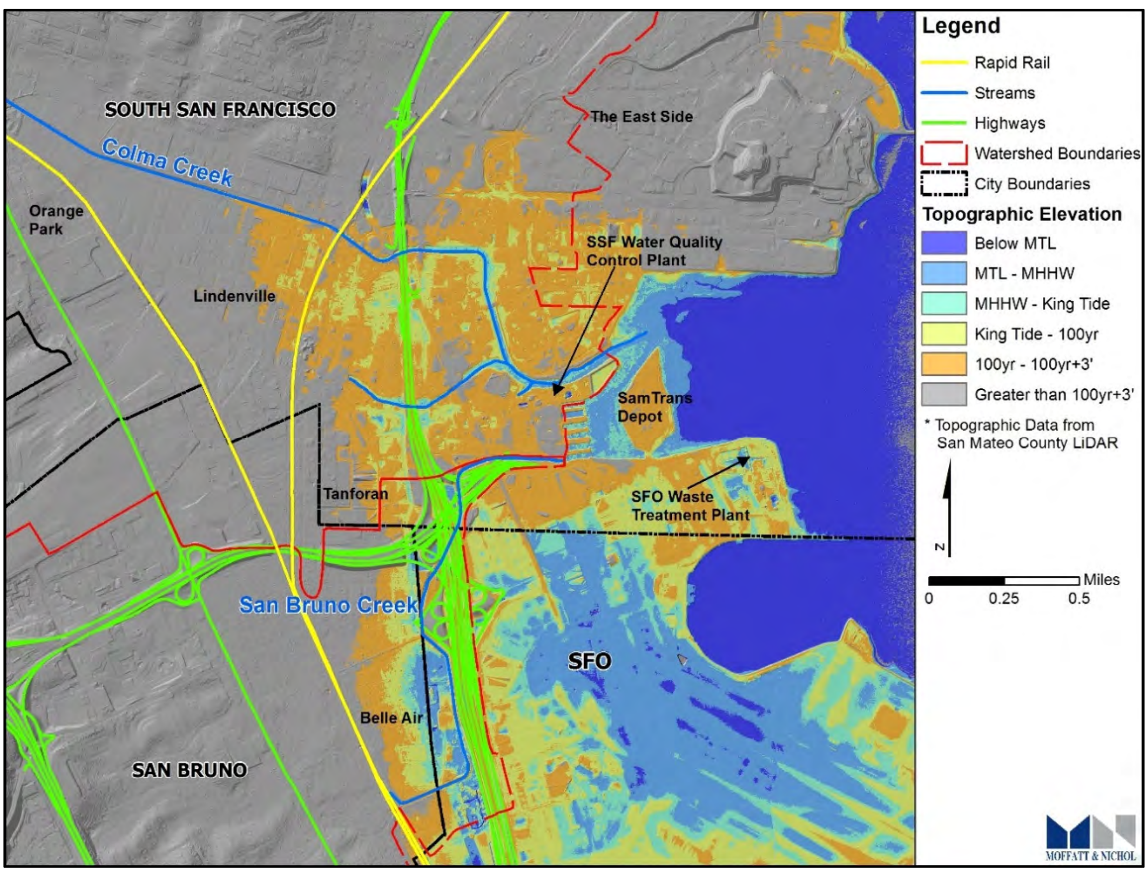

Figure 2-2. Topographic Elevations in the Lower Watersheds

2.2 Colma Creek Watershed

2.2.1 Physical Description

Colma Creek extends from San Bruno Mountain to its outlet at the San Francisco Bay just north of the San Francisco Airport and south of Point San Bruno. (See location map in Figure 2-3.) Colma Creek flows through portions of Colma, South San Francisco, San Bruno, and Daly City. The western border of the basin is the San Andreas Fault while the northern edge terminates at the San Bruno Mountain ridge and the south is bounded by Interstate 380. The total drainage area is approximately 15.8 square miles and is mostly developed.

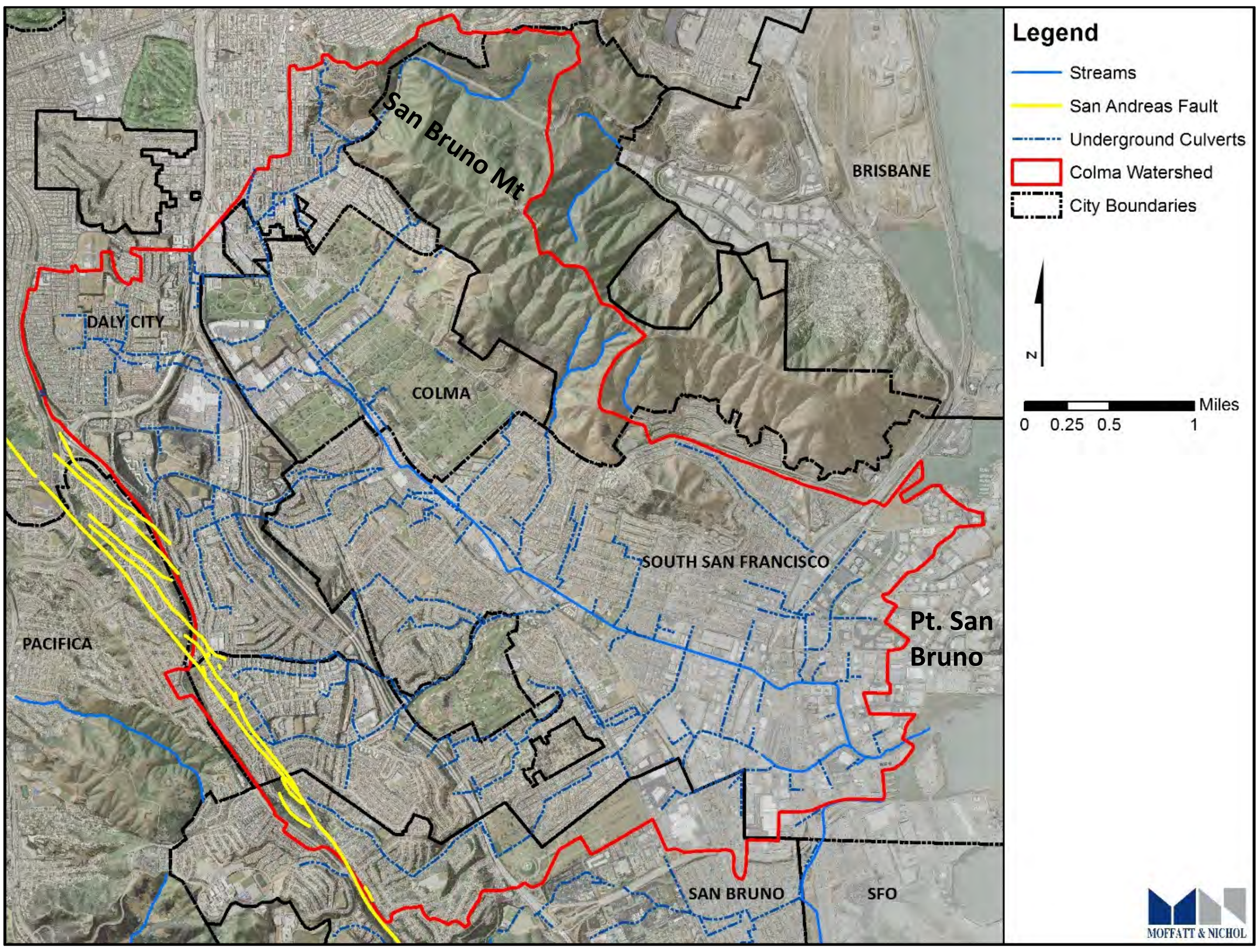

Figure 2-3. Colma Creek Watershed Location Map

2.2.2 Existing Flood Control Infrastructure

The San Mateo County Flood Control District (SMCFCD), oversees the Colma Creek Flood Control Zone, established in 1964 to alleviate flooding in the City of South San Francisco. The Colma Creek flood control project originally spanned 3 miles from the San Francisco Bay up to Mission Road in South San Francisco. In the period through 1978, the project included the replacement of the bridges at Utah Avenue, South Airport Boulevard, Linden Avenue, and Spruce Avenue. Recent improvements since 1995 have extended the project further upstream to Daly City. Additional projects include the 2003 replacement of the Mainline Railroad Bridge over the creek in collaboration with the Peninsula Joint Powers Board, and the raising of the San Mateo Avenue Bridge in 2006 (SMCFCD, 2006).

The Colma Creek channel was improved in 2006 with the construction of a 70-ft wide rectangular concrete channel from Spruce Avenue to San Mateo Avenue near downtown City of South San Francisco. These channel improvements impacted existing salt mash in the channel. To mitigate these impacts, the Flood Control District is constructing the Colma Creek Flood Control Habitat Mitigation Project, which will develop habitat for the California Clapper Rail where Colma Creek enters San Francisco Bay below Utah Avenue. The various improvements to the channel in the lower reach of Colma Creek are illustrated in Figure 2-4.

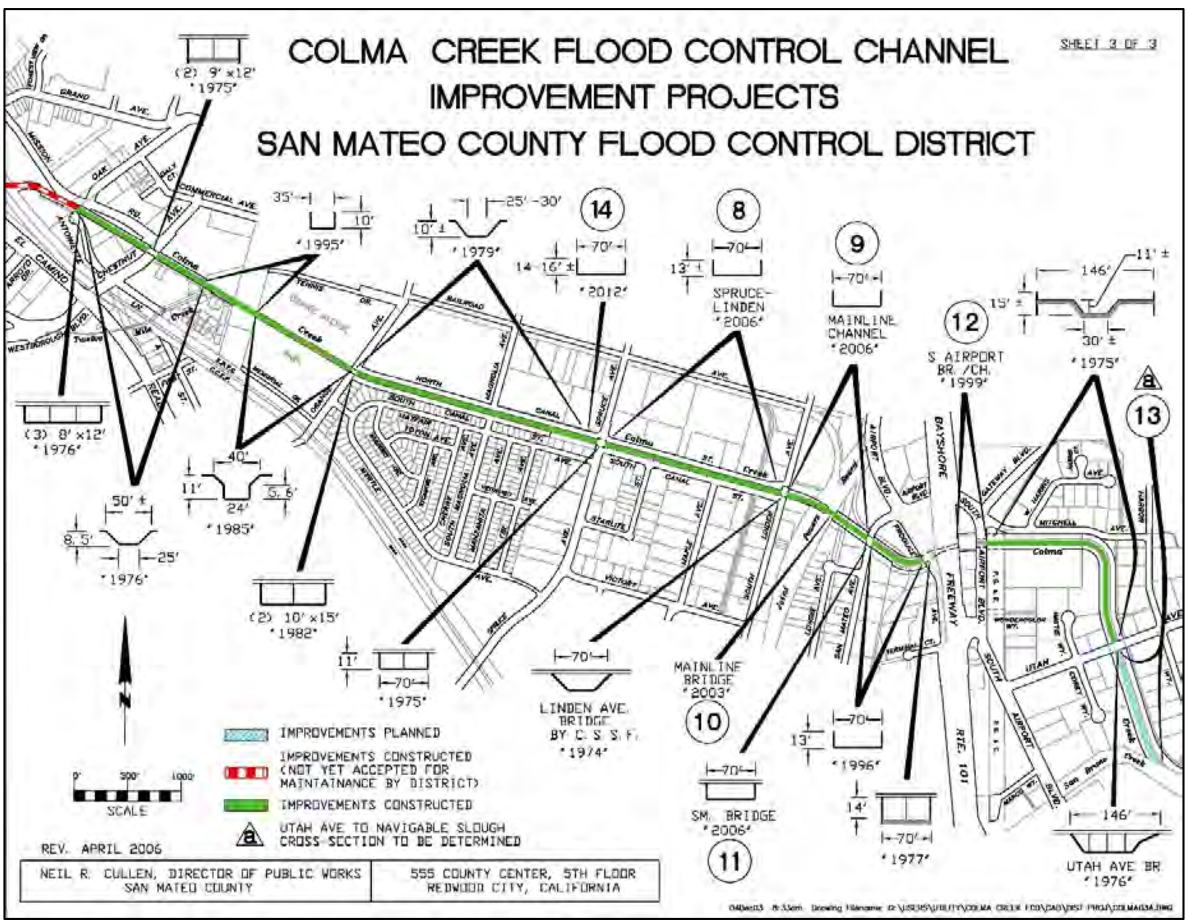

Figure 2-4. Colma Creek Flood Control Channel Improvements (SMCFCD, 2006)

The City of South San Francisco (SSF) Department of Public Works (DPW) is currently operating seven pump stations in the lower Colma Creek watershed. These pump stations have all been rehabilitated or updated within the last 20-years. Table 2-1 details their catchment areas contributing runoff to each station, along with the maximum pumping capacity of each. SSF is currently beginning the process of performing a storm drain master plan for the city. Currently, there are no results available from that study. The city provided geospatial data for their storm drain system, which is illustrated along with the location of the City's seven pump stations on Figure 2-5.

Table 2-1. Pump Stations within the Lower Colma Creek Watershed (SSF)

Pump Station Name	Operating Agency	# of Pumps	Catchment Area (acres)	Receiving Water for Discharge	Max Pump Capacity of Station (cfs)	Date Pump Station Last Updated
Airport Blvd Northbound	DPW SSF	1	0.3	Colma Creek	4.2	2000
Airport Blvd Southbound	DPW SSF	1	0.3	Colma Creek	4.2	2000
Shaw Road	DPW SSF	2	8.3	Colma Creek	8.9	2006
South Maple Ave.	DPW SSF	2	5.5	Colma Creek	6.2	1997
South Linden	DPW SSF	1	1.3	Colma Creek	3.3	2004
San Mateo	DPW SSF	2	22.5	Colma Creek	6.7	2003
South Airport Blvd	DPW SSF	1	5.8	Colma Creek	2.7	2001

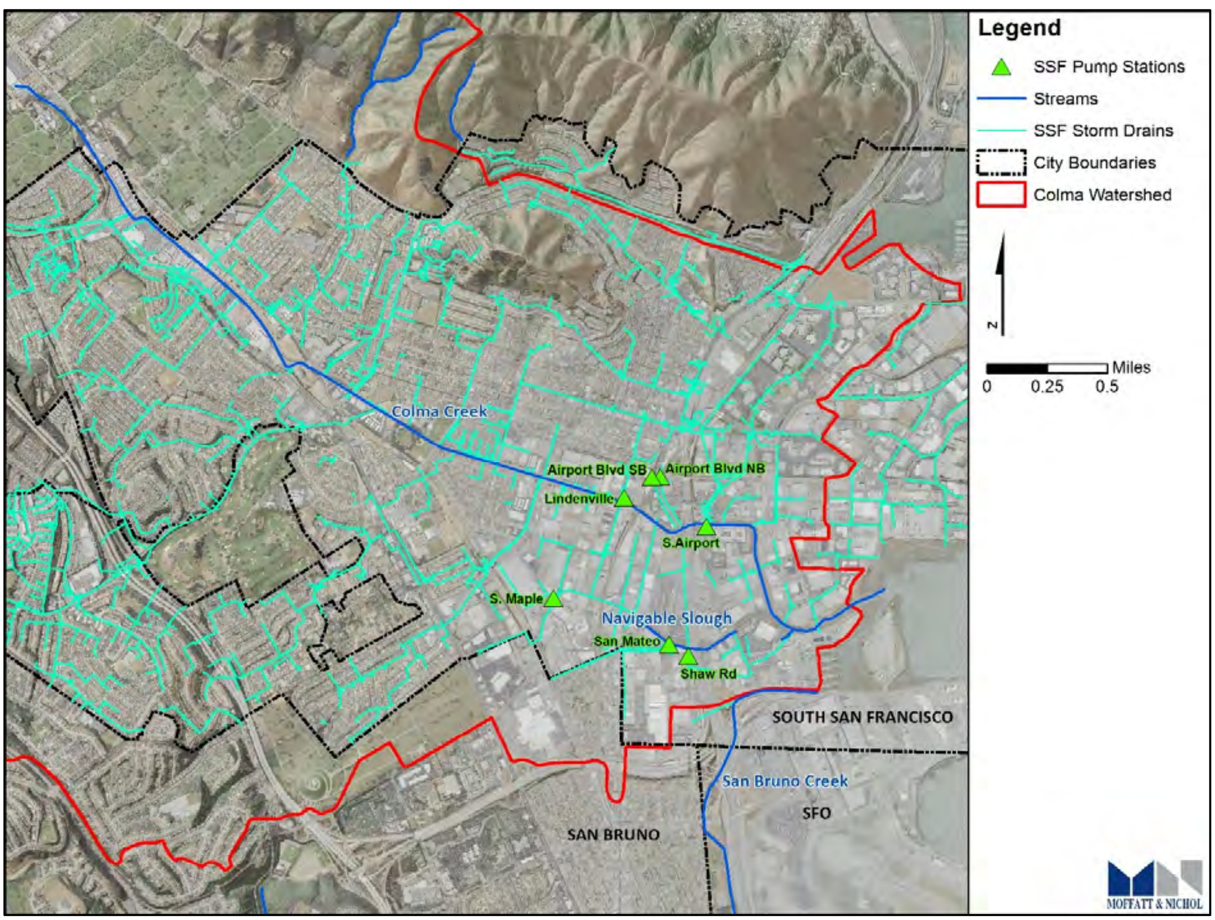

Figure 2-5. SSF Storm Drains and Pump Stations within Colma Creek Watershed

2.2.3 Critical Infrastructure Elements

There are multiple critical infrastructure elements that are located within the lower Colma Creek watershed. These include:

- BART tracks and stations
- Caltrain tracks and station
- PG&E electrical substations
- Caltrans Highways

The BART and Caltrain lines both pass through the lower watershed. The BART line runs in a tunnel below ground for roughly 5.5-miles from immediately south of the Colma station to roughly 500 feet south of 1st Avenue and Cupid Row Canal in San Bruno. The Caltrain line is on above-ground track through the entire reach from South San Francisco to Millbrae. The South San Francisco BART station is located immediately adjacent to the Colma Creek flood control channel, while the San Bruno BART station is located near Navigable Slough and Tanforan. The South San Francisco Caltrain station is also in the lower watershed, roughly 0.5-mile north of the flood control channel and adjacent to Hwy-101.

There are four PG&E electrical substations located in the Colma Creek watershed. Two are located in the vicinity of the flood control channel in the lower watershed. The Lawndale substation is just south-east of the South San Francisco BART station and is less than 200-ft from the Colma Creek channel. Ground elevations at the substation based on the County LiDAR dataset are approximately +76’ NAVD88. The East Grande substation is located near the South San Francisco Caltrain station and approximately 0.5-mile north of the flood control channel. Ground elevations at the substation based on the County LiDAR dataset are approximately +12.0’ to +14.0’ NAVD88. Figure 2-6 illustrates this infrastructure in the San Bruno Creek watershed, along with the USGS flow-gage on Colma Creek.

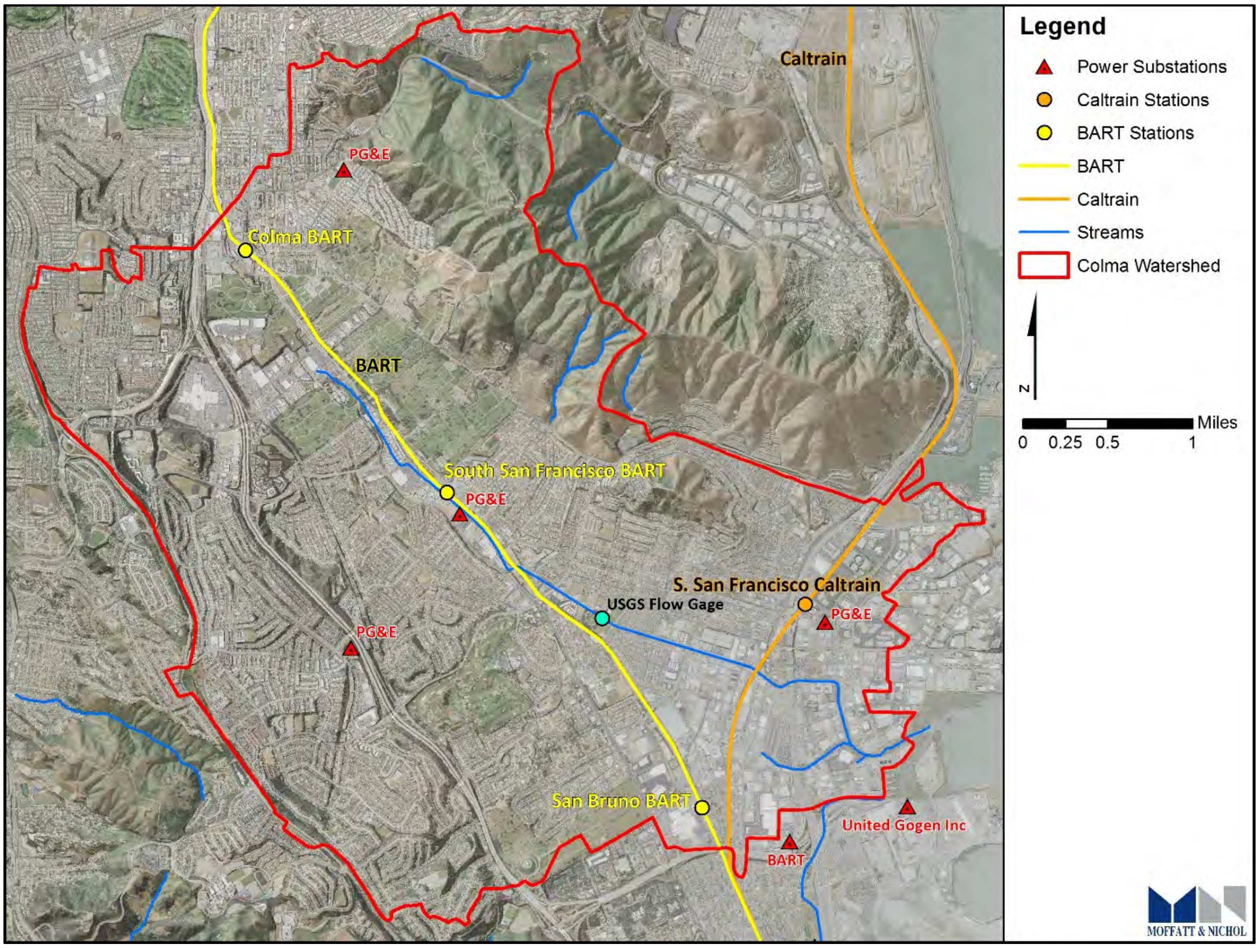

Figure 2-6. Infrastructure within the Colma Creek Watershed

There are two major highways located in the lower Colma Creek watershed under the jurisdiction of Caltrans. U.S. Highway-101 and CA State Route-82 (also called El Camino Real) both run north-to-south through the watershed. A number of drainage design reports and as-built plan-sets were provided by Caltrans for reference in this study. A list of the most pertinent Caltrans documents that were provided are listed below.

1) As-Built Plans for Hwy-101 in the City of South San Francisco between North City Limits and 0.35 mile south of Colma Creek (Caltrans, 1947)
2) As-Built Plans for Hwy-101 in the City of South San Francisco and Brisbane from 0.2 mile south of Sierra Point off-ramp overcrossing to Grand Ave undercrossing (Caltrans, 1988)
3) As-Built Plans for Hwy-101 Bridge Widening at Colma Creek (Caltrans, 1969)
4) Drainage Plans for Colma Creek Flood Control Project at Produce Avenue Bridge (San Mateo County, 1975)
5) Drainage Plans and Plan Set for Route 380 from Cherry Ave to 0.2 mile east of Route 101 and on Route 101 from 0.7 mile south of San Bruno Ave to South San Francisco Belt Railroad overhead (Caltrans, 1971 & 1973)
6) Drainage Analyses and Plan Set for El Camino Real in San Bruno and South San Francisco between 0.1 mile south of Sneath Lane and 0.1 mile north of Orange Ave (Caltrans, 1969)

The locations of the Caltrans infrastructure listed above in these studies is illustrated by number in Figure 2-7. These reports are summarized in more detail in Appendix C.

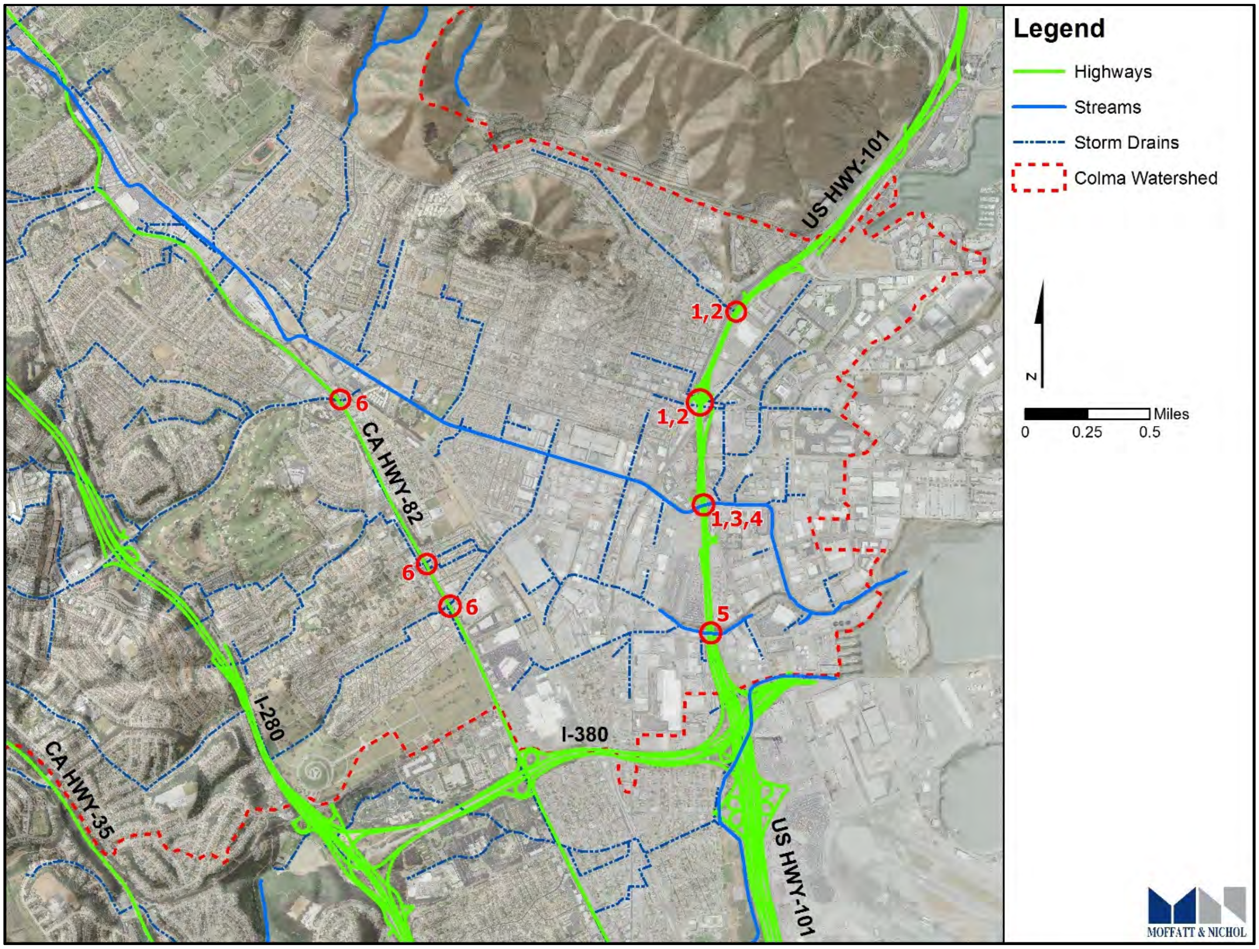

Figure 2-7. Highways within the Colma Creek Watershed

2.3 San Bruno Creek Watershed

2.3.1 Physical Description

San Bruno Creek collects runoff from the City of San Bruno, a drainage area of approximately 4.5 square miles, which lies south of the Colma Creek drainage basin. Most of the San Bruno Creek watershed drains through pipes in the City's storm drain system. The San Bruno Channel outlet to the San Francisco Bay is approximately 1,400 feet to the south of the Colma Creek outlet (Figure 2-8). The channel exits to Bay through a tide gate structure. The watershed is bounded by the City of South San Francisco and Colma Creek to the north, the City of Millbrae and the South Lomita Canal/Highline Canal to the south, the City of Pacifica and the Coast Range to the west, and the San Francisco International Airport to the east.

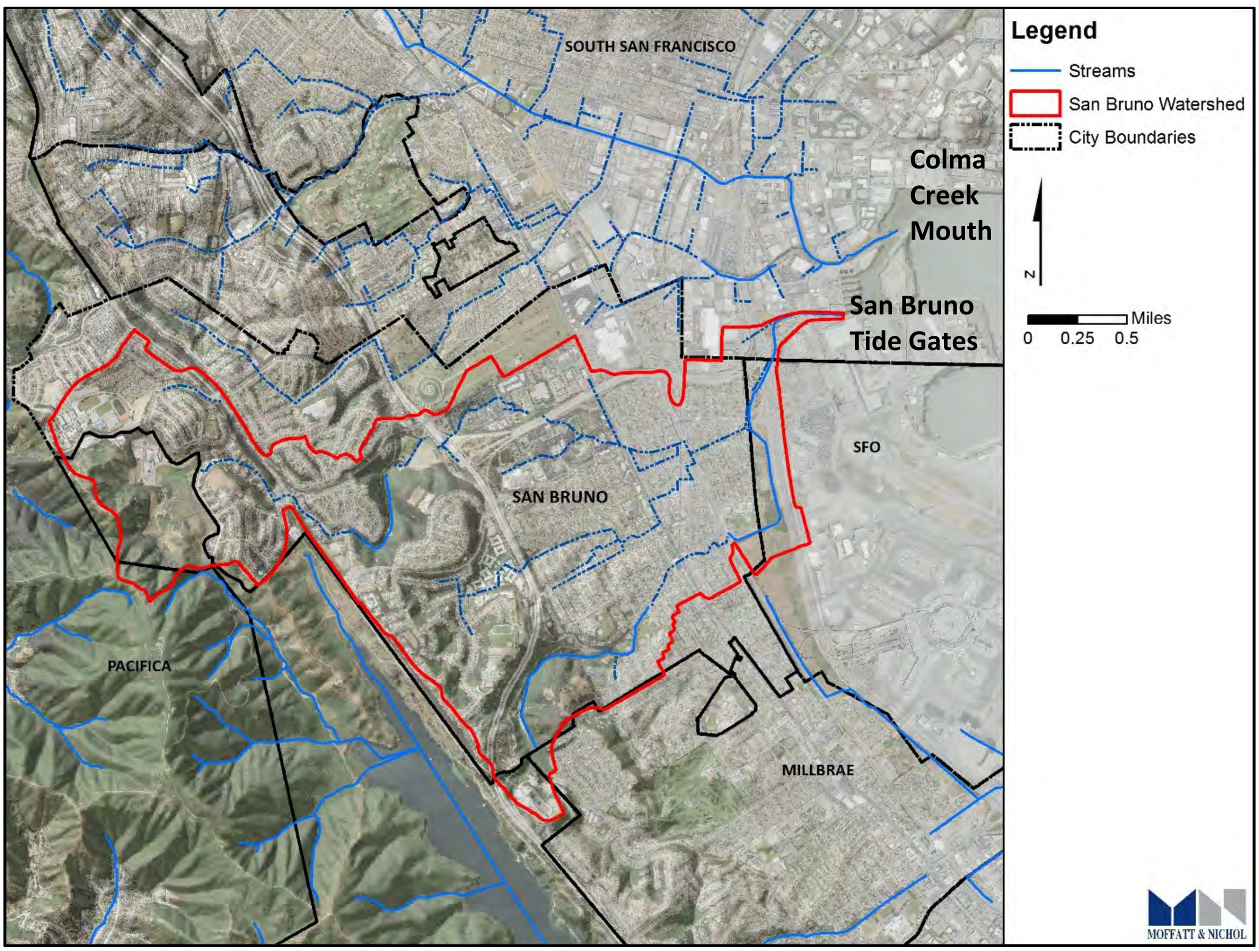

Figure 2-8. San Bruno Creek Watershed Vicinity Map

2.3.2 Existing Flood Control Infrastructure

The SMCFCD oversees the San Bruno Creek Flood Control Zone, which was established in 1967 to construct flood control and drainage improvements in the lower reach of San Bruno Creek. The SMCFCD maintains two pump-stations and the open channel sections of San Bruno Creek in the lower portion of the watershed. One open channel section is the Cupid Row Canal, which spans between the storm drain outlet at the Caltrain tracks and the box culverts at San Bruno Avenue. The North Channel is the other open channel section, which spans from San Bruno Avenue to the Hwy-101 culverts and then from Hwy-101 to the tide gates at the terminus of San Bruno Creek. The lower San Bruno Creek system is illustrated in Figure 2-9.

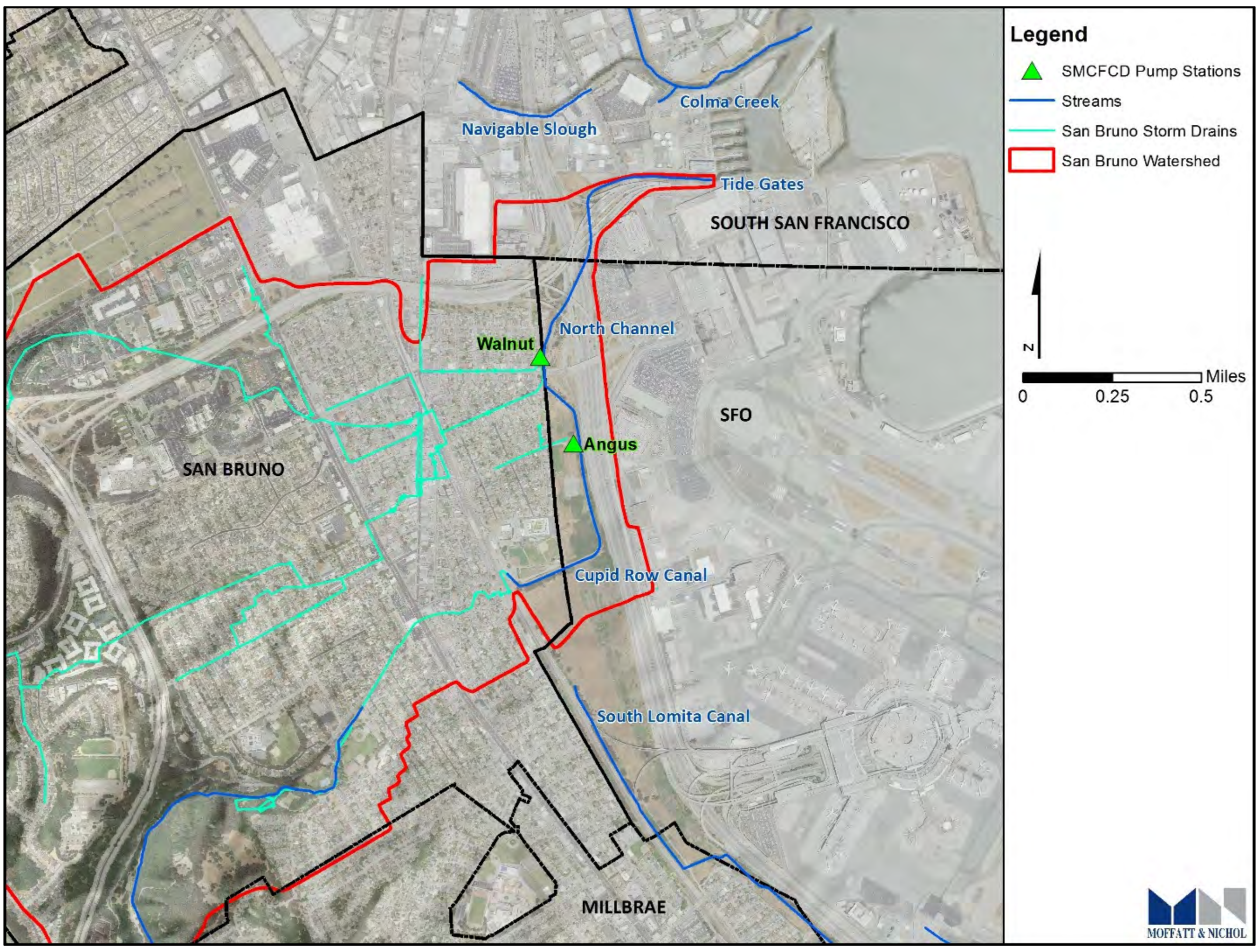

Figure 2-9. Storm Drains and Pump Stations within San Bruno Creek Watershed

The tide gate structure where the North Channel exits to the San Francisco Bay consists of four, 5-feet diameter circular pipes with flap gates on the downstream side (see Figure 2-10). Drawings suggest that the channel and tide gate structure were designed for the 25-year return period flow of 1,100 cfs with the tidal elevation at 6.8 ft NAVD88, which is Mean Higher High Water at the site (MHHW) (SMCFCD, 1965).

Figure 2-10. San Bruno Channel. (a) Tide gate Structure, Downstream Side (b) Flap Gate

A recent channel improvement project performed as a collaboration between the Flood Control District and SFO was the Recovery Action Plan for the San Francisco Garter Snake (LSA, 2008). The plan entailed the removal of excessive vegetation and sediment deposition in Cupid Row Canal, which was impacting habitat for the California Red Legged Frog and the San Francisco Garter Snake. The Cupid Row Canal is located primarily on SFO property immediately west of Hwy-101.

The two pump stations that the Flood Control District maintains in the lower San Bruno Creek watershed are the Walnut Pump Station and the Angus Pump Station. The location of the two stations is illustrated in Figure 2-9. A Preliminary Design Report was prepared in 2012 for the Flood Control District to evaluate the alternatives for rehabilitation of the existing stormwater pumping stations versus construction of new pumping stations (Brown & Caldwell, 2012).

The Walnut Pump Station was constructed in 1967 and modified in 1997 and consists of four vertical propeller pumps, each with an independent discharge and each discharge pipe was provided with a flap gate (Brown & Caldwell, 2012). The pumps discharge into the North Channel immediately downstream (north) of San Bruno Avenue. The pump station receives storm runoff from an area of approximately 60 acres and the design 25-year peak flow for this area was 45 cfs. Based on the study, the pump station was recommended for rehabilitation, and wet well and pump modifications were not recommended (Brown & Caldwell, 2012).

The Angus Pump Station was constructed in 1967 and has two identical vertical propeller pumps, each with an independent discharge and each discharge pipe has a flap gate (Brown & Caldwell, 2012). The pumps discharge into Cupid Row Canal, adjacent to Angus Avenue. The pump station receives storm runoff from an area of approximately 45 acres and the design 25-year peak flow for this area was 34 cfs. Based on the study, the pump station was recommended for rehabilitation, and wet well and pump modifications were not recommended (Brown & Caldwell, 2012). The pump station characteristics are summarized in Table 2-2.

Table 2-2. Pump Stations within the lower San Bruno Creek Watershed (SMCFCD)

Pump Station	Number of pumps	Discharge Pipe Sizes (Dia.)	Watershed Area (acres)	25-yr Design Flowrate (cfs)	Output Receiving Channel
Walnut	4	2x - 16" 2x - 24"	60	45 cfs (20,200 gpm)	North Channel
Angus	2	2x - 36"	45	34 cfs (15,300 gpm)	Cupid Row Canal (Crystal Spring Channel)

The City of San Bruno recently completed a city-wide Storm Drain Master Plan (SDMP) study of the hydrology and hydraulics of the existing storm drain system (GHD, 2014). The design capacity of the City's storm drain system was the 25-year design storm event and the hydraulic analysis was done using Bentley's SewerGEMS software. The storm drain system is illustrated in Figure 2-9.

The SDMP determined that there are multiple capacity deficiencies in the system and identified six Priority 1 improvements and seven Priority 2 improvements that are recommended for the storm drain system (GHD, 2014). The SDMP also recommended the rehabilitation of the San Bruno Creek tide gate to restore full functionality at the discharge point of San Bruno Creek into the San Francisco Bay.

2.3.3 Critical Infrastructure Elements

There are multiple critical infrastructure elements that are located within the lower San Bruno Creek watershed. These include:

- BART tracks
- Caltrain tracks and station
- PG&E electrical substations
- Caltrans Highways

The BART and Caltrain lines both pass through the lower watershed, and the San Bruno Caltrain station is located near the upstream point of the Cupid Row Canal. The BART line runs in a tunnel below ground for roughly 5.5-miles from immediately south of the Colma station to roughly 500 feet south of 1st Avenue and Cupid Row Canal in San Bruno. The Caltrain line is on above-ground track through the entire reach from South San Francisco to Millbrae.

There are also two electrical substations located in the lower watershed, between the Caltrain line and Hwy-101. One is operated by BART and is located on Shaw Road at the north-west corner of the Interstate-380 and Hwy-101 interchange. Ground elevations at the substation based on the SFO LiDAR dataset are approximately +14' NAVD88. The other substation located within the lower watershed is the San Francisco International Airport substation operated by PG&E. It is located adjacent to Cupid Row Canal in the parcel of land owned by SFO between Hwy-101 and the Belle Air neighborhood. Ground elevations at the substation based on the SFO LiDAR dataset are approximately +10.5' to +11.0' NAVD88.

Figure 2-11 illustrates this infrastructure in the San Bruno Creek watershed.

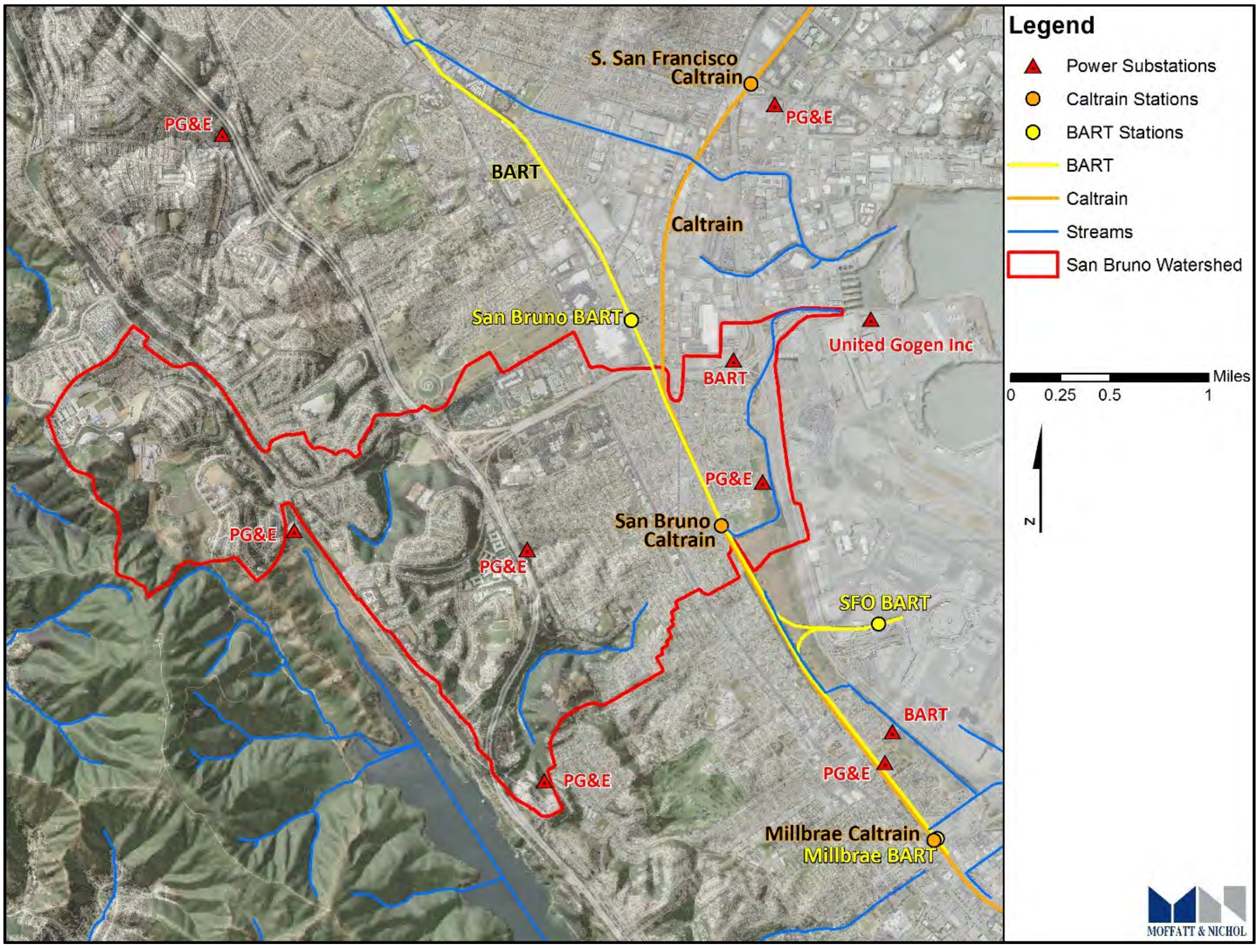

Figure 2-11. Infrastructure within the San Bruno Creek Watershed

There are also three major highways located in the lower San Bruno Creek watershed under the jurisdiction of Caltrans. U.S. Highway-101 and CA State Route-82 (also called El Camino Real) both run north-to-south through the watershed. Interstate-380 runs from Interstate-280 to the interchange with Hwy-101 in the east, adjacent to SFO. A number of drainage design reports and as-built plan-sets were provided by Caltrans for reference in this study. A list of the most pertinent Caltrans references provided are:

1) Drainage Report for Route 101 from 0.2 km north of Millbrae Avenue over crossing to 0.3 km north of Route 380 separation, on Route 380 from San Francisco International Airport to San Bruno Avenue overcrossing and at the San Francisco International Airport (PB/MC, 1996)
2) Drainage Plans and Plan Set for Route 380 from Cherry Ave to 0.2 mile east of Route 101 and on Route 101 from 0.7 mile south of San Bruno Ave to South San Francisco Belt Railroad overhead (Caltrans, 1971, 1973 & 1976)
3) As Built Construction Plans of San Bruno Channel Dredging at Intersection of Hwy-101 and I-380, (Caltrans, 2000)
4) Drainage Analysis for Route 186 (I-380) from Cherry Ave to 0.1 mi east of Route 82 and for Route 82 from San Bruno Ave to 0.1 mi north of Sneath Lane (Caltrans, 1972)

The locations of the Caltrans infrastructure referenced in these studies is illustrated by number in Figure 2-12. These report are summarized in more detail in Appendix C.

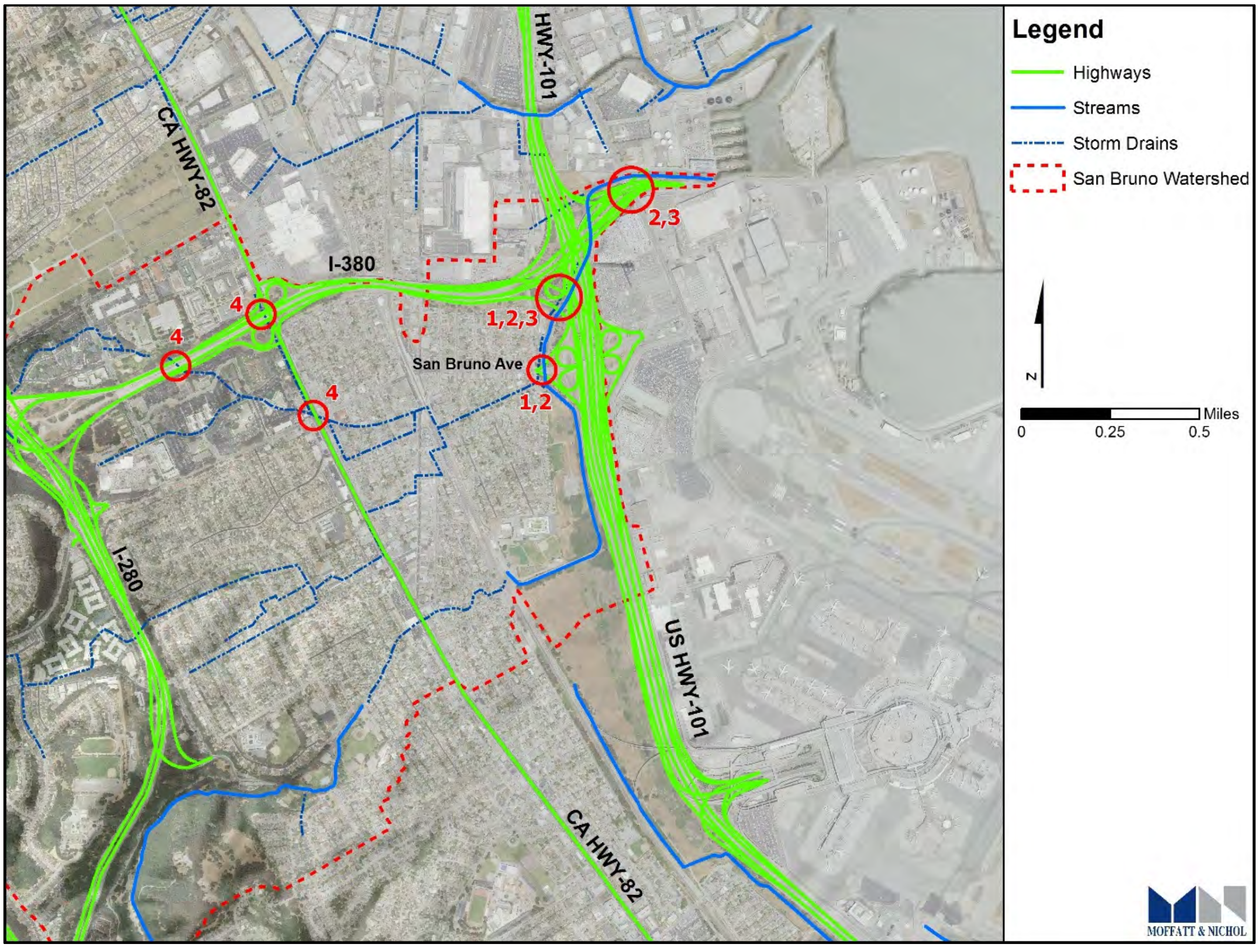

Figure 2-12. Highways within the San Bruno Creek Watershed

2.4 Water Levels

Water levels at the project site are dominated by a mixed semi-diurnal tide, where two unequal highs and lows occur each tidal day. A tidal day is the time of the rotation of the Earth with respect to the Moon, approximately 24 hours and 50 minutes. The SFO shoreline is approximately equidistant to the two closest active National Oceanic and Atmospheric Administration (NOAA) tidal gages (Alameda and Redwood City); however, both are over 10 miles away and not representative of the tides at the project site due to amplification as the tide propagates southward into the South Bay. NOAA has established tidal harmonic constituents at several closer locations based on short-term deployments that bound the tidal datums at the project site. The constituents and derived datum referenced to MLLW were available at Oyster Point, 3 miles north of the project site, and the San Mateo Bridge, approximately 7 miles east-southeast from SFO.

These gage sites do not have established conversions from tidal to geodetic (North American Vertical Datum of 1988, NAVD88) datum. Computed adjustments were available from several other sources. The conversion at the Oyster Point Marina gage was available from previous Moffatt & Nichol work at the marina, where a GPS occupation of the tidal station benchmark found

NAVD88 to be 0.45 ft above MLLW (Tucker & Associates, 2011). At the San Mateo Bridge gage, NAVD88 was found to be 0.80 ft above MLLW, surveyed as part of a recent USGS bathymetric survey of the South Bay (Foxgrover et al., 2007). Due to the location of these gages in relation to SFO, the tidal range and NAVD88 datum conversion at SFO is expected to be between those of the two gages.

The U.S. Army Corps of Engineers conducted an extreme water level analysis for locations throughout the bay due to the higher than expected water levels during the 1983 El Niño South Oscillation (ENSO) (United States Army Corps of Engineers (USACE), 1984). The results from this study for the two tidal gages are included with the gage datums in Table 2-3 below. While the 1% annual chance Still Water Level (SWL) at the airport will be calculated as part of the Coastal Engineering Assessment task of the shoreline protection study, the USACE 1984 study gives reasonable extreme water level values near the project site that should be close to the re-computed value.

Table 2-3. Tidal Datums and 1% Annual Chance SWL in Project Vicinity

Gage	9414392 Oyster Point		9414458 San Mateo Bridge	
datum planes	**MLLW (ft)**	**NAVD88 (ft)**	**MLLW (ft)**	**NAVD88 (ft)**
MHHW	+7.18	+6.73	+7.72	+6.92
MHW	+6.54	+6.09	+7.09	+6.29
DTL	+3.59	+3.14	+3.86	+3.06
MTL	+3.84	+3.39	+4.14	+3.34
MSL	+3.77	+3.32	+4.11	+3.31
MLW	+1.14	+0.69	+1.19	+0.39
MLLW	+0.00	-0.45	+0.00	-0.80
NAVD	+0.45	0.00	+0.80	0.00
1% Annual Chance SWL	+10.10	+9.65	+10.70	+9.90
NAVD88 datum source	Oyster Pt. Survey		USGS 2005 Survey	

2.5 Precipitation

Mean annual precipitation values within the two watersheds ranges from approximately 21-inches at SFO up to 30-inches on San Bruno Mountain in the northern part of the Colma Creek watershed and 32-inches on Sweeney Ridge, which separates the San Bruno Creek watershed from the western slope and Pacifica (PRISM, 2014).

Two precipitation gages operated by the California Department of Water Resources (DWR) are located in the vicinity of the two watersheds, one at San Francisco International Airport (Gage ID: SFF) and one at North San Andreas (Gage ID: NSN) on the coastal ridgeline. Hourly incremental precipitation data is available for these gages from the DWR's California Data Exchange Center (CDEC).

Recurrence interval precipitation volumes for various durations are available from NOAA's Precipitation Frequency Data Server (PFDS), which is a point-and-click interface developed to deliver NOAA Atlas 14 precipitation frequency estimates. Table 2-4 presents the precipitation frequency estimates from the PFDS for the location at the centroid of the two watersheds, for reference. For this location at the center of the watersheds, a 100-year 24-hour storm total is approximately 6 inches. The mean annual precipitation isohyetals are illustrated in Figure 2-13, along with the location of the CDEC precipitation gages and the centroid of the two watersheds.

Table 2-4. NOAA Atlas 14 Precipitation Frequency Estimates at Centroid of Watersheds

NOAA point precipitation frequency estimates (inches)									
Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500
5-min	0.14	0.17	0.21	0.24	0.28	0.32	0.36	0.40	0.45
10-min	0.20	0.24	0.30	0.34	0.41	0.46	0.51	0.57	0.65
15-min	0.25	0.29	0.36	0.42	0.49	0.55	0.62	0.69	0.78
30-min	0.34	0.40	0.49	0.57	0.67	0.76	0.85	0.94	1.07
60-min	0.48	0.57	0.70	0.80	0.95	1.07	1.19	1.32	1.51
2-hr	0.70	0.83	1.00	1.15	1.36	1.52	1.69	1.87	2.12
3-hr	0.87	1.03	1.25	1.43	1.68	1.89	2.10	2.32	2.62
6-hr	1.21	1.46	1.78	2.05	2.42	2.72	3.02	3.34	3.79
12-hr	1.53	1.90	2.39	2.80	3.36	3.80	4.26	4.73	5.39
24-hr	1.97	2.52	3.25	3.85	4.67	5.31	5.97	6.65	7.59

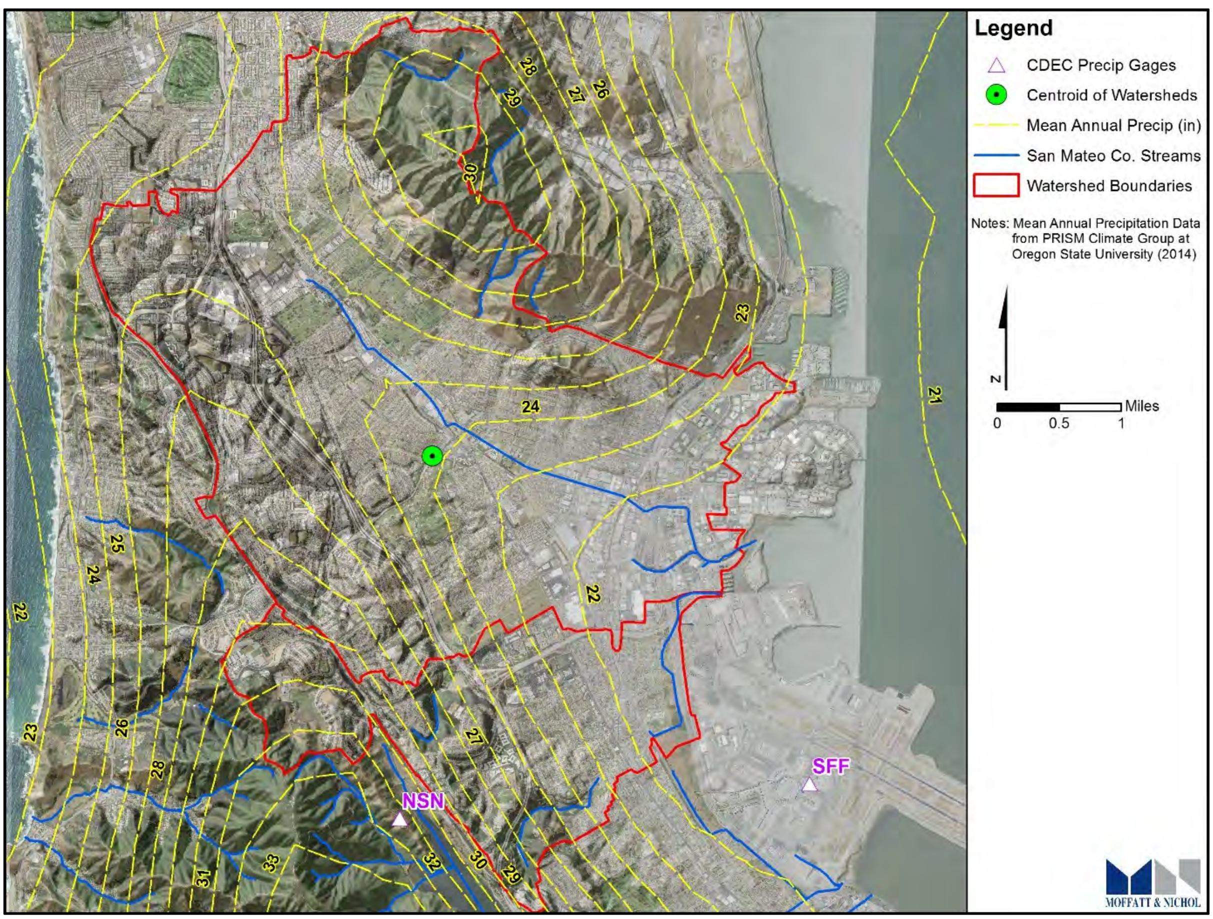

Figure 2-13. Mean Annual Precipitation in Creek Watersheds.

2.6 Stream Gages

The Colma Creek watershed contains one stream gage, located at Orange Memorial Park. Stream gage data was collected at this site by United States Geological Survey (USGS) from 1964 until 1996 (33-years) and by the City of South San Francisco from 2010 to 2011. According to the USGS, the drainage area of Colma Creek at the gage is 10.8 square miles. The location of the Orange Park stream gage is illustrated above in Figure 2-6. Flood flow frequency estimates for the stream gage were based on the methodology outlined in USGS Hydrology Bulletin #17B (USGS, 1981). The flood frequency discharge values for the stream gage are presented in Table 2-5 and the flood frequency curve for the stream gage is presented in Figure 2-14. The flood frequency calculations are described in more detail in Appendix B.

There are no stream gages located within the San Bruno Creek watershed.

Table 2-5. Colma Creek Gage Flood Frequency Discharges (from Appendix B)

Annual Exceedance Probability (%)	Return Period (years)	Creek Gage Discharge (cfs)
50	2	1,589
20	5	2,367
10	10	2,877
2	50	3,967
1	100	4,416
0.2	500	5,433

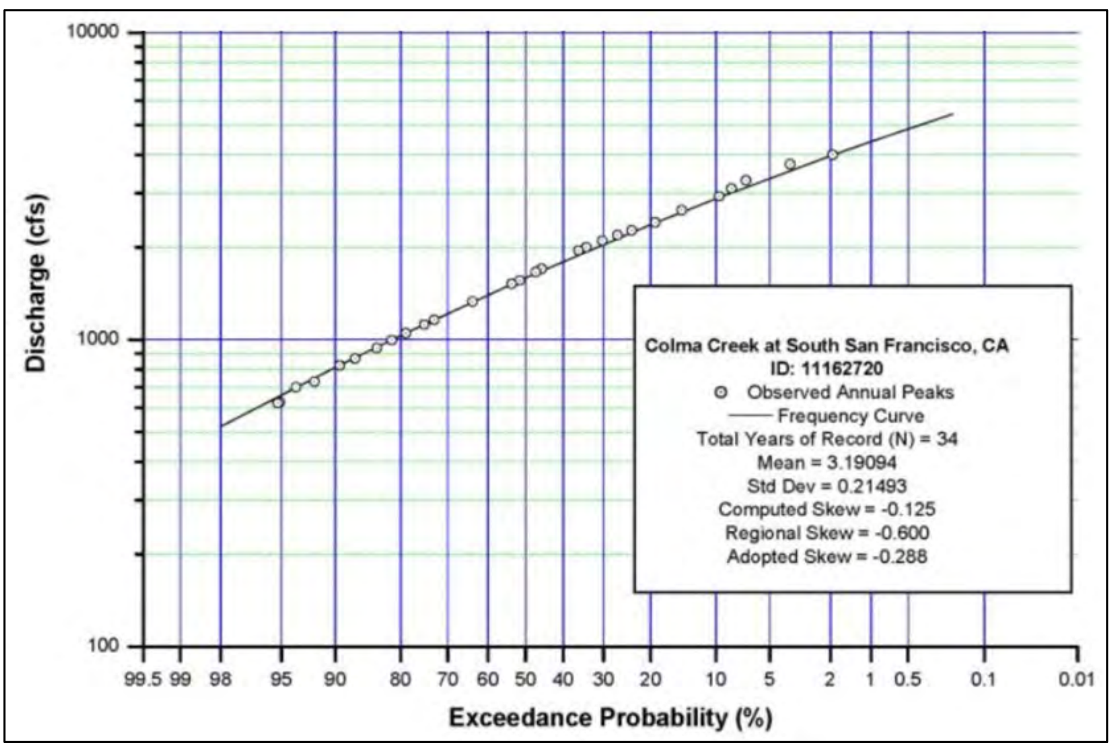

Figure 2-14. Colma Creek Stream Gage Flood Frequency Plot (from Appendix B)

2.7 Survey Data

The collection of additional survey data was necessary to facilitate the development of the hydraulic model for the open channel portion of lower San Bruno Creek. Therefore, survey transect data was collected by Meridian Surveying along the open channel sections of Cupid Row Canal and North Channel, with the cross-sections spaced at roughly equal increments along the channel. The in-channel data was used to augment the high resolution LiDAR data sets that were available from SFO and the County of San Mateo. The field survey was performed by Meridian on 11/14/2014 and 11/17/2014, and the extent of the survey points are illustrated in Figure 2-15. The survey data is also presented in Appendix A.

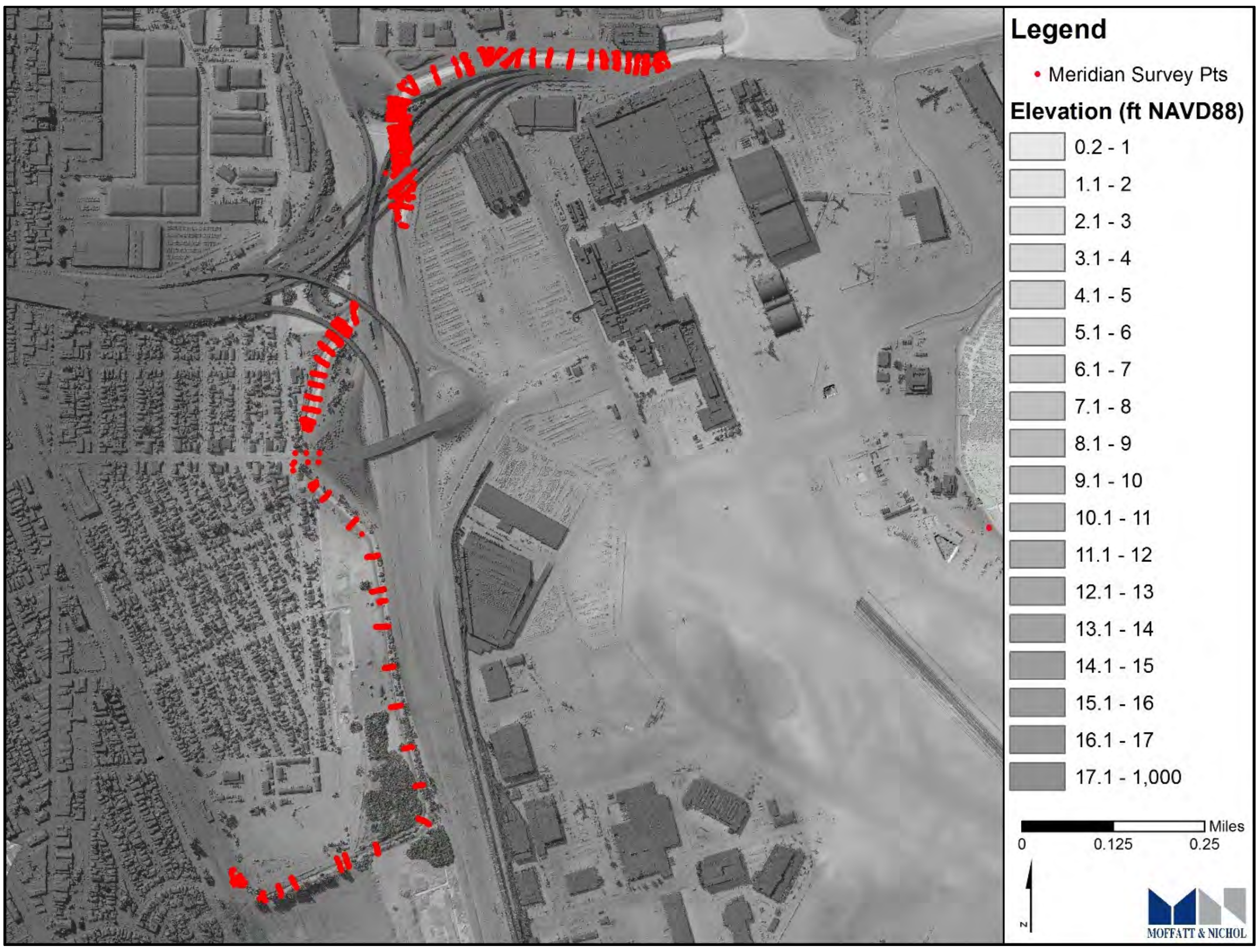

Figure 2-15. Survey Data Collected on San Bruno Creek, November 2014.

2.8 FEMA Analyses and Results

2.8.1 Previous Studies

FEMA performed a county-wide Flood Insurance Studies (FIS) for San Mateo County in 2012, which included the cities of San Bruno and South San Francisco. The original FIS for South San Francisco was performed in 1980 and covered all significant flooding sources affecting the City. The historical FIRMs for the City are dated September 1981 (FEMA, 2012).

The flood control channel of Colma Creek appears to not have been studied in detail by FEMA since its designation as Flood Hazard Zone A. However, overbank areas in SSF have been designated as Flood Hazard Zone AE with flood elevations shown on the FIRMs, which would have been derived from detailed analyses. Figure 2-16 illustrates the existing, effective FEMA FIRM data for San Mateo County.

There is an area north of the Colma Creek channel mapped as Flood Hazard Zone AE with flood elevations of +18’ and +19’ at the intersection of Spruce Avenue and N. Canal Street near downtown SSF. N. Canal Street appears to be acting as an overland flow path, with a contiguous Flood Hazard Zone AE that spans from Orange Avenue in the west to Linden Avenue and the Caltrain tracks in the east. In that same reach of Colma Creek, there is a larger area to the south of the channel that is also mapped as Flood Hazard Zone AE with a flood elevation of +12’. In this location, flood flows that overtop the Colma Creek south bank between S. Maple Avenue and S. Linden Avenue pool up against the raised embankment of the Caltrain line and flow south along S. Linden Avenue.

The mostly commercial area in South San Francisco is centered at Utah Avenue and is bounded by South Airport Boulevard to the west, the Colma Creek channel to the north and east, and Navigable Slough to the south. This area has been mapped by FEMA as Flood Hazard Zone AO for areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow. The flood hazard zone is also indicative of flood depths which are derived from detailed analysis. For Navigable Slough, the FEMA FIRMs indicate that the 100-year discharge is contained within the channel.

There were no previous FIS or FIRMs for the City of San Bruno prior to the recent county-wide FIS, and the City had historically been mapped as Flood Zone D, which represent areas with possible but undetermined flood hazards. The two open channel sections of lower San Bruno Creek, Cupid Row Canal, and North Channel were part of Unincorporated San Mateo County on the historical FIRMS. The channels are designated by Flood Hazard Zone A and were not studied in detail by FEMA.

Figure 2-17 below shows the extents of the flood hazard areas that were previously assigned to SFO and vicinity in the 1984 San Mateo Unincorporated County FIRMs. This map has been superseded by the current effective San Mateo County FIRM, which has removed SFO due to its planned inclusion in the forthcoming City and County of San Francisco (CCSF) FIRM.

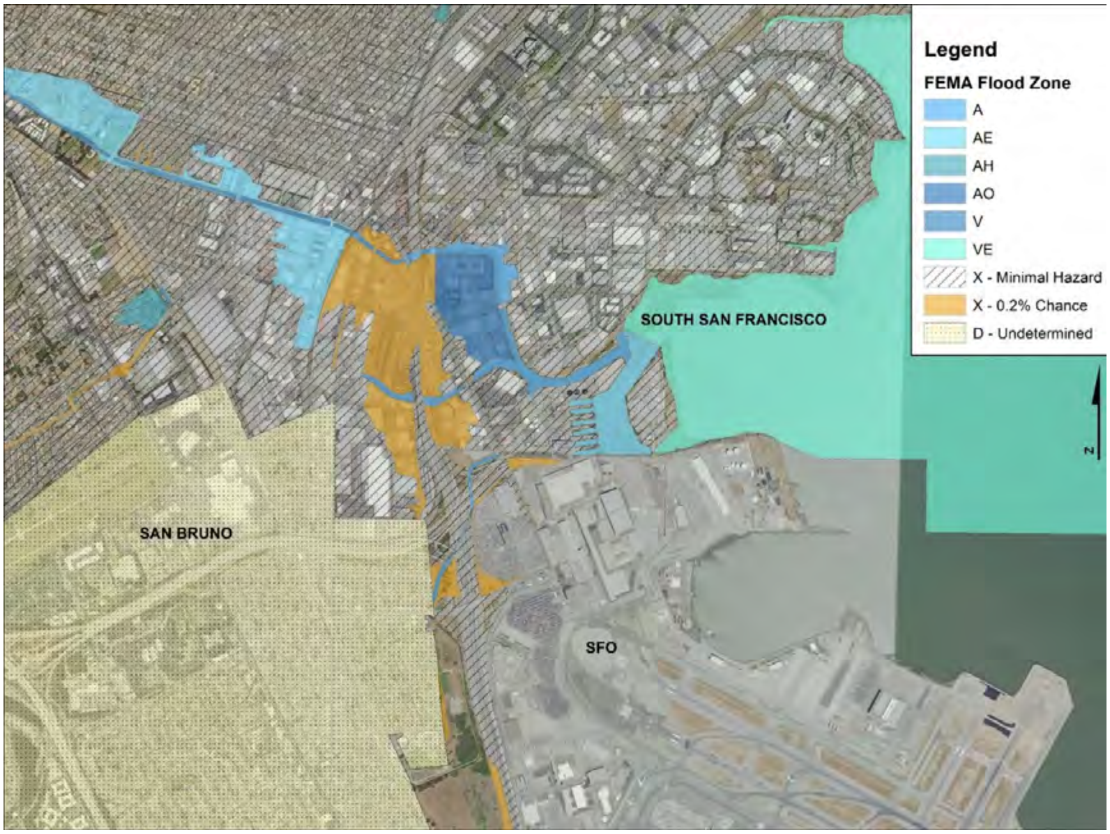

Figure 2-16. Existing FEMA Flood Zones in the Lower Watersheds (FEMA, 2012)

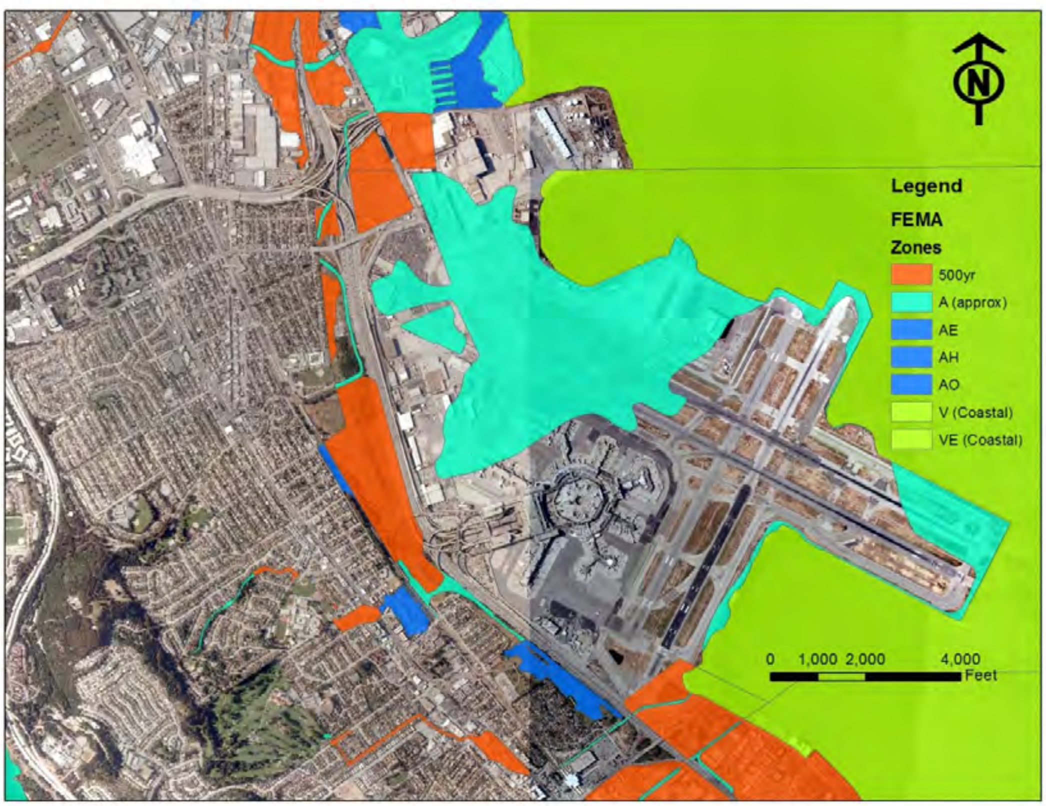

Figure 2-17. Flood Hazard Areas in SFO Vicinity from San Mateo County 1984 FIRM

2.8.2 Recent FEMA Flood Analysis and Results

Until recently, SFO has been included in flood maps prepared by FEMA for San Mateo County, an existing participant in the NFIP. These maps classify portions of SFO as subject to flooding by the one-percent-annual-chance flood. However, SFO was not required to comply with flood management provisions resulting from the mapping since it is administratively part of the CCSF, which did not participate in the NFIP. With the CCSF's entry into the NFIP in 2010, SFO was removed from the effective San Mateo County FIRM and will be included in the upcoming CCSF FIRM. The CCSF maps will be based on a comprehensive study of flood hazards with particular emphasis on coastal flooding hazards at the bay shoreline.

While an effective FIRM for CCSF has not yet been issued, preliminary results of FEMA flood mapping for SFO based on the new study locate the entire airport property in the floodplain, with 1 percent annual chance flood elevations ranging from +10 to +14 ft NAVD along the airport shoreline. Additionally, the interior areas of airport are assigned a Base Flood Elevation (BFE) of +10 ft NAVD88. These BFE results (see Figure 2-18) were computed during the CCSF Coastal Flood Hazard Study using transect-based wave runup calculations (BakerAECOM, 2013). Input wave and water level data for the transect model was obtained from a Bay-wide modeling effort that directly simulated the water level variation and wind-wave generation for a 31-year period (Danish Hydraulic Institute (DHI), 2011). Accompanying documentation indicates that a BFE of +10.4 ft NAVD88 was adopted for analysis purposes in the development of the draft work maps. FEMA FIRMs round the BFE to the nearest whole foot.

The recent FEMA Coastal Flood Hazard Studies for the San Francisco Bay also included the County of San Mateo. The draft flood maps included revised Flood Hazard Zones for the lower Colma Creek watershed, where the proposed BFE propagates up the creek and is able to overtop the flood control channel's banks. These revisions to the Colma Creek system include additional Flood Hazard Zone AE areas on the south side of the channel. The large area south of the channel and between the Caltrain tracks on the west and South Airport Boulevard on the east is now proposed to be mapped as Zone AE +10', while the existing maps have this area mapped as Zone X, 0.2% Annual Chance Flood Hazard (500-year recurrence). The regions south of Navigable Slough at Shaw Road and at South Airport Boulevard are also now proposed to be mapped as Zone AE +10', while the existing FIRMs have this area mapped as Zone X, 0.2% Annual Chance Flood Hazard. Again, these changes stem from the proposed BFE propagating up Navigable Slough and overtopping the channel's south banks. The draft FEMA FIRM data for the Colma Creek region is illustrated in Figure 2-18.

The FEMA Coastal Flood Hazard Study for San Mateo County did not include a riverine component. Therefore, the riverine hydraulics of the Colma Creek flood control channel was not re-assessed. The proposed changes to the Colma Creek system FIRMs extend to the Caltrain tracks. The flood hazard zones upstream of the Caltrain tracks (west of the tracks) were carried over from the San Mateo Countywide FIS from 2012.

The Coastal Flood Hazard Study also did not assess riverine flooding within the San Bruno Creek watershed. However, a significant portion of the lower San Bruno Creek watershed, east of the Caltrain tracks, is now shown as Flood Hazard Zone AE with a flood elevation of +10' NAVD on the draft FIRMs. This region of the City of San Bruno, between the Caltrain tracks and Hwy-101 and south of Interstate-380, is known as the Belle Air neighborhood. Since no shoreline exists in the immediate vicinity of this interior flood area, which is substantially removed from the source of coastal flooding, it appears that the extent of flooding has been determined by projecting the BFE across any contiguous area(s) that are topographically below the BFE, irrespective of overland flow distance.

For the portion of the Belle Air neighborhood that is north of San Bruno Avenue and Pine Street, the source of flood waters appears to be from the south bank of Navigable Slough. Navigable Slough appears to have low spots below the BFE. The flood volume reaches Belle Air via the flow path along Shaw Road, underneath I-380, and then along 7th Avenue.

For the portion of the Belle Air neighborhood that is south of San Bruno Avenue and Pine Street, there are two sources of the flood waters that are mapped on the draft FIRMs. The first source floods within the SFO property due to existing deficiencies in the airport's perimeter defenses. This flooding would first have to fill the topographic basin where the airport is located up to an elevation of approximately +9.4' NAVD88, after which the flood waters could begin to overtop and cross Highway-101. The second source of flood waters to the Belle Air neighborhood south of San Bruno Avenue and Pine Street comes from the coastline south of SFO at Millbrae Avenue, which then flows north for approximately 12,000-ft along an overland flow-path adjacent to Hwy-101. The draft FEMA FIRM data for the San Bruno Creek region is illustrated in Figure 2-18.

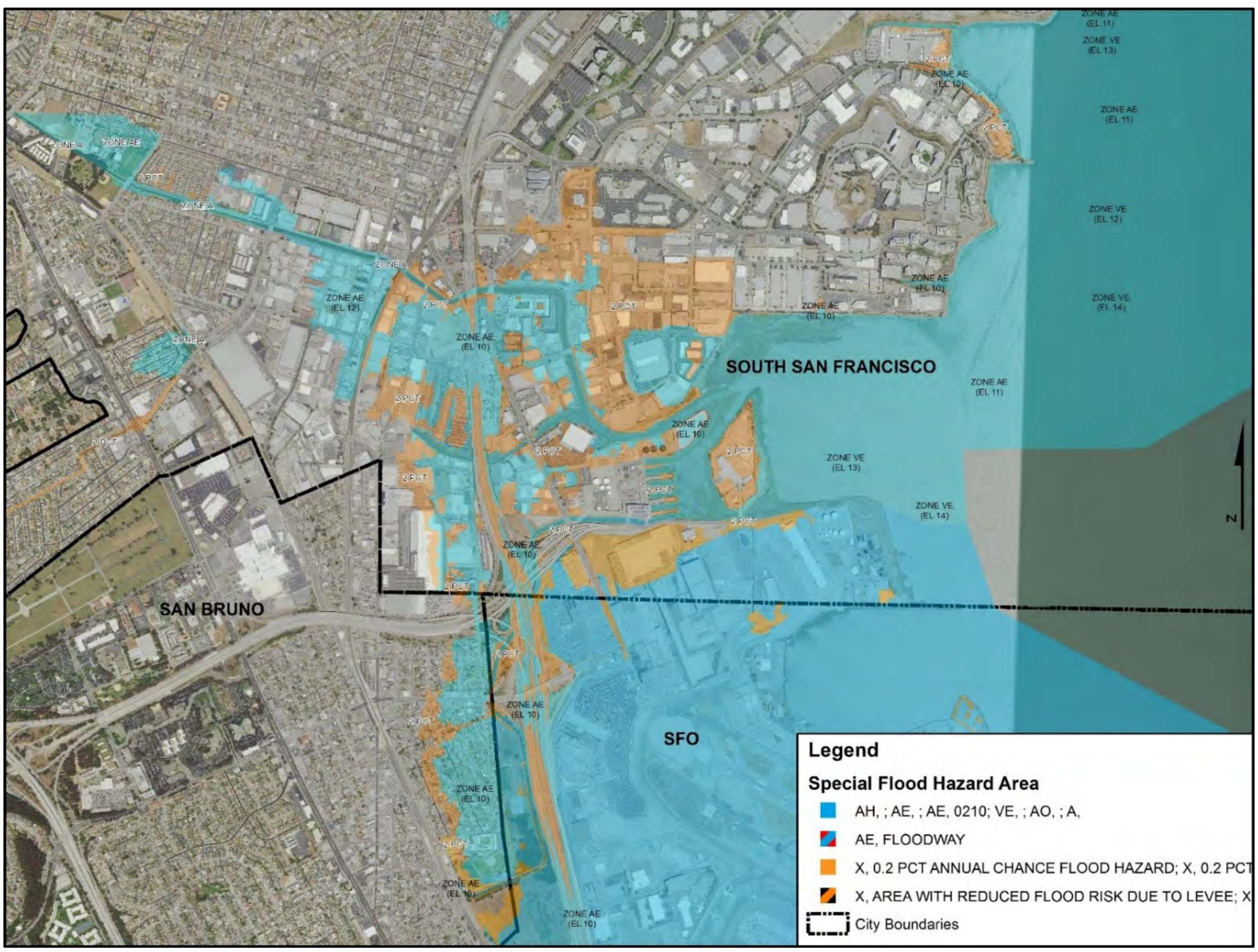

Figure 2-18. Draft FEMA Flood Zones in the Lower Watersheds from CCSF and SMC Coastal Flood Hazard Studies (FEMA Draft, 2015)

3.0 SEA LEVEL RISE

The issue of sea level rise (SLR) and how to mitigate for an increase in water level has been a subject of much discussion in recent years. It has only been within the past 25 years that climate change has been studied to determine associated risks to be considered for development and investment planning.

3.1.1 Global and Regional Sea Level Rise Projections

Numerous peer-reviewed publications about climate change and sea level rise have been published in recent years, and sea level rise projections vary from study to study. A wide variation in projections of global and regional SLR is caused by significant uncertainties in future emissions of greenhouse gases, the effects upon global temperatures, and the effects in turn upon ice sheets and other drivers of the sea level.

For practical purposes, it is important to use relative sea level rise (RSLR) at a specific location. Relative sea level rise takes into account any vertical motion of land: the motion may be upward, decreasing the effects of sea level rise on the adjacent land (e.g., northwest Washington State), or downward, exacerbating the effects (e.g., Louisiana near the mouth of the Mississippi). For San Francisco, the rate of relative sea level rise has historically been similar to the global rate.

This document focuses on three governmental reports that describe future scenarios.

- The Climate Program Office (CPO) of the National Oceanic and Atmospheric Administration (NOAA) has developed four global scenarios based on a high level of confidence that global sea-level will rise between 0.7 ft and 6.6 ft between 1992 and 2100 (NOAA 2012).
- The National Research Council (NRC) was requested by the States of California, Oregon, and Washington, as well as by NOAA, USGS, and USACE to develop relative sea level rise scenarios on a regional basis for the west coast of the contiguous United States (NRC 2012). San Francisco is one of the locations for which a specific projection is provided.
- The Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) used this information to provide guidance for planning and decision making for projects in California (CO-CAT 2013). This document uses the set of projections provided by NRC.

The global NOAA projections and regional NRC projections are based on a different starting point: 1992 for NOAA and 2000 for NRC. However, NOAA 2012 provides equations for converting the projections to different years between 1992 and 2100. The resulting projections are provided in Table 3-1.

Table 3-1. Global and Relative Sea Level Rise Projections. NOAA 2012 and NRC 2012.

	Global Sea Level Rise in feet NOAA 2012				Relative Sea Level Rise in feet NRC 2012		
Year	Highest	Intermed. High	Intermed. Low	Lowest	High	Projected	Low
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	0.9	0.6	0.3	0.2	1.0	0.5	0.1
2050	2.0	1.2	0.6	0.3	2.0	0.9	0.4
2100	6.5	3.9	1.6	0.6	5.5	3.0	1.4

The *Lowest* scenario for global sea level rise corresponds to a linear extrapolation of historical measurements, with no acceleration, while the *Intermediate High* and *Intermediate Low* values are similar to the *Projected* and *Low* values for relative sea level rise. Figure 3-1 shows the data above in graphical form.

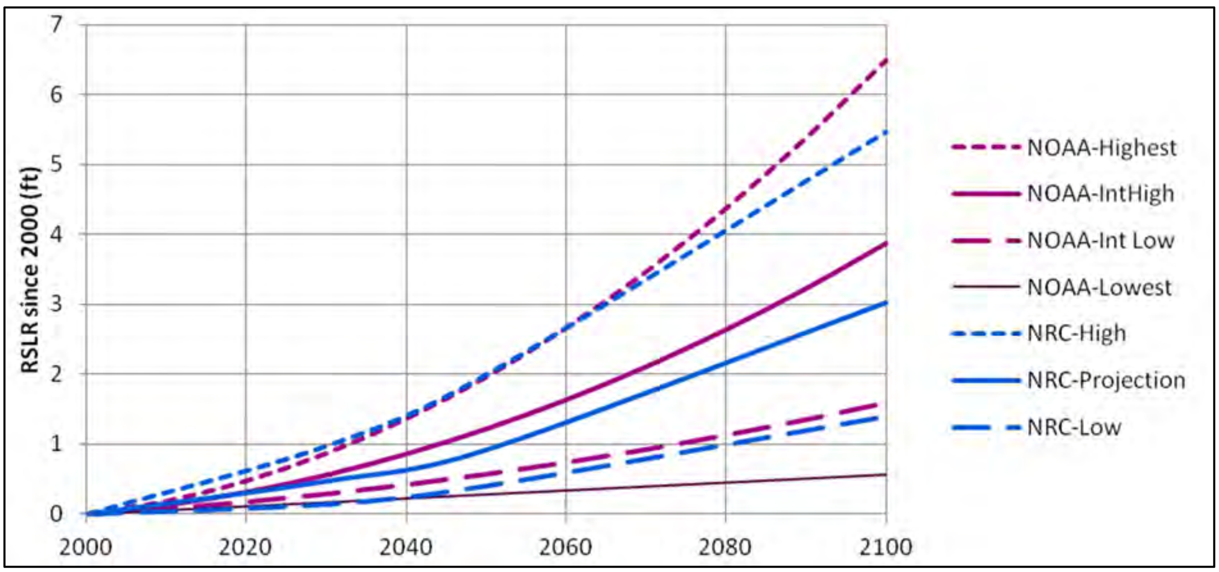

Figure 3-1. Global and Relative Sea Level Rise Projections. NOAA 2012 and NRC 2012.

3.1.2 Sea Level Rise at San Bruno and Colma Creeks.

In order to plan for future SLR, it is generally not useful to focus on specific dates and the SLR expected on those dates. A better approach is to consider specific increases and to understand the needs for additional flood protection based on those increased levels. This report considers 1-ft, 2-ft, and 3-ft of RSLR. Table 3-2 shows the range of dates at which these increases are projected to occur, based on the projections in Table 3-1. The *Lowest* projection, which corresponds to a continuation of the historical rate of SLR, is excluded from this analysis.

Table 3-2. Range of Dates at which Specific RSLR Values are Projected

RSLR Value	Earliest Date	Latest Date
1-ft	2030	2080
2-ft	2050	2125
3-ft	2065	2155

4.0 HYDROLOGIC AND HYDRAULIC MODELING

The purpose of the numerical modeling of this study was to perform a hydrologic and hydraulic study of the lower Colma and San Bruno Creeks and to assess flood risk from elevated water levels in the Bay now and in the future with Sea Level Rise. Tasks necessary to complete the assessment included: (1) a hydrologic analysis using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) to develop recurrence interval design flowrates for the two creek systems; (2) the development of 1-dimensional hydraulic models for each creek in the USACE's Hydrologic Engineering Centers River Analysis System *(*HEC-RAS*)* to determine water surface profiles for each creek under a range of environmental conditions; (3) a statistical analysis to develop a coincident frequency determination for each creek to relate the combined occurrences of flood events and tidal elevations in the San Francisco Bay; and (4) a hydraulic and statistical analysis of increased tidal elevations to assess the impacts of sea-level rise of water surface profiles in the two creeks.

4.1 Hydrologic Modeling of Creeks

This section presents the methodology and results of the hydrologic analysis for the development of design flowrates for the Colma Creek and San Bruno Creek watersheds using the HEC-HMS model. HEC-HMS is a software program created by the USACE to simulate the process of precipitation and runoff in watersheds. The program creates hydrographs for basin runoff and stream routing. The general methodology for estimating flood-frequency discharges for each of the surface creeks was based on a modified version methodology outlined in the *Santa Clara County Drainage Manual* (SCCDM, 2007).

Precipitation patterns were based on the SCCDM 2007 and local Mean Annual Precipitation (MAP) values located at the centroid of each sub-basin. The pattern was based upon the maximum 24 hours of rainfall during the three-day December 1955 storm event, still considered to be the storm of record for northern California. The hourly distribution of rainfall from 1955 has been adjusted and balanced to preserve local rainfall intensity-duration-frequency statistics. Thus the 24-hour rainfall distribution may be used even where shorter duration storms are more critical, such as the smaller urbanized basins of Colma Creek and San Bruno Creek. A detailed description of the precipitation analyses can be found in Appendix B.

A unit hydrograph is a numerical representation of the time response of catchment runoff caused by one inch of excess rainfall applied uniformly over a unit of time. The SCS-dimensionless unit hydrograph from the Natural Resources Conservation Service's (NRCS) TR-55 Manual, Urban Hydrology for Small Watersheds (USDA, 1986) was used in this study. The curve number (CN) method from the TR-55 Manual was then applied to estimate storm water runoff potential for the subbasins (USDA, 1986). Curve numbers were estimated for each basin based on hydrologic soil group, land use/cover, percent imperviousness, and antecedent moisture condition (AMC), with AMC defined as the moisture content of a soil prior to any precipitation event. Land uses and the corresponding percent impervious areas were determined based on aerial photographs and City and County zoning maps. Hydrologic soil group was derived from the NRCS soils survey data for San Mateo County (USDA, 1991). A detailed description of the curve-number analysis can be found in Appendix B.

4.1.1 Colma Creek

Individual basin data and Colma Creek geometry information were entered into HEC-HMS to calculate discharges based on watershed parameters, design storms, and stream routing. Detailed HEC-HMS input and output data can be found in Appendix B. The hydraulic study of Colma Creek used the same watershed as illustrated in Figure 2-3. The Colma Creek model included the inflow from the Navigable Slough watershed, which is a small tributary that merges with Colma Creek adjacent to the Costco store, roughly 1000-ft downstream from Utah Ave.

As described in Section 2.6, the Colma Creek watershed contains one stream gage (shown in Figure 2-6), located at Orange Memorial Park. Stream gage data was collected at this site by United States Geological Survey (USGS) from 1964 until 1996 (33 years) and by the City of South San Francisco from 2010 to 2011. The availability of stream gage data within the watershed allowed for the Colma Creek HEC-HMS model to be calibrated to measured flows.

The flood frequency estimates for the stream gage, calculated based on the methodology in USGS Hydrology Bulletin #17B (USGS, 1981), were used to calibrate the Antecedent Moisture Condition (AMC) and to modify the curve numbers for each storm return period so that the HEC-HMS model replicated the flood-frequency characteristics at the stream gage. A comparison of the flood frequency estimates for the stream gage with the resultant discharge values from the HEC-HMS model are presented in Table 4-1.

Table 4-1. Colma Creek Calibration to USGS Flood Frequency Curve (from Appendix B)

Annual Exceedance Probability (%)	Return Period (years)	Creek Gage Q (cfs)	Q from HMS (cfs)	Calibration Difference (%)
50	2	1,589	1,607	1
20	5	2,367	2,483	5
10	10	2,877	2,896	1
2	50	3,967	-	
1	100	4,416	4,543	3
0.2	500	5,433	-	

Table 4-2 summarizes the estimated discharges for return periods of interest at various locations within the lower Colma Creek watershed. The discharge estimates reflect stream routing in Colma Creek but do not reflect flows leaving the channel due to upstream flow constrictions.

Table 4-2. Estimated Colma Creek Discharges (from Appendix B)

Location	2-year Discharge (cfs)	5-year Discharge (cfs)	10-year Discharge (cfs)	25-year Discharge (cfs)	50-year Discharge (cfs)	100-year Discharge (cfs)
Orange Avenue	1,607	2,483	2,896	3,550	4,050	4,543
Linden Ave	1,931	2,978	3,441	4,250	4,850	5,435
Highway 101	1,960	3,022	3,489	4,300	4,900	5,516
Utah Avenue	2,127	3,268	3,733	4,600	5,275	5,937
Navigable Slough	146	206	215	280	315	360
San Francisco Bay	**2,194**	**3,385**	**3,841**	**4,750**	**5,450**	**6,083**

The 25-year and 50-year design discharges shown in Table 4-2 were estimated for each location by plotting the 2, 5, 10, and 100-year flows on a log scale, as illustrated in Figure 4-1. These design discharges are comparable to the FEMA flows for Colma Creek, which have not changed since the 1980 Flood Insurance Study for South San Francisco. Additional detail on the development of the design discharges for Colma Creek can be found in Appendix B.

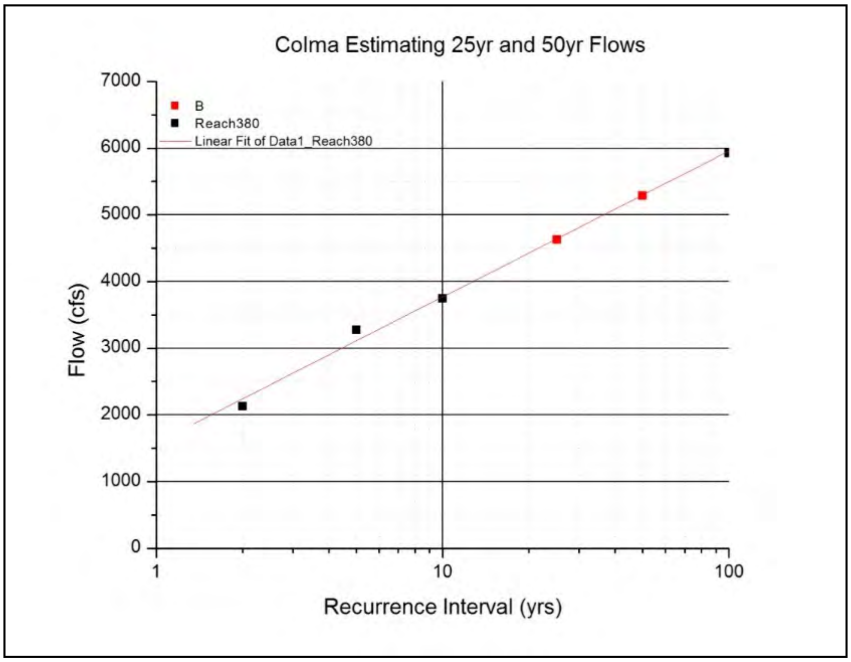

Figure 4-1. Colma Creek 25yr and 50yr Discharge Estimates (from Appendix B)

4.1.2 San Bruno Creek

The City of San Bruno completed in 2014 a city-wide Storm Drain Master Plan (SDMP) study of the hydrology and hydraulics of the existing storm drain system (GHD, 2014). The design capacity of the City's storm drain system was the 25-year design storm event. The hydraulic analysis was done using Bentley's SewerGEMS software.

The SDMP used the TR-55 method for the hydrologic analysis, the same as was applied in this study for Colma Creek. However, the SDMP applied a design rainfall event based on the SCS Type I 24-hour distribution, which is different than the one applied in this study, from the Santa Clara County Drainage Manual (SCCDM, 2007). The SDMP project included the collection of flow monitoring data from points within the storm drain system, which captured an approximately 2-year storm event during the monitoring period. The SDMP's hydrologic model was calibrated to this 2-year storm event, and these model parameters were then applied for the 25-year design storm, which may or may not be applicable.

This hydrologic study of San Bruno Creek used the same watersheds as the SDMP, as illustrated in Figure 4-2, but applied the SCCDM methodology used in the analysis of Colma Creek, in which the hydrologic model is calibrated to the design storm of interest. Since there were no available stream gage data available for San Bruno Creek, and due to the close proximity to the Colma Creek watershed, the same rainfall pattern and losses that were calibrated for the Colma Creek analysis were applied to the San Bruno watershed. As a result of this discrepancy in calibration method, the flows in this analysis do not match those predicted in the SDMP. However, the flows developed are consistent with those produced by the San Mateo County Flood Control District's *San Bruno Creek Flood Control Zone* report from 1965 (Wilsey, Ham & Blair, 1965).

Table 4-3 summarizes estimated discharges for return periods of interest at various locations. The hydrologic flows shown in Table 4-3 do not account for any capacity limited systems upstream and therefore assume that all flows reach the headwaters of Cupid Row Canal and the North Channel. Additional detail on the development of the design discharges for San Bruno Creek can be found in Appendix B.

Table 4-3. Estimated San Bruno Creek Discharges (from Appendix B)

Discharge Point	Frequency					
	2yr (cfs)	5yr (cfs)	10yr (cfs)	25yr (cfs)	50yr (cfs)	100yr (cfs)
Cupid Row Canal @ Lions Park	80	140	200[3]	250[2]	300	350
San Bruno Channel @ San Bruno Ave	380	630	910	1,130	1,330	1,520
San Bruno Channel d/s Highway 101	480	810	1,160	1,440[1]	1,710	1,960

1. The San Mateo County Flood Control district calculated the 25yr discharge at 1,100 cfs for this location in 1965 (Wilsey, Ham, & Blair 1965)
2. Design drawings from the San Mateo County Flood Control District show that the channel was designed for 250 cfs (Wilsey, Ham, & Blair 1965)
3. The "Recovery Action Plan for the San Francisco Garter Snake" estimated the 10yr flow in Cupid Row Canal at 165 cfs (LSA Associates, 2008)

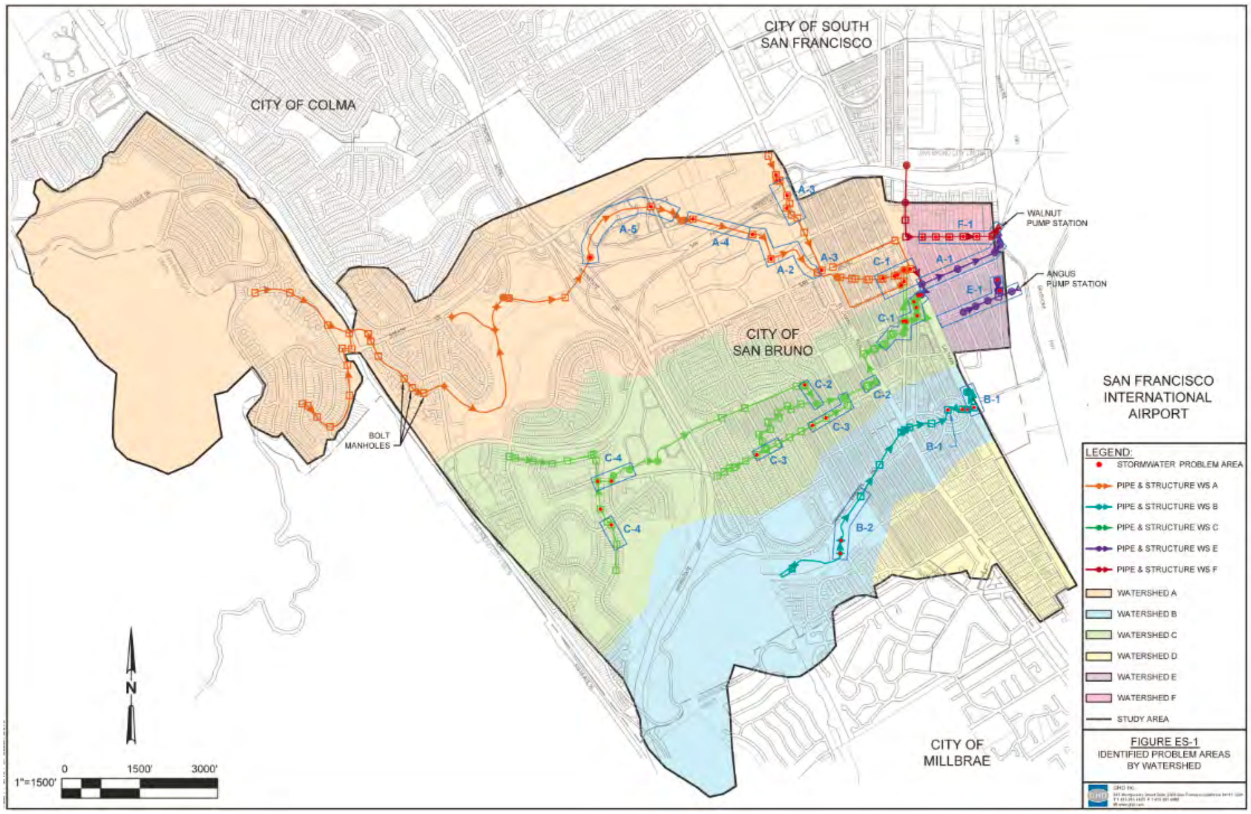

Figure 4-2. San Bruno Creek Watersheds from City of San Bruno's SDMP (GHD, 2014)

4.2 Hydraulic Modeling of Creeks

This section presents the methodology and channel capacity results of the hydraulic analysis for the development of water surface profiles in Colma Creek and San Bruno Creek using the Hydrologic Engineering Center River Analysis System (HEC-RAS) model. HEC-RAS is a software program developed by the USACE to model steady or unsteady one-dimensional flow in rivers using a graphical user interface. Additional detail on the development of the HEC-RAS models for Colma Creek and San Bruno Creek can be found in Appendix B.

4.2.1 Run Matrix of Flow/Tailwater Combinations

Both Colma Creek and San Bruno Channel discharge into the San Francisco Bay, which is tidally influenced. A range of boundary conditions were applied to the hydraulic model to assess different scenarios of high flood flows with different tidal elevations and sea level rise projections and to facilitate the estimation of frequency of occurrence for high water levels in San Francisco Bay coinciding with high creek discharges. For HEC-RAS, the boundary conditions represent the flood flowrates entered into the model and the water level used to define the downstream extent of the model. Both of these data points are required for the model to calculate water surface profiles. For both Creek models, the applied downstream boundary conditions ranged from tidal elevations of 4.5-ft to 14.0-ft NAVD, which were assessed with each of the 2, 5, 10, 25, 50, and 100-year flood events from the watersheds. The HEC-RAS simulation matrix that was used for the study is shown in Table 4-4.

Table 4-4. HEC-RAS Simulation Matrix of Flow/Tailwater Combinations

Tailwater	Flood Event Discharge					
(ft)	2yr	5yr	10yr	25yr	50yr	100yr
4.5	x	x	x	x	x	x
5.0	x	x	x	x	x	x
5.5	x	x	x	x	x	x
6.0	x	x	x	x	x	x
6.5	x	x	x	x	x	x
7.0	x	x	x	x	x	x
7.5	x	x	x	x	x	x
8.0	x	x	x	x	x	x
8.5	x	x	x	x	x	x
9.0	x	x	x	x	x	x
9.5	x	x	x	x	x	x
10.0	x	x	x	x	x	x
10.5	x	x	x	x	x	x
11.0	x	x	x	x	x	x
11.5	x	x	x	x	x	x
12.0	x	x	x	x	x	x
12.5	x	x	x	x	x	x
13.0	x	x	x	x	x	x
14.0	x	x	x	x	x	x

4.2.2 Colma Creek

The HEC-RAS model prepared for this flood risk study was based on a previous HEC-2 model created in 2004 by Schaaf & Wheeler, using cross section information obtained by the USACE for the Flood Insurance Study. HEC-2 is a DOS-based software program developed by the USACE that computes water surface elevations for one-dimensional steady flow in rivers. The HEC-2 model has been updated with information field surveyed by Schaaf & Wheeler in November 2011. One of the primary purposes of the field survey is the verification of bridge opening dimensions and creek sedimentation. The model extends from the outlet of Colma Creek at San Francisco Bay to just upstream of the Spruce Street crossing. It encompasses nine bridge crossings including Highway 101 and the Joint Powers Authority (Caltrain).

Work completed by the Colma Creek Flood Control Zone of the San Mateo County Flood Control District at the end of 2011 consisted of repairing 380 feet of flood walls and installing a concrete bottom slab beginning approximately 300 feet upstream of the Spruce Street crossing. The construction documents for this project were used to verify cross sections at the upstream boundary of the HEC-RAS model. Figure 4-3 shows the HEC-RAS model schematic.

The Colma Creek HEC-RAS modeling was performed using steady-state hydraulic simulations to represent uniform flow conditions. Lateral structures were added to the steady state models to simulate spills over weirs that are set along the banks; however, lateral structures can create numerical instability and problems with flow convergence in a HEC-RAS simulation. To minimize these issues, the lateral structures were turned off (HEC-RAS analyzes the spills, but does not remove the flow from the channel). This creates a water surface elevation that extends vertically up, known as “glass walls.” This type of analysis is done to determine the elevation of a floodwall or levee that will contain all the flow within the channel. This assumption was considered reasonable for the lower Colma Creek flood control channel, which is set within a heavily developed urban area that abuts the channel on either bank.

A second HEC-RAS analysis was performed for Colma Creek to determine the hydraulic capacity of the flood control channel capacity at various tidal elevations in the Bay. This analysis looked at the lateral structures for spills and determined the maximum flow the channel could contain without spilling at different boundary conditions. A threshold of 50 cfs was allowed to spill, but any spill greater indicated that the channel was undersized.

The results of the glass-walls analysis for Colma Creek are presented below in Section 4.4, Increased Flooding Potential. The results of the channel capacity calculations for Colma Creek with various downstream tidal elevations are presented in Table 4-5 of this section.

Table 4-5. Colma Creek Channel Capacity Results (from Appendix B)

Tidal Elev.	**Upstream of Linden**		**Linden to Hwy-101**		**Downstream of Hwy-101**	
(ft NAVD88)	**Colma** (cfs)	**Nav. Slough** (cfs)	**Colma** (cfs)	**Nav. Slough** (cfs)	**Colma** (cfs)	**Nav. Slough** (cfs)
6.0	3,200	192	3,200	192	2,000	120
6.5	3,200	192	3,200	192	1,950	117
7.0	3,200	192	3,200	192	1,900	114
7.5	3,200	192	3,200	192	1,800	108
8.0	3,200	192	3,200	192	1,700	102
8.5	3,150	189	3,150	189	1,000	60
9.0	3,100	186	3,100	186	0	0
9.5	3,000	180	3,000	180	0	0
10.0	2,900	174	2,900	174	0	0
10.5	2,800	168	2,800	168	0	0
11.0	2,700	162	2,700	162	0	0
11.5	2,600	156	2,400	144	0	0
12.0	2,500	150	2,100	126	0	0
12.5	1,600	96	1,050	63	0	0
13.0	700	42	0	0	0	0

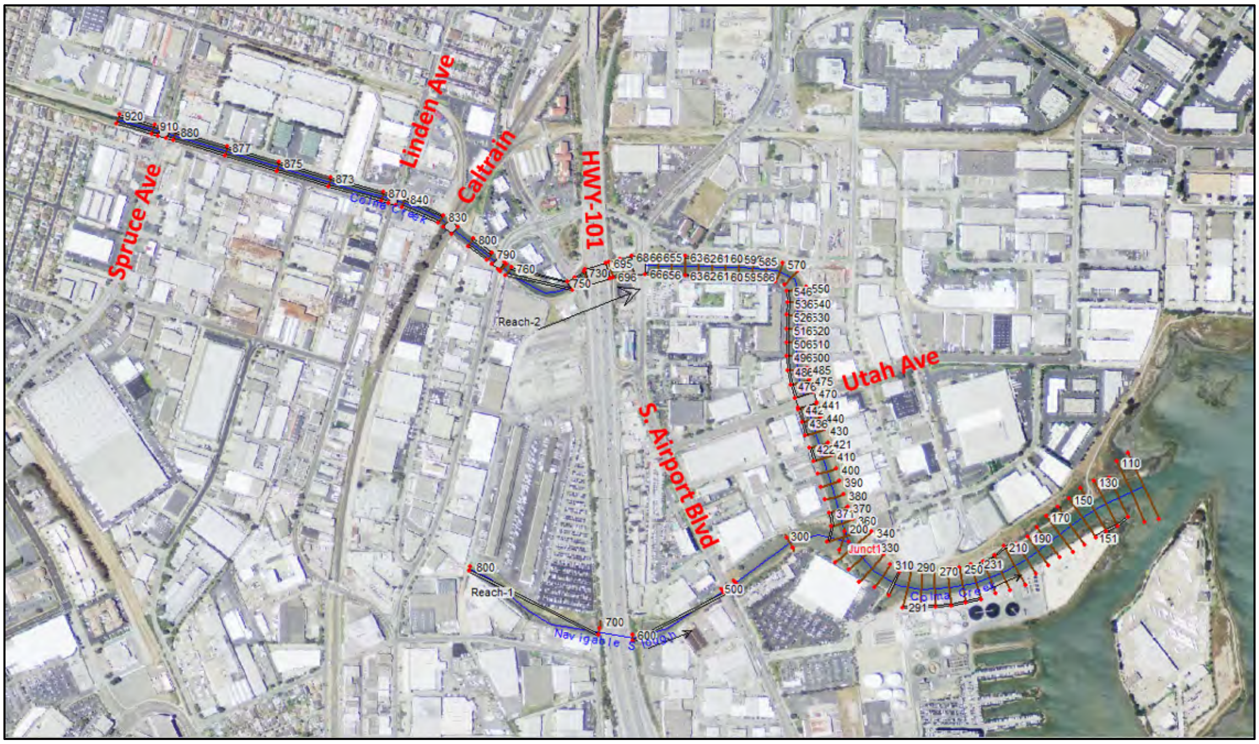

Figure 4-3. Schematic of Colma Creek HEC-RAS Model

4.2.3 San Bruno Creek

The HEC-RAS model developed by Schaaf & Wheeler as part of the SFO Shoreline Protection Study (M&N, 2013) was used as a basis for developing the San Bruno Creek and Cupid Row Canal model for this study. The previous model only extended to the downstream side of the Hwy-101 culverts and did not include the area upstream of the Hwy-101 culverts and Cupid Row Canal. Therefore, the survey data collected along Cupid Row Canal and the North Channel by Meridian Surveying for this study was used to augment the available LiDAR data for cutting cross-sections in the GeoRAS application.

The Meridian field survey did not include surveying from a boat. Therefore, in the deeper section of the North Channel downstream of Hwy-101, the cross sections did not extend into the deeper water. In this reach, the thalweg of the channel was lowered in the HEC-RAS model by about 3-4 ft to account for the low flow channel. This lowering was based on depth measurements taken by Meridian at the bridge crossings in the North Channel along with the Caltrans as-built plan-set for the channel deepening that was performed in 2000.

The HEC-RAS model starts at the headwaters of the Cupid Row Canal near Lions Park and ends at the tide gate structure to the San Francisco Bay. Cupid Row Canal flows into the North Channel through a culvert under San Bruno Ave. Figure 4-4 shows the HEC-RAS cross sections for the Cupid Row to San Bruno Channel.

The same hydraulic capacity analysis from Colma Creek was also performed for San Bruno Creek to assess the channel capacity at various tidal elevations in the Bay. This analysis determined the maximum flow that the channel could contain without spilling at different boundary conditions. A threshold of 50 cfs was allowed to spill, but any spill greater indicated that the channel was undersized. The results of the channel capacity calculations for San Bruno Creek with various downstream tidal elevations are presented in Table 4-6.

The lower reaches of San Bruno Creek, comprised of the Cupid Row Canal and the North Channel, are set within a relatively less developed urban area than Colma Creek. As a result, there are locations along San Bruno Creek where flood flows that leave the channel are contained as overbank storage in surface depressions adjacent to the channel. These areas include the undeveloped, open-space property owned by SFO that is west of Hwy-101 and east of the Belle Air neighborhood that Cupid Row Canal passes through. There is a surface depression storage areas between San Bruno Avenue and the Hwy-101 culverts that is maintained by San Mateo County, as well as storage downstream of Hwy-101 adjacent to the SFO long-term parking lot. In an effort to properly track and account for the volumes of flood flows that leave the channel during storm events, these areas of surface depression were added to the San Bruno Creek HEC-RAS model as storage areas. The stage-storage relationship for each storage area was calculated using the SFO LiDAR data set in GIS. Tracking overbank volumes in HEC-RAS required unsteady simulations, where runoff hydrographs from the HEC-HMS model and tidal time series were entered as the upstream and downstream boundary conditions, respectively. The peak of each tidal time-series was aligned with the peak flow rate at the San Bruno Creek tide gates. The tide gates were represented in the model as orifices with gate-control, preventing storm surge from propagating up the North Channel. The full run-matrix from Table 4-4 was then run to track both the water surface profiles in the channels as well as the volumes and elevation of water stored in the overbank areas. The results of the unsteady analysis for San Bruno Creek is presented in Section 4.4, Increased Flooding Potential.

Table 4-6. San Bruno Creek Channel Capacity Results (from Appendix B)

Tidal Elev.	**Upstream of San Bruno Ave**	**Downstream of Hwy-101**
(ft NAVD88)	**Cupid Row** (cfs)	**San Bruno Canal** (cfs)
6.0	120	860
6.5	120	860
7.0	120	860
7.5	100	800
8.0	80	740
8.5	70	625
9.0	60	510
9.5	40	390
10.0	0	270
10.5	0	160
11.0	0	0
11.5	0	0
12.0	0	0
12.5	0	0
13.0	0	0

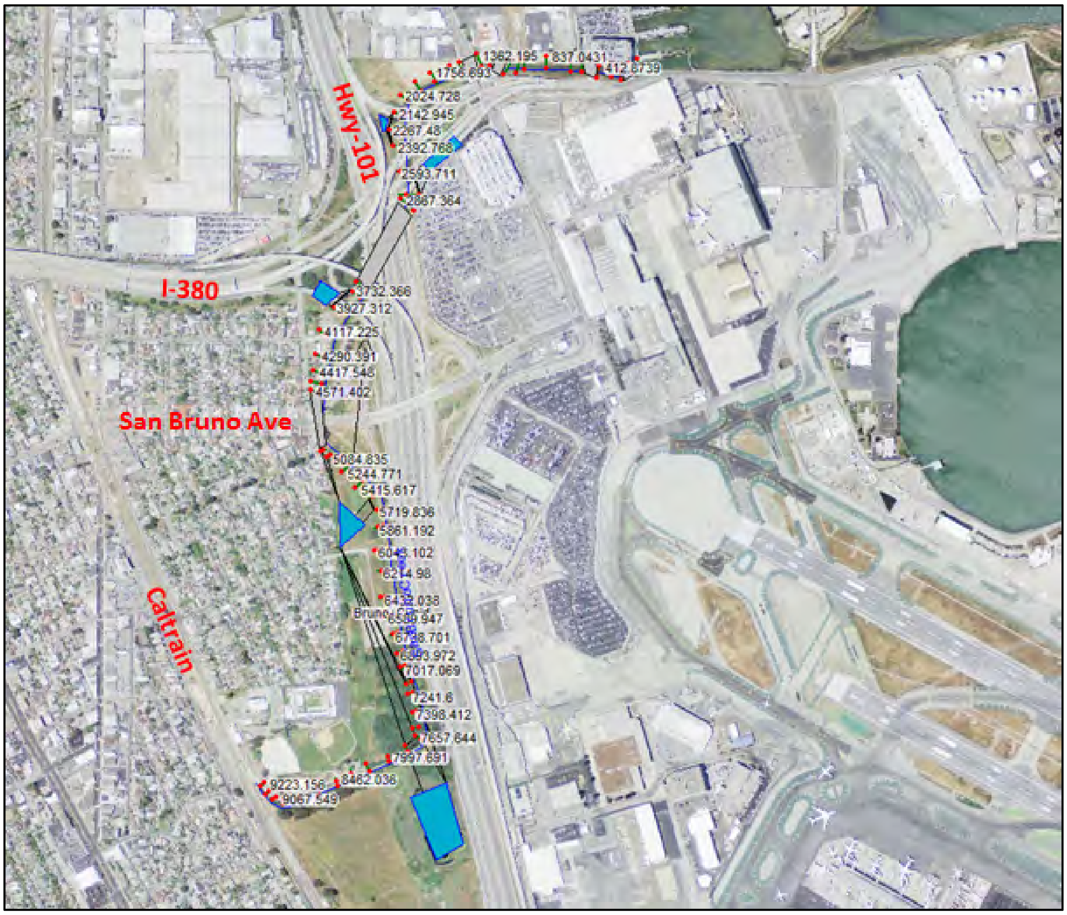

Figure 4-4. Schematic of San Bruno Creek HEC-RAS Model

4.3 Risk Assessment (Coincident Frequency)

Flooding results from the combination of high creek discharge and high water levels in San Francisco Bay. There are observed data that justify the expectation that high creek discharges may coincide with high water levels in San Francisco Bay. The winter storms that lead to flooding in the creeks are associated with low barometric pressures, which lead directly to higher tides. However, since the occurrence frequencies of this correlation are uncertain, this study performed a statistical analysis similar to a joint probability analysis for each creek.

The assessment analyzed the correlation between daily discharge in Colma Creek (USGS, 2014) and tidal elevations in San Francisco Bay (NOAA, 2014) over a 20-year joint period of record. Specifically, it considered tidal residuals – the difference between measured and astronomical tides – which capture the meteorological influence. The analysis concluded that higher tidal residuals are associated with relatively high creek daily discharge values. However, there is not a linear correlation between the two. Instead, there is a threshold in the creek daily discharge values at 50 to 100 cfs. If the creek discharge is above the threshold value then higher tidal residuals are observed. However, the tidal residuals do not increase further for extremely high creek discharge values.

There were two main conclusions: (1) There is a threshold in the creek daily discharge value, at 50 to 100 cfs daily mean discharge, above which higher tidal residuals are observed. (2). Once the threshold in the creek daily discharge is reached, further increases in the creek discharge are not associated with further increases in the tidal residuals .

These results supported the conclusion that there is little correlation between the tidal residuals and the creek discharge when the analysis is limited to days with creek discharges above the threshold. However, the tidal residuals on those days are relatively large compared to the data set as a whole and extreme high tidal residuals are always associated with creek discharges above the threshold. Therefore, an appropriate functional form for the conditional relationship between the creek discharge and the tidal residuals is, in effect, a step function: different probability distributions for the tidal elevation are defined for high discharge days (with the Colma Creek daily discharge greater than 100 cfs) and low discharge days (all other days).

The flooding results shown in this report reflect a direct implementation of this statistical relationship for the coincident frequency for high water levels in San Francisco Bay and high creek discharge, which represents a significant improvement over past methodology in the ability to predict the combined recurrence interval of flood elevations in the creeks. Determining the location in each of the creeks where the water surface profile in the channel is independent of the downstream tidal elevation was also critical in defining the extents within the lower watersheds that are susceptible to the effects of future sea-level rise. Additional detail on the coincident frequency statistical analysis can be found in Appendix D.

4.4 Increased Flooding Potential

The full set of results from the HEC-RAS run-matrix were combined with the probability distribution function derived from the coincident frequency analysis detailed in Appendix D to calculate the coincident frequency recurrence intervals for water levels in each of the creeks. Within the lowest reaches of the creeks at their channel mouths, the resultant 1% annual coincident recurrence water surface in the channel (100-yr event) would be the result of a 100-yr tidal elevation in the Bay, independent of the flowrate in the creeks. Further up the watersheds, the resultant 1% annual coincident recurrence event would be the result of a 100-yr storm, so the water surface in the channel is not affected by the tidal elevations in the Bay. Determining this location in each of the creeks where the water surface profile in the channel is independent of the downstream tidal elevation was critical in defining the extents within the lower watersheds that are susceptible to the effects of future sea-level rise. The following section presents the results of the combined hydraulic and coincident frequency analyses for each of the creeks in this study.

4.4.1 Colma Creek

The results of the combined hydraulic and coincident frequency analyses for Colma Creek were predicated on the “glass-wall” HEC-RAS simulations for the flood control channel to determine the flood-wall or levee elevation that would be necessary to contain the entire flood event within the channel. In these simulations, overbank flooding was not permitted and the water surface elevation was extended vertically up. Therefore, the resultant water surface profiles from these simulations represent a theoretical condition. In reality the water surface elevations in the channel would be lower due to the amount overbank flooding that currently occurs within the lower Colma Creek watershed due to floodwall deficiencies, as evidenced by the effective FEMA FIRMs for South San Francisco. However, the San Mateo County Flood Control District’s design criteria for the channel is a 50-yr design storm plus 2-ft of freeboard. The results of this study are illustrative of the flood-wall elevations that would be required to maintain this level of protection.

Figure 4-5 illustrates profiles of the Colma Creek top-of-bank elevations from the San Francisco Bay up to the Spruce Avenue Bridge, along with the 10-yr, 50-yr, and 100-yr coincident water surface profiles for the existing tidal condition without SLR. For reference, the notation for right and left bank in this report follows the standard U.S. Army Corps of Engineers practice of labeling the channel banks looking in the downstream direction. In the lowest portion of the Creek, downstream of the Utah Avenue Bridge, from the mouth to approximately Station 2,500-ft the resultant water surface profiles show that flood stages in this area are driven by tidal elevations. This area has improved coastal defenses and the top-of-bank elevations are above the 100-yr coincident flood stage.

The reach of Colma Creek between Utah Avenue and South Airport Boulevard is known to have existing deficiencies, as evidenced by the resultant water surface profiles. San Mateo County is currently in the process of performing engineering studies to raise the southern flood wall in this reach to help mitigate flooding in the commercial district between South Airport Boulevard and the Creek, centered at Wondercolor Lane and at Utah Avenue. The degree to which the floodwall elevations are deficient in this reach is exaggerated in the water surface profiles due to the “glass-wall” simulations. In reality, the large volume of flooding that leaves the channel upstream of Hwy-101, from the Caltrain tracks up to Spruce Avenue, would lower the water surface profiles in the reach between Utah Avenue and South Airport Boulevard.

The reach of Colma Creek upstream of Hwy-101, from the Caltrain tracks up to Spruce Avenue, has a channel capacity coinciding with approximately a 10-year flood event for the existing tidal condition without SLR. The effective FEMA FIRMs for South San Francisco shows overbank flooding from the channel between Spruce and the Caltrain tracks, centered on Linden Avenue.

Figure 4-6 illustrates the 100-yr coincident water surface profiles for Colma Creek with zero SLR along with SLR values of 1-ft, 2-ft, and 3-ft. A comparison of the four water surface profiles shows that SLR has a significant impact on flood elevations in the creek for the lowest reach downstream of Utah Avenue. In the reach between Utah Avenue and Hwy-101, SLR appears to have a much smaller impact on the water surface profiles. And in the reach upstream of Hwy-101, SLR appears to have only a negligible impact on flood stages in the creek.

Figure 4-7 shows the level of coincident recurrence interval protection (channel capacity) being provided in the Colma Creek flood control channel with zero SLR along with SLR values of 1-ft, 2-ft, and 3-ft. Based on these results, the reach of Colma Creek most susceptible to impacts from SLR is the lowest reach downstream of Utah Avenue to the Creek’s mouth. One piece of critical infrastructure located within the lowest reach of Colma Creek is the City of South San Francisco Water Quality Control Plant, which is on the Creek’s south bank immediately upstream of the confluence with San Francisco Bay.

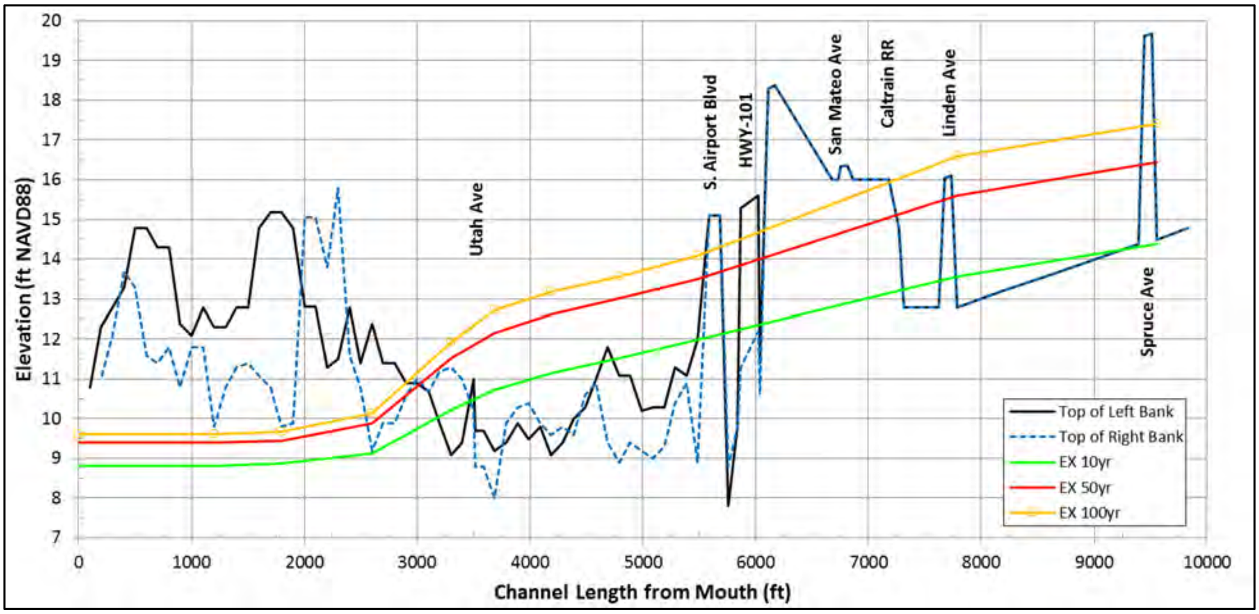

Figure 4-5. Colma Creek 10, 50, and 100-yr Coincident Water Surface Profiles for Existing Condition (no SLR)

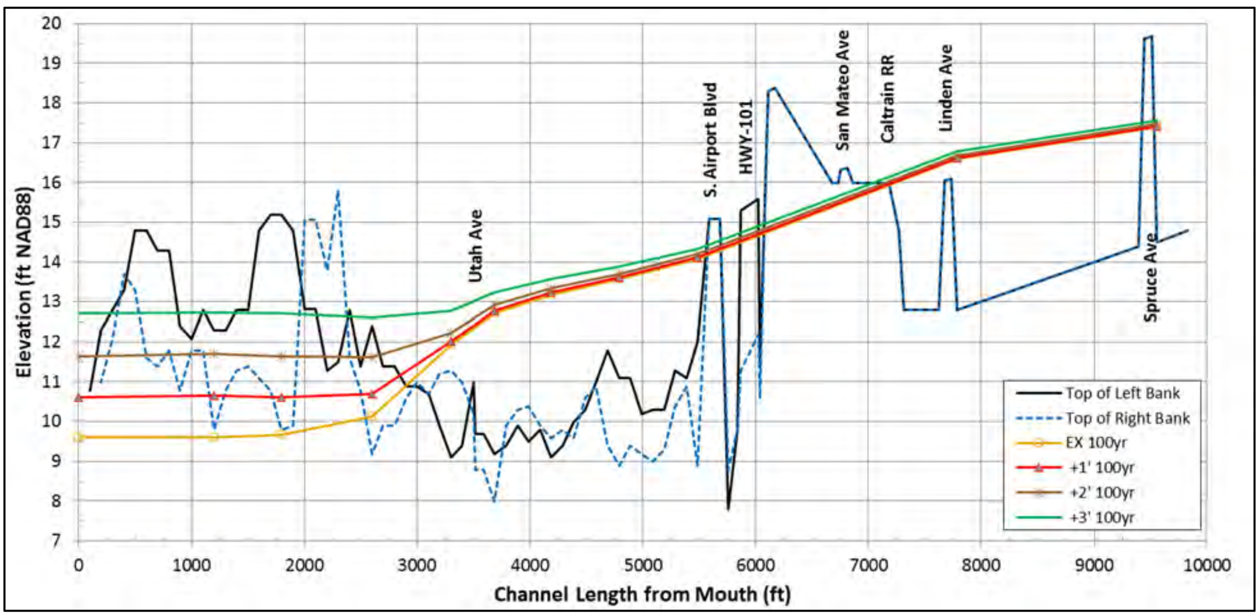

Figure 4-6. Colma Creek 100yr Coincident Water Surface Profiles with SLR of 0-ft, 1-ft, 2-ft, and 3-ft.

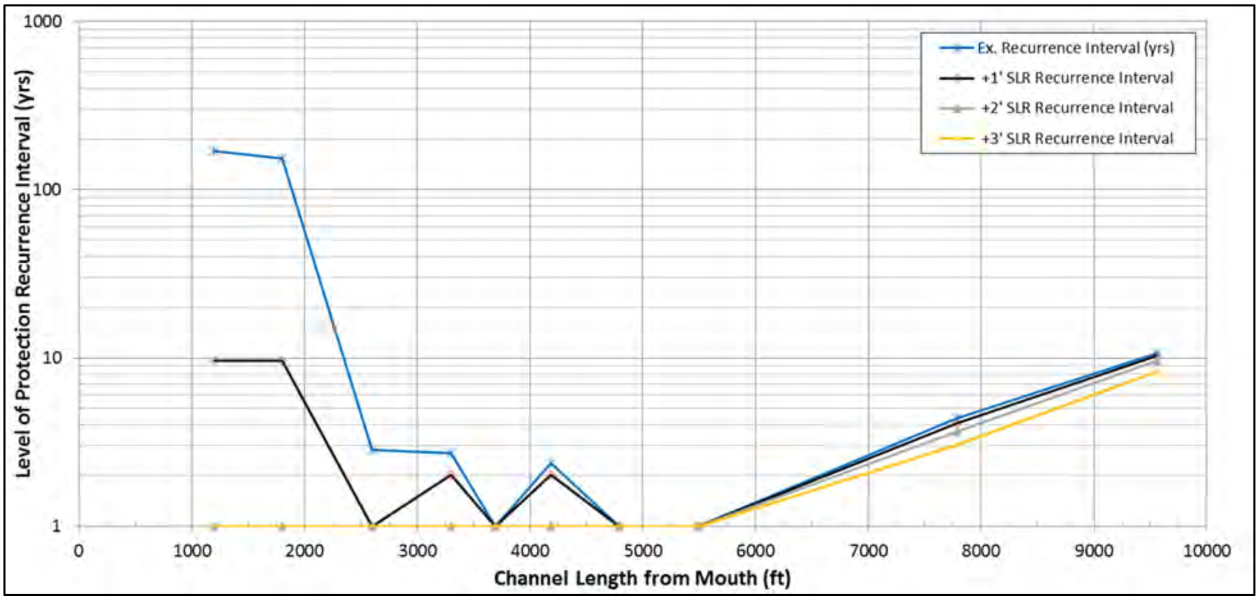

Figure 4-7. Colma Creek Level of Coincident Recurrence Interval Protection in Channel with SLR of 0-ft, 1-ft, 2-ft, and 3-ft.

4.4.2 San Bruno Creek

The results of the combined hydraulic and coincident frequency analyses for San Bruno Creek were predicated on the unsteady HEC-RAS simulations, in which overbank flooding was accounted for in the model within storage elements and the tide gates acted to prevent higher tidal elevations from propagating back up the channel.

Figure 4-8 illustrates profiles of the San Bruno Creek top-of-channel bank elevations from the San Francisco Bay up to the Caltrain tracks adjacent to Lions Park, along with the 10-yr, 50-yr, and 100-yr coincident water surface profiles for the existing tidal condition without SLR. Since the lower reaches of San Bruno Creek are protected from storm surge by a set of tide gates, the effects of tides on the water surface profiles is different than for Colma Creek, which is open to the Bay. In lower San Bruno Creek, the tides influence water levels in the creek due to backwater effects from flood flows being trapped upstream of the tide gates during high-tides.

The reach of North Channel downstream of the Hwy-101 culverts is able to contain approximately a 10-year flood event due to a few low-spots on the channel banks. However, the flood elevations in this lower reach are being moderated by the overbank flooding that occurs in the San Bruno Creek system upstream of the Hwy-101 culverts. The majority of this flooding occurs on the west side of Cupid Row Canal, adjacent to the Belle Air neighborhood, and to a lesser degree in the reach of North Channel between San Bruno Avenue and Hwy-101. Figure 4-9 shows the extent of the 100-yr coincident overbank flooding for San Bruno Creek for the existing tidal conditions with zero SLR. In the overbank area west of Cupid Row Canal and south of San Bruno Avenue, the Belle Air neighborhood starts being impacted at a flood elevation of approximately +4.5' NAVD88. Based on the existing condition results (no SLR), this elevation correlates to approximately a 6-yr coincident frequency event.

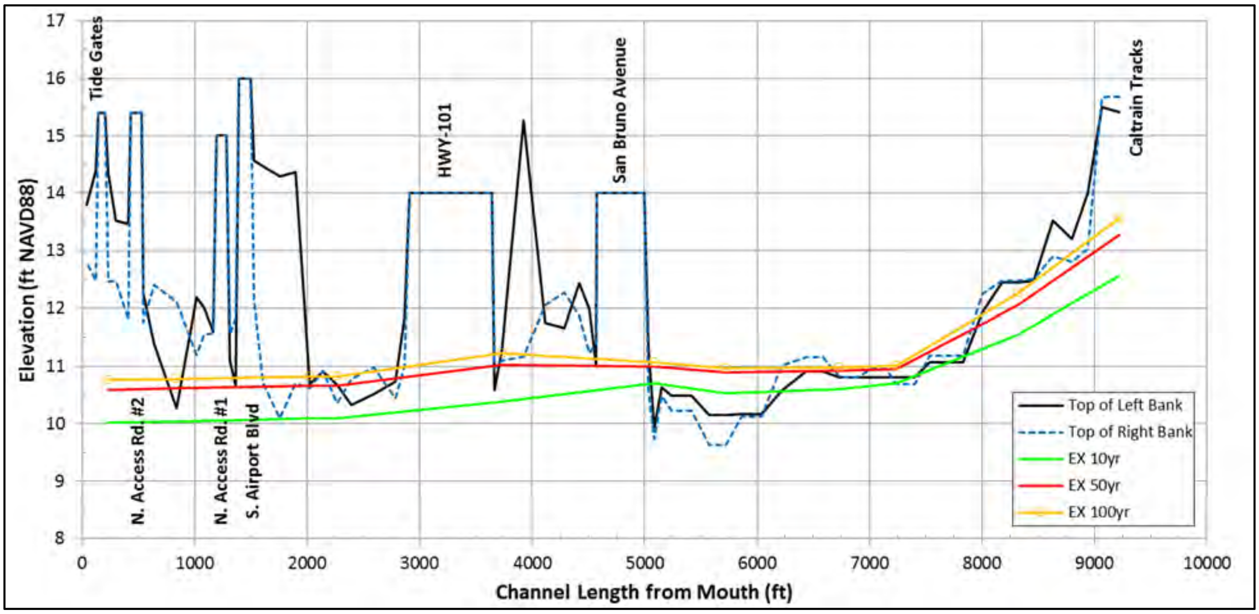

Figure 4-8. San Bruno Creek 10, 50, and 100yr Coincident Water Surface Profiles for Existing Condition (no SLR)

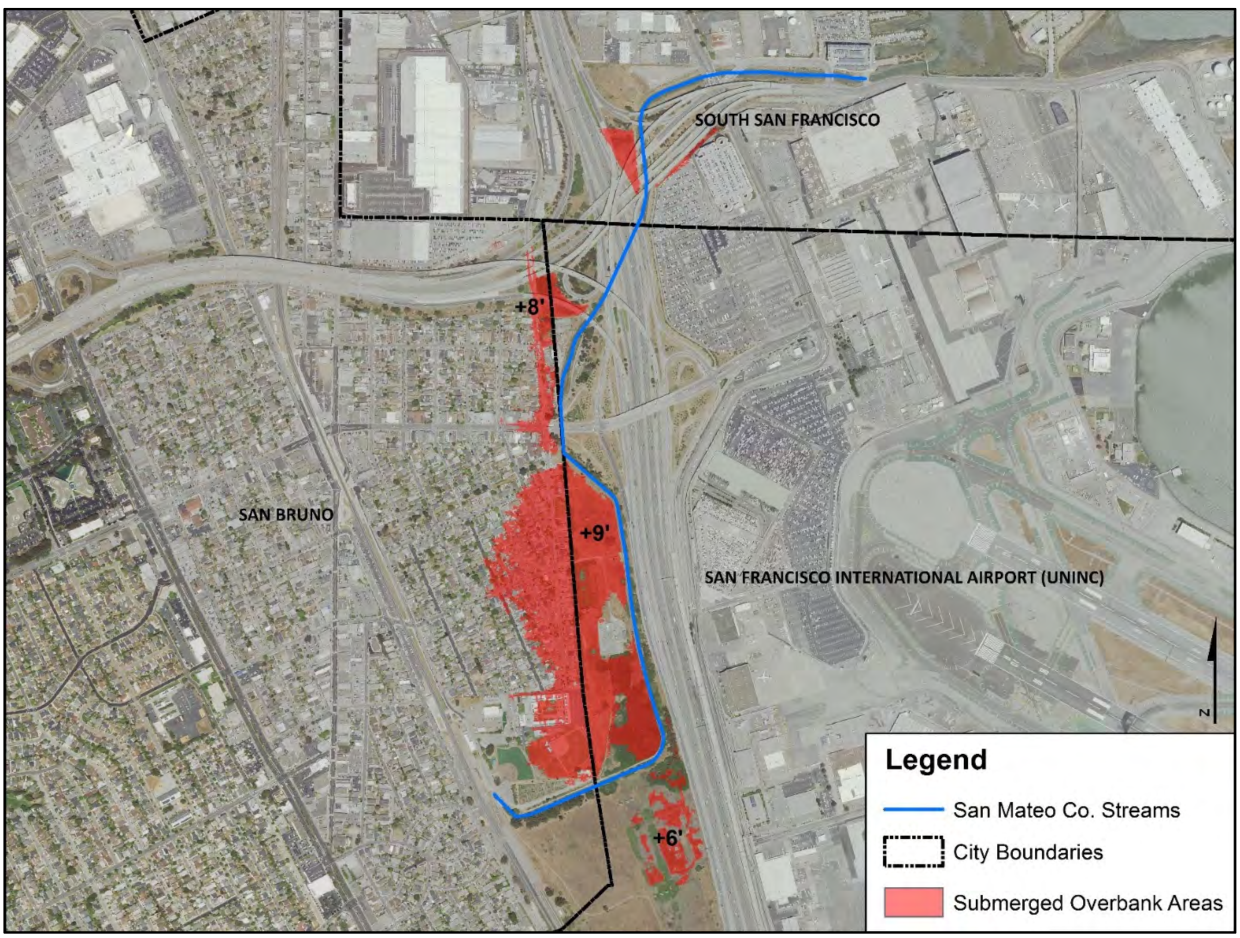

Figure 4-9. San Bruno Creek 100yr Coincident Overbank Flooding for Existing Condition (no SLR)

Based on inlet control hydraulic calculations, the Caltrans culverts underneath Hwy-101, which are four 10'x8' concrete boxes, have the capacity to pass the 100-yr flowrate calculated for this study (1,520 cfs). Similarly, the culvert underneath San Bruno Avenue, which is a single 10'x8' concrete box, also has the capacity to pass the 100-yr flowrate for Cupid Row Canal (350 cfs). Therefore, the overbank flooding upstream of Hwy-101 and San Bruno Avenue is not the result of these culverts being undersized.

There are two primary factors contributing to the overbank flooding upstream of Hwy-101 and San Bruno Avenue. The first is the relatively low top-of-bank elevations on the Cupid Row Canal immediately upstream of San Bruno Avenue, as seen from roughly Sta-5000 to Sta-6000 in Figure 4-8 above. The second is the tide gate structure at the Creek's outlet to the Bay. Based on the findings of the Schaaf & Wheeler analyses for the SFO Shoreline Protection Study (M&N, 2013), the tide gate structure is undersized for the 100-year discharge of 1,960 cfs with a corresponding MHHW elevation of +6.8' NAVD88 downstream. Drawings suggest that the channel and tide gate structure were designed for the 25-year flow of 1,100 cfs with a +6.8' NAVD88 tide (SMCFCD, 1965). The prior SFO Shoreline Protection Study found that with a downstream tide of 6.8-feet, the tide gate structure is sized to pass approximately 1,050 cfs without flooding over the banks upstream, which are at an elevation of between +10.0' to +12.0' NAVD88 (M&N, 2013). However, that HEC-RAS model extended only up to the Hwy-101 culverts. The findings of this study show that with the 10-year flow condition and a +6.8' NAVD88 tide, overbank flooding is already encroaching upon the Belle Air neighborhood because of backwater effects from the tide gates limiting the capacity of the San Bruno Avenue and Hwy-101 culverts due to tailwater control.

Figure 4-10 illustrates the 100-yr coincident water surface profiles for San Bruno Creek with zero SLR along with SLR values of 1-ft, 2-ft, and 3-ft. The tide gates prevent elevated tides from entering the North Channel, but the consequences of SLR will cause increased backwater effects in the creek due to flood flows being trapped upstream of the tide gates during high-tides. A comparison of the four water surface profiles shows that SLR has more of an impact on flood elevations in the creek for the lowest reach downstream of the Hwy-101 culverts. This apparent impact is also the result of there being much less available overbank storage in North Channel below Hwy-101, which means that more of the flood flows are forced to be contained within the channel. Upstream of the Hwy-101 and San Bruno Avenue culverts, the effects of SLR are reflected in the resultant peak flood elevations in the overbank storage areas.

Figure 4-11 shows the level of coincident recurrence interval protection (channel capacity) being provided in the San Bruno Creek flood control channel with zero SLR along with SLR values of 1-ft, 2-ft, and 3-ft. Based on these results, the entire reach of San Bruno Creek from the tide gates up through Cupid Row Canal should be considered susceptible to impacts from SLR.

Figure 4-12 shows the effects of SLR on the 100-yr coincident overbank flooding on the west side of Cupid Row Canal, adjacent to the Belle Air neighborhood. For this area, +3' of SLR increases the 100-yr flood level by ~ 1.2-ft and the 10-yr flood level by more than 2.5-ft. The curves are cut-off at the 10-yr recurrence interval due to more uncertainty for the more frequent events. However, the results do illustrate that the impacts of SLR will increase the frequency of overbank flooding in the Belle Air neighborhood, to the point that it would become roughly an annual occurrence event.

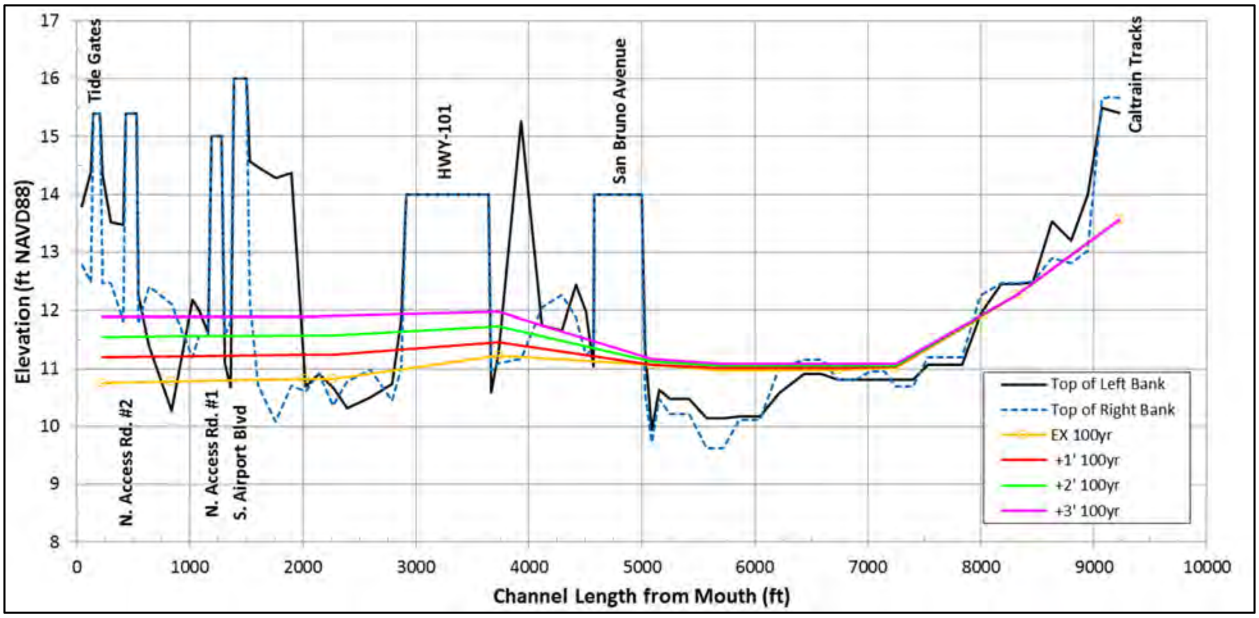

Figure 4-10. San Bruno Creek 100yr Coincident Water Surface Profiles with SLR of 0-ft, 1-ft, 2-ft, and 3-ft.

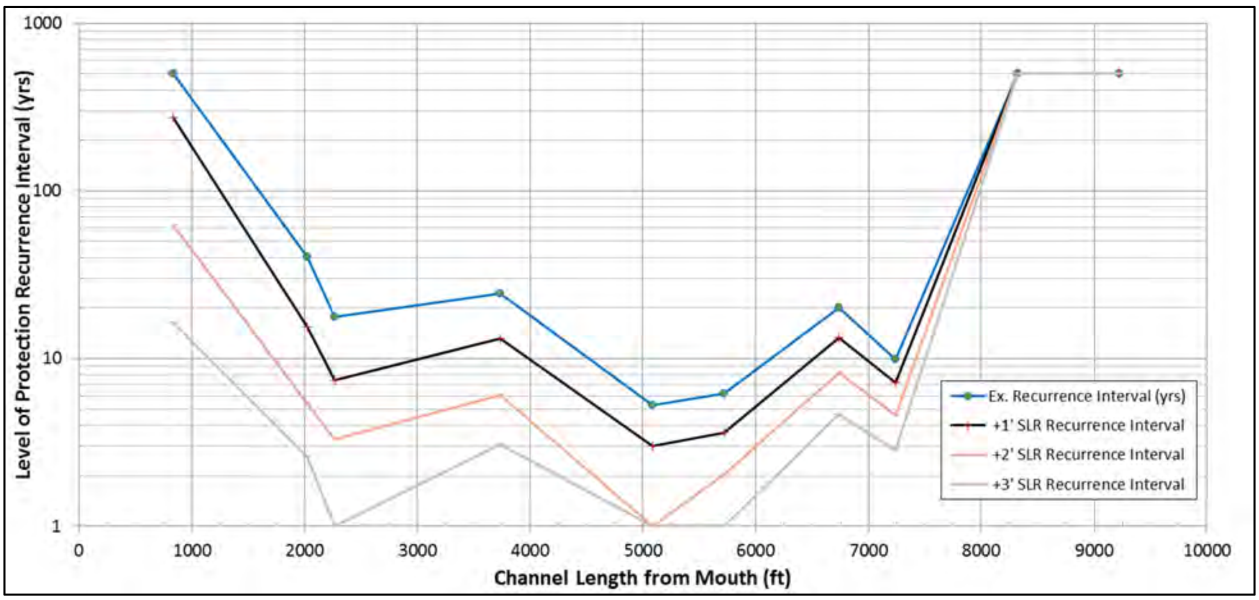

Figure 4-11. San Bruno Creek Level of Coincident Recurrence Interval Protection in Channel with SLR of 0-ft, 1-ft, 2-ft, and 3-ft.

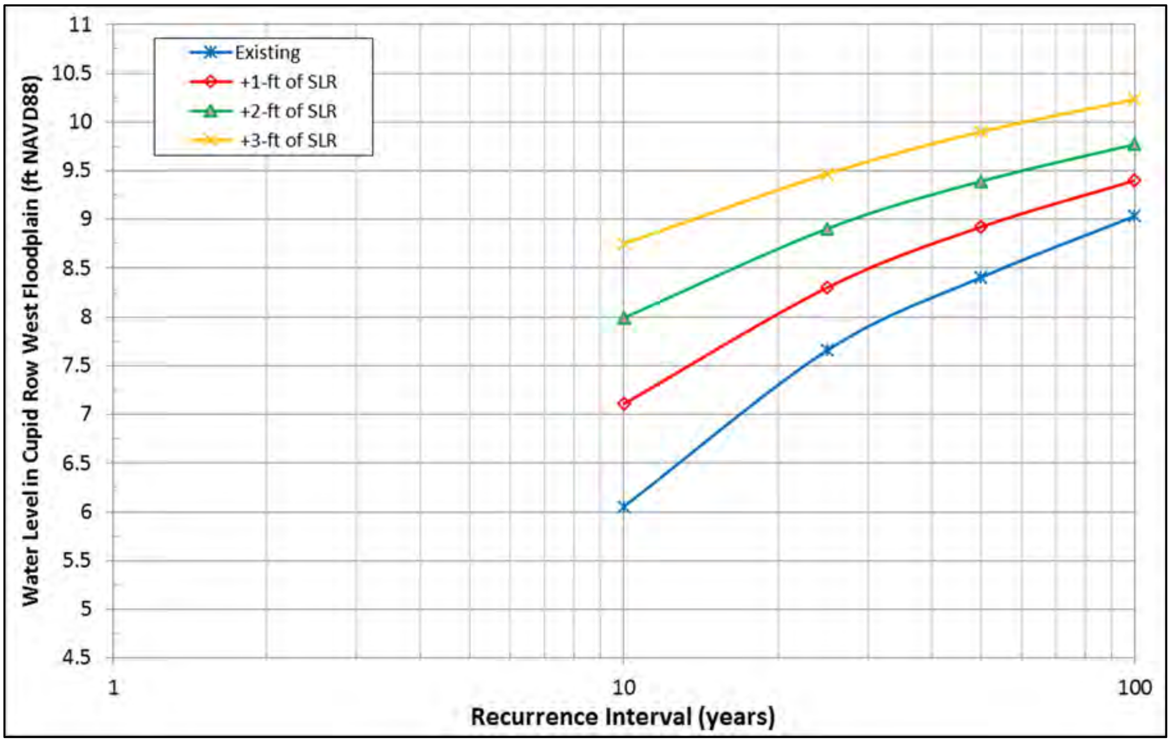

Figure 4-12. San Bruno Creek 100yr Coincident Overbank Flooding in Cupid Row West with SLR of 0-ft, 1-ft, 2-ft, and 3-ft.

5.0 ASSESSMENT OF SYSTEM DEFICIENCIES

The purpose of this section is to identify reaches/sections of the creeks that are vulnerable to sea level rise.

5.1 Colma Creek

5.1.1 Critical System Features

The system features providing flood protection for the lower watershed of Colma Creek are comprised of the following elements (see Figure 2-4 and Figure 2-5):

- The concrete-lined rectangular flood control channel from Spruce Avenue down to Produce Avenue, maintained by the SMCFCD;
- The concrete flood walls along the flood control channel from Produce Avenue down to Utah Avenue, maintained by the SMCFCD;
- The levees along the channel from Utah Avenue to the mouth of Colma Creek at the San Francisco Bay, maintained by the SMCFCD;
- The seven pump-stations maintained by the City of South San Francisco that help drain the low-lying areas of the City and discharge to Colma Creek or Navigable Slough.

5.1.2 Vulnerabilities

<u>Upstream of Highway-101</u>

The reach of Colma Creek upstream of Hwy-101, from the Caltrain tracks up to Spruce Avenue, has a channel capacity coinciding with approximately a 10-year flood event for the existing tidal condition without SLR. The effective FEMA FIRMs for South San Francisco shows overbank flooding from the channel between Spruce and the Caltrain tracks, centered on Linden Avenue. However, in this reach upstream of Hwy-101, SLR appears to have only a negligible impact on flood stages in the creek. Figure 5-1 illustrates the reach upstream of Hwy-101.

<u>Highway-101 to Utah Avenue</u>

The reach of Colma Creek between Utah Avenue and South Airport Boulevard is known to have existing deficiencies, which were confirmed by the results of this study. SMCFCD is currently in the process of performing engineering studies to raise the southern flood wall in this reach to help mitigate flooding in the commercial district between South Airport Boulevard and Colma Creek, centered at Wondercolor Lane and at Utah Avenue. Currently, the large volume of flooding that leaves the channel upstream of Hwy-101, from the Caltrain tracks up to Spruce Avenue, acts to lower the flood stage in the reach between Utah Avenue and South Airport Boulevard. Should improvements be made to the Colma Creek flood control channel in the upstream section between Spruce Avenue and the Caltrain tracks, then the floodwalls on Colma Creek downstream of Hwy-101 would have to be increased to account for this additional flood volume. In the reach between Utah Avenue and Hwy-101, SLR appears to have a much smaller impact on the water surface profiles than further downstream. Figure 5-1 illustrates this reach in the lower watershed.

Downstream of Utah Avenue to Creek Mouth

In the lowest portion of the Creek, downstream of the Utah Avenue Bridge to the Creek's mouth, flood stages are driven by tidal elevations. This area has improved coastal defenses and the current top-of-bank elevations are above the existing condition 100-yr coincident flood stage. The results of the study show that this lowest reach of Colma Creek is most susceptible to impacts from SLR due to the significant effect that tidal elevations have on flood elevations in this section of the creek. The findings show that even 1-ft of SLR would necessitate the levees to be raised for the system to continue providing a 100-yr recurrence interval level of protection. One piece of critical infrastructure that is located within the lowest reach of Colma Creek is the City of South San Francisco Water Quality Control Plant on the Creek's south bank, immediately upstream of the confluence with San Francisco Bay (see Figure 5-1).

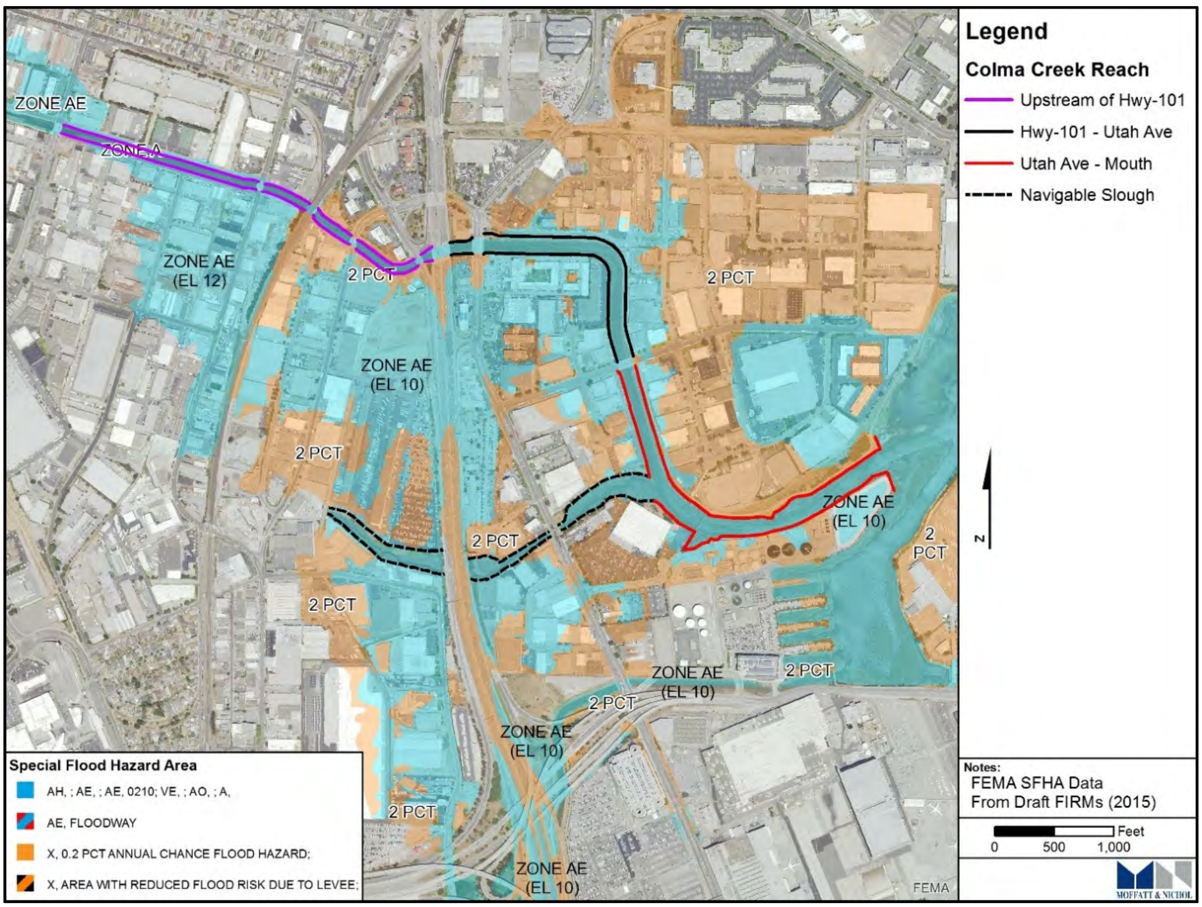

Figure 5-1. Location of Colma Creek Reaches in Lower Watershed

Navigable Slough

Navigable Slough is an unimproved earthen channel that drains a small area of the City of South San Francisco and is tributary to Colma Creek (see Figure 5-1). The south channel bank of Navigable Slough has low-spots below elevation +10' NAVD88 in two locations, between South Airport Blvd. and Hwy-101 and also upstream (west) of Hwy-101. The reach of Navigable Slough upstream of Hwy-101 has spots on the south bank that are below elevation +9' NAVD88, as illustrated in the profile along the south bank shown in Figure 5-2. The location of this profile-section relative to Colma Creek is shown in Figure 5-3. Overbank flooding from this reach of

Navigable Slough is significant because there is a lower-elevation flow-path along Shaw Rd. and underneath I-380 that connects this overbank flooding with the San Bruno residential neighborhood at Walnut St. and 7th Ave, which is located within the San Bruno Creek watershed.

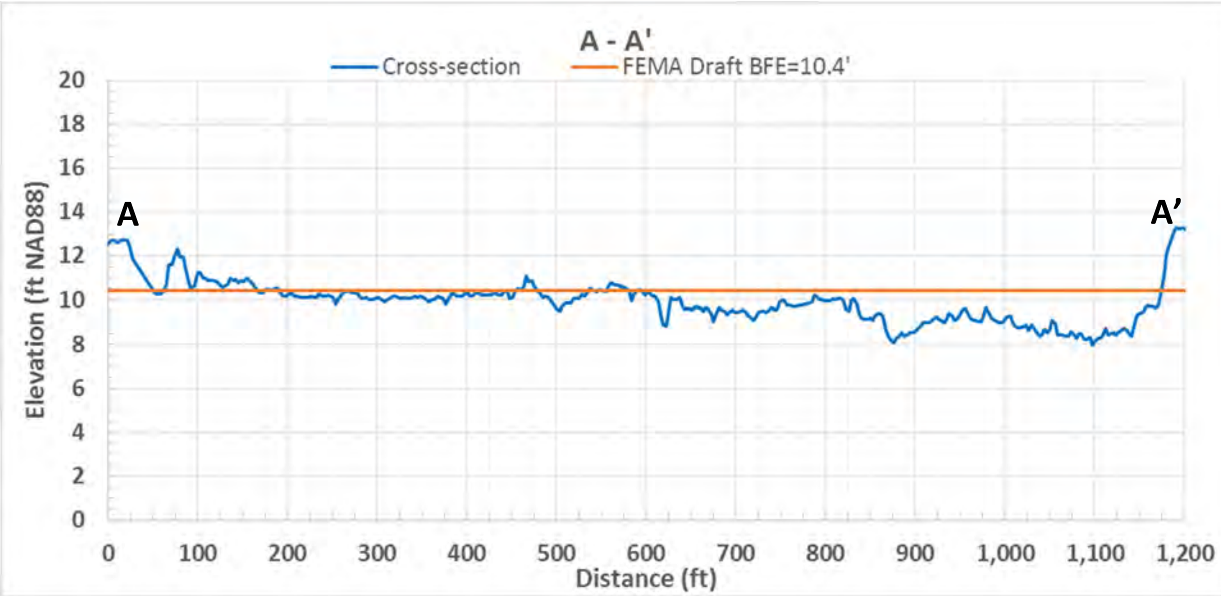

Figure 5-2. Profile Along South Bank of Navigable Slough

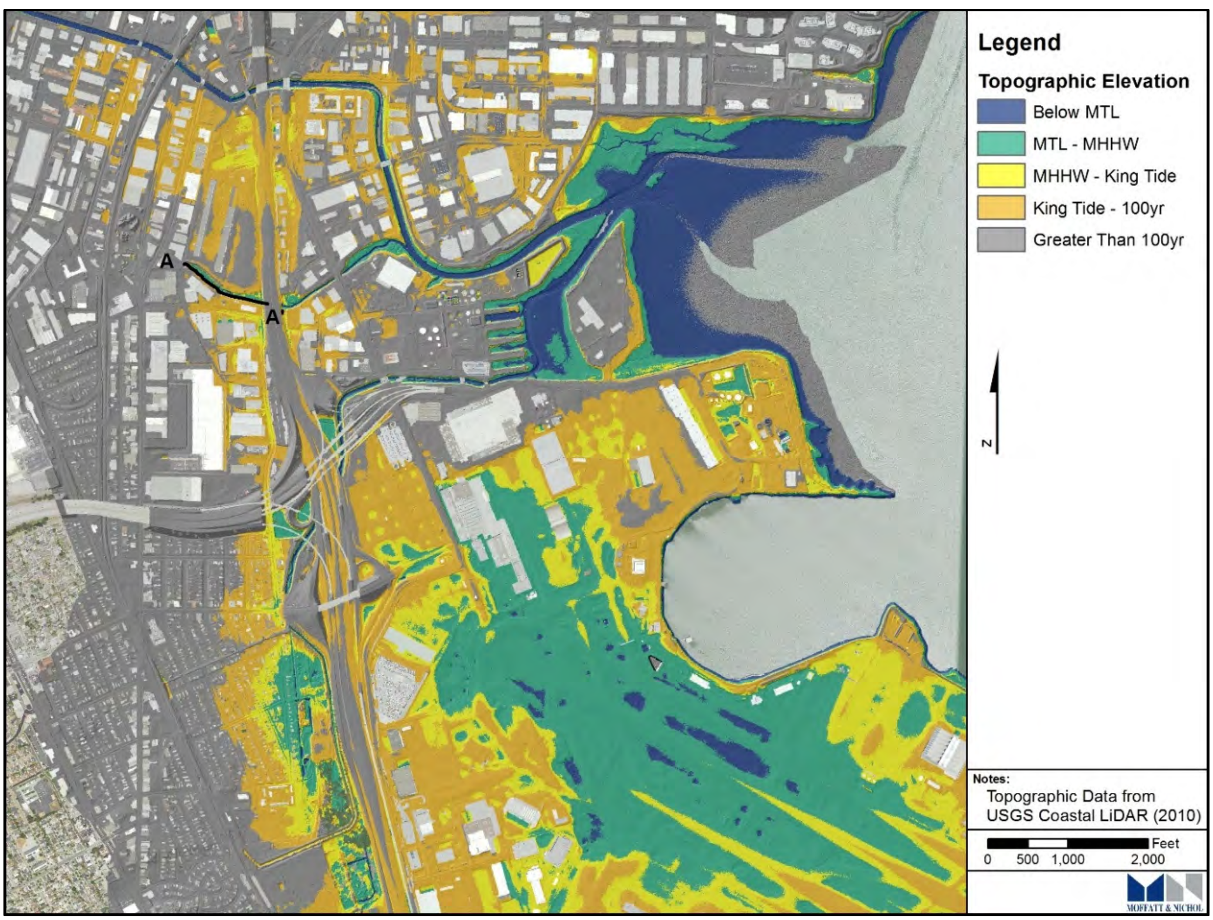

Figure 5-3. Location of Navigable Slough Profile Section

SSF Pump Stations

The City of South San Francisco has just recently begun the process of developing a storm drain master plan for the city. There are no conclusions or recommendations yet from that effort. It is unknown at this time whether the City's pump-stations have a sufficient capacity to accommodate the effects of SLR on the storm drain system.

Underground BART Lines

Underground sections of BART's W-line, which include trackway and stations from Colma to Millbrae, experience water intrusion due to the relatively high water table in the region, based on information provided via anecdotal evidence from BART's maintenance staff. SLR is anticipated to raise the water table and potentially exacerbate this vulnerability.

5.2 San Bruno Creek

5.2.1 Critical System Features

The system features providing flood protection for the lower watershed of San Bruno Creek are comprised of the following elements:

- The tide gate structure at the outlet of San Bruno Creek to the San Francisco Bay, maintained by the SMCFCD (see Figure 2-10) ;
- The two pump-stations, Walnut PS and Angus PS, maintained by the SMCFCD;
- The concrete box culverts that pass San Bruno Creek underneath Hwy-101, designed by Caltrans and maintained by the SMCFCD;
- The concrete box culvert that passes Cupid Row Canal underneath San Bruno Avenue, designed by Caltrans and maintained by the SMCFCD;

5.2.2 Vulnerabilities

San Bruno Creek Tide Gate Structure

The tide gate structure where the North Channel exits to the San Francisco Bay consists of four 5-feet diameter circular pipes with flap gates on the downstream side. The tide gate structure is about 60- feet long and spans approximately 100-feet over the channel. Drawings suggest that the channel and tide gate structure were designed for the 25-year return period year flow of 1,100 cfs with a tidal elevation of 6.8 ft NAVD88, which is MHHW tide at the site (SMCFCD, 1965).

For reference, the 25-year flowrate calculated in this study is 1,440 cfs. One contributing factor to this disparity in flow magnitude is most likely the additional development and resultant imperviousness within the San Bruno Creek watershed that has occurred over the past 50 years. The 10-year flowrate calculated in this study is 1,160 cfs, meaning the tide gates are now providing capacity for only an approximately 10-year design storm event.

The Hwy-101 culverts on San Bruno Creek, upstream of the tide gate structure, are four 8'x10' concrete boxes, which are significantly larger than the tide gate structure. The Hwy-101 boxes are capable of passing the 100-year design storm based on inlet control conditions, without any influence from downstream tailwater. However, in reality, the tide gate structure causes backwater within the system which limits the amount of flow that the Hwy-101 boxes can pass due to this outlet control condition.

Belle Air Neighborhood

There are two primary factors contributing to the overbank flooding upstream (south) of the San Bruno Avenue culvert. The first is the relatively low top-of-bank elevations on the west bank of Cupid Row Canal immediately upstream of San Bruno Avenue, and the second is backwater effects from the tide gate structure at the Creek's outlet to the Bay. The findings of this study show that with the 10-year flow condition and a +6.8' NAVD88 tide, overbank flooding is already encroaching upon the Belle Air neighborhood because of backwater effects from the tide gates limiting the capacity of the San Bruno Avenue and Hwy-101 culverts.

The consequences of SLR will cause increased backwater effects in the Creek due to flood flows being trapped upstream of the tide gates during high-tides. SLR will result in increased peak flood elevations in the overbank storage areas upstream of the Hwy-101 and San Bruno Avenue culverts, which will also increase the frequency of overbank flooding in the Belle Air neighborhood, to the point that it would become roughly an annual occurrence event.

Walnut Street and 7th Avenue Neighborhood

The San Bruno residential neighborhood at Walnut St. and 7th Ave. is vulnerable to overbank flooding from both the North Channel section of San Bruno Creek as well as from Navigable Slough. Backwater effects from the tide gate structure on San Bruno Creek result in elevated flood profiles in the Creek upstream of the Hwy-101 box culverts, which contribute to overbank flooding in the Walnut St. and 7th Ave neighborhood. The topographic elevations in this neighborhood are 2 - 3 feet greater than those in the San Bruno neighborhood of Belle Air, which is immediately to the south.

The reach of Navigable Slough upstream (west) of Hwy-101 has spots on the south bank that are below elevation +9' NAVD88. Overbank flooding from this reach of Navigable Slough, in the Colma Creek watershed, flows south along Shaw Rd. and underneath I-380, which then connects with the neighborhood at Walnut St. and 7th Ave and contributes to the residential flooding there (Shaw Road changes to 7th Avenue after crossing under I-380 and then continues in a southerly direction).

SFO Long-Term Parking Lot

The SFO Long-Term Parking Lot is susceptible to overbank flooding from south bank of San Bruno Creek, in the reach between the Hwy-101 culverts and South Airport Blvd. Low spots on the south bank are at elevations between +9' and +10' NAVD88. Some of the overbank flows would likely pond in the area under the highway overpass and re-enter the channel after the storm peak has passed. Other flows could potentially leave the main channel and flood SFO property. The elevation of South Airport Boulevard is slightly above +12.0' NAVD88, and it is believed that no flood flows would travel south along the street. The majority of the Long-Term Parking Lot is below elevation +10' NAVD88, with areas as low as +7' NAVD88, and would most likely receive the majority of the flood flows from the south bank of San Bruno Creek in this reach.

Underground BART Lines

Underground sections of BART's W-line from Colma to Millbrae experience groundwater intrusion, and SLR could potentially exacerbate this vulnerability by raising the water table.

6.0 CONCEPTUAL ADAPTATION MEASURES

The purpose of this section is to describe potential conceptual adaptation measures for the reaches/sections that have been identified as vulnerable to Sea Level Rise.

6.1 Colma Creek

6.1.1 Colma Creek Flood Control Channel Improvements

Floodwalls and Set-Back Levees

Due to the highly urbanized nature of the communities along Colma Creek, with development right up the edge of channel from the head waters of Colma Creek to the Bay, the options for adaptive flood mitigation options are limited. A complicating factor for mitigating flooding within the lower Colma Creek watershed is that improvements to the channel's floodwalls between Linden Ave and Spruce Ave would pass more flood volumes down to the lower reaches of the Creek below Hwy-101, which already has deficiencies in the existing flood wall elevations. The existing volume of overbank flows that leave Colma Creek upstream of Hwy-101 is providing flooding relief for the downstream reach. Any future channel improvements on Colma Creek downstream of Hwy-101 should factor in the potential for additional flood volumes related to upstream channel improvements. Based on physical constraints within the lower watershed, the primary flood mitigation option available for the SMCFCD is to raise the elevation of the existing levees and floodwalls.

The SMCFCD is limited in its ability to widen the Colma Creek flood control channel because of the limits of their jurisdiction, which could be a constraint on the potential use of set-back levees within the Colma Creek system.

Colma Creek Tide Gate & Pump Station

An alternative to increasing the floodwall and levee elevations on the Colma Creek flood control channel to mitigate for the impacts from SLR in the lower watershed is to construct a tide gate structure at the mouth of Colma Creek. The tide gate would prevent storm surges and increasing tidal elevations from propagating up the creek and causing flooding in the reach between the mouth and Hwy-101. This concept would require a large structure, over 200-ft long, to span the creek and tie into existing high ground, most likely adjacent to the City of South San Francisco Water Quality Control Plant. There is very little available open space areas in the lower watershed of Colma Creek to store runoff during a flood event. Therefore, a pump-station would also be required in this alternative to pass the relatively large discharges in Colma Creek during flood events without causing backwater flooding as a result of the tide gates. The potential alignments for a tide gate and pump station on Colma Creek are illustrated in Figure 6-1.

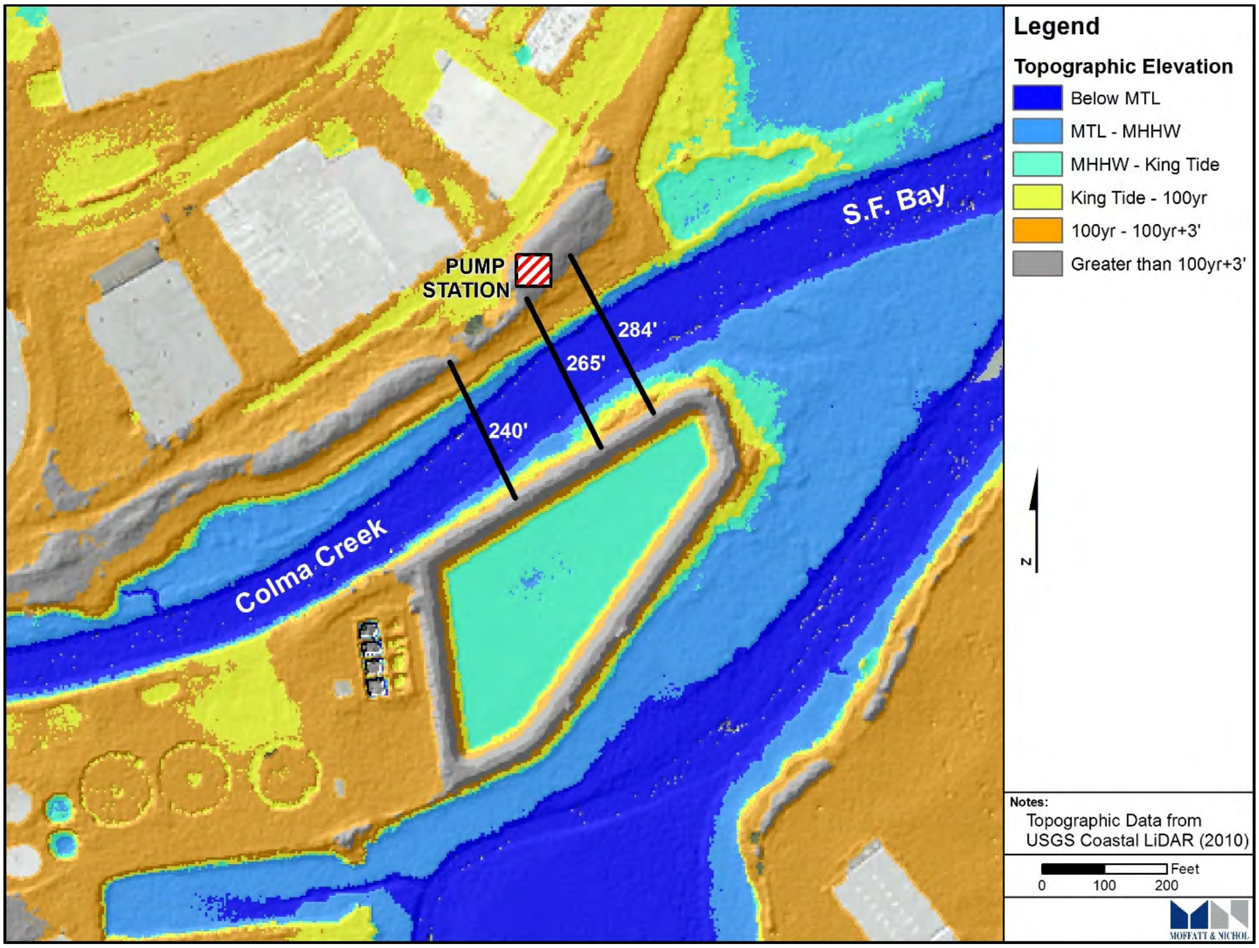

Figure 6-1. Colma Creek Tide Gate & Pump Station Potential Alignments

<u>Channel Deepening</u>

The reach of Colma Creek upstream of Hwy-101 is a concrete lined channel; therefore, channel deepening is not an option. Dredging the downstream reach of Colma Creek below Hwy-101, where the channel is not concrete lined, could potentially provide some additional storage within the system. However, it has been difficult in the past for the SMCFCD to obtain environmental permits to perform de-silting of the creek. Also, as normal tidal elevations increase over time due to SLR, the benefits of channel deepening will diminish as the baseline tailwater elevation rises within the system.

6.1.2 Navigable Slough Improvements

The existing south banks of Navigable Slough have low-spots that could contribute to flooding in SSF and San Bruno. However, the volume of stormwater that is routed to the Slough from SSF is relatively low. Therefore, storm surges could be prevented from moving up Navigable Slough by incorporating a flap gate on the existing culvert that passes Navigable Slough underneath South Airport Boulevard. This design would have to consider the potential for backwater effects upstream of the tide gates in Navigable Slough.

6.1.3 Colma Creek Surface Detention Storage

Another potential strategy to mitigate flooding within the Colma Creek system is to provide additional storage for flood volumes within the watershed through surface detention basins or underground storage vaults, to mitigate the existing overbank flooding that is occurring in the lower watershed. Due to the highly urbanized nature of the lower watershed, there are not many viable locations within the lower watershed to construct a detention basin.

One potential open-space site is Orange Memorial Park, which is located immediately adjacent to the Creek, roughly a half-mile upstream from the Spruce Avenue Bridge. Orange Park is relatively small and wouldn't be able to provide sufficient storage to mitigate all of the flooding issues in Colma Creek, but the 23-acre park could provide some relief as a detention basin. The storage volume from a 6-ft deep basin at the park would be sufficient to reduce the 100-yr hydrograph at Orange Park to a 25-yr peak.

Another potential site for detention storage within the lower watershed are the paved lots located immediately west of Produce Avenue in the City of South San Francisco. The Produce Terminal and the Park 'N Fly parking lot are the largest components of this contiguous set of private parcels, which sit between the Colma Creek channel and Navigable Slough. The combined site is approximately 30-acres, which could provide some flood relief as an underground storage vault. The storage volume from a 2-ft deep vault underneath the lots would be sufficient to reduce the 100-yr hydrograph at Utah Avenue to a 50-yr peak (independent of any storage at Orange Park).

In the middle and upper portions of the Colma Creek watershed, the majority of open areas are occupied by golf courses, such as the California Golf Club, or by the cemeteries in the City of Colma. The privately owned California Golf Club is located at a higher elevation than the Creek banks, making it infeasible to route flood volumes to the property by gravity flow.

There are a number of private parking lots in the middle and upper portions of the watershed that could potentially be used for storage by installing underground vaults. For example, the parking lot of the Costco big-box store at El Camino Real and Hickey Boulevard in South San Francisco is approximately 9-acres and is located immediately adjacent to the Colma Creek channel.

6.1.4 Regional Tidal-Barrier Structure

A larger regional tidal-barrier structure could be built spanning from the San Mateo County Transit District (SamTrans) peninsula (the leaf) north or west to the Bay Trail and Littlefield/Utah Ave, creating a wetlands basin behind the gates, as shown in Figure 6-2. The gates could be left predominately open and then closed at low tides ahead of large approaching storm events. This alternative would necessitate a large structure, greater in size than the ~110-ft long Palo Alto Flood Basin gates, and could be designed as an operable sluice gate structure. The benefit of this regional flood mitigation measure is that it would provide protection for both Colma Creek and San Bruno Creek. The tidal gates could be left open most of the year and could facilitate the creation of new inter-tidal wetland habitat on the upstream side of the gates. During heavy rains and high tides the gates could be closed to provide a catch basin for high fluvial water flows.

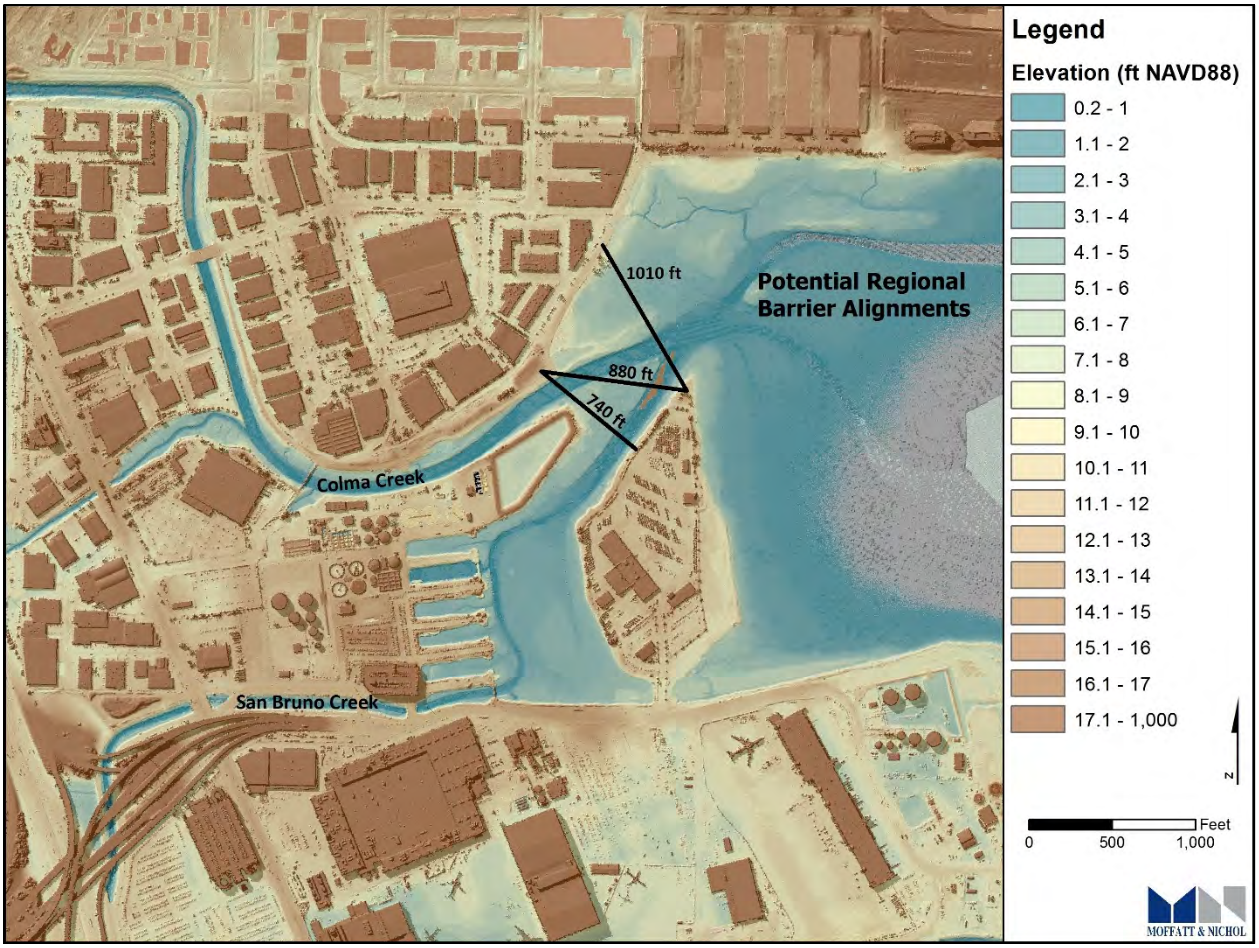

Figure 6-2. Regional Tide-Barrier Structure Potential Alignments

6.1.5 Alternative Management Concepts

Low-Impact Development

Another recommendation from this study's Working Group is that elements of the Low-Impact Development (LID) approach should also be applied as part of the overall strategy for addressing fluvial flooding risk by reducing imperviousness within the Colma Creek watershed. Common elements of LID include pervious pavement, cisterns and rain barrels, and French drain systems for groundwater recharge. The San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook, published by the San Mateo Countywide Water Pollution Prevention Program (SMCWPP, 2009) is an example of available guidance documents on incorporating LID design elements into urban environments.

However, it should be noted that the SMCFCD and the cities of South San Francisco and San Bruno are already participants in the San Mateo Countywide Water Pollution Prevention Program, which was mandated by the California Regional Water Quality Control Board (RWQCB) Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit that was adopted in 2009. Provision C.3 of the permit requires that new development and redevelopment incorporate LID techniques to prevent increases in runoff flows. Therefore, the implementation of LID design elements within the watersheds has theoretically already begun.

6.2 San Bruno Creek

6.2.1 Lower San Bruno Creek (North Channel) Improvements

As part of the SFO Shoreline Protection Feasibility Study (M&N+AGS, 2015) significant crest elevation deficiencies were found in the lower reach of North Channel, downstream of Hwy-101. As part of that SFO study, Schaaf & Wheeler identified four potential solutions for flood mitigation in the North Channel:

Pump Station on North Channel

The San Bruno Creek tide gate structure is only sized to convey 1,050 cfs given a downstream boundary condition at MHHW, which is approximately a 10-yr flow. One alternative is to construct a pump station that would carry the excess flows around the tide gate and into the San Francisco Bay. The pump station would require a footprint approximately 40-feet wide by 80-feet long. A possible location for the pump station is shown in Figure 6-3(a).

The main constraint on the pump station alternative is the high capital cost for a pump station that is not anticipated to be used frequently. A large generator would also need to be included to ensure proper function during a flood event (M&N+AGS, 2015).

Floodwalls on North Channel

Floodwalls could be constructed on both the left and right banks of the North Channel. Because the water is confined between the two floodwalls, the design flood elevation would increase versus the existing condition. The average bank elevation is around +12 ft NAVD88, and the floodwalls would also have to provide 3-ft of freeboard. There are two roadway crossing for the North Access Road that would require automatically closed flood gates such as those provided by FloodBreak®.

A possible alignment for the floodwalls is shown in Figure 6-3(b). The alignment on the right bank, within the airport property, turns south along South Airport Road. This alignment shortens both floodwalls significantly compared to the option of continuing the walls the entire length of the San Bruno Reach. However, it allows the south parking lot to flood during the 1%-annual-chance flood. The South Airport Road is at an elevation above the BFE, so it acts as a barrier to water in the parking lot (M&N+AGS, 2015).

Set-back Levee on North Channel

By setting a floodwall back from the channel and allowing flood flows to pond over the road, the height of the floodwall is reduced. Additionally, since the floodwall does not constrain the floodwaters so tightly, flooding on the north side of the channel is not exacerbated and it is not necessary to construct a second floodwall on the north bank. No automatic gates are required in this case.

Two possible alignments for the setback floodwall are shown Figure 6-4(c). The shorter alignment follows the South Airport Road, as is shown for the dual floodwall alternative shown in Figure 6-3(b): the south parking lot floods with this shorter alignment. The longer alignment more than doubles the length of the floodwall to protect the parking lot. In both cases, a slight incline to raise the roadway about 6 to 12-inches on North Access Road is required (M&N+AGS, 2015).

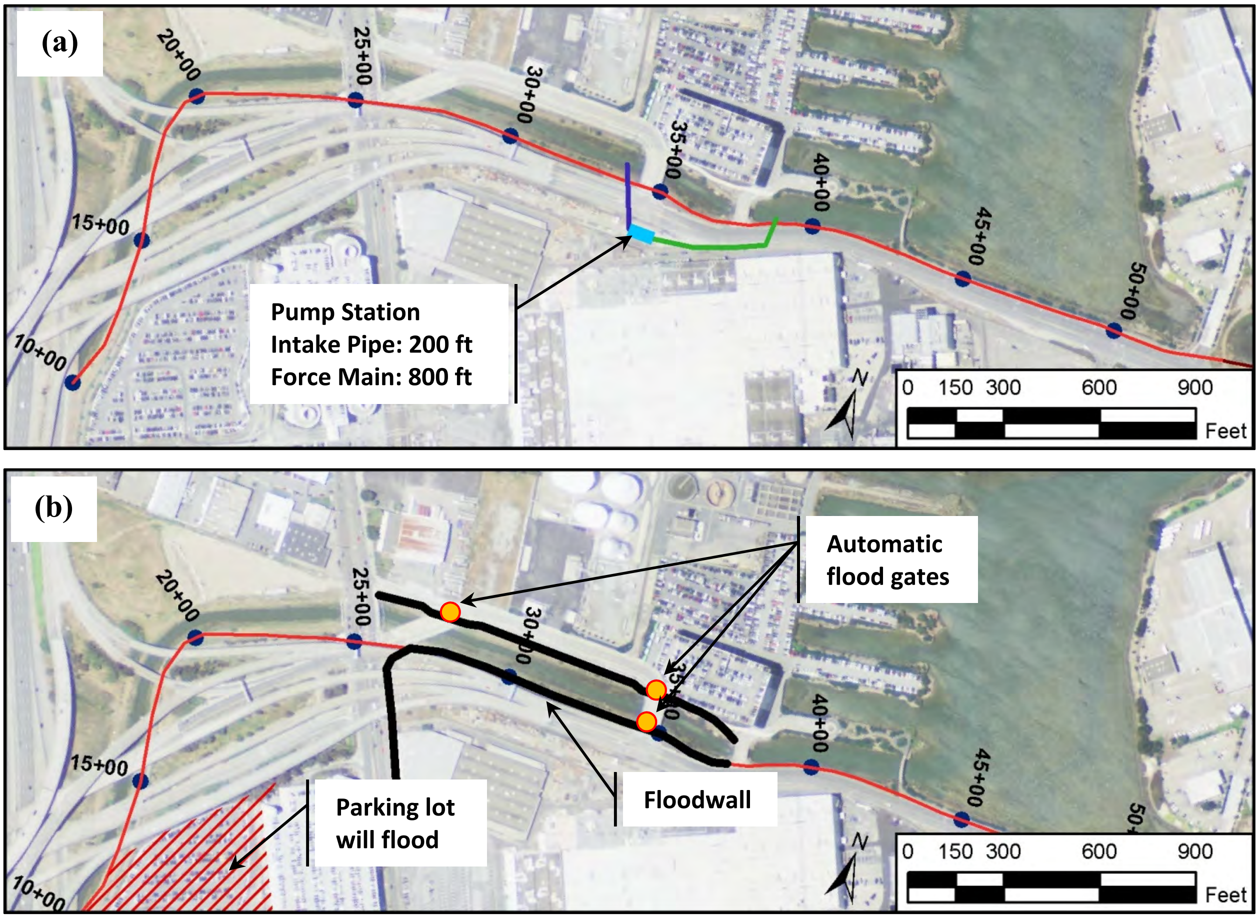

Figure 6-3. Alternatives for the North Channel (a) Pump Station (b) Floodwalls with South Parking Lot Flooding (M&N+AGS, 2015)

Upgrade the Tide Gate Structure (SMCFCD)

One mitigation alternative is to upgrade the current San Bruno Creek tide gates, located on the North Access Road by the multi-story SFO parking garage, to increase the flow capacity. The current tide gate structure is not considered adequate for any significant increases in fluvial flows or increased SLR. The existing tide gate structure has four 5-ft diameter culverts. For reference, the existing San Bruno Creek culvert underneath Hwy-101 has four 8-ft x 10-ft boxes. Both the Caltrans Hwy-101 culvert and the San Bruno Avenue culvert on San Bruno Creek have the capacity to convey the 100-yr creek flow rate, so these structures are not considered a constriction on the Creek.

Replacing the tide gate structure with one-size culverts to pass the 100-year storm event with a MHHW boundary condition would alleviate flooding of the SFO Long-Term Parking Lot and flooding upstream of Hwy-101 in residential areas of the City of San Bruno. A tide gate structure of two 10-feet by 10-feet square flap gates would lower upstream water surface elevations and lessen upstream flooding. A tide gate of this size would be comparable to the flap gate on the Millbrae Canal (12-feet by 10-feet). As part of the tide gate upgrade, the structure could also be certified through FEMA as a flood control structure, which would also have benefits for the City of San Bruno.

The tide gate location is shown in Figure 6-4(d). A roadway crosses the channel on top of the culvert supporting the tide gate, so the roadway would have to be closed for the duration of the construction project. However, as shown, there is an alternative crossing nearby, and this area does not appear to have a high level of traffic (M&N+AGS, 2015).

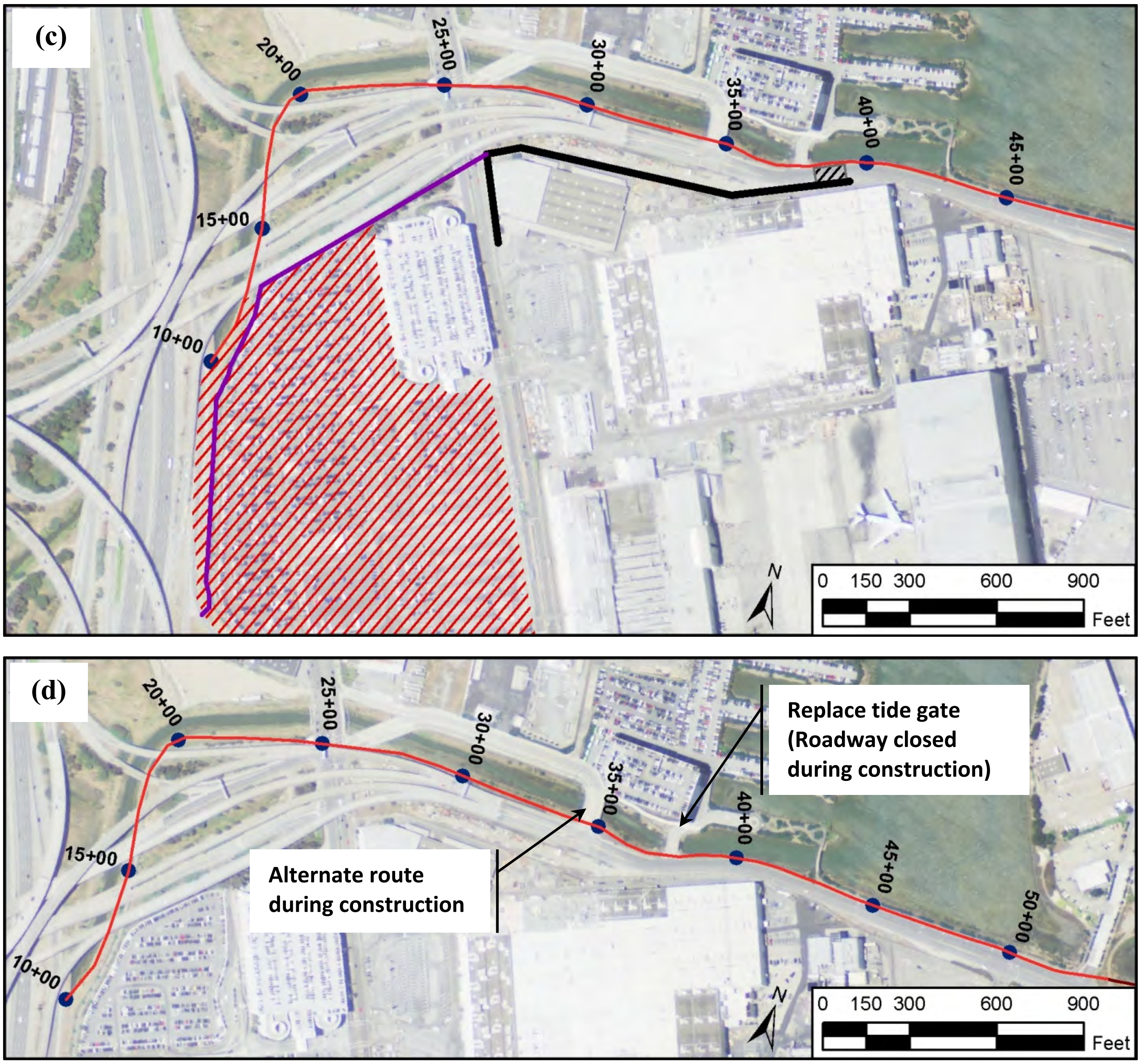

Figure 6-4. Alternatives for the North Channel: (c) Setback Floodwall (d) Replace Tide Gate (M&N+AGS, 2015)

6.2.2 San Bruno Creek Surface Detention Storage

Surface Detention and Set-Back Levees in Cupid Row Canal

Another mitigation alternative is to use the open space area on the west side of Hwy-101, which is owned by SFO, for flood retention storage. This could be accomplished by building set-back levees at the edge of the Belle Air neighborhood, between 7th Ave, San Bruno Ave and Highway 101, which is the Cupid Row Canal portion of the Creek. A potential set-back levee alignment is shown in Figure 6-5.

This alternative would have to account for critical infrastructure in the area, such as the PG&E sub-station within the Cupid Row Canal open-space and the adjacent Hwy-101; the increase in ponding depth within the area should not adversely affect this infrastructure. The design would also have to consider existing habitat in the open space for the San Francisco Garter Snake and the California Red-legged Frog, which are federally and state listed endangered species. Surface detention/wetland alternatives in the vicinity of SFO could potentially be constrained due to bird-strike hazards for the airport that would also have to be addressed.

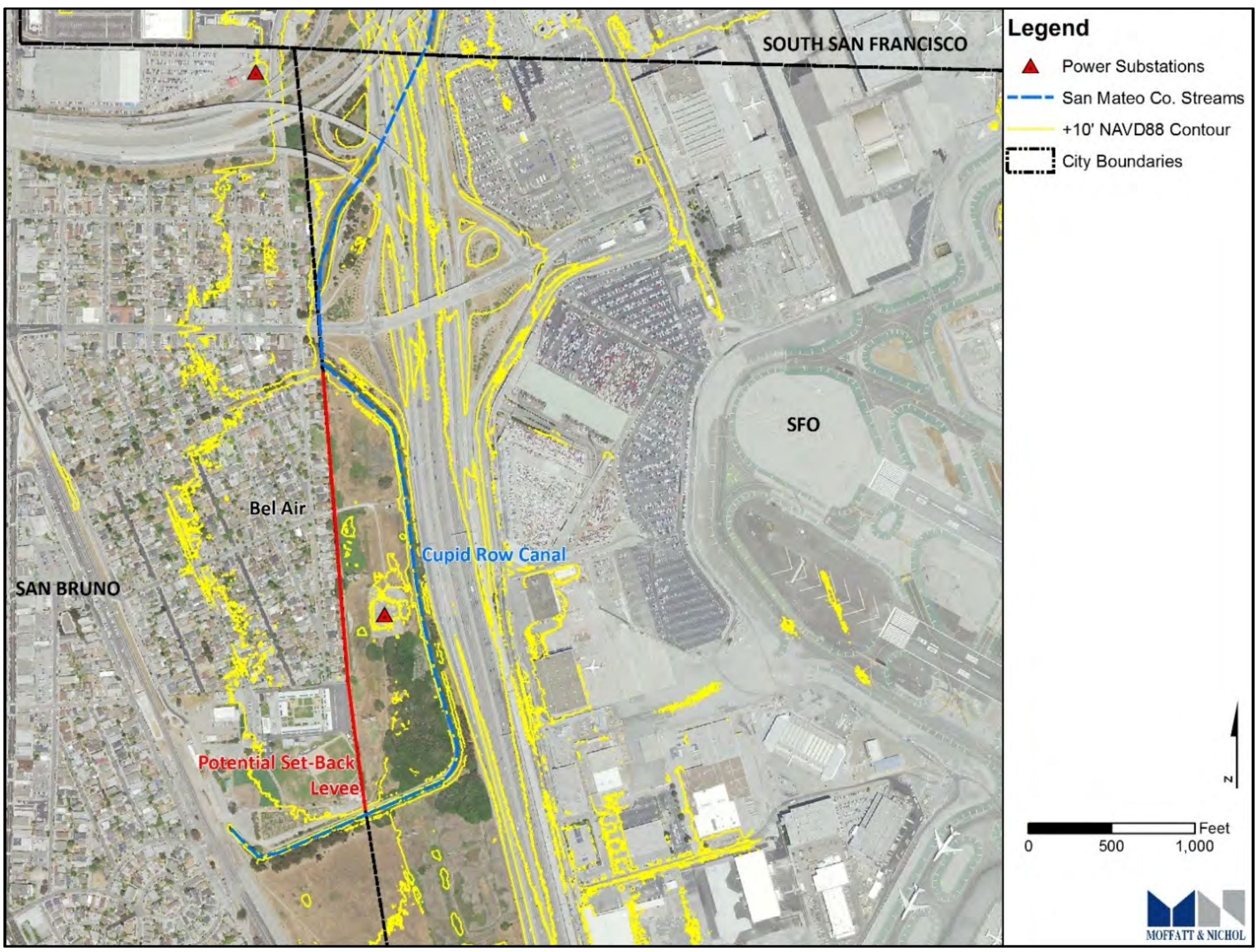

Figure 6-5. Potential Cupid Row Canal Set-Back Levee Alignment

Surface Detention in South Lomita Canal (Millbrae)

Another mitigation strategy that was identified at the last Working Group meeting is the potential for passing flood flows from Cupid Row Canal south into the South Lomita Canal in Millbrae. The structures that pass the South Lomita Canal underneath Hwy-101 have been identified as having additional capacity. Similar to surface detention storage in Cupid Row Canal, the South Lomita Canal area between the BART tracks and Hwy-101 could potentially have the capacity to retain more water from the San Bruno Creek watershed. The design would also have to consider the existing habitat in the open space for the San Francisco Garter Snake and the California Red-legged Frog, and this alternative could potentially be constrained due to bird-strike hazards for SFO. The increase in ponding depth within the area must not adversely affect existing infrastructure, such as the adjacent Hwy-101 and the BART trackway which is at grade in this area. The South Lomita Canal area is illustrated in Figure 6-6.

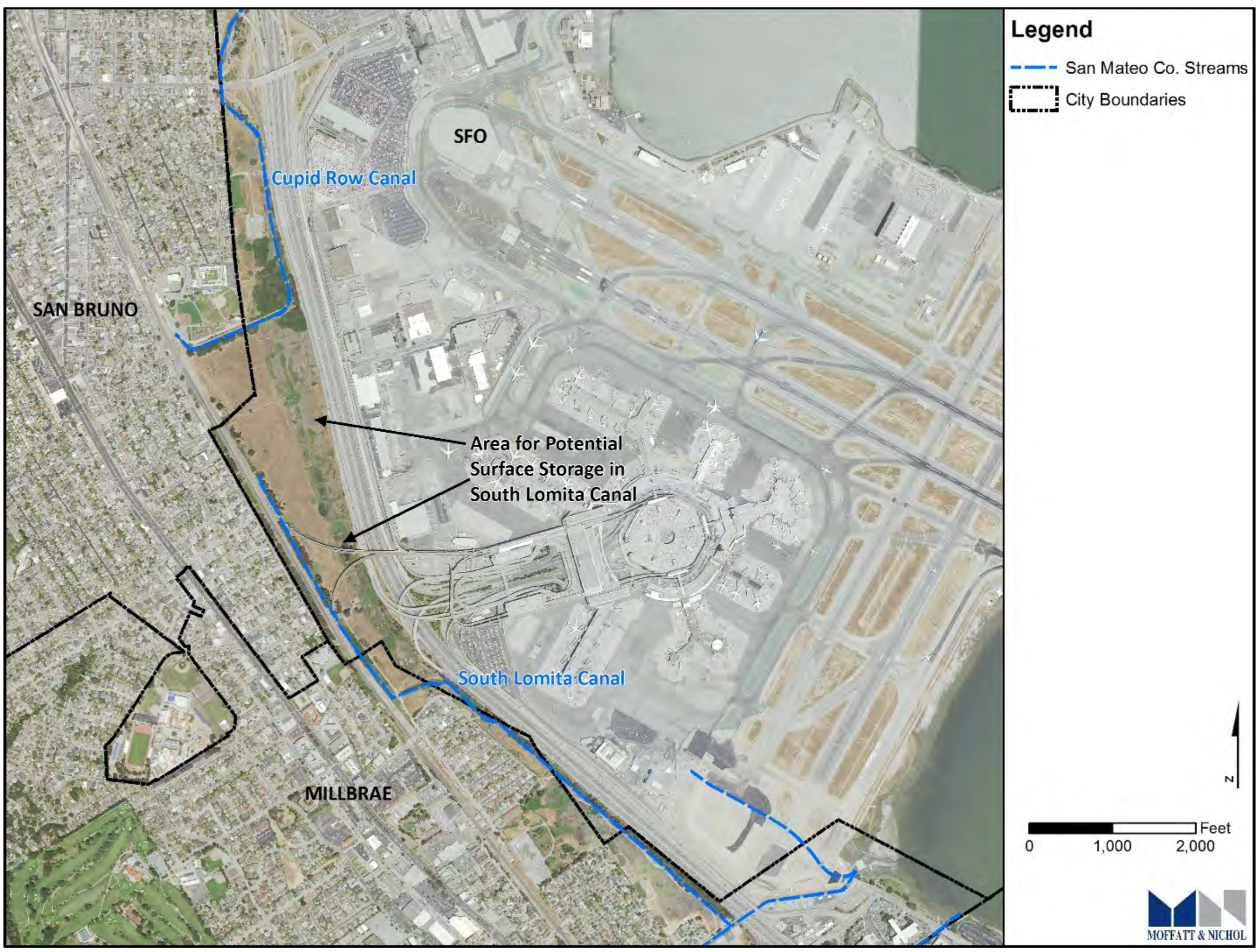

Figure 6-6. Potential South Lomita Canal Detention Storage

Surface Detention in the SFO Long Term Parking Lot (SFO)

Another adaptation strategy identified by working group participants was to use the SFO Long Term Parking Lot, which is currently at a relatively low elevation adjacent to the Creek, for additional surface detention storage. To offset the loss of parking capacity for SFO, an additional elevated parking structure within the footprint of the lot was proposed, which would have a high capital improvement cost. However, a design-build team has already been awarded a project by SFO to build a multi-story long-term parking structure within the surface parking lot, which could constrain the potential for surface detention within the lot. The SFO Long Term Parking Lot area is illustrated in Figure 6-7.

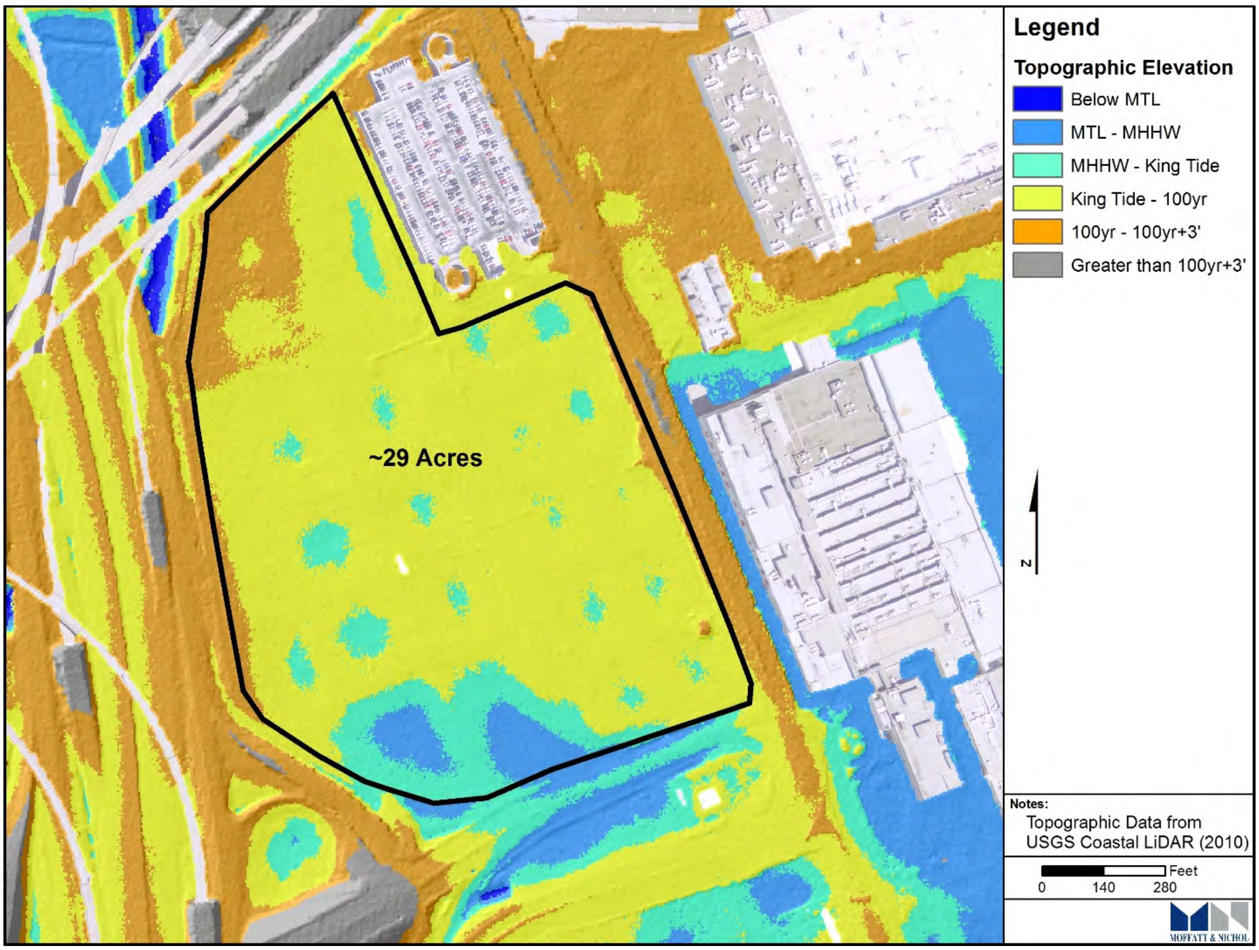

Figure 6-7. Potential Detention Storage in SFO Long-Term Parking Lot

Upstream Surface Detention

The City of San Bruno Storm Drain Master Plan (SDMP) proposed one possible upstream detention basin within the San Bruno Creek watershed near City Park, indicated at Crystal Spring Park (GHD, 2014). The Crystal Springs basin is in Watershed-B that drains directly to Cupid Row Canal. The proposed basin storage volume was 25 ac-ft, with a basin depth of 11-ft. However, the City believes that a more suitable location for this detention basin is at Lions Park in the Belle

Air neighborhood, since Lions Park is at the end of the storm conveyance system, adjacent to Cupid Row Canal.

A detention basin with a capacity of 25 ac-ft, whether in Crystal Springs or Lions Park, would be effective in reducing the extent flooding in the Belle Air neighborhood. That 25 ac-ft volume corresponds to the overbank volume in the west floodplain of Cupid Row Canal under existing conditions of a 15-year recurrence flood event and a flood elevation of approximately +7' NAVD88. Surface detention of 25 ac-ft in Watershed-B also has the potential to mitigate the severity of overbank flooding from a 100-yr flood event in Cupid Row Canal down to roughly a 50-yr flood. The upstream detention basins proposed in the SDMP are illustrated in Figure 6-8.

The SDMP also recommended one proposed upstream detention basin at Crestmoor Canyon (GHD, 2014). The Crestmoor Canyon basin is in Watershed-A, which drains to the North Channel immediately downstream of San Bruno Avenue. The proposed basin storage volume was 64.5 ac-ft, with a basin depth of 15-ft. Surface detention of 64.5 ac-ft in Watershed-A has the potential to mitigate the severity of overbank flooding from a 100-yr flood event in lower San Bruno Creek down to roughly a 20-yr flood. As stated in the SDMP, "The detention in watershed A (Project AD-2) would benefit both watersheds A and C and should be done as soon as funds are available." (GHD, 2014). The estimated cost for this project was approximately $3 million.

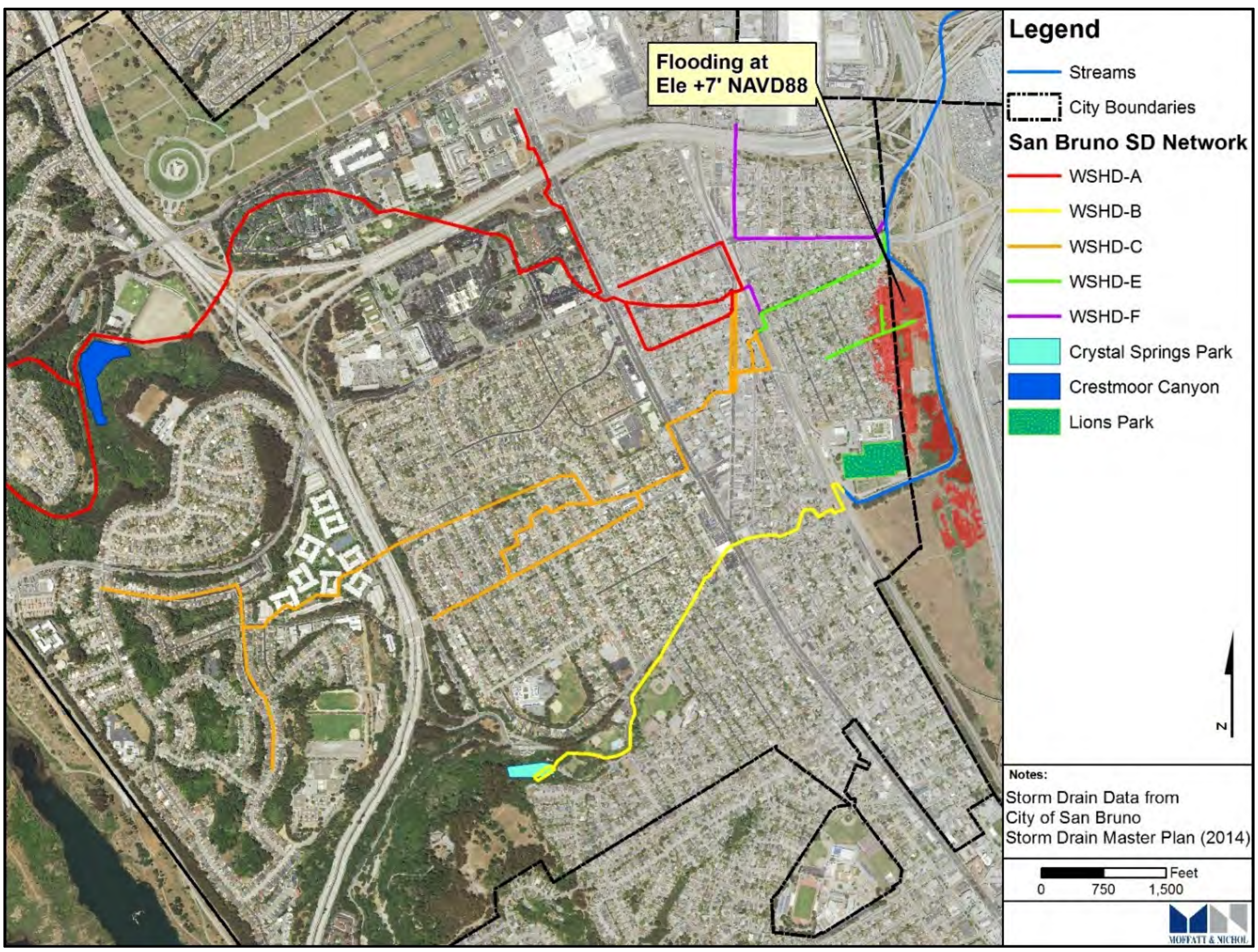

Figure 6-8. City of San Bruno SDMP Detention Basin Alternatives

Surface Detention between Hwy-101 and San Bruno Avenue (SMC)

This option envisions detention storage in the area immediately upstream of the Hwy-101 boxes, in SMCFCD's jurisdiction. This area has existing low spots that could be used for storage with the addition of set-back levees. Endangered species habitat has not been identified within this area, although the design would have to consider the potential for there being sensitive habitat in the area. Similar to Cupid Row Canal detention storage, this alternative could potentially be constrained due to bird-strike hazards for SFO.

6.2.3 Regional Tidal-Barrier Structure

The larger regional tidal-barrier structure alternative described in the Colma Creek section, spanning from the SamTrans peninsula (the leaf) north or west to the Bay Trail and Littlefield/Utah Avenue, would also provide the same flood protection benefits for the San Bruno Creek watershed.

6.2.4 Alternative Management Concepts

Low-Impact Development

Elements of the Low-Impact Development (LID) approach should also be applied as part of the overall strategy for addressing fluvial flooding risk by reducing imperviousness within the San Bruno Creek watershed. Common elements of LID include pervious pavement, cisterns and rain barrels, and French drain systems for groundwater recharge. LID strategies that promote groundwater infiltration in the lower watershed would also have to consider the potential impact from exacerbating groundwater intrusion into BART's underground assets in the region.

6.3 Adaptation Alternatives Criteria Matrix

The purpose of this section is to define the criteria that was developed with the Working Group that could be implemented moving forward as a means of assessing the viability of potential adaptation strategies. A list of the proposed adaptation strategy criteria, along with a brief description of each, is presented here:

- Construction Costs – how expensive is the strategy to design and build;
- Operational Costs – are there high long-term operation and maintenance costs associated with the strategy, such as the high costs of operating and maintaining a pump-station;
- Expected Performance (to meet intended purpose) - how effective is the strategy in mitigating increased flooding due to SLR;
- Environmental Impact - does the strategy have associated environmental impacts, e.g. increases in greenhouse gas emissions, or impair existing environment quality, such as existing endangered species habitat;
- Regulatory Constraints – does the strategy entail an extensive environmental permitting process, such as a full EIR document for CEQA, or is the strategy more easily permitted;
- Jurisdictional Constraints – can the strategy be implemented by a single jurisdiction, or does it require a regional collaborative effort from multiple jurisdictions;
- Stakeholder Support – does the strategy have the backing of the local stakeholder agencies and the local community;
- Land Ownership – could the strategy be implemented on public lands or would it have to be located on private property with potentially high land acquisition costs;
- Ability to Adapt in future – can the strategy be adjusted or adapted to changing conditions in the future, such as additional future SLR, or is the strategy inflexible;
- Constructability – can the strategy be constructed relatively quickly and easily, or does the project require a complicated construction effort with a long timeline;
- Environmental Benefits – does the strategy have the potential for benefits to the environment, such as through the restoration of wetlands, the addition of new habitat for endangered species, or the expansion of urban green space as a result of LID;
- Social and other Ancillary Benefits – the potential for value-added benefits of certain solutions to society and the community.

Table 6-1 and Table 6-2 present the adaptation alternatives criteria matrix for the Colma Creek and San Bruno Creek adaptation strategies identified in this study, respectively. The criteria that were identified have been left blank in the matrix awaiting further evaluation in subsequent studies. Since the scale of these alternatives vary significantly (e.g. detention vaults versus a major regional barrier), several different ways of evaluating these criteria should be developed in the next phase of work for these watersheds, such as a 5-point scale with assigned weighting factors. Weighting factors for the various criteria could be utilized by the stakeholders to emphasize criteria deemed to be more critical to the overall project success or criteria that are considered to be underrepresented within the matrix. There may have to be an initial, fatal flaw screening, after which a more refined screening could be performed. For example, if the necessary land is not available, then the alternative would not remain as an option.

Table 6-1. Adaptation Alternatives Criteria Matrix for Colma Creek

		Adaptation Options Criteria											
	Adaptation Strategy	Construct. Costs	Operat-ional Costs	Expected Performance (to meet intended purpose)	Environ-mental Impact	Regulatory Constraints	Jurisd-ictional Constraints	Stake-holder Support	Land Owner-ship	Ability to Adapt in future	Construct-ability	Environ-mental Benefits	Social & Ancillary Benefits
Colma Creek	Raise Floodwalls & Levees on Colma Creek												
	Set-back Levees for Colma Creek												
	Colma Creek Tide Gate & Pump Station												
	Channel Deepening / Dredging												
	Navigable Slough Improvements - South Bank / S. Airport Blvd. Culverts*												
	Upstream Detention - (Underground / Detention Basins)												
	Downstream Detention - (e.g. Produce Terminal)												
	Regional Tidal-Barrier												
	Low-Impact Development (LID)												

Note: * This Adaptation Strategy was identified as a near-term alternative that could potentially be implemented more quickly and efficiently.

Table 6-2. Adaptation Alternatives Criteria Matrix for San Bruno Creek

		Adaptation Options Criteria											
	Adaptation Strategy	Construct. Costs	Operat-ional Costs	Expected Performance (to meet intended purpose)	Environ-mental Impact	Regulatory Constraints	Jurisd-ictional Constraints	Stake-holder Support	Land Owner-ship	Ability to Adapt in future	Construct-ability	Environ-mental Benefits	Social & Ancillary Benefits
San Bruno Creek	Downstream Pump Station on North Channel												
	Floodwalls on North Channel												
	Set-back Levee on North Channel												
	Replace San Bruno Creek Tide Gate*												
	Cupid Row Canal Set-back Levee with Cupid Row Detention												
	Downstream Detention in South Lomita Canal												
	Downstream Detention in SFO Long-term Parking Lot												
	Upstream Detention - (Basins from City of San Bruno SDMP)*												
	Downstream Detention between Hwy-101 and San Bruno Ave												
	Regional Tidal-Barrier												
	Low-Impact Development (LID)												

Note: * These Adaptation Strategies were identified as near-term alternatives that could potentially be implemented more quickly and efficiently.

7.0 FINDINGS AND RECOMMENDATIONS

Significant findings and potential recommendations for next steps are listed in this section. Based on the data collection, stakeholder outreach and analyses performed for this study, it is apparent that a coordinated approach to addressing basin-wide flooding issues would be very advantageous to the region. There is valuable data related to the drainage system, flood prone areas, design criteria, and potential mitigations that resides with the individual stakeholders, and there is some coordination that occurs which follows jurisdictional boundaries.

7.1 Findings

A list of the significant findings of the study is presented below:

- The lower watersheds contain significant public infrastructure.
- The lower watersheds contain valuable habitat for threatened and endangered species.
- Residential neighborhoods in the lower watersheds are susceptible to severe flooding; the San Mateo County Flood Control District, the SSF and San Bruno Public Works Departments, and local residents are all aware of the problem.
- An updated analysis of riverine flooding for the region's Flood Insurance Study has not been performed in 30-years.
- The development within lower watersheds, east of the Caltrain tracks, has been built on reclaimed marshlands which are settling, resulting in the need for protection by levees.
- The existing San Bruno Creek tide gates only has the capacity to pass a 10-yr flowrate, which contributes to backwater flooding within the lower creek system.
- San Mateo County has existing flow gage data on Colma Creek at Orange Park, but this gage should be augmented with additional water-level gages in the lower watersheds to facilitate future engineering studies.
- SLR has a significant impact on flood elevations in Colma Creek downstream of Utah Ave. In the reach between Utah Ave and Hwy-101, SLR appears to have a much smaller impact on the water surface profiles. And in the reach upstream of Hwy-101, SLR appears to have only a negligible impact on flood stages in the creek.
- The high concentration of existing development in the Colma Creek watershed requires a watershed-based approach and prioritization of mitigation based on vulnerabilities.
- SLR will exacerbate backwater flooding in San Bruno Creek, and the entire creek from the tide gates up through Cupid Row Canal is susceptible to impacts from SLR. SLR will increase the frequency of overbank flooding in the Belle Air neighborhood, to the point that it would become about an annual occurrence event.
- Upgrading the San Bruno Creek tide gate structure would have immediate benefit in reducing flood elevations within the lower watershed.

- The San Bruno SDMP proposed two upstream detention basins that would mitigate the severity of overbank flooding in Cupid Row Canal and the North Channel.

7.2 Recommendations

7.2.1 Establish Governance Structure, Collaboration Strategy, and a Regional Working Group

Currently, the Colma Creek Flood Control Zone includes the cities of Colma, South San Francisco, San Bruno, Daly City, as well as the San Mateo County Flood Control District. The Colma Creek Flood Control Zone Citizens Advisory Committee meets regularly so that the respective agencies can coordinate flood control improvement projects within each of their jurisdictions. The San Bruno Creek Flood Control Zone currently does not have a comparable Citizens Advisory Committee, since the watershed is located almost entirely within the City of San Bruno.

There would be value for the Working Group that was assembled for this study to continue collaborating, as there is no other similar forum. It may be possible to even form a governance structure to facilitate the continued collaboration of all the stakeholders, such as a Regional Watershed Management Working Group to address the complex problems of coastal and fluvial flooding within the watersheds' various jurisdictions, which would be exacerbated by SLR.

7.2.2 Develop Regional Watershed Management Plans

Establishing a vision for the management of the lower watersheds by conducting/developing Regional Watershed Management Plans would benefit the stakeholders. The combined watersheds of Colma Creek and San Bruno Creek pass through multiple jurisdictions, including portions of Colma, South San Francisco, San Bruno, Daly City, and Unincorporated San Mateo County. Since some of the proposed flood mitigation and SLR adaptation strategies focus on implementing design elements throughout the larger watershed areas, such as smaller surface detention basins and LID, developing an overall regional watershed management plan for the combined Colma Creek and San Bruno Creek watersheds would help the jurisdictions plan and prioritize these smaller design elements in a concerted manner.

7.2.3 Conduct Focused Research & Studies

Based on discussions at the Working Group meetings, there would be value in performing focused research and studies to assess the viability of potential adaptation strategies for the region and to evaluate the adaptation strategy criteria for a more refined screening of the alternatives. Examples of these subsequent studies could include:

- Document lessons learned from other regions by reviewing region-wide adaptation studies from neighboring flood control agencies, such as the Santa Clara Valley Water District, the Alameda County Public Works Agency, the Contra Costa County Flood Control District, and the Marin County Flood Control District.
- Perform environmental studies to evaluate potential impacts to Endangered Species Habitat from the adaptation alternatives, such as the viability of storing additional stormwater

runoff in the Cupid Row Canal and South Lomita Canal lowlands, which are existing Endangered Species Habitat.

- Conduct Flood Insurance Studies for riverine flooding.
- Perform groundwater percolation tests to assess the viability of various land uses for upstream detention and LID within the watersheds.
- Document the existing land uses and temporary easements within the watersheds.
- Complete an asset inventory for assets susceptible to SLR issues in the watersheds.

7.2.4 Initiate Implementation Plans for Identified Alternatives

The next phase of engineering studies and research for this project should focus on the adaptation strategy alternatives which could seemingly be implemented more quickly and efficiently than some of the other more long-term strategies. For example:

- Improvements to Navigable Slough would have immediate benefit to neighborhoods within both SSF and San Bruno.
- One of the two surface detention basins proposed in the recent San Bruno SDMP, Crestmoor Canyon, was recommended as soon as funds are available (GHD, 2014) and would help mitigate the severity of overbank flooding in Cupid Row Canal and the North Channel.
- The existing San Bruno Creek tide gates are not a FEMA certified and accredited structure. Acquiring FEMA accreditation would potentially have benefit to the residential communities in lower San Bruno in regards to FEMA Special Flood Hazard Zones and the need of homeowners to purchase flood insurance.

7.2.5 Develop an Information-Sharing Platform

As part of the cooperative nature of a regional Working Group, information on stormwater infrastructure, natural resources, and other factors affecting how flood control and LID resources are managed should be shared among stakeholders. Increased information sharing will aid in allowing all stakeholders to better manage their aspects of stormwater infrastructure in the area and will help avoid duplication of efforts for new data gathering and data assimilation.

An information-sharing platform could also facilitate the sharing of Geographical Information System (GIS) data and relevant engineering and scientific information amongst the stakeholders. The platform could also enable the stakeholders to improve monitoring and reporting on various aspects of the two watersheds.

7.2.6 Education/Public Outreach

Some of the recommended adaptation strategies in this study would be greatly facilitated by having a broader level of support and understanding from the public, such as ballot measures for countywide bonds or more stringent requirements for LID techniques. There is a potential benefit to the stakeholders in undertaking efforts to educate the public through outreach programs on the implications of SLR to their communities and the adaptation strategies that have been identified to mitigate for these effects.

7.2.7 Identify Potential Grants and Funding Sources

Given that the benefits of flood and SLR mitigation are region-wide, opportunities for grant funding, assessments, bonds, and levies should be investigated. Potential sources of funding for subsequent studies in the lower Colma Creek and San Bruno Creek watersheds include:

- Climate Ready Grant Program: Climate Ready Grants are funded by the California Coastal Conservancy, and the purpose of the grant program is to help advance planning and implementation of on the ground actions that will lessen the impacts of climate change on California's coastal resources.
- IRWM Grant Program: The Integrated Regional Water Management (IRWM) Grants are funded by the California Department of Water Resources as a collaborative effort to manage all aspects of water resources in a region. IRWM involves multiple agencies, stakeholders, individuals, and groups, and attempts to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions.
- Coastal Resiliency Grant Program: The Coastal Resiliency Grants are administered by NOAA's National Ocean Service, focusing primarily on the support of regional approaches to building resilience of coastal regions, communities, and economic sectors through planning and implementation actions. The grant program emphasizes nature-based infrastructure (e.g. wetlands) to build coastal resilience that provides benefits to coastal communities (storm protection) and coastal ecosystems (habitat).
- Countywide Bonds: The San Mateo County Flood Control District is a Countywide Special District that was created by State legislation in order to provide a mechanism to finance flood control projects. Countywide bond measures could be used to fund improvements within the Colma Creek and San Bruno Creek Flood Control Zones.

7.2.8 Incentivize Basin-Wide LID

Currently, the Municipal Regional NPDES Permit for San Mateo County has a threshold of 5,000 square feet of impervious surface for new development and redevelopment projects to incorporate LID techniques; that threshold could be reduced or eliminated. The cities could also prioritize implementing LID techniques on public lands within their jurisdictions. There may be value to each of the cities within the two watersheds to incentivize the additional use of LID within the watersheds.

8.0 REFERENCES

Brown & Caldwell. (2012). *Walnut and Angus Stormwater Pumping Stations, Preliminary Design Report*. Prepared for San Mateo County Flood Control District.

Caltrans. (1947). As-Built Plans for Hwy-101 in the City of South San Francisco between North City Limits and 0.35 mile south of Colma Creek.

Caltrans. (1968 and 1972). City of San Bruno Drainage Analysis, Intersection of El Camino Real (Route 82) and Route 186.

Caltrans. (1969). As-Built Plans for Hwy-101 Bridge Widening at Colma Creek.

Caltrans. (1969). Drainage Analyses and Plan Set for El Camino Real in San Bruno and South San Francisco between 0.1 mile south of Sneath Lane and 0.1 mile north of Orange Ave.

Caltrans. (1988). As-Built Plans for Hwy-101 in the City of South San Francisco and Brisbane from 0.2 mile south of Sierra Point off-ramp overcrossing to Grand Ave undercrossing.

Caltrans. (1971). Drainage Plans of Intersection of I-380 and Hwy-101.

Caltrans. (1971, 1973 & 1976). Drainage Plans and Plan Set for Interstate 380 from Cherry Ave to 0.2 mile east of Hwy-101 and on Hwy-101 from 0.7 mile south of San Bruno Ave to South San Francisco Belt Railroad overhead.

Caltrans. (1972). Drainage Analysis for Route 186 (I-380) from Cherry Ave to 0.1 mi east of Route 82 and for Route 82 from San Bruno Ave to 0.1 mi north of Sneath Lane.

Caltrans. (1973). As-Built Construction Development Plans of North Channel at Intersection of HWYs 101 and 380.

Caltrans. (1973). As-Built Drainage Plans of North Channel underpassing Hwy-101.

Caltrans. (1973). Plans and Drainage Report for Navigable Slough.

Caltrans. (1997). As-Built Cross Culverts along Hwy-101 at Armour Ave, California Ave, & Grand Ave.

Caltrans. (2000). As-Built Construction Plans of San Bruno Channel at Intersection of HWYs 101 and 380.

Caltrans. (2000). As-Built Construction Plans of San Bruno Channel Dredging at Intersection of Hwy-101 and I-380.

CO-CAT (2013). *State of California Sea-Level Rise Guidance Document*. March.

Foxgrover, A. C., Jaffe, B. E., Hovis, G. T., Martin, C. A., Hubbard, J. R., Samant, M. R., & Sullivan, S. M. (2007). *2005 Hydrographic Survey of South San Francisco Bay, California, U.S. Geological Survey Open-File Report 2007-1169* (p. 113).

GHD (2014). *City of San Bruno Storm Drain Master Plan, Final Report*. Prepared for the City of San Bruno. June 2014.

Moffatt & Nichol + AGS JV. (2013). San Francisco International Airport: SFO Shoreline Protection Study. Phase 2 – Coastal Analysis Report.

Moffatt & Nichol + AGS JV. (2015). San Francisco International Airport: SFO Shoreline Protection Study. Evaluation and Recommendations Report.

NGS (2015). Vertical Datums. http://www.ngs.noaa.gov/datums/vertical/

NOAA Climate Program Office (2012). *Global Sea Level Rise Scenarios for the United States National Climate Assessment*. Technical Report OAR CPO-1. December.

NOAA. (2014). NOAA Tides & Currents: Water Levels – Station Selection. <http://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels>

NRC, Committee on Sea Level Rise in California, Oregon, and Washington 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*.

Pacific Institute (2012). *The Impacts of Sea Level Rise on the San Francisco Bay.* A White Paper from the California Energy Commission's California Climate Change Center, CEC-500-2012-014, July 2012.

PB/MC. (1996). Drainage Report for Hwy-101 from 0.2 km north of Millbrae Avenue overcrossing to 0.3 km north of Interstate 380 separation, on Interstate 380 from San Francisco International Airport to San Bruno Avenue overcrossing and at the San Francisco International Airport.

PRISM Climate Group. (2014). Oregon State University, http://prism.oregonstate.edu; created 5/2/2014.

San Mateo County. (1975). Drainage Plans for Colma Creek Flood Control Project at Produce Avenue Bridge.

San Mateo Countywide Water Pollution Prevention Program (2009). *The San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook.* First ed., January 2009.

San Mateo County Flood Control District (2006). Colma Creek Flood Control Channel Improvements Projects, Plan-Set. Rev. April 2006.

Schaaf & Wheeler. (2012). City of South San Francisco: South San Francisco / San Bruno Water Quality Plant Flood Protection Study. June.

Santa Clara County. (2007). *Drainage Manual*, California, August 2007.

Tucker & Associates. (2011). *Survey Report for the United States Army Corps of Engineers Navigation Project at Oyster Point Marina, South San Francisco, CA* (p. 4).

United States Army Corps of Engineers (USACE). (1984). *San Francisco Bay Tidal Stage vs. Frequency Study*.

USACE, San Francisco District. (2011). San Francisquito Creek, San Mateo and Santa Clara Counties, California. Without Project Conditions: Coincident Frequencies Analysis.

USDA. (1986). *Urban Hydrology for Small Watersheds, TR-55.* Natural Resources Conservation Service. June 1986.

USDA. (1991). *Soil Survey of San Mateo County, Eastern Part, and San Francisco County, California.* Natural Resources Conservation Service. May 1991.

USGS. (1981). *Guidelines for Determining Flood Flow Frequency*, Bulletin 17B of the Hydrology Subcommittee; Revised September 1981; Editorial Corrections March 1982

USGS. (2014). USGS Water Data for the Nation. http://waterdata.usgs.gov/nwis

Wilsey, Ham & Blair, (1965). *San Bruno Creek Flood Control Zone.* Prepared for San Mateo County Flood Control District, August 1965.

APPENDIX A – TOPOGRAPHIC SURVEY

APPENDIX A: Survey Data

The collection of additional survey data was necessary to facilitate the development of the hydraulic model for the open channel portion of lower San Bruno Creek. Therefore, survey transect data was collected by Meridian Surveying along the open channel sections of Cupid Row Canal and North Channel, with the cross-sections spaced at roughly equal increments along the channel. The in-channel data was used to augment the high resolution LiDAR data sets that were available from SFO and the County of San Mateo.

The field survey was performed by Meridian Surveying on 11/14/2014 and 11/17/2014.

The extent of the survey points are illustrated in Figure A-1.

The survey data points (P,N,E,Z,D) presented in tabular format below.

The control on the survey was the same control used for SFO Shoreline Protection survey (M&N+AGS, 2013).

Coordinate system:	CA State Plane Zone 3 Horizontal NAD83 Epoch 2007
Datum:	Vertical NAVD88 (Geoid 2009)
Units:	US Survey Feet

NGS control used

NGS PID	Name
DG6888	Seaplane (Held)
AB7679	HPGN D CA 04 GF
AB7676	HPGN D CA 04 FG

SFO Control Tied

BM 3
BM11
BM 15
BM 16
BM 60
CP1
CP2
K2

Field codes used:

EW – edge of water	FL – Flow line
AB - aggregate base	TB – top of bank
BW – back of wall	GB - Grade Break
EC – edge of concrete	NG- Natural Ground
LP – Low point	

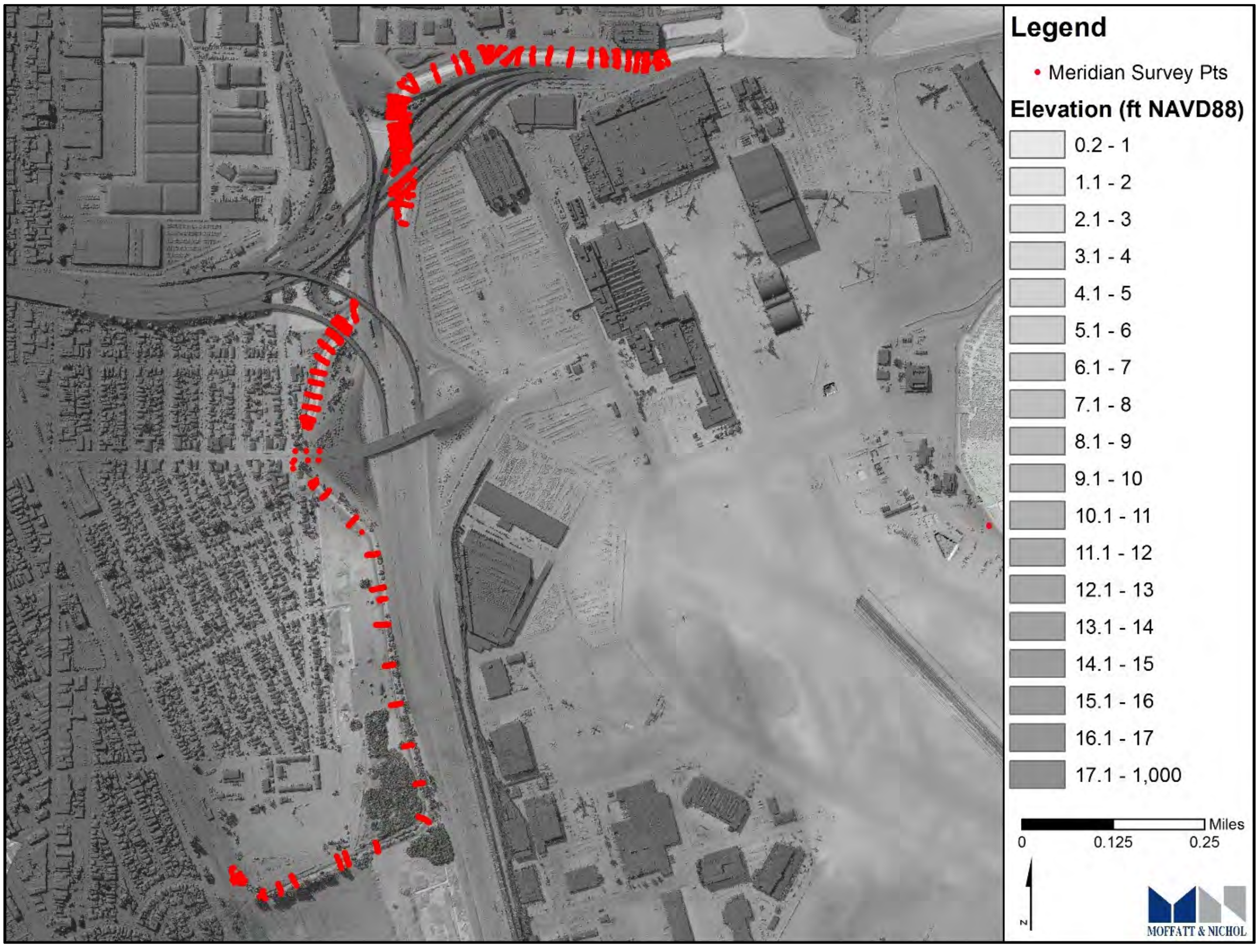

Figure A-1. Survey Data Collected on San Bruno Creek, November 2014.

APPENDIX B – HYDROLOGIC AND HYDRAULIC MODELING REPORT

Schaaf & Wheeler
Consulting Civil Engineers

870 Market Street, Suite 1278
San Francisco, CA 94102
(415) 433-4848
FAX (415) 433-1029

FINAL MEMO

TO:	Moffatt & Nichol	DATE:	January 22, 2015
FROM:	Robin J Lee, PE Dan Schaaf, PE	JOB #:	MOFF.02.14
SUBJECT:	**Hydrologic and Hydraulic Modeling for the SFO/San Bruno Creek/Colma Creek Resiliency Study**		

This technical memorandum provides an overview of Schaaf & Wheeler's hydrologic and hydraulic modeling assessment of San Bruno Creek (including Cupid Row Canal) and Colma Creek (including Navigable Slough). This analysis is meant to assist in the development of adaptive management strategies to protect the Cities of San Bruno and South San Francisco and the International Airport (SFO) from existing flooding problems and potential future problems that may arise from sea level rise (SLR).

Data

Models

In 2013, a hydraulic model was developed for San Bruno Creek that included the channel downstream of highway 101 to the tide gate structure. In 2012, HEC-RAS models were created for Colma Creek and Navigable Slough for an assessment of the treatment plant located near the mouth of Colma Creek.

As-Builts

Moffat & Nichol collected storm drain data from both South San Francisco and San Bruno. In addition, as-built information was provided by Caltrans and the San Mateo Flood Control District.

Reports

In 2014, the City of San Bruno completed a Storm Drain Master Plan (SDMP) that looked at the capacity of the system based on the 25yr flows (GHD, 2014).

Survey

Meridian spent three days in the field collecting cross section information along Cupid Row Canal and San Bruno Channel. These cross sections did not extend into the low flow channels where water was present.

Hydrologic Flows

Colma Creek and Navigable Slough

In 2012, Schaaf & Wheeler studied the risk of flooding at the South San Francisco/San Bruno Water Quality Control Plant (WQCP). This study evaluated the risk posed to the WQCP from San Francisco Bay tide and wind generated wave run-up. Potential flooding hazards from Colma

Creek, Navigable Slough, San Bruno Channel, and localized runoff were also analyzed. The findings of this analysis are summarized in the report entitled *South San Francisco/San Bruno Water Quality Control Plant Flood Protection Study*, 2012. The hydrologic analysis performed in 2012 was used for this study as the methodology and findings of the 2012 study were approved by FEMA. The HEC-RAS model was used as the basis and then updated based on Caltrans as-built plans for the highway 101 crossing.

Watershed

Colma Creek extends from San Bruno Mountain to its outlet at the San Francisco Bay just north of the San Francisco Airport and south of Point San Bruno. (See a vicinity map in Figure 1.) Colma Creek drains portions of Colma, South San Francisco, San Bruno, and Daly City. The southern border of the basin is the San Andreas Fault while the northern edge terminates at the San Bruno Mountain ridge and the west is bounded by California State Highway 1. The total drainage area is approximately 16 square miles and is mostly developed. Land uses and the corresponding percent impervious areas were determined based on aerial photographs and City and County zoning maps.

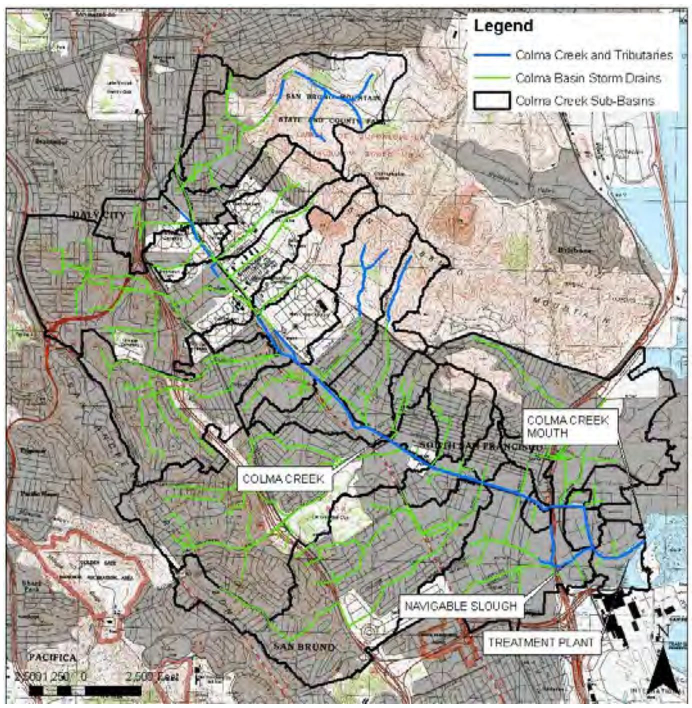

Figure 1: Colma Creek Watershed Boundaries

Methodology

A modified version of the hydrograph method outlined in the *Santa Clara County Drainage Manual* (SCCDM 2007) was used to estimate flood-frequency discharges for the surface creeks.

Precipitation

Precipitation patterns were based on the SCCDM 2007 and local Mean Annual Precipitation (MAP) values located at the centroid of each sub-basin. The pattern was based upon the maximum 24 hours of rainfall during the three-day December 1955 storm event, still considered to be the storm of record for northern California. The hourly distribution of rainfall from 1955 has been adjusted and balanced to preserve local rainfall intensity-duration-frequency statistics. Thus the 24-hour rainfall distribution may be used even where shorter duration storms are more critical, such as the smaller urbanized basins of Colma Creek. Detailed analyses can be found in *South San Francisco/San Bruno Water Quality Control Plant Flood Protection Study*, 2012.

Rainfall-Runoff Modeling

A unit hydrograph is a numerical representation of the time response of catchment runoff caused by one inch of excess rainfall applied uniformly over a unit of time. Many different techniques are available to estimate unit hydrographs. The SCS-dimensionless unit hydrograph was used. Further detail is provided in *South San Francisco/San Bruno Water Quality Control Plant Flood Protection Study*, 2012.

Infiltration and Other Losses

Direct runoff was estimated by subtracting soil infiltration and other losses from the rate of rainfall. The Curve Number (CN) Method is an empirical methodology derived by the Soil Conservation Service (SCS) to estimate direct runoff. The method assumes an initial amount of rainfall is absorbed by tree cover, stored in depressions, and infiltrates soil before any direct overland runoff will occur. The CN represents the storm water runoff potential in a drainage basin. Curve numbers vary from 0 to 100; with 0 equating to no runoff from a basin and 100 indicating that all precipitation will run off. The CN was estimated as a function of hydrologic soil group, land use/cover, and antecedent moisture condition (AMC), with AMC defined as the moisture content of a soil prior to any precipitation event. AMC is characterized by the SCS as:

AMC I soils are dry

AMC II average conditions

AMC III heavy rainfall, or light rainfall with low temperatures; saturated soil

Soil group, land use and percent impervious were used to determine Soil Conservation Service (SCS) curve numbers for each basin (See *South San Francisco/San Bruno Water Quality Control Plant Flood Protection Study*, 2012). The curve numbers were modified for each storm return period based on a calibration of the design precipitation event to flood-frequency analysis at a known stream gauge located at Orange Memorial Park. Stream gauge data collected by United States Geological Survey (USGS) from 1964 until 1995 and by the City of South San Francisco from 2010 to 2011 were analyzed to determine flood frequency characteristics. Flood flow frequency calculations were based on USGS Hydrology Bulletin #17B. The flood frequency curve for the stream gauge is presented by Table 1 and Figure 2. The resulting peak flood discharges were used to calibrate the Antecedent Moisture Condition (AMC) and modify the curve numbers accordingly, so that the hydrologic model replicates flood-frequency characteristics at the local stream flow gauge.

Table 1: Calibration to Colma Creek Flood Frequency Curve

Exceedance Probability	Return Period (years)	Creek Gauge Q (cfs)	Q from HMS (cfs)	Calibration Difference (%)
0.98	1.02	521	-	
0.9	1.11	812	-	
0.8	1.25	1,032	-	
0.5	2	1,589	1,607	1
0.2	5	2,367	2,483	5
0.1	10	2,877	2,896	1
0.02	50	3,967	-	
0.01	100	4,416	4,543	3

0.002	500	5,433	-	

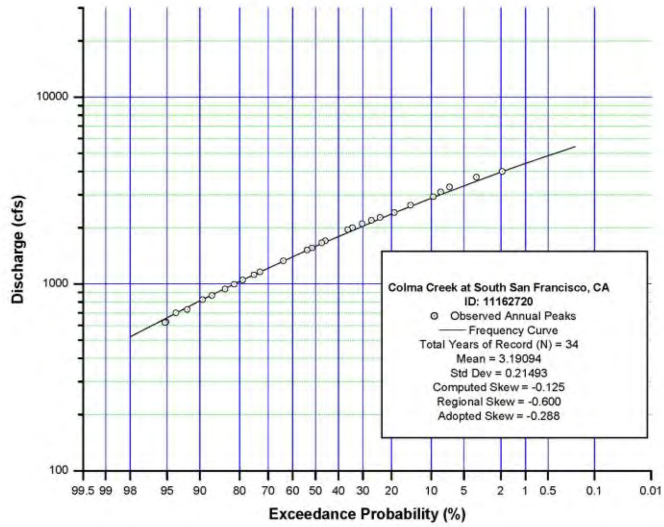

Figure 2: Colma Creek Stream Gauge Flood Frequency Plot

Hydrologic Modeling

Individual basin data and Colma Creek geometry information were entered into the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to calculate discharges based on watershed parameters, design storms, and stream routing. HEC-HMS is a software program created by the USACE to simulate the process of precipitation and runoff in water sheds, the program creates hydrographs for basin runoff and stream routing. Detailed HMS output data can be found in *South San Francisco/San Bruno Water Quality Control Plant Flood Protection Study*, 2012. The Colma Creek model includes the inflow from the Navigable Slough watershed.

Table 2 summarizes estimated discharges for return periods of interest at various locations. The discharge estimates reflect stream routing in Colma Creek but do not reflect spill due to upstream flow constrictions. In addition to defined drainage basins, flow enters Colma Creek from a newly constructed pump station. The design flow rate of the pump station, with all three pumps running simultaneously is 69 cfs. This flow is proportionally added to the HEC-RAS model upstream of Produce Avenue.

Table 2: Estimated Creek Discharges from 2012 Study

Location	2-year Discharge (cfs)	5-year Discharge (cfs)	10-year Discharge (cfs)	25-year Discharge (cfs)	50-year Discharge (cfs)	100-year Discharge (cfs)
Colma Creek & Navigable Slough						
Orange Avenue	1,607	2,483	2,896	3,550	4,050	4,543
Linden Ave	1,931	2,978	3,441	4,250	4,850	5,435
Highway 101	1,960	3,022	3,489	4,300	4,900	5,516
Utah Avenue	2,127	3,268	3,733	4,600	5,275	5,937
Navigable Slough	146	206	215	280	315	360
San Francisco Bay	**2,194**	**3,385**	**3,841**	**4,750**	**5,450**	**6,083**

The 2, 5, 10, and 100-year design discharges were plotted on a log scale to estimate the 25-year and 50-year design discharges at each location.

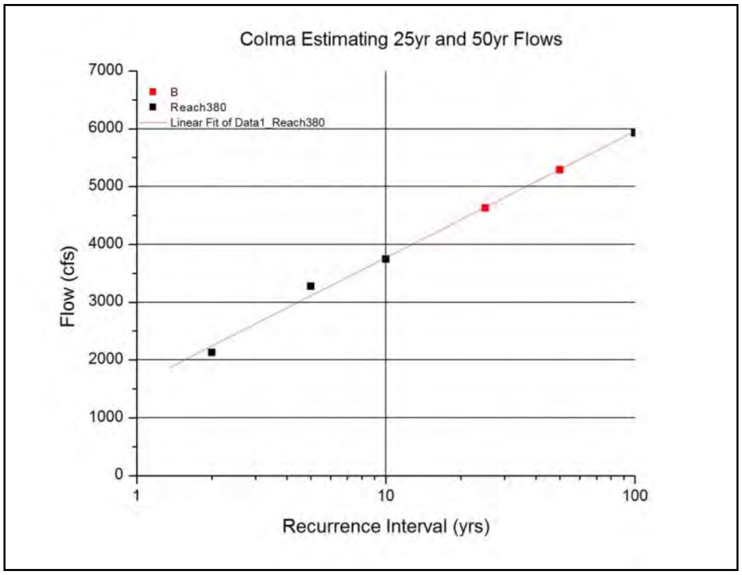

Figure 3: Colma Creek 25yr and 50yr Discharge Estimates

The Flood Insurance Study for San Mateo County was recently republished in March of 2014, however, the flows on Colma Creek have not changed since the 1980 analyses was done in South San Francisco by Tudor Engineering. The flows on Colma Creek that are reported in the FIS by FEMA are within reason to the flows shown in Table 2. The FIS reports the flow at San Francisco Bay on Colma Creek at 5,800 cfs for the 100yr event, whereas the analysis conducted in 2012 reported this flow at 6,600 cfs. This could be due to an increase in urbanization or more historical data collected at the Colma Creek gage. Navigable Slough is reported in the FIS with a 100yr flow of 300 cfs, whereas the 2012 analysis estimates this flow at 360 cfs.

The flows calculated in 2012 are conservative estimates when compared to FEMA's FIS report.

San Bruno and Cupid Row Canal

In 2014, GHD produced the San Bruno Storm Drain Master Plan (SDMP to study the capacity of the City's storm drain system under the 25-year design storm event. The hydraulic analysis was done using Bentlet's SewerGEMS software. The hydrologic analysis used the SCS method as was done for the Colma Creek analysis. The rainfall was based on the SCS Type I 24hr storm distribution. The hydrologic model was then calibrated to flow monitoring data that captured approximately a 2-year event. The same model parameters were then used for the 25-year design storm, which may or may not be applicable.

In order to be consistent to the analysis done on Colma Creek that was approved by FEMA, the same watersheds were used, but a different rainfall pattern and calibration procedure was applied. In the Colma Creek analysis, the hydrologic model is calibrated to the design storm of interest.

The result is that the flows in this analysis do not match those predicted in the SDMP. However, the flows developed match what was produced by the San Mateo County Flood Control District's *San Bruno Creek Flood Control Zone* report from 1965.

Watershed

San Bruno Channel collects runoff from the City of San Bruno, a drainage area of approximately 2,800 acres which lies south of the Colma Creek drainage basin. The San Bruno Channel outlet is approximately 1,400 feet to the south of the Colma Creek outlet (Figure 5).

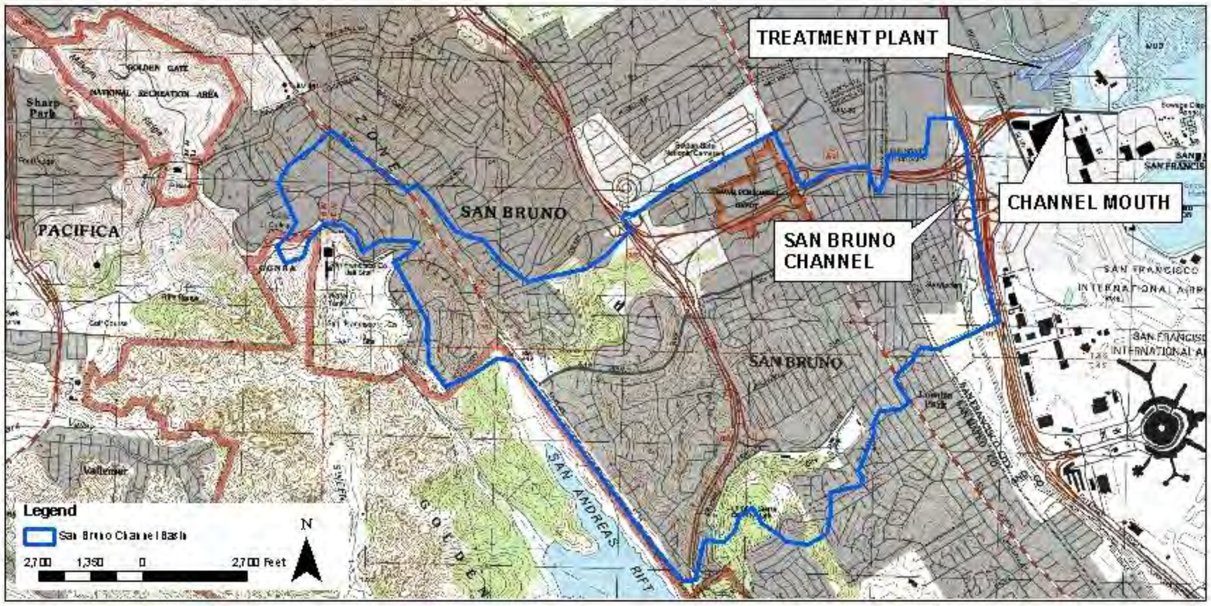

Figure 5 – San Bruno Watershed

San Bruno is divided into six main watersheds A through F. With the exception of watershed D, all watersheds drain to the San Bruno Channel. Table 3 shows the areas of these watersheds and Figure 6 depicts them graphically.

Table 3: San Bruno Watershed Areas

Watershed	Area (acres)
A	1415
B	505
C	650
D[1]	150
E[3]	50
F[3]	75
G[2]	5
Total	**2,850**

1. *Watershed D does not drain to San Bruno Channel*
2. *Watershed G was not in SDMP, area that drains downstream of where San Bruno Channel daylights at San Bruno Ave.*
3. *Watersheds drain to the Angus and Walnut pump stations, but were modeled as inflow hydrographs for this modeling effort*

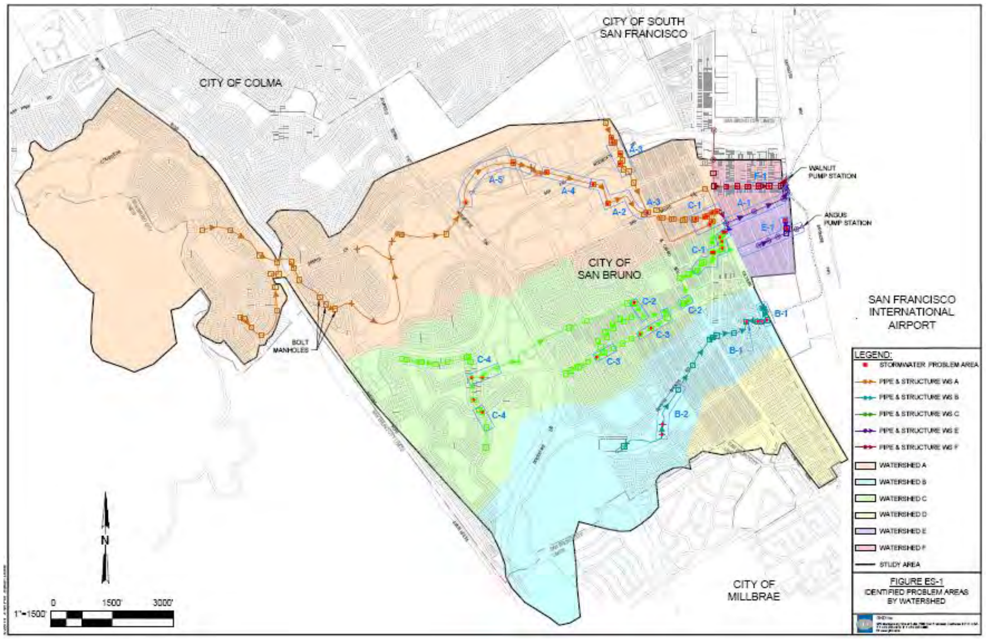

Figure 6: San Bruno Channel Six Main Watersheds

Watersheds A and C drain to the Belle Air Boxes and then to San Bruno Channel near San Bruno Ave and 7th Ave. Watersheds E and F drain to pump stations that also discharge to San Bruno Channel at San Bruno Ave and 7th Ave. Watershed B drains to the headwaters of the Cupid Row Canal near Lions Park. Watershed D drains outside the study area. A small subbasin downstream of highway 101 was also created to analyze the flows that enter the San Bruno Channel downstream of San Bruno Ave.

Methodology

Due to the proximity to the Colma Creek watershed, the same rainfall pattern and losses were applied to the San Bruno watershed that were calibrated for the Colma Creek analysis. The watershed delineations in the SDMP were used to identify the flows to Cupid Row Canal and those to the San Bruno Channel. Land cover and percent impervious values were developed from the National Land Cover Dataset (NLCD, 2011). Soil information was downloaded from the NRCS Soil Survey (CA689). The land cover and soil data within each watershed were used to develop curve numbers. Hydrologic flows were calculated in HEC-HMS and then routed into a HEC-RAS model for the Cupid Row Canal to the San Bruno Channel.

Hydrologic Modeling

The six individual basins within the San Bruno watershed geometry information are entered into the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to calculate discharges based on watershed parameters, and design storm.

Table 3 summarizes estimated discharges for return periods of interest at various locations. The discharge estimates reflect subbasin hydrographs at the most downstream point of the subbasin but do not reflect detailed routing within each reach. The flow at San Bruno Ave is the addition of the hydrographs from subbasins A, C, E, and F. Because the watersheds do not peak at the same time, the flows seen at San Bruno Avenue are slightly different then the summation of the peak flows. In addition, the hydrologic flows do not account for any capacity limited systems upstream. The hydrologic flows shown in Table 3 assume that all flows reach the headwaters of Cupid Row Canal and the San Bruno Channel.

Table 4: San Bruno Watershed Hydrologic Flows

Discharge Point	Frequency 2yr (cfs)	5yr (cfs)	10yr (cfs)	25yr (cfs)	50yr (cfs)	100yr (cfs)
Cupid Row Canal @ Lions Park	80	140	200[3]	250[2]	300	350
San Bruno Channel @ San Bruno Ave	380	630	910	1,130	1,330	1,520
San Bruno Channel d/s Highway 101	480	810	1,160	1,440[1]	1,710	1,960

1. *The San Mateo County Flood Control district calculated the 25yr discharge at 1,100 cfs for this location in 1965*
2. *Design drawings from the San Mateo County Flood Control District show that the channel was designed for 250 cfs (Wilsey, Ham, & Blair 1965)*
3. *The "Recovery Action Plan for the San Francisco Garter Snake"* estimated the 10yr flow in Cupid Row Canal at 165 cfs (LSA Associates, 2008)

Hydraulic Modeling

Colma Creek and Navigable Slough

Peak flows at critical intervals along Colma Creek determined using HEC-HMS for the 2, 5, 10, 25yr, 50yr, and 100-year return intervals, 24-hour duration storm events (see Table 2) are entered into a Hydrologic Engineering Center River Analysis System (HEC-RAS) model to determine bank-full creek capacities and the resultant spills. HEC-RAS is a software program developed by the USACE to model steady or unsteady one-dimensional flow in rivers, using a graphical user interface. The HEC-RAS model prepared for this flood risk study is based on a previous HEC-2 model created in 2004 by Schaaf & Wheeler using cross section information obtained by the USACE for the Flood Insurance Study. HEC-2 is a DOS based software program also developed by the USACE that computes water surface elevations for one-dimensional steady flow in rivers. The HEC-2 model has been updated with information field surveyed by Schaaf & Wheeler in November 2011, with one of the primary purposes of the field survey being the verification of bridge opening dimensions and creek sedimentation. The model extends from the outlet of Colma Creek at San Francisco Bay to just upstream of the Spruce Street crossing. It encompasses nine bridge crossings including Highway 101 and the Joint Powers Authority (Caltrain).

Work completed by the Colma Creek Flood Control Zone of the San Mateo County Flood Control District at the end of 2011 consisted of repairing 380 feet of flood walls and installing a concrete bottom slab beginning approximately 300 feet upstream of the Spruce Street crossing. The construction documents for this project have been used to verify cross sections at the upstream boundary of the HEC-RAS model. Figure 7 shows the HEC-RAS model layout.

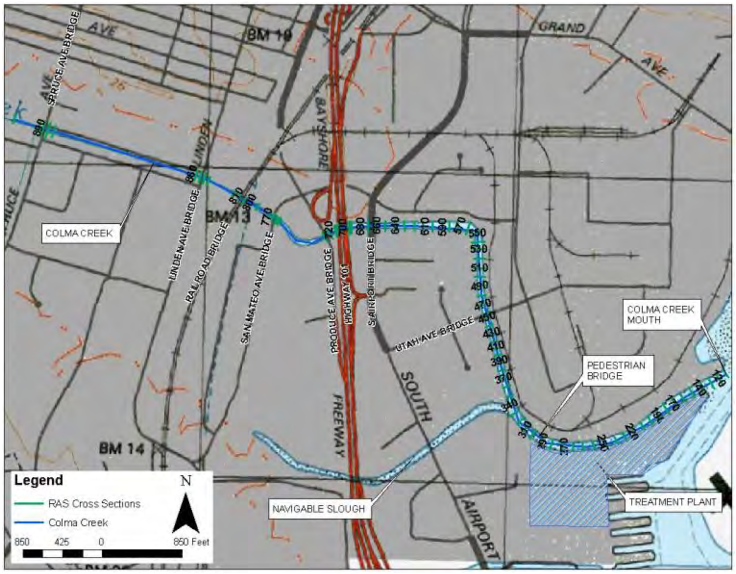

Figure 7: HEC-RAS Cross Section Locations for Colma Creek

San Bruno Channel and Cupid Row Canal

The HEC-RAS model developed for the SFO Shoreline Protection Study was used as a basis for developing the San Bruno and Cupid Row Canal model. The area upstream of highway 101 and Cupid Row Canal were not included in this model. Meridian was hired to conduct survey information along Cupid Row Canal and San Bruno. Initial cross sections were cut using LiDAR data and GeoRAS. These cross sections were then updated with the survey data collected by Meridian. Because the cross sections did not extend into the water, the thalweg of the channel was lowered about 3-4-ft in order to account for the low flow channel that was not surveyed. Figure 8 shows the HEC-RAS cross sections for the Cupid Row to San Bruno Channel. The model starts at the headwaters of the Cupid Row Canal near Lions Park and end at the tide gate structure to the San Francisco Bay. Cupid Row Canal flows into the San Bruno Channel through a culvert under San Bruno Ave. Hydrologic flows in Table 4 were entered into the model.

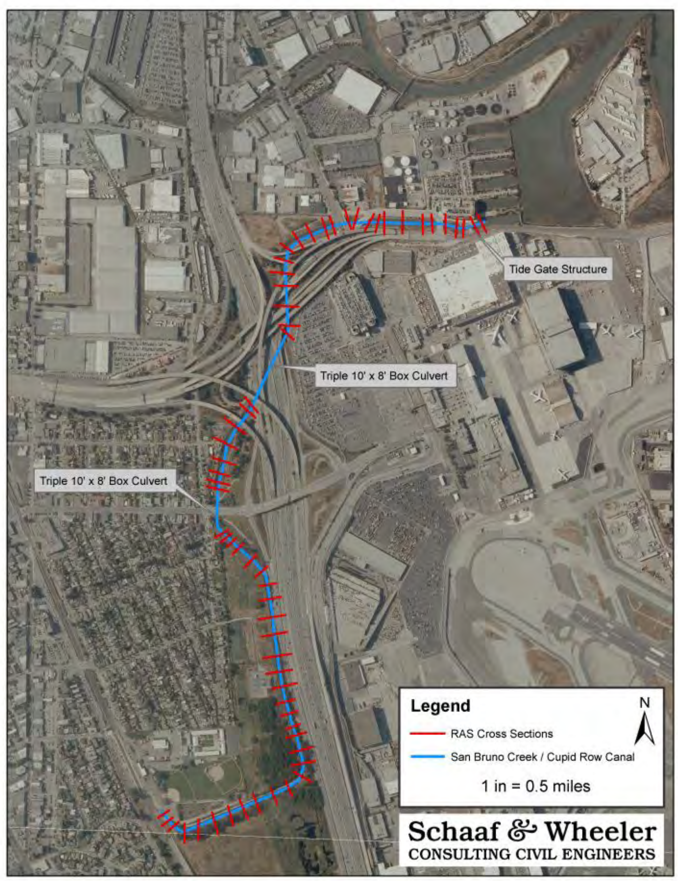

Figure 8: HEC-RAS Cross Section Locations for San Bruno Channel and Cupid Row Canal

Tidal Boundary Conditions

Both Colma Creek and San Bruno Channel discharge into the San Francisco Bay which is tidally influence. Tidal boundary conditions were developed by Moffat & Nichol. A range of boundary conditions were applied to the hydraulic model to assess different scenarios of high tide with different sea level ride projections. Boundary conditions ranged from 6-ft to 15.3-ft NAVD.

Results

Glass Wall Analysis

HEC-RAS was run in steady state to minimize instability in the model. This is the approach that was used on Colma Creek in 2012. Lateral structures are added to steady state models to simulate spills over weirs that are set along the banks. The lateral structures can create instability in a model and problems with flow convergence. To minimize these issues, the lateral structures were turned off (HEC-RAS analyzes the spills, but does not remove the flow from the channel). This creates a water surface elevation that extends vertically up, known as "glass walls." This type of analysis is done to determine floodwall or levee heights that will contain all the flow within the channel. This analysis was run with boundary conditions ranging from 6.0-ft to 15.3-ft.

Channel Capacity Analysis

The second analysis was to determine the channel capacity at boundary conditions from 6-ft to 13-ft at half foot intervals. This analysis looked at the lateral structures for spills and determined the maximum flow the channel could contain without spilling at different boundary conditions. A threshold of 50 cfs was allowed to spill, but any spill greater was considered that the channel was undersized. Tables 5 and 6 show the results of this analysis.

Table 5: Colma Creek Capacity

	u/s Linden		Linden to hwy 101		d/s hwy 101	
W.S. El	**Colma**	**Nav. Slough**	**Colma**	**Nav. Slough**	**Colma**	**Nav. Slough**
6.0	3,200	192	3,200	192	2,000	120
6.5	3,200	192	3,200	192	1,950	117
7.0	3,200	192	3,200	192	1,900	114
7.5	3,200	192	3,200	192	1,800	108
8.0	3,200	192	3,200	192	1,700	102
8.5	3,150	189	3,150	189	1,000	60
9.0	3,100	186	3,100	186	0	0
9.5	3,000	180	3,000	180	0	0
10.0	2,900	174	2,900	174	0	0
10.5	2,800	168	2,800	168	0	0
11.0	2,700	162	2,700	162	0	0
11.5	2,600	156	2,400	144	0	0
12.0	2,500	150	2,100	126	0	0
12.5	1,600	96	1,050	63	0	0
13.0	700	42	0	0	0	0

Table 6 – San Bruno and Cupid Row Channel Capacities

W.S. El	u/s San Bruno Ave*	d/s Hwy 101
	Cupid Row	San Bruno Canal
6.0	120	860
6.5	120	860
7.0	120	860
7.5	100	800
8.0	80	740
8.5	70	625
9.0	60	510
9.5	40	390
10.0	0	270
10.5	0	160
11.0	0	0
11.5	0	0
12.0	0	0
12.5	0	0
13.0	0	0

Spill Analysis

The final analysis was to look more closely at the spills and optimize the models to allow spills to occur, thus lowering the water surface elevations, rather than the artificial glass walls. This analysis was conducted on boundary conditions from 6-ft to 10-ft at half foot intervals. The process was to look at optimizing as many lateral structures as possible to allow the channel to spill. With the increasing boundary condition height, more and more lateral structures had to be turned off to allow the model to run. Part of this is due to the instability in the model with water surface elevations 2-ft or more above the lateral structure weirs.

QA/QC

Under the scope of work for this project, Moffatt & Nichol (M&N) were tasked with QA/QC of the models and mapping the extent of flooding. Errors were identified in structures entered into the San Bruno model. One was the highway 101 box culvert was modeled as three boxes, when recent as-builts show four boxes. In addition, the Cupid Row Canal passes under San Bruno Ave in one box culvert, not three. These culverts were updated.

San Bruno and Cupid Row Survey Data

M&N compared the bottom of the channel elevations with as-built drawing and a Caltrans dredging plan from 2000 and noted that the elevation of the bottom of the channels in San Bruno and Cupid Row canal seemed higher than the plans. Because the survey did not include points within the water, the survey data ended at the edge of water. M&N determined that the low flow channel was about three to four feet and lowered the channel thawleg (bottom of the channel) by three to four feet. The bank elevations of the channel remained the same, so the capacity of the channel was increased.

Unsteady-State Modeling

The San Bruno and Cupid Row system is complex due to low lying areas that act as storage ponds where flood waters can leave the channel and pond in areas. It is not certain as to whether these stored flows will eventually re-enter the channel, or if they will infiltrate over time. Regardless, the release of these flood waters into storage areas will lower the elevation of water in the channel. The only way to model storage areas in HEC-RAS is to run an unsteady-state model with lateral structures connected to storage ponds. This allows the model to track the flood volumes overtime. Two dimensional modeling in the future will allow the tracking of the flood flows. Figure 9 shows the unsteady state model schematic.

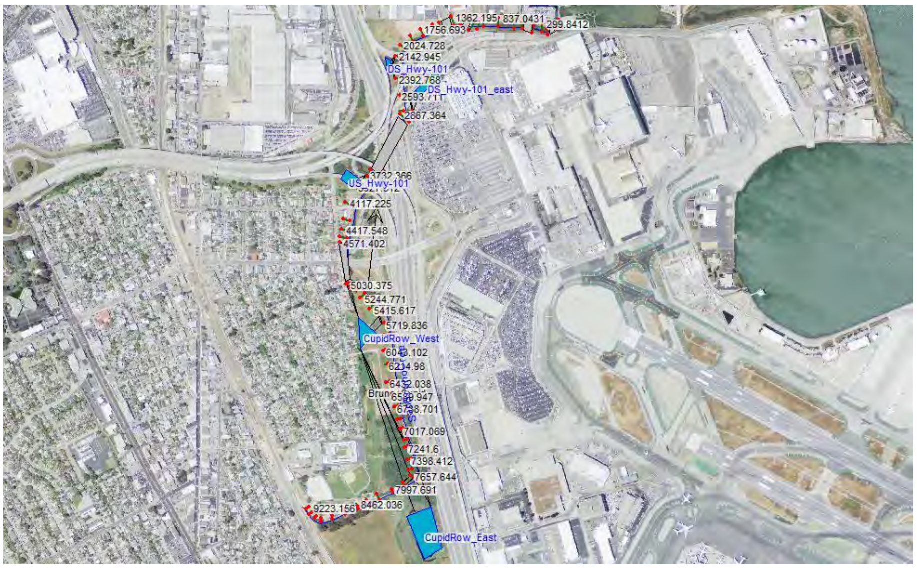

Figure 9. San Bruno Unsteady-State Model

In order to model the tide gates the culvert was changed to an orifice to prevent reverse flow through the gates as HEC-RAS does not have a method for modeling a culvert with flap gates. The unsteady-state model lowered the water surface elevation in the reach downstream of Highway 101 to around 10.5-ft NAVD for the 100-year flow with a tide of 7-ft. By the time the flood flow reaches the tide gate, the flow has dropped down from 2,000 cfs to about 1,000 cfs due to the upstream flows that were lost over the banks into the storage areas.

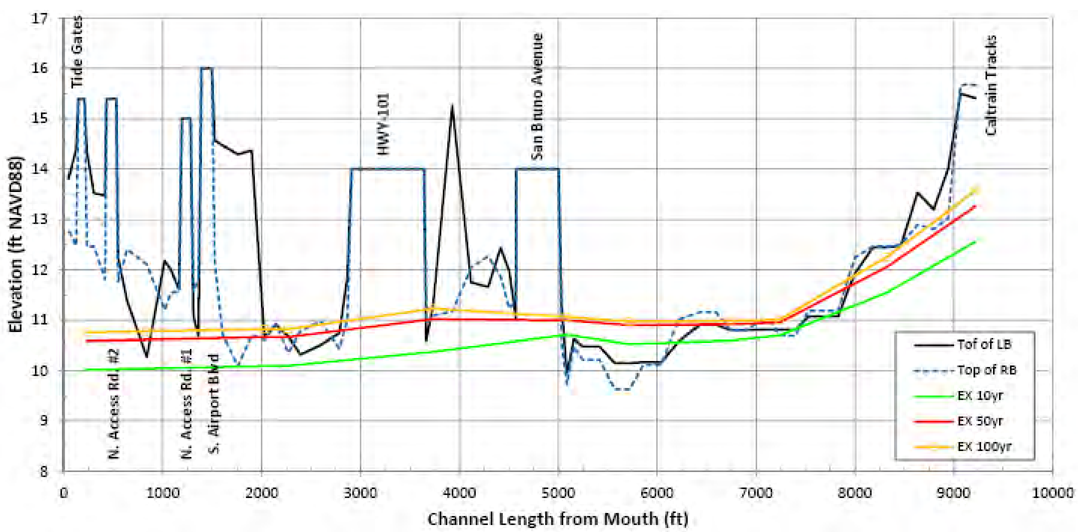

Figure 10. San Bruno Creek Coincident Frequency Water Levels

There is a significant backwater effect from the box culverts under Highway 101 and under San Bruno Ave which cause flooding in the Cupid Row Canal.

Pump Stations

Watershed F discharges into San Bruno Channel via the Walnut Pump Station. Watershed E discharges into the Cupid Row Canal via the Angus Pump Station. For this modeling effort, the pump stations were not included, which likely overestimates the peak flows in the Canal and Channel as the pump stations are unlikely to keep up with the peak discharges. Future work should include the existing pump station capacities and any future CIP work that intends to increase the capacity of the pump stations.

Adaptive Management Strategies

Adaptive management strategies are to be developed by Moffat & Nichol and will be modeled to determine their efficacy. It should be noted that the San Bruno SDMP currently includes a CIP to rehabilitate the tide gate structure on San Bruno Channel for a estimated project cost of $250,000. Prior to this work being completed, an increase in the tide gate capacity should be further modeled to identify if that structure should be replaced instead of rehabilitated.

Limitations

The hydraulic models can be used for planning level decisions, but more detailed models should be developed to better understand how the flood flows are stored and travel overland. It is recommended that 2D modeling be done to analyze the paths of the spills from the channel. Programs like HEC-5 or FLO2D could be employed for this analysis.

APPENDIX C – SUMMARY OF CALTRANS INFORMATION

1.0 Introduction

Appendix C summarizes the various reports that were provided by the local stakeholder agencies for the data collection phase of this project, primarily by Caltrans and the County of San Mateo. These reports detail previous drainage and flood control projects done within the Colma Creek and San Bruno Creek watersheds. These precedents provide data against which present data can be compared and information about drainage patterns that can be used to predict future occurrences of flooding due to sea level rise.

The following information was provided after a request to various stakeholders to collect information about previous flooding analyses as well as infrastructure data within the watersheds of Colma Creek and San Bruno Creek. A meeting request letter was sent to all of the stakeholders listed below:

- Caltrans District 4
- City of South San Francisco
- San Mateo County Transit District (Caltrain)
- San Mateo County Department of Public Works
- City of San Bruno
- Bay Area Rapid Transit District (BART)
- Pacific Gas and Electric Company (PG&E)

The meeting request letters included a list of questions to highlight the requested information prior to the meetings. A meeting was held with the City of South San Francisco on October 8, 2014, and another meeting with Caltrans District 4 on October 9, 2014. Individual teleconference meetings were also held with the San Mateo County Department of Public Works, the City of San Bruno, and PG&E. Information was also received from the San Mateo County Transit District through email.

Available flooding and hydraulic analysis documents provided by the stakeholders were reviewed, and supplemented the current flooding study with the prior information; the majority of information was provided by Caltrans District 4. Summaries of the flooding analyses and documents received from the stakeholders are presented below.

1.1 Colma Creek Watershed

Summaries of the flooding analyses and documents regarding the Colma Creek Watershed are presented below.

As-Built Plans for Hwy-101 Bridge Widening at Colma Creek. (13 pages, 1969, 2011)

These as-built plans show the channel surface (cross section) of upstream of Colma Creek at the intersection of Hwy-101, in 1967, 2001, and 2008. The channel surfaces show erosion in the areas between bents 2, 3 and 4, and sediment deposition in the areas between bents 1 and 2, and bents 4, 5, and 6 of the bridge during the period of 1967 to 2008. The as-built plans show the dimensions of the bridge structure. (10 pages from 1969 and 3 pages from 2011)

Drainage Plans for Colma Creek Flood Control Project at Produce Avenue Bridge (12 pages, 1975)

This document is a letter from County of San Mateo to Caltrans presenting a summary of the flood control analyses for the Produce Avenue Bridge. It presents the assumptions and results of HEC-2 Water Surface Profile Program calculations about the proposed Produce Avenue Bridge project. A parametric study was performed using HEC-2 for a 100-year discharge against three separate tides including Mean Higher High Water, MHHW (elevation 3.5 feet USGS Mean Sea Level, MSL), a 1-year tide (4.4 feet USGS MSL), and a 2-year tide (5.3 feet USGS MSL). The input data for three separate tides are presented below.

a) Colma Creek Backwater computations with fully improved channel Q_{100} against MHHW (3.5 feet MSL): Q_{100} = 5,800 cubic feet per second (cfs) at mouth, Q_{100} = 5,900 cfs at Hwy-101, and Q_{100} = 4,800 cfs at Spruce Avenue;

b) Colma Creek Backwater computations Q_{100} against 1-year high tide (4.4 feet MSL): Q_{50} = 5,100 cfs at mouth, Q_{50} = 4,400 cfs at Hwy-101, and Q_{50} = 4,200 cfs at Spruce Avenue;

c) Q_{100} against 2-year high tide (5.3 feet MSL): Q_{50} = 5,100 cfs at mouth, Q_{50} = 4,400 cfs at Hwy-101, and Q_{50} = 4,200 cfs at Spruce Avenue;

d) Q_{50} against Highest Tide Plus Wind (6.9 feet MSL): Q_{50} = 5,100 cfs at mouth, Q_{50} = 4,400 cfs at Hwy-101, and Q_{50} = 4,200 cfs at Spruce Avenue.

The input cross sections appeared to be the same for Cases A, B, and C, but different for Case D. The Water Surface (WS) profile for Cases A, B, and C at the Hwy-101 Bridge was 10.05 feet, 10.07 feet, and 10.13 feet, respectively. The WS profile for Case D at the Hwy-101 Bridge was 10.64 feet. The study concluded that the backwater curve was influenced to a minor degree by the beginning step about 1 mile downstream. It was found that using the same cross section for Case D, the WS profile would be 10.2 feet.

The study presented adopted peak discharge values for selected locations along Colma Creek. For example, with future urbanization, Colma Creek below Spruce branch (with discharge area of 12.72 square miles) would have a Peak Discharge of about 4,400 cfs and 5,000 cfs for 50-years and 100-years, respectively. Among the list of the adopted peak discharge locations are Cypress Lawn Confluence, Hickey Boulevard, Evergreen Drive Tributary, Twelvemile Creek, USGS gage, Industrial Branch, and the mouth of the Colma Creek.

As-Built Plans for Hwy-101 in the City of South San Francisco and Brisbane from 0.2 mile south of Sierra Point off-ramp overcrossing to Grand Ave undercrossing (6 pages, 1988)

These drainage plans show the location and details of 2 inlets connected to Reinforced Concrete Boxes (RCB) at the intersection of Hwy-101 and Oyster Point Boulevard, at boundary area between the City of South San Francisco and City of San Bruno.

Colma Creek – Guadalupe Canyon Basin Storm Drain Master Plan (59 pages, 1991)

This report consists of the analysis of the existing storm drain system that accepts storm runoff from the Colma-Guadalupe drainage system. It was written by CH2M Hill in February 1991. The project area is bounded by John Daly Boulevard to the north and Serramonte Boulevard to the south and consists of 1800 acres. The project drains in a southeasterly direction from Guadalupe Canyon to Serramonte Boulevard in the Town of Colma.

The report presents alternatives for the level of protection against flooding that could be achieved by constructing improvement projects in phases. Seven alternatives were analyzed and improvements were evaluated for gravity flow conditions. A pressure flow analysis of a portion of the system under surcharged flow conditions was also conducted. The advantage of operating the system in such a manner is to maximize conveyance system capacities by allowing the water surface elevation to exceed the crown of the pipeline, creating added head through the system producing greater system capacities.

1.2 San Bruno Creek Watershed

Summaries of the documents regarding the San Bruno Creek Watershed are presented below.

City of San Bruno Drainage Analysis, Intersection of El Camino Real (Route 82) and Route 186 (5 pages, 1968 and 1972)

The drainage analysis was for a highway development at intersection of El Camino (Route 82) and proposed Route 186 (Interstate 380). The input information for drainage calculation included:

> -Mean annual rainfall in San Bruno is 19 inches (District 4 Mean Manual Rainfall Isopleths of October, 1968);
>
> -P_{60} value is 1.25 inches per hour (San Francisco Airport, USWB No. 7769 Maximum Rainfall Intensity Duration Chart dated April, 1967);
>
> -Rational Method using Chart 7-811.6, Runoff factors are 90% for Pavement, and 50% for U.S. Navy Property and adjacent areas, and
>
> -Time of Concentration applied by using Chart 7-811.6 and minimum of 10 minutes.

There is a 24-inch diameter reinforced concrete pipe (RCP) at Station B 319+00 and a 30-inch diameter RCP at Station B 324+85 crossing beneath the proposed highway (Route 186) and empties into San Bruno Creek. These two storm drain systems are used primarily to drain the U.S. Navy property between the highway and northerly to Sneath Lane and from Route 82 (El Camino) westerly to Third Street (U.S. Navy).

There is also a letter from 1972 by Moffatt and Nichol (M&N) with requested data about San Bruno Creek crossing Interstate 380, dated 1972. The information requested is as follows:

> The box is a standard 10 feet (span) x 8 feet (height) RCB. Downstream flow line is 57.8 feet (USGS MSL 1929). Slope is 0.0039.
>
> The contributing area of the box at Interstate 380 is 1,110 acres.

Q_{100} =780 cfs, Q_{10} = 530 cfs.

Based on a comment in the letter, the Hydraulics Section did not recommend a connection of the 10'x8' box to the 72-inch storm drain, as the 72-inch pipe requires a head of 12 feet to handle the Q_{100}. This would causes severe flooding upstream property owners. A head of 6 feet is required for the 72-inch pipe to pass the Q_{10}.

Drainage Analyses and Plan Set for El Camino Real in San Bruno and South San Francisco between 0.1 mile south of Sneath Lane and 0.1 mile north of Orange Ave (6 pages, 1969)

The drainage analysis is about a Caltrans construction project along El Camino Real (Stations 241+00 to 325+00) in the City of San Bruno. The watershed area is adjacent to Orange Avenue. The input information for drainage calculation included:

-Mean annual rainfall is 20 inches (District 4 Mean Manual Rainfall Isopleths of October, 1968);

-P_{60} value is 1.2 inches per hour (District 4 Mean Manual Rainfall Isopleths of October, 1968);

-I_{10}/I_{100} hourly rainfall ratio of 0.70; and

-Runoff Coefficients included Residential and Hilly Terrain = 50%, Golden Gate national Cemetery = 25%, Pavement = 90%.

Drainage Plans and Plan Set for Interstate 380 from Cherry Ave to 0.2 mile east of Hwy-101 and on Hwy-101 from 0.7 mile south of San Bruno Ave to South San Francisco Belt Railroad overhead (4 pages, 1971)

This document is a letter from San Mateo County to Caltrans (January 28, 1971). The letter is about an area that is bounded by Pine Street to the south, San Mateo Avenue to the west, City of South San Francisco to the north, and Bayshore Freeway (Hwy-101) to the east. The area is approximately 125 acres and is drained by Pump Station No. 1.

The existing storm drain system is designed for 25 years. Pump Station #1 has 3 pumps capable of pumping at a rate of 16,500 gallons per minute (GPM) against a total dynamic head of 16.5 feet, and 19,980 GPM pumping against a total dynamic head of 8.0 feet. A high tide of 6.1 MSL was determined to be compatible with the 25 years design storm criteria. The location of the pump station was described as being at San Bruno Avenue and Seventh Avenue (Walnut PS).

Drainage Plans of Intersection of I-380 and Hwy-101 (5 pages, 1971)

The drainage plans included the runoff calculation of three areas entitled as A, B, and C. Area B is the entire City of San Bruno. Area A and C are located at the west side of Hwy-101 and north of the City of San Bruno.

The input data for runoff calculation included:

-The watershed is about 760 acres, 2,870 acres, and 410 acres for areas A, B, and C, respectively.

-The Q_{100} is 640 cfs, 1,750 cfs, and 590 cfs for areas A, B, and C, respectively.

-The Q_{10} is 440 cfs, 1,175 cfs, and 395 cfs for areas A, B, and C, respectively.

-P_{60} is 1.25 inch per hour (in/hr), and Rain Intensity (I) is 1.68 in/hr, 1.15 in/hr, and 1.25 in/hr for areas A, B, and C, respectively.

As-Built Drainage Plans of North Channel under-passing Hwy-101 (4 pages, 1973)

These drainage plans show some information about the location and cross section of the North Channel crossing Hwy-101. The cross section included four RCB Culverts, each about 8 feet by 10 feet.

-Watershed is about 2,870 acres

-I is 1.15 inch per hour

-P_{60} is 1.25 inch per hour

-Q_{100} is 1,750 cfs, and Q_{50} is 1,175 cfs.

Drainage Report for Drainage Report for Hwy-101 from 0.2 km north of Millbrae Avenue overcrossing to 0.3 km north of Interstate 380 separation, on Interstate 380 from San Francisco International Airport to San Bruno Avenue overcrossing and at the San Francisco International Airport (24 pages, 1996)

The drainage report is prepared by PB/MC for San Francisco International Airport (SFIA). The project included the construction of new inbound and outbound ramps and structures serving the SFO's new International Terminal. The primary goal of the report was to identify the drainage impacts resulting from the construction of the proposed project. This report outlines the design criteria used for mitigating project impacts.

The off-site drainage boundary is from the ridge near Skyline Boulevard in the City of Millbrae, toward San Francisco Bay. The flow conveyance is through a series of pipes and open channels. There had been observed some flooding in the greater project region west of Hwy-101. However, the embankment of the Southern Pacific Railroad (Caltrain), which runs along the western side of Hwy-101, forms a barrier against flood flow and protects Hwy-101 from potential flooding.

Mean annual rainfall in project area is about 432 mm. The study assumed mild temperatures and most of the precipitation in the winter months, between October and April for the project.

There are two canals which service the project region: Cupid Row and South Lomita. Cupid Row Canal is located on the west side of Hwy-101 and flows in a northerly direction. It crosses Hwy-101 between the San Bruno Avenue and I-380 interchange. It is located east of Hwy-101 and is subject to tidal influence. Cupid Row Canal is owned by San Francisco International Airport (SFIA) and operated by the San Mateo County Flood Control District (SMCFCD). According to the drainage report, Cupid Row Canal, within the project area, has not experienced any flooding in recent history and has been operating properly.

The South Lomita Canal flows in a southerly direction along the west side of Hwy-101. It is an earthen canal with some concrete lined portions. The unlined portions of the canal are overgrown with vegetation. Maintenance of the canal is severely limited because the area is a wetland habitat for several endangered species. The freeway runoff from Caltrans' FM Station 135+00 to FM Station 150+00 (1,500 feet) is conveyed to South Lomita Canal. At the north of the Millbrae Avenue interchange, South Lomita Canal is pumped into the Millbrae Canal. The Millbrae Canal conveys the flow across Hwy-101 into the SFIA right-of-way and ultimately into the Bay. South Lomita Canal is owned and operated by SFIA. The canal is currently operating under capacity. According to the drainage report, this segment of the canal has not experienced any flooding in recent history, and the pump operated properly during the rainy season.

The on-site drainage area consists of paved and unpaved surfaces within the Caltrans right-of-way. The general flow pattern of the existing on-site cross culverts is from east to west. The on-site drainage areas consist of three sections.

FM Station 111+00 to FM Station 121+50 is divided into northbound and southbound sections. In the northbound section, Drainage Plans D-4, D-6 and D-7 show the runoff collection in this area is achieved by drainage ditches along the outside shoulder of Hwy-101 and by sheet flow to the unpaved areas of the eastern quadrants of the San Bruno Interchange. The piping network flows in a southeasterly direction, and the system eventually outlets after a series of pumps and detention ponds to the San Francisco Bay. In the southbound section, the runoff from the northwest quadrant of the San Bruno Avenue/Hwy-101 interchange are sheet flows to unpaved areas of the interchange. The unpaved areas are graded to concentrate the runoff toward drainage inlets which are part of a network that conveys the flow to the Cupid Row Canal. The highway and collector/distributor road drainage from FM Station 116+00 to FM Station 121+50 is achieved by drainage inlets and is carried through a piping system to a pump station south of the collector/distributor road at FM Station 116+20.

FM Station 121+50 to FM Station 149+50 is divided into northbound and southbound sections. In the northbound section, the runoff generated here flows to the toe-of-slope gutters. These gutters also collect one-half of the runoff generated by McDonnell Road, which runs along the east side of Hwy-101. The collected runoff is directed to cross culverts located at approximately five to seven hundred meter intervals. These cross culverts direct flow from the east side of Hwy-101 to the west side, where the flow is then discharged to the South Lomita Canal. In the southbound section, the drainage is accomplished through a network of drainage inlets and pipes. These drainage systems convey the collected runoffs to South Lomita Canal either directly or via unpaved creeks.

FM Station 149+50 to FM Station 151+20 has runoff which is collected by a toe-of-slope gutter along the east side of Hwy-101. This gutter is drained by a network of drainage inlets and conveyed with a piping system to a pump station on the west side of Hwy-101. The runoff collected by this system, along with the runoff from the South Lomita Canal, are pumped into the Millbrae Canal, which conveys runoff easterly along Hwy-101 onto the SFIA property.

The storm runoff quantities were calculated using rational formula and following input data:

$$Q = 0.28CIA$$

Runoff Coefficients (Caltrans Highway Design Manual 1995 (HDM) Table 819.2B):

Drainage Surface	Coefficient	25 Years	100 Years
Paved Area	0.9	0.99	1.00
Unpaved Area	0.5	0.55	0.62

A 10 minute minimum time of concentration (Tc) was assumed for the on-site drainage design.

The rainfall Intensity Duration Frequency (IDF) curves were based on rainfall information by the Department of Water Resources rain gauge at the San Francisco International Airport. Based on an empirical equation developed on rainfall data from 1944 to 1990:

$I = A*D^B$

Where:

A is a constant based on rainfall frequency:

- for a 10 year frequency, A=0.88
- for a 25 year frequency, A=1.04
- for a 100 year frequency, A = 1.28;

D = rainfall duration in hours;

B = site specific constant (-0.484)

I = intensity (in/hr).

The maximum intensity at 4 minutes is:

	10 year Storm (inches/hour)	25 year Storm (inches/hour)	50 year Storm (inches/hour)	100 year Storm (inches/hour)
Maximum Intensity at 4 minutes	3.0	3.5	3.9	4.3

Drainage Plans D-1 to D-17 were missing.

Lined gutters and ditches are designed to carry the runoff generated by the 25-year design storm event. The minimum slope of 0.25% for earth and 0.12% for lined ditches were used, as specified in Section 834.3 of HDM.

The majority of the existing drainage systems were constructed during reconstruction of the freeway in 1977 and 1988.

According to the drainage report, some of the existing drainage inlets were observed to be completely barred or partially silted.

1.3 Existing Structures and Infrastructure

Summaries of the documents regarding the existing structures and infrastructures within Colma and San Bruno Creek Watersheds, received from Caltrans District 4, are presented below.

Plans and Drainage Report for Navigable Slough (5 pages, 1971)

This document consists of a letter, drainage chart, and plans of construction on Hwy-101 and adjacent drainage areas.

The letter presents data at Hwy-101 for Navigable Slough, a drainage area of 410 acres: Q_{100} = 590 cfs, weighted runoff factor = 0.78, T_c = 28 minutes. The existing 96-inch RCP at South Airport Boulevard was incapable of passing the Q_{100}, and therefore the water surface was limited to the soffit of the existing 96-inch, at elevation +5.5’ NGVD29. The South Airport Boulevard culvert was supplemented with an additional culvert, approximately 60 inches in diameter. The original 5’ x 4’ RCB at Hwy-101 was supplemented with an additional 10’ x 6’ RCB in 1975. The Q_{100} in 1975 was calculated to be 590 cfs.

The construction plans show the extent of construction along Hwy-101, from north to south, and I-380, from east to west, in the vicinity of Navigable Slough.

The drainage plans indicate the locations and dimensions of the drainage system. The RCB added in 1975 is specified to be 10’ x 6’ x 224’.

The drainage area map indicates the location of the original 5’ x 4’ RCB and the additional 10’ x 6’ RCB. A set of four 10’ x 8’ RCBs is also indicated farther south along Hwy-101 (at San Bruno Creek).

As-Built Construction Development Plans of North Channel at Intersection of Hwy-101 and Interstate 380 (12 pages, 1973)

The construction development plans show that the North Channel RCB Culvert includes four rectangular barrels, each 8 feet by 10 feet, and about 729 feet long beneath about 4 feet maximum fill with Type 1 retaining walls at various angles adjacent to the headwalls.

As-Built Cross Culverts along Hwy-101 at Armour Ave, California Ave, & Grand Ave (1 page, 1997)

This plan shows the location of three cross culverts along Hwy-101 between stations 217+15 and about 240+00. These stations are at 217+15, 229+50, and 240+00.

Station 217+15, just opposite Armour Avenue west of the freeway, is a cross culvert consisting of a single 6.5’ x 3.5’ RCB.

Station 229+50 has a 24-inch RCP cross culvert draining to a combined system consisting of 18-inch and 24-inch RCPs at the R/W. The as-builts show these two pipes draining to a 30-inch CIP which passes the flow beneath the railroad tracks.

Station 240+00, in the vicinity of Grand Avenue, has 24-inch pipes crossing the freeway from west to east, toward the railroad tracks.

As-Built Construction Plans of San Bruno Channel at Intersection of Hwy-101 and Interstate 380 (6 pages, 2000)

As-built plans show that the San Bruno Channel RCB Culvert includes four rectangular barrels, each 8 feet by 10 feet, and about 222 feet (Sta 8+30.58 to Sta 10+52.78) long. There is about 0.5 to 1 foot sediment inside the culvert structure. The downstream section is roughly 438 feet long (Sta 3+93.17 to Sta 8+30.58) open channel, 40 feet wide with 1:4 slopes at both sides. The upstream section is roughly a 165 feet long (Sta 10+52.78 to Sta 12+17.29) open channel, 40 feet wide with 1:4 slopes at both sides. The slope of the bottom of channel alignment is approximately 0.12%, at elevation -0.7 feet to -1.5 feet.

Walnut and Angus Stormwater Pumping Stations, Preliminary Design Report (2012)

This report was prepared by Brown and Caldwell for the San Mateo County Department of Public Works. The report was prepared based on the 1991 Colma Creek – Guadalupe Canyon Basin Storm Drain Master Plan Study and includes 2 pump stations named Walnut Pump Station and Angus Pump Station. A general data about the pump stations are below.

Pump Station	Number of pumps	Watershed (acres)	25-yrs flow (cfs)	Output Channel	Pump On (feet)	Top of Berm Elevation (feet)
Walnut	4	60	45 cfs (20,200 gpm)	North Channel	3, 3.5, 5, 5.5	11, 13
Angus	2	45	34 cfs (15,300 gpm)	Cupid Row Canal (Crystal Spring Channel)	3.5, 4	8.7

1.4 Miscellaneous

Tide Criteria: Caltrans Procedure for Design in Tide-Affected Waterways Tributary to San Francisco Bay (9 pages, 1976)

This letter is a discussion about the potential combinations of “frequency of tidal stage” and “frequency of the discharge rate” for design. It outlines the general considerations and some suggested methods of reasonably approximating the appropriate design water surface elevation to use in design when the outlet end of a system is influenced by tides.

Recommendation: A minimum of 2 discharge/tide combinations should be used as the basis for design backwater determinations in tidally influenced watercourses. One should include the design frequency discharge, the other the design frequency tidal stage. Each should be paired with a corresponding tidal or discharge event of such magnitude that the compound frequency of the two events occurring simultaneously equals the design frequency. Intermediate combinations should be evaluated where it appears that they may yield the controlling stages. Reservoir and channel routing, and detailed head loss calculations for constrictions, etc. should also be made as warranted.

1.5 References

Brown & Caldwell. (2012). *Walnut and Angus Stormwater Pumping Stations, Preliminary Design Report*. Prepared for San Mateo County Flood Control District.

Caltrans. (1947). As-Built Plans for Hwy-101 in the City of South San Francisco between North City Limits and 0.35 mile south of Colma Creek.

Caltrans. (1968 and 1972). City of San Bruno Drainage Analysis, Intersection of El Camino Real (Route 82) and Route 186.

Caltrans. (1969). As-Built Plans for Hwy-101 Bridge Widening at Colma Creek.

Caltrans. (1969). Drainage Analyses and Plan Set for El Camino Real in San Bruno and South San Francisco between 0.1 mile south of Sneath Lane and 0.1 mile north of Orange Ave.

Caltrans. (1988). As-Built Plans for Hwy-101 in the City of South San Francisco and Brisbane from 0.2 mile south of Sierra Point off-ramp overcrossing to Grand Ave undercrossing.

Caltrans. (1971). Drainage Plans of Intersection of I-380 and Hwy-101.

Caltrans. (1971, 1973 & 1976). Drainage Plans and Plan Set for Interstate 380 from Cherry Ave to 0.2 mile east of Hwy-101 and on Hwy-101 from 0.7 mile south of San Bruno Ave to South San Francisco Belt Railroad overhead.

Caltrans. (1972). Drainage Analysis for Route 186 (I-380) from Cherry Ave to 0.1 mi east of Route 82 and for Route 82 from San Bruno Ave to 0.1 mi north of Sneath Lane.

Caltrans. (1973). As-Built Construction Development Plans of North Channel at Intersection of HWYs 101 and 380.

Caltrans. (1973). As-Built Drainage Plans of North Channel underpassing Hwy-101.

Caltrans. (1973). Plans and Drainage Report for Navigable Slough.

Caltrans. (1976). Tide Criteria: Caltrans Procedure for Design in Tide-Affected Waterways Tributary to San Francisco Bay.

Caltrans. (1997). As-Built Cross Culverts along Hwy-101 at Armour Ave, California Ave, & Grand Ave.

Caltrans. (2000). As-Built Construction Plans of San Bruno Channel at Intersection of HWYs 101 and 380.

Caltrans. (2000). As-Built Construction Plans of San Bruno Channel Dredging at Intersection of Hwy-101 and I-380.

CH2M Hill. (1991). *Colma Creek – Guadalupe Canyon Basin Storm Drain Master Plan*. February.

PB/MC. (1996). Drainage Report for Hwy-101 from 0.2 km north of Millbrae Avenue overcrossing to 0.3 km north of Interstate 380 separation, on Interstate 380 from San Francisco International Airport to San Bruno Avenue overcrossing and at the San Francisco International Airport.

San Mateo County. (1975). Drainage Plans for Colma Creek Flood Control Project at Produce Avenue Bridge.

Wilsey, Ham & Blair. (1965). *San Bruno Creek Flood Control Zone.* Prepared for San Mateo County Flood Control District. August.

APPENDIX D – COINCIDENT FREQUENCY ANALYSIS

1.0 RISK ASSESSMENT (COINCIDENT FREQUENCY)

The coincident frequency for high water levels in San Francisco Bay and high creek discharge, leading to flooding, was evaluated for this study using a moderately rigorous statistical analysis. The exact theory is simplified through a series of explicit approximations. This section describes each of the following items:

- The standard (and exact) probability theory that underlies the analysis.
- The first approximation, which relates to the set of San Francisco Bay water levels used as downstream boundary conditions (San Francisco Bay water levels). The analysis assumes the high creek discharge coincides with a high tide, but not necessarily the higher high tide.
- The second approximation, which relates to the correlation between the creek discharge and the downstream boundary conditions. The analysis simplifies this correlation by limiting the San Francisco Bay water levels to a subset that has historically coincided with high creek discharges. However, it does not use a quantitative correlation between the Bay water levels and the creek discharge.

The spreadsheet implementation of the statistical analysis follows directly from the theory and approximations.

1.1 Standard Probability Theory

List of Symbols

b	tidal elevation in San Francisco Bay
h	actual water surface elevation in the creek
H_f	creek water surface elevation of concern (overtopping or flood elevation)
n_h	the number of high tides occurring in a given year, equal to 706
q	peak creek discharge
s	sea level rise

List of Functions

$p_b(b)$, $p_q(q)$	individual probability density functions for b and q
$p_{bq}(b,q)$	joint probability density function for b and q
$p_b(b\|q)$	conditional probability density function for b given q
$P()$	general exceedance probability function
$\eta(b,q)$	water surface elevation in the creek, as a function of the peak discharge q and the tidal elevation b
$\mu(h,b)$	peak discharge that gives a creek water surface elevation h given a tidal elevation b

Statistical Framework

The probability that the creek water surface elevation (WSE) h is greater than or equal to H_f in the absence of sea level rise (SLR) is given by the following:

$$P\left(h \geq H_f\right) = \int db \int_{\mu(H_f,b)}^{\infty} dq\, p_{bq}(b,q) \quad (1)$$

In this (and all subsequent) equations, the integral with respect to b is assumed to cover all possible values of b. The lower limit of the integral with respect to q is the discharge needed for the creek WSE to equal H_f. That is, the integral with respect to q provides the probability that the discharge is at least large enough, given the Bay water level, to cause a creek WSE equal to H_f.

An equivalent equation is in the following form:

$$P\left(h \geq H_f\right) = \int db \int_{\mu(H_f,b)}^{\infty} dq\, p_b(b|q) p_q(q) \quad (2)$$

The effect of SLR is to modify the probability density function (PDF) for b:

$$P\left(h \geq H_f\right) = \int db \int_{\mu(H_f,b)}^{\infty} dq\, p_b(b-s|q) p_q(q) \quad (3)$$

The following three sections describe how the standard probability expression in Equation (3) is used in the San Francisco Creeks flood risk analysis.

1.2 Downstream Boundary Conditions

This section describes the probability distribution function (PDF) for the downstream boundary conditions involving the first approximation in the analysis. An exact model would consider all possible downstream boundary conditions, and would base the creek WSE on a non-stationary model. Different creek elevations would result from rising tides, falling tides, etc. The present analysis simplifies this by using a stationary runoff model with fixed downstream boundary conditions.

The analysis assumes the peak discharge coincides with a high tide: this may be the higher high or the lower high tide. This assumption is based on the length of the discharge hydrographs. Figure 1-1 shows a typical set of discharge hydrographs for Colma Creek; the discharge is near its peak for two to four hours. Therefore, it would be over-conservative to assume the peak discharge always coincides with a higher high tide. A moderately conservative assumption is that the peak discharge coincides with one of the high tides: there is one opportunity for flooding in each tidal cycle.

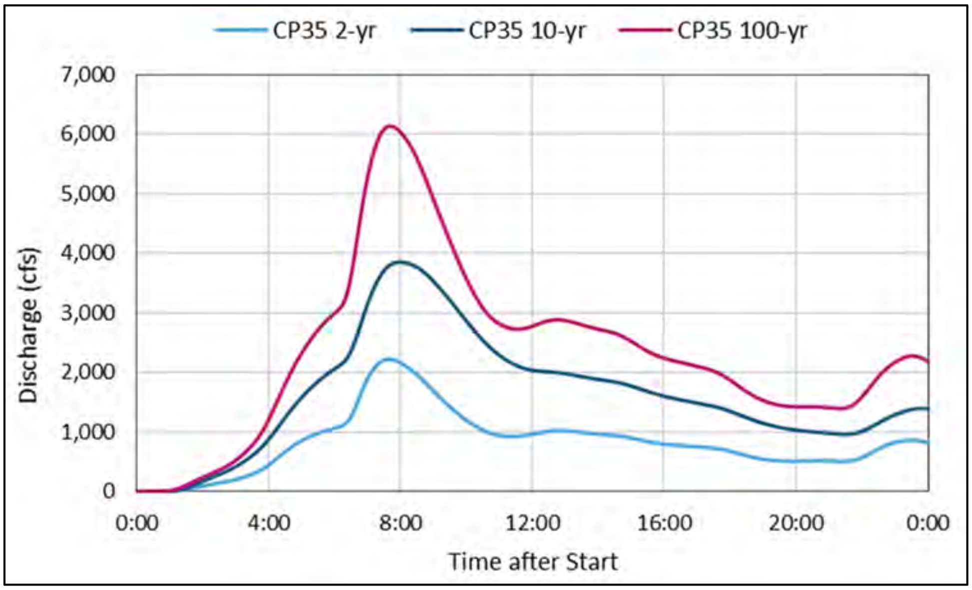

Figure 1-1. HEC-HMS Results for Colma Creek

With this assumption, $p_b(b)$ is interpreted as the PDF of high tide elevations, and the creek WSE is calculated using a stationary HEC-RAS model (see Appendix B). The probabilities in Equations (1) through (4) are probabilities per tidal cycle.

1.3 Correlation between Creek Discharge and Bay Water Levels

There are physical reasons to suppose that high creek discharges are likely to coincide with high water levels in San Francisco Bay. The winter storms that lead to flooding in the creeks are associated with low barometric pressures, which lead directly to higher tides.

However, the statistical significance of this correlation is controversial. Two recent studies have reached opposite conclusions:

- The USACE, San Francisco District investigated the correlation between discharge in San Francisquito Creek and San Francisco Bay water levels (USACE, 2011). They focused on events with discharge greater than 1,200 cfs. These were considered the only significant events, because the 2-year event for this creek is 1,900 cfs. There are 38 such events in the record. The USACE concluded that there is a correlation between the creek discharge and the Bay water levels, but that it is not statistically significant: the calculated R^2 value was 0.06.
- Schaaf & Wheeler (S&W) investigated the coincidence between the discharge in Colma Creek and San Francisco Bay water levels (Schaaf & Wheeler, 2012). They focused on the high water levels and high discharge that occurred during the storm of February 2-3, 1998. S&W concluded that high discharge values are likely to coincide with high San Francisco Bay water levels. They defined a coincident 100-year tidal elevation for use as a downstream boundary condition in their flood protection study for Colma Creek and San Bruno Creek.

This section analyzes the correlation between daily discharge in Colma Creek (USGS, 2014) and tidal elevations in San Francisco Bay (NOAA, 2014). The correlation is considered in two ways:

- The correlation between the meteorological components of the tides (the tidal residuals) and the creek discharge is shown for illustrative purposes.
- The conditional PDF $p_b(b|q)$ is examined quantitatively and an explicit form is developed for use in the statistical risk assessment, as shown in Equation (4).

The only creek considered in this section is Colma Creek, but the results are valid for Navigable Slough and San Bruno Creek. The joint period of record for Colma Creek discharge and tidal elevations in this region of San Francisco Bay is March 1976 through November 1996, while no similar data set is available for the other two creeks. However, the resulting conditional PDF depends only on whether the creek discharge is high enough to cause flooding – so it can be used without change for all three creeks.

1.4 Tidal Residuals

This section explores the correlation between the tides at Alameda and the daily discharge in Colma Creek. Specifically, it considers tidal residuals – the difference between measured and astronomical tides – which capture the meteorological influence. There are two main conclusions:

- Relatively high creek daily discharge values, above 50 to 100 cfs daily mean discharge, are associated with higher tidal residuals.
- Given that the creek discharge is high, the correlation between tidal residuals and creek discharge is small.

This result explains how the USACE and Schaaf & Wheeler studies reached opposite conclusions regarding the correlation between tides and creek discharge.

It is stressed that the daily discharge values considered in this correlation analysis are not directly comparable to the peak discharge values used in runoff analysis, such as those in Figure 1-1. Because the runoff hydrographs are much shorter than a day, the peak discharge will be several times higher than the daily mean discharge.

The cutoff discharge used in the correlation analysis, 100 cfs, has a return period of two to three months.

Figure 1-2 is a scatterplot of the daily discharge in Colma Creek (logarithmic scale) against that day's maximum tidal residual at the Alameda gage. The R^2 value, 0.1975, is relatively small. However, because of the large number of data points (over 6,000), the correlation is highly statistically significant.

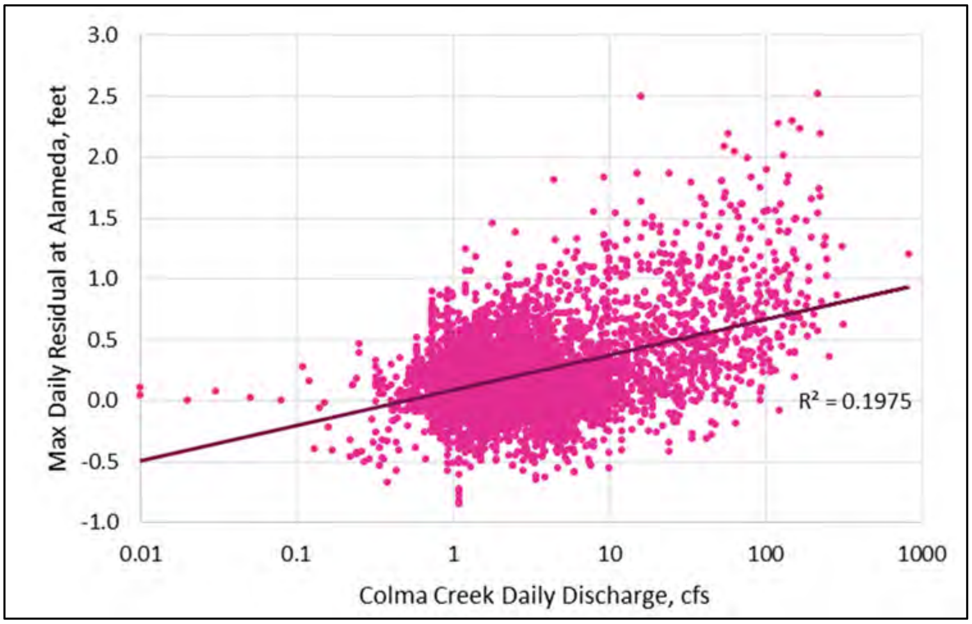

Figure 1-2. Correlation between Tidal Residual at Alameda and Colma Creek Daily Discharge

Figure 1-3 shows the same information as Figure 1-2, except that the x-axis has a linear scale. The trendline is identical to that in Figure 1-2: this second figure highlights the fact that it is a logarithmic fit to the data. This figure suggests that the tidal residual is 0.5 to 1.0 foot higher when the Colma Creek daily discharge exceeds about 50 to 100 cfs. The trendline flattens off at higher residuals.

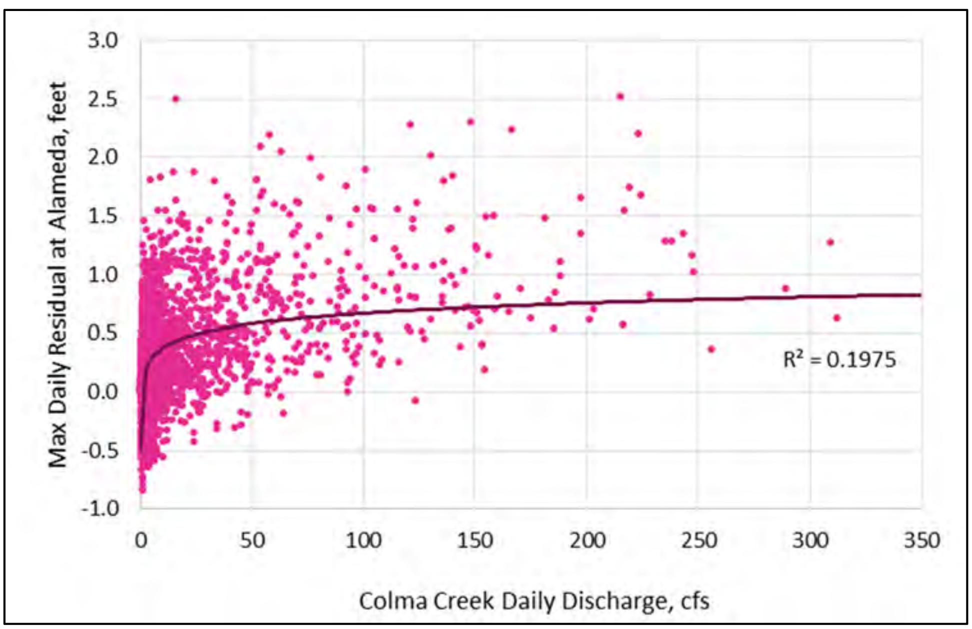

Figure 1-3. Correlation between Tidal Residual at Alameda and Colma Creek Daily Discharge – Linear Discharge Scale

Figure 1-4 is the last correlation plot. It shows the same data as the previous two plots, focusing on higher creek discharge values.

- The *Average* line shows the average tidal residual for those days when the Colma Creek daily discharge exceeds a certain value. For example, the point at 100 cfs gives the average tidal residual for those days on which the Colma Creek discharge was at least 100 cfs.
- The trendline shows the trend for those days on which the Colma Creek daily discharge was greater than 100 cfs.

The *Average* line is nearly horizontal for discharge values greater than 50 or 100 cfs, indicating little effect of the discharge on the tidal residuals once a threshold discharge is reached. Similarly, the trendline nearly flat. The R^2 value is very small, only 0.011, and the correlation is not statistically significant.

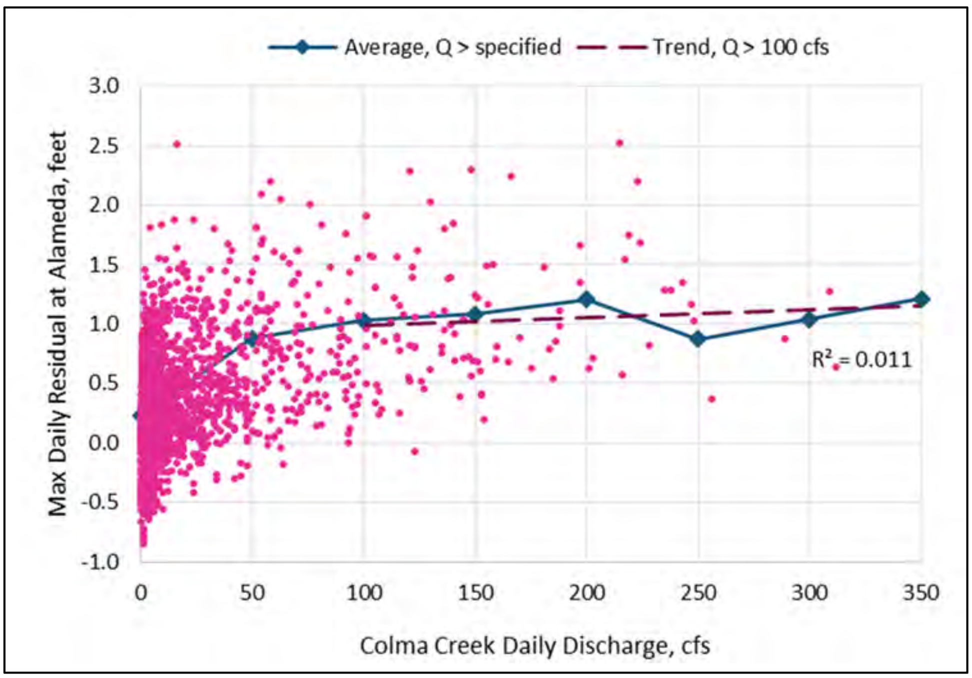

Figure 1-4. Correlation between Tidal Residual at Alameda and Colma Creek Daily Discharge – Analysis Focused on Higher Discharge Values

The results support the conclusion that there is little correlation between the tidal residuals and the creek discharge *when the analysis is limited to days with higher creek discharges*. However, the tidal residuals on those days are relatively large compared to the data set as a whole.

1.5 Tidal Elevations

This section develops a functional form for the conditional PDF $p_b(b|q)$, where b is the tidal elevation in San Francisco Bay and q is the daily discharge in Colma Creek. The second major simplification in the overall analysis is to assume that the tidal elevation – on high discharge days, with the Colma Creek daily discharge greater than 100 cfs – is uncorrelated with the creek discharge. In other words, the conditional PDF can be written in the following form:

$$p_b(b|q) = p_b(b|q(Colma) > 100\ cfs) \quad (4)$$

The tides in this and subsequent sections are from the synthetic time series for the vicinity of SFO, developed by M&N (2013). The distribution describes the actual tide, which is needed for the risk analysis, rather than the tidal residuals.

Figure 1-5 introduces the analysis by showing the exceedance probability for all high tides. The y-axis is the probability that each tidal elevation is met or exceeded on any given tidal cycle. The data sets in this figure are the following:

- The triangles give the probability calculated directly from data in the joint period of record for Colma Creek and the synthetic SFO tides.
- The circles give probabilities based on the annual tidal maxima. These annual tidal maxima were used to estimate 100-year flood level for San Francisco Airport (M&N+AGS, 2013): they use the entire period of record for the synthetic SFO tides.
- The dashed line is the Generalized Extreme Value Distribution (GEVD) fit to the annual tidal maximum.

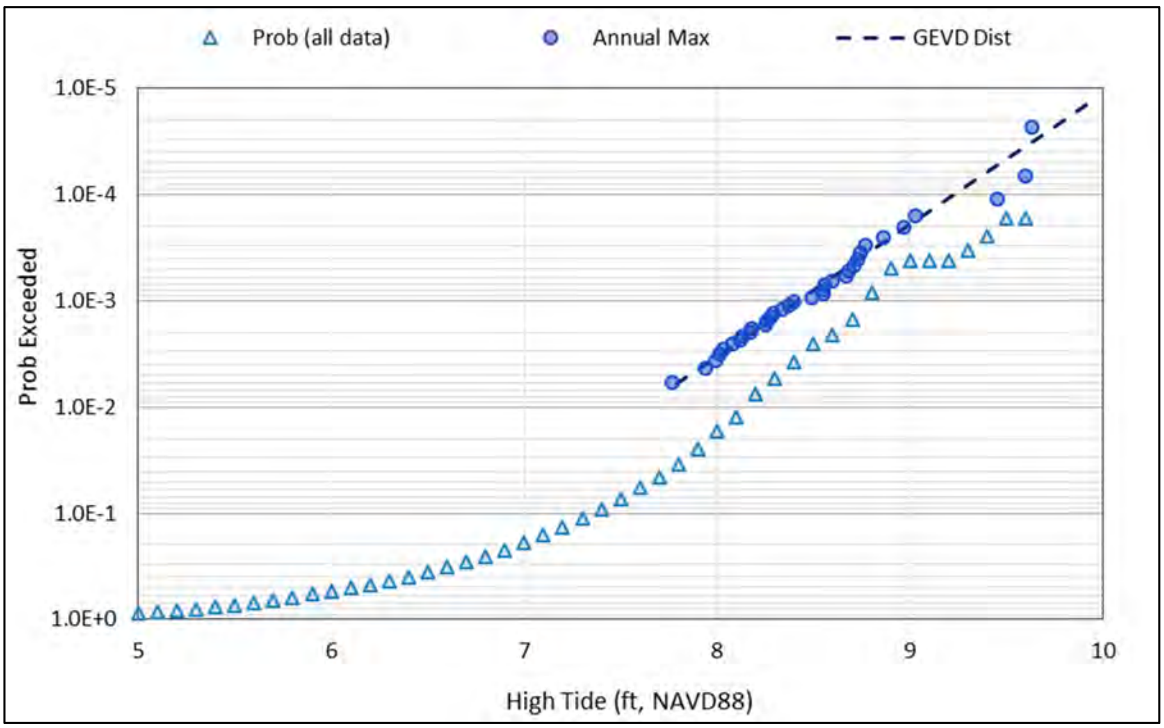

Figure 1-5. Exceedance Probabilities for High Tides at SFO, with Annual Maximum Tides used in GEVD Distribution

The distribution of the annual tidal maximum and the GEVD distribution are normally expressed in terms of return periods, *r*. These return periods, in years, are converted to exceedance probabilities per tidal cycle, *P*, using the number of high tides n_h in a year:

$$P = 1 - \left(1 - \frac{1}{r}\right)^{1/n_h} \quad (5)$$

The quantity n_h takes the value 706, based on a tidal cycle of about 12.5 hours.

Once this conversion is made, the exceedance probabilities calculated directly from the tidal record should match well with the GEVD distribution, at least for the higher tidal elevations. The slight discrepancy in Figure 1-5 results from the shorter period of record used in the direct calculation. The joint period of record for the Colma Creek discharge and the SFO tides was stormier than normal, which leads to a greater probability that a given tidal elevation will be exceeded.

Figure 1-6 shows the equivalent set of exceedance probabilities limited to those days when the Colma Creek daily discharge exceeds 100 cfs. The figure also shows a smooth fit to the exceedance probabilities. In this case, the GEVD distribution is converted to a probability per tidal cycle using the quantity n_h*, the number of tidal cycles per year with a Colma Creek discharge above 100 cfs:

$$P = 1 - \left(1 - \frac{1}{r}\right)^{1/n_h*} \qquad (6)$$

The quantity n_h* is much smaller than n_h – approximately 11, as opposed to n_h = 706 for all tides. As a result of limiting the analysis to stormy days, there is much better agreement between the two data sets.

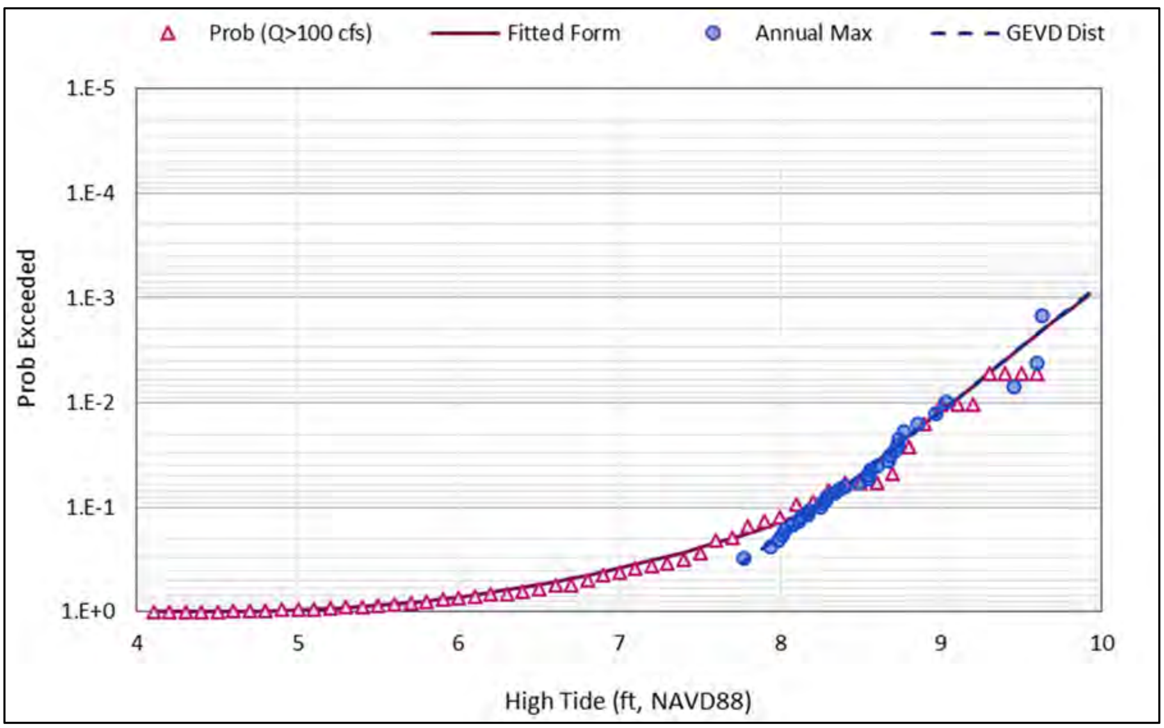

Figure 1-6. Exceedance Probabilities for High Tides at SFO, with Annual Maximum Tides used in GEVD Distribution, Both Limited to Q(Colma) > 100 cfs

Figure 1-7 illustrates the data using probability histograms rather than exceedance probabilities. It shows the PDF for tidal elevations based on all tides (equivalent to the triangles in Figure 1-5), the tides coinciding with high creek discharge (Figure 1-6), and the smooth fitted form used in subsequent analysis.

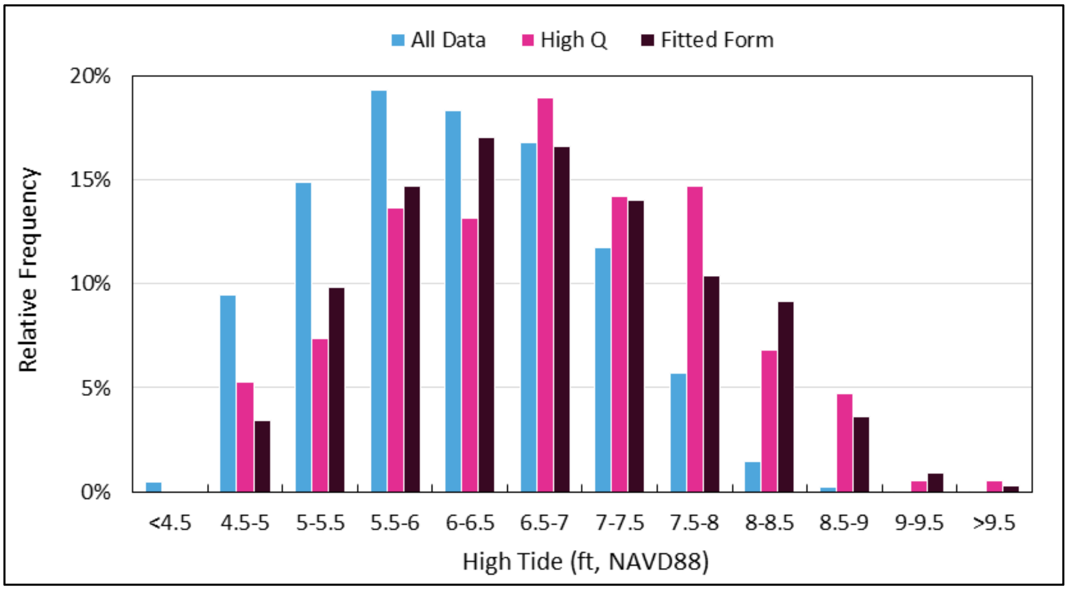

Figure 1-7. Probability Distribution Histograms for High Tides at SFO, All Tides and with Q(Colma) > 100 cfs, together with Fitted Distribution

This fitted form is used as the conditional distribution in Equation (3): $p_b(b|Q(\text{Colma}) > 100 \text{ cfs})$.

1.6 Creek Water Surface Elevation and Return Periods

The probability per tidal cycle that a particular creek elevation H_f is met or exceeded is given by Equation (3). Taking into account the above simplification gives the following form:

$$P(h \geq H_f) = \int db \int_{\mu(H_f,b)}^{\infty} dq\, p_b(b - s|Q(Colma{>}100\ cfs)p_q(q) \qquad (7)$$

A minor reorganization gives the following:

$$P(h \geq H_f) = \int db\, p_b(b - s|Q(Colma{>}100\ cfs)) \int_{\mu(H_f,b)}^{\infty} dq\, p_q(q) \qquad (8)$$

However, the integral with respect to q is just the conditional exceedance probability $P(q \geq \mu(H_f, b))$. This is the probability that q is large enough to create a creek WSE H_f, given b. Equivalently, it is the probability that the creek WSE h is greater than H_f, given b. So this becomes:

$$P(h \geq H_f) = \int db\, p_b(b - s|Q(Colma{>}100\ cfs))\, P(h \geq H_f|b) \qquad (9)$$

The function $p_b(b|Q(\text{Colma}) > 100 \text{ cfs})$ is just the fitted distribution shown in Figure 1-7.

1.7 Implementation

The flooding results shown in this report reflect a direct spreadsheet-based implementation of Equation (9). The conditional exceedance probability $P(h \geq H_f|b)$ is prepared as a matrix of results taken directly from the HEC-RAS model results developed by Schaaf & Wheeler and described in Section 4-2 and Appendix B.