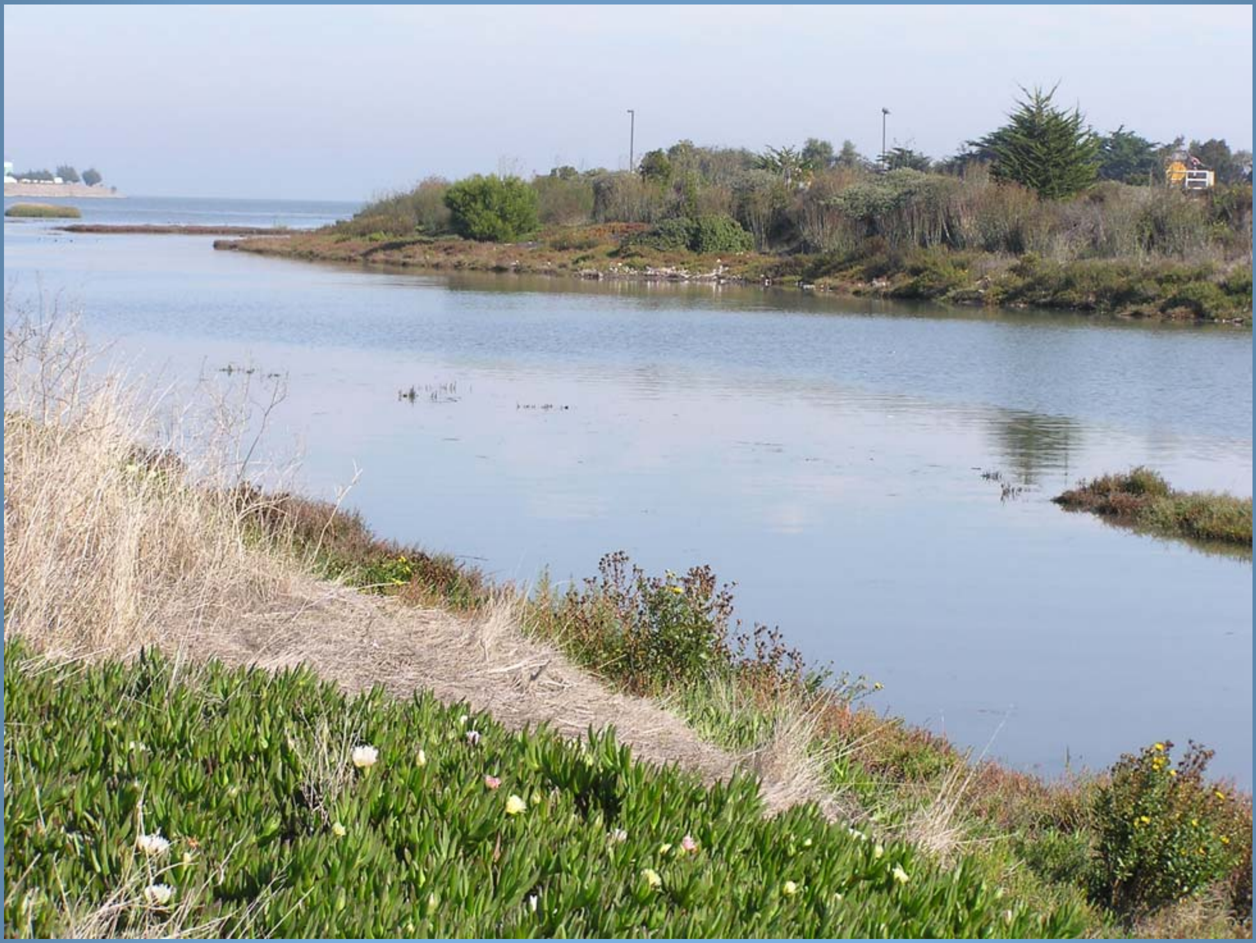
City of South San Francisco

South San Francisco/San Bruno Water Quality Control Plant
Flood Protection Study



Schaaf & Wheeler
Consulting Civil Engineers

June 2012

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Executive Summary

Schaaf & Wheeler has been retained to study the risk of flooding at the South San Francisco/San Bruno Water Quality Control Plant (WQCP). This study evaluates 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 are also analyzed. A discussion of climate change and its potential impact on the aforementioned risks is also provided. This study has been created for use by the City of South San Francisco and Carollo Engineers as they plan and design beneficial plant upgrades, including future projects to reduce flooding exposure.

The South San Francisco/San Bruno WQCP is exposed to risk of flooding from three distinct sources in addition to runoff from the site itself:

San Francisco Bay. High tides and wind generated waves pose a potential threat of flooding to the WQCP from its eastern perimeter.

Colma Creek. Colma Creek and the tributary Navigable Slough drain a 16 square mile watershed. Colma Creek forms the northern boundary of the WQCP and thus exposes the Plant to potential flooding hazards. In particular, high tides could coincide with high creek flows to exacerbate the risk of flooding.

San Bruno Channel. Forming a southern boundary to the Plant, San Bruno Channel discharges into San Francisco Bay independently of Colma Creek.

At present the WQCP is situated within a range of elevations that protect the grounds and equipment from the aforementioned flood hazard risks. However, further investigation is needed to ascertain the reliability and efficacy of the site storm water drainage system under high tide conditions. If that system is undersized, lacks mechanical redundancy, or lacks standby power, local rainfall runoff could result in scattered shallow ponding on site.

Some level of flood protection is afforded by channel constrictions upstream of Utah Avenue that cause excess floodwaters to spill from Colma Creek, whereby those spills are trapped behind overland flow barriers such as the Caltrain railroad tracks and Highway 101. Analysis shows, however, that even if these channel constrictions are removed by future improvement projects, there is sufficient flow capacity in Colma Creek between Utah Avenue and San Francisco Bay to accommodate the full estimated 100-year flood discharge without overtopping the creek banks. Thus, despite a preliminary Flood Insurance Rate Map for San Mateo County that shows the WQCP exposed to 100-year flood hazards of indeterminate elevation, there is no significant regulatory 100-year flood hazard at the plant.

Future sea level rise due to global climate change could, however, affect flood risk exposure, primarily due to changes in extreme San Francisco Bay tides. The San Francisco Bay Conservation and Development Commission (BCDC) has published estimates of mean sea level rise that range from 16 inches by mid-century (2050) to 55 inches by 2100. Assuming the elevations of extreme tides would rise in direct proportion to any increase in mean sea level, a small portion of the WQCP's northwestern parking lot would be subject to 100-year tidal inundation by mid-century. (Extreme predictions of sea level rise by the end of the century would affect wide swaths of the South San Francisco bay front including the WQCP.) Given the uncertainty of sea level rise predictions, the uncertainty of the relationship to extreme tide behavior, and the long time frame until problems are anticipated, an adaptive approach whereby future planning efforts remain abreast of climate change predictions and impacts is recommended.

Study Description

The City of South San Francisco through Carollo Engineers has retained Schaaf & Wheeler to study the risk of flooding at the South San Francisco/San Bruno Water Quality Control Plant (WQCP or Plant). This Flood Protection Study evaluates the risk posed to the WQCP from San Francisco Bay tide and wind generated wave run-up. Potential flooding hazards from Colma Creek, San Bruno Channel, and localized runoff are also analyzed. A discussion of climate change and its potential impact on the aforementioned risks is also included with each portion of the study. This study has been created for use by the City and Carollo Engineers as they plan and design beneficial Plant upgrades, including future projects to reduce flooding exposure.

Basis of Datum Information

Detailed information about the site is based on a survey of the WQCP performed by Towill, Inc. in 2011. The Towill survey was performed on a unique vertical datum (known herein as Plant Datum); therefore results have been converted from National Geodetic Vertical Datum of 1929 (NGVD) to the Plant Datum by adding 0.93 foot, using the conversion provided by Towill. All elevations within this study are listed as both NGVD and Plant Datum. Figure 1 graphically references the various relevant vertical datums used herein. (Refer to Appendix A for the Plant topographic survey.)

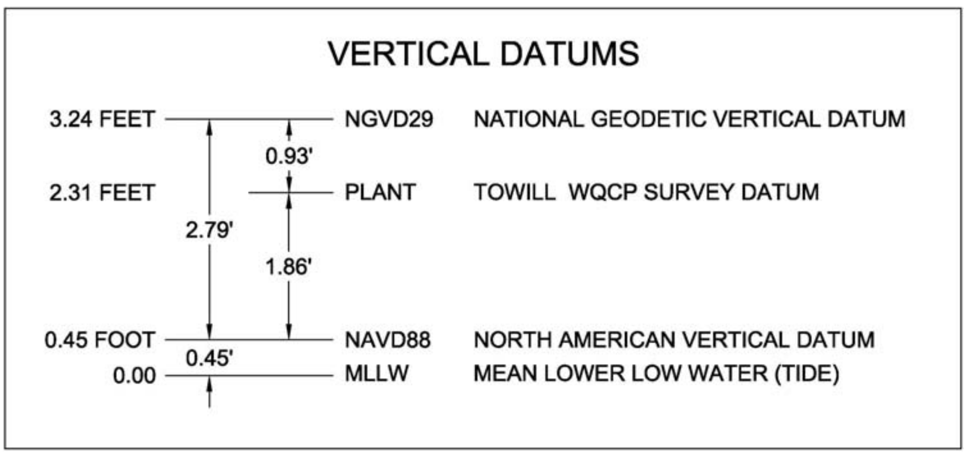

Figure 1: Local Vertical Datums Used in Flood Risk Study

General Flood Risk Exposure

The South San Francisco/San Bruno WQCP is exposed to risk of flooding from three distinct sources as shown on Figure 2:

San Francisco Bay. High tides and wind generated waves pose a potential threat of flooding to the WQCP from its eastern perimeter.

Colma Creek. Colma Creek and the tributary Navigable Slough drain a 16 square mile watershed. Colma Creek forms the northern boundary of the WQCP and thus exposes the Plant to potential flooding hazards. In particular, high tides could coincide with high creek flows to exacerbate the risk of flooding.

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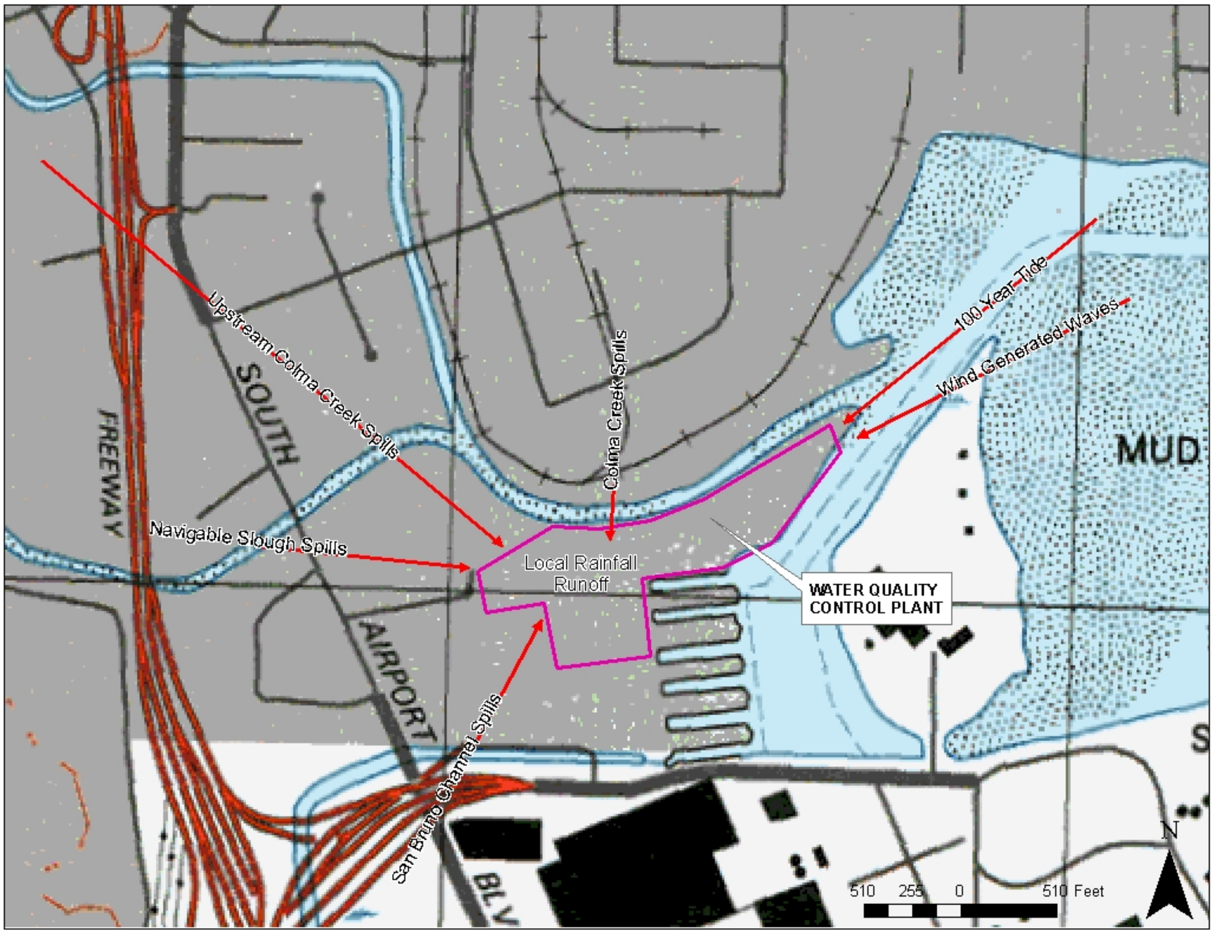


Figure 2: General Flood Hazard Exposure at WQCP

Overland flooding from one of these sources, even when not directly adjacent to Plant property, could also expose the Plant to flood hazards. For instance upstream channel or bridge constrictions along Colma Creek force water out of the creek channel during extreme discharge events. Flood routing of these upstream spills must be checked to assess their potential threat to Plant property. Finally, storm water runoff generated by rain falling on the Plant site is also analyzed.

San Francisco Bay Flood Hazards

The effective Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) Panel Number 0650620008B for the City of South San Francisco, California (September 2, 1981) places the Waste Water Treatment Plant in Special Flood Hazard Area (SFHA) Zone C, which is defined as an area of minimal flooding. (See Appendix B for map.) Colma Creek directly north of the Plant has been defined as Zone A, an area of 100-year flooding where the base flood elevation has not been determined. The FIRM shows that the reach of Colma Creek directly adjacent to the Plant is contained by its banks during the 100-year storm event. Tidal lands to the southeast of the Plant, including the outlet of San Bruno Channel, have been designated Zone A1, an area of 100-year flooding.[1]

The flood elevation is 7 feet NGVD (7.93 feet Plant Datum). Bay water to the east of the Plant at the mouth of Colma Creek has been defined as Zone V1,[2] an area of 100-year coastal flooding subject to wave action. This also results in a flooding elevation of 7 feet NGVD (7.93 feet Plant Datum).

A Letter of Determination for new floodplain mapping within San Mateo County is due in April 2012. A Preliminary FIRM panel dated January 21, 2011 shows the WQCP within SFHA Zone A, which designates an area of 100-year flooding with no base flood elevations determined. The Preliminary FIRM also shows that the reach of Colma Creek directly adjacent to the Plant is in the same Zone A as the Plant, which is distinctly separated from Zone AE flood hazards at the mouth of the creek. Tidal lands to the southeast of the Plant, including the outlet of San Bruno Channel, are designated Zone AE, areas of 100-year flooding with base flood elevations determined.[3] This is defined on the new FIRM as 10 feet NAVD, a rounded elevation equivalent to 7 feet NGVD.[4] Bay water to the east of the Plant at the mouth of Colma Creek is shown as Zone VE,[5] an area of 100-year coastal flooding subject to wave action. This also results in a flooding elevation of 10 feet NAVD, which is equivalent to 7 feet NGVD (7.93 feet Plant Datum) on the effective FIRM.

Due to rounding, the elevation of tidal flooding mapped on the new FIRM is 0.21 foot higher than the elevation of tidal flooding mapped on the effective FIRM, relative to existing ground elevations throughout the Plant. This is a regulatory artifact and is not associated with sea level rise or climate change, which is addressed later in this report.

Regulatory Flood Risk at Plant

The lowest perimeter ground elevation at the WQCP is about 8.2 feet Plant Datum (7.3 feet NGVD) at the northwestern parking lot; therefore according to the effective FIRM, the site is not flooded during an independent 100-year tidal event, without considering coincident flooding from other sources such as Colma Creek or local runoff.

The new FIRM shows Zone A flooding at the Plant and along the adjacent reach of Colma Creek, but without designated base flood elevations. Consequently an analysis of coincident 100-year flood risk has been completed, with results presented later in this report. Tidal one-percent flooding is shown at

[1] A numbered "A" Zone represents older FEMA nomenclature. The number designates the relative risk of flooding for insurance rating purposes. The number divided by two gives the difference (in feet) between 100-year flood elevations and 10-year flood elevations. For example, in an A1 zone there is a one-half foot difference.

[2] A numbered "V" Zone is similar in definition to a numbered "A" Zone, but with wave hazards.

[3] Zone AE replaces numbered A zones.

[4] To convert NGVD to NAVD in South San Francisco 2.79 feet are added. (National Geodetic Survey, *VERTical CONversion (VERTCON) Transformation Program Between NGVD 29 and NAVD 88 Version 2.1* for Latitude 37°40'36.84 Longitude 122°427'34.56", June 2004.) Base flood elevations shown on FIRMs are rounded to the nearest whole number by adding 3 feet. Thus 7 feet NGVD becomes 10 feet NAVD.

[5] Zone VE replaces numbered V zones.

elevation 10 feet NAVD (8.14 feet Plant Datum), so the site will still be protected by its perimeter ground elevations from regulatory 100-year tidal flood hazards when the new FIRM becomes effective. Neither the effective nor the new FIRM shows the perimeter ground around the WQCP as a regulatory levee subject to FEMA certification requirements. Figure 3 shows the extent of ground elevations that are lower than the regulatory flood hazard from tidal flooding at elevation 10 feet NAVD, adjusted for the Plant survey datum. The vast majority of the Plant site and equipment are not subject to 100-year tidal flood inundation. Of particular concern is the electrical distribution switchgear panels located next to the effluent pump station motor control building near the inundation area shown in the northeast boundary of the Site.

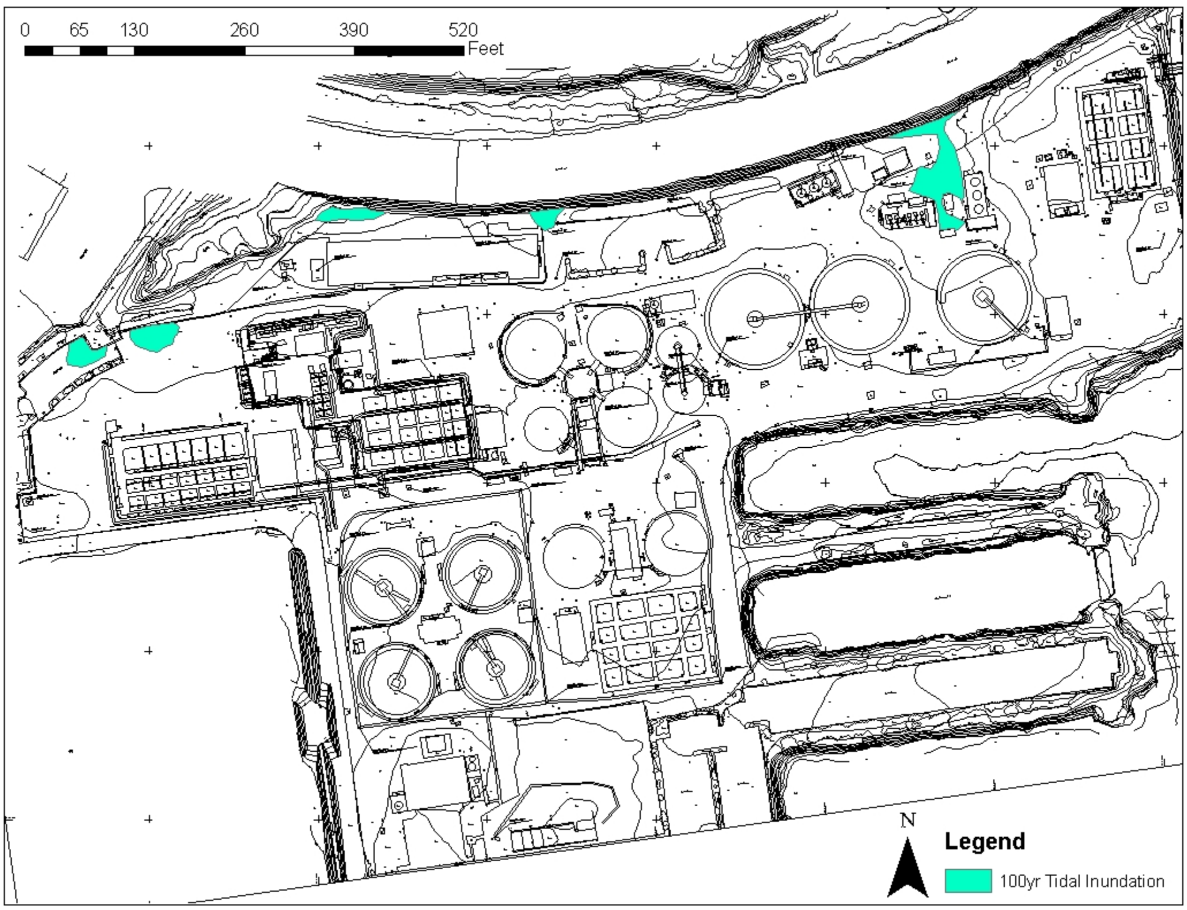


Figure 3: 100-Year Zone AE Tidal Inundation at the WQCP

Historic Tide Levels

The U.S. Army Corps of Engineers has established a *19-year mean tide cycle* for San Francisco Bay and other geographical locations on the West Coast. This cycle represents average tide heights over a specific period known as the tidal epoch, which spans the 19 years it takes for every possible combination of relative positions for the sun, moon and earth to occur. A mixed tide cycle predominates on the West Coast of the United States. This cycle consists of two high tides (one higher than the other) and two low tides (one lower than the other) each lunar day.

Based on calculations for these relative celestial positions, it is possible to predict tides for any day of the year at any time of the day. *Astronomic tides,* created by the gravitational forces of the moon and sun acting on earth's oceans, are provided in tide prediction calendars. The mean tide cycle is simply the long-term average of astronomic tides. *Observed tides*, on the other hand, are actual tidal elevations recorded by National Oceanic and Atmospheric Administration (NOAA) gauging stations located throughout coastal areas. Observed tides reflect not only the astronomic influence of the moon and sun, but also the influence of low-pressure systems that often accompany storm systems and may be referred to as "storm surges". Observed tide data provide what is referred to as the "stillwater surge".

Flood risks posed by stillwater surge on San Francisco Bay are evaluated by examining the statistical frequency at which certain tide elevations are reached over time. A 1984 study by the USACE established the one-percent (100-year) exceedance tide elevation at the mouth of Colma Creek as 6.9 feet NGVD (7.83 feet Plant Datum). This is within one tenth of one foot of the mapped stillwater surge. It may be noted that the Plant is also generally protected from the USACE's calculated 500-year tide elevation of 7.1 feet NGVD (8.03 feet Plant Datum) at the mouth of Colma Creek.

The National Oceanic and Atmospheric Administration (NOAA) maintains historic tide gauges at various locations within San Francisco Bay, although South San Francisco is not one of those locations. The Presidio tide gauge in San Francisco and published differences in tide elevations for San Francisco Bay are used to calculate tide levels at the WQCP site in South San Francisco.[6] (It must be noted that differences between vertical tidal datums are not constant throughout San Francisco Bay.) Various tides for South San Francisco are listed in Table 1. It can be seen that according to NOAA, the site will not be inundated by the average (mean) high water, higher-high water or highest observed (from 1983-2001) water level, which occurred in January 1983.

Table 1: Tide Levels (feet)

		at Presidio		Adjust	at South San Francisco			
		(MLLW)	(NAVD)	(feet)	(MLLW)	(NAVD)	(NGVD)	(Plant)
HOWL	Highest Observed Water	8.66	8.72	1.2	9.86	9.41	6.62	7.55
MHHW	Mean Higher High Water	5.84	5.90	1.2	7.04	6.59	3.80	4.73
MHW	Mean High Water	5.23	5.29	1.2	6.43	5.98	3.19	4.12
MTL	Mean Tide Level	3.18	3.24	0.6	3.78	3.33	0.54	1.47
MSL	Mean Sea Level	3.12	3.18	0.6	4.32	3.87	1.08	2.01
MLW	Mean Low Water	1.14	1.20	0.0	1.14	0.69	-2.10	-1.17
MLLW	Mean Lower Low Water	0.00	0.06	0.0	0.00	-0.45	-3.24	-2.31
NAVD88	Vertical Datum	-0.06	0.00		0.45	0.00	-2.79	-1.86
NGVD29	Vertical Datum	2.66	2.72		3.24	2.79	0.00	0.93

NOAA defines these key tidal occurrences as follows:

Highest Observed Water Level: The highest instantaneous water level observed over the National Tidal Datum Epoch.
Mean Higher-High Water: The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.
Mean High Water: The average of all the high water heights observed over the National Tidal Datum Epoch.
National Tidal Datum Epoch:[7] The specific 19-year period adopted as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datums such as MLLW.

[6] *NOAA Tide and Current Tables 2011*, San Francisco Bay, South, 2011.
[7] http://tidesandcurrents.noaa.gov/datum_options.html

Wave Hazards

The South San Francisco/San Bruno Water Quality Treatment Plant has also been analyzed for flood hazards due to wind generated wave inundation. In addition to astronomic and barometric tidal considerations, the effects of wind generated waves must also be considered to assess the level of protection needed at the Plant. Wind generated waves are not measured by the various tide stations around San Francisco Bay and are not incorporated into the stillwater surge analyses reported above.

As discussed previously, the FEMA FIRM depicts wave hazard areas and differentiates those hazard areas from stillwater surge hazards using a special flood hazard area zone break. The new Preliminary FIRM shows the Plant, Colma Creek, and areas landward from the peninsula of high ground (elevations range from 9 feet to 12 feet NGVD based on available topographic information) as subject to Zone A flooding, which in this context represents tidal inundation without wave action. The FEMA zone break crosses the mouth of Colma Creek from the northern tip of the outcropping to the opposite bank. While the FIRM provides no indication that wave hazards affect the Plant, this flood study examines the potential for wind-wave attack and wave run-up at the northeastern corner of the Plant adjacent to the mouth of Colma Creek, partly so that climate change impacts can also be evaluated.

Wave heights are a function of wind velocity and duration, as well as fetch, which is the distance over water that the wind is blowing against any particular shoreline. As a wave reaches a confining barrier such as the shore, the energy in the wave is converted to a “run-up” that increases the overall water surface elevation. The magnitude of run-up depends upon wave height, wavelength (period), and slope of the embankment.

Wave run-up generally applies to the more moderate slopes of shores and embankments such as levees. Nomenclature for wind-generated waves and on-shore wave run-up is illustrated in Figure 4.

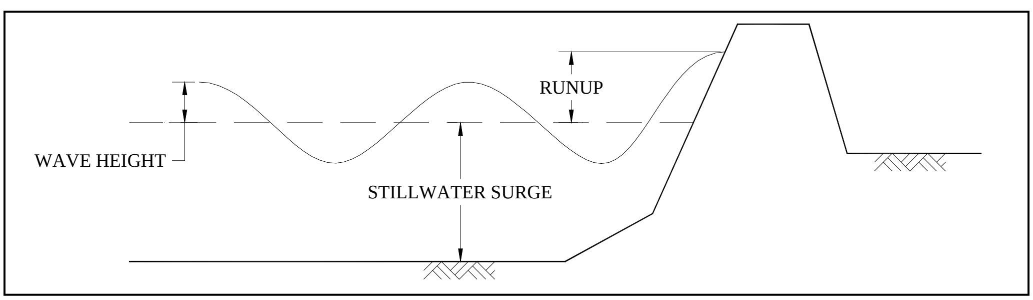


Figure 4: Wave Hazard Nomenclature

Shore Protection Manual (USACE, 1989) methods for estimating wave heights and wave run-up are used throughout this flood hazard analysis. Fetches, wind data, wave generation, and wave run-up at the Plant are sequentially explained in more detail below.

Fetches

Wind exposures from the northeast to east have been analyzed. Fetch lengths are between 3,800 feet and 68,300 feet. Table 2 shows the applicable fetch characteristics, which are provided graphically in Figure 5 and Figure 6. The latter figure shows the northeastern fetch in detail and how high ground partially blocks the eastern fetch exposure. In fact as described below, due to the presence of this high ground, the Plant is only exposed to wave setup from the northeast and a reflection of waves from the eastern fetch. Data for the lengths of fetch and average water depths along the fetch have been measured from the NOAA 44th Ed, April 2006 soundings map, San Francisco Bay, Southern Part, ID# 18651.

Table 2: Fetch Data

Fetch	Length (ft)	Average Depth (ft) to Mean Lower Low Water (MLLW) tide Elevation	Average Depth (ft) to 100-year tide elevation (NAVD)
NE	3,800	0.5*	10.4
E	68,300	10.9*	20.8

*add 0.45 foot for NAVD88, subtract 3.24 feet for NGVD29

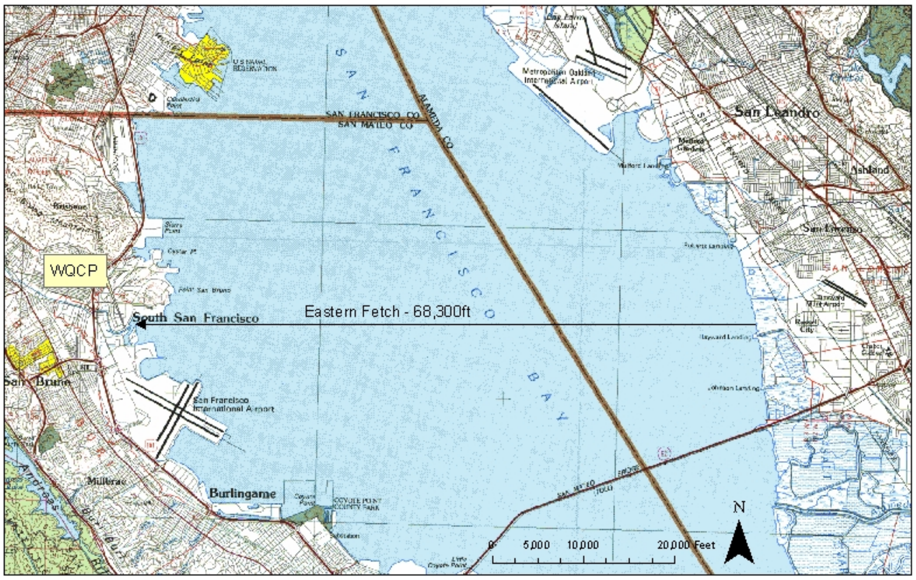


Figure 5: Eastern Wave Fetch

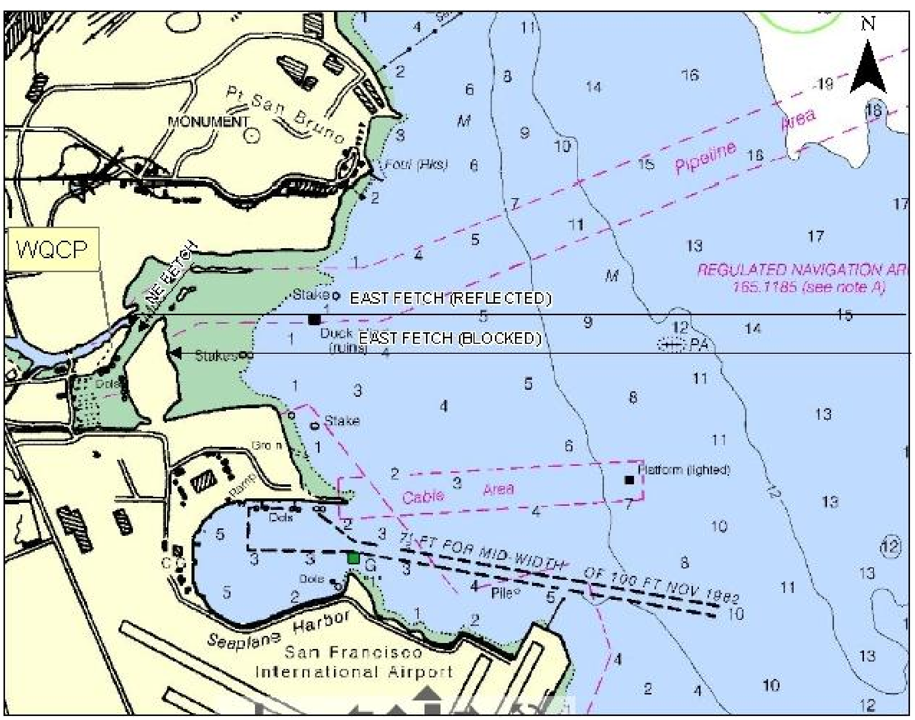


Figure 6: Northeast and Detailed East Wave Fetches

Wind

For wind-driven waves to develop on the Bay with the indicated fetch length, about one to two hours of sustained wind speed are required. Wind data from a gauge at San Francisco International Airport (SFO) is used for the wave hazard analyses. SFO is about two miles south-southeast of the study area. Wind data from 1973 to 1999 is available in yearly maximum 2-minute and maximum yearly formats. Table 3 summarizes the data. (For a full data table see Appendix C.)

Table 3: Wind Data

Wind	Average Yearly 2-Minute Max Wind (mph)	Average Yearly Max Wind (mph)
NE	18	21
E	18	21

For the Water Quality Control Plant (WQCP), based on the length of fetch, angle of approach, and wind speeds; the most critical direction is from the east. The eastern fetch is mostly blocked from the WQCP by the peninsula of high ground, but wind wave action will still occur at the site due to reflection as shown in Figure 6. For waves to develop, 1- to 2-hour durations are required. Using Figure 5-26 (Appendix C) from the Shore Protection Manual (SPM) the easterly 2-minute wind can be converted to 1- and 2-hour winds yielding 15.4 mph and 14.7 mph, respectively, for the easterly gusts.

Due to the close proximity of the SFO gauge to the water, there is no need to correct for geographic location, and the gauge can be assumed to represent over water speeds. For this analysis, it is assumed that during the winter months, air temperature is approximately the same as water temperature. Therefore the only adjustment to be made is a height adjustment. The correction factor to convert the SFO winds measured at a height of 20 feet to the SPM assumed height of 10 meters is 1.07 (SPM equation 5-12, attached). The 1- and 2-hour winds with this adjustment are 16.4 and 15.8 mph, respectively. To be conservative, a wind speed of 20 mph is used.

As can be seen in the SFO wind rose provided as Figure 7,[8] winds at the WQCP are primarily from the west and northwest, with wind speeds up to 24.6 mph (11m/s). Therefore, the frequency of high wind and wave events (which generally require wind from the west) is relatively low at this site due to the protection provided by Point San Bruno to the north and the San Francisco Bay Peninsula to the west. In addition, winds from the northeast and east rarely exceed 12 mph (5.4m/s) according to the wind rose.

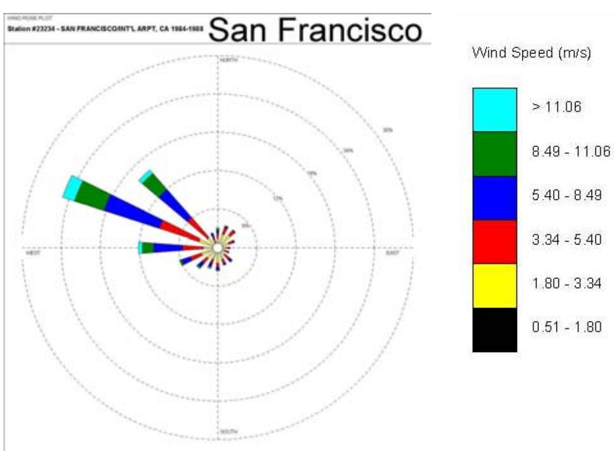


Figure 7: Wind Rose, San Francisco International Airport, 1984-1988

[8] California Air Resources Board

Wave Hazards from Northeastern Fetch

Because the WQCP is only susceptible to wind waves from the northeast direction generated within the outlet of Colma Creek, a 2-minute wind of a gust of 25 mph is used. Following the procedure outlined above, an adjusted 1-hour wind of 23 mph is calculated. To be conservative, a wind speed of 25 mph is used for the analysis. Using Table 5-36 from the SPM (attached in Appendix C), a wind of 25 mph, a fetch of 3,800 feet, and an average depth of 10.4 feet produces waves with a height of 0.8 foot and a period of 1.5 seconds. Waves of up to 1 foot have been observed by Plant personnel.

Wave Run-up

The northeast fetch has been analyzed for wave run-up potential at the northeastern edge of the Plant at the mouth of Colma Creek. At this location, a storage basin is surrounded by an earthen levee with a top elevation of 15.7 feet Plant Datum (14.8 feet NGVD or 17.5 feet NAVD).

The U.S. Army Corps of Engineers software program Automated Coastal Engineering Software (ACES) is used to estimate the wave run-up at the northeastern corner of the Plant levee. Due to reflection of the eastern wind waves, both wind scenarios will approach the treatment plant in the same location and direction. A water surface elevation of 9.8 feet NAVD (7.9 feet Plant Datum) representing the 100-year tide and the toe of slope elevation 4 feet NAVD (2.1 feet Plant Datum) result in a starting water depth of 5.8 feet NAVD at the WQCP levee. The levee height is 17.6 feet NAVD (15.7 feet Plant Datum), the near-shore slope is approximately 11.3% and the levee slope is 33.3%. Since the levee structure slope is not reinforced with rip-rap or other rough surface, a conservative analysis for a smooth slope is used in ACES.

For a north-east (NE) wind, the resulting run-up height is 1.02 foot above the base (100-year) stillwater surge level, which is set equal in elevation to 8.02 feet NGVD, 10.81 feet NAVD, or 8.95 feet Plant Datum. (Additional discussion about the conservative nature of this assumption is provided below.)

Wave Hazards from the Eastern Fetch

Wave height and period for the easterly fetch are determined using the Shore Protection Manual (USACE, 1984) Figure 5-38 (attached in Appendix C). Using a 20 mph wind, a fetch length of 68,300 feet, and an average depth of 20.8 feet produces waves with a height of 2.2 feet and a period of 3.1 seconds. If the predicted wave height of 2.2 feet is conservatively added to the one-percent stillwater surge, the resulting elevation of 9.2 feet NGVD is effectively blocked by the peninsula of high ground (9 to 12 feet NGVD).

Waves from the east that make it past the peninsula into the mouth of Colma Creek would not directly attack the WCQP, but would be reflected off of the opposite creek bank. The following equation from the Coastal Engineering Manual (USACE EM-1110-2-1100, 2003) is used to predict the reflected wave height:

$$H_r = C_r H_i$$

where H_r is the height of the reflected wave, C_r is the bulk reflection coefficient, and H_i is the height of the incident wave. The bulk reflection coefficient is given as:

$$C_r = \frac{a\xi^2}{\left(b+\xi^2\right)} \qquad \xi = \frac{\tan\alpha}{\sqrt{\dfrac{2\pi H_i}{gT^2}}}$$

where tan α is the inverse of the reflecting slope and T is the wave period.

Waves from the east reflect against a 3:1 bank slope with a wave period of 3.1 seconds. Assuming a smooth and impermeable bank, Allsop (1990) gives a as 0.96 and b as 4.8. Using the given equations, the bulk reflection coefficient is 0.32 and a 2.2 feet incident wave is reflected as a 0.7 foot high wave, to which the WQCP could be exposed at its northeastern point.

Wave Run-up

For an eastern wind, the wave run-up height is 3.49 feet above the base (100-year) level, or 10.49 feet NGVD (13.28 feet NAVD or 11.42 Plant Datum). Wave run-up could overtop the perimeter of the outlying peninsula, but this wave run-up would not reach the Plant. For the reflected eastern fetch wave the run-up height is 1.83 feet. Therefore the wave run-up elevation is conservatively set at 7 feet NGVD plus 1.83 feet or 8.83 feet NGVD. ACES output for wave run-up is located in Appendix D.

Discussion

It is assumed that only one fetch will result in wind wave exposure to the Plant at any given time. Therefore; the highest wave or wave run-up elevation is due to wave run-up from a reflected wave from the east, as summarized by Table 4.

Table 4: Wave Hazard Summary

Exposure	100-year Tide Elevation (feet NGVD)	Maximum Wave Height (feet)	Wave Run-up (feet)	Wave Hazard Elevation (feet NGVD)
NE	7.0	0.80	1.02	8.02
E direct	7.0	blocked	n/a	7.00
E reflected	7.0	0.70	1.83	**8.83**

For levee systems, FEMA requires one (1) foot of freeboard above the higher of the wave or wave run-up height. This would mean that a bay front levee would need to be at an elevation of 9.83 feet NGVD (10.76 feet Plant Datum). Based on the survey of the WQCP performed by Towill in October of 2011, the existing levee elevation of 14.8 feet NGVD (15.7 Plant Datum) is sufficient to protect WQCP facilities from 100-year wave hazards at the northeast corner of the site. Site elevations are lower further upstream Colma Creek, but significant waves will break before propagating up the creek.

The foregoing analysis provides a conservative method for evaluating wind-wave hazards. Maximum fetch-limited wave heights have been added directly to the 100-year stillwater surge elevation. In reality, however, the combined probability of this occurring is less than one percent annually. A recent wind–wave analysis in San Mateo that replicated 30 years of hourly tides and winds estimated a one-percent coincident wave hazard elevation of 10.1 feet NGVD compared to an elevation of 10.7 feet NGVD, when the maximum wave height was added to the 100-year stillwater surge of 7 feet NGVD.

Tsunami Hazards

The South San Francisco/San Bruno Water Quality Treatment Plant has also been analyzed for flood hazards due to tsunami waves. Tsunami inundation has been mapped by the California Department of Conservation, California Emergency Management Agency. The basis of inundation mapping was the Mean High Water and incorporates both locally and distance generated wave events. It can be seen in the figure below that the north eastern portion of the Site may be inundated during a tsunami event. Tsunami occurrence is based on earthquake action and location, which can be both unpredictable and infrequent. Although there is risk of tsunami inundation at the Site, it is infeasible for the WQCP to design for tsunami events.

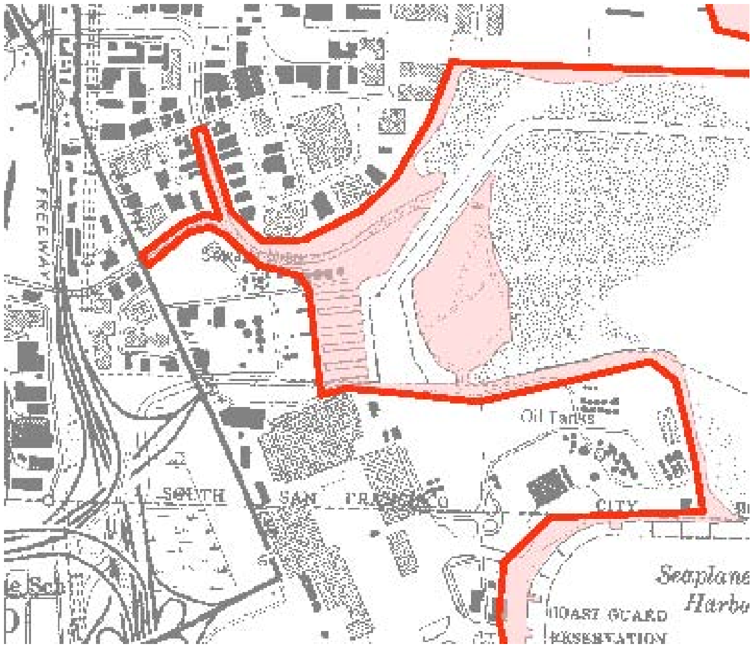


Figure 8: Tsunami Inundation Map

Colma Creek Flood Hazards

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 8.) 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.

Figure 9: Colma Creek Watershed Vicinity

Methodology

A modified version of the hydrograph method outlined in the Santa Clara County Drainage Manual (SCCDM 2007) is used to estimate flood-frequency discharges for the surface creeks that potentially threaten the Plant with flooding. The HEC-RAS backwater analysis program is then used to determine base flood elevations for Colma Creek and Navigable Slough, and channel capacities to establish upstream spill locations, volumes, and rates. This information is used to estimate the limits of flooding.

Precipitation

Precipitation patterns are based on the SCCDM 2007 and local Mean Annual Precipitation (MAP) values located at the centroid of each sub-basin. The pattern is 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. Appendix E contains precipitation and intensity calculations for each sub-basin and the SCCDM 24-hour, 5-minute duration rainfall pattern for each MAP. The 10-year, 6 hour rainfall event, which will be used for future planning at the WQCP, results in total precipitation of 2.04 inches and follows the general rainfall pattern for the 10-year, 24-hour event shown in Figure 9.

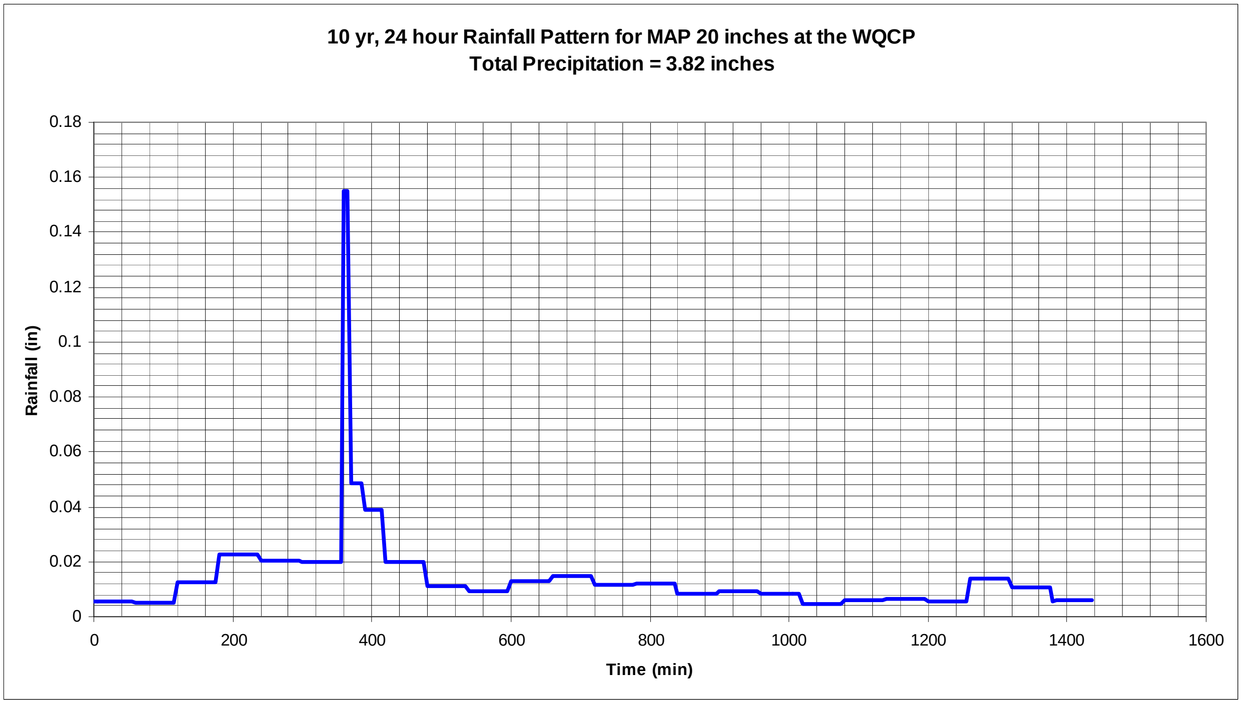
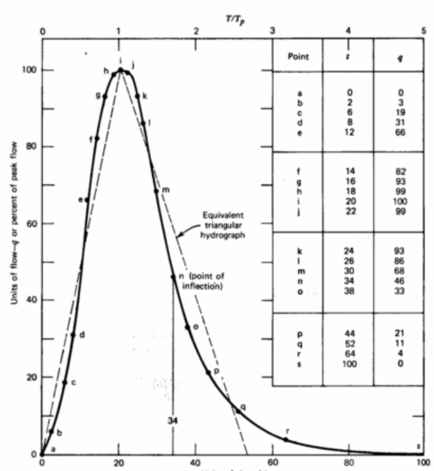


Figure 10: 10-Year, 24-Hour Rainfall Distribution

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 is used herein as shown in Figure 10. The SCS lag time equation provides an estimate of basin lag, which is defined as the time from the center of the unit rainfall event to the runoff peak. The SCS equation for basin lag is:



$$T_{LAG} = L^{0.8} \frac{(S+1)^{0.7}}{1900\sqrt{Y}} \qquad S = \frac{1000}{CN} - 10$$

Figure 11: SCS Dimensionless Unit Hydrograph

where T_{LAG} is lag time in hours, L is the hydraulic length of watershed in feet, S is the maximum retention in the watershed in inches, Y is the average basin slope in percent, and CN is the SCS curve number for the watershed as described subsequently.

Watershed Parameters

The drainage basin and sub-basins used in this study have been delineated using Digital Elevation Map (DEM) LiDAR (light detection and ranging) data provided by the County of San Mateo. (See Figure 11 for drainage sub-basin delineation.) The 10,300 acre (16.1 square mile) drainage basin is mostly developed, including industrial and high density residential zones. Land uses and the corresponding percent impervious areas are determined based on aerial photographs and City and County zoning maps.

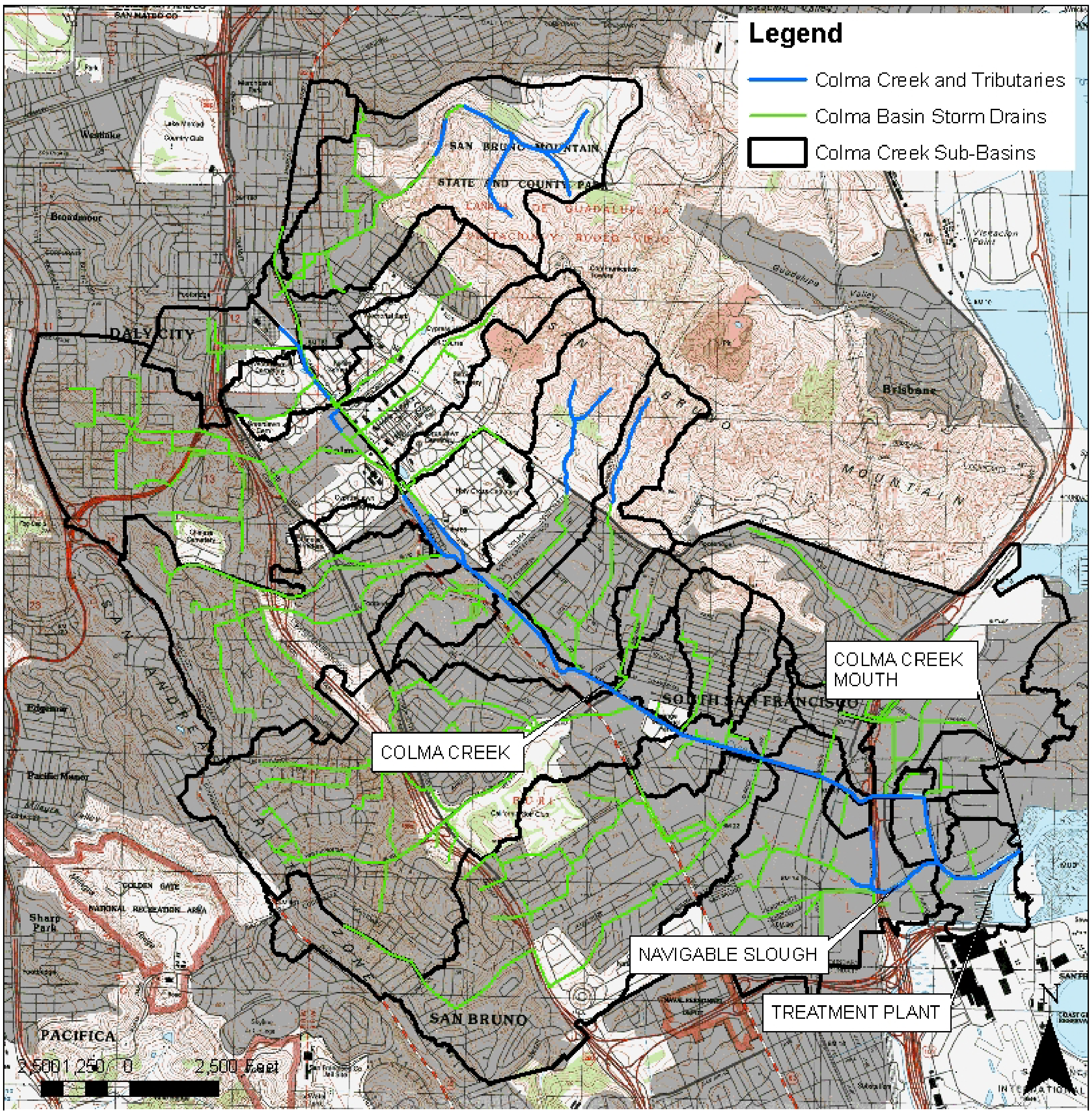


Figure 12: Colma Creek Watershed Boundaries

Infiltration and Other Losses

Direct runoff is 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 is 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 types are determined using National Resources Conservation Service (NRCS) soils maps. Soils are assigned to one of four hydrologic soil groups (A, B, C or D) based on infiltration and runoff potential. Soils within the D group result in the highest rate of surface runoff, all else equal. The Colma Creek watershed is generally underlain by group D soils in the lower lying areas and group B soils in the elevated areas.

Soil group, land use and percent impervious are used to determine Soil Conservation Service (SCS) curve numbers for each basin. (See Appendix F.) The curve numbers are 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 have been analyzed to determine flood frequency characteristics. Flood flow frequency calculations are based on USGS Hydrology Bulletin #17B. The flood frequency curve for the stream gauge is presented by Table 5 and Figure 12. The resulting peak flood discharges are 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. It should be emphasized that the calibration is only valid for each of the specific design storms referenced previously.

Table 5: 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	-	

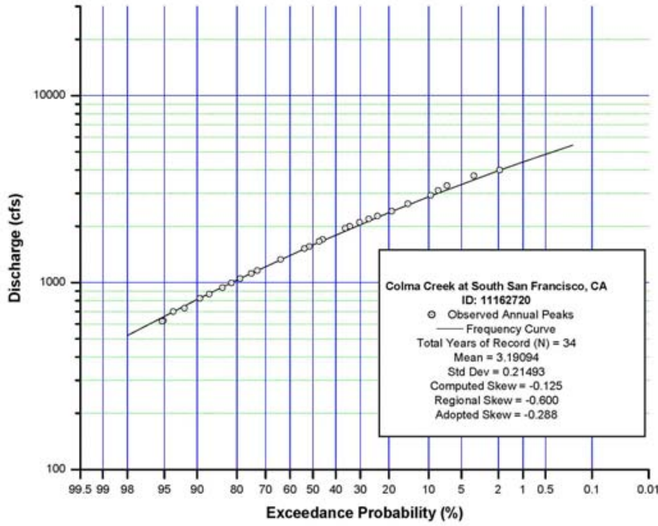


Figure 13: Colma Creek Stream Gauge Flood Frequency Plot

Watershed Modeling

Individual basin data and Colma Creek geometry information are 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 Appendix G. The Colma Creek model includes the Navigable Slough watershed; a separate HMS model has been created for San Bruno Channel.

Table 6 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 6: Estimated Creek Discharges

Location	2-year Discharge (cfs)	5-year Discharge (cfs)	10-year Discharge (cfs)	100-year Discharge (cfs)
Colma Creek				
Orange Avenue	1,607	2,483	2,896	4,543
Spruce Avenue	1,924	2,967	3,427	5,414
Linden Avenue	1,931	2,978	3,441	5,435
San Mateo Avenue	1,938	2,989	3,451	5,454
Highway 101	1,960	3,022	3,489	5,516
Airport Boulevard	2,104	3,235	3,695	5,878
Utah Avenue	2,127	3,268	3,733	5,937
Navigable Slough	2,220	3,408	3,850	6,134
San Francisco Bay	2,194	3,385	3,841	6,083
Navigable Slough				
at Colma Creek	146	206	215	360

Hydraulic Analysis

Peak flows at critical intervals along Colma Creek determined using HEC-HMS for the 2, 5, 10 and 100-year return intervals, 24-hour duration storm events (see Table 6) 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) Railroad. Due to the difficulty of access, these two bridges could not be verified during the field survey and the original HEC-2 model cross sections are assumed to be accurate.

Recent 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. The plans do not change the existing grade or flood wall height, and therefore do not change the hydraulic model. Figure 13 provides the location of HEC-RAS cross sections. The HEC-RAS model is based on the National Geodetic Vertical Datum of 1929 (NGVD29).

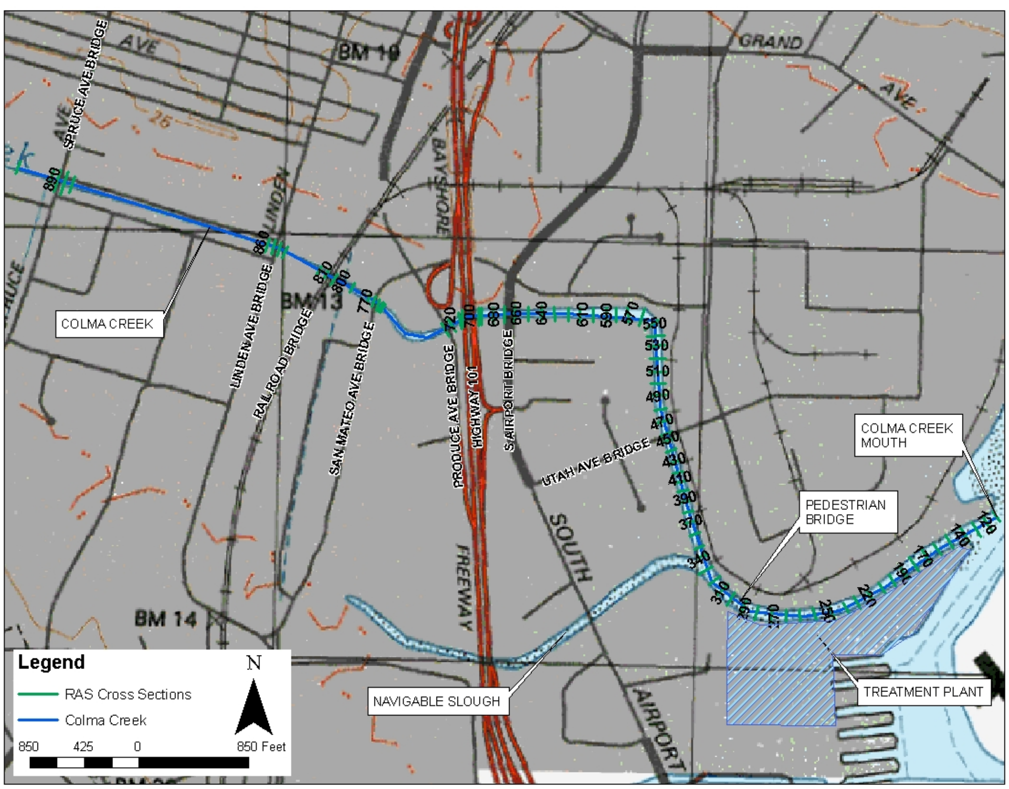


Figure 14: HEC-RAS Cross Section Locations

Coincident Tide as Tailwater Condition

The starting water surface elevation at the mouth of Colma Creek is determined by a coincident tide analysis which results in a water surface elevation for each storm event return interval reflecting peak creek discharges coincident with the higher high tide in San Francisco Bay.

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. Furthermore, the relationship between coincident tides and maximum annual runoff can be quantified and used in the model, providing for a more statistically correct solution than an arbitrarily selected tide condition.

The El Niño storm of February 2-3, 1998 provided an ideal event for examining potential correlations between runoff events and tide action. While stream runoff as measured by local gauges often approached historic recorded levels, observed tides in San Francisco Bay were substantially higher than predicted. Figure 14 shows predicted and recorded tides in early February 1998 at NOAA's Golden Gate (San Francisco Presidio) gauge. Recorded tides during the week of this runoff event were consistently higher (on the order of 2 feet) than the astronomic (predicted) tide heights due to storm surge.

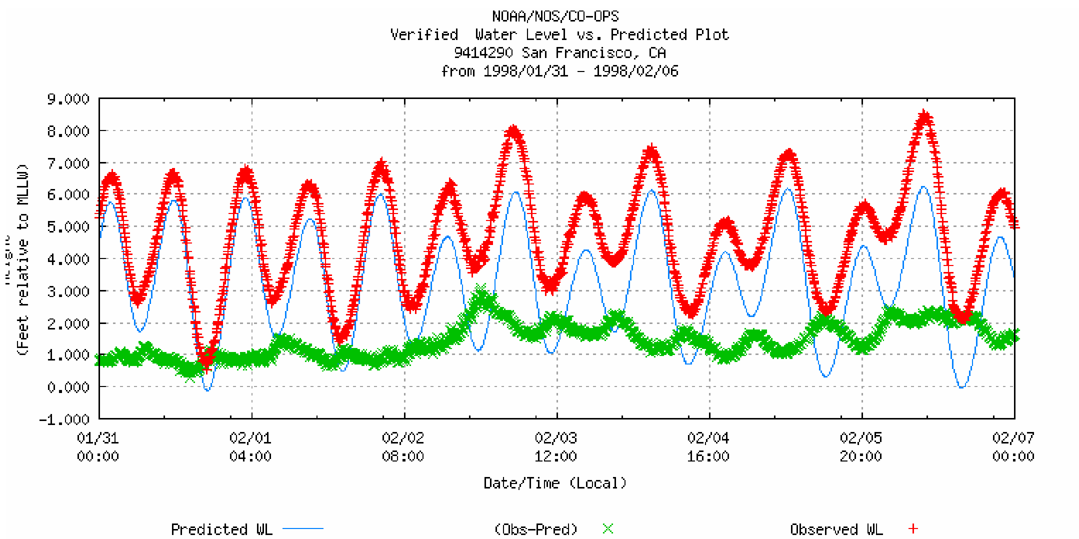


Figure 15: Impact of Storm Surge on San Francisco Bay Tide

Historic tide records have been examined to see whether the phenomenon demonstrated in February 1998 at the Golden Gate occurred elsewhere in the Bay Area and during other heavy runoff events in the past. Results of this investigation presented in Table 7 indicate that during the 1998 runoff event, similar rises in tide elevations (over astronomic predictions) were experienced at other recording tide stations in the Bay.

Table 7: Storm Surge during February 1998 Event

Location	Maximum Difference Between Predicted and Recorded Tides in feet	
	Higher High	Lower Low
Golden Gate	2.0	3.0
Alameda	2.0	2.7
Redwood City	2.0	2.7
Monterey Harbor	1.7	1.8

The observed phenomenon presented in Table 7 is not strongly dependent upon tide gauge location, particularly within San Francisco Bay, and is exhibited during many historic storm events. Data indicate that higher tides as observed during the February 1998 event are not an isolated incident; rather, higher than predicted tides can be expected during storm events that generate significant runoff. Increases in the data set between observed tides over predicted tides range from 0.3 foot to 2.0 feet for the higher high tide, and from 0.9 foot to 3.0 feet for the lower low tide.

From observed historical data, it appears that storm-related forces induce higher tides during rainfall events, and by extension, runoff events. This phenomenon may be due to a number of meteorological or hydrologic factors. NOAA refers to the term "inverse barometer effect", and defines it as higher tides that are caused by lower barometric pressures associated with winter storm systems. References to "storm surges", the meteorological effects of low barometric pressures and/or strong southerly winds, are also found in the literature.

The exact nature and cause of this phenomenon, however, are not as important as potential impacts to backwater conditions at Colma Creek. To model an appropriate San Francisco Bay tidal cycle during a storm event of particular return period (with tides adjusted to the mouth of Colma Creek, 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 Colma Creek at the USGS stream flow gaging station; and this gauge data is also used to calibrate the rainfall-runoff model. This procedure is as described by Dixon (1986), whose hypothesis was that high tide events tend to occur the same day as flood flow events using conditional probability:

$$P(x,y) = P(x|y)\, P(y)$$

where $P(x,y)$ is the probability of occurrence of x and y; $P(x|y)$ is the probability of occurrence of x given y; $P(y)$ is the probability of occurrence of y; x is tide elevation; and y is maximum annual peak discharge. Since we are interested only in annual maximum discharges, $P(y)$ is one and the probability of joint occurrence, $P(x,y)$, is equal to the probability of x given y.

Appendix H details the calculation of the coincident higher high tide at Colma Creek, the summary of which is shown in Figures 15 and 16. Verified tide data are taken from National Ocean and Atmospheric Administration (NOAA) Tides and Currents for The Presidio, San Francisco Bay and modified as outlined in Table 1 to reflect tides at the mouth of Colma Creek. Figure 16 shows the entire coincident tide cycle at the mouth of Colma Creek, and compares the analytically derived tide cycle to observed tides during the February 1998 event that have been adjusted to the Colma Creek location.

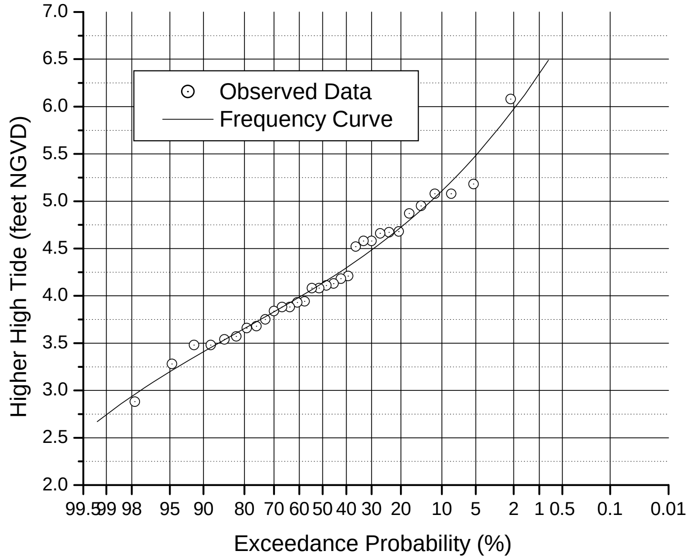


Figure 16: Coincident Higher High Tide Frequency Plot at South San Francisco

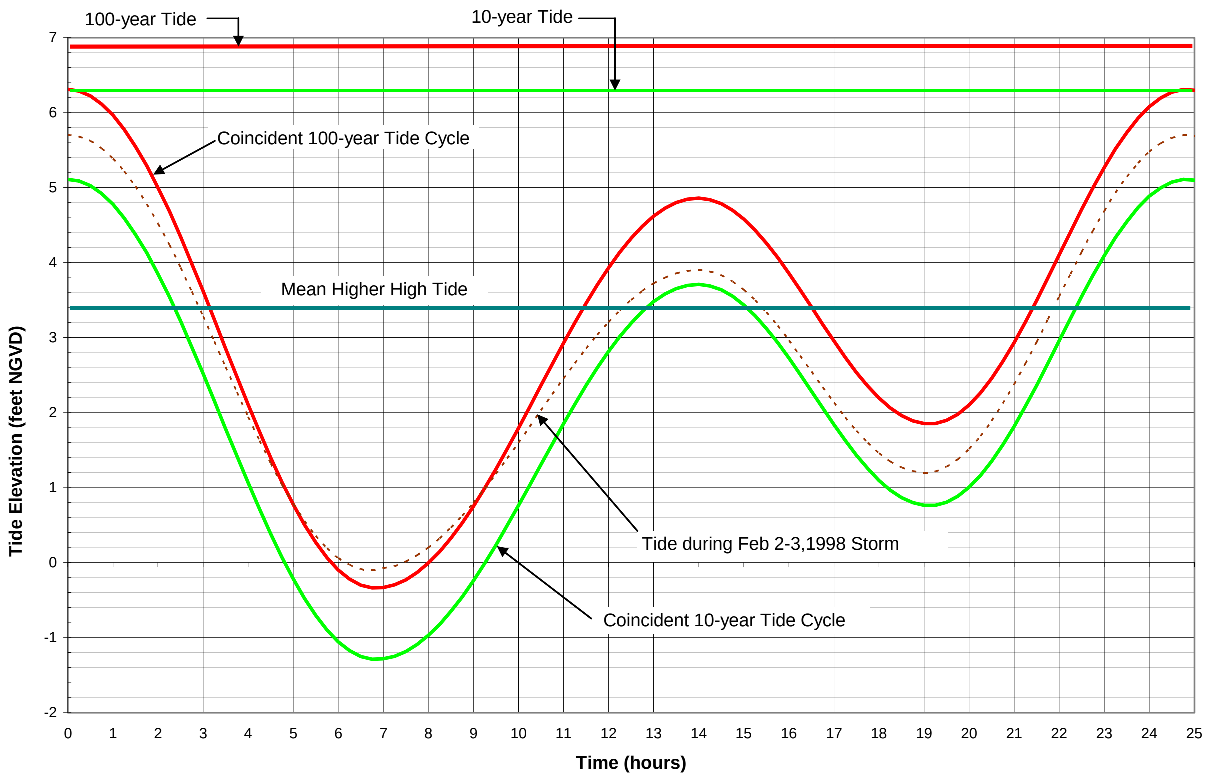


Figure 17: Coincident Tide Cycle at Mouth of Colma Creek

Colma Creek Flood Risks

Flood risks for the 10- and 100-year runoff events have been analyzed in detail. The HEC-RAS model shows that there is significant spilling upstream from Utah Avenue, which reduces the discharge of runoff in Colma Creek as it passes by the Plant. Figures 17 and 18 show the predicted flood hazard areas, noting that while these are not certified flood maps to NFIP standards, the flood hazards shown between Spruce Avenue and San Francisco Bay are very similar to the special flood hazard areas shown on the Preliminary FIRM due to become effective in April 2012.

Due to the natural "perch" of ground extending away from Colma Creek banks and the presence of flood walls, spill upstream of Highway 101 that leaves over the south creek bank does not return to the creek; but rather, is trapped behind the railroad and raised freeway median barrier. South overbank spill between Highway 101 and Utah Avenue is stored in the area between Airport Boulevard and the creek, is attenuated (i.e. the peak decreases due to the storage), and returns to Colma Creek through Navigable Slough. High ground at the Plant site on the south bank of Navigable Slough protects the WQCP from flooding.

The resulting 100-year water surface elevations for Colma Creek have been compared to ground elevations from the Plant Survey (Appendix A) to evaluate flood risks at the Plant. HEC-RAS results (Appendix I) have been converted from NGVD29 to the Plant Datum by adding 0.93 foot. The lowest elevation at the northern edge of the plant is 8.2 feet (Plant Datum) while the highest water surface elevation is 7.7 feet (Plant Datum). Therefore, although there are only about 6 inches of capacity freeboard, the treatment plant is not subject to flooding from Colma Creek during the 100-year storm event.

An additional study of the creek has been performed to evaluate the flood protection currently provided by upstream flow restrictions and spills. That is, if remediation projects are completed that channel all of the discharge in Colma Creek and Navigable Slough to the reach adjacent to the WQCP, would there be flooding at the site due to future expansions of bridge openings or extensions of creek flood walls? An HEC-RAS model has been run with infinitely high flood walls that do not allow water to spill outside the creek banks upstream of the Plant. Even with this extreme conservative condition ("No Upstream Constrictions" in Table 8), the maximum water surface elevation is 8.0 feet (Plant Datum) and would not inundate the site.

Water surface profiles for the coincident 2-, 5- and 10-year storm events have also been computed for information. Water surface elevations are tabulated below.

Table 8: Predicted Water Surface Elevations for Colma Creek at WQCP

Storm Event	Highest Water Surface Elevation (Plant Datum)	Lowest Plant Elevation (Plant Datum)
2-year	5.5	8.2
5-year	6.3	8.2
10-year	6.6	8.2
100-year	7.7	8.2
100-year (No Upstream Constrictions)	8.0	8.2

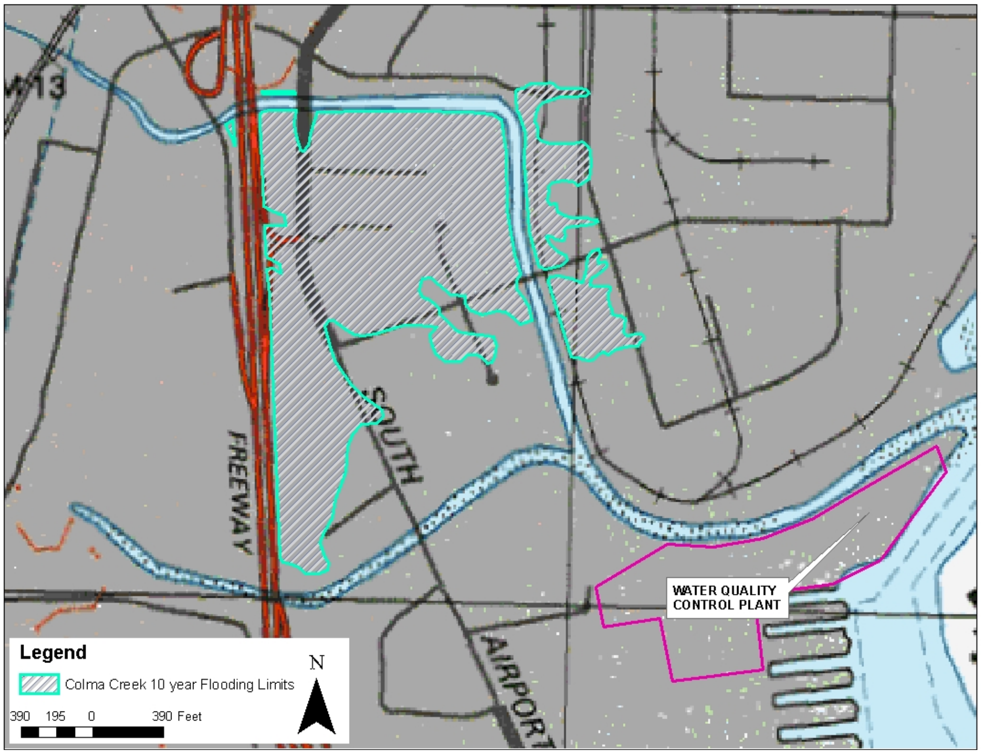


Figure 18: 10-Year Flooding Near WQCP

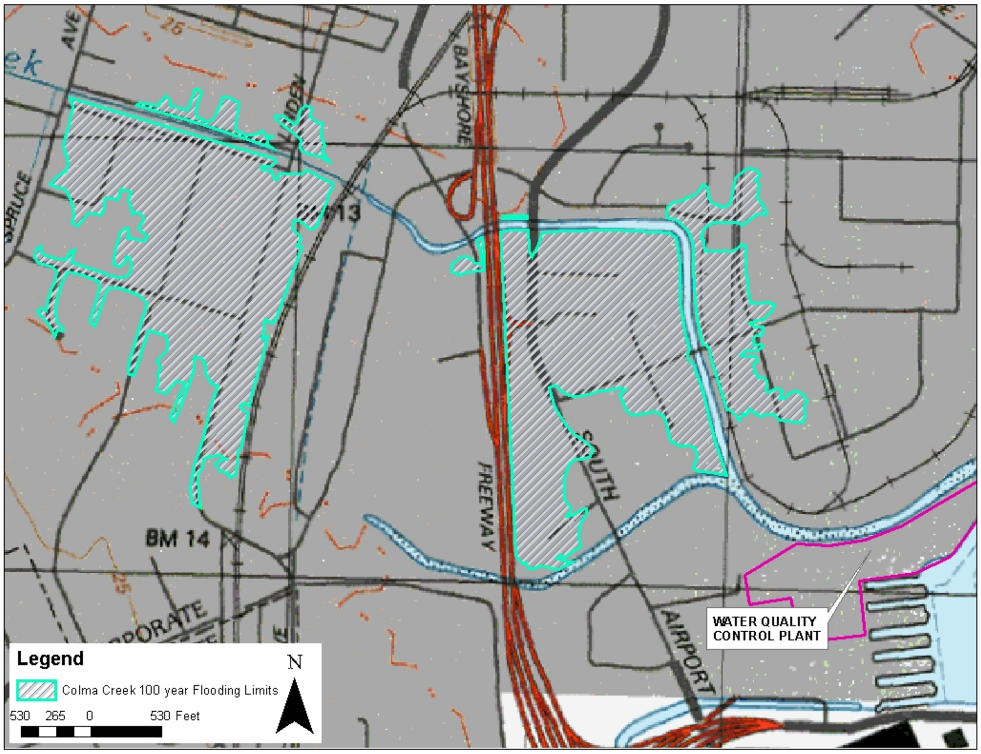


Figure 19: 100-Year Flooding Near WQCP

Navigable Slough Flood Hazards

Tributary to Colma Creek, Navigable Slough flows from west to east, and reaches a confluence with Colma Creek just northwest of the Plant. This tributary's drainage area is approximately 630 acres and results in a peak 100-year discharge of 360 cubic feet per second. Detailed geometric information is not available for the tributary, so Schaaf & Wheeler performed a field survey to determine approximate channel shape and invert information. These data have been used in conjunction with San Mateo County LiDAR data to determine if the discharge within the tributary exceeds its banks during the 100-year storm event. A downstream water surface elevation (WSEL) is taken from the 100-year Colma Creek HEC-RAS model junction point. The conservative HEC-RAS model where no upstream spilling is allowed from Colma Creek upstream of the junction is used to determine the starting elevation, thereby ensuring the highest possible WSEL for the tributary model. The 100-year peak flow is modeled through Navigable Slough, and it is found that the water surface profile does exceed bank full capacity during the 100-year storm event. Figure 19 shows 100-year flooding limits for Navigable Slough. Spills occur just upstream and downstream of Highway 101, but do not impact the Plant due to intervening high ground.

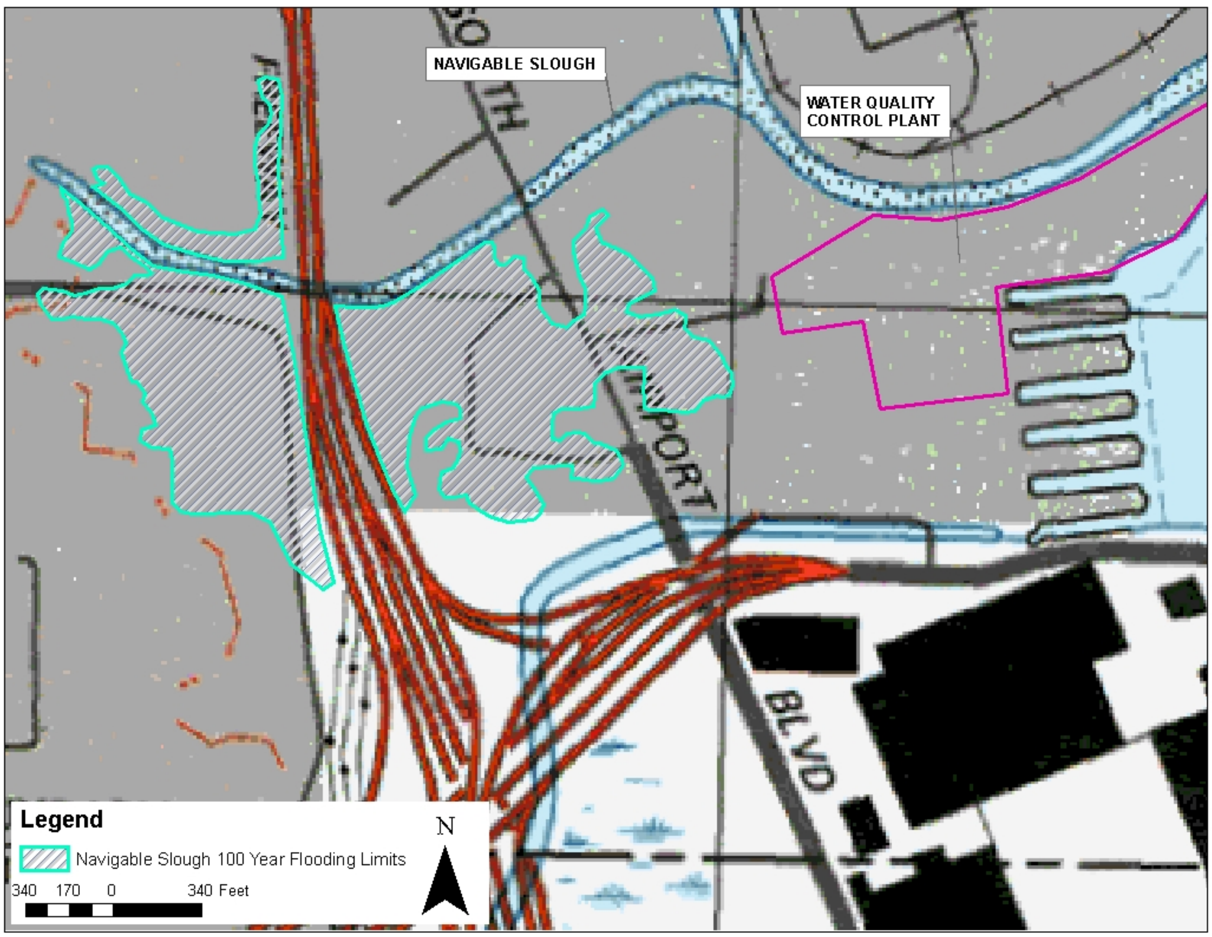


Figure 20: 100-Year Flooding at Navigable Slough

San Bruno Channel Flood Hazards

San Bruno Channel collects runoff from the City of San Bruno, a drainage area of approximately 2,400 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 20). The San Bruno basin has been analyzed for peak 100-year flow based on the methodology described above using one contributing basin that encompasses the entire drainage area. HMS is used to determine peak runoff and the time to peak based on the MAP, calibrated AMC, Curve Number, rainfall patterns described for the Colma Creek model. The resultant peak 100-year discharge is 1,810 cubic feet per second. Since no channel geometry information is available, Schaaf & Wheeler performed a field survey to define basic channel geometry. (Bridge crossing dimensions and detailed topography information was not gathered due to issues with access.) The field survey information along with County LiDAR data has been used to create a HEC-RAS model. (See Appendix I for model output.) A downstream water surface elevation equal to the coincident 100-year tide at the mouth of Colma Creek is used due to the close proximity of the two channels. The 100-year peak flow is modeled through the channel, and it is found that the channel does not exceed bank full capacity during the 100-year storm event.

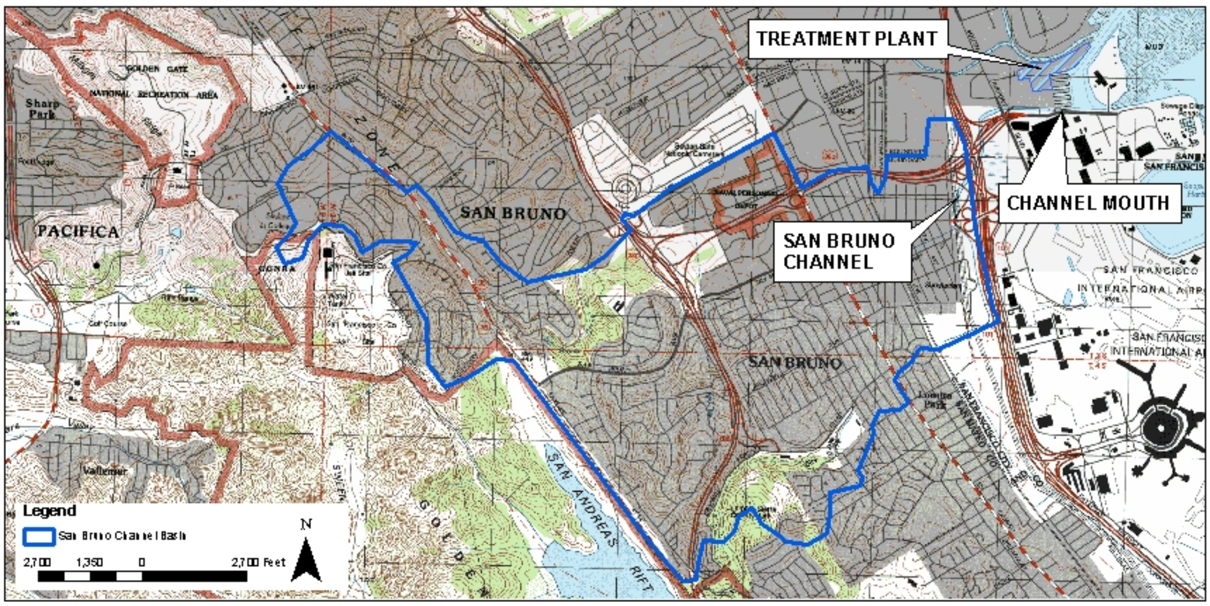


Figure 21: San Bruno Channel Drainage Basin

Climate Change Impacts to Flood Hazards at the WQCP

The San Francisco Bay Conservation and Development Commission (BCDC) released a report in April of 2009 (revised September 2011) titled *Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on the Shoreline*. This report includes scientific research regarding global climate change and its potential effects on future San Francisco Bay water levels. The report concludes that, depending on the volume of green house gases emitted, sea level rise could be as much as 16 inches by the middle of this century (2050) and 55 inches by the end of the century (2100). To evaluate potential impacts of rising sea levels on flood hazard risks at the Water Quality Control Plant, an additional 16 and 55 inches respectively are added to predicted stillwater surge elevations to examine flood risks due to tidal inundation, wind generated wave hazards and the Colma Creek, Navigable Slough, and San Bruno Channel flooding analyses.

Tidal Inundation

The science is not settled regarding the impact of a rising mean sea level on statistically extreme tide elevations. However, in the absence of better information, a rising mean sea level is often treated like a vertical datum adjustment. That is, a rising sea is the same as subsiding land, and a change in extreme tide elevations equivalent to the increase in mean sea level can be applied.

By applying sea level rise to the FEMA 100-year tide event, the resulting 100-year tide levels would be 8.3 feet NGVD (9.3 feet Plant Datum) and 11.6 feet NGVD (12.5 feet Plant Datum) for the 2050 and 2100 sea level rise estimates, respectively. During a future 100-year tide, BCDC sea level rise scenarios suggest that isolated portions of the WQCP site could reach flooding depths of less than half a foot by 2050, without threatening Plant facilities, but up to 4.7 feet with extensive flooding by the year 2100 based on a minimum site elevation of 7.8 feet Plant Datum. Figure 21 shows the extents of future flood inundation under the BCDC sea level rise scenarios.

Climate Change Impact on Wind-Wave Hazards

Again, there is no definitive scientific method to evaluate the impact of global climate change on wind patterns relative to tides and the generation of wind wave hazards. According to the San Francisco BCDC, sea level rise could be as much as 16 inches by the middle of this century (2050) and 55 inches by the end of the century (2100). To reflect this change as a datum shift and its effect on wind-wave hazards at the WQCP, an additional 16 and 55 inches respectively are added to the stillwater surge elevation and the wind and wave run-up analyses are repeated. The increased 100-year tidal water surface elevations of 11.1 feet NAVD (9.3 feet Plant Datum) and 14.4 feet NAVD (12.5 Plant Datum) are utilized to repeat the fetch and wave calculations described previously, and presented in Table 9.

Table 9: Climate Change Fetch Data

Fetch	Length (ft)	Average Depth (ft) to Mean Lower Low Water (MLLW) tide Elevation		Average Depth (ft) to 100 year tide elevation (NAVD88)	
		16” Rise	55” Rise	16” Rise	55” Rise
NE	3,800	1.8*	5.1*	11.7	15.0
E	68,300	12.2*	15.5*	22.1	25.4

*add 0.45 foot for NAVD88, subtract 2.79 feet for NGVD29

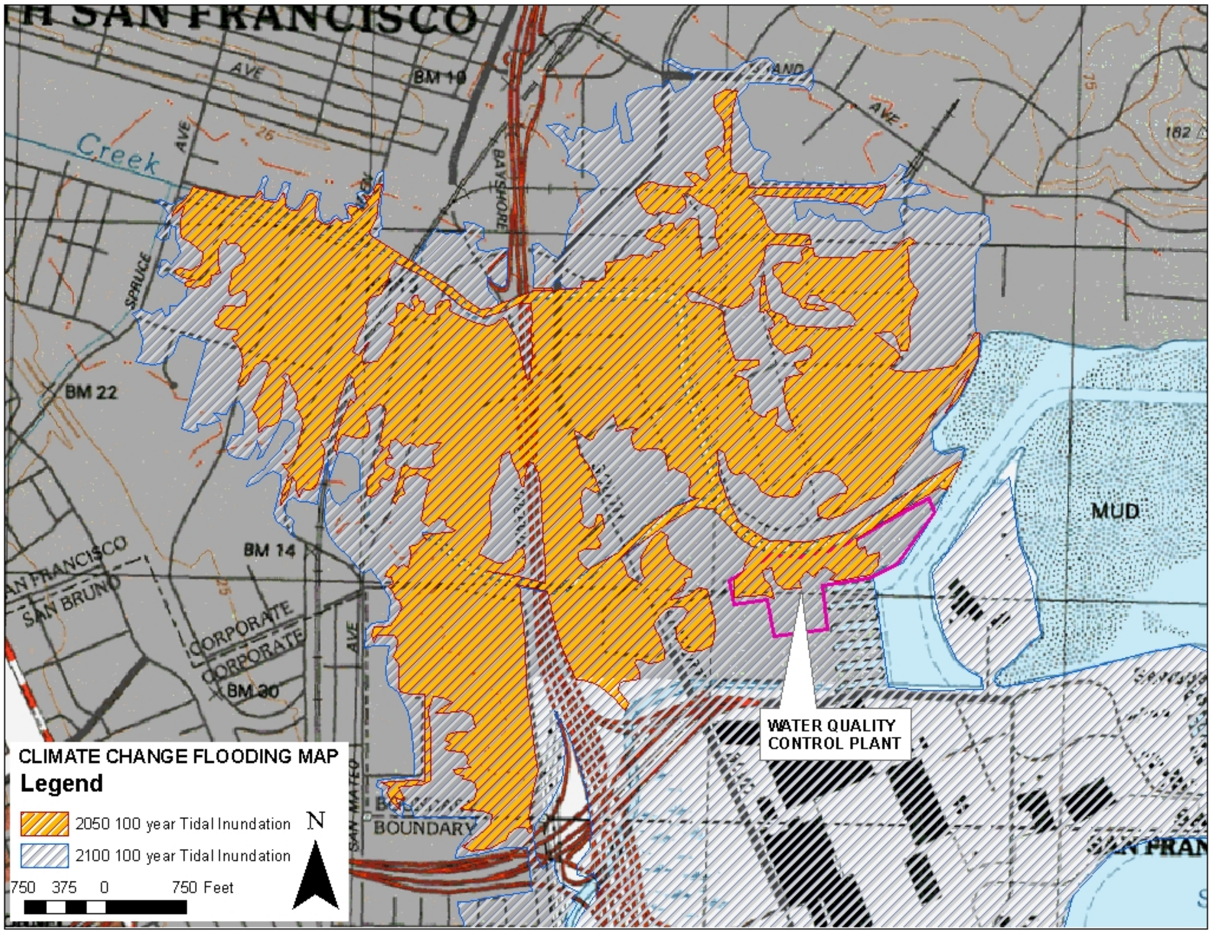


Figure 22: Inundation under BCDC Sea Level Rise Scenarios

It is assumed that wind speeds are not altered in the next century due to climate change, simply because there is no quantifiable way to adjust wind speed for speculative climate change impacts. For the easterly fetch a wave height of 2.2 feet and period of 3.1 seconds is determined using a 20 mph wind, fetch length of 68,300 feet and average depths of 22.1 feet and 25.4 feet. For the northeasterly fetch a wind speed of 25 mph, a fetch of 3,800 feet, and average depths of 11.7 feet and 15.0 feet are used to calculate a wave height of 0.8 foot and a period of 1.5 seconds. Due to the level of accuracy associated with the tables used to calculate wave height and period, they are not changed from the current condition. (See Appendix C for calculations.)

The ACES program is used to estimate the wave run-up at the northeastern peak of the levee. Water surface elevations of 11 feet NAVD (9.2 Plant Datum) and 14.3 feet NAVD (12.5 Plant Datum) representing the 100 year tide in 2050 and 2100 and the toe of slope elevation 4 feet NAVD (2.2 Plant Datum) result in a starting water depth of 7 feet and 10.3 feet respectively at the WQCP levee. The levee height of 17.5 feet NAVD (15.7 Plant Datum) and levee slopes do not differ from the current conditions. See Table 10 and Appendix D for ACES run-up results.

Table 10: Climate Change Wave Run-Up Results

Fetch	16-inch Rise (2050)		55-inch Rise (2100)	
	Run-up Height (feet)	Elevation (Plant Datum)	Run-up Height (feet)	Elevation (Plant Datum)
NE	1.017	10.2	1.017	13.5
E	3.487	12.7	3.475	16.0

<u>Evaluating Future Mitigation Requirements for Wave Hazards</u>

FEMA currently requires one (1) foot of freeboard above the wave height. This would mean that the bay front levee would need to be at a height of 13.7 feet (Plant Datum) to withstand a 16-inch rise in sea level and elevation 17 feet (Plant Datum) to withstand a 55-inch rise in sea level. Based on the Plant survey performed by Towill, the existing levee height of 15.7 feet (Plant Datum) is sufficient to protect the levee from 100-year wave induced tidal inundation by mid-century sea level rise, but would be subject to overtopping by the end of the century.

Due to the speculative nature of sea level rise, and in particular its impact on wind generated waves in San Francisco Bay, it is recommended that no future mitigation planning take place until better planning data are available.

Climate Change Impacts on Colma Creek Flood Hazards

The Colma Creek water surface elevations have been determined using the HEC-RAS model created for the previous analysis. This numeric analysis assumes that precipitation and runoff would not substantially change in the future due to climate change, because there is no quantitative consensus available to use. Only the 100-year, 24-hour storm is analyzed. The water surface elevations resulting from utilizing a starting downstream coincident tide elevation of 6.3 feet NGVD (7.2 feet Plant Datum) plus 16 and 55 inches due to climate change are 7.6 feet NGVD (8.5 feet Plant Datum) and 10.9 feet NGVD (11.8 feet Plant Datum) respectively.

Table 11: Climate Change Impacts to Colma Creek Flooding

100-year, 24-hour Storm Event	Highest Water Surface Elevation	Lowest Plant Perimeter Elevation	Lowest Interior Plant Elevation
	(Plant Datum)	(Plant Datum)	(Plant Datum)
2050 - 16" Rise	8.6	8.2	7.8
2100 - 55" Rise	11.9	8.2	7.8

Spilling would occur from the creek under both sea level rise estimates. The BCDC increase in sea level by mid-century would cause flooding inundation of the Treatment Plant by Colma Creek of about 0.9 foot. This flooding would occur in the northern portion of the Plant along Colma Creek. The BCDC increase in sea level by year 2100 to a coincident tide elevation of 11.9 feet Plant Datum would cause creek inundation of the Plant to a depth of 4.1 feet. These water depths are based on 100-year storm creek flooding with a coincident tide, as apposed to the flooding depths based on the increased 100-year tide inundation discussed previously.

Navigable Slough Sea Level Rise Impacts

The downstream convergence with Colma Creek with BCDC 2050 and 2100 sea level rise scenarios has been used to test Navigable Slough for increased flooding during the 100-year storm event. Flooding occurs at both the mid and end of century coincident tide sea level rise elevations primarily due to the increase in tidal backwater as shown on Figure 19.

San Bruno Channel Sea Level Rise Impacts

The model created previously for San Bruno Channel has been re-run using coincident starting water surface elevations of 7.6 feet NGVD (8.5 feet Plant Datum) and 10.9 feet NGVD (11.8 feet Plant Datum) representing the mid- and end-century coincident tide sea level rise estimates, respectively. During the 100-year storm at mid-century, an anticipated sea level rise of 16 inches would not cause San Bruno Channel to spill over its banks. A sea level rise of 55 inches would cause significant spilling of San Bruno Channel as shown on Figure 21.

Conclusion Regarding Future Mitigation Requirements

Due to the speculative nature of sea level rise and the fact that predicted impacts due to a 16-inch rise in mean sea level by mid-century (BCDC) are not particularly problematic, the City does not need to consider flood protection mitigation against climate change impacts in any detail at this time.

Localized Runoff Risk

Due to the nearly impervious surface of the WQCP, the site will experience very little infiltration and almost completely direct storm water runoff during most large storm events. The site is primarily covered by asphalt paving with large impervious surfaces due to treatment tanks and structures. Onsite ground slopes are relatively flat, with an average slope around 0.5 percent. The Rational Method is used to obtain the on-site runoff volume for the 100-year, 24-hour storm, assuming any remaining pervious surfaces are completely saturated and storm water cannot be pumped into Colma Creek for some reason such as power failure. Results are indicated by Table 12.

Table 12: Site Hydrology Data

WQCP Site Runoff		
Area	630,725	sf
Area	14.5	ac
Land Use	Industrial	
Hydrologic Soil Group	D	
Neighboring Southern Property Runoff		
Area	106,240	sf
Area	2.4	ac
Land Use	Industrial	
Hydrologic Soil Group	D	
Total Volume		
MAP	20	in
Precipitation $X_{100,24hr}$	5.7	in
Rainfall Volume	96.3	ac-in
Volume of Inundation	8.0	ac-ft

Assuming site drainage infrastructure is inoperable, Figure 20 shows approximate inundation by the volume of runoff resulting from the 100-year, 24-hour storm event, which is more than sufficient to fill the site to its natural release elevation along its perimeter adjacent to Colma Creek. Due to a large embankment on the western edge of the plant, and low elevations to the northwest, run-on is only possible from the southern neighboring property. Assuming that all of the adjacent southern runoff makes it onto the WQCP property, the site will experience a total runoff volume of 96 ac-in. The extent of local ponding at the natural release elevation (which is higher than the current 100-year tide) is depicted in Figure 22.

Site Drainage

Existing on-site drainage is analyzed for capacity based on the 100-year, 24-hour storm runoff occurring on-site only. Drainage structures and invert information are based on the Towill Plant Survey. Pipe size and direction are unknown for many of the inlets due to blockage by dirt or fabric debris inserts or bolted shut lids.

Most of the northeast portion of the site drains via overland flow and a few small inlets to a sump pump. The sump pump then pressurizes the runoff and discharges to the wet well of the effluent pump station. The southern portion of the site has a developed infrastructure of valley gutters and inlets which culminate in an eighteen inch discharge pipe. Due to the low invert elevation of 2.8 feet Plant Datum, the 18-inch pipe connects to Storm Water Station No. 1 which discharges to the inlet side of Flow Splitter No. 1 of the primary clarifiers.

Runoff from the northeastern sector of the site is directed by overland flow to a few drainage inlets. These inlets have inserts which made the pipe elevations and directions not observable at the time of survey. According to the plant superintendent, these inlets are connected with an underground pipe network and discharge by gravity just outside the plant front gate, into the slough south of the pedestrian bridge over Colma Creek. Due to the missing information regarding pipe infrastructure and discharge points, it is not possible to determine whether the site would be flooded by local drainage during the 100-year storm assuming drainage systems are operable.

However, it is noted that perimeter ground elevations adjacent to Colma Creek are raised relative to more interior elevations. So while the raised perimeter provides protection against tidal and creek flooding, it also creates the possibility of trapping local runoff within the site when the tide is sufficiently high to preclude gravity drainage or storm water pumps are not functional.

Given the potentially problematic nature of this trapped storm water runoff generated on site, and from the adjacent property to the south, further investigation into the Plant's storm water drainage system is warranted.

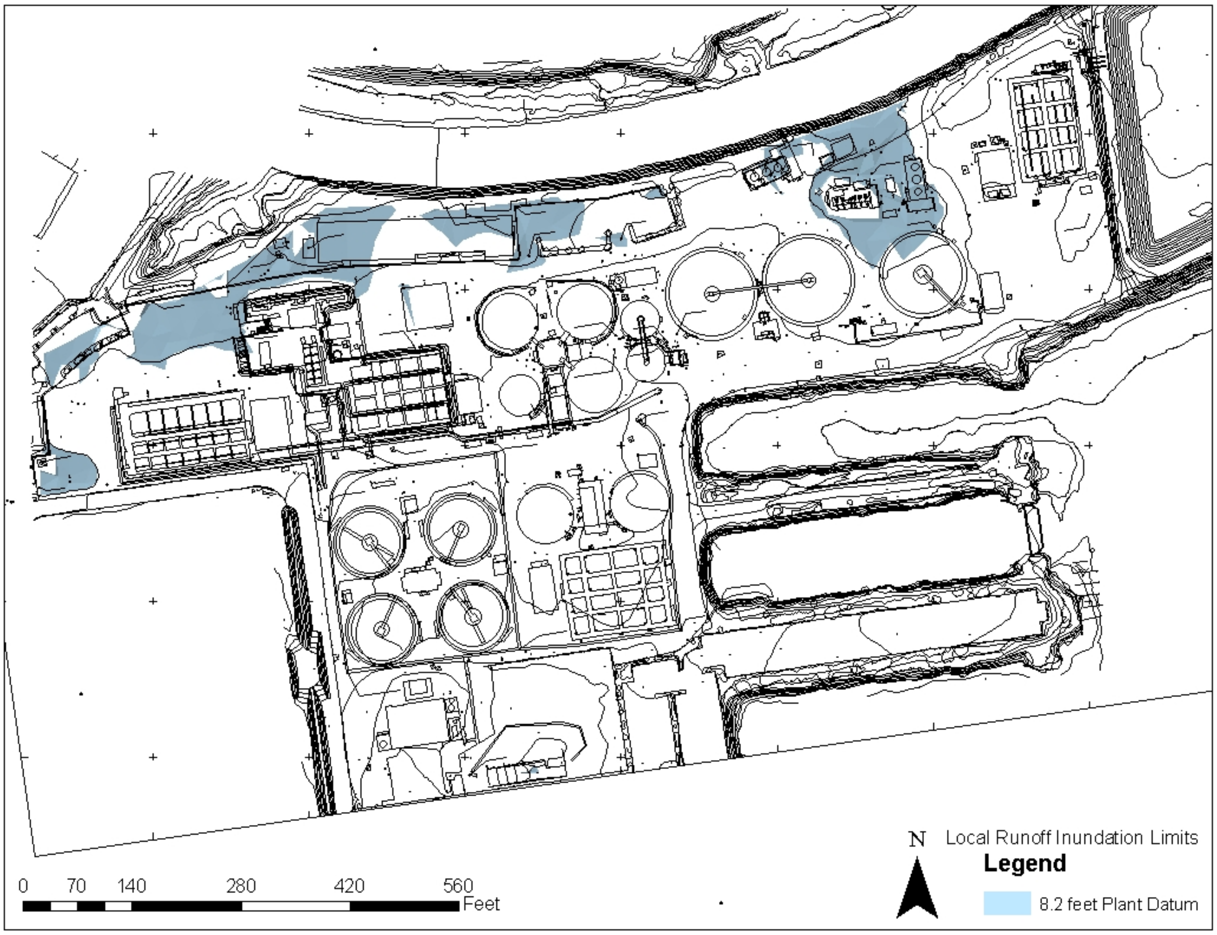


Figure 23: Potential Inundation from Site Run-On in 100-Year, 24-Hour Storm

Conclusions

At present the WQCP is situated within a range of elevations that protect the grounds and equipment from the aforementioned flood hazard risks. However, further investigation is needed to ascertain the reliability and efficacy of the site storm water drainage system under high tide conditions. If that system is undersized, lacks mechanical redundancy, or lacks standby power, local rainfall runoff could be trapped by higher grades at the site's perimeter (that protects the site from Colma Creek and San Francisco Bay) and result in shallow and isolated ponding on site. During periods of heavy rain coincident with high tides, ponded water has been observed to depths of approximately six inches near the concrete pad for the effluent pump electrical switchgear.

Some level of flood protection is afforded by channel constrictions upstream of Utah Avenue that cause excess floodwaters to spill from Colma Creek, whereby those spills are trapped behind overland flow barriers such as the Caltrain railroad tracks and Highway 101. Analysis shows, however, that even if these channel constrictions are removed by future improvement projects, there is sufficient flow capacity in Colma Creek between Utah Avenue and San Francisco Bay to accommodate the entire estimated 100-year flood flow without upstream losses due to capacity restrictions. Thus, despite a preliminary Flood Insurance Rate Map for San Mateo County that shows the WQCP exposed to 100-year flood hazards of indeterminate elevation, there is no significant regulatory 100-year flood hazard at the plant.

Future sea level rise due to global climate change could, however, affect flood risk exposure, primarily due to changes in extreme San Francisco Bay tides. The San Francisco Bay Conservation and Development Commission (BCDC) has published estimates of mean sea level rise that range from 16 inches by mid-century (2050) to 55 inches by 2100. Assuming that the elevations of extreme tides would rise in direct proportion to any increase in mean sea level, a small portion of the WQCP parking lot would be subject to 100-year tidal inundation by mid-century. (Extreme predictions of sea level rise by the end of the century would affect wide swaths of the South San Francisco bay front including the WQCP.) Given the uncertainty of sea level rise predictions and their relationship to extreme tide behavior and the long time frame until problems are anticipated, an adaptive approach whereby future planning efforts remain abreast of climate change predictions and impacts is recommended.

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