BAYFRONT CANAL HYDROLOGY
AND
HYDRAULIC EVALUATION

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EXECUTIVE SUMMARY

The following report presents an evaluation of the Bayfront Canal drainage system located in the Cities of Redwood City and Menlo Park. The Bayfront Canal system also conveys runoff from Atherton, unincorporated San Mateo County and Woodside that is conveyed to the Bayfront Canal in the Atherton Channel and local storm drain lines. The project vicinity is shown on Figure 1 and the project drainage area is shown on Figure 2. Currently, there are multiple locations within the drainage area that experience significant flooding on a regular basis. These areas are shown on Figure 3 and include:

1. Friendly Acres neighborhood (Redwood City and Menlo Park)
2. Douglas Pump Station Vicinity (Redwood City)
3. Fifth Avenue Pump Station Vicinity (Redwood City)
4. Fair Oaks Neighborhood (County of San Mateo)

To date, correcting individual drainage problems has been made difficult by the interrelationship of flooding between sites. There is a justifiable concern that correcting flooding at any one site will worsen flooding in other locations within the drainage area. Redwood City is currently working to reduce the frequency of flooding in the vicinity of the Bayfront Canal by providing a connection to Managed Ponds within the proposed Salt Pond Restoration Project. With this connection, a portion of the peak flows in excess of the Bayfront Canal capacity could be stored within the proposed Managed Ponds. No other improvements are currently being pursued, although there are multiple Cities that would benefit from correcting the Bayfront Canal drainage system deficiencies.

KEY DRAINAGE ELEMENTS

Key drainage areas and facilities within the Bayfront Canal system are shown on Figure 3. The following are the key components of the system.

1. <u>Bayfront Canal</u> – Collects runoff from approximately 9.5 square miles of drainage area. Properties adjacent to the Canal flood frequently.
2. <u>Bayfront Canal Tide Gate</u> – All flow to the Bayfront Canal must pass through the Bayfront Canal Tide Gates to reach San Francisco Bay. The existing tide gates are undersized, thereby contributing to flooding along the Bayfront Canal.
3. <u>Highway 101</u> – Highway 101 acts as a barrier that prevents surface flow from southwest of Highway 101 from entering the Bayfront Canal. Culverts and pump stations (Douglas Avenue and 5th Avenue Pump Stations) that convey flow across

Highway 101 are undersized. As a result, flooding occurs on the southwest side of Highway 101 during major storm events.

4. Douglas Avenue Drainage Area – Douglas Avenue drainage area is a low-lying area southwest of Highway 101 served by 5th Avenue pump station and Douglas Avenue pump station. The Stanford Outpatient Center is located within this low-lying area, specifically between Broadway and Highway 101. The site vicinity floods during a 2-year storm.
5. Atherton Channel – The Atherton Channel is the primary source of runoff to the Bayfront Canal.
6. North Fair Oaks – North Fair Oaks is an unincorporated neighborhood within San Mateo County. A portion of North Fair Oaks southwest of the Railroad Tracks floods frequently. Efforts to reduce the frequency of flooding have been stopped because fixes to this area would worsen downstream flooding. Runoff to this area is pumped at the undersized Athlone Pump Station into Atherton Channel.

POTENTIAL CORRECTIVE MEASURES FOR BAYFRONT CANAL

A range of corrective measures has been investigated for providing long-range improvements that will reduce the potential for flooding within the Bayfront Canal drainage area. The following potential improvements are investigated:

1. Connecting to Managed Ponds.
2. Pumping to Flood Slough
3. Increasing the height of the top of berm along Bayfront Canal
4. Increasing Pumping Capacity of Fifth Avenue and Douglas Pump Stations
5. Increasing Pumping Capacity of Athlone Pump Station
6. Storing Runoff within the Town of Atherton
7. Increasing the area of the Tide Gates

BENEFIT OF INDIVIDUAL CORRECTIVE MEASURES

The following are benefits of potential improvements as stand-alone measures. The measures are sensitive to future sea level rise and the timing of peak storm events versus the daily tidal pattern. The study compares improvements against a wide range of potential sea level rise scenarios.

1. Managed Ponds within the South Bay Salt Pond Restoration Project

Currently, the City of Redwood City is investigating conveying a portion of the Bayfront Canal flow to proposed Managed Ponds within the South Bay Salt Pond Restoration Project adjacent to Bayfront Park and Flood Slough.

The analyses of the existing condition with the Managed Ponds show that the improvements provide some flood reduction benefit to the various Trailer Parks adjacent to the Canal but does not eliminate flooding that occurs on a regular basis. So, Managed Ponds as a standalone measure does not fully address flooding in the Bayfront Canal drainage system.

2. Flood Slough Pump Station

As an alternative, a pump station that would pump flows from Bayfront Canal to Flood Slough, around the Tide Gates, was investigated. For the purposes of this study, a conceptual Pump Station near Flood Slough is used. Based on existing conditions, without the connection to the Managed Ponds, or upstream improvements or increased top of bank elevations, the maximum pumping rate that is effective is about 1,500 cfs. Any further increase in pumping does not provide significant benefit because the Bayfront Canal hydraulic capacity becomes the constraining factor which prevents keeping the Canal's water level below existing top of bank, thus resulting in some overtopping. Therefore, Flood Slough pump station alone is not effective in addressing Canal flooding issues.

3. Raise Top of Bank Elevations along Bayfront Canal

The ability to store water within the Bayfront Canal is currently constrained by the depth at which runoff overtops the adjacent channel banks. Additional depth for storage can be created by protecting the low-lying properties adjacent to Bayfront Canal using raised embankments or floodwalls with Supplemental Pumping. The extent of increased embankments also include low-lying portions of the Atherton Channel. The height of the embankment required as a standalone measure is not feasible and therefore is not analyzed as a standalone measure.

4. Increasing Pumping Capacity of Fifth Avenue and Douglas Pump Stations

The Bayfront Canal improvements do not directly reduce the flooding within the low-lying area southwest of Hwy-101. To reduce flooding in this area, the pumping capacity at either the Douglas Avenue Pump Station or the Fifth Avenue Pump Station must be increased. Currently, increasing the pumping capacity alone is not feasible because it would worsen Bayfront Canal flooding. However, if completed in conjunction with the Bayfront Canal improvements, both areas will benefit.

5. Increasing Pumping Capacity of Athlone Pump Station

The Bayfront Canal improvements do not directly reduce the flooding within the low-lying North Fair Oaks neighborhood (southwest of the railroad tracks). To reduce flooding in this area, the pumping capacity at the Athlone Pump Station must be increased. Currently, increasing the pumping capacity is not feasible because it would worsen Bayfront Canal flooding. However, if completed in conjunction with Bayfront Canal improvements, both areas will benefit.

6. Storing Runoff within the Town of Atherton

The Town of Atherton's Townwide Drainage Study recommends providing additional storage along the Atherton Channel to reduce flooding potential within the Town of Atherton. If this recommendation is implemented, the spill from Atherton Channel to North Fair Oaks would be reduced and there would be a corresponding lowering of water levels within North Fair Oaks neighborhood.

7. Tide Gate Expansion

The existing tide gates severely restrict flows and cause flows to back up onto properties adjacent to the Bayfront Canal. It is possible to lower water levels during low tide by increasing the number of tide gates that convey flow from the Bayfront Canal to the Bay. However, tide gates are not effective at conveying flow under submerged conditions which occur during high tides or with sea level rise. Therefore, this option is not considered further.

Combination of Corrective Measures

The level of protection for the Bayfront Canal system can be improved significantly by a combination of increasing the available storage and installation of a pump station to discharge to Flood Slough. The results depend on whether the Managed Ponds can be used as part of the solution. For purposes of this review, two combinations of measures are considered:

Combination 1: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and with (c) Managed Ponds

Combination 2: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and (c) without Managed Ponds

A total of three sets of embankment elevations are used for evaluating the benefits of increasing the top of bank elevation. These are referred to as Embankment Plan A, Embankment Plan B and Embankment Plan C for Bayfront Canal and Embankment Plan X, Embankment Plan Y and Embankment Plan Z for Atherton Channel. In many locations, the current top of bank elevation exceeds the minimum proposed top of bank elevation and no action is necessary. Extensive photos and topographic information have been developed and are available for review.

The evaluated pumping rate and embankment plan combinations that provide protection from 10-year, 25-year and 100-year storms are shown in Table ES-1.

TABLE ES-1:
Required Pumping Rate and Embankment Plan Combination versus Level of Protection

Level of Protection / Embankment Plan	Pumping Rate With Managed Ponds (cfs)	Pumping Rate Without Managed Ponds (cfs)
10-Year		
A (EL. 8.0’ to 10’)	1,360	1,380
B (EL. 8.5’ to 10’)	660	1,200
C (EL. 9.5’ to 11’)	410	1,080
25-Year		
A (EL. 8.0’ to 10’)	1,500	1,500
B (EL. 8.5’ to 10’)	1,180	1,400
C (EL. 9.5’ to 11’)	510	1,190
100-Year		
C (EL. 9.5’ to 11’)	920	1,540

For the 100-year storm event, it is not possible to pump at a rate that will provide a water level lower than the embankment heights of Embankment Plans A and B because of constraints in the flow capacity between the confluence with the Atherton Channel and the proposed Flood Slough Pump Station.

As shown, the Managed Ponds will allow for a smaller or similar pump size for all conditions, but the difference is greatest when the amount of storage is increased by either including the Managed Ponds or by raising the top of embankment elevation.

CONCLUSIONS AND RECOMMENDATIONS

The low-lying areas in the vicinity of the Bayfront Canal are subject to frequent inundation. Currently, the 2-year or greater storm event will cause flooding to low-lying areas adjacent to the canal. In addition, there are two upstream areas that also flood more frequently than a 2-year storm event. Correcting the upstream flooding problems on an individual basis has not been feasible because of the impact that such corrective measures would have on the flooding of adjacent drainage areas and in the vicinity of the Bayfront Canal.

The Bayfront Canal flooding cannot be reduced to an acceptable level by any single solution alone, i.e., by a) only pumping to Flood Slough; b) only increasing the available storage using the Managed Ponds; or c) only increasing the available depth in the Canal. In other words, no single measure could lower water levels to a level that would provide an acceptable level of flood protection throughout the drainage area. Instead, a combination of measures is more effective and should be implemented.

1.0 Introduction

The Bayfront Canal (Canal) is located just north of Highway 101 in the City of Redwood City (City). The Canal extends from west to east, from Douglas Court to Marsh Road and is bounded to the north by Cargill's salt ponds and to the south by residential and industrial properties. The Bayfront Canal system also conveys runoff from Atherton, unincorporated San Mateo County and Woodside that is conveyed to the Bayfront Canal in the Atherton Channel and local storm drain lines. Atherton Channel flows into the Bayfront Canal a few hundred feet west of Marsh Road. The combined flow discharges into Flood Slough through a tide gate control structure. Bayfront Canal conveys runoff from approximately 9 square miles of tributary drainage area that is located primarily on the south side of Highway 101. The largest discharge to the Bayfront Canal is the Atherton Channel. The Atherton Channel has a 6.5 square miles drainage area. The project vicinity is shown on Figure 1 and the project drainage area is shown on Figure 2.

The Bayfront Canal is approximately 8,000 feet in length. The top width varies along the length and is about 40 feet on average. The Canal's north bank varies from elevation 9.2 to 11.7 NAVD (all elevations used in this report are NAVD in feet unless otherwise noted). The south bank varies from elevation 7.7 to 11.7 with adjacent property elevations ranging from elevation 6.2 to 11.0. Properties adjacent to the Canal have experienced frequent flooding during moderate to severe storm events due to overtopping of the Canal's south bank.

Background

Currently, there are multiple locations within the drainage area that experience significant flooding on a regular basis. These areas are shown on Figure 3 and include:

1. Friendly Acres neighborhood (Redwood City and Menlo Park)
2. Douglas Pump Station Vicinity (Redwood City)
3. Fifth Avenue Pump Station Vicinity (Redwood City)
4. Fair Oaks Neighborhood (County of San Mateo)

To date, correcting individual drainage problems has been made difficult by the interrelationship of flooding between sites. There is a justifiable concern that correcting flooding at any one site will worsen flooding in other locations within the drainage area. Redwood City is currently working to reduce the frequency of flooding in the vicinity of the Bayfront Canal by providing a connection to Managed Ponds within the proposed Salt Pond Restoration Project. With this connection, a portion of the peak flows in excess of the Bayfront Canal capacity could be stored within the proposed Managed Ponds. No other improvements are currently being pursued, although there are multiple Cities that would benefit from correcting the Bayfront Canal deficiencies.

2.0 Referenced Studies

Numerous flood studies have been conducted for the Bayfront Canal. A major study was conducted in 1983 by BKF Engineers with support from HydroComp. In 1988, HydroComp revised their analysis to reflect additional years of rainfall data and concluded that the peak flow rates developed in the original study were based on too short of a time span. HydroComp evaluated runoff to the Bayfront Canal using additional years of rainfall and tide records. The revision resulted in a significantly higher design flow rate.

This revision was sent to the City of Redwood City, but did not get incorporated into the studies that have been conducted since. As a result, recent studies have used flows from the original 1983 data rather than the corrected 1988 flows. The 1983 study provided a 100-year event peak flow rate of 1,250 cfs at the tide gates. The reviewed 1988 analyses recommended that a peak flow rate of 2,200 cfs be used. This included 1,600 cfs in the Atherton Channel and 600 cfs from remaining drainage areas. The 600 cfs appears to be a total of flow that can reach the Bayfront Canal and includes direct rainfall from north of Highway 101 and flow restrictions associated with the 78-inch diameter inverted siphon, Douglas Avenue Pump Station and 5th Avenue Pump Station.

The following is a list of references used in this report followed by a section stating key findings from each reference. For purposes of this investigation, we have not reviewed studies prior to 1983.

Studies Presenting Design Flow Rates to Bayfront Canal

- *Bayfront Canal Investigation for the City of Redwood City* prepared by BKF Engineers dated October 1983 (BKF 1983)

- *Bayfront Canal Status Report* by BKF Engineers dated May 24, 1988 (BKF 1988)

The hydrology of the Bayfront Canal was investigated in BKF 1983 and 1988. The Canal was evaluated for a multiple year period to determine 10- and 100-year water levels based on simultaneous tide and storm event conditions. For the BKF 1983, the study period was 1940 through 1960. For BKF 1988, records dating to 1911 were used. The 1983 study provided a 100-year event peak flow rate of 1,250 cfs at the tide gates. This includes 380 cfs from the area not including Atherton Channel. The reviewed 1988 analyses recommended that a 100-year event peak flow rate of 2,200 cfs be used at the Tide Gates. The letter reports a flow rate of 1,600 cfs for Atherton Channel. Based on the context, it appears that this is for the 100-year event. It is not clear from context whether the 2,200 cfs flow rate is constrained by upstream system limitations, such as pumping limits.

- *Town of Atherton Town-wide Drainage Study,* prepared by Nolte Associates and dated June 28, 2001 (Nolte 2001)

- *Storm Drainage Report for Town of Atherton – Drainage Criteria* study, currently being prepared (2013 BKF Study)

  Hydrologic and hydraulic conditions within Atherton are described in the report, *Town of Atherton Town-wide Drainage Study,* prepared by Nolte Associates and dated June 28, 2001 (Nolte 2001). BKF has referenced this study to prepare an updated hydrologic and hydraulic model. The update is part of the *Storm Drainage Report for Town of Atherton – Drainage Criteria* study, currently being prepared (2013 BKF Study). The 2013 BKF Study includes more recent base data (i.e., San Mateo County LiDAR data and various cities and County storm drain system maps) for revising drainage delineations, and using rainfall, storm distribution, land-use, runoff transformation, and routing methods per Santa Clara County Drainage Manual.

- *Draft Hydrology Study, Atherton Creek at Haven Court*, prepared by Schaaf & Wheeler and dated July 8, 2002 (S&W 2002)

  This Report references BKF 1983 and is used as the basis for flows used in the later reports.

Bayfront Canal and Associated Drainage Area - Evaluations of Proposed Improvements

- Bayfront Canal Improvement Project by Winzler & Kelly dated December 2003 (W&K 2003)

  Report for City of Redwood City. The report references the 1983 BKF flows and the S&W 2002 Report. The report presents options for resolving Bayfront Canal flooding. Flows are not increased to account for upstream pump station modifications.

The Canal topography developed as a part of W&K 2003 (MASTTOPO.dwg) was used to build the model for BKF 2013. A datum conversion factor of 2.7 feet was added to convert the topographic elevations from NGVD29 to NAVD88.

- *Stanford Outpatient Center Flood Risk Analysis* technical memorandum (Stanford Outpatient Technical Memo) dated November 4, 2010 prepared by BKF.

  The report reviewed flooding at the Stanford Outpatient Center. Analyses were based on flows from W&K 2003.

- *Bayfront Canal and South Bay Salt Ponds S5/R5 Flood Mitigation Feasibility Study* prepared by Moffatt & Nichol dated May 22, 2012 for City of Redwood City

  The report investigates potential use of managed ponds within the South Bay Salt Pond Restoration Project. Statistical tidal gage data collected by Moffatt & Nichol as part of the *Bayfront Canal and South Bay Salt Ponds S5/R5 Flood Mitigation Feasibility Study* dated May 22, 2012 for City of Redwood City was used for the hydraulic analysis. The stage-storage data of ponds S5/R5 and R3 were also used for the analysis.

Design Parameters

- Santa Clara County Drainage Manual dated 2007

  Hydraulic criteria from this manual were used to develop the hydrologic and hydraulic model for this study with modifications as described in Appendix A. The project area is in San Mateo County. There are no County-wide Standards available for San Mateo County suitable for the project.

Sea Level and Sea Level Rise

San Francisco Bay Tidal Stage vs. Frequency Study by the U.S. Army Corps of Engineers, San Francisco District dated October 1984 (COE 1984)

Living with a Rising Bay by San Francisco Bay Conservation and Development Commission (BCDC) dated October 6, 2011 (BCDC 2011)

Guidance on Incorporating Sea Level Rise by the California Department of Transportation (Caltrans) dated May 16, 2011, (Caltrans Guidance 2011)

Information on 100-year tide elevations and sea level rise prior to 1984 is presented in COE 1984. The Federal Emergency Management Agency has adopted 100-year tide levels from this study for use in establishing base flood elevations adjacent to San Francisco Bay. Information on anticipated sea level rise is presented in the reports, Living with a Rising Bay by San Francisco Bay Conservation and Development Commission (BCDC) dated October 6, 2011 (BCDC 2011), and, the report Guidance on Incorporating Sea Level Rise by the California Department of Transportation (Caltrans) dated May 16, 2011, (Caltrans Guidance 2011)

3.0 Key Drainage Elements

Key drainage areas and facilities within the Bayfront Canal system are shown on Figure 3. The following subsections describes key components of the system.

Bayfront Canal Tide Gate

The system outfalls through the undersized Bayfront Canal Tide Gates (Tide Gates) that discharges to Flood Slough. Photographs of the Tide Gates are shown in Exhibit 1. All flows to the Bayfront Canal ultimately discharge through these Tide Gates. The Gates are operated and maintained by the City of Redwood City. The existing Tide Gates constrain the amount of flow that can be discharged to the Bay. When the flow capacity of the Tide Gates is exceeded as a result of either too much flow to the Bayfront Canal, high tide levels within the Bay or a combination of the two events, flooding occurs within low-lying areas adjacent to the Bayfront Canal. One critical location is the Trailer Villa neighborhood.

The current 100-year tide in the project area is about elevation 10.2 (NAVD). There are areas within the Bayfront Canal area that are lower than this elevation. With sea level rise, the 100-year tide level will increase. The Tide Gates are a necessary feature to protect low-lying developed areas during extreme tide events. As such, the Tide Gates cannot be removed without a commitment to increase the embankment heights along the Bayfront Canal and Marsh Road.

Bayfront Canal

The Bayfront Canal conveys flows from a 6,066-acre drainage area to Flood Slough through the Tide Gates. The top width of the Bayfront Canal varies from 40 to 80 feet. The depth varies from 6 to 11 feet from the Canal flow line to the top of bank. Currently, the Canal has adequate flow capacity when the Tide Gates do not restrict flows. The flow capacity of the Canal would become a constraint if the pumping rates from Douglas Avenue or Fifth Avenue Pump Station were to increase. Currently, properties on low-lying lands adjacent to the Bayfront Canal flood frequently, primarily due to the flow capacity restriction that occurs at the existing Tide Gates, rather than the flow capacity of the Canal.

Highway 101

Highway 101 (Hwy-101) is parallel to the Bayfront Canal and is between much of the Bayfront Canal drainage area and the Canal itself. Hwy-101 acts as a barrier to surface flows. Flow is pumped under Hwy-101 at the Douglas Avenue and Fifth Avenue Pump Stations. In addition to the pump stations, flow is conveyed by gravity via a 78-inch diameter inverted siphon under Hwy-101 and by a culvert where Atherton Channel crosses under Hwy-101.

The Fifth Avenue Pump Station is significantly undersized. There are plans to expand the Fifth Avenue Pump Station from 30 cfs to 300 cfs. These plans are on hold because the downstream flooding issues associated with the Bayfront Canal have not been resolved.

The Douglas Avenue Pump Station is sized to convey runoff from the tributary drainage area that directly flows to the Pump Station. However, because of deficiencies in the adjacent drainage systems (Atherton Channel, Fifth Avenue Pump Station and 78-inch Inverted Siphon), during major storm events, there is significant overflow that is conveyed as surface flow to the low lying area in the vicinity of the Douglas Avenue Pump Station. As a result, frequent flooding has occurred in the low-lying area in the vicinity of the Douglas Avenue Pump Station. The existing Stanford Outpatient Center, the future Stanford in Redwood City project, and the Genentech facility are all affected by the flooding in this area.

Douglas Avenue Drainage Area

The low-lying area in the vicinity of the Douglas Avenue Pump Station that includes the Stanford Outpatient Center is hydraulically separated from the Bayfront Canal by Hwy-101. Because there is no surface flow away from this area, the only way to discharge storm water from this area is through either the Douglas Avenue or Fifth Avenue Pump Stations. To correct flooding in the area, pumping capacity must be increased.

The Stanford Outpatient Center which is adjacent to the Douglas Avenue Pump Station is a medical facility that was constructed in 2000 with the building finished floor raised above the expected 100-year water level for the project area. However, access to and from the facility is restricted when Broadway floods, requiring postponement of some medical procedures whenever there is a forecast of a major storm event.

Two options are available for increasing pumping capacity. One option is to increase the pumping capacity at Douglas Avenue Pump Station. The pumping capacity at this location is restricted by the existing force main from the pump station to Bayfront Canal. A second option is to increase the pumping capacity at the Fifth Avenue Pump Station. The conveyance under Hwy-101 and the outfall to the Bayfront Canal that support a higher pumping rate are already constructed, resulting in less limitations on pump station expansion.

Based on current constraints (i.e., existing force main capacity and downstream channel capacity), increasing the Athlone Pump Station to 100 cfs and Fifth Avenue Pump Station to 300 cfs appear to be reasonable upper limits. With these improvements, the 25-year water level is reduced from elevation 9.8 to elevation 9.1. A gravity hydraulic connection between the Douglas Avenue Pump Station and Fifth Avenue Pump Stations may be required to take full advantage of this additional pump capacity. Addition analyses is required to confirm the need for a hydraulic connection between Douglas Avenue Pump Station and upgraded Fifth Avenue Pump Station.

Atherton Channel

The largest drainage facility that conveys flow to the Bayfront Canal is the Atherton Channel. The Atherton Channel drainage area accounts for roughly 70 percent of the total area draining to the Bayfront Canal and contributes approximately 39 percent of the Canal's total flow. The proportional amount of flow is less than the proportionate area because the Atherton Channel drainage area has a higher percentage of pervious surfaces and tree cover compared to drainage areas within Redwood City and Menlo Park. Flows from Atherton Channel enter the Bayfront Canal 400 feet upstream of the Tide Gates. The flow capacity of Atherton Channel is limited, and spill from the Channel occurs at several locations. Spill from the Channel flows overland to the North Fair Oaks area and Friendly Acres, and as a result contributes to flooding that occurs in these areas.

Improvements to the Atherton Channel adjacent to Marsh Road were completed in August 2016. This Project improved the stability of the Channel but did not increase the flow capacity.

North Fair Oaks

The North Fair Oaks Area is within unincorporated San Mateo County. Surface flows to this area include local runoff and Atherton Channel spills. The JPB/CalTrain tracks act as a barrier to surface flows resulting in ponding next to the tracks in the North Fair Oaks neighborhood. Per the Redwood City Storm Drain Master Plan, this area is served by a 42-inch diameter storm drain line. The 42-inch diameter storm drain line was not constructed because of the flooding problems identified in the Bayfront Canal. Instead, a storm drain pump station (Athlone Pump Station) was constructed that pumps 35 cfs to the Atherton Channel. The pump station is currently undersized for the combined local runoff and spills from Atherton Channel. Flooding occurs frequently in this area.

4.0 Engineering Analysis

Engineering analyses are summarized in this section and described in detail under Appendix A. The analyses are separated into a Hydrology Section and a Hydraulics Section. In the Hydrology Section, the amount and the intensity of rainfall combined with the drainage area characteristics are used to compute associated runoff hydrographs for 2, 5, 10, 25 and 100-year rainfall events. The Hydraulics Section describes the routing of flows through the existing drainage system to establish a baseline condition, and through various system upgrades to evaluate potential reductions in water level with potential corrective improvements. The Hydraulic analyses generate water levels associated with the flow rates developed in the Hydrology Section.

Model Peer Review

Peer review is a critical aspect of building a robust and reliable model. In 2013, Schaaf and Wheeler (S&W) peer reviewed the methodologies, assumptions, and data used to develop the hydrology and hydraulic models. BKF held a meeting with the City of Redwood City, Menlo Park, County of San Mateo and Stanford to discuss preliminary findings and to hand over the 2013 report and models. BKF had incorporated S&W comments prior to the meeting with the parties and distributing the model. Moffett and Nichol (M&N) who assisted the City of Redwood City with the Salt Ponds feasibility analyses also peer reviewed and provided comments. M&N also incorporated BKF's findings pertinent to the Salt Ponds into their feasibility study. The peer review comments and response are provided under Appendix A. It is important that the integrity of the models be maintained by all parties conducting future evaluations. As such, user controls should be put in place to ensure accuracy and consistency of the model results.

4.1 Hydrology

The Bayfront Canal 9.48 square mile drainage area consists of the following six drainage subareas:

Atherton Channel area	6.59 square miles (70% of total)
Second Avenue drainage area	0.65 square miles (7% of total)
Broadway and Douglas Pump Station areas	0.58 square miles (6% of total)
Fifth Avenue drainage area	0.44 square miles (5% of total)
East Bayshore drainage area	0.32 square miles (3% of total)
Shelby Lane drainage area	0.90 square miles (9% of total)

The percentage of the total drainage area shown above correspond to individual tributary area contribution and is not representative of the percentage of flow contributed by these individual drainage areas. Figure 2 shows the drainage area delineations with respect to Bayfront Canal. The following describes key input parameters used to develop the system-wide hydrologic and hydraulic model.

4.1.1 Impervious Area

The percentage of impervious area for each drainage area was developed using available zoning and land-use maps from the Town of Atherton, City of Redwood City, and City of Menlo Park. The impervious percentages were adjusted to reflect local development densities for similar land uses and current conditions as taken from aerial photographs of the area.

4.1.2 Runoff Characteristics

Site soil conditions from the United Stated Natural Resources Conservation Service (NRCS) Web Soil Survey are utilized for the analyses. Soils within Atherton Channel drainage area are primarily classified as having a high percolation potential with the remaining drainage areas in the Bayfront canal drainage area being high in clay with low percolation potential. Most of the Atherton Channel drainage area consists of large parcels that are well vegetated with substantial tree cover whereas, the areas within Redwood City and unincorporated San Mateo County consist primarily of high density residential and commercial parcels. The percentage imperviousness and Curve Number (CN) are tabulated in Table 4.1 below. A high CN represents impervious soils, while a low CN represents areas with high percolation potential.

Table 4.1 Percentage Impervious Area and Curve Number

Drainage Area	Area (acres)	Area (sq. miles)	% Impervious	CN
Atherton Channel	4,217	6.59	34%	47 to 78
2nd Ave	415	0.65	68%	78
Broadway	205	0.32	79%	78
Douglas	166	0.26	95%	78
5th Ave	284	0.44	61%	78
East Bayshore	205	0.32	78%	78
Selby	573	0.90	30%	47
Total not Including Atherton Channel	1,849	2.89	60%	--
Total	6,066	9.48	42%	--

4.1.3 Precipitation and Storm Distribution

Table 4.2 below shows the 24-hour depths and peak 15-minute intensity corresponding to various Mean Annual Precipitation isohyets (MAPs). The mean annual precipitation is highest in the higher elevation portion of the drainage areas in Woodside and the western portion of Atherton and is least near the Bay. An alternating block rainfall distribution curve that matches the Intensity-Duration Frequency (IDF) Curves of rainfall intensity was used to spread the total depth over a 24-hour period. The rainfall intensity is increased in areas with higher mean annual precipitation. The areas with a high MAP have higher rainfall intensity than areas with a low MAP.

Table 4.2 24-Hour Depth and Peak 15-Minute Intensity

Mean Annual Precipitation	10-Year		25-Year		100-Year	
	Intensity (in/hr)	Depth (inches)	Intensity (in/hr)	Depth (inches)	Intensity (in/hr)	Depth (inches)
18"	1.60	3.91	1.91	4.67	2.30	5.39
20"	1.66	4.06	1.98	4.86	2.40	5.61
22"	1.74	4.26	2.08	5.09	2.51	5.88
24"	1.80	4.42	2.16	5.28	2.60	6.09
26"	1.88	4.61	2.25	5.52	2.72	6.36
28"	1.95	4.77	2.33	5.70	2.81	6.58

The 6- and 12-hour storm totals for a mean annual precipitation of 20 inches for the range of storm events are shown in Table 4.2a below.

Table 4.2a Rainfall Amount for 6- and 12-hour Storms for Mean Annual Precipitation of 20- inches

Storm Recurrence Interval	6-hour	12-hour
	(inches)	(inches)
2-year	1.21	1.71
5-year	1.71	2.42
10-year	2.03	2.87
25-year	2.43	3.44
100-year	3.02	4.26

4.1.4 Routing

Storage within Atherton Channel and through Bear Gulch Reservoir was incorporated into the model. The reservoir stage-storage curve and operational level were provided by the California Water Service Company.

4.1.5 Peak Flow Rates

The peak flow rates from the various drainage areas within the Bayfront Canal drainage area were modeled to provide a runoff hydrograph from each area for each return frequency rainfall event. Peak flows provided would reach the Bayfront Canal at different times, with flow from smaller drainage areas reaching first and flows from larger drainage areas (i.e. Atherton Channel) arriving later in the storm event. As a result, the peak runoff rate at the Bayfront Canal cannot be determined by summing individual flow rates. Also, the design storm peak flow rates from the individual drainage areas are based on no localized flooding. Localized flooding associated with undersized pump stations and culverts causes unintentional stormwater detention that lowers the discharge to the downstream system. Peak flow rates from the individual drainage areas are summarized in Table 4.3.

Table 4.3 24-Hour Design Storm Peak Flow Rates

Drainage Area	10-Yr Peak Discharge (cfs)	25-Yr Peak Discharge (cfs)	100-Yr Peak Discharge (cfs)	Percentage of Total 25-Year Flow	HydroComp 100-Yr Peak Discharge (cfs)
Atherton Channel (see note 1)	1,018	1,244	1,543	39%	1,600
2nd Ave	426	523	641	17%	NA
Broadway	241	293	356	9%	NA
Douglas	221	266	321	8%	NA
5th Ave	297	367	452	12%	NA
East Bayshore	194	236	287	7%	NA
Selby Lane	180	228	304	7%	NA
Subtotal (see note 2)	1,559	1,913	2,361	61%	NA
Total (see note 3)	2,577	3,157	3,904	100%	NA

1. The runoff computed excludes Atherton Channel capacity limitations to carry all of the runoff generated from respective tributary areas.
2. Subtotal does not include Atherton Channel.
3. Total runoff is the sum of the individual peak flow rates and does not account for the difference in timing when the peak flows reach the Bayfront Canal. The 2013 Hydrologic Model routes individual hydrographs from each drainage area and includes reduction in the peak flow rate with storage.

The peak flow developed for Atherton Channel is based on all flow contained in the channel and excludes reductions in flow that occur when runoff spills from the channel. Note that Atherton Channel represents 39% of the flow but 70% of the area. This discrepancy is caused by the difference in development (low density, high tree cover lots in Atherton, high density and commercial uses in much of the remaining drainage areas) and the difference in percentage impervious surface (about 34 % impervious area in Atherton versus in excess of 60 % impervious area in remaining drainage areas).

Accounting for differences in timing, but not localized flooding or storage in the Bayfront Canal, the peak flow to the Bayfront Canal would be about 2,600 cfs and 3,170 cfs during a 25-year and 100-year event, respectively. With limitations associated with culverts and pump stations, the peak flow to the Bayfront Canal during any storm greater than a 25-year storm event will be about 1,350 cfs. An inflow of 1,350 cfs is only slightly greater than the corresponding 25-year peak flow rate in the Atherton Channel of 1,240 cfs. The reduction is associated with limitations such as undersized pump stations and culverts, as well as reduction in the peak flow rate caused by storage of runoff. Storage within the drainage area occurs within the Bayfront Canal as well as the unintentionally storage that occurs within low-lying areas upstream of the Railroad Tracks and Hwy-101.

The peak flow rates generated using the hydrologic data are used in the hydraulic model discussed below to evaluate existing system capacity deficiencies and potential corrective measures.

4.2 Hydraulic Analyses

The water level in the Bayfront Canal is currently controlled by discharge through tide gates at the east end of the Canal. The tide gates consist of five 4-foot by 4-foot openings (or 16 square feet each) which allows for a maximum of 825 cfs to be discharged to Flood Slough for conditions with a water level at elevation 8 (approximate start of flooding at Trailer Vista RV Park) and a low tide condition. The peak flow rate that can be conveyed to the Bayfront Canal with existing facilities is 1,350 cfs. Inflow to the Bayfront Canal is from the following drainage areas shown on Figure 2:

1) 78-inch diameter pressure storm drain (inverted siphon under Highway 101) that serves the 2nd Avenue, Selby Lane, and Broadway Drainage areas.
2) 42-inch diameter force main from the Douglas Avenue Pump Station that serves the Douglas Avenue Drainage area.
3) Two 48-inch and two 42-inch diameter force main pipes that were constructed from the 5th Avenue Pump Station, which serves the 5th Avenue Drainage area. The existing pump station has a capacity of 30 cfs. The future pump station planned by Redwood City would have a capacity of 280 cfs. However, construction is currently on hold pending approval and property access rights.
4) Minor gravity storm drain systems serving the drainage area east of Highway 101.
5) Atherton Channel.

4.2.1 Douglas Avenue Drainage Area

The Douglas Avenue Pump Station drainage area is shown on Figure 2. The discharge facilities from the Douglas Avenue Drainage Area to the Bayfront Canal are shown on Exhibit 2. Hwy-101 is a barrier to flow leaving the drainage area. The only discharges from the Douglas Avenue drainage area are a 78-inch diameter inverted siphon under Highway 101 and the Douglas Avenue Pump Station. The 78-inch diameter inverted siphon receives pressurized flow from the Broadway Pump Station and pressurized gravity flow from two 48-inch lines that serve the 2nd Avenue Drainage area. The 78-inch line conveys flows via an inverted siphon under Highway 101 to the Bayfront Canal. Spill toward the low-lying area near the Stanford Outpatient area will occur at Spring Street when the water level at the inlet to the 48-inch diameter gravity line on Douglas Avenue exceeds elevation 13.5, the local high point near Spring Street and Douglas Avenue. When the water level at

Spring Street is less than elevation 13.5, all flow is conveyed to the Bayfront Canal without spill from the 78-inch line drainage area.

Analyses are based on full flow capacity of the 78-inch siphon. Redwood City relies on pressure flow to clean the inverted siphon and does not have a routine maintenance program for inspection or cleaning of this line. It is possible that the flow capacity of this line is reduced by accumulation of debris and/or sediment at the low point of the siphon.

The existing 5th Avenue Pump Station is currently under capacity and therefore flow in excess of the 5th Avenue Pump Station capacity overflow towards the adjacent low-lying area served by Douglas Avenue Pump Station

Douglas Avenue Pump Station is sized for runoff from only the Douglas Avenue Drainage Area, with no excess capacity for pumping overflow from upstream drainage areas. Ponding occurs frequently in the vicinity of the pump station because the pump station is at the low point of the drainage area, there is a potential for a large amount of overflow received from upstream drainage areas and because overland release from the low-lying area is blocked by Hwy-101. In addition, there are no other outfall locations that could serve as an alternative discharge point for the Douglas Ave drainage area. Therefore, when ponding occurs in the vicinity of the Stanford Outpatient Center, the Douglas Pump Station provides the only means for dewatering the area. The current Douglas Avenue Pump Station is not capable of handling overflows from all of the adjacent drainage areas.

4.2.2 Atherton Channel

Flooding due to overtopping of Atherton Channel banks is expected at several locations including at the crossing at Alameda de las Pulgas, in the vicinity of Isabella Avenue and along Marsh Road in the vicinity of Fair Oaks Avenue. The capacity of the channel at the restrictions varies from an event less intense than a 5-year storm up to a 25-year storm event. Based on detailed review of storage within the drainage area, it appears that most spill from Atherton Channel is stored southwest of the railroad tracks and does not reach the low-lying area southwest of Hwy-101.

4.2.3 Model Setup

Water levels for the various alternatives are determined using a hydraulic model that routes stormwater flows developed from the hydrologic model through modeled components that include the following existing facilities:

1. Bayfront Canal
2. Bayfront Canal Tide Gates to Flood Slough
3. Atherton Channel
4. 5th Avenue Pump Station
5. 78-inch Inverted Siphon
6. Douglas Avenue Pump Station
7. Broadway Pump Station

The hydraulic model includes major storm drains, as well as the street flow path that conveys excess flow and provides surface storage in the vicinity of the 5th Avenue and Douglas Pump Stations. The model accounts for the unintentional storage that occurs as flooding that is caused by undersized pump stations and culverts.

The BKF model includes storage within the South Bay Salt Ponds Restoration project ponds S5 and R5, conveyance from the Bayfront Canal to the Ponds, and a tide gate within the ponds for specific alternatives analyzed.

4.2.4 Design Tide Elevations

The design tide elevations are presented in the report San Francisco Bay Tidal Stage versus Frequency Study by the US Army Corps of Engineers, San Francisco District dated October 1984 (Corp 84 Report). The reported 100-year tide is elevation 7.4 National Geodetic Vertical Datum 1929 (NGVD 29). The 100-year tide elevation at the site is elevation 10.1 (elevation 7.4 NGVD 29 + 2.7 = 10.1 NAVD 88). At the Redwood City gage, the Mean Higher High Water is elevation 7.0 NAVD 88, or about 3.1 feet lower than the current 100-year tide level.

Traditionally, Mean Higher High Water (MHHW) has been used as the backwater condition where riverine (freshwater) runoff meets an estuarine (saltwater) body. However, evidence shows that mean tide elevations are not an appropriate boundary condition during storm events and tide elevations in San Francisco Bay are elevated (relative to predicted tides) during periods of heavy rainfall.

To model an appropriate San Francisco Bay tidal cycle during a storm event of particular return period (with tides adjusted to Redwood City), elevations for each critical point in the tide cycle are adjusted based on the one-percent conditional probability of coincident occurrence with the annual maximum discharge of San Francisquito Creek at Stanford, which represents the closest USGS stream flow gaging location with sufficient length of record for analysis; and this gage data is also used to calibrate the rainfall-runoff model.

Table 4.4 below lists other tidal elevations. A MHHW during a 25-year storm (elevation 8.8 NAVD) coinciding with 25-year peak runoff was used for evaluating alternatives.

Table 4.4 Design Tide Elevations

Tide Level	19-Year Mean NAVD 88	19-Year Mean During a 25-Year Storm NAVD 88
Mean Higher High Water	7.0	8.8
Mean High Water	6.4	7.0
Mean Tide Level	3.2	5.0
Mean Sea Level	3.2	5.0
Mean Low Water	0.0	3.0
Mean Lower Low Water	-1.2	1.5

4.2.5 Model Validation

Prior to conducting existing (baseline) and proposed alternative analysis, the model was validated using field observed data from two recent storm events, January 20, 2010, and, November 30, 2012. The intensity of the storm for both the events corresponds to a 2-year event.

The analysis of the January 20, 2010, storm event showed flooding near Stanford Outpatient Center to elevation 8.1 at the peak of the storm event. The model predicted flooding above elevation 8.0 from 9:50 AM until 11:05 AM. The field observations show areas surrounding Stanford Outpatient (Broadway Street and back parking lots) being flooded during that time period and that the flooding appeared to correspond to a range between elevation 8.2 to 8.5.

For the November 30, 2012, storm event, Atherton Channel HEC-RAS model was used to compare the results to the field observations made at the inlet to the Marsh Road box culvert near Fair Oaks. The depth of flow in the HEC-RAS model resulting from the precipitation was very close to the corresponding depth observed in the field.

4.2.6 Model Results of Baseline System

Existing system analyses were conducted to establish a baseline condition for use in comparing impacts due to proposed upstream improvements that would increase flow to the Bayfront Canal and improvements within Bayfront Canal to lower water levels. Analyses were conducted for the 2-, 5-, 10-, 25- and 100-year storm events. Results of the analyses are discussed below.

Douglas and 5th Avenue Flooding

The model results show that flooding will occur within the low lying areas of 5th Avenue and Douglas Avenue drainage areas during any storm more intense than a 2-year storm event. The flooding of Douglas Avenue low-lying area is due to insufficient capacity of Douglas Pump Station to convey runoff generated from the Douglas Avenue drainage area in combination with flow in excess of the capacity of the drainage systems serving adjacent drainage areas. The elevations of flooding during the 10- and 25-year storm events are approximately elevation 8.0 and 9.8 respectively. Currently, there is minimal hydraulic linkage between the flooding adjacent to the Bayfront Canal and flooding at Douglas Avenue and 5th Avenue.

The flooding of 5th Avenue drainage area is due to insufficient capacity of 5th Avenue Pump Station to pump runoff generated from 5th Avenue drainage area resulting in spill to the Douglas Avenue low-lying area. The elevation of flooding during the 10-year and the 25-year are approximately elevation 8.0 and 9.8, respectively within the 5th Avenue drainage area.

Improvements to either the Douglas Avenue or 5th Avenue Pump Stations without additional downstream improvements would increase the flow to the Bayfront Canal, potentially worsening the downstream flooding issue if no corresponding improvements are provided downstream.

Athlone Terrace Flooding

The model results show that runoff overtops Atherton Channel in the vicinity of Marsh Road upstream of Fair Oaks Avenue for both the 10- and 25-year storm events. Based on the County LiDAR data, flows that overtop Atherton Channel would travel northeast along Marsh Road to low-lying areas south of Southern Pacific Rail Road (S.P.R.R). It is anticipated that a majority of the overtopped flows would reach Athlone Terrace, a low lying area north of Marsh Road. This area has experienced flooding many times in the past. The Athlone Terrace neighborhood is located in North Fair Oaks drainage area. In addition to spilled flows from Atherton Channel, the Athlone Terrace receives excess flow from the North Fair Oaks drainage area. The Athlone Pump Station is located just north of S.P.R.R. railroad tracks, across from the low-lying area, and pumps flows back to Atherton Channel. The maximum capacity of Athlone pump station is 35 cfs. It is not anticipated that ponded flows will overtop the S.P.R.R. railroad tracks. Therefore, this ponded flow does not contribute to peak flows observed downstream of the tracks.

The model shows minor overtopping of Atherton Channel between Marsh Road box culvert outlet and Highway 101 during 25-year event. The model does not show overtopping of this section of Atherton Channel during the 10-year event. Any upgrade to reduce flooding potential in the Fair Oaks area would increase flows to the Bayfront Canal.

Bayfront Canal Flooding

In addition to the flooding upstream of Highway 101, the model shows significant flooding of properties adjacent to the Bayfront Canal due to overtopping of the Canal's south bank. The overtopping elevation of the Canal's south bank was set at elevation 7.7. This location generally corresponds to the bank elevations adjacent to Trailer Villa RV Park located at 3401 E. Bayshore Road. The depth of flooding at the Trailer Villa during the 25-year storm event is approximately 3 feet, corresponding to elevation 11.

5.0 Potential Corrective Measures

A range of corrective measures has been investigated for providing long-range improvements that will reduce the potential for flooding within the Bayfront Canal drainage area. The following potential improvements are investigated:

1. Connecting to Managed Ponds.
2. Pumping to Flood Slough
3. Increasing the height of the top of berm along Bayfront Canal
4. Increasing Pumping Capacity of Fifth Avenue and Douglas Pump Stations
5. Increasing Pumping Capacity of Athlone Pump Station
6. Storing Runoff within the Town of Atherton
7. Increasing the area of the tide gates

5.1 Sea Level Rise and Concurrent Tide

Alternatives for reducing the potential for ponding within the Bayfront Canal drainage area are sensitive to future sea level rise and the timing of peak storm events versus the daily tidal pattern. There is a wide range of potential sea level rise scenarios. Improvements are compared against a range of potential concurrent events.

The level of protection provided by various improvements varies depending on the tide level concurrent with the peak rainfall. To address this uncertainty, four scenarios are evaluated for these analyses and are based on a storm concurrent with high, medium and low concurrent tide levels. For proposed conditions where pumping is used, the concurrent tide is not critical and only a single tide scenario is used.

Two adjustments are made to the tidal pattern. The first adjustment is that the normal daily lunar tidal cycle depths are increased to account for storm surge concurrent with the design rainfall event. Significant storm events are typically associated with low barometric readings, strong winds and increased storm water runoff into the Bay. Combined, these factors cause Bay tide levels to be higher during significant storm events than would otherwise occur during a typical lunar tide cycle. The tide scenarios are adjusted to account for the storm surge.

The second adjustment is associated with future sea level rise. Guidelines published by both Caltrans and Bay Conservation and Development Commission (BCDC) recommend designing for 18 inches sea level rise for 2050. For planning purposes, results are presented for analyses that account for future sea level rise scenarios of 18 inches and 36 inches.

5.2 Benefit of Individual Corrective Measures

This section discusses the limited benefits of potential improvements as stand-alone measures.

1. Managed Ponds within the South Bay Salt Pond Restoration Project

   Currently, the City of Redwood City is investigating conveying a portion of the Bayfront Canal flow to proposed Managed Ponds within the South Bay Salt Pond Restoration Project adjacent to Bayfront Park and Flood Slough. The Managed Ponds would include two 4-foot by 4-foot supplemental tides gates for discharging flows to the Bay. This solution provides supplemental storage that would detain a portion of flood waters during conditions with a high tide, but would not eliminate flooding of properties adjacent to the Canal.

   Our analyses of the proposed Managed Ponds solution show that the water levels will be slightly reduced with construction of the facilities, when compared to the existing drainage system. When proposed upstream pump station improvements are taken into account, the level of flooding decreases compared to existing conditions, but less than with no upstream improvements.

   The Managed Ponds (area of Pond S5/R5 is 66.4 acres and of R3 is 279.4 acres for a total area of 345.8 acres) include two 4-foot by 4-foot supplemental tide gates. Incorporating Managed Pond R3 in combination with S5/R5 was evaluated by the City but was not recommended as part of the improvements considered for this alternative because the cost of improvements outweighed the benefits provided by R3.

   The scenario with no changes to either the existing Tide Gates or the existing pumps at Douglas Avenue and 5th Avenue pump stations was also reviewed. For a 12-hour storm with the tide concurrent with the peak of the storm, the water level in the

Bayfront Canal at the 5th Avenue Pump Station discharge for existing conditions with and without the Managed Ponds is shown in Table 5.1.A.

TABLE 5.1.A:
Water Level in Bayfront Canal
Managed Ponds with Existing Constrained Inflows

Return Period	Existing Conditions Peak Water Level (feet, NAVD)	Managed Ponds Peak Water Level (feet, NAVD)	Benefit (feet)
2-year	9.20	8.09	1.11
5-year	9.30	8.37	0.93
10-year	9.34	8.47	0.87
25-year	9.38	8.68	0.70
100-year	9.42	8.73	0.69

The same scenario was evaluated except increased flows associated with upgraded pumps at 5th Avenue and Athlone Terrace pump stations were included for the future condition. No change in inflow was made for the existing condition. For a 12-hour storm with the tide concurrent with the peak of the storm, the water level in the Bayfront Canal for existing conditions versus conditions with the Managed Ponds and upgraded upstream improvements is shown in Table 5.1.B.

TABLE 5.1.B:
Water Level in Bayfront Canal
Managed Ponds with Upgraded Upstream Pumping

Return Period	Existing Conditions Peak Water Level (feet, NAVD)	Managed Ponds with Upstream Improvements Peak Water Level (feet, NAVD)	Benefit (feet)
2-year	9.20	8.30	0.90
5-year	9.30	8.76	0.54
10-year	9.34	8.95	0.39
25-year	9.38	9.00	0.38
100-year	9.42	9.16	0.30

The low points within the various Trailer Parks range from about elevation 6.2 to about elevation 8.3. Note that the analyses include overtopping of the Cargill Levees to the north.

The advantages and disadvantages of this potential improvement are listed below.

Advantages of Storage within Managed Ponds:

1. Long-term maintenance would be a part of the Salt Pond Restoration Project.
2. For minor storm events, solution is independent of tide levels.
3. Level of protection can be increased by adding more tide gates within the Managed Ponds.
4. Reduces Water Levels in the Bayfront Canal compared to existing conditions for both the condition with no upstream improvements and with upstream increases in pumping capacity.

Disadvantages of Storage within Managed Ponds:

1. Requires an expensive culvert to convey flow from the Bayfront Canal to the Managed Pond.
2. During major storm events, system is dependent on tide levels.
3. Does not address future sea level rise. For BCDC design sea level rise for 2050 of 18 inches, the Bayfront Canal water level during a 25-year storm event against mean sea level with storm surge will increase by approximately 1 foot.
4. The benefit to the Bayfront Canal vicinity is reduced when upstream improvements are included.
5. The solution reduces but does not eliminate the possibility of flooding of properties adjacent to Bayfront Canal south bank. However, flooding will still occur during a typical year.

2. Flood Slough Pump Station

A pump station could be installed to pump flows from Bayfront Canal to Flood Slough, around the Tide Gates. The system requires high volume, low head pumping units. The pump station could be situated adjacent to the existing tide gates. A pumping solution will lower the water level at the pump station. Eventually, a point is reached where further lowering of the water level provides no additional benefit because the flow capacity of the Bayfront Canal becomes the constraint.

Based on existing conditions, without salt ponds, upstream improvements or increased top of bank elevations, the maximum pumping rate that is effective is about 1,500 cfs. Any further increase in pumping does not provide significant benefit because the Bayfront Canal hydraulic capacity becomes the constraint. The following tables present water levels based on the conditions used to evaluate the Managed Ponds.

The scenario with no changes to either the existing Tide Gates or the existing pumps at Douglas Avenue and 5th Avenue pump stations was also reviewed. For a 12-hour storm with the tide concurrent with the peak of the storm, the water level in the Bayfront Canal at the 5th Avenue Pump Station discharge for existing conditions versus with 1,500 cfs pumping with existing constrained inflow is shown in Table 5.2.A.

TABLE 5.2.A:
Water Level in Bayfront Canal
Pumping at 1,500 cfs from Bayfront Canal to Flood Slough with Existing Constrained Inflows

Return Period	Existing Conditions Peak Water Level (feet, NAVD)	Pumping 1,500 cfs Peak Water Level (feet, NAVD)	Benefit (feet)
2-year	9.20	6.16	3.04
5-year	9.30	6.43	2.87
10-year	9.34	6.50	2.83
25-year	9.38	6.55	2.83
100-year	9.42	6.61	2.85

The scenario with the 1,500 cfs Pump and upgraded pumps at 5th Avenue and Athlone Pump Stations was reviewed. For a 12-hour storm with the tide concurrent with the peak of the storm, the water level in the Bayfront Canal for existing conditions versus with 1,500 cfs and Upgraded Upstream Pumping is shown in Table 5.2.B.

TABLE 5.2.B:
Water Level in Bayfront Canal
Pumping at 1,500 cfs from Bayfront Canal to Flood Slough with Upgraded Upstream Pumping

Return Period	Existing Conditions Peak Water Level (feet, NAVD)	Pumping 1,500 cfs Upstream Improvements Peak Water Level[1] (feet, NAVD)	Benefit (feet)
2-year	9.20	6.42	2.78
5-year	9.30	7.36	1.94
10-year	9.34	7.50	1.84
25-year	9.38	7.51	1.87
100-year	9.42	7.55	1.91

[1] Increasing pumping associated with Fifth Avenue Pump Station and Athlone Pump Station upgrades would increase flows to the Bayfront Canal, resulting in higher Canal water levels, and less associated benefit from Flood Slough pumping.

The low points within the various Trailer Parks range from about elevation 6.2 to about 8.3. Analyses of existing conditions include overtopping of the Cargill Levees to the north.

The advantages and disadvantages of this potential improvement are summarized below.

Advantages of Flood Slough Pump Station:

1. Independent of tide levels and can be sized to address future sea level rise.
2. Allows for increased pumping from Fifth Avenue, Douglas Avenue and Athlone Pump Stations.
3. Reduces the existing flooding issue in the vicinity of Douglas Avenue Pump Station that affects the Stanford Outpatient Center from elevation 9.7 during a 25-year event to elevation 9.0 with associated increases in upstream pumping rates. Reduces the frequency that Broadway will be inundated.

Disadvantages of Flood Slough Pump Station as Stand-alone Improvement:

1. Pump Station is expensive to construct
2. Pump Station would require regular maintenance and would have an on-going operation and maintenance cost
3. Flooding will continue to occur within low-lying areas of the Drainage Area
4. Requires a structure within Bayfront Park

3. Raise Top of Bank Elevations along Bayfront Canal

Runoff in excess of the drainage system capacity can either be stored or pumped. One method to increase storage capacity is to increase the surface area available for storing runoff, such as the Managed Ponds alternative discussed previously. A second method is to increase the depth available for storing runoff. The ability to store water within the Bayfront Canal is currently constrained by the depth at which runoff overtops the adjacent channel banks. The deeper the water can pond without causing damage, the greater the available storage volume.

Additional depth for storage could be created by protecting the low-lying properties adjacent to Bayfront Canal using raised embankments or floodwalls with Supplemental Pumping. Currently, properties along the northwestern portion of the canal are protected by a combination of sandbags that are acting as floodwalls and local on-parcel pumping systems that discharge on-parcel flows to the Bayfront Canal. For existing conditions, the height of sand bags is between about elevations 8.5 and 9.2. The on-lot pump stations are currently sized for a 5-year storm event. The on-lot pumping capacities should be increased to be consistent with level of protection provided by the Bayfront Canal system. The level of protection on both sides of the Bayfront Canal should be consistent. Floodwalls protecting the Lands of Cargill to the northeast should be raised consistent with the height of the floodwalls to the southwest.

In general, floodwalls acting as a single improvement will not provide a significant benefit to the level of protection. Note that by increasing the top of bank height, the allowable depth within the Managed Ponds is increased, and, in combination, makes the Managed Ponds more effective in storing runoff.

The extent of increased embankments includes low-lying portions of the Atherton Channel. If this alternative is selected, further review is needed of the trade-off between increasing the flow capacity at culverts versus raising embankments.

If used as a stand-alone measure, raising the channel banks will allow flooding to about 6-inches above the level of the lowest embankment height of the levees to the north. Raising embankment heights as a stand-alone measure is not effective and is not analyzed.

4. Increasing Pumping Capacity of Fifth Avenue and Douglas Pump Stations

There is no direct reduction in flooding within the low-lying area southwest of Hwy-101 associated with Bayfront Canal improvements. To reduce flooding in this area, the pumping capacity at either the Douglas Avenue Pump Station or the Fifth Avenue Pump Station must be increased. Currently, increasing the pumping capacity has not been feasible because it would worsen Bayfront Canal flooding. However, if completed in conjunction with Bayfront Canal improvements, both areas will benefit.

At the Fifth Avenue Pump Station, the flow conveyance capacity under Hwy-101 and the outfall to the Bayfront Canal that support a higher pumping rate are already constructed resulting in less limitations on pump station expansion. Based on current constraints, increasing the Fifth Avenue Pump Station to 300 cfs is a reasonable upper limits. With these improvements, the flooding frequency in the low-lying area in the vicinity of the Douglas Avenue Pump Station can be reduced significantly. The amount of improvement is dependent on the level of protection provided at the Bayfront Canal and Atherton Channel.

5. Increasing Pumping Capacity of Athlone Pump Station

There is no direct reduction in flooding within the low-lying, North Fair Oaks neighborhood (southwest of the railroad tracks) associated with Bayfront Canal improvements. To reduce flooding in this area, the pumping capacity at the Athlone Pump Station must be increased. Currently, increasing the pumping capacity has not been feasible because it would worsen Bayfront Canal flooding. However, if completed in conjunction with Bayfront Canal improvements, both areas will benefit.

For the purposes of this study, the Athlone Pump Station discharge capacity is increased to 100 cfs. Further study is needed to develop a recommended increase in the peak pumping rate. With an improvement to 100 cfs, the flooding frequency in the low-lying area of North Fair Oaks can be reduced by about 0.5 feet for a given storm event. The water level in North Fair Oaks for existing conditions is compared to the water level with improved pumping in Table 5.3.

TABLE 5.3:
Water Level in North Fair Oaks
100 cfs Pump Capacity at Athlone Pump Station

Return Period	Existing Pumps Water Level (elevation)	Improved Pumping Water Level (elevation)	Benefit (feet)
2-year	23.1	22.5	0.6
5-year	24.0	23.5	0.5
10-year	24.5	23.9	0.6
25-year	25.0	24.5	0.5
100-year	25.8	25.3	0.5

6. Storing Runoff within the Town of Atherton

The Town of Atherton's Townwide Drainage Study Update by NV5 dated April 2015 recommends providing additional storage along the Atherton Channel to reduce flooding potential within the Town of Atherton. If this recommendation is implemented, the spill from Atherton Channel to North Fair Oaks would be reduced and there would be a corresponding lowering of water levels within North Fair Oaks.

7. Tide Gate Expansion

It is possible to lower water levels by increasing the number of tide gates that convey flow from the Bayfront Canal to the Bay. The existing Tide Gate severely restricts flows and cause flows to back up onto properties adjacent to the Bayfront Canal.

There are two locations where the Tide Gates could be expanded. The first site is the location of the existing Tide Gate. The existing structure could be removed and replaced with a structure that allows for a significant increase in the area of gated openings. This would require revising the layout of the structure to increase the available length. The second location is within the Managed Ponds. This would disrupt lands within an area already being impacted. Because tide gates are not effective at conveying flow under submerged conditions which occur during high tides or with sea level rise, this option is not considered further.

Summary of Individual Improvement Analyses

The discussion above shows that no single measure is effective in providing a significant level of long-term flood protection that would be satisfactory to all stakeholders within the drainage area.

6.0 Combination of Measures

The flow and storage capacity of the Bayfront Canal is limited by the maximum elevation that the water can rise without overtopping banks. The lowest bank elevation of the Canal is about elevation 7.7. The alternatives evaluated (under Section 3.3.5) show water rising above elevation 9.2 when a MHHW elevation of 8.8 corresponding to year 2000 was used. In order for the alternatives to provide the same level of flood protection for future years, it is necessary to raise the bank elevations along Bayfront Canal and Atherton Channel (between Highway 101 and Bayfront Canal) above elevation 9.2 to compensate for rise in sea level, or provide pumping to compensate for increased water levels associated with increased tide levels.

The level of protection for the Bayfront Canal system can be increased by a combination of increasing the available storage and installation of a pump station for discharge to Flood Slough. The results are sensitive to whether the Managed Ponds can be used as a part of the solution. For purposes of this review, two alternatives consisting of different combination of measures are considered:

Combination 1: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and with (c) Managed Ponds

Combination 2: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and (c) without Managed Ponds

The water level within the Bayfront Canal and Atherton Channel for a given flow rate varies depending on the water level at the confluence with the Atherton Channel. This water level can be lowered by increasing the pumping rate to Flood Slough. At a certain pumping rate, the water level at the confluence is controlled by the flow capacity of the channel between the confluence and the pump station inlet, therefore, additional pumping capacity provides no benefit to the upstream system.

For these analyses, combinations were developed to determine the pumping rate required to lower the water level at the confluence of the Bayfront Canal and Atherton Channel to a given water level. These “confluence water levels” were then used to establish required embankment heights to contain Bayfront Canal flows for given storm events.

The elevation of the top of bank necessary to contain flows varies because the Canal hydraulic grade line increases from downstream to upstream. As such, the top of bank elevation near the confluence is lower than top of bank elevation at the northernmost end of the Bayfront Canal and the upstream limit of Atherton Channel.

A total of three sets of embankment elevations are used for evaluating the benefits of increasing the top of bank elevation. These are referred to as Embankment Plan A, Embankment Plan B and Embankment Plan C for Bayfront Canal and Embankment Plan X, Embankment Plan Y and Embankment Plan Z for Atherton Channel.

TABLE 6.1 Bayfront Canal Embankment Plans – Height and Length

Wall Height Above Ground (ft)	Cumulative Length of Wall by Embankment Plan (ft)		
	Embankment Plan A (EL. 8.0' to 10')	Embankment Plan B (EL. 8.5' to 10')	Embankment Plan C (EL. 9.5' to 11')
0.5	1,000	873	0
1	491	437	121
1.5	922	922	1,032
2	0	390	437
2.5	0	0	922
3	0	0	390
Total Length (ft)	2,413	2,622	2,902

1. Total length of Bayfront Canal is 7,200 ft. The Embankment improvements are only along the south bank. No improvements are proposed on the north bank.

TABLE 6.2 Atherton Channel Embankment Plans – Height and Length

Wall Height Above Ground (ft)	Cumulative Length of Wall by Embankment Plan (ft)		
	Embankment Plan X (EL. 10' to 17.5')	Embankment Plan Y (EL. 10.5' to 18')	Embankment Plan Z (EL. 11.5' to 18.5')
0.5	206	574	74
1	889	115	696
1.5	397	1,024	120
2	382	61	912
2.5	254	726	173
3	436	254	382
3.5	0	436	598
4	0	0	436
Total Length (ft)	2,564	3,190	3,391

1. Total length of Atherton Channel is 2,300 ft. The Embankment improvements are on both sides of the Channel.

In many locations, the current top of bank elevation exceeds the minimum proposed top of bank elevation and no action is necessary. Extensive photos and topographic information have been developed and are available for review.

The evaluated pumping rate and embankment plan combinations that provide protection from 10-year, 25-year and 100-year storms are shown in Table 6.3.

TABLE 6.3 Required Pumping Rate and Embankment Plan Combination versus Level of Protection

Level of Protection / Embankment Plan	Pumping Rate With Salt Ponds (cfs)	Pumping Rate Without Salt Ponds (cfs)
10-Year		
A (EL. 8.0’ to 10’)	1,360	1,380
B (EL. 8.5’ to 10’)	660	1,200
C (EL. 9.5’ to 11’)	410	1,080
25-Year		
A (EL. 8.0’ to 10’)	1,500	1,500
B (EL. 8.5’ to 10’)	1,180	1,400
C (EL. 9.5’ to 11’)	510	1,190
100-Year		
C (EL. 9.5’ to 11’)	920	1,540

For the 100-year storm event, it is not possible to pump at a rate that will provide a water level lower than the embankment heights of Embankment Plans A and B because of constraints in the flow capacity between the confluence with the Atherton Channel and the proposed Flood Slough Pump Station.

As shown, the Managed Ponds will allow for a smaller or similar pump size for all conditions, but the difference is greatest when the amount of storage is increased by either including the Managed Ponds or by raising the top of embankment elevation. The advantages and disadvantages of this potential combination of improvements are listed below.

Advantages of Combination 1: Salt Restoration Pond Connection, Pump Station to Flood Slough and increased Embankment Heights:

1. Independent of tide levels and can be sized to address future sea level rise.
2. Allows for increased pumping from Fifth Avenue and Athlone Pump Stations.

3. Significantly reduces the existing flooding issue in the vicinity of Douglas Avenue Pump Station, including the frequency that Broadway will be inundated. The reduction is dependent on the Level of Protection provided.
4. Allows pump size to be reduced, reducing long-term maintenance cost and improving system reliability.

Disadvantages of Combination 1: Salt Restoration Pond Connection, Pump Station to Flood Slough and increased Embankment Heights:

1. Pump Station is expensive to construct, but cost is reduced because of available storage.
2. Pump Stations require regular maintenance and would have an on-going operation and maintenance cost
3. Raising embankment heights blocks overland release of runoff, requiring localized pump stations to pump runoff over the embankment.
4. Requires a structure within the Bayfront Park

If the Managed Ponds are not integrated into the Project, larger pump sizes would be needed for most conditions. The advantages and disadvantages of this potential combination of improvements are listed below.

Advantages of Combination 2: Pump Station to Flood Slough and increased Embankment Heights without a connection to Managed Ponds:

1. Project can proceed independent of Managed Ponds.
2. Reduction in Pump Station size is greater for higher embankment heights.
3. Allows for increased pumping from Fifth Avenue, Douglas Avenue and Athlone Pump Stations.
4. Significantly reduces the existing flooding issue in the vicinity of Douglas Avenue Pump Station, including the frequency that Broadway will be inundated. The reduction is dependent on the Level of Protection provided.

Disadvantages of Combination 2:Pump Station to Flood Slough and increased Embankment Heights without a connection to Managed Ponds:

1. Pump Station is expensive to construct, but cost is reduced because of available storage.
2. Raising embankment heights blocks overland release of runoff, requiring localized pump stations to pump runoff over the embankment.
3. Pump Stations require regular maintenance and would have an on-going operation and maintenance cost
4. Requires a structure within Bayfront Park

Cost Associated with Level of Protection

A summary of construction costs associated with the various pumping rates and wall heights with and without managed ponds are provided in Table 6.4 and 6.5, respectively. The costs provided include 25% contingency but do not included cost for design and permitting which could increase the total costs presented by an additional forty percent (40%). Appendix B includes types of flood walls assumed to raise embankment heights and construction details. A planning level pump station design and costs are also included under Appendix B.

Appendix C includes exhibits showing the length and height of embankment plans A, B and C along the Bayfront Canal and Atherton Channel.

Table 6.4
Flood Slough Pump Station and Increased Embankment Heights with Managed Ponds (Combination 1)

Level of Protection	Combination of Improvements				Total Cost [2]
	Managed Salt Ponds	Atherton Channel Embankment Plan	Bayfront Canal Embankment Plan	Pump Station Capacity (cfs)	
10-Year Storm	Yes	X (EL. 10' to 17.5')	A (EL. 8.0' to 10')	1,360	$16.1M + MSP
	Yes	X (EL. 10' to 17.5')	B (EL. 8.5' to 10')	660	$11.3M + MSP
	Yes	X (EL. 10' to 17.5')	C (EL. 9.5' to 11')	410	$10.0M + MSP
25-Year Storm	Yes	Y (EL. 10.5' to 18')	A (EL. 8.0' to 10')	1,500	$17.6M + MSP
	Yes	Y (EL. 10.5' to 18')	B (EL. 8.5' to 10')	1,180	$15.9M + MSP
	Yes	Y (EL. 10.5' to 18')	C (EL. 9.5' to 11')	510	$11.4M + MSP
100-Year Storm	Yes	Z (EL. 11.5' to 18.5')	C (EL. 9.5' to 11')	920	$14.9M+ MSP

1. All costs are for planning-level estimates of probable construction costs for the purpose of comparison. Costs are for construction only and do not include any provision for engineering, permitting, administration, parcel acquisition, etc.
2. All costs associated with restoration for the Ravenswood South Bay Salt Ponds are outside the scope of this study. Costs associated with Managed Salt ponds are identified as "MSP" for clarity.

Table 6.5
Flood Slough Pump Station and Increased Embankment Heights without Managed Ponds (Combination 2)

Level of Protection	Combination of Improvements				Total Cost
	Managed Salt Ponds	Atherton Channel Embankment Plan	Bayfront Canal Embankment Plan	Pump Station Capacity (cfs)	
10-Year Storm	No	X (EL. 10' to 17.5')	A (EL. 8.0' to 10')	1,380	$16.3M
	No	X (EL. 10' to 17.5')	B (EL. 8.5' to 10')	1,200	$15.5M
	No	X (EL. 10' to 17.5')	C (EL. 9.5' to 11')	1,080	$15.5M
25-Year Storm	No	Y (EL. 10.5' to 18')	A (EL. 8.0' to 10')	1,500	$17.6M
	No	Y (EL. 10.5' to 18')	B (EL. 8.5' to 10')	1,400	$17.5M
	No	Y (EL. 10.5' to 18')	C (EL. 9.5' to 11')	1,190	$16.9M
100-Year Storm	No	Z (EL. 11.5' to 18.5')	C (EL. 9.5' to 11')	1,540	$19.5M

1. All costs are for planning-level estimates of probable construction costs for the purpose of comparison. Costs are for construction only and do not include any provision for engineering, permitting, administration, parcel acquisition, etc.
2. All costs associated with restoration for the Ravenswood South Bay Salt Ponds are outside the scope of this study. Costs associated with Managed Salt ponds are identified as "MSP" for clarity.

7.0 Conclusions and Recommendations

The low-lying areas in the vicinity of the Bayfront Canal are subject to frequent inundation. Currently, the 2-year or greater storm event will cause flooding to low-lying areas adjacent to the canal. In addition, there are two upstream areas that also flood more frequently than a 2-year storm event. Correcting the upstream flooding problems has not been possible because of the impact that improvements would have on the flooding in the vicinity of the Bayfront Canal.

A range of corrective measures has been investigated for providing long-range improvements that will reduce the potential for flooding within the Bayfront Canal drainage area. These include:

1. Pump Station

   A pump station located in the vicinity of the existing tide gates would be effective in conveying flows from the Bayfront Canal to San Francisco Bay. The Pump Station would become a long-term adaptive measure that could be revised or expanded if sea level rise constrains gravity discharge to the Bay. A pump station solution alone will not eliminate flooding of properties adjacent to the Canal as the capacity of the existing Canal without any embankment improvements becomes the limiting factor. However, a pump station is a key element and must be part of a combination of measures to be effective.

2. Managed Ponds

   The amount of flow that can pass through the existing tide gates is controlled by the duration and elevation of the low and high tide during a storm event. The City's solution of diverting Canal flood waters to managed ponds with supplemental tides gates at the Managed Ponds may provide required storage necessary to detain flood waters for the duration of high tide but does not eliminate flooding of properties adjacent to the Canal. Managed Ponds used in conjunction with a pump station would provide storage ahead of the pumps and would result in a significantly smaller pump station than if only the storage currently available within the Bayfront Canal is considered.

3. Modify Existing Tide Gates

   The existing tide gate structure consists of five 4-foot by 4-foot openings with flap gates to prevent reverse flow during high tide. The existing tide gate openings are significantly smaller than the Canal cross-sectional area. As such, the existing tide gate acts as a significant obstruction to the conveyance capacity of the Canal.

Therefore, modifications to the existing tide gate openings will greatly benefit the conveyance capacity of the Canal. However, there is little benefit in upsizing tide gates if the pump station is installed because the pump station would reduce Bayfront Canal water levels upstream of the gates. Considering the pump station need to be part of any effective solution, Tide Gate improvements will need not be part of the solution.

4. Floodwalls
   Floodwalls should be constructed along the south bank of the Bayfront Canal to reduce flooding potential to the existing residences, offices and commercial buildings. The ability to store water within the Bayfront Canal is currently constrained by the depth at which runoff overtops the adjacent channel banks. Additional depth for storage can be created by protecting the low-lying properties adjacent to Bayfront Canal using raised embankments or floodwalls with Supplemental Pumping. The extent of increased embankments also include low-lying portions of the Atherton Channel. In general, floodwalls acting as a single improvement will not provide a significant benefit to the level of protection. The height of the embankment required as a standalone measure is not feasible and therefore is not analyzed as a standalone measure.

Improvements to Upstream Drainage Areas

The low-lying area in the vicinity of the Douglas Avenue Pump Station that includes the Stanford Outpatient Center is hydraulically separated from the Bayfront Canal by Hwy-101. The only discharge from this low-lying area is the Douglas Avenue Pump Station. To correct flooding in the area, pumping capacity must be increased. Based on current constraints, increasing the Douglas Avenue Pump Station to 100 cfs and Fifth Avenue Pump Station to 300 cfs are reasonable upper limits. Lowering water levels in the Bayfront Canal with no corresponding increase in pumping capacity south of Hwy-101 would provide minimal decrease in water levels in the low-lying area in the vicinity of the Douglas Pump Station that includes the Stanford Outpatient Center.

A Combination of Improvements

Bayfront Canal flooding cannot be reduced to an acceptable level by a single measure, i.e., (a) by only pumping to Flood Slough; (b) by only increasing the available storm water storage by increasing the surface area of Salt Ponds; (c) by only increasing the available storage depth in the Canal. No single measure was identified that could lower water levels to a level that would provide an acceptable level of flood protection throughout the drainage area. In conclusion, the recommendation is to use a combination of measures.

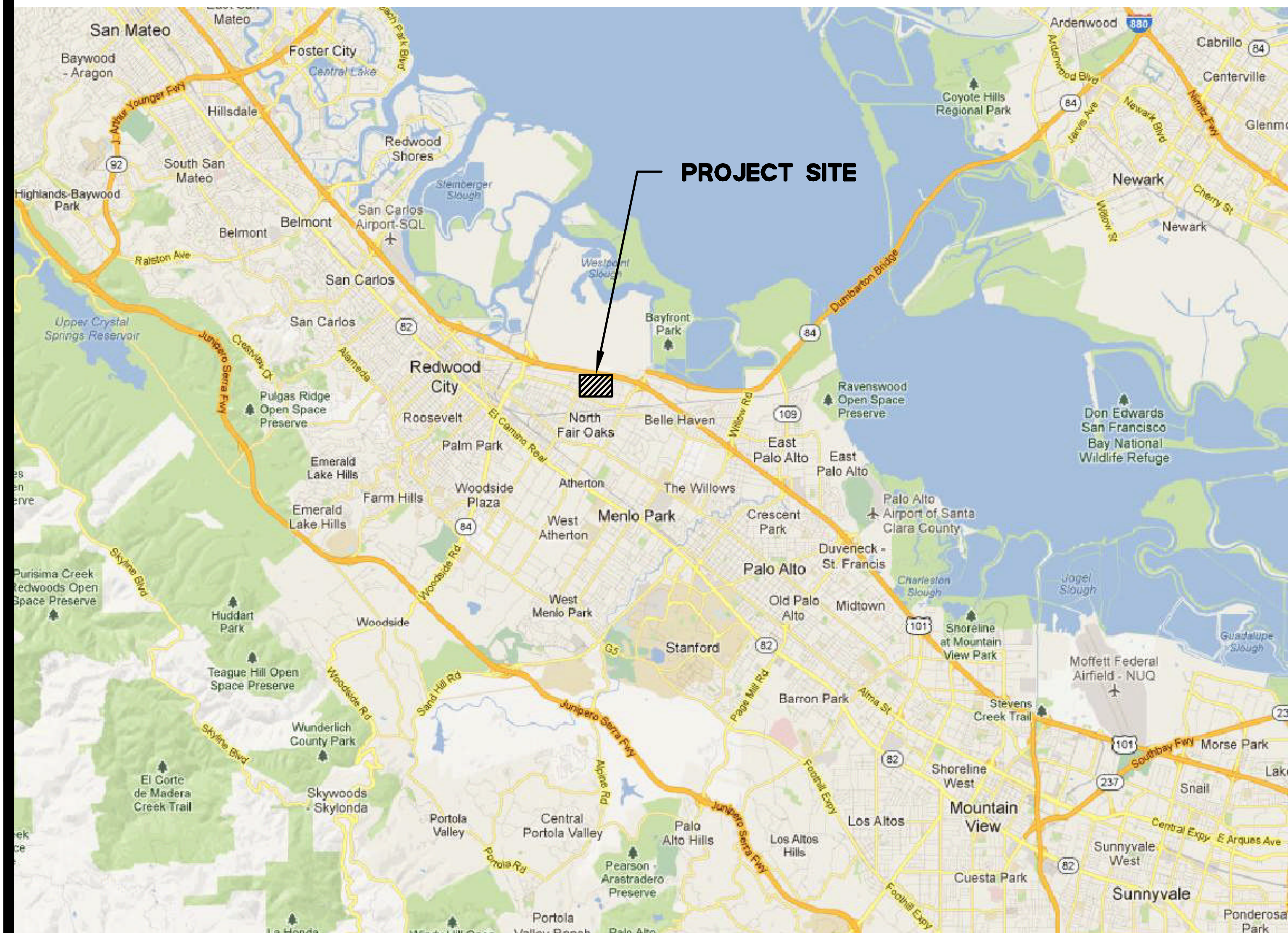
The level of protection for the Bayfront Canal system can be increased by a combination of measures. We evaluated a combination of flood slough pump station and flood walls with and without Managed Ponds. The combination of measures evaluated include:

Combination 1: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and with (c) Managed Ponds

Combination 2: (a) Flood Slough Pump Station and (b) Increased Embankment Heights, and (c) without Managed Ponds

The analyses show that the Managed Ponds will allow for a smaller pump size for all conditions, but the difference is greatest when the amount of storage is increased by either including the Managed Ponds or by raising the top of embankment elevation. Our cost analyses show that the magnitude of improvements required for different levels of protection (i.e., 10-, 25- and 100-year) are not significantly different.

FIGURES



VICINITY MAP
FIGURE 1

BKF

LEGEND

- DRAINAGE SUBAREA BOUNDARY
- ATHERTON CHANNEL DRAINAGE BOUNDARY
- BAYFRONT CANAL
- EXISTING STORM DRAIN SYSTEM
- ATHERTON CHANNEL

BAYFRONT CANAL DRAINAGE BASINS

FIGURE 2

BKF

LEGEND

- PIPE
- OPEN CHANNEL
- CULVERT
- OVERLAND FLOW PATH
- PUMP STATION
- NODE
- PORTION OF ATHERTON CHANNEL NOT IN SWMM MODEL

BAYFRONT CANAL SWMM LAYOUT

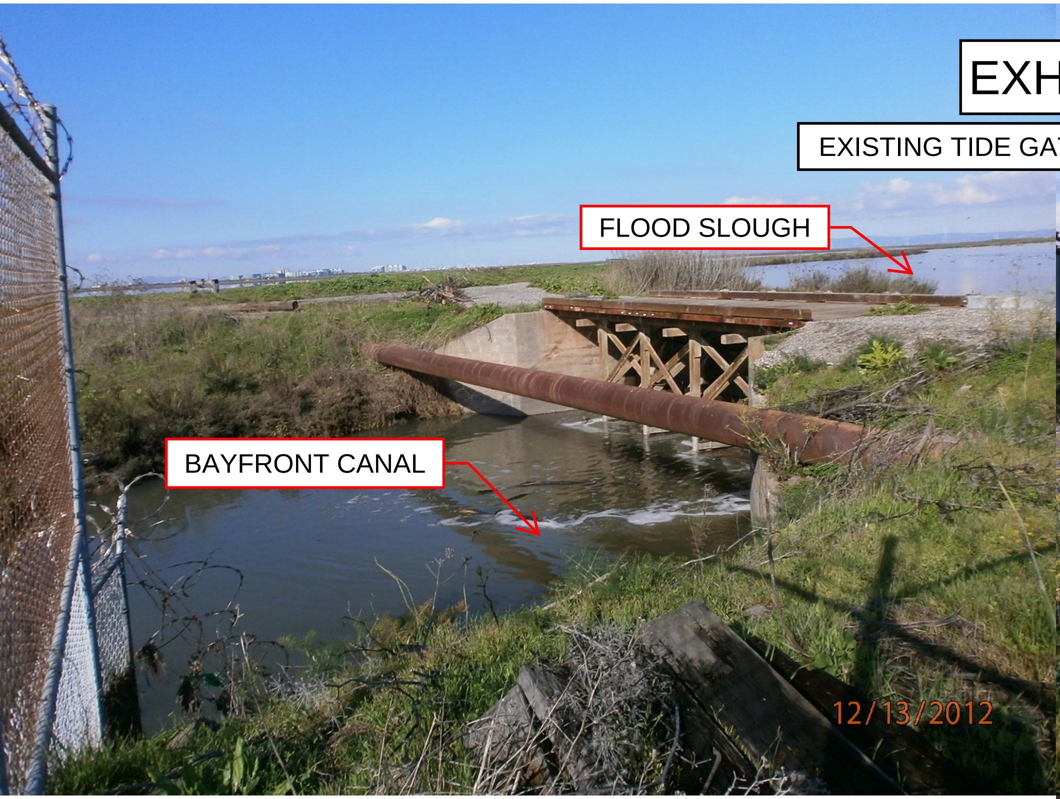
FIGURE 3

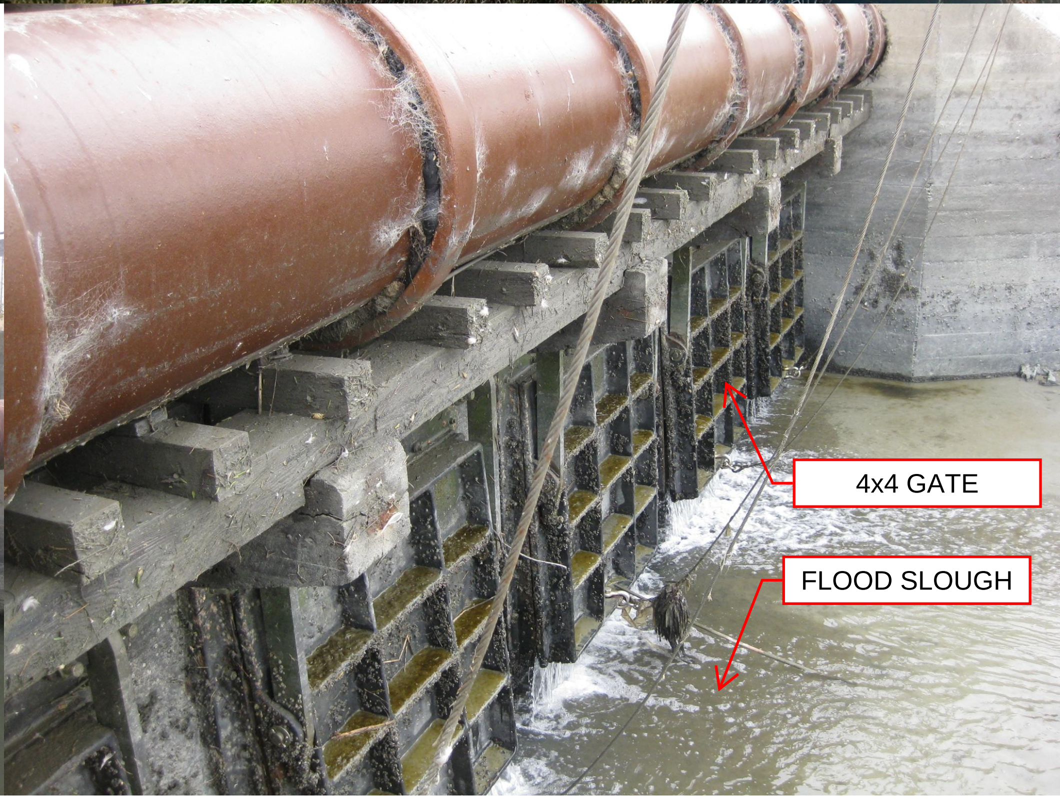
BKF

EXHIBITS

EXHIBIT 1

EXISTING TIDE GATE TO FLOOD SLOUGH





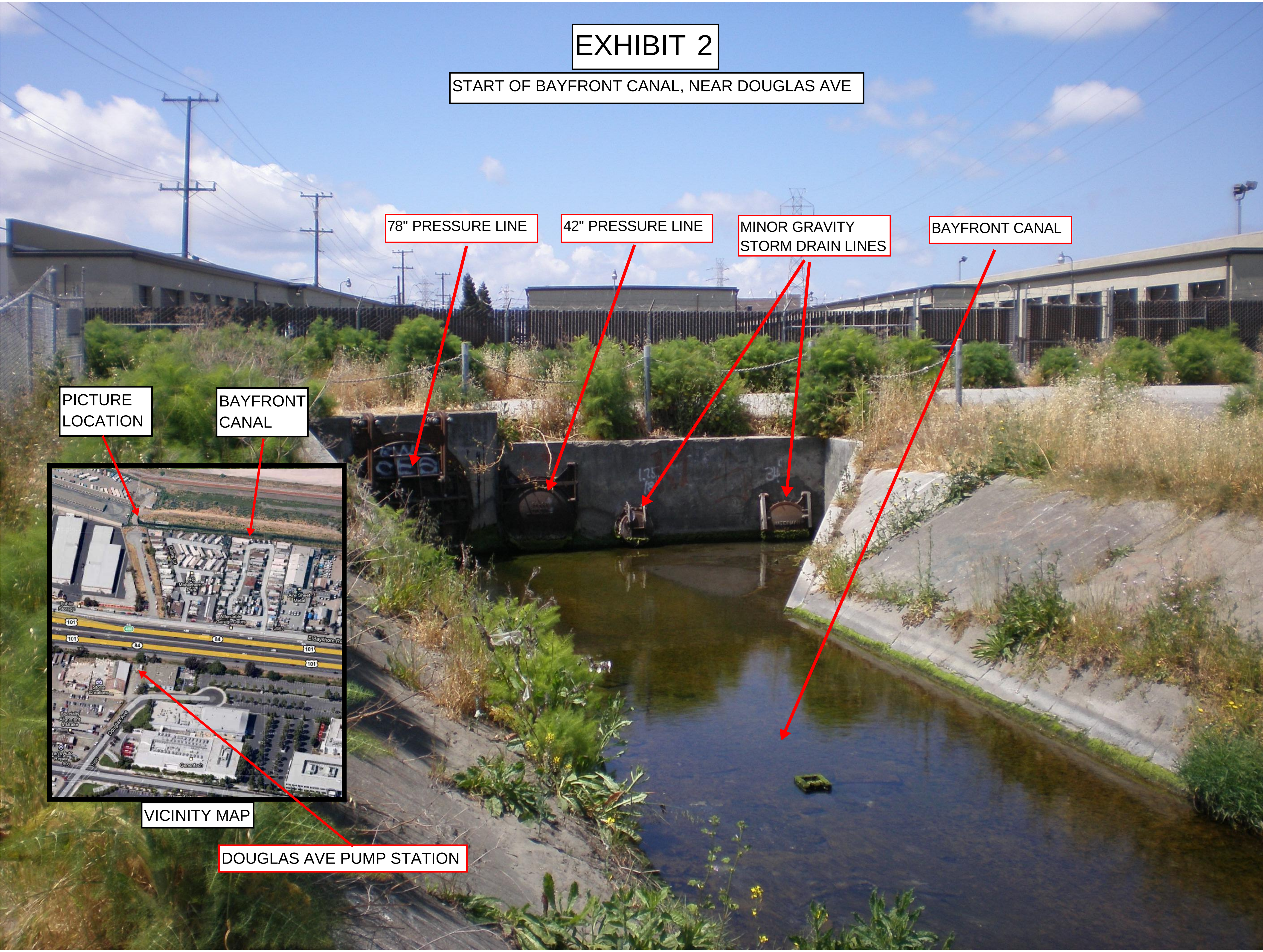
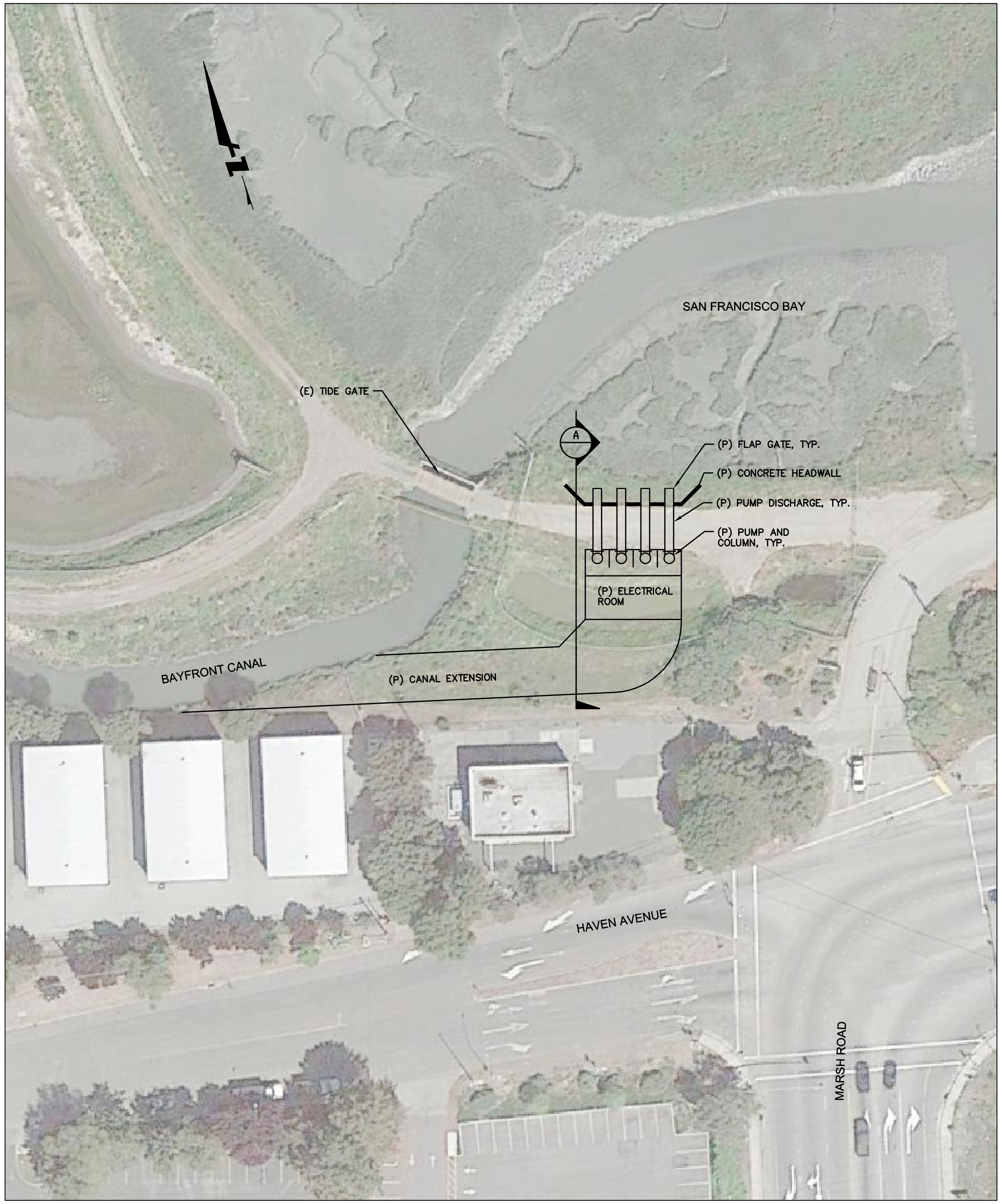
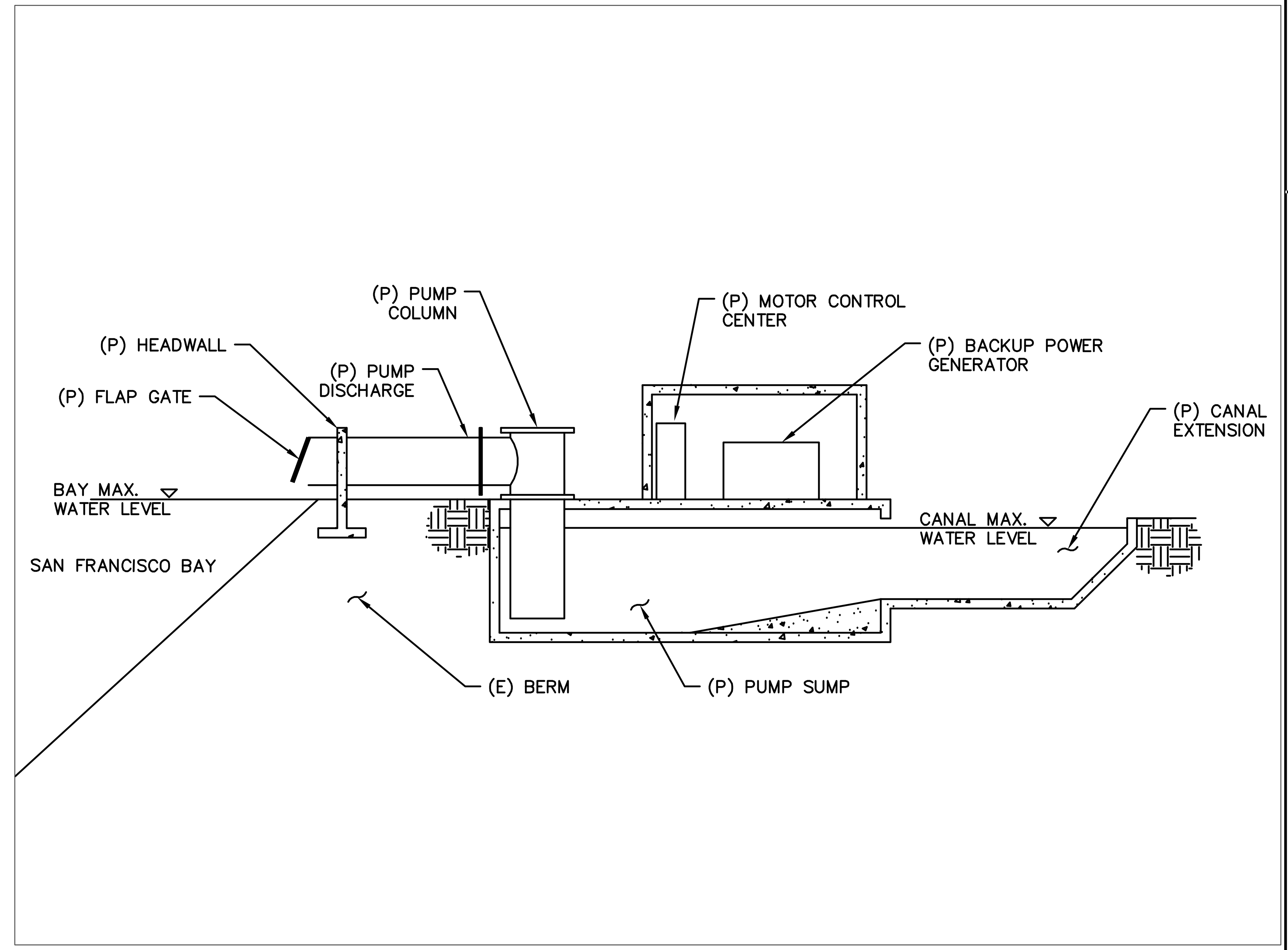


EXHIBIT 2
START OF BAYFRONT CANAL, NEAR DOUGLAS AVE
78" PRESSURE LINE
42" PRESSURE LINE
MINOR GRAVITY
STORM DRAIN LINES
BAYFRONT CANAL
PICTURE
LOCATION
BAYFRONT
CANAL
VICINITY MAP
DOUGLAS AVE PUMP STATION



1 **PLAN VIEW**

NTS



A **SECTION**

NTS

EXHIBIT-3

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BKF
ENGINEERS / SURVEYORS / PLANNERS

BAY FRONT CANAL
410 CFS STORMWATER PUMP STATION
PRELIMINARY LAYOUT

CALIFORNIA

No.	Revisions
A	Conceptual Engineering

Date: 04/13/2016
Scale: AS SHOWN
Design: EB, JF
Drawn: JF
Approved: EB
Job No: 20130168

Drawing Number:

OF