APPENDIX G
Groundwater and Sea Level Rise Addendum, Stormwater Memorandum, and Sea Level Rise Adaptation Strategy

Sea-level rise impacts on shallow groundwater in Moffett Park

A technical addendum to the Moffett Park Specific Plan

November 2021

Prepared for the City of Sunnyvale

Sunnyvale

Prepared by SFEI, with technical review by ESA & Pathways Climate Institute

SFEI SAN FRANCISCO ESTUARY INSTITUTE

ESA

pathways CLIMATE INSTITUTE

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Contents

1. Introduction

Sea-level rise (SLR) can raise the shallow groundwater table near coastal shorelines, with the pace and extent of groundwater rise depending on the geologic and hydrologic conditions of the shallow aquifer and the surrounding soils. Rising groundwater can damage buried infrastructure, roadway subgrades, and building foundations, re-mobilize buried soil contaminants, increase liquefaction risk, cause construction challenges, and can ultimately emerge above the ground as surface flooding. Higher water tables also reduce channel drainage capacity for stormwater, adding to surface flooding problems. Traditional shoreline flood risk management structures like levees and floodwalls are generally not designed to address groundwater rise associated with sea-level rise, though they can include subsurface elements to reduce groundwater flow rates. Adaptive strategies like expanding capacity of stormwater systems, raising finished floor elevations, cutoff walls, pumping, and waterproofing buried utilities can help increase community resilience to rising groundwater levels.

Moffett Park, part of the City of Sunnyvale, is located near the San Francisco Bay (Bay) shoreline. Former salt ponds and wetland restoration areas separate Moffett Park from the Bay. Development in Moffett Park requires an understanding of the existing and potential future groundwater levels to inform climate-smart development and infrastructure planning, as extreme rainfall events and SLR are likely to exacerbate flood risk. For more information about SLR and flood impacts in Moffett Park, refer to the Sunnyvale SLR Adaptation Strategy, a technical addendum to the Moffett Park Specific Plan (MPSP) (ESA & SFEI, 2020). The present technical addendum builds on this previous work and provides additional context about the existing and future shallow groundwater table, its projected impacts, and potential adaptation strategies to address these impacts within Moffett Park.

2. Background

Where shallow freshwater aquifers are connected to oceans and estuaries, the rate of rise in groundwater levels in response to rising sea levels is determined by geologic and hydrologic conditions near the shoreline. In “recharge-limited” areas the elevation of the groundwater table is controlled primarily by rainfall, with a higher water table observed during and after rainfall events, and a lower water table during the dry seasons and drought years. Water tables in recharge-limited areas near the shoreline will likely rise at the same rate as sea levels. In other areas, SLR pushing groundwater levels upward can result in more groundwater discharge into channels, limiting the overall rise in the water table. This dynamic occurs in “topography-limited” systems (Michael et al., 2013) (Figure 1). The rate of groundwater rise in topography-limited systems may be slower than the rate of SLR; however, impacts are still likely to occur. For example, saltwater intrusion (saline groundwater moving inland) will be exacerbated by SLR in topography-limited systems, and a reduction in stream channel capacity can mean exacerbated flood impacts during storm events.

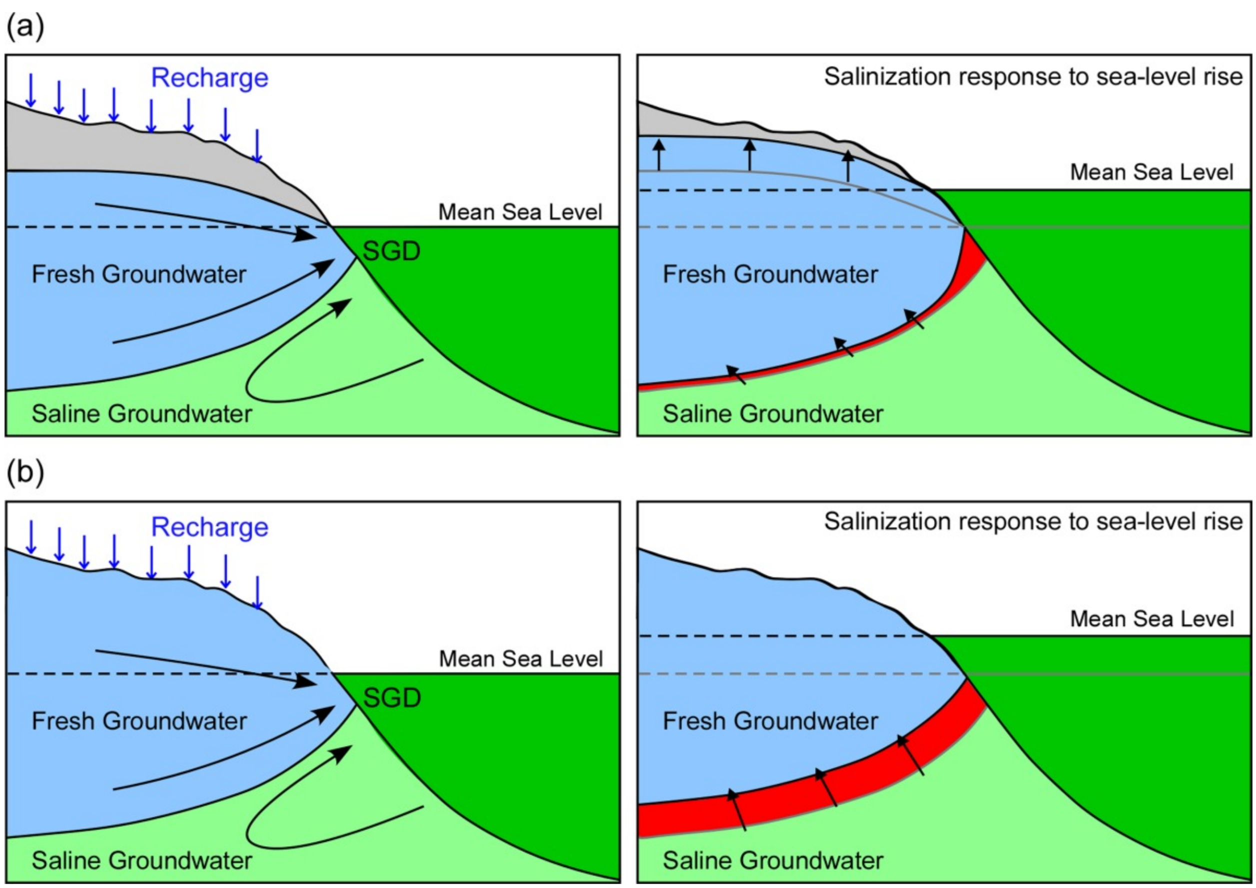


Figure 1. Diagram of (a) recharge-limited and (b) topography-limited coastal groundwater systems. “SGD” is submarine groundwater discharge. From Michael et al. (2013).

A recent analysis of the projected impacts of rising sea levels on the long-term equilibrium shallow groundwater table along the California coast (Befus et al., 2020) found that for about 70% of the state's coastline, including Moffett Park, the total rise in the water table was limited by discharge to channels ("topography-limited"). However, the low-lying urban areas around San Francisco Bay with poor surface drainage may be among the most vulnerable to groundwater hazards (Befus et al., 2020). The northern part of Moffett Park falls into this category as it is a subsided area mostly below mean high tide with a stormwater system that requires pumping to discharge to the Bay.

As sea levels rise, higher mean water levels in the Bay will likely cause shallow groundwater to rise in Moffett Park, first affecting subsurface infrastructure and eventually causing groundwater emergence. The minimum depth to groundwater measured is approximately 3-6 feet below the ground surface, so groundwater is unlikely to be emergent before sea levels rise three feet, which is likely by the end of the 21st century (CNRA-OPC, 2018). The minimum depth to groundwater generally occurs during or after heavy rainfall events in wet winters with above-average rainfall.

Layers of dense clay found below the ground surface in the Moffett Park area may also affect the relationship between sea-level rise and the water table. The rate of groundwater flow through a dense clay layer is very low. Long-term rise in mean sea level can affect the water table even if rates of flow are slow, but the slower flow rates are likely to attenuate the inland rise of groundwater. Some information about the hydrogeology in Moffett Park is provided in the following section. A more robust analysis of subsurface geology and its impact on future groundwater flow dynamics is needed, and will require a detailed 3-dimensional hydrogeological groundwater model.

3. Review of existing information

A. Topography

Much of the Moffett Park area is below the high tide elevation (Figure 2). Berms separate the former salt evaporation ponds bayward of the city from the low-lying urban area. Regional groundwater pumping from the deeper aquifer from the early 1900s through the mid-1960s led to widespread ground subsidence of up to 8 ft in some places, consolidating the subsurface soils (Figure 3). From the 1960s to present, the rate of subsidence has largely been halted by reducing groundwater extraction for drinking water and recharging the deeper aquifers (Santa Clara Valley Water District, 2016). The ground elevation is highest in the southwest corner of Moffett Park, and the ground surface slopes down to the northeast. The corresponding groundwater flow direction is also to the northeast, as shown on Figure 2 (AECOM, 2019; Brown and Caldwell, 1987; Earth Resources Technology, Inc, 2020).

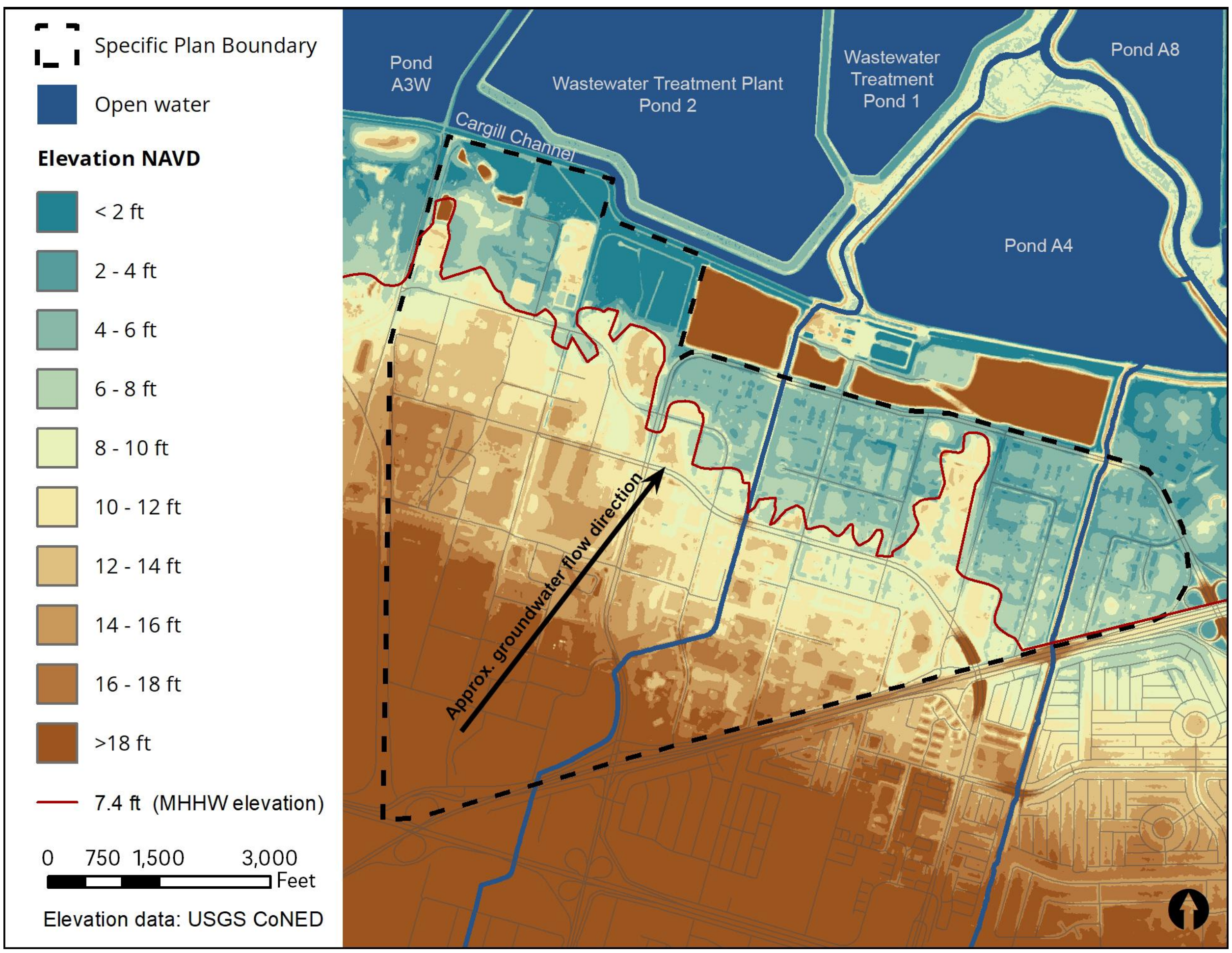


Figure 2. Topography of Moffett Park. Mean Higher High Water is about 7.4 ft NAVD (North American Vertical Datum of 1988).

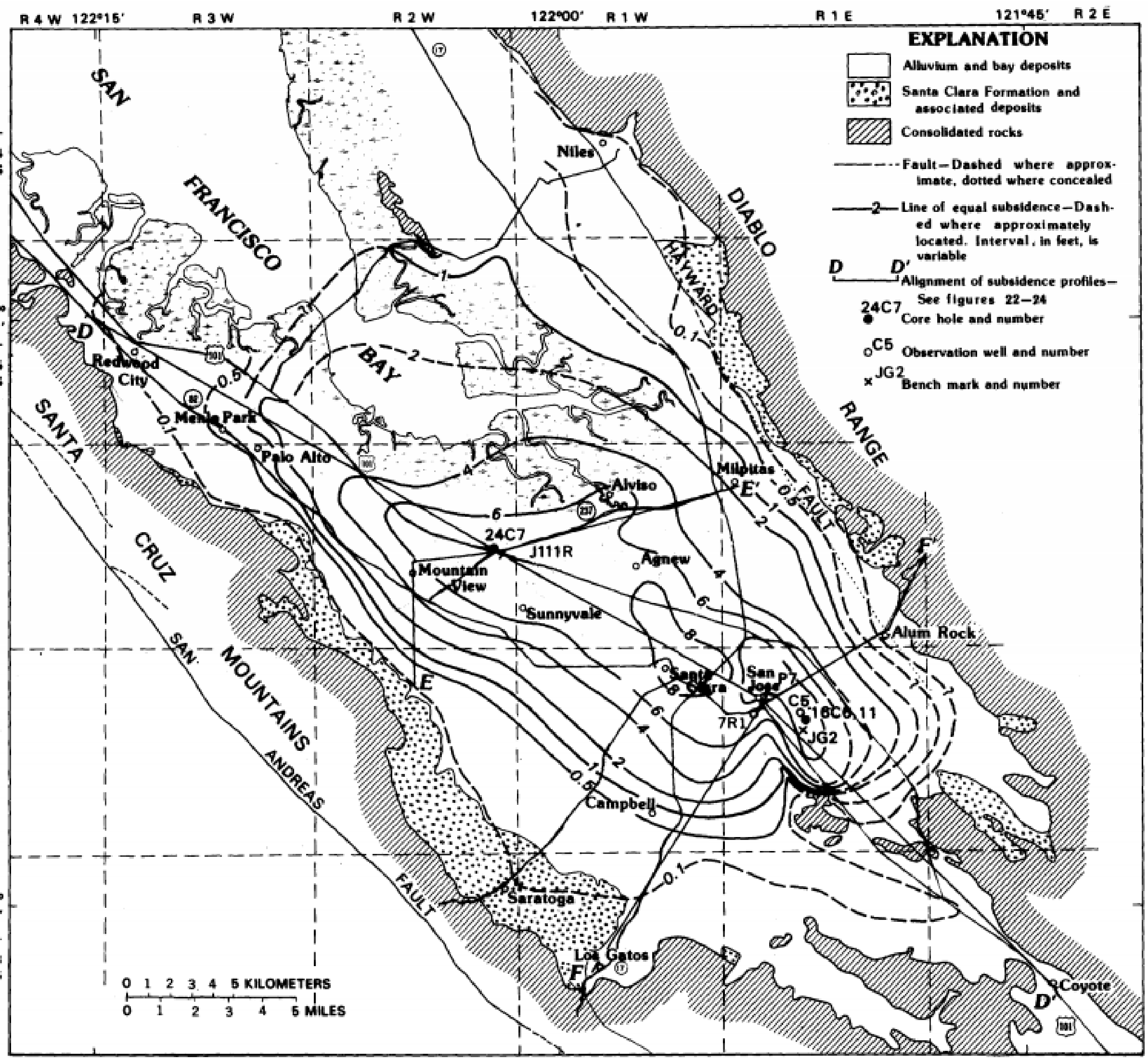


FIGURE 21.—Land subsidence from 1934 to 1967, north Santa Clara County.

Figure 3. From 1934 - 1967, land along the Sunnyvale shoreline subsided about 6 feet, largely due to groundwater withdrawals. Figure from Poland & Ireland, 1988.

B. Hydrogeology

The Moffett Park area lies at the bayward edge of a system of convergent alluvial fans in the Santa Clara Valley. As stream banks shifted laterally over time, they left behind alluvial and sedimentary deposits of sand, clay, and silt (Helley et al., 1979). Nearer the Bay, tidal deposits also influenced geologic conditions, and organic-rich clays can be found up to 10 feet above mean sea level in the surficial deposits of this area (Brown and Caldwell, 1987). Therefore, the subsurface geology of the Moffett Park area is complex, with lenses of fine-grained clays interwoven with coarser sandy deposits (AECOM, 2019; Brown and Caldwell, 1987; Ecology and

Environment, Inc., 1990; Iwamura, 1980; Santa Clara Valley Water District, 2016). The majority of the groundwater is found within larger pore spaces in the coarser deposits (i.e. the larger pore spaces can hold more water). The clay layers are less permeable so groundwater moves very slowly through them. In Moffett Park there is a large area of thin, sinuous, near-surface aquifers, which have limited connectivity with one another and the Bay and are separated by clay aquitards (Figure 4).

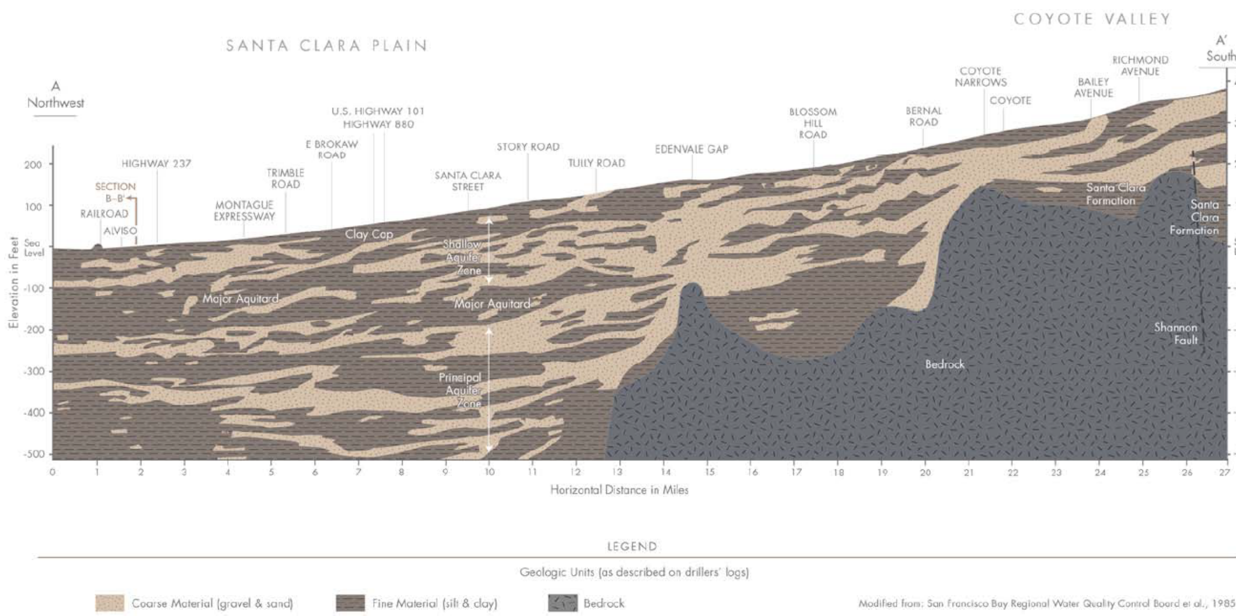
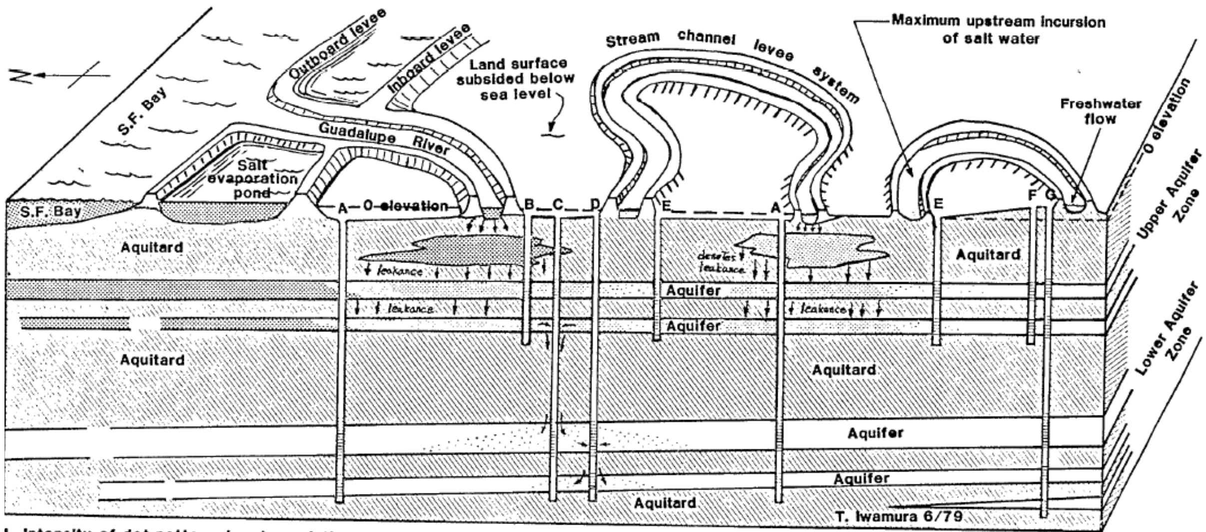


Figure 4. Drawing of the complex geology underlying the Moffett Park area, showing aquifers interspersed with layers of dense clay. The shoreline is toward the left side of the figure. Figure from SCVWD (2016).

According to soil survey data in the SSURGO (Soil Survey Geographic Database: field survey data compiled by the National Cooperative Soil Survey), soils in the area are poorly drained, and a typical soil profile is clay to 35 inches below ground surface, with clay loam, gravelly loam, and clay layers below (USDA-NRCS, n.d.). The shallowest aquifers in Moffett Park are composed of silty/clayey sands. They are found at 5-25 feet below ground surface and are about 5-20 feet thick (Brown and Caldwell, 1987; Ecology and Environment, Inc., 1990). Underneath this layer a clay aquitard mostly seals off the upper aquifer. There is some connectivity between the upper and deeper aquifers (Figure 5), and some evidence of saltwater intrusion in both layers.



1. Intensity of dot pattern denotes relative concentration of salts in water.

"A" Wells : Perforated only in lower aquifer zone ; no water quality impairment ; previously flowing artesian wells.

"B" Well : Perforated in upper aquifer zone ; water quality impairment of aquifer by salt water intrusion.

"C" Well : Compositely perforated in upper and lower aquifer zone ; contamination of lower aquifer zone resulting from interaquifer transfer of water.

"D" Well : Perforated in lower aquifer zone ; water quality impaired from interaquifer flow occurring in well C.

"E" Wells : Perforated in upper aquifer zone ; water quality slightly impaired as wells are located farther from sources of intrusion.

"F" Well : Perforated in upper aquifer zone ; water quality unimpaired as well is beyond zone of intrusion.

"G" Well : Compositely perforated well ; water quality unimpaired by intrusion.

Figure 5. There is some recharge from the surface into upper aquifers, though extensive aquitards restrict movement between aquifers. Figure from Iwamura (1980).

Rainfall is the main source of fluctuation in the groundwater table. A 1985-1986 investigation of groundwater underlying Moffett Park that measured depth to water on a monthly basis found that rainfall affected groundwater levels seasonally, though the water table fluctuated by less than a foot from the wet season to the dry season (Brown and Caldwell, 1987). Consistent with other low-lying areas near the Bay shoreline, the highest water table elevations were measured at the end of the wet season in the late spring/early summer, and the lowest water table elevations at the end of the dry season in late fall.

There is some evidence of connectivity between the open drainage channels and shallow groundwater in and near Moffett Park. For example, farmers in the baylands area along the tidal reaches of the Guadalupe River historically reported damage to crops from saltwater intrusion (Iwamura, 1980). An investigation in the 1980s found there was a connection between the Lockheed stormwater channel (which runs from south to north along E Street) and the shallow aquifer (Brown and Caldwell, 1987). A similar condition likely exists at the stormwater ditch adjacent to the Sunnyvale East Channel. The Sunnyvale East and West channels themselves are primarily earthen (i.e. not concrete-lined) in Moffett Park; however, the channel beds are at higher elevations above today's groundwater levels. Multiple investigations of possible hydraulic connections between shallow groundwater in the Moffett Park area and the Bay have found little evidence of tidal influence on shallow groundwater levels except near tidal channels (Behrens & Gurdak, 2020; Brown and Caldwell, 1987)). More information on tidal connectivity is provided in Section D of this chapter.

C. Contamination

Groundwater and soils in the Moffett Park area have been impacted by the history of industrial activities in the area and cleanup efforts at contaminated sites. Much of the public documentation about groundwater conditions in Moffett Park is associated with contamination from Lockheed Plant One and other sites (e.g. Sunnyvale Naval Industrial Reserve Ordnance Plant, Onizuka Air Force Station, and leaking underground storage tank cleanup sites) where remediation and monitoring has been required by regulatory agencies. Lockheed Plant One is an approximately 660-acre site on the western side of Moffett Park (Figure 6). Manufacturing and chemical facilities were built at the site in the early-to-mid-twentieth century and construction was largely completed by 1963 (Ecology and Environment, Inc., 1990). The Regional Water Quality Control Board issued a cleanup order in 1988 due to pollutant impacts to soil and groundwater from contaminants including volatile organic compounds (VOCs), hexavalent chromium, and nitrate. To manage the contaminated groundwater plume, which was traveling east, a groundwater extraction and treatment system with 11 extraction wells was installed and has been operating since 1993 (Regional Board, 2000). The extraction system remains in place, removing and treating about 60 gallons of groundwater per minute and discharging treated groundwater to the City of Sunnyvale sanitary sewer system. Not all of the extracted groundwater comes from the shallowest aquifers; the wells are screened in both the shallowest aquifer as well as two deeper ones. The system removed a total of 33 million gallons of groundwater in 2017 (AECOM, 2019) and so far has been effective at preventing plume migration and removing VOCs (Regional Board, 2000).

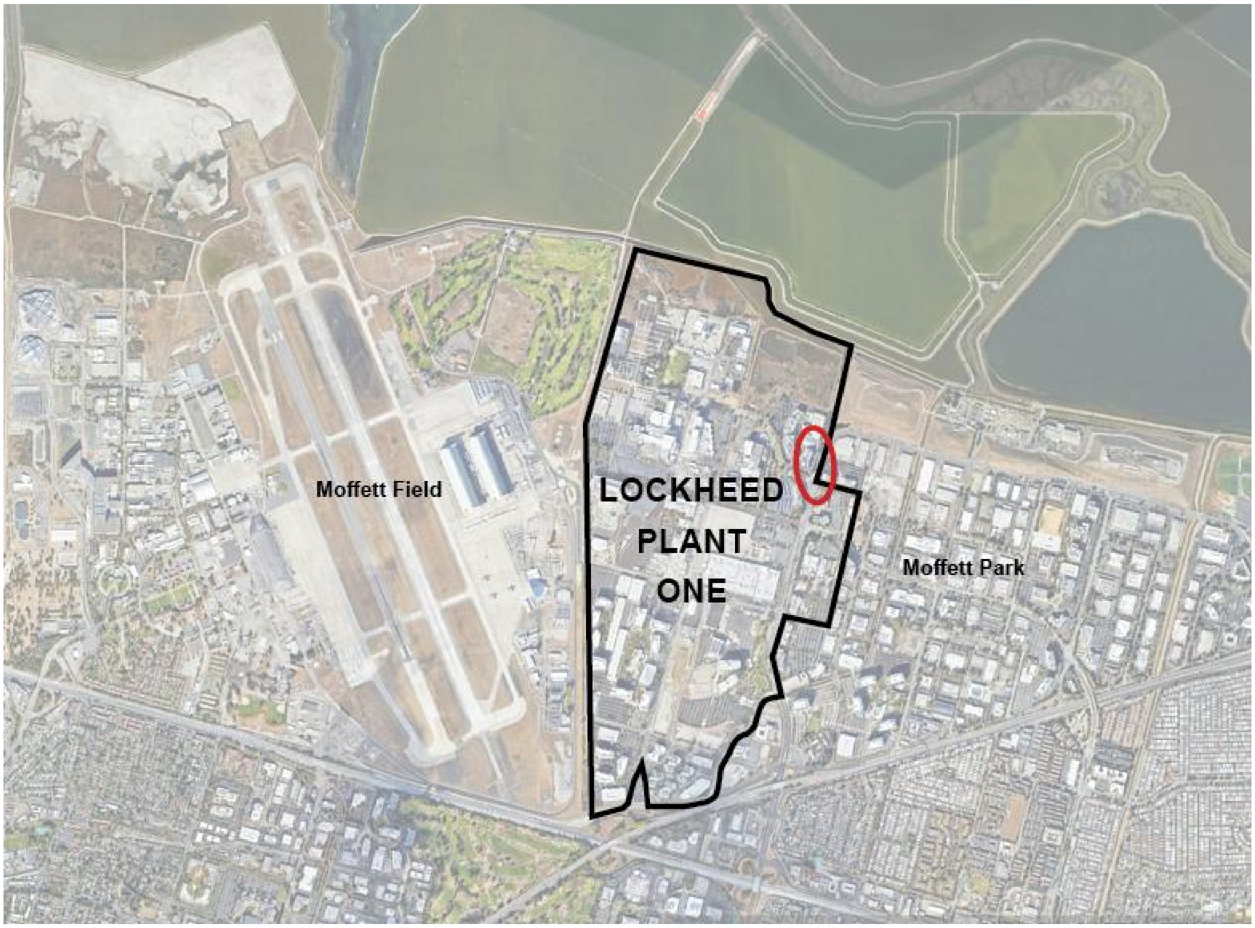


Figure 6. Approximate boundary of the original Lockheed Plant One facility. The red oval indicates the approximate location of the extraction and treatment system. Figure based on Figure 1 from Regional Board (2000).

Another source of groundwater contamination near Moffett Park (outside the Specific Plan area) is the Superfund site at Moffett Field (former Navy, current NASA campus), which has more than 30 hazardous waste sites. The Moffett Field site has been under a cleanup order since 1989, and groundwater extraction and treatment are used as a remedy for VOCs. The site includes 11 extraction wells at two locations. The smaller northern system pumps and treats 20 gallons of groundwater per minute and discharges to Stevens Creek. The larger southern system pumps and treats up to 120 gallons per minute and is discharged into the NASA stormwater retention pond. In 2019 the NASA extraction system removed and treated more than 21 million gallons of groundwater (Earth Resources Technology, Inc, 2020).

Pumping affects groundwater levels, and the Lockheed and NASA extraction systems cause localized depressions in the water table. A map of groundwater levels at the NASA campus created using measured groundwater elevations shows the relatively contained area of influence around each extraction well (Figure 7).

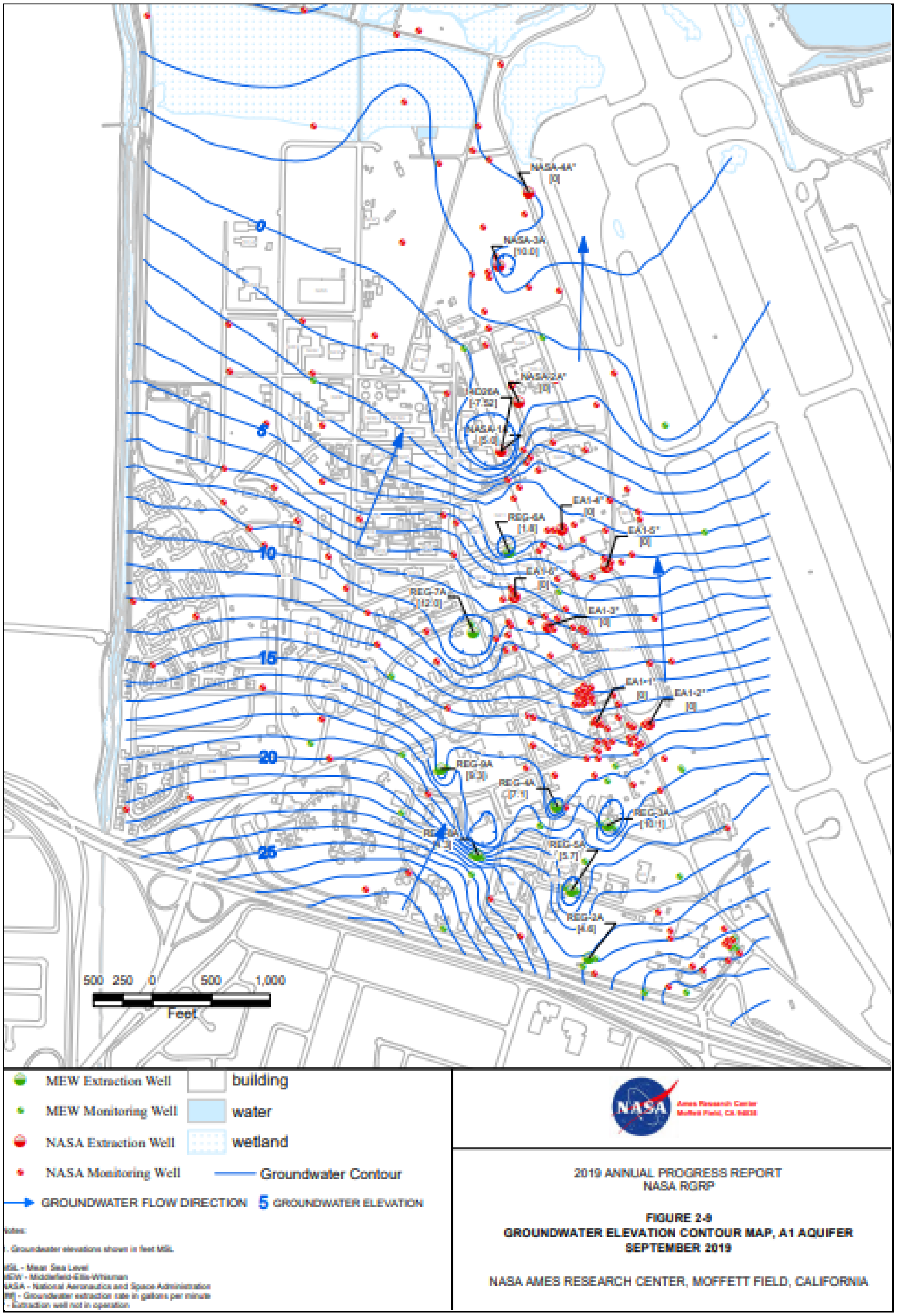


Figure 7. Though the NASA Ames Research Center and Moffett Field campus is west of the Moffett Park study area, this contour map provides a good example of the localized influence of extraction wells on the water table in the general vicinity of Moffett Park. Elevations are feet MSL. Figure from Earth Resources Technology, Inc, 2020.

The City of Sunnyvale landfill, located just north of Moffett Park, is also under an order from the Regional Water Quality Control Board to monitor and maintain groundwater quality (Regional Board, 2004). The landfill closed in 1993 and is capped from above but is not lined below. To prevent groundwater contamination, landfill leachate (water seeping through the landfill waste) is extracted in 8 locations. The extraction system intercepts leachate and prevents it from flowing into sewer pipes to the adjacent Water Pollution Control Plant, which is not equipped to treat the types of contaminants present in the leachate with its regular treatment process. Though the leachate contains VOCs, no compounds in the leachate nor the groundwater beneath the landfill exceed USEPA criteria, and all contaminants are stable or declining (Regional Board, 2004). The extraction system maintains leachate levels at about the same elevation as groundwater levels.

D. Historical & present groundwater elevations

An empirical source of information about groundwater levels that has been used in multiple regional and local assessments of groundwater conditions (May et al., 2020; Plane et al., 2019) is the Water Board's Geotracker database, which tracks groundwater quality and the depth to the groundwater table in monitoring wells at contaminated sites such as Lockheed Plant One in Sunnyvale. Figure 8 shows the minimum depth to water information (the highest groundwater table elevation) for the Moffett Park area from the Geotracker database, 2005-present. In Figure 8, the wells in the Geotracker database have been selected to display only monitoring wells measuring the shallowest aquifer that have minimum depth to water values measured during the wet season. Depth to groundwater decreases going toward the Bay and is zero (at ground surface) at the Lockheed Martin stormwater ponds where there are seasonal wetlands.

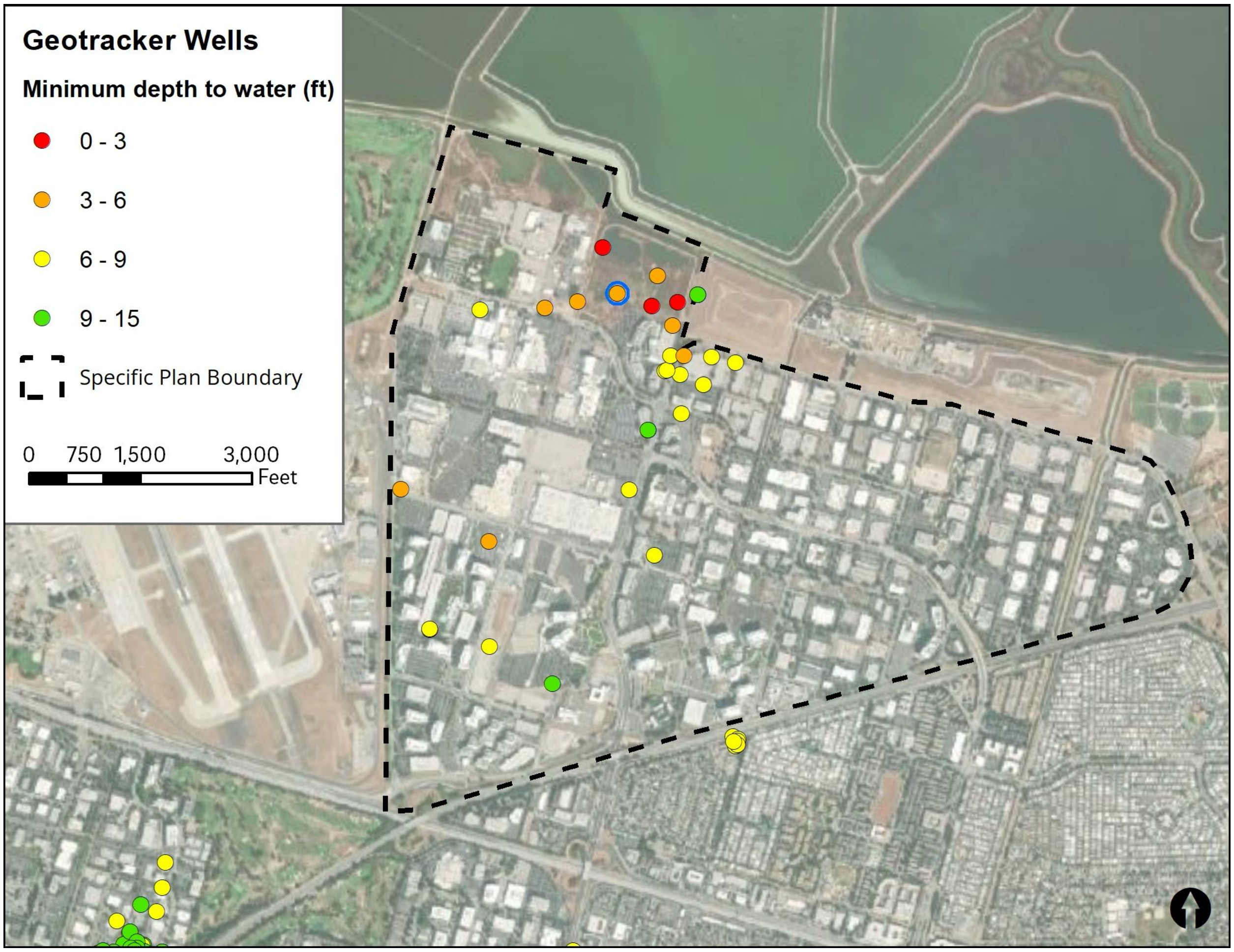


Figure 8. Minimum measured depth to water values from ground surface at Geotracker wells in the Moffett Park area. Many wells have minimum values in the 6-9 foot range. Wells near the Lockheed Martin stormwater ponds in the northwest of Moffett Park have measured depth to water values less than 6 feet. Time series data for the well circled in blue is shown in Figure 9 below.

Plotting data from individual wells over time can also provide useful insights. Though some monitoring wells have been in place since the 1980s, information is only readily available through Geotracker from 2005 onward. The time series show that most wells have a fairly stable depth to water over time, with seasonal fluctuations. See Figure 9 for a typical example. Water tables are higher in the wet season (April values in Figure 9) and lower in the dry season (October values in Figure 9. Most monitoring wells are sampled twice per year to track seasonal differences, but the highest and lowest annual water level elevations may not be captured using this infrequent monitoring approach.

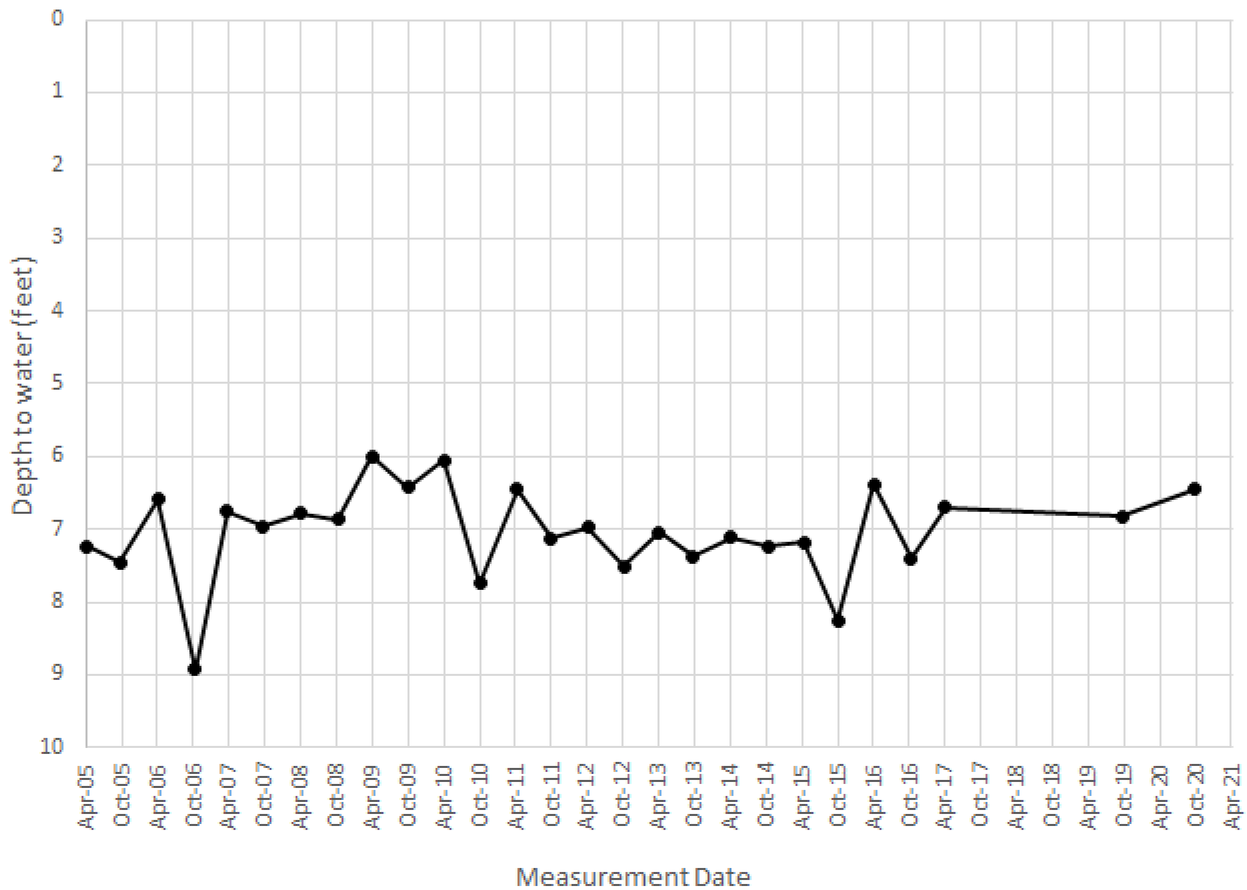


Figure 9. Depth to water over time at an example monitoring well (the well with global ID SL1821F605, field point 175-10, circled in blue in Figure 8 above). This well is located north of 1st Ave and south of the Lockheed stormwater ponds. Note shallower measurements taken in April and deeper measurements taken in October.

A recent regional analysis provides depth to water maps for the coastal communities along the San Francisco Bay shoreline (including Sunnyvale) based on Water Board Geotracker data (Plane et al., 2019) (Figure 10). The analysis used depth to water measurements from the monitoring wells in the database, tidal datums in the Bay, and a digital elevation model of the ground surface to create an interpolated existing shallow groundwater surface. The maps are based on the minimum measured depth to water values at each well between 1996 and 2016 and approximate the highest annual groundwater surface, which is likely to occur during wet winters. In Moffett Park, the shallowest depth to water values are found near the Lockheed Martin stormwater ponds and the Sunnyvale East channel. The depth to water values in Moffett Park largely fall within the 3 to 9 foot range (i.e., the existing groundwater surface is about 3 to 9 feet below the ground surface). The Plane et al. (2019) analysis only mapped areas within one kilometer of an existing monitoring well; therefore a groundwater surface was not produced for the area near the Sunnyvale East stormwater channel.

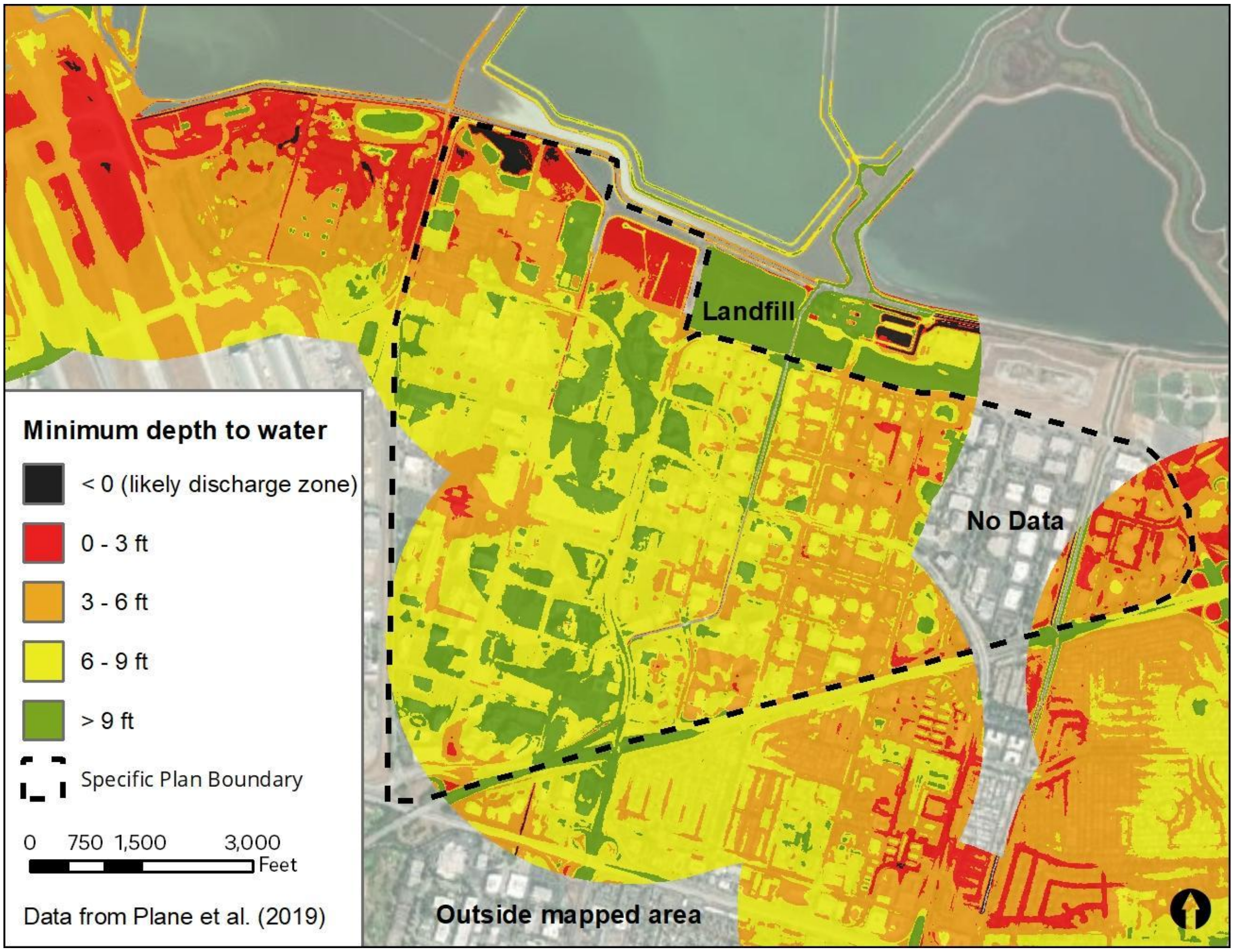


Figure 10. Estimated depth to water in Moffett Park, based on an interpolation between measured values in the Geotracker database.

Additional depth to water data sources were also reviewed. For example, the California Department of Water Resources (DWR) maintains a database of well completion reports with depth to water information, though most measurements are from 1990 or earlier. Figure 11 shows selected points from the DWR database, digitized and georeferenced to approximate locations on the map. This dataset provides additional coverage east of Lockheed Plant One, where most of the wells in the Geotracker database are located. The points from the DWR database are generally consistent with the regional mapping from Plane et al., 2019 and help validate accuracy of the interpolated groundwater surface. However, a DWR well completion report from 1982 provides a depth to water measurement west of the Lockheed extraction wells that is not consistent with the groundwater surface. It is likely that changes to ground surface elevations at this site have occurred over the past 40 years, and/or the installation and operation of the nearby Lockheed groundwater extraction system could explain the discrepancy.

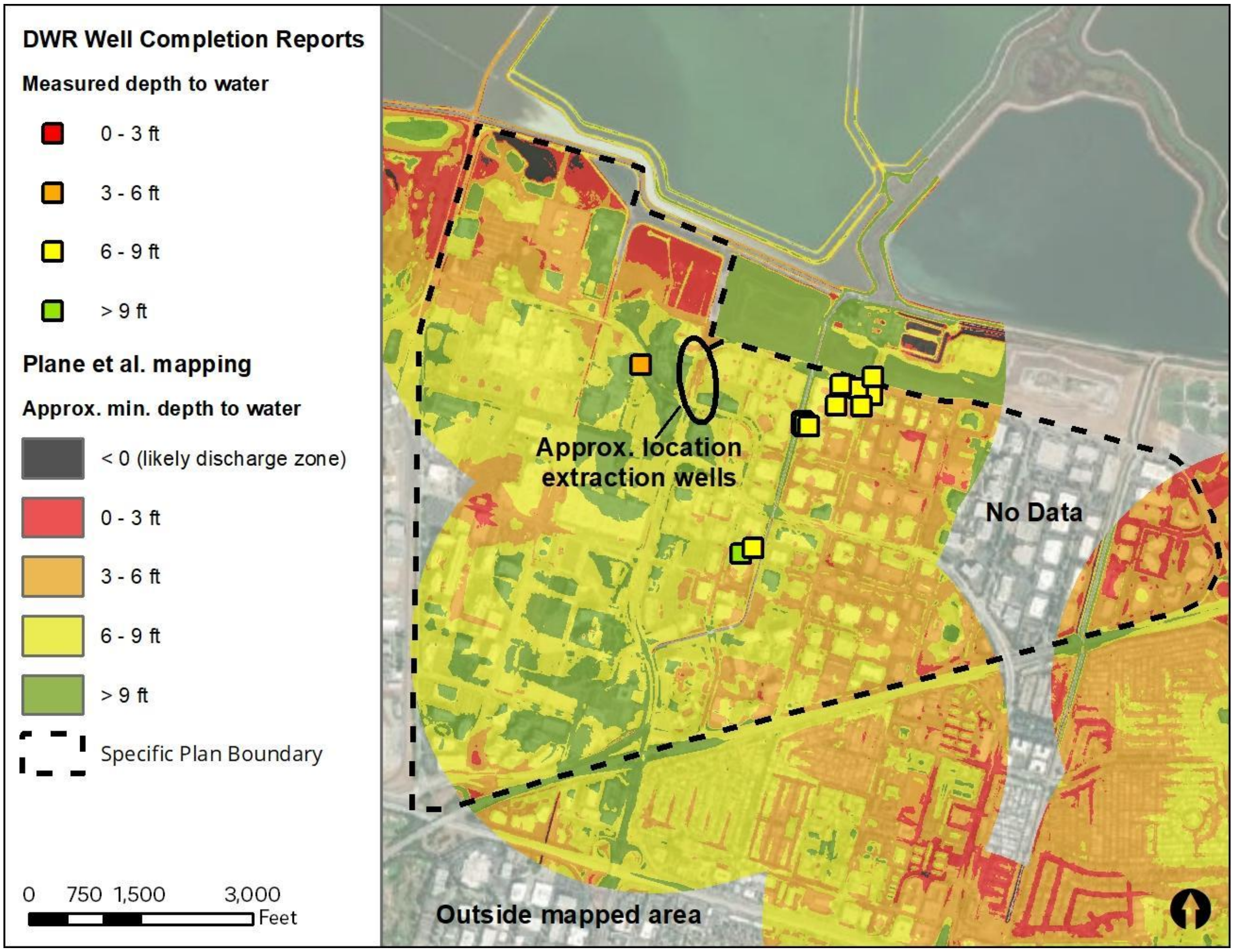


Figure 11. Depth to water information from the DWR Well Completion Reports database generally matches the mapping in Plane et al (2019).

Another way of visualizing the data is to look at groundwater elevation (relative to NAVD88) rather than depth to water (Figure 12). The mapping in Figure 12 is based on a quick interpolation of the points shown in Figure 8 (refined Geotracker dataset). Groundwater elevation maps (as opposed to depth to water) allow for examination of relative groundwater elevations across Moffett Park, especially given the building pads, landfill, and other modified topographies that are reflected in the depth to water mapping. The groundwater elevation map shows the water table elevation declining from higher elevation areas down to the shoreline. Despite the lack of data between Sunnyvale East and West channels from the Plane et al. (2019) study (Figure 11), it is expected that the groundwater elevation contours are generally consistent with the area to the west (south of the landfill and nearer Sunnyvale West Channel), and that this area likely has similar depth to groundwater conditions to the area to the west (3-6 feet depth to water).

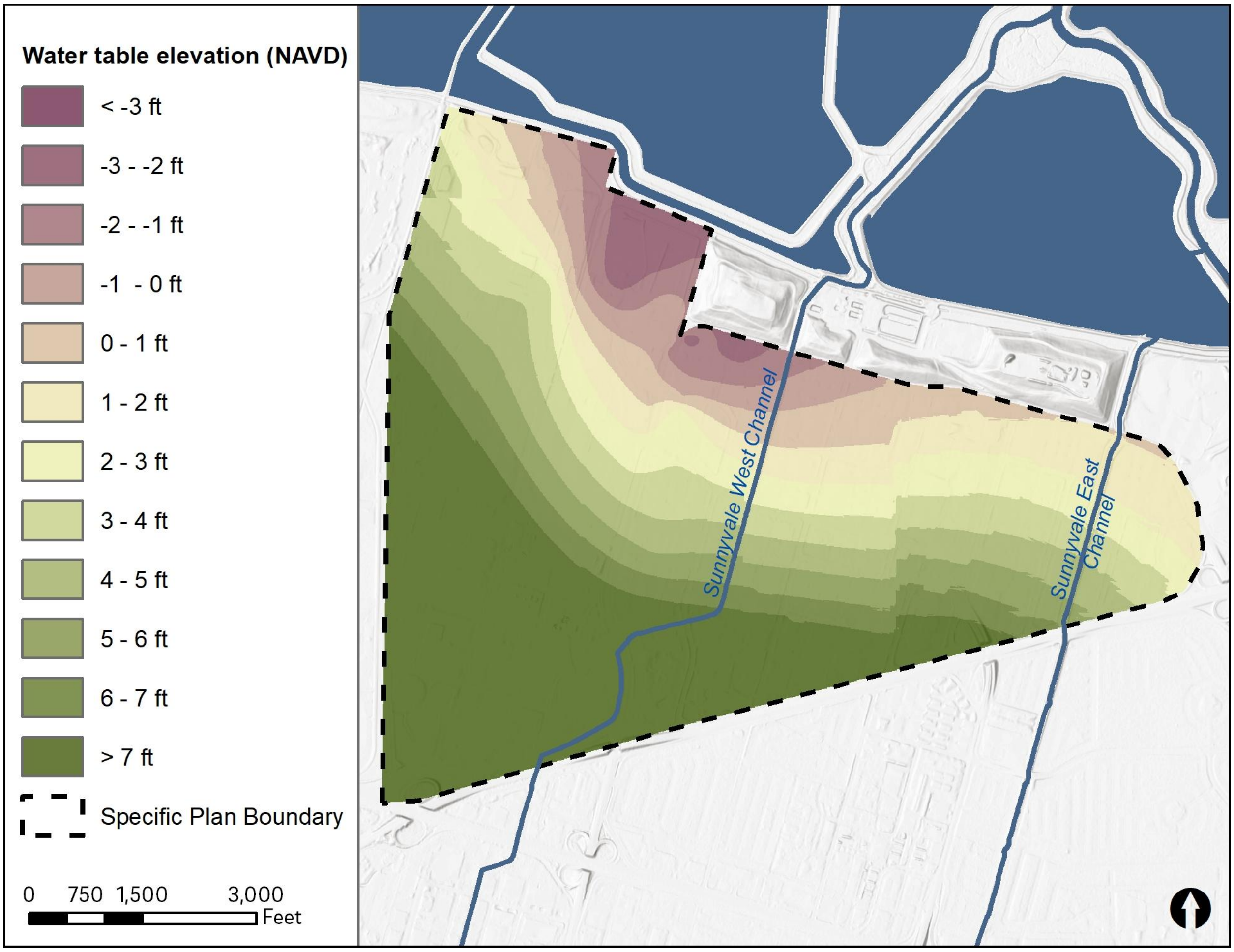


Figure 12. Groundwater elevations in Moffett Park decline going northeast toward the shoreline. Interpolation based on depth to water data from Geotracker and ground elevation data from the USGS CoNED digital elevation model. Lack of depth to water data in the eastern portion of Moffett Park means values may be less accurate in this area.

The groundwater surface can also be explored in areas where ponding water is visible above the ground surface. Based on Google Earth's historical imagery, the elevation of the water surface in the Lockheed stormwater retention ponds (northwest corner of Moffett Park) has remained at or below about 0 ft NAVD over the last decade, which is fairly consistent with measured values from nearby monitoring wells. It is not clear to what extent the stormwater management system (pumping from the adjacent channel) may be affecting water levels in the ponds. Further investigation is warranted.

E. Tidal Influence

In places where tidal fluctuations can be observed in monitoring wells, sea-level rise is likely to result in a direct rise in the groundwater surface. However, long-term rise in mean sea levels may affect the water table regardless of tidal connectivity today. Multiple studies over the years have examined groundwater elevations in and near the Moffett Park area to assess the influence of the tides on the shallow aquifer. These studies (Behrens & Gurdak, 2020; Brown and Caldwell, 1987) found that, in general, no tidal influence was measurable at the locations monitored.

A recent study conducted by Valley Water examined the change in water levels and chloride concentrations at 20 wells of varying depths, as shown in Figure 13. Only two of the wells (Wells 1 and 2) were measuring water levels associated with the shallowest aquifer (5-20 ft below ground surface) and neither well exhibited tidal fluctuations. However, two wells near the Guadalupe River (Wells 3 and 4) exhibited a tidal response, and the authors hypothesized that bridge construction activities at CA-237 had pierced the thick mud, creating a connection between the Bay and aquifer near the well locations.

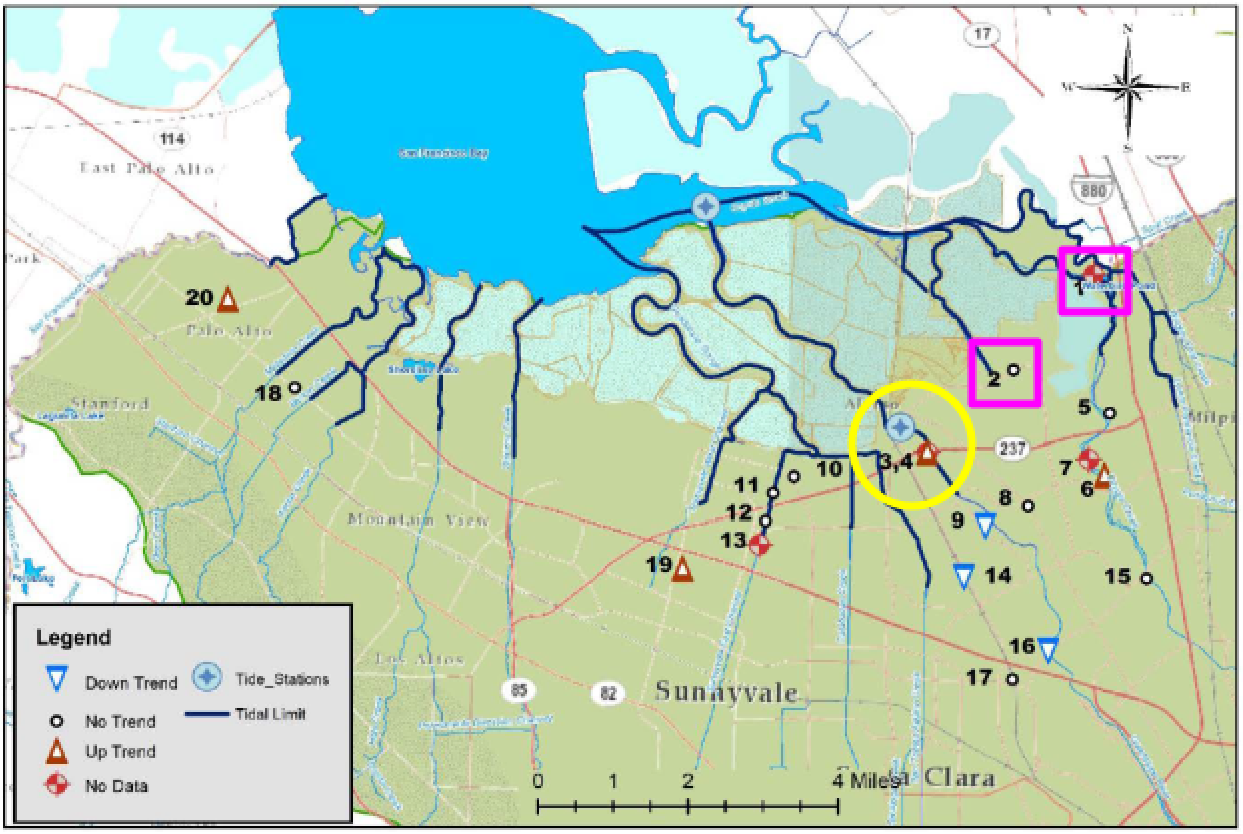


Figure 13. Wells 3 and 4, indicated by the yellow circle, showed a tidal signature. The shallower of these two wells measures the aquifer 27-32′ below ground surface and the deeper well measures the aquifer 73-78′ below ground surface. Wells 1 and 2, indicated by the pink squares, measure the shallow aquifer. Figure adapted from Behrens & Gurdak, 2020.

Due to geologic conditions (clay layers with low hydraulic conductivity), the rate of groundwater flow is likely several orders of magnitude slower than tides. Tides rise and fall twice per day in the Bay, and in the far South Bay the tides can have a range of more than 8 feet (the difference between the highest and lowest tidal elevations). However, groundwater generally moves at a very slow rate, measured in feet per year (or feet per decade) and not feet per day. Thus, tidal influence is not evident in Moffett Park's water table.

The presence of the former salt evaporation ponds bayward of Moffett Park may further mute tidal influence on the groundwater table inland of the ponds. Water levels in the former salt ponds bayward of Moffett Park are managed with hydraulic connections to the Bay. The water surface of the ponds is maintained at about mean sea level: approximately 3-4 ft NAVD (a muted tidal response may occur depending on the management of the hydraulic connections). Tidal fluctuation in groundwater levels is most likely to be seen near tidally influenced channels. This was the case in the Valley Water study referenced above (Behrens & Gurdak, 2020) (Figure 13).

Though the water table in Moffett Park is not tidally influenced today, this does not necessarily indicate that it will not be affected by changing sea levels in the future. Sea-level rise is a slow-paced (and generally monotonically rising) trend often measured in millimeters per year. This rate is more comparable and consistent with groundwater movement than tidal fluctuations, and more likely to influence a longer-term rise in the groundwater table.

4. Future change in groundwater levels

The two major climate variables that affect the elevation of the groundwater table are sea level and rainfall. According to recent projections, sea levels in San Francisco Bay are likely to rise 3.4 feet by 2100, with a rise of 6.9 feet possible (CNRA-OPC, 2018). Rainfall projections are less certain, but the frequency of extreme rainfall events is likely to increase (cal-adapt.org) and rainfall patterns are expected to become volatile with periods of extreme drought separated by more intense extreme storms (He & Gautam, 2016).

A. Modeling of future change

The regional mapping developed by Plane et al. (2019) examined the response of the shallow coastal groundwater surface to SLR using a linear rise in groundwater levels with SLR (i.e. 1 foot of SLR = 1 foot of groundwater rise). The linear approach assumes an unconfined, recharge-limited aquifer.

The shallow aquifer underlying Moffett Park is complex, with silty/clayey sands intermixed with ribbons of more impermeable clay, and portions of the aquifer may be confined at the surface. The surface-expressed groundwater in the Lockheed stormwater retention ponds currently lies several feet below mean sea level, suggesting limited connectivity between the Bay and groundwater. The area may also be somewhat topography-limited, as indicated by surface expression of groundwater in these ponds. With Moffett Park's geologic conditions and the potential for rising groundwater to be drained into the stormwater system, the linear model may not be the best fit for Moffett Park.

However, the water table is likely to respond to a rise in mean sea levels over the long term, even in areas with low hydraulic conductivity. Therefore, although it is possible that the linear approach may overestimate groundwater rise in this area, assuming a 1:1 rise of groundwater with sea level provides a useful upper bound for planning purposes.

Dynamic modeling, which accounts for groundwater recharge and discharge, can provide insights about rising groundwater that the linear model cannot. Befus et al. (2020) used MODFLOW, a US Geological Survey hydrologic model that simulates the flow of groundwater, to assess the response of the long-term equilibrium groundwater surface to SLR along the entire California coast. The modeling provides useful context about regional change in groundwater conditions due to SLR. However, the 10-meter resolution of the model does not capture the complex local stormwater drainage channel and pumping systems of Moffett Park. The model also relies on homogenous soil characteristics, with three model variations representing three soil hydraulic conductivity values. Although the model predicts topography-limited conditions for Moffett Park, the model also predicts much higher groundwater levels under existing conditions than measured values indicate. The differences between modeled values and depth to water measurements from wells throughout the area indicate that the stormwater management system and accurate hydraulic conductivity data to represent the variable soil conditions are important input datasets needed for adequate characterization of the groundwater surface of Moffett Park.

B. Factors affecting future groundwater levels

The rate of groundwater rise in Moffett Park may be reduced if rising groundwater is intercepted by the retention ponds and stormwater collection system and routed to the Lockheed Martin channel and the stormwater ditch west of Sunnyvale East Channel for pumped removal. The stormwater channels flow to pump stations, so any groundwater discharged to them will still need to be pumped out to the Bay.

Change in ground surface elevations can also affect the relative rise in groundwater levels. Ground subsidence has been largely halted in the area due to Valley Water's water import and recharge policies. Though unlikely, increased rates of subsidence in the future could decrease relative depth to water. Raising ground levels also affects depth to water. Though placement of fill does not affect groundwater elevations, it does increase depth to water by placing structures higher above the water table.

Changes to management of the ponds along the shoreline may also affect future groundwater levels. Today, berms surrounding the former salt evaporation ponds protect the Sunnyvale area from flooding and may limit tidal influence on aquifers in the Moffett Park area. Changes to the management of these ponds in the future as they are restored may affect groundwater dynamics by bringing the tides in closer to the developed areas. The impact of tidal restoration on groundwater dynamics in adjacent areas is an important question for the San Francisco Bay region that has not yet been thoroughly investigated.

Even with tidal restoration, it is unlikely that a tidal signal will be seen in shallow aquifers across Moffett Park due to the clayey soils which slow groundwater flow. Since storm surges also occur at the tidal time scale, it is unlikely that the impacts of Bay storm surge events would be seen in Moffett Park's water table. Instead, the slow upward creep of mean sea levels is more likely to drive changes in aquifer conditions. Because groundwater levels are higher in the wet season, impacts will be observed first during wet winters when the groundwater surface is at its highest.

5. Impacts

Due to existing groundwater elevations and geologic conditions, Moffett Park will not be the first place in the Bay to experience severe impacts from rising groundwater. However, given the low ground elevations, the stormwater system's dependence on pumping, potential impacts to the wastewater system, and several contaminated sites in the area, it is important to consider impacts that may need to be addressed to keep the area safe and infrastructure functional as the climate changes. Monitoring and modeling can help pinpoint the onset and magnitude of future risks as the state of knowledge about this climate impact evolves (see Chapter 7), and adaptation strategies are implemented to mitigate impacts (see Chapter 6).

The following list outlines some of the impacts of rising groundwater that may affect Moffett Park as sea levels rise.

- **Corrosion.** Groundwater rise is caused by a toe of saline groundwater intruding farther inland. Near the shoreline, groundwater may become more saline as a result of SLR. A recent Valley Water study found an increasing trend in groundwater salinity over the last 15 years in several of the wells that were measured. This was especially true for wells nearer the Bay (Behrens & Gurdak, 2020). Increasing salinity can increase potential for corrosion of subsurface infrastructure.

- **Buoyancy.** Rising groundwater can exert buoyant forces on foundations, buried utility lines, pipes, roads, and other infrastructure, causing these structures to float or shift.

- **Seepage.** Subsurface structures can be subject to flooding via groundwater seepage through permeable places in the walls and floor.

- **Infiltration.** Groundwater can enter stormwater and sanitary sewer pipes through cracks and joints. Many wastewater agencies already manage this impact today, but flows are likely to increase with rising groundwater levels. Infiltration into sewer pipes can slightly lower groundwater levels in adjacent areas, but also has the effect of reducing capacity for stormwater and/or sanitary sewer flows and potentially causing backups in the system.

- **Liquefaction.** Higher water tables can increase liquefaction risk during an earthquake. Witter et al. (2006) assigned liquefaction susceptibility categories to geologic deposits around the Bay partly as a function of groundwater depth within the deposit. Moffett Park's liquefaction risk today is rated as "moderate," already accounting for the high water tables in this area. Areas primarily composed of mud are unlikely to liquify; the hazard is more severe in areas of artificial fill and areas with alluvial sand lenses. Given the level of damage associated with liquefaction events, it is worth considering the potential for increased risk from rising groundwater levels and designing new structures accordingly.

- **Damage to vegetation.** Saturated soils and higher salinity levels can damage plants that are not adapted to these conditions.
- **Contaminant mobilization.** SLR may affect the movement of contaminated groundwater plumes. Existing remediation sites at the NASA Moffett Field and Lockheed Martin campuses, as well as the Sunnyvale landfill, will need to address the impacts of changing groundwater conditions on their operations. So far, the groundwater extraction and treatment systems have been effective at containing groundwater plumes, but SLR may mean modifications are required for managing contaminated groundwater. Facility managers and regulatory agencies will need to work together to address this adaptation challenge.
- **Emergence flooding.** Across much of Moffett Park, depth to water is 3-6 feet, and in many places groundwater is deeper than 6 feet below ground surface. Therefore, emergence flooding is unlikely to be a concern in the near future: subsurface impacts will be seen sooner. Flooding as a result of rising groundwater may first be seen during storm events in wet winters. As average water table elevations increase, groundwater may seep into channels, increasing base flow and decreasing channel capacity, so that when storms occur there may be reduced capacity to convey stormwater. When SLR exceeds three feet or more (likely toward the end of the century, but possible as early as 2070), emergence flooding may become a regular occurrence if adaptation strategies are not implemented.

6. Adaptation strategies

Multiple approaches can be used to address the risk of rising groundwater, including strategies to accommodate more water in the urban landscape, improve the existing drainage system, make structures more resilient, and reduce groundwater levels at the site and district scales. Other Bayfront cities that are already grappling with the impacts of rising groundwater are actively implementing adaptation strategies to reduce future damage. For example, Palo Alto has expanded the types of projects that require geotechnical investigation to ensure that designs adequately account for water table elevations today and in the future. In Alameda, trenches for utility lines are being over-excavated and filled with crushed rock in areas where high water tables are impacting pipelines, as well as in areas where groundwater is anticipated to rise and impact pipelines in the future.

The strategies described in this chapter provide a framework for the types of adaptation actions that could be implemented to manage changing groundwater conditions in Moffett Park. A combination of these strategies may be necessary, with larger-scale strategies employed toward the latter half of the century as the rise in sea levels approaches three feet and beyond. Some strategies will be easier to implement during the redevelopment process, and should be considered in design guidelines.

A. Add three feet to groundwater design levels

For many of the impacts listed in the previous section, adaptive design strategies already exist. Geotechnical investigations of existing groundwater levels and soil corrosion potential are required by the California Building Code, which is adopted by the City of Sunnyvale's code. When indicated by geotechnical investigations, building design strategies are used today to mitigate many of the impacts listed in the previous section. Examples include corrosion-resistant materials, wall and foundation designs that resist lateral and uplift pressure from shallow groundwater, drain tile and sump pumps to manage seepage, foundations designed for possible liquefaction, and waterproofing of belowground electrical lines.

When geotechnical investigations are conducted, a design groundwater level is recommended based on historical maximum groundwater conditions. Given that historical conditions are no longer a reliable predictor of future groundwater levels, it is advisable to consider a higher design level that is more representative of projected future conditions. This is true for structures of all types, including those constructed at and below grade, as well as utility trenches, roadbeds, etc. For example, in the case of possible future undergrounding of power lines at the Sunnyvale East Channel, higher future groundwater levels should be considered in the design process.

The Moffett Park Specific Plan's SLR strategy targets improved flood protection for up to three feet of SLR, providing about a 50-year buffer as sea levels are not projected to rise three feet until 2070 or later (ESA & SFEI, 2020). Adding three feet to the historical maximum groundwater level as a design guideline is a conservative strategy for the 50-year planning horizon (see Chapter 4). Though designing for higher groundwater levels could increase construction costs, it may be cheaper to design with a factor of safety than repair damages later. In addition to designing for higher groundwater levels, it is advisable to plan for more saline groundwater conditions than the current levels, using waterproof and/or corrosion-resistant materials below the design level.

Many wastewater facilities already have subsurface structures and use adaptive below-grade design techniques as they are frequently located near the Bay in areas with shallow groundwater. A recent geotechnical investigation for the upgrades at the Sunnyvale Water Pollution Control Plant provides a useful example, as there are proposed below-grade structures that will need to be constructed below groundwater levels (Fugro Consultants, Inc., 2016). Geotechnical studies provide guidance on engineering, dewatering for construction, and other considerations for design and building in areas with shallow groundwater.

B. Account for higher groundwater levels in stormwater system upgrades

An overhaul of the stormwater system would improve the City of Sunnyvale's ability to manage combined flooding by increasing capacity for water entering developed areas from rainfall, overtopping, and groundwater. Stormwater system upgrades should take into account higher groundwater levels in addition to higher sea levels and the potential for more intense rainfall events. Pump station capacity may need to be improved, especially as increased infiltration to the stormwater system adds to baseline pumping requirements.

In other urban areas along the SF Bay shoreline, like Redwood Shores, Alameda, Bay Farm Island, and Foster City, groundwater already drains from developed areas to constructed channels and from there to pump stations. Ditches in Moffett Park likely already drain some groundwater to pump stations, and flows of groundwater in the stormwater system will likely increase as sea levels rise. One adaptation strategy could be to take advantage of natural discharge (exfiltration from groundwater into channels due to topographic limitation) by expanding capacity of surface channels and/or increasing the density of channels. Preserving open space adjacent to existing channels increases flexibility for future modifications to increase channel capacity for groundwater flows in addition to stormwater runoff. New channels could be added in areas with the shallowest groundwater to help convey flows to pump stations. Due to the discontinuous aquifer system, effects of this adaptation strategy are likely to be localized to the area around each channel, rather than felt at the district scale. However, if the channel collection system focuses on the north side of the district, between the district and the Bay, it may be better positioned to attenuate the effects of SLR in the Bay on the rest of the district.

The low hydraulic conductivity of Moffett Park's soils may mean it is more feasible here than in other places to use pumping as a technique to stay ahead of rising groundwater levels. French drains could be used to direct shallow groundwater away from sensitive infrastructure to basins and/or channels. When groundwater levels are lower, the channels and basins may be dry. During the wet season they would fill with groundwater, acting as detention basins. Pumps could remove water from the channels, creating a positive pressure gradient to wick groundwater from the developed areas. This system would also allow for easy monitoring of groundwater levels.

C. Site open spaces to allow more groundwater and stormwater detention

Groundwater is shallowest (emergent) in Moffett Park at the Lockheed Martin stormwater ponds. Protecting open space around this area and allowing more room for stormwater and groundwater detention in the future is advisable. In addition to protecting open space along the Sunnyvale East Channel and stormwater ditch (Figure 14), it may also be advisable to protect more open spaces in the eastern portion of Moffett Park and in the adjacent area east of the Moffett Park Specific Plan boundary, with depressions designed as seasonal detention ponds for groundwater and stormwater. Siting public green spaces in low-elevation areas and designing them to accommodate temporary or seasonal floodwaters can increase their function as multi-benefit spaces. Connecting these spaces to one another and to the stormwater system could allow more flexibility of use over the long term as environmental conditions change.

Figure 14. Stormwater channels, pumps, and ponds in Moffett Park (MPSP study area shown with a dashed line).

D. Encourage site-scale designs that accommodate higher groundwater levels

In addition to district-scale interventions for siting stormwater detention and riparian open spaces, it is also possible to implement parcel-scale interventions to increase resilience to rising groundwater. In areas that will require a great deal of fill material to meet required finished floor elevations, it may be possible to use cut-and-fill strategies to create on-site detention and/or retention ponds and generate fill for building pads in the process. One emerging creative design strategy is to build floating or pile-supported structures on the resulting artificial ponds, allowing more space for water in the urban environment (see Hill & Henderson 2021 for details and diagrams of floating structures). Raising finished floor elevations with fill is an effective strategy to reduce vulnerability to rising groundwater, but it can be costly and material is limited. Using local fill material can decrease construction costs and free up material for the region to use in other critical SLR adaptation projects.

When green stormwater infrastructure is used to reduce stormwater runoff volume and pollutants entering storm drains, ensure that interventions are designed with rising groundwater in mind. Green infrastructure designed to current groundwater levels may not function as well when groundwater rises nearer to the ground surface. Underdrains connected to the stormwater system can help ensure green infrastructure installations continue to function even if rising groundwater levels slow infiltration rates.

The planting palette used in landscaped areas can also be designed with groundwater conditions in mind. In places where groundwater is well below the ground surface, it is best to use drought-tolerant plants that require less water. In places where groundwater is near the surface, use plant species adapted to wet conditions with higher salinity (refer to the plant palettes included in the MPSP Urban Ecology Technical Report, Appendix C) (SFEI, 2020).

F. Encourage consideration of SLR in groundwater remediation plans

Though mobilization of buried contaminants by rising groundwater may be an issue in many places, not just in Moffett Park, no comprehensive strategies currently exist for the Bay Area or California to assess, and if necessary, to address this potential threat. Changes to remediation strategies at individual sites may be required to ensure public safety if groundwater levels rise and cause contaminants to spread to new locations. The City of Sunnyvale can coordinate with regulatory agencies like the Department of Toxic Substances Control and the Regional Water Quality Control Board to encourage the consideration of SLR and rising groundwater in updates to remediation plans and requirements for contaminated sites and landfills.

G. Install a cutoff wall

A longer term strategy (i.e. beyond three feet of SLR) could be to install a cutoff wall or seepage barrier to reduce connectivity between Bay water levels and groundwater in Moffett Park. More study and engineering would be required to determine the potential effectiveness of this strategy, the locations where a cutoff wall would be useful, and the depth of the barrier that would be required. One option may be co-locating the cutoff wall with the proposed shoreline levee improvements. This strategy may not be the most practical solution because in addition to preventing flows coming in, it prevents groundwater flow outward to the Bay, interrupting natural dynamics and trapping more groundwater inland of the barrier that needs to be managed. However, since Moffett Park already has groundwater levels lower than mean sea level and a stormwater system to discharge water to the Bay, the stormwater system provides the foundation for managing water on the landward side of a cutoff wall. Exploration of the utility and feasibility of barrier installation would require further study of groundwater flow paths with dynamic modeling.

7. Data needs and potential next steps

This technical memorandum outlines existing knowledge about groundwater conditions in Moffett Park. However, the information presented here is incomplete. There is less information about groundwater levels on the east side of Moffett Park than the west side, where there is a wealth of information from monitoring wells at Lockheed Plant One. It is still unclear where the individual aquifers are connected to one another, to channels and ponds, and to the Bay. Groundwater levels along the shoreline today are below mean sea level, and further investigation is needed to better understand the factors causing this condition. Future studies, including implementation of a long-term monitoring strategy, could better calibrate and validate models, and inform the design of stormwater and groundwater management upgrades.

A valuable near-term investment would be to track groundwater levels over time in the area where there is no long-term tracking of groundwater levels: the east side of Moffett Park. Figure 15 shows approximate locations for groundwater monitoring that would help create a more complete picture of groundwater conditions in Moffett Park.

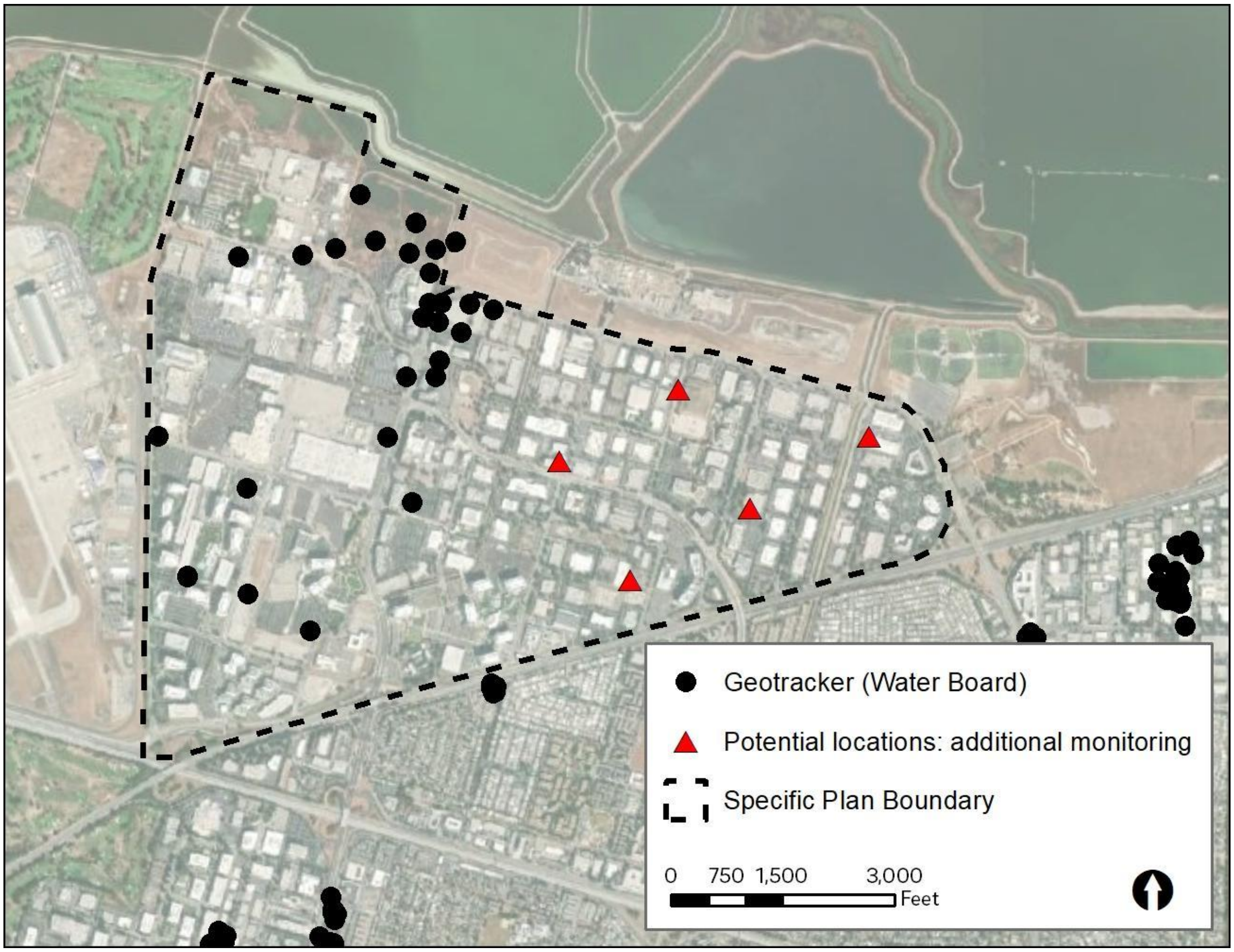


Figure 15. Adding monitoring locations east of the Lockheed monitoring wells could help create a more comprehensive dataset of groundwater conditions.

It may not be necessary to bore new wells to do this monitoring if levels in existing wells can be measured more frequently. According to Valley Water's well database, there are many existing monitoring wells in this area. There are about 40 wells in the database on the east side of Moffett Park that measure the shallow aquifer (total depth ≤ 45 ft) and are listed as "active", though the depth of the screened intervals, the condition, and the accessibility of these wells is unclear (Figure 16). Groundwater monitoring data is not collected, or at least not posted, for any of these wells except one. Data for this well, located adjacent to the Sunnyvale East Channel, is collected once per year in the dry season. Data from the monitoring wells at the landfill could also be leveraged to help better understand groundwater conditions along the shoreline north of Moffett Park.

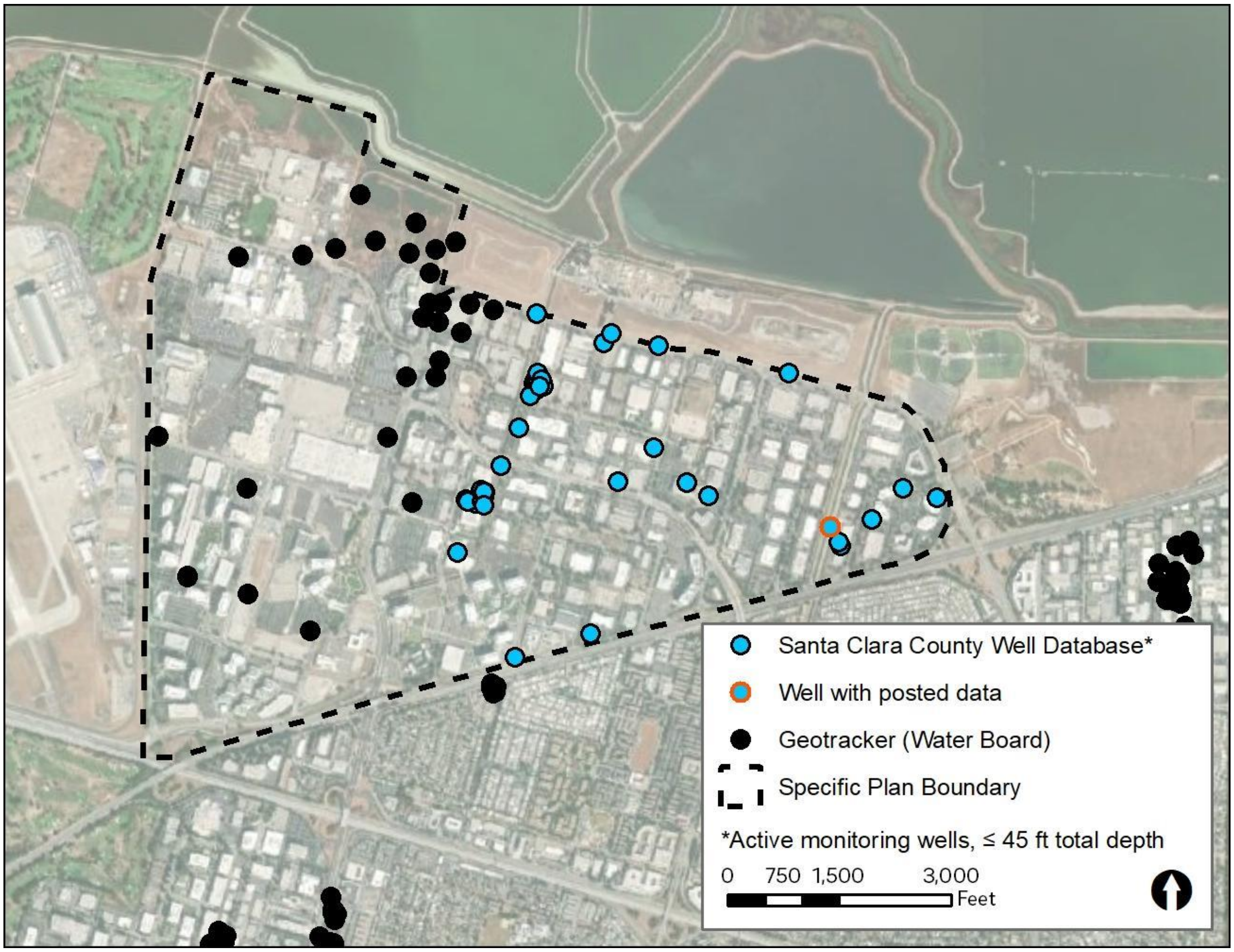


Figure 16. There are about 40 wells in the data gap area east of the Lockheed Martin monitoring wells that could be monitored more frequently for depth to water conditions.

Both short- and long-term monitoring of groundwater levels in the shallow aquifer of interest (<10 ft depth) would provide useful tools for adaptive management and decision making. Table 1 outlines major management questions, the hydrologic questions that could help answer them, and the data that would be needed to address the hydrologic questions.

Table 1. Management questions that need to be answered to inform planning, along with associated hydrologic questions and data needs.

Management Questions	Hydrologic Questions	Data Needs
• What is the range of groundwater levels over a year? Will they impact development? • How will groundwater levels change over time? Will they impact development in the future? • What groundwater levels should be used for structure and stormwater system design?	• What soil types and hydraulic conductivities are present in Moffett Park? How interconnected is the shallow aquifer in Moffett Park? Where is it interconnected?	• Soil and hydraulic conductivity mapping • Depth to water and salinity data collected simultaneously hourly at multiple monitoring wells over a period of one year.
	• What is the seasonal variability in the water table and how do intense rainfall events affect groundwater conditions?	• Monthly measurements over a period of years.
	• How will long-term SLR impact groundwater levels in Moffett Park?	• Monthly averaged measurements over a period of years, filtered to remove seasonality.

Implementing a groundwater monitoring plan, using either new or existing wells, could help provide valuable data for Moffett Park. If the data collected is highly variable across wells, it may be valuable to add more wells to gain a finer-resolution dataset. As described in Table 1, different frequencies of measurement are required to answer different questions, but all of the questions require more frequent data collection than once or twice a year, which is the current practice.

High-frequency monitoring (hourly) requires use of data loggers, which measure depth to water, or depth to water and salinity. The data loggers can be periodically downloaded or connected via the cell network to automatically transmit data. Data loggers collect water elevation data using pressure transducers, which require a separate barometric correction sensor, and measure salinity using a proxy of conductivity. One barometric correction sensor would suffice to cover the whole MPSP area. Data loggers could be strategically placed for a period of intensive monitoring at 5 to 10 wells across Moffett Park. The monitoring frequency could then be scaled back, and depth to water and salinity data could be collected either by manual measurement or data logger on a monthly basis.

A key to understanding existing and future groundwater levels and flow patterns in Moffett Park will be development of a 3D subsurface map of soil type and associated hydraulic conductivity. This map would be an essential input to future groundwater models, as an important variable in hydrogeologic modeling is hydraulic conductivity, which describes the rate of groundwater flow through pore spaces. Hydraulic conductivity varies between geologic types: clay substrates have lower hydraulic conductivity, and sand substrates have higher hydraulic conductivity. With Moffett Park's heterogeneous soil types, mapping will be required to refine the inputs to a future groundwater model.

Local-scale dynamic modeling will be useful when designing future changes to Sunnyvale's drainage system, including changes to help manage rising groundwater. When designing upgrades to the system, understanding how adaptation strategies will affect flow patterns will be essential. Groundwater flow and transport models like MODFLOW can help elucidate these dynamic processes. Coupled surface-groundwater flood modeling that considers rainfall hydrology, the stormwater system, groundwater, and potentially coastal flooding, will be required to make informed decisions about the hazards and to design improvements for an integrated stormwater and groundwater management system.

Partnerships will be essential going forward to ensure streamlined data collection, analysis, and communication of results. Valley Water is responsible for managing groundwater in Santa Clara County. Under the California Sustainable Groundwater Management Act (SGMA), Valley Water's groundwater management plan must be updated every five years. Valley Water is currently in the process of updating the groundwater management plan for 2021. While the primary focus of the work is on deeper water supply aquifers, shallow groundwater is also relevant to the plan and coordination on development of future monitoring plans may be in the mutual interest of both Valley Water and the City of Sunnyvale. Rising groundwater is also an area of growing research interest more broadly. Connections with academic institutions can be leveraged to get students involved in monitoring and modeling efforts, providing an educational opportunity for emerging researchers and bringing in scientific expertise.

Setting up a monitoring plan is a near-term action that would help Moffett Park start to increase resilience to rising groundwater. Better data can feed into more accurate models, which will help engineers create more successful adaptation strategies in the future. Coordinating with partners to develop a monitoring plan can set the foundation for collaborative development of adaptation strategies over the longer term.

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Sunnyvale Shoreline Resilience Vision

Technical Memorandum: Stormwater Management

San Tomas Aquino Creek, with Pond A8S and Pond A4 in the distance. Photo by Scott Dusterhoff, SFEI

Version 2

Prepared by SFEI and ESA
May 2021

Contents

1. Introduction

The purpose of this memo is to explore opportunities to improve stormwater management in the Moffett Park area of the City of Sunnyvale, particularly in the context of planned flood management and restoration changes along the shoreline. Stormwater plans for the area could be shared with the US Army Corps of Engineers for use in Phase III of the South San Francisco Bay Shoreline Study. Potential objectives to explore include increasing capacity to reduce flood risks, simplifying complex plumbing, discharging cleaner water to the Bay, supporting habitat restoration, improving public access, and reusing fill material in existing berms to construct new levees. Opportunities could include straightening stormwater channels to discharge more directly to the Bay, reducing the need for conveying and pumping stormwater along the shoreline, increasing detention capacity close to the Bay, and improving the quality of stormwater before it is discharged to the Bay.

Currently, a system of catch basins, pipes, detention ponds, channels, and pump stations along the Sunnyvale shoreline is used to manage stormwater. This region's topography is relatively flat, sloping down from south to north, with the lowest elevations along the shoreline, adjacent to the former salt ponds. Stormwater is first routed northwards through stormwater pipes and then lifted into the downstream end of the stormwater channels, such as East and West Sunnyvale channels, via pump stations. Some of the stormwater is detained in detention ponds along the shoreline before being pumped into the channels. Over the next couple of decades, there is likely to be significant restoration of marshes in the former salt ponds and the construction of a flood management levee between Stevens and Calabazas Creek.

On February 4, 2021, a technical workshop was held to discuss Sunnyvale's existing stormwater system and brainstorm desired improvements (Figure 1). Attendees included representatives from each key stakeholder organization in the Sunnyvale Shoreline Resilience Vision group: Valley Water, Google, City of Sunnyvale, NASA, Lockheed Martin, South Bay Salt Pond Restoration Project/US Fish and Wildlife Service, and the Midpeninsula Regional Open Space District. This document memorializes that conversation, including common goals & objectives, information on existing stormwater systems, and stormwater strategies that could be integrated with the shoreline levee and marsh restoration projects.

Figure 1. Collaborative whiteboard from stormwater workshop.

2. Hydrologic Setting

There are three potential sources of flooding for the Sunnyvale shoreline area: coastal flooding due to levee overtopping or failure, riverine flooding due to levee overtopping or failure, and internal flooding due to precipitation which the stormwater system does not adequately convey to the Bay (Figures 2 and 3). Existing berms built for salt production have protected the City of Sunnyvale and NASA Ames campus from coastal flooding and have never failed in the past, but they are not FEMA-accredited and not designed for future sea level rise. The Shoreline Project, a joint effort between Valley Water, Coastal Conservancy, and the US Army Corps of Engineers, is planning, designing, and constructing a shoreline levee to replace the protection provided by the salt pond berms. After the coastal levee is constructed and the Sunnyvale East and West channel upgrades are completed, internal flooding from insufficient stormwater capacity will be the primary remaining flood risk for the area.

Figure 4 shows a simplified overview of Sunnyvale's interconnected stormwater system. Detailed information about each drainage area is provided in Section 5.

Figure 2. The existing flood risk areas for a 1% flood event from FEMA's effective map, including riverine, interior, and coastal flood risks (assume levee failure).

Figure 3. Residual flood risk in Moffett Park after construction of a shoreline flood risk management levee and completion of Sunnyvale East and West channel upgrades.

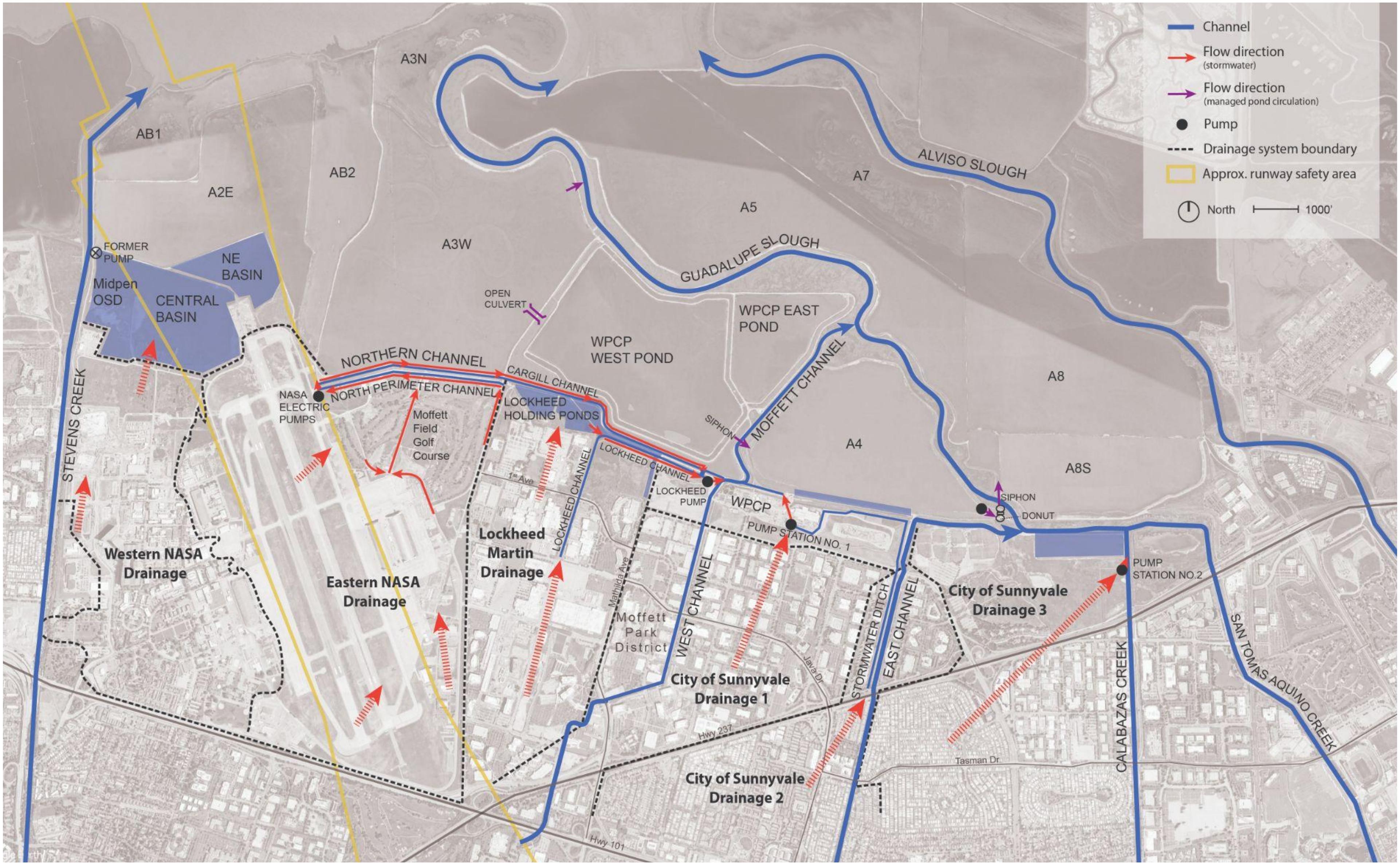


Figure 4. Diagram of Sunnyvale's existing stormwater system

USFWS Managed Ponds

The US Fish & Wildlife Service, managers for the Don Edwards National Wildlife Refuge, and South Bay Salt Pond Restoration Project (a joint effort of the US Fish & Wildlife Service, the California Coastal Conservancy, and the California Department of Fish & Wildlife) are moving forward with restoring tidal influence in Pond A5-Pond A8 complex and reconnecting Calabazas Creek to Pond A8S (Figure 4). This concept could be extended to the Moffett Ponds to the west. USFWS is currently consolidating the Pond AB1-A3W complex into two ponds by breaching internal berms and shoring up outer berms. These will remain in their current condition as managed ponds for the foreseeable future (at least 25 years).

A complex circulation system is used to maintain salinity and dissolved oxygen levels for wildlife in the ponds north of Sunnyvale. Bay water is brought into Pond A2E from a gate in the northern berm. Water then cycles through the pond system to Pond A3W before discharging to Guadalupe Slough. The Cargill Channel is connected to Pond A3W with an open culvert and to Pond A4 with a siphon; water is pumped from the Cargill Channel into Pond A4 to manage salinity levels. The Pond A4 pumps are operated by Valley Water and are run almost continuously to keep salinity levels in Pond A4 from getting too high. When water levels in Pond A4 drop, water flows by gravity from Pond A3W through the Cargill Channel to Pond A4. Water from Pond A4 is pumped to a 'donut' and then siphoned north to Pond A8, bypassing Guadalupe Slough.

3. Relevance to Shoreline Project

The alignment and design of a future flood risk management levee between Stevens and Calabazas Creeks will need to accommodate the stormwater system. The construction of a new levee and the restoration of some of the ponds may offer opportunities to update the conveyance and storage of stormwater along the shoreline to reduce the residual risk after construction. In addition, the developed areas inboard of the levee will not be removed from the FEMA Special Flood Hazard Area (SFHA) unless the stormwater system meets FEMA accreditation standards for interior drainage.

The present stormwater infrastructure routes discharges around the former salt ponds. With the 2004 acquisition of these ponds by the USFWS for inclusion in the Don Edwards National Wildlife Refuge as wetlands habitat, there may be opportunities to simplify the stormwater system. In particular, restoration of some ponds to tidal marsh offers the potential to reduce east-west conveyance channels and discharge more directly to the Bay at new locations along the levee alignment. In addition, there may be opportunities for more stormwater polishing and detention in nature-based features such as wetlands.

The presence of stormwater infrastructure, such as open water channels and ponds, adjacent to the levee alignment could constrain the design of the new levee. For example:

- The present alignment of stormwater channels, particularly those running east-west, leaves little space for a new levee.
- Levees whose primary purpose is to furnish flood protection from seasonal high water are subject to water loading for periods of only a few days or weeks a year. Embankments that are subject to water loading for prolonged periods or permanently will be designed to different criteria (USACE 2000)[1].
- FEMA O&M requirements require visual inspection of the inboard toe, which is obstructed if there is a water channel along the inboard toe.

At the stormwater workshop, opportunities for improving stormwater management to take advantage of planned changes to the shoreline were explored. Of particular interest are stormwater plans for the area that could be shared with the US Army Corps of Engineers.

4. Stormwater Improvement Objectives

The group discussed potential objectives for improving the stormwater system. Objectives outlined were:

1) reduce residual flood risks following construction of the new East and West Sunnyvale channels and construction of a new Shoreline levee (Figures 2 and 3);

2) simplify complex plumbing and provide more space for a new levee alignment;

3) discharge cleaner water to the Bay more directly;

4) support habitat restoration; and,

5) improve public access.

5. Existing Conditions in Stormwater Drainage Areas

Between Stevens Creek and Calabazas Creek, there are six drainage areas that collect and convey stormwater to the shoreline; two on the NASA Ames Research Center campus, one on the Lockheed Martin campus, and three in the City of Sunnyvale.

[1] USACE 2000. Design and Construction of Levees. Engineer Manual EM 1110-2-1913.

NASA Ames Western Drainage Area

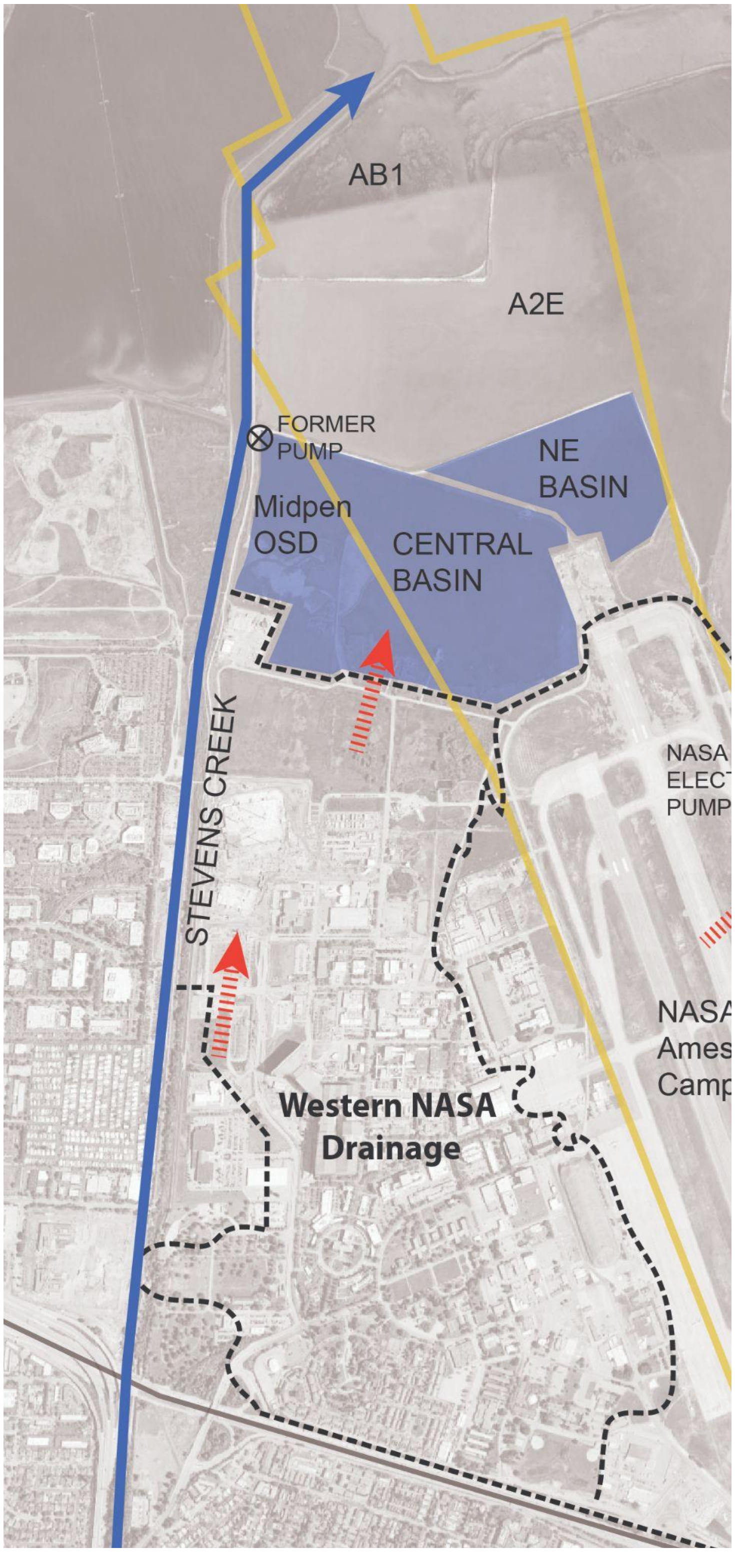


Figure 5. Diagram of existing stormwater management system for the NASA Western Drainage.

The western drainage area of the NASA Ames Research Center flows by gravity to the north into two basins: the Central and Northeast Basins (Figure 5). The western portion of the Central Basin is owned by the Midpeninsula Regional Open Space District and is known as the Stevens Creek Shoreline Nature Study Area. It is functionally a part of NASA's stormwater system; there is no berm separating it from the rest of the Central Basin.

Stormwater flows by gravity to the Central and Northeast Basins, where it is detained and evaporates. Historically stormwater was pumped occasionally from the Central Basin to Stevens Creek during particularly wet winters. This discharge to the creek, using a pump in the northwest corner of the MROSD property, was a holdover from when the Navy managed the property. NASA did not have a permanent permit to discharge from this location and received temporary discharge permits from the Water Board. The pump was removed in 2005. Flows into both the Central and Northeast basins have increased because of groundwater discharging to the same location.

NASA Ames Eastern Drainage Area

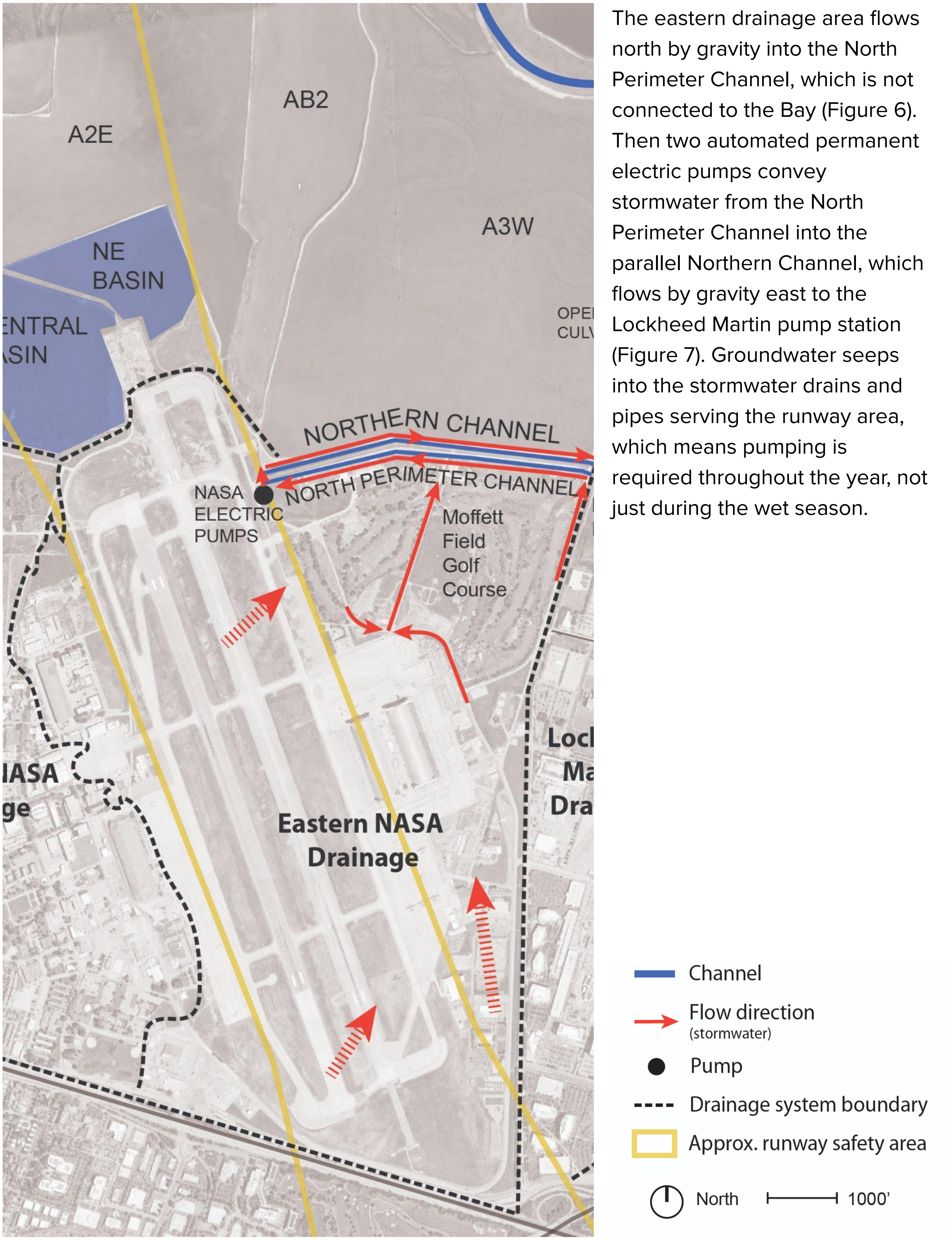


Figure 6. Diagram of existing stormwater management system for the NASA Eastern Drainage.

The eastern drainage area flows north by gravity into the North Perimeter Channel, which is not connected to the Bay (Figure 6). Then two automated permanent electric pumps convey stormwater from the North Perimeter Channel into the parallel Northern Channel, which flows by gravity east to the Lockheed Martin pump station (Figure 7). Groundwater seeps into the stormwater drains and pipes serving the runway area, which means pumping is required throughout the year, not just during the wet season.

Lockheed Martin Drainage Area

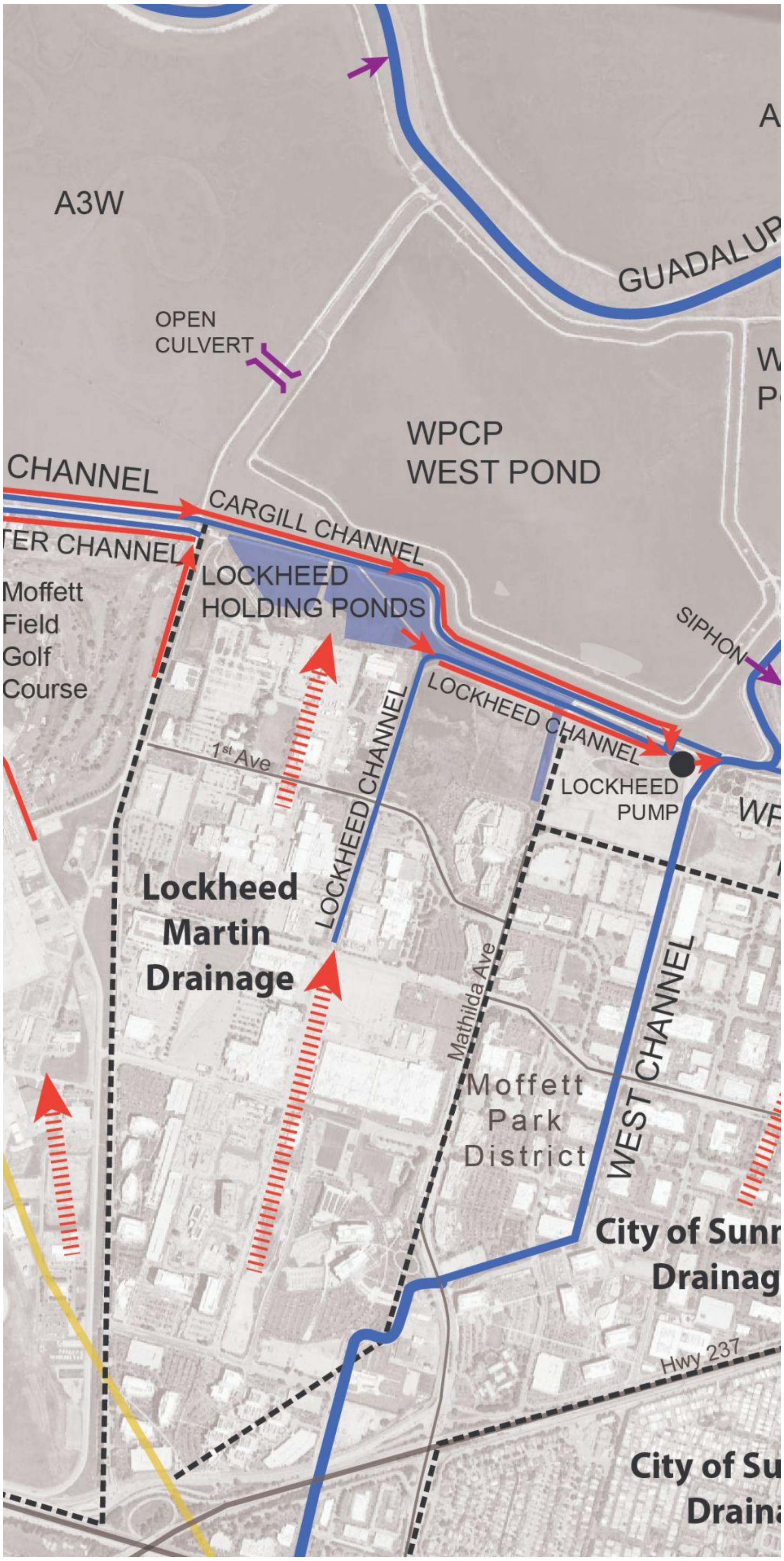
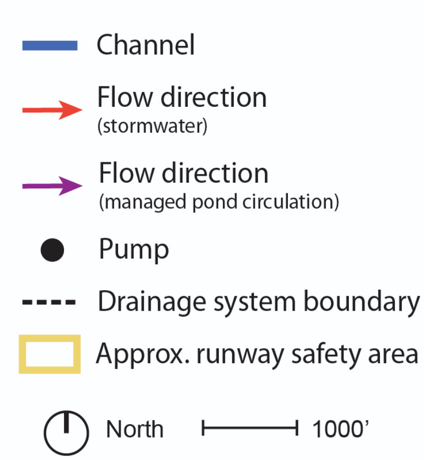


Figure 7. Diagram of existing stormwater management system for the Lockheed Martin Drainage.

Lockheed Martin manages the stormwater drainage area located east of the NASA campus boundary and west of Mathilda Avenue (Figure 7). Stormwater flows by gravity to detention ponds located at the northern edge of the area, where debris settles out.

Much of the detention ponds are dry for most of the year, and the eastern pond is used as secondary storage for high flow events. From the detention ponds, water flows along the Lockheed Martin Channel to the Lockheed Martin pump station.

A pipe connects the Northern and Lockheed Martin channels upstream of the pump station to convey stormwater from the Northern Channel to the Lockheed Martin Channel. Currently, less than 10% of the stormwater pumped by



Lockheed Martin is from the Lockheed Martin-owned property; the rest of the flows come from the NASA Eastern Drainage Area and gravity flow from other parcels in the drainage area that are south of the Lockheed Martin campus. The pump station conveys stormwater from the Lockheed Martin Channel into Sunnyvale West/Moffett Channel, which then flows to Guadalupe Slough and the Bay.

Lockheed Martin manages the pump station and owns the equipment but does not own the property that it sits on. They have an agreement with NASA to help offset the costs of running the pump station. There are multiple challenges associated with operating the aging pumping system. For example, the Lockheed Channel upstream of the pump station has silted up, and it is difficult to get permits to clear out the sediment. Additionally, pipe corrosion has increased brackish groundwater seepage and Lockheed Martin is considering adding a plastic lining. The pump station currently contains three pumps, each rated for 25,000 cubic feet per minute, that run on natural gas.

Pumping responsibilities defaulted to Lockheed Martin years ago as they were the largest property owner and the majority of storm water originated on their property. As the business has downsized and the majority of storm water originates on neighboring property, Lockheed Martin feels that stormwater management is best handled by the appropriate public municipality. This approach is similar to other private property owners where there is stormwater from other entities flowing through their property to the Bay, which is managed by the city.

City of Sunnyvale Drainage Areas

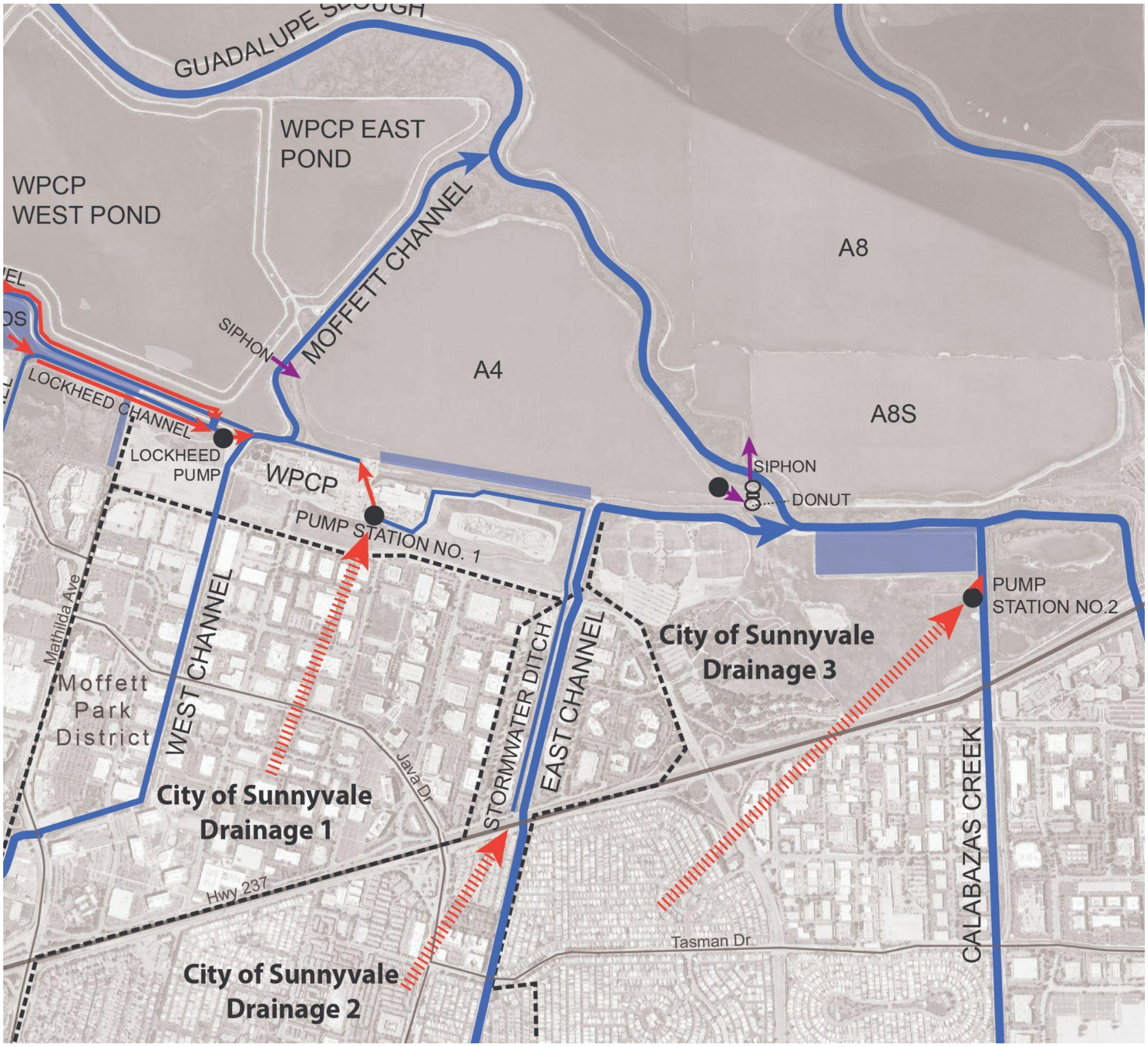
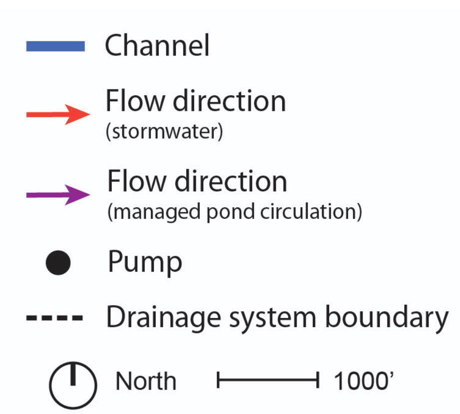


Figure 8. Diagram of existing stormwater management system for the Moffett Park drainage basins.



The City manages an extensive stormwater system with about 3,000 pipes, 100 outfalls, 4-5 watersheds, and two pump stations. Pump Station No. 1 drains the Moffett Park area north of Hwy 237 (shown as City of Sunnyvale Drainage 1 in Figure 8) as well as water collected in the stormwater ditch parallel to the East Channel (shown as City of Sunnyvale Drainage 2 in Figure 8). Pump Station No. 2 drains the area south of Hwy 237 to Tasman Drive (shown as City of Sunnyvale Drainage 3 in Figure 8). Sunnyvale East and West Channels were designed with capacity for a 10-year flood event; the current enhancement project will provide 100-year event protection. Extensive subsidence in northern Sunnyvale means this area is too low to convey stormwater into Sunnyvale East and West Channels by gravity, so stormwater must be pumped out of this area. The eastern drainage area flows to the Southwest Ditch (basically an elongated forebay for Pump Station No. 1) and is pumped to Sunnyvale West Channel at Pump Station No. 1.

The total pump capacity for Pump Station No. 1 is approximately 54,750 gpm. There are two main pumps: one with a capacity of 19,500 gpm and a 30” outfall and a second with a capacity of 27,500 gpm and a 36” outfall. The third pump, a jockey pump, has a capacity of 7,750 gpm and an 18” outfall. The total pump capacity for Pump Station No. 2 is approximately 59,900 gpm. Pump Station No. 2 has seven total outfall/discharge pipes, including four 30" pipes (three are in use the other is capped) and two 14" pipes. The large pumps for the 30” outfalls have a capacity of 18,500 gpm each and the low flow pumps at the 14” outfalls have a capacity of 2,000 gpm each.

The Moffett Park Specific Plan will affect stormwater management in the district. In this process, the City is studying opportunities to make Moffett Park an eco-innovation district by diversifying land uses, implementing green infrastructure, and incorporating innovative stormwater management concepts. The Plan will be presented to Council for consideration in 2022.

Google is a major landowner in the City of Sunnyvale’s Moffett Park district, and many Google properties drain to the City of Sunnyvale’s stormwater system. Google is prioritizing building LID (Low Impact Development) at the parcel scale to intercept and infiltrate rainfall before it enters the stormwater system. Google is already planning to build a channel enhancement project at Caribbean Drive providing riparian habitat including a willow grove. This project has already been entitled and is moving forward for construction.

Remaining Questions About Existing Conditions

Further exploration is needed to better understand existing groundwater pumping and treatment systems, including the reasons for increased groundwater discharge in recent years.

In addition, it would be valuable to gain a more thorough understanding of the resource conflicts that may arise due to changes in the stormwater system. In particular, it would be useful to know which listed wildlife species currently use the stormwater ponds and channels as habitat areas.

Finally, the ownership of some of the pumps is unclear at this time and it will be necessary to clarify this going forward.

6. Constraints

Cost and funding are major constraints to upgrading the existing stormwater system. Each organization is constrained by limited budgets and competing priorities. A complete overhaul of the stormwater system is unlikely to occur at once due to funding constraints; therefore, careful planning and coordination will be required to achieve the goals outlined in this memo.

An important consideration in any redesign of the stormwater system is groundwater. Groundwater is already near the surface in many places along the shoreline, and groundwater levels may rise with sea level. This is likely to increase the strain on stormwater systems in terms of volume and also lead to pipe corrosion. Existing infrastructure is already limiting groundwater levels in the district due to inflow into existing stormwater pipes. There is limited knowledge about the shallow aquifer in the Sunnyvale area, particularly in regards to its connectivity to the Bay, which will determine the rate of rise in the future.

In general, an important constraint to consider is management of the tradeoff between stormwater detention and sediment supply to the baylands. However, the watersheds that feed most of the stormwater channels in this area are small and highly urbanized. Sediments found in the East and West channel are a result of tidal rather than watershed influence. Stevens, Calabazas, and San Tomas Aquino creeks might be more promising sources of sediment for the baylands since Valley Water is already removing sediment in the lower reaches of these creeks.

In the NASA Ames segment of the shoreline, the Moffett Field runway presents another constraint, as detention basins and seasonal wetlands near the runway could increase bird strike risk for airplanes. Another runway safety risk to consider in considering future changes to the stormwater and flood protection system is the required setback between a future flood risk management levee and the end of the runway. Finally, special-status species such as the snowy plover in NASA's stormwater basins (primarily seen at the MROSD parcel) create limitations on how the present stormwater systems, particularly detention basins, are managed and redesigned.

7. Opportunities

The following opportunities for improving the stormwater system were identified by participants at the workshop, and are presented here organized by the objective they would help achieve.

1) Reduce the size and number of shore-parallel channels running east-west by discharging stormwater along former channels between Pond A3W and the oxidation ponds or directly into Pond A4 or Pond A3W. This could include flow through restored tidal marshes (Figure 9).

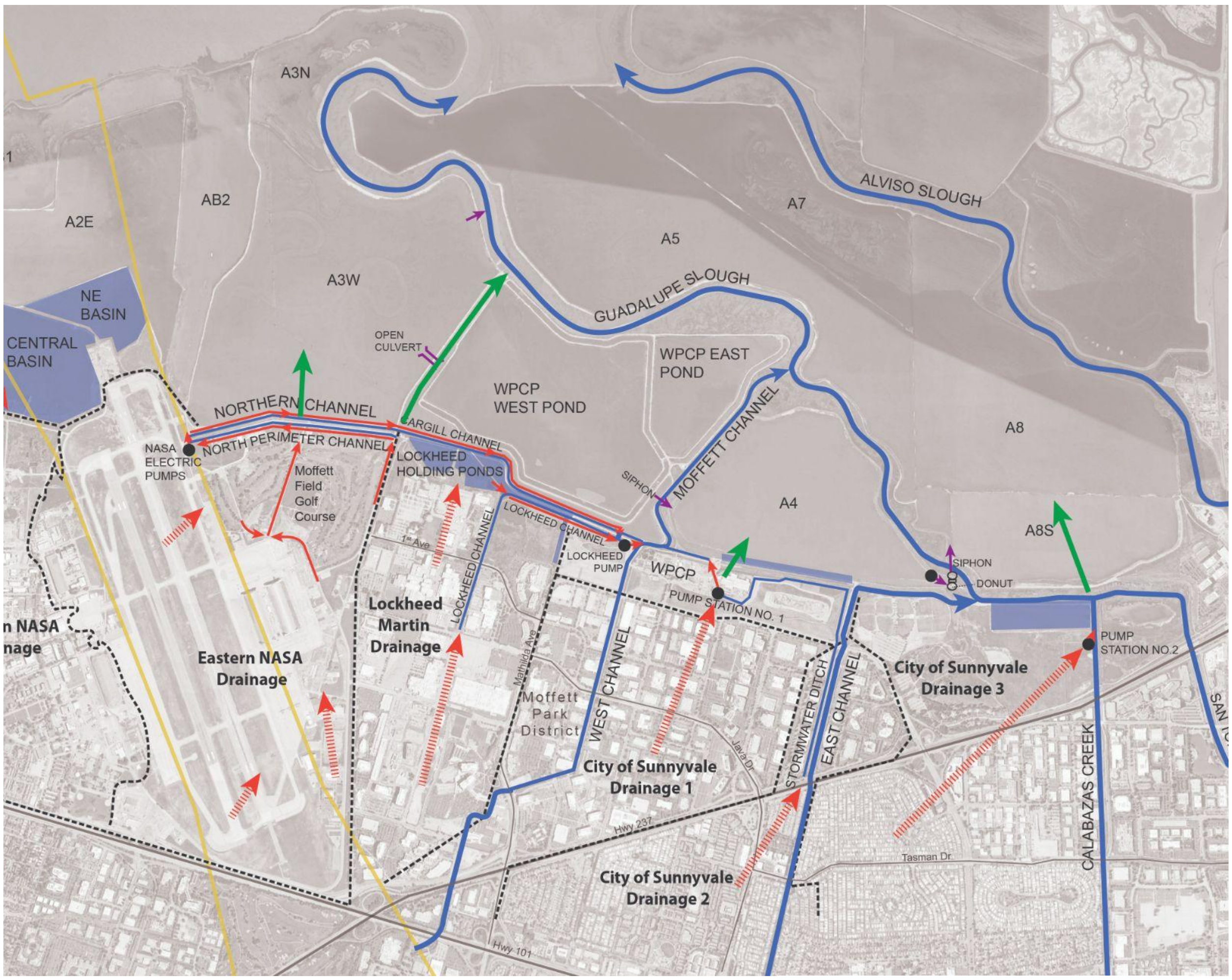
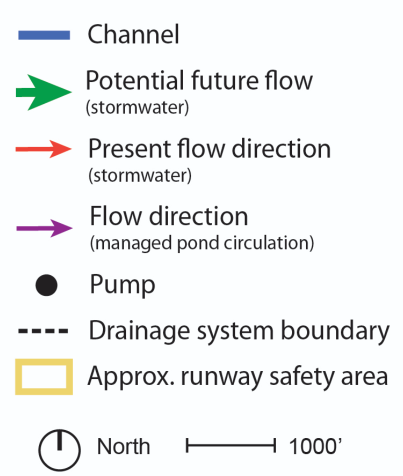


Figure 9. Opportunity (green arrows) to route stormwater directly to former salt ponds.



2) Combine the Northern Perimeter channel and Lockheed Martin channels with the Northern Channel to create more space and fill for a future levee (Figure 10).

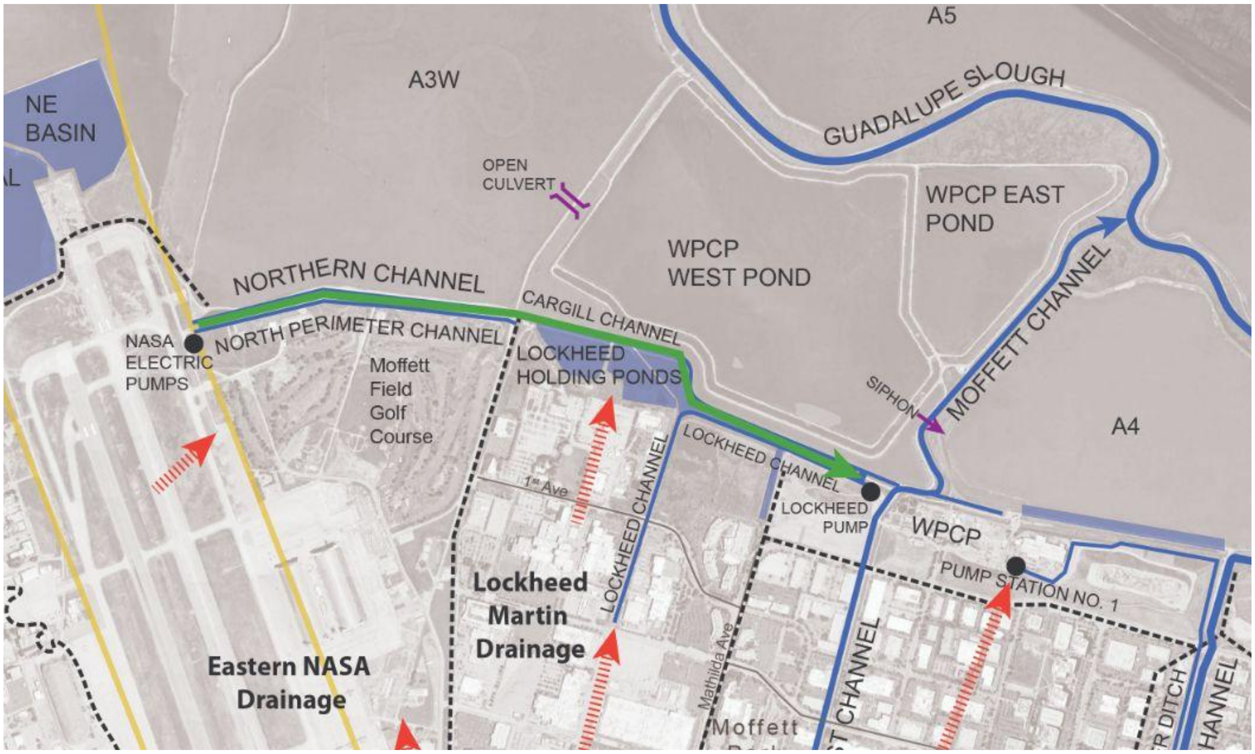
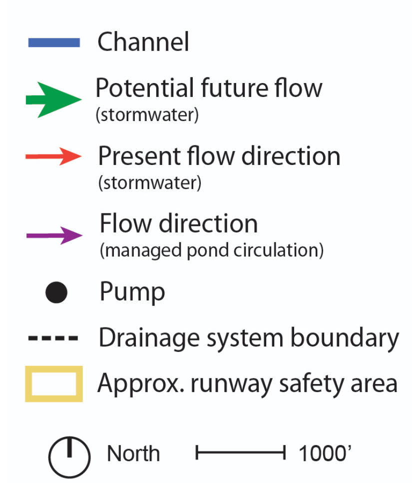


Figure 10. Opportunity (green arrow) to save space by combining the Northern and North Perimeter channels with the Lockheed channel.



3) Create more detention along the golf course reach (Figure 11).

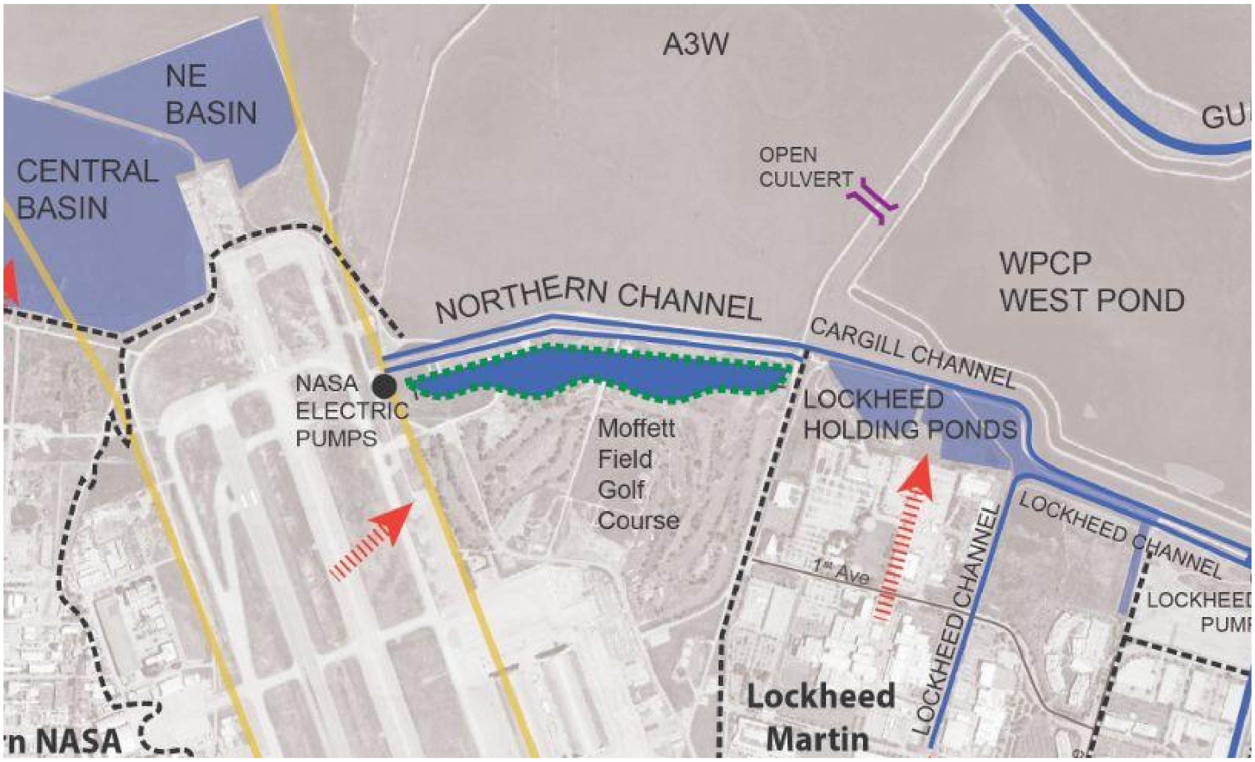
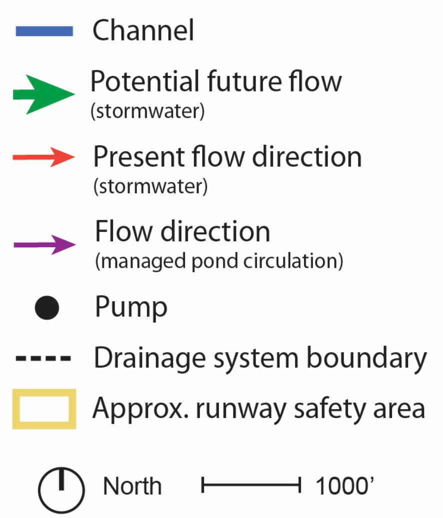


Figure 11. Opportunity to create a new detention basin along the golf course reach.



4) Reduce flood risk associated with stormwater backwatering inland of the levee (including combined flood risk associated with rising groundwater)

- Expand interior drainage to help manage shallow groundwater and storm drain backups. NASA is already pumping constantly to manage high groundwater tables and urban drool (dry weather runoff) and with sea-level rise, rising groundwater may reduce channel capacity and increase internal flood risk. Expanding interior drainage capacity could reduce this risk.

- Incorporate Low Impact Development (LID) strategies and green infrastructure on private parcels and streets to reduce stormwater runoff. Master planning efforts including the Moffett Park Specific Plan as well as Google, Lockheed Martin, and NASA master plans can propose LID designs to intercept and infiltrate rainfall before it enters the stormwater system.

- Develop a robust hydrologic model incorporating stormwater, sea level rise, and rising groundwater to allow for a better understanding of existing flows and potential impacts of additional green infrastructure projects.

- Develop a groundwater monitoring plan to better understand the magnitude of existing and future flood risks presented by groundwater emergence.

5) Simplify complex plumbing, reduce the burden on existing stormwater infrastructure, and reduce maintenance costs

- Increase groundwater reuse to reduce pumping capacity requirements.

- Reduce pumping requirements at the Lockheed Martin pump station by reducing flows from Moffett Park and NASA Ames (via flow diversion and/or LID installation).

6) Discharge cleaner water to the Bay more directly

- Polish stormwater using horizontal levees prior to flowing into the restored marsh (or consider other stormwater cleanup options to meet Water Board requirements for discharge to habitat areas).

- Explore the idea of connecting the NASA Eastern Drainage directly to the ponds north of Moffett Field (Figure 12).

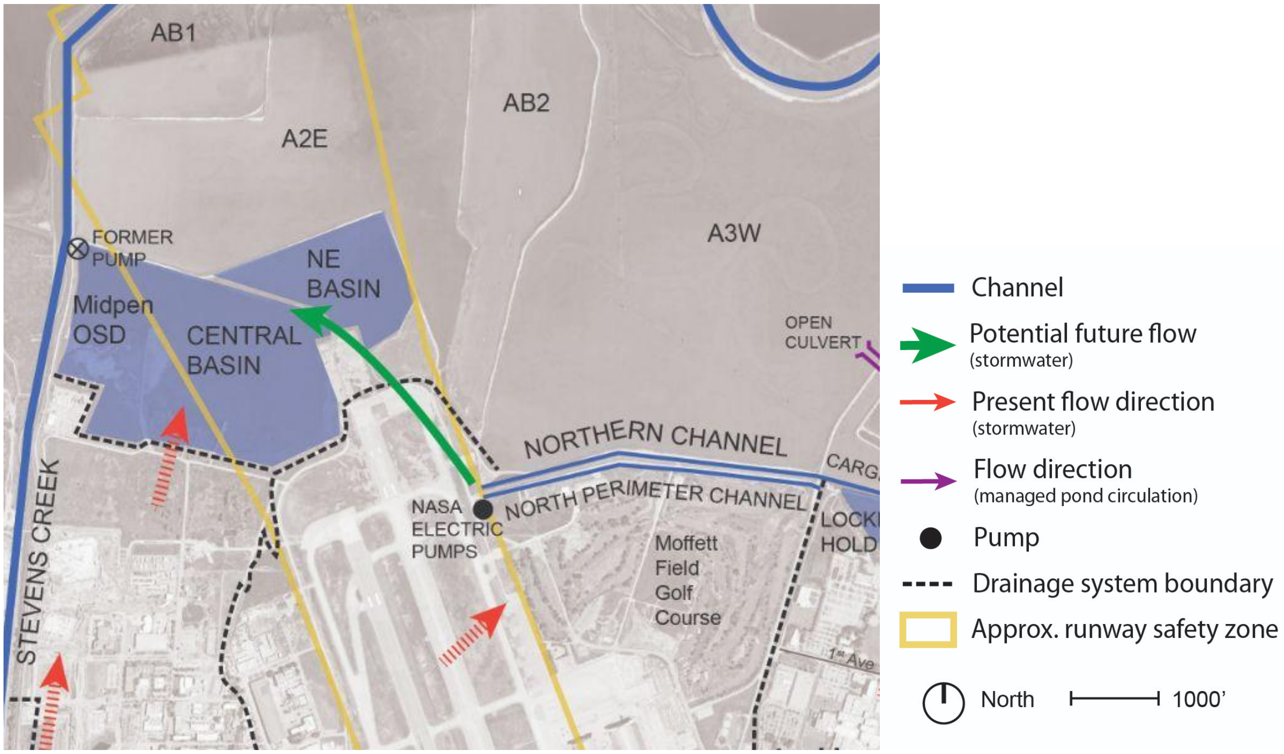


Figure 12. Connect NASA Eastern Drainage to the Central/Northeast Basins.

- Improve habitat value of MROSD parcel. This could require pumping to maintain dry conditions in the future as groundwater levels rise (same for Central and Northeast NASA basins).

7) Support habitat restoration

- Deliver stormwater directly to restored tidal marshes and managed ponds to mimic natural systems.
- Direct more sediment to marsh restoration projects, in the same vein as efforts already underway to connect Calabazas and San Tomas Aquino Creeks directly to Pond A8S. Flood control channels in Sunnyvale are not a major sediment source, but reconnecting Stevens Creek to restored areas could improve resilience of restored ponds in this area in the future.
- Explore opportunities for habitat and stormwater detention in low-lying areas.
- Restore Pond A4 to tidal marsh (or maybe managed pond) and deliver stormwater directly to this pond.

9) Reuse fill material in existing berms to construct new levees

- Decommission channels that are not connected to the Bay and repurpose fill material used in their berms for the shoreline flood-risk management levee. Re-plumb the system so open channels do not run adjacent to the shoreline levee, which may be unacceptable to the Corps as they can impact levee stability.

SUNNYVALE SEA-LEVEL RISE ADAPTATION STRATEGY: BACKGROUND

Prepared for
City of Sunnyvale

November 2020

Sunnyvale

SUNNYVALE SEA-LEVEL RISE ADAPTATION STRATEGY: BACKGROUND

Prepared for
City of Sunnyvale

November 2020

550 Kearny Street
Suite 800
San Francisco, CA 94108
415.896.5900
www.esassoc.com

Prepared by:

ESA

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1. Study Purpose and Summary Adaptation Strategy

The City of Sunnyvale enjoys temperate weather, access to open space and vistas, and connections to natural hydrology because of its close proximity to San Francisco Bay (Bay). However, when Bay water levels increase above their typical elevations, this shoreline's non-accredited levees[1] are currently susceptible to overtopping, threatening northern areas of Sunnyvale with flooding. In addition, much of the city's stormwater drains through low-lying areas near the shoreline and out to the Bay. This drainage can be impeded by elevated Bay water levels and cause flooding.

These flood hazards will be exacerbated by future sea-level rise. Sea-level rise is a consequence of climate change caused by global increases in greenhouse gas emissions. These gases have increased and will continue to increase Earth's temperatures. The increased temperatures then cause sea-level rise through thermal expansion of the oceans and melting of ice sheets. Sea-level rise of about 8 inches has already occurred in the last century, and several feet or more of sea-level rise is projected by the end of this century. By elevating Bay water levels, sea-level rise will increase the frequency and severity of flooding along the Sunnyvale shoreline.

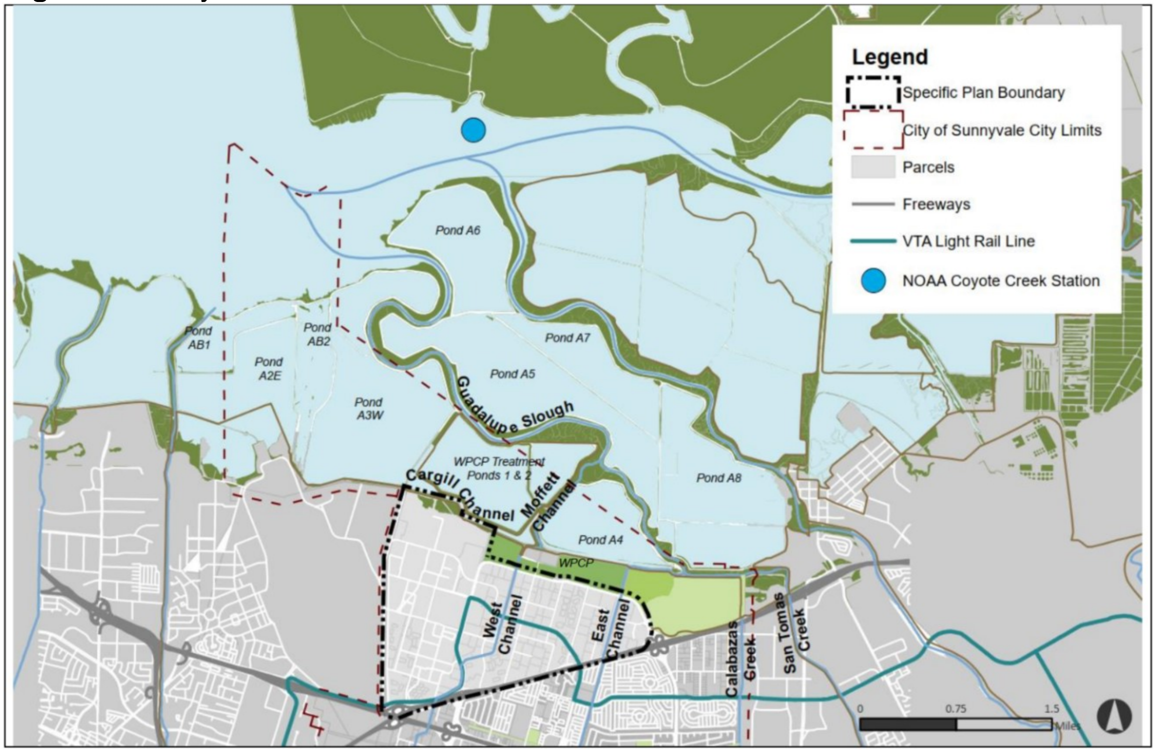
To plan for these existing and future hazards, the City of Sunnyvale (City), as part of the Moffett Park Specific Plan revision (**Figure 1**), initiated the development of this adaptation strategy. The study's goal is to develop a sea-level rise adaptation strategy that can be implemented for the benefit of the City and Sunnyvale residents. To meet this goal, this study has the following objectives:

- Assess existing flood risk and flood risk that includes future sea-level rise projections.
- Integrate reasonable and feasible sea-level rise adaptations appropriate to the City's shoreline.

To achieve these objectives, this strategy considers existing flood hazard mapping and vulnerability assessments for Sunnyvale's shoreline. Based on this assessment, the study draws together adaptation measures from several sources into a complete strategy. Adaptation measures that address sea-level rise for the Sunnyvale shoreline include larger, regional flood management and adaptation.

[1] The levees protecting Moffett Park provide protection from substantial amounts of flooding, but are not accredited as meeting Federal Emergency Management Agency (FEMA) design criteria. Hence, FEMA (2015) considers these levees "non-accredited" and maps much of the developed area of Moffett Park within the flood hazard area. For additional details about FEMA levee accreditation, see Section 2.2.1.1.

Figure 1. Study Area



Because the Moffett Park Specific Plan Area (Plan Area) covers nearly all of the City acreage that is most exposed to increasing flood hazards with sea-level rise, this adaptation strategy also serves the city as a whole. Key infrastructure elements upon which the entire city relies, the Water Pollution Control Plant and the Sunnyvale Materials Recovery and Transfer Station solid waste processing facility, are just outside the Plan Area; their adaptation to sea-level rise should be coordinated with the Moffett Park strategy. Other parts of Sunnyvale exposed to sea-level rise and not in the Plan Area are a private sports complex and Baylands Park. While the effects of sea-level rise will be felt most directly within Moffett Park, other parts of the city will be affected indirectly: stormwater for most of the city flows through the Plan Area, the Plan Area is a vital tax base, and an avenue for public access to the Bay shoreline. The adaptation strategy focuses on the adaption process for up to 3 feet of sea-level rise, which is considered likely by the end of the 21st century. Greater amounts of sea-level rise are projected to have a less likely chance of occurring in this century, but become increasingly likely in the next century. Addressing sea-level rise beyond 3 feet will require additional planning and adaptation.

This study builds on prior efforts by the Santa Clara Valley Water District (Valley Water), the U.S. Army Corps of Engineers (USACE), and the City that identified areas vulnerable to sea-level rise. In particular, Valley Water and USACE developed flood hazard mapping and a preliminary coastal flood protection approach as part of the South San Francisco Bay Shoreline Study. In addition, Valley Water has conducted flooding analyses and developed riverine flood improvement measures for the Sunnyvale East and West Channels Flood Protection Project. In addition to these two key flood protection projects, this study has also been informed by the South Bay Salt Pond Restoration Project and the Sunnyvale Shoreline Resilience Vision.

Based on these agencies and sources, this study recommends the series of measures in **Table 1** as the City's adaptation strategy for sea-level rise. Implementation of these measures will provide Moffett Park with improved flood protection for up to 3 feet of sea-level rise. More than 3 feet of sea-level rise is not projected to occur until about 2070 at the earliest, so this strategy is likely to afford 50 years of implemented protection. The last measure, long-term adaptation planning, will initiate the process for assessing and adapting to greater than 3 feet of sea-level rise.

TABLE 1
SUMMARY OF SUNNYVALE ADAPTATION STRATEGY

Measure Name	Flood Hazard	Actions	Flood Design Criteria	Participants	Schedule
South San Francisco Bay Shoreline Phase III Feasibility Study	Coastal flooding with • Levee crest below base flood elevation • Levee not meeting geotechnical standards	• Protect: Improve coastal levees, habitat transition zone • Accommodate: Restore marsh	100-year coastal flood event + freeboard + sea-level rise	• Lead: USACE • Non-federal sponsors: Valley Water, Coastal Conservancy • Local partner: City	• Preliminary Feasibility Study flood hazard and benefit/cost ratio: 2007–2017 • USACE Feasibility study: 2021 (Earliest potential start date pending receipt of federal funds) • Design and Construction: tbd
South Bay Salt Ponds Restoration Project	• Wave overtopping • Levee erosion	• Realign: Breach outboard levees • Accommodate: Restore marsh	Not applicable	• Coastal Conservancy • U.S. Fish and Wildlife Service	• Design: Concurrent with Shoreline Phase III design • Construction: After completion of Shoreline Phase III improvements
Sunnyvale East & West Channels Flood Protection Project	• Conveyance of watershed runoff and high Bay water levels	• Protect: Raise levees and floodwalls • Accommodate: Channel setbacks	100-year fluvial discharge + freeboard + 2 feet sea-level rise	• Valley Water • City • Google	• Planning and design 2007–2020 • Permitting 2016–2021 • Construction 2021–2023
Finished Floor Elevation	• Inundation within developed areas	• Accommodate: Raise finished floor elevation above FEMA minimum	100-year base flood elevation + 1 foot sea-level rise for non-residential buildings	City	tbd

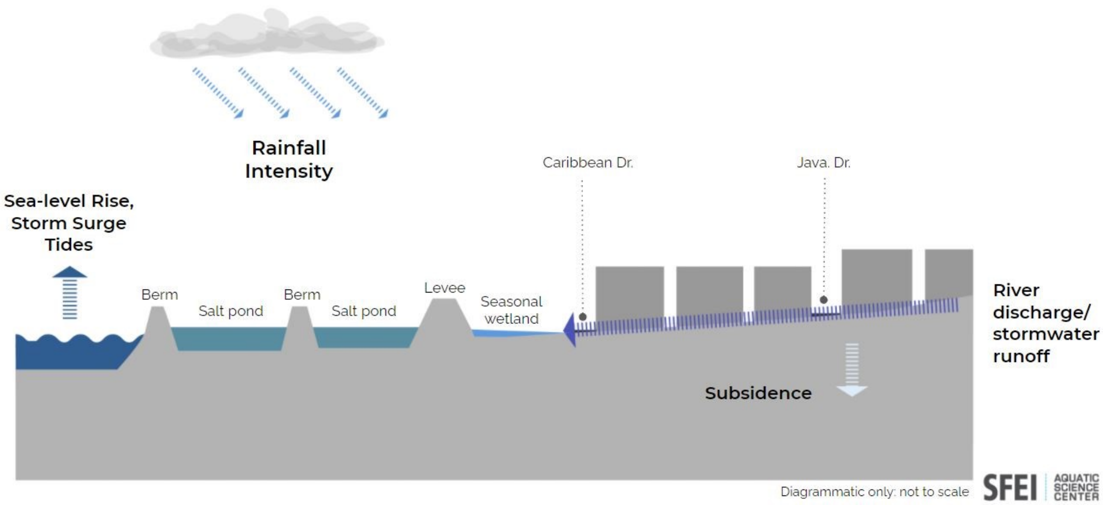
Stormwater Vulnerability Assessment	• Precipitation runoff and ponding	• Accommodate:
		  ○ Collect and discharge stormwater with pump stations
		  ○ Enhance northwest detention wetlands
			Future sea-level rise and precipitation (to be determined)	City	tbd

Groundwater Data Collection	• Increased surface and subsurface inundation and salinity	• Accommodate: Quantify existing groundwater conditions underlying Project Area	tbd	City	2021
Groundwater Vulnerability Assessment	• Increased surface and subsurface inundation and salinity	• Accommodate: Characterize the timing and extent of groundwater change • Protect: Revise building code and upgrade existing structures as needed	• Up to 3 feet of sea-level rise • Greater than 3 feet sea-level rise	City	tbd
Water Pollution Control Plant Master Plan	• Coastal and fluvial flooding	• Protect: Site ring levee	100-year base flood elevation	City	• Surrounding floodwall levee: 2024
Long-term adaptation planning	• Coastal, fluvial, stormwater, and groundwater flooding beyond 3 feet of sea-level rise	• Consider realignment, raise barrier elevations, raise building elevations, groundwater management, and stormwater improvements	More than 3 feet sea-level rise	City	2018–ongoing

2. Flood Hazards

This section summarizes the sources of flood hazards (**Figure 2**) that can threaten the Plan Area with inundation. The hydrologic setting section first provides an introduction to and context about the Plan Area. The next section describes the existing flood hazards from coastal and riverine sources. The third section describes the potential ways in which climate change may affect the existing flood hazards.

Figure 2. Sources of Flood Hazard



2.1 Hydrologic Setting

The primary hydrologic sources affecting the Plan Area are San Francisco Bay, which borders the northwest corner of the Plan Area, and the Sunnyvale East and West Channels, which pass through the Plan Area from south to north before discharging to the Bay (Figure 1). The Plan Area is relatively flat, with low elevations due in part to past subsidence. The adjacent Baylands provide some separation between the Plan Area and the open Bay, as do the non-accredited levees and landfill that border its north side. Shallow groundwater underlies the Plan Area, and appears as small ponds in the northwest of the Plan Area. These elements are described in more detail below.

2.1.1 Topography

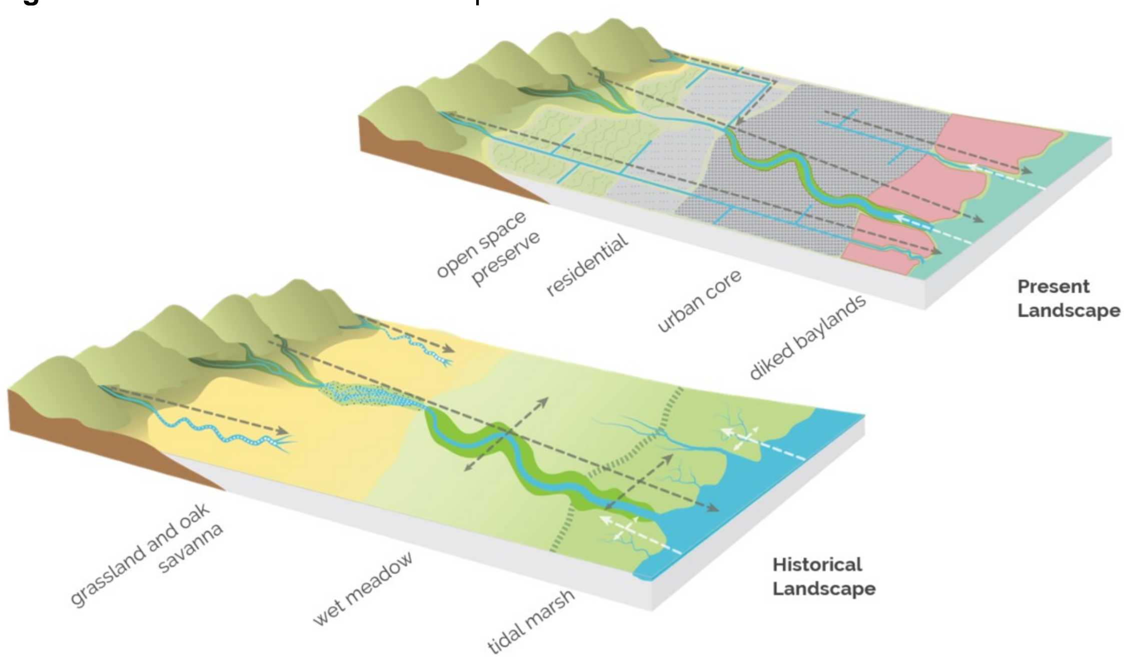
The Plan Area's topography hosts its hydrology, determining how water is conveyed through and across the region. The Plan Area is quite flat, with lower elevations to the north sloping gently upwards to the south. Substantial regional groundwater pumping in the first half of the 20th century caused the ground surface in the Plan Area to subside approximately 6 feet by the 1960s (Poland and Ireland, 1988). Further subsidence was halted by switching to local and imported surface water supplies and recharging the groundwater aquifer. Minimal additional subsidence has occurred since the 1970s, so the present-day ground surface remains about 6 feet below its original elevation at the start of the 20th century.

The ground surface is as low as 3–4 feet relative to the North American Vertical Datum of 1988 (NAVD88) in developed areas just south of Caribbean Drive and several feet lower in the northwest portion of the Plan Area, where stormwater collects in undeveloped areas. For reference, the mean tide level in San Francisco Bay is 3.3 feet NAVD88 and high tides are several feet higher than that. Non-accredited levees and a landfill border the north side of the Plan Area, blocking potential inundation from the Bay. Non-accredited levees are also present along the banks of the Sunnyvale East and West channels.

2.1.2 Baylands Land Use

The Baylands refers to the mosaic of channels, non-accredited levees, and managed wetlands that are located between Moffett Park and the open Bay (Figure 1). Prior to European development in the Bay area, these Baylands were large expanses of tidal marsh and tidal slough channels (**Figure 3**). The marshes were then surrounded by levees to create a network of evaporative ponds for salt production by private companies. They have since been acquired by public agencies and are now managed for a mix of wastewater treatment and wetlands habitat. Different land uses have different tolerances for flood inundation. For example, tidal marsh welcomes flood inundation whereas oxidation ponds that are part of water quality treatment processes would not be as tolerant of flood inundation.

Figure 3. Past and Present Landscape



2.1.2.1 Water Pollution Control Plant Treatment Ponds

The City of Sunnyvale owns and operates the Water Pollution Control Plant (WPCP) to treat wastewater from the city before discharging to the Bay. As key infrastructure for managing water quality in the Bay, the WPCP needs to be protected from flooding. Treatment Ponds 1 and 2 are an integral part of the current wastewater treatment process, as they help remove pollutants and restore oxygen to the effluent before discharge to the Bay.

The WPCP Master Plan (City of Sunnyvale, 2017) describes the plant facilities' needs through 2035. The WPCP Master Plan calls for the City of Sunnyvale to complete the following actions in the next few years:

- Transition about half the plant's flow to a conventional treatment process within the plant's main footprint that will perform the treatment currently performed in the treatment ponds.
- Consolidate operations into a smaller footprint.
- Construct a floodwall around the main plant site in coordination with the Valley Water Sunnyvale East Channel and West Channel Flood Protection Project.
- Explore a potential partnership with Valley Water to develop water purification facilities.

The oxidation ponds will be needed as a required element of the facilities for the foreseeable future. The Master Plan contemplated a longer term prospect of transitioning treatment of all plant flow within the plant's footprint during a second phase. However, after consideration of anticipated performance of the first phase of conventional treatment and anticipated regulatory triggers, it is probable that the oxidation ponds will be sufficient to address community needs. Even if implemented, the second phase will not be completed until after 2035. In addition, some portions of the ponds would still be needed for wet-weather equalization, temporary water storage, and emergency overflow. Unused portions of the ponds could potentially be restored, although they are relatively deep and contain organic matter that has settled out from the treatment process.

2.1.2.2 Pond A4

Pond A4 is an open-water pond located between East Channel and Moffett Channel. The pond was acquired by Valley Water in 2003. It is filled by a combination of groundwater and precipitation sources. It does not receive surface water from the Bay, Guadalupe Slough, Sunnyvale East and West Channels, or Moffett Channel. The pond is currently managed as open water habitat. Water is pumped from Cargill Channel into the pond and then routed to Pond A5, to improve water quality, particularly to prevent elevated salinity due to evaporation. In the future, Valley Water plans to use Pond A4 for habitat restoration, possibly supplemented with soil dredged from stream channels to preserve flood conveyance.

2.1.2.3 South Bay Salt Pond Restoration Project

The South Bay Salt Pond Restoration Project is a collaboration between the California Department of Fish and Wildlife, California Coastal Conservancy, and U.S. Fish and Wildlife Service to restore 15,000 acres of former salt production ponds and manage the resulting wetlands for native plants and animals. The project's ponds north of Moffett Park are owned and managed by the U.S. Fish and Wildlife Service.

East of Guadalupe Slough, the U.S. Fish and Wildlife Service manages the Pond A8-A5-A7 complex as a muted tidal wetland with the intent of eventually restoring full tidal connectivity to the complex, as has already been done for Pond A6 at the north end of the complex. Full restoration of the Pond A8-A5-A7 complex will proceed once mercury contamination concerns have been addressed (confirmation of this is in progress with the San Francisco Bay Regional Water Quality Control Board), and will likely occur in tandem with Valley Water's project to realign Calabazas Creek and San Tomas Aquinas Creek to discharge into Pond A8. West of Guadalupe Slough and northwest of Moffett Park, Pond A3W is deeply subsided and will remain as open water for waterbirds. Ponds AB1 and A3N are planned for full restoration to tidal marsh, but contain Pacific Gas and Electric Company towers that will need to be raised. The future preferred habitat for Ponds A2E and AB2 is unknown at this time and will be determined by the project's adaptive management approach.

2.1.3 San Francisco Bay

Water levels in the Bay are controlled by water level fluctuations in the Pacific Ocean that travel through the Golden Gate and propagate throughout the Bay. Changes in ocean water levels occur daily due to the astronomic tide, which are water level fluctuations caused by forces between the astronomic bodies of the earth, the sun, and the moon. The Bay experiences a semidiurnal tide, with each day having two high and two low tides of unequal heights. The astronomic tide range varies by a few feet on about a two-week cycle, with larger tide ranges called "spring" tides and lower tide ranges called "neap" tides. The largest spring tides of the year usually occur in December or January and are known as "king tides."

The National Oceanic and Atmospheric Administration (NOAA) maintains a network of tide gages that report observed tides and tidal datums within the Bay. Common tidal datums, which are statistics used to characterize local water levels, include:

- Mean higher high water (MHHW)—average of each day's highest tide.
- Mean sea level (MSL)—average of all stages of the tide.
- Mean lower low water (MLLW)—average of each day's lowest tide.

South San Francisco Bay has a larger tide range than the Pacific Ocean and other parts of the Bay. This larger tide range occurs because the Bay bathymetry, bottom friction, and reflection of the prior tide modulate tides propagating into the South Bay. The net effect is tide range amplification that increases with distance south from the mouth of the Bay. The tidal range increases from 5.8 feet at the San Francisco tide gage (NOAA Station #9414290) to 9.0 feet at the Coyote Creek tide gage (NOAA Station #9414575), the closest NOAA-operated tide gage to Sunnyvale (Figure 1). **Table 2** shows tidal datums at the Coyote Creek gage.

TABLE 2
SOUTH SAN FRANCISCO BAY TIDAL DATUMS AT COYOTE CREEK

Tidal Datum	Elevation (feet, NAVD88)
Mean higher high water	7.6
Mean sea level	3.3
Mean lower low water	-1.4

SOURCE: NOAA Station #9414575

In addition to astronomic tides, storm events that cause flooding occur during winter, from weather systems originating in the Pacific Ocean. Flood conditions above the typical astronomic tides are caused by atmospheric and oceanic processes. The processes that raise ocean water levels are mostly associated with winter storm events, so the resulting water level increase is often termed "storm surge." Storm-related processes that cause storm surge are lower atmospheric pressure and wind. In addition, changes in large-scale oceanic circulation, particularly during winters with El Niño conditions, can cause higher-than-normal water levels for several months at a time. Depending on the intensity of each of these processes, as well as their coincident occurrence relative to astronomic tides, storm surge can result in Bay water levels up to about 3 feet higher than astronomic tides alone. Winter storm winds can also generate wind setup and waves that may pose an additional flood hazard, particularly when the waves ride on a storm surge–elevated water surface.

Historical high water levels during storm surge events in San Francisco Bay are listed in **Table 3**, along with the estimated 99%, 10%, and 1% annual chance[2] still water levels. These flood stage statistical water levels are based on the hydraulic analysis used by FEMA (2015a) for its revised coastal flood mapping and are tabulated in AECOM (2016). As still water levels, they do not include the additional effects of wave runup. While water levels have been recorded continuously for over a century at San Francisco, water level data have been recorded only intermittently at Coyote Creek, limiting the number of storm surge observations at this location.

2 "Annual chance" refers to the probability of a flood event being equaled or exceeded each year. An alternate naming convention is based on the return interval concept, where the return interval is the inverse of the annual chance. For example, the 99% annual chance may also be called the 1-year event and the 1% annual chance may also be called the 100-year event.

TABLE 3
FLOODWATER LEVELS IN SAN FRANCISCO BAY

Annual Chance (Return interval) OR Event	Coyote Point[2]	San Francisco[3]
Daily (mean higher high water)	7.6	6.1
99% annual chance (1-year, approx. king tide)[1]	8.6	7.2
December 4, 2014	8.9	7.8
February 10, 2017	9.0	7.4
10% annual chance (10-year)[1]	9.8	8.3
December 3, 1983	10.7	8.8
1% annual chance (100-year)[1]	11.4	9.5

NOTES:
1 Based on AECOM (2016).
2 NOAA Station 9414863.
3 NOAA Station 9414290 (NOAA, 2020).

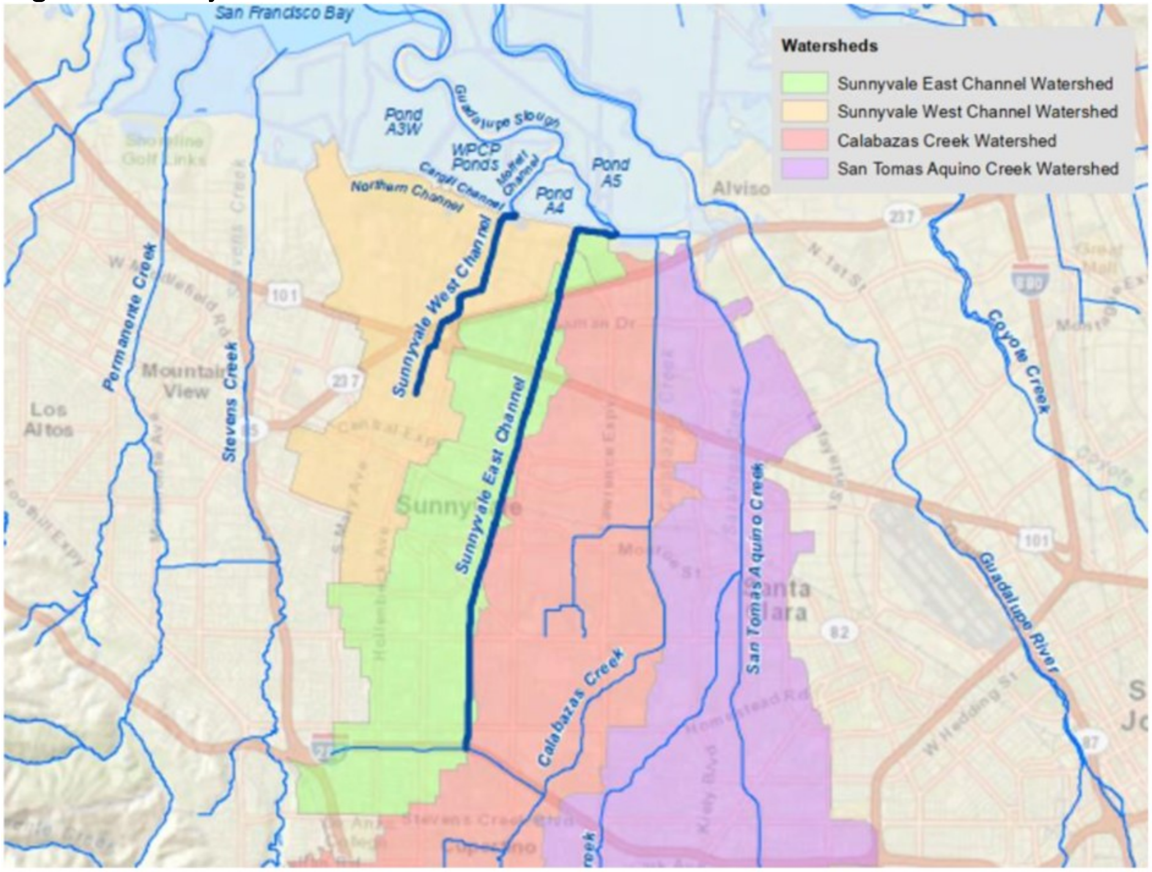
2.1.4 Precipitation and Stormwater

San Francisco Bay's regional climate is characterized by dry, warm summers and wet, rainy winters. Typically, the South Bay receives approximately 90% of its precipitation in the fall and winter months. The average annual rainfall in Sunnyvale is about 15 inches, with substantial inter-annual variations due to large-scale phenomena such as drought and El Niño.

Once on the ground, precipitation is collected by the City's stormwater network and routed to drainage channels and creeks. Most of the city's runoff is directed into the Sunnyvale East and West Channels, which run from south to north through the city and eventually into the Bay. South of Moffett Park, the stormwater system can discharge to the channels by gravity. However, because of the land surface subsidence in Moffett Park, stormwater from the Plan Area is first routed northwards through stormwater pipes and then lifted into the downstream end of the channels via pump stations.

The channels were built in the 1960s to carry stormwater drainage from Sunnyvale and adjacent areas to the Bay and to alleviate flooding. Together, the channels drain a watershed of approximately 15 square miles, encompassing most of Sunnyvale, as well as parts of Mountain View, Cupertino, and unincorporated Santa Clara County. **Figure 4** shows the location of the channels and their respective watershed areas (Valley Water, 2013). The channels and their levees were designed with capacity to carry flows from the storm drain systems during a 10-year storm. In their lower reaches through Moffett Park, this design flow capacity is not sufficient for FEMA accreditation, so these sections of the levees are not accredited by FEMA. The contributing watersheds for the two channels are urbanized with predominantly impermeable surfaces, so have reduced infiltration and rapid runoff during precipitation events.

Figure 4. Sunnyvale East and West Channels and Watersheds



2.1.4.1 Sunnyvale West Channel

The West Channel is approximately 3 miles long and drains approximately 2.9 square miles. The West Channel runs from Maude Avenue to near the southwest corner of Pond A4, where it connects to Moffett Channel. Moffett Channel is approximately 4,300 feet long by 125 feet wide, with varying depth (2–15 feet). Moffett Channel routes stormwater from West Channel into Guadalupe Slough, which then flows into San Francisco Bay. Due to its proximity to Guadalupe Slough, water levels in Moffett Channel and the lower part of the West Channel (up to Mathilda Avenue) are influenced both by runoff and Bay Water levels. The channel's estimated 1% annual chance discharge downstream of State Route 237 is 360 cubic feet per second (FEMA, 2015a).

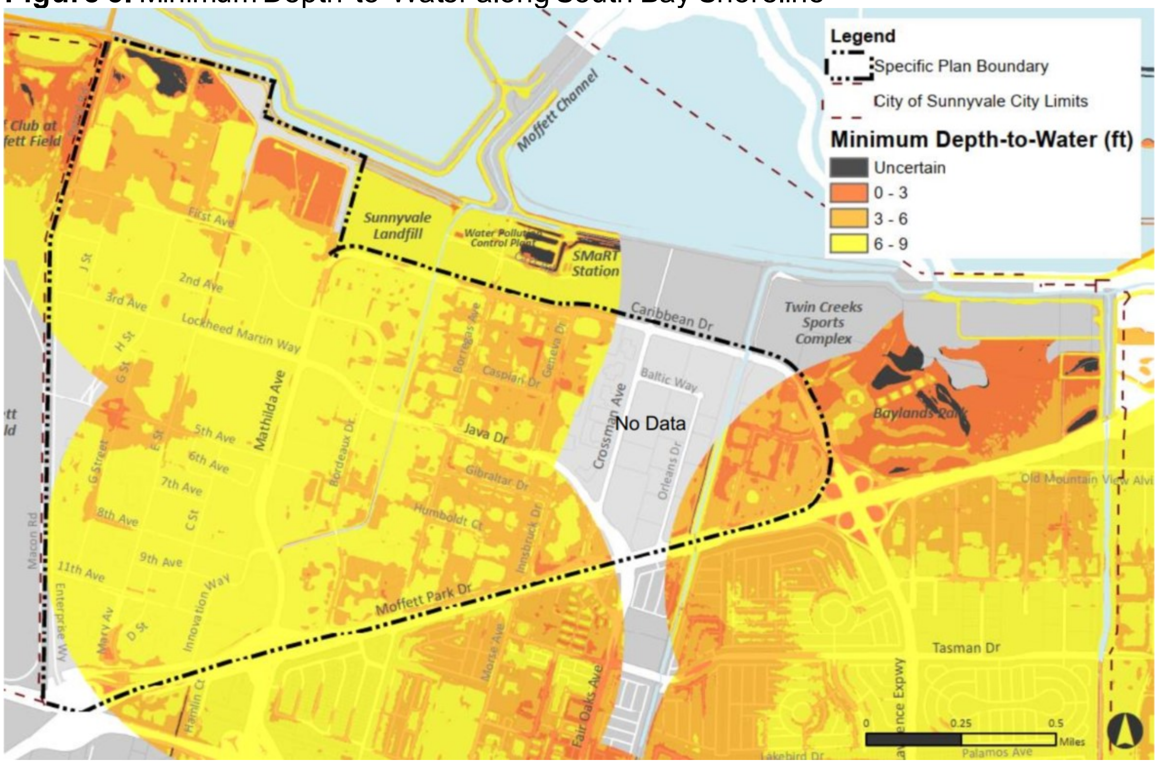
2.1.4.2 Sunnyvale East Channel

The East Channel is approximately 6.5 miles long, extending from Interstate 280 to the channel's confluence with Guadalupe Slough. The East Channel drains about 6.1 square miles and is influenced both by Bay water levels and runoff from Guadalupe Slough to about halfway between Tasman Drive and U.S. Highway 101. The East Channel is tidally influenced from its mouth up to State Route 237. The channel's estimated 1% annual chance discharge downstream of Caribbean Drive is 1,100 cubic feet per second (FEMA, 2015a).

2.1.5 Groundwater

Shallow groundwater can be found throughout the Plan Area, with its depth below the ground surface determined by Bay water levels and rainfall. As shown in **Figure 5**, Plane et al. (2019) estimate that most of the Plan Area has minimum depth-to-water of at least 3 feet and about half the Plan Area has a minimum depth-to-water of 6 feet or more.

Figure 5. Minimum Depth-to-Water along South Bay Shoreline



Data were not available from Plane et al. (2019) to map the groundwater elevations in the adjacent area just to the west of the East Drainage Channel. This portion of the Plan Area has similar ground surface elevations and is likely to have depth-to-water similar to the mapped areas on other side, i.e., 3–6 feet to groundwater. On the west side, there is an existing drainage ditch which likely serves to intercept and drain groundwater. Assuming the water levels in this ditch are well-connected to the local groundwater, this surface water provides ready access to monitoring groundwater water levels in this area that could be used to augment the mapping.

In general, the depth-to-water is greater in the southwest and decreases to the northeast. As minimum depths occurring over the period 1996–2016, these depths-to-water likely represent the rainy season maximum during wetter years.

2.2 Existing Flood Hazards

This section describes existing flood hazards posed by coastal flooding from the Bay (Section 2.1.3) and fluvial flooding from the Sunnyvale East and West Channels (Section 2.1.4).

No new analysis was conducted for this study. Instead, the strategy relies upon flood hazard studies previously conducted by FEMA, Valley Water, and USACE. These studies consider historic hydrologic data and then conduct hydrologic, hydraulic, and statistical analyses to estimate flooding extents and depths that could result from predicted flood events. Interpretation of the flood analyses is also tailored to a particular institution's application.

2.2.1 Coastal Flooding

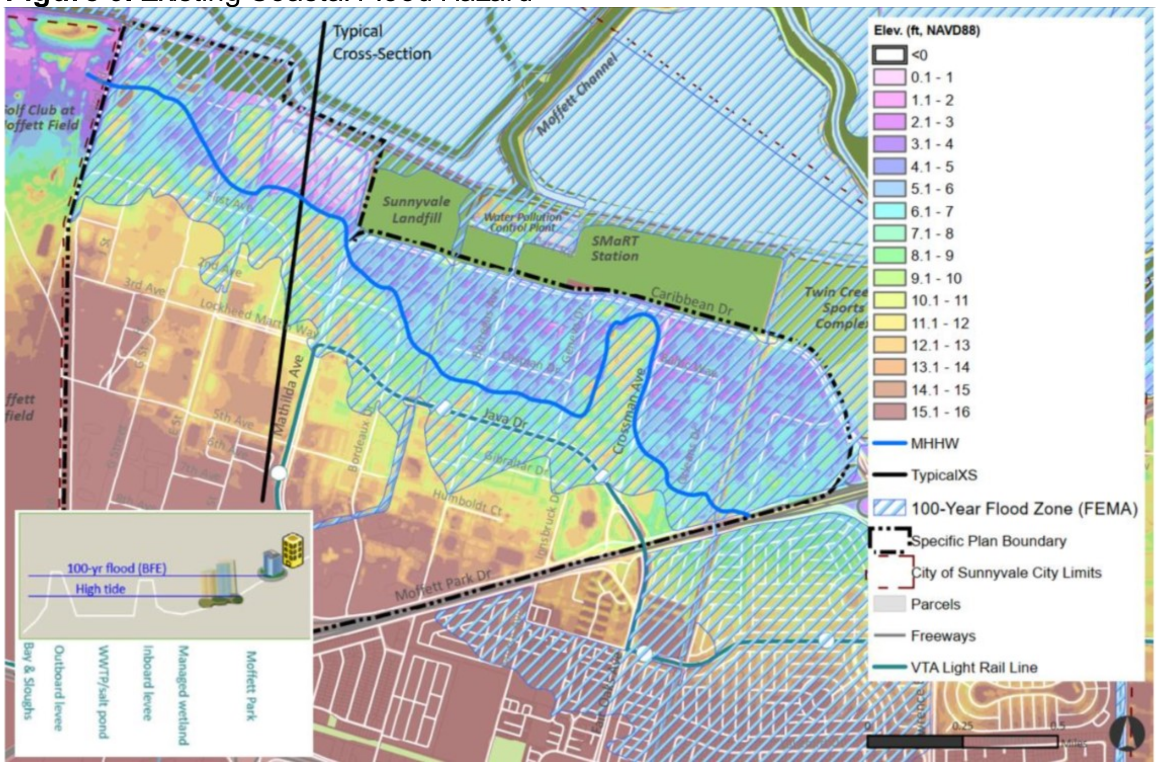
Coastal flooding in the Plan Area refers to floodwaters sourced from the Bay. Flooding is more likely during a storm surge event, like those described in Section 2.1.3. However, some areas of the Plan Areas are low enough in elevation that, if not for the Baylands' non-accredited levees, they could be inundated by daily high tides. Assumptions regarding levee failures substantially affect the mapped extent of coastal flooding in the Plan Area, as described below.

2.2.1.1 FEMA Flood Insurance Rate Mapping

As part of the National Flood Insurance Program (NFIP), FEMA conducts nationwide flood hazard mapping. The resulting Flood Insurance Rate Maps (FIRMs) are used to identify flood-prone areas, to support the NFIP, and to reduce flood damages. FEMA focuses on identifying the flooded extent and water levels that have a 1% annual chance of being equaled or exceeded, often termed the "100-year flood." The flood elevation associated with the 1% chance event is referred to as the base flood elevation (BFE). Areas predicted to be inundated in a 1% chance event are delineated on the FIRM as Special Flood Hazard Areas (SFHAs), and commonly referred to as the "100-year floodplain." Buildings and other structures in an SFHA must meet certain requirements to receive a floodplain development permit and to qualify for NFIP insurance and federally backed mortgages. FEMA does not consider sea-level rise or other climate change impacts when mapping SFHAs.

The FIRM currently in effect for the Sunnyvale shoreline was approved in 2009. It is based on a BFE estimated from long-term water level records at the Golden Gate and historic flood events, particularly flood events from 1983 when the highest observed water levels occurred. While the current and preliminary FIRMs (FEMA, 2009, 2015b) show the locations of the coastal levees along the Sunnyvale and neighboring shorelines, these levees are designated as non-accredited. These levees do not meet FEMA's accreditation criteria for crest elevation and geotechnical properties. Thus, for mapping purposes, these levees and floodwalls that are assumed to fail completely during a flood event and allow water to propagate landward unimpeded. The 2009 FIRM is based on projecting the BFE inland from the open Bay, and all hydraulically connected areas below the BFE are mapped within the SFHA. As shown in **Figure 6**, the existing SFHA extends over the northern half of the Plan Area to just south of Java Drive. Parts of the Plan Area that are farther south are on ground that is higher than the BFE.

Figure 6. Existing Coastal Flood Hazard



In 2015, FEMA released draft preliminary FIRMs for the South Bay as potential updates to the 2009 current effective FIRM. In addition to re-analyzing water levels by using a longer historic record and hydrodynamic modeling, the 2015 mapping also considers the flood hazard from waves. The 2015 methodology determined that waves add to flood hazard in the Baylands north of the Plan Area and would need to be considered in the design of levee improvements between the Baylands and the Plan Area to achieve FEMA accreditation. Even though they are non-accredited, the existing levees are considered by FEMA to attenuate waves inland of the levees such that waves do not significantly affect flood hazard mapping within the Plan Area. Because the 2015 preliminary maps found the open Bay BFE to be slightly higher, the 2015 preliminary FIRM shows the SFHA extending up 1,000 feet farther south and at a slightly higher elevation than the 2009 current effective FIRM.

In 2016, Valley Water submitted an appeal to the 2015 draft maps (NIBS, 2020). The appeal postulates that BFEs in the Plan Area are more than 1 foot lower than the BFE in the open Bay. This contrasts with the 2009 current effective and 2015 preliminary FIRMs, which assume that the open Bay BFE projects into the Plan Area without any reduction in elevation. The appeal is based on additional hydrodynamic modeling that assumes multiple breaches in the Baylands' non-accredited levees that are north of the Plan Area. The modeling indicates that the Baylands ponds store floodwaters during the few hours of peak high tide water levels, resulting in lower water levels moving inland across the ponds and into the Plan Area. Scientific review by the National Institute of Building Sciences (NIBS) found Valley Water's technical approach to be reasonable and more correct than the methodology used to draft the 2015 preliminary maps. FEMA is still considering the NIBS review and deciding on its response to the appeal.

In areas within both the coastal SFHA and riverine SFHA, FEMA maps whichever source results in higher and more extensive flooding. North of State Route 237, the mapped SFHA is inundated from the Bay as a coastal source; south of State Route 237, the mapped SFHA is inundated from fluvial sources, as discussed below.

2.2.1.2 2017 Preliminary Feasibility Study for the Santa Clara County Shoreline

Valley Water conducted flood hazard mapping for the Santa Clara County shoreline from San Francisquito Creek in Palo Alto to Guadalupe River in San José (Valley Water, 2017). The purpose of this mapping was to inform the feasibility of implementing levee improvements, environmental enhancements, and recreation improvements and to prepare for future phases of the South San Francisco Bay Shoreline Study.

When compared to the 2009 current effective and 2015 preliminary FIRMs, the 2017 Preliminary Feasibility Study's modeling predicted similar Bay water levels outboard of non-accredited levees for the 1% annual chance event. However, within the Plan Area landward of the levees, the 2017 Preliminary Feasibility Study predicts water levels approximately 1 foot lower than the FEMA predictions. These differences result from the 2017 Preliminary Feasibility Study explicitly modeling levee breaching in the Baylands and the resulting limited hydraulic conveyance of inland flooding past the levees, similar to the methodology used by Valley Water in its appeal of the 2015 preliminary maps (NIBS, 2020). In contrast, the methodology used for the 2009 and 2015 FIRMs projects Bay water levels inland without any consideration of how remaining levee segments and the limited duration of peak water levels will affect inland conveyance. Because the 2017 Preliminary Feasibility Study predicts lower inland water levels, its predictions of flood inundation depths and extents are also smaller relative to the FEMA mapping.

The 2017 Preliminary Feasibility Study's flood hazard mapping was combined with an economic analysis of potential flood damages and levee construction costs. Then, by comparing the flood damage for existing conditions as compared to proposed levee improvements, the Study evaluated the benefit-cost ratio for levee improvements. A benefit-cost ratio greater than one indicates that the benefit reaped from a project would be greater than the cost to construct the project. The Study found the benefit-cost ratio to be greater than ten for much of the Plan Area, indicating substantial benefits of levee improvements that reduce flood damages. The benefit-cost ratio would need to be revisited based on updated cost and damages data as part of the future South San Francisco Bay Shoreline Phase III Feasibility Study (described in Section 3.2).

2.2.2 Fluvial Flooding

The Sunnyvale East and West Channels are at risk of flooding due to several factors: (1) insufficient conveyance capacity for discharge from the channels' watersheds; (2) backwater flows from Calabazas and San Tomas Aquino Creeks during 100-year discharge in these creeks and (3) elevated Bay water levels.

Flood risk is most severe when all three factors occur simultaneously, which is possible because all three are associated with winter storm events. In the 1960s, the channels were designed to convey the 10-year event, the same design for the stormwater system. As a result, the channels lack sufficient capacity to convey the 100-year event with sufficient freeboard to meet FEMA requirements.

Calabazas Creek and San Tomas Aquino Creek discharge into Guadalupe Slough upstream of where the Sunnyvale Channels discharge into Guadalupe Slough. The combined discharge from these two watersheds (21 square miles for Calabazas Creek and 45 square miles for San Tomas Aquino Creek) is predicted to raise water levels in Guadalupe Slough such that water could back up the East and West Channels. These elevated water levels at the end of the channels compromises the capacity of the channels to adequately convey larger discharges from their own watersheds.

The downstream portions of the Sunnyvale Channels are tidally influenced. Presently, mean high tide extends to State Route 237 in the East Channel and to Matilda Road in the West Channel. When storm surge events occur, as described in Section 2.1.3, Bay water levels back up to the mouths of these channels, and have a similar effect of impeding the discharge capacity of the channels.

Modeling conducted for FEMA's flood insurance study map for the City of Sunnyvale indicate that flooding from the channels would occur for a 100-year storm event. Generally, the flood risks are larger in the downstream reaches of the drainage channel, where the 100-year water surface elevation is due to the combination of water levels in the Bay, backwater flow from Calabazas and San Tomas Aquino Creeks, and large runoff volumes from the watershed (Valley Water, 2010). In the downstream reaches of the channels, the floodwall and levee crest elevations need to be raised several feet, up to approximately five feet in some spots, to meet FEMA accreditation requirements.

2.3 Climate Change

The accumulation of human-produced greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and climate change. This section documents expected impacts on hydrology and flood hazard in the Plan Area as a consequence of climate change, including projected sea-level rise, and changes in precipitation and groundwater.

2.3.1 Sea-Level Rise

Along the Bay shoreline, the change towards warmer climate will cause sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets. Over the last century, the tide gauge in San Francisco has recorded sea-level rise of 8 inches (NOAA, 2020). In addition to this observed past sea-level rise, the best available science, as reviewed specifically for California by a panel of national experts (Griggs et al., 2017), predicts that sea-level rise will continue and accelerate throughout this century and into the next century.

Because future greenhouse gas emissions and climate response are not precisely known, the exact sea-level rise scenario that will occur is also not precisely known at this time. To accommodate this uncertainty, the State of California (OPC, 2018) recommends considering a range of scenarios for climate change adaptation planning and assuming higher emissions. **Table 4** lists sea-level rise projections for 2030, 2050, 2070, and 2100 relative to sea-level in 2000. OPC's "likely range" for low risk aversion is estimated to have a 66% chance of occurrence, whereas the medium-high risk aversion range is estimated to have a 0.5% chance of exceedance. OPC also identifies an extreme sea-level rise scenario, the "H++" scenario. Although current conditions indicate that the H++ scenario is very unlikely to occur, its occurrence cannot be completely ruled out for the second half of this century. Consideration of the H++ scenario is recommended for projects that have minimal adaptive capacity and warrant extreme risk aversion, which was not deemed appropriate for the Plan Area. Most recently, the state's strategy calls for constructing adaptation measures by 2050 that provide resilience for at least 3.5 feet of sea-level rise (OPC, 2020).

TABLE 4
SEA-LEVEL RISE PROJECTIONS FOR SAN FRANCISCO

Scenario	2030	2050	2070*	2100
OPC (2018) Current State Guidance				
66% Likely Occurrence: Low Risk Aversion	0.5	1.1	1.9	3.4
0.5% Chance of Exceedance: Medium-High Risk Aversion	0.8	1.9	3.5	6.9
NRC (2012) Prior State Guidance				
Projection	0.5	0.9	1.8	3.0
Upper end of Range	1.0	2.0	3.6	5.5
USACE (2013) for Shoreline Phase I Project (Valley Water, 2017)				
Intermediate	0.4	0.7	1.0	1.8
High	0.8	1.6	2.6	5.1

NOTES:
OPC (2018) assumes high emissions scenario.
* 2067 for USACE (2013), as selected for the Shoreline Phase I Project.

In addition to the state's current sea-level rise projections, prior projections from the state and the USACE still inform some of the sea-level planning affecting the Plan Area. For example, prior to the state's most recent assessment of sea-level rise scenarios (Griggs et al., 2017), the state relied on the National Research Council (2012) projections for sea-level rise. This assessment used different terminology and did not include probabilities. Sea-level rise planning that started prior to 2018, such as the Bay Conservation and Development Commission's Adapting to Rising Tides (ART) effort, typically use these projections, e.g. 5.5 ft (66 inches) of sea-level rise by 2100

(BCDC, 2016). The approach used to project sea-level rise for the 2017 Preliminary Feasibility Study (Valley Water, 2107) is USACE (2013), since the USACE would be the lead agency for any future phases of the South San Francisco Bay Shoreline Study. USACE practice also calls for using a fifty-year project lifespan, which was selected as 2017 to 2067 for the Shoreline Phase I Project.

The projections from OPC (2018), NRC (2012), and USACE (2013) for the 2017 Preliminary Feasibility Study (Valley Water, 2017) are compared in Table 4. Other agencies and researchers around the world have interpreted the available information about sea-level rise and provide slightly different projections for future sea-level rise. Given the evolving science and uncertainty about future greenhouse gas emissions, variations in projected future sea-level rise are inevitable. In the face of this uncertainty, current guidance is to plan and implement adaptation measures for a substantial amount of sea-level rise and then continue to monitor and adjust long-term planning in the coming decades. When the values in Table 4 are rounded to the nearest foot, the projections are in general agreement and support implementing measures to adapt to three feet of sea-level rise and planning for higher amounts of sea-level rise in the long term.

Table 5 shows how flood stage water levels in the Bay near Sunnyvale would change with different amounts of sea-level rise. The table's cells are shaded such that the same shading indicates correspondence between existing conditions with zero sea-level rise and future conditions. For example, the existing 10-year water level of 9.8 feet NAVD88 will occur with a 1-year return interval with 1 foot of sea-level rise and with a daily return interval with 2 feet of sea-level rise. With three feet of sea-level rise, the Plan Area will experience water levels on an annual basis (99% annual chance) that only have a 1% annual chance of occurring today.

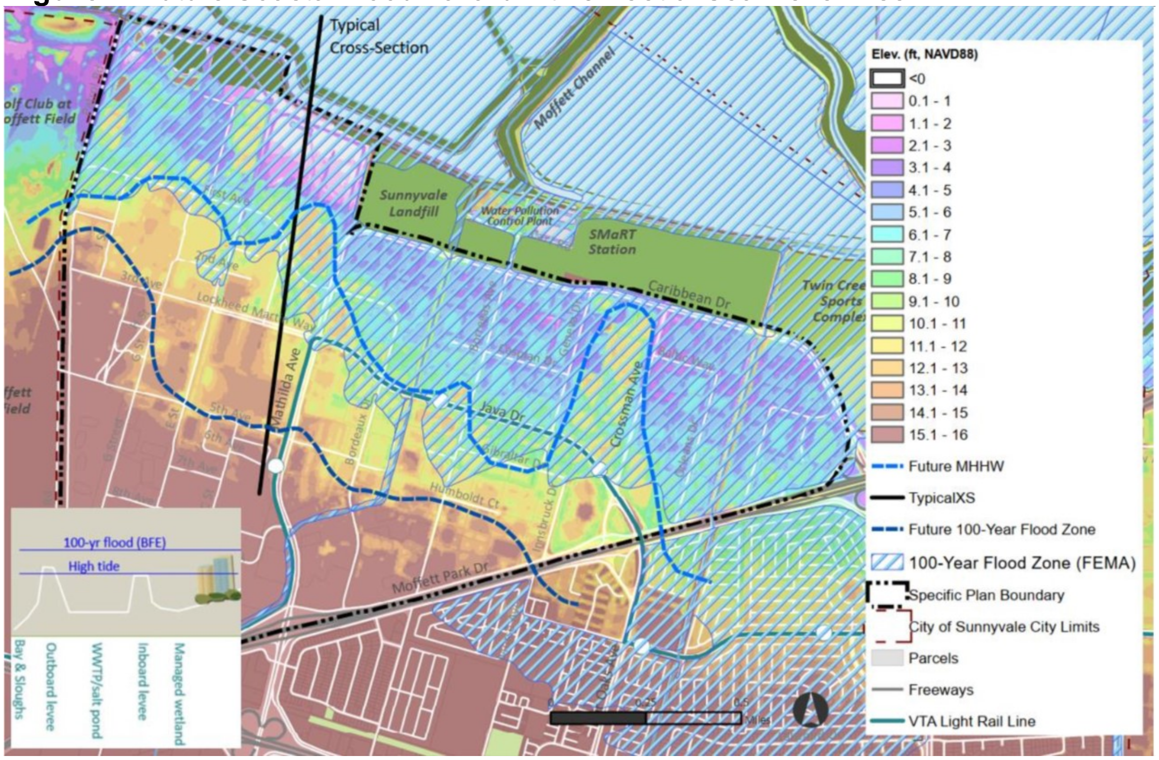
For the Plan Area, the potential extent of the coastal flood hazard with three feet of sea-level rise is shown in **Figure 7**.

TABLE 5
FUTURE WATER LEVELS WITH SEA-LEVEL RISE NEAR SUNNYVALE, IN FEET NAVD88

Annual Chance (Return Interval)	0 Feet Sea-Level Rise	1 Foot Sea-Level Rise	2 Feet Sea-Level Rise	3 Feet Sea-Level Rise	5 Feet Sea-Level Rise
(Daily Mean Higher High Water)	7.4	8.4	9.4	10.4	12.4
99% annual chance (1-year)	8.6	9.6	10.6	11.6	13.6
10% annual chance (10-year)	9.8	10.8	11.8	12.8	14.8
1% annual chance (100-year)	11.4	12.4	13.4	14.4	16.5

SOURCES: AECOM, 2016; OPC, 2018

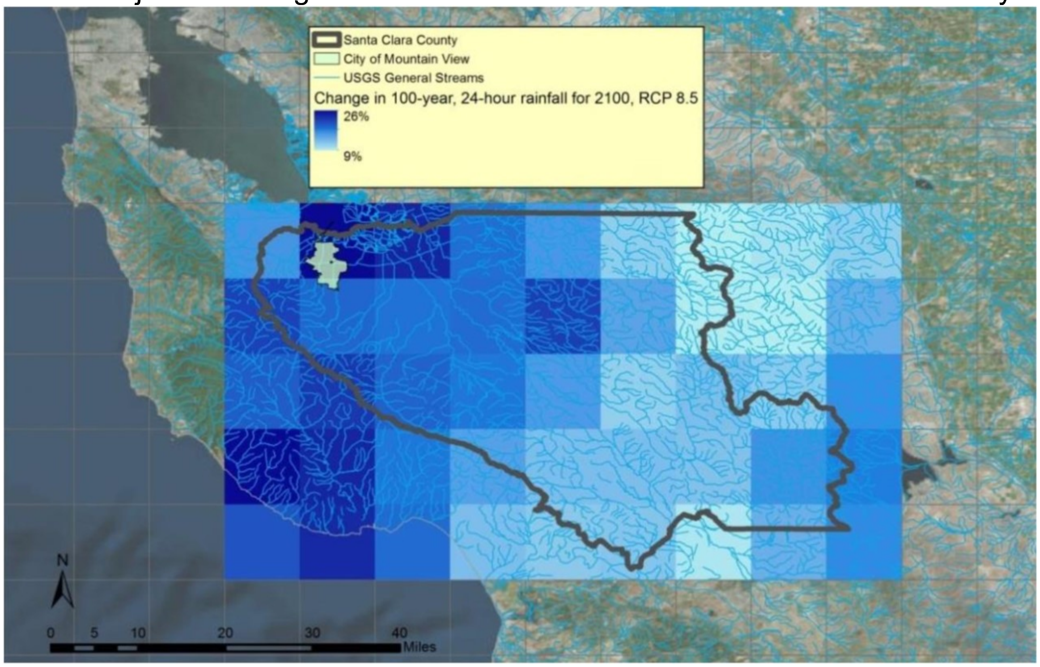
Figure 7. Future Coastal Flood Hazard with 3 Feet of Sea-Level Rise



2.3.2 Precipitation

Climate change is anticipated to increase the frequency and intensity of precipitation events and, consequently, watershed discharge, although not all geographies will experience this shift uniformly. Regional climate modeling predicts more intense precipitation for the West Coast and California, particularly during the wettest storms that cause the most flooding (Cayan et al., 2016; Dettinger, 2016). Higher amounts of precipitation will result in more severe flood hazards from riverine flows, stormwater and groundwater sources, to infrastructure and human life if no adaptation actions are pursued. **Figure 8** shows that projected increases in the 100-year 24-hour rainfall in the Sunnyvale watershed within Santa Clara County ranging from 30% to 80% by 2100 (Schaaf & Wheeler and ESA, 2017).

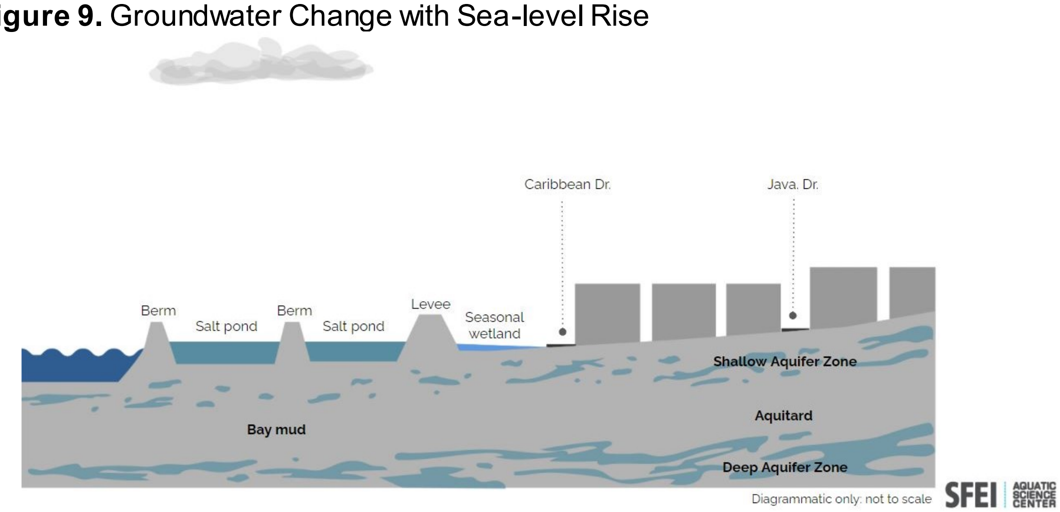
Figure 8. Projected Change in 100-Year 24-Hour Rainfall for Santa Clara County



2.3.3 Groundwater

Currently, the minimum depth-to-water is greater than 3 feet in most of the Plan Area (Figure 5). With sea-level rise, groundwater in areas by the shoreline is also expected to rise and saline groundwater to translate landward (**Figure 9**). Plane et al. (2019) assume a one-to-one linear increase in groundwater elevation for an unconfined aquifer within 0.6 miles of the shoreline. Given that the Plan Area has a predominantly confined shallow aquifer system, using the Plane et al. (2019) assumption probably provide an over-estimate of increases in groundwater elevation caused by sea-level rise.

Figure 9. Groundwater Change with Sea-level Rise



With this one-to-one linear increase in groundwater elevation, most of the Plan Area would not see any surface expression of groundwater for at least 3 feet of sea-level rise and about half the

Plan Area would not see any surface expression of groundwater for at least 6 feet of sea-level rise. The northeast Plan Area, between the East Drainage Channel and East Caribbean Drive, appears to be most vulnerable to rising groundwater manifesting at the surface, with only about 3 feet minimum depth-to-water. Because the Plane et al. (2019) data are the minimum depth-to-water over a 20-year period, the corresponding hazards with 3 feet of sea-level rise causing surface expression of groundwater would only be during the rainy season during wetter years.

The managed seasonal wetlands in the northwest of the Plan Area would likely be inundated more frequently and with greater depths. These areas are at least several feet below most adjacent ground surface and almost 10 feet below the base flood elevation which governs the lowest finished floor elevation for structures. Thus, structures meeting finished floor elevation requirements would face negligible hazard from rising groundwater. Roads and other surface infrastructure in these low-lying areas may be exposed to more frequent ponding of groundwater. In addition, higher water levels in these wetlands would reduce their storage capacity for accommodating stormwater runoff from the Plan Area.

Rising groundwater may have impacts on underground structures before the water table reaches the ground surface, but most underground infrastructure is already resistant to wetting. The hazard of increased frequency and depth of inundation would need to be evaluated on a case-by-case basis for individual subsurface structures.

3. Adaptation Strategy

This section describes adaptation strategy measures that are currently being planned for key infrastructure around the city of Sunnyvale and South San Francisco Bay. For many of these measures, Valley Water is the lead implementing agency, and the City has been an active participant in the visioning and planning process for these measures. As presented here, the focus is on how the measures meet the City's goal of providing flood protection and sea-level rise resilience for Moffett Park.

Although the levee measures are described individually, a complete perimeter is needed to protect the Plan Area from multiple flood sources and pathways. Any low spots or weak points where floodwater can penetrate can reduce or negate the benefits of better flood protection in other parts of the perimeter.

Implementing all of the elements of this strategy is a substantial effort that will likely take years. Even though protecting all the Plan Area depends upon completing the full strategy, in some portions of the Plan Area, early phases of adaptation may achieve improved protection before the entire adaptation effort is complete. For example, between the East Channel and West Channel would be more protected once measures to address flooding from these two channels are constructed, because the high ground of the landfill already isolates this area from most Bay flood pathways.

3.1 Adaptation Approach

As explained in Section 0, Moffett Park and other City infrastructure are already exposed to flood hazards from the Bay, stormwater, and the fluvial drainage channels. Sea-level rise will exacerbate these flood risks and also raise groundwater levels. Possible adaptation approaches are described in the next section (Section 3.1.1) and the City's integration of these approaches to develop its strategy is described in the following section (Section 3.1.2).

3.1.1 Potential Adaptation Approaches

To adapt to increasing flood hazard due to sea-level rise, there are three basic approaches: realign, protect, and accommodate (California Coastal Commission 2015). These adaptive management approaches are interpreted for Moffett Park as follows:

- **Realign—**This approach relocates or removes assets landward and to higher elevations, thereby realigning the defended shoreline to reduce exposure. This can be achieved at the planning level by rezoning or limiting development in floodplains. Acquisition and buyout programs, transfer-of-development-rights programs, removal of structures, and habitat restoration are examples of realignment measures.

- **Protect**—This approach uses physical barriers to defend the perimeter of developed areas such that assets landward of the barriers are less likely to be inundated. The most substantial flood protection benefits are due to structural "gray" barriers, such as levees and floodwalls. "Green" natural features such as marshes can complement structural barriers with incremental flood protection benefits and improved shoreline habitats.

Physical barriers can be implemented either by initially constructing as high as possible; or in an adaptive manner, by starting at elevations appropriate for existing conditions while providing capacity to make future upgrades in response to sea-level rise. For example, levee construction may plan for a base wider than necessary for its initial elevation, to facilitate future increases in crest elevation.

- **Accommodate**—This approach prepares for occasional flooding by modifying assets and practices to tolerate inundation with less damage, thereby increasing resilience and speeding recovery. For instance, accommodation includes specifying finished floor elevations to raise key building components above flood levels, as well as floodproofing to reduce and resist the hydraulic forces caused by inundation. In addition, this approach includes improving a community's flood preparedness practices, such as maintenance, flood event procedures, and recovery planning.

An overall strategy to reducing flood risk typically combines aspects of all these approaches, to share flood management among approaches and entities.

3.1.2 Overview of City Strategy

The approach to adapt the Plan Area shoreline to sea-level rise combines aspects of all three of the basic approaches. This site-specific approach is based on the flood hazards that Sunnyvale and neighboring communities are facing, as well as the opportunities and constraints of the setting and adaptation measures. This approach includes implementable measures that would reduce the flood risk for existing conditions and up to approximately 3 feet of sea-level rise. The best available science indicates that sea-level rise greater than 3 feet is unlikely to occur for 50 years or more. Within this window of five decades or more, these adaptation strategies can support safe and economically viable development in the Plan Area.

After this overview of the City's adaptation strategy, details of the adaptation measures which employ realignment, protection, and accommodation to address adapt to 3 feet of sea-level rise are provided in Section 3.2 to Section 3.7 below.

3.1.2.1 Realignment

Where feasible, the adaptation strategy for the Sunnyvale shoreline includes landward realignment of flood protection measures, thereby allowing natural processes to create and sustain wetland habitats. This realignment reduces overall flood management costs, because it results in shorter length of shoreline to be protected. Instead of maintaining the outboard salt pond berms and levees (**Figure 10**), the current coastal levee alignment has been revised substantially landward (**Figure 11**). The outer levees will be breached, facilitating marsh restoration and enabling the construction of habitat transition zones or "horizontal levees" along the landward edge of the restored ponds. In addition, options to widen the East and West Channels are being planned to expand the riparian habitat along these channels. Realignment that reduces the extent of existing development within the Plan Area is not consistent with the City's preference to maintain safe and economically viable development within the Plan Area for up to 3 feet of sea-level rise.

Figure 10. Sea-level Adaptation – Preserve Existing Levee Alignment

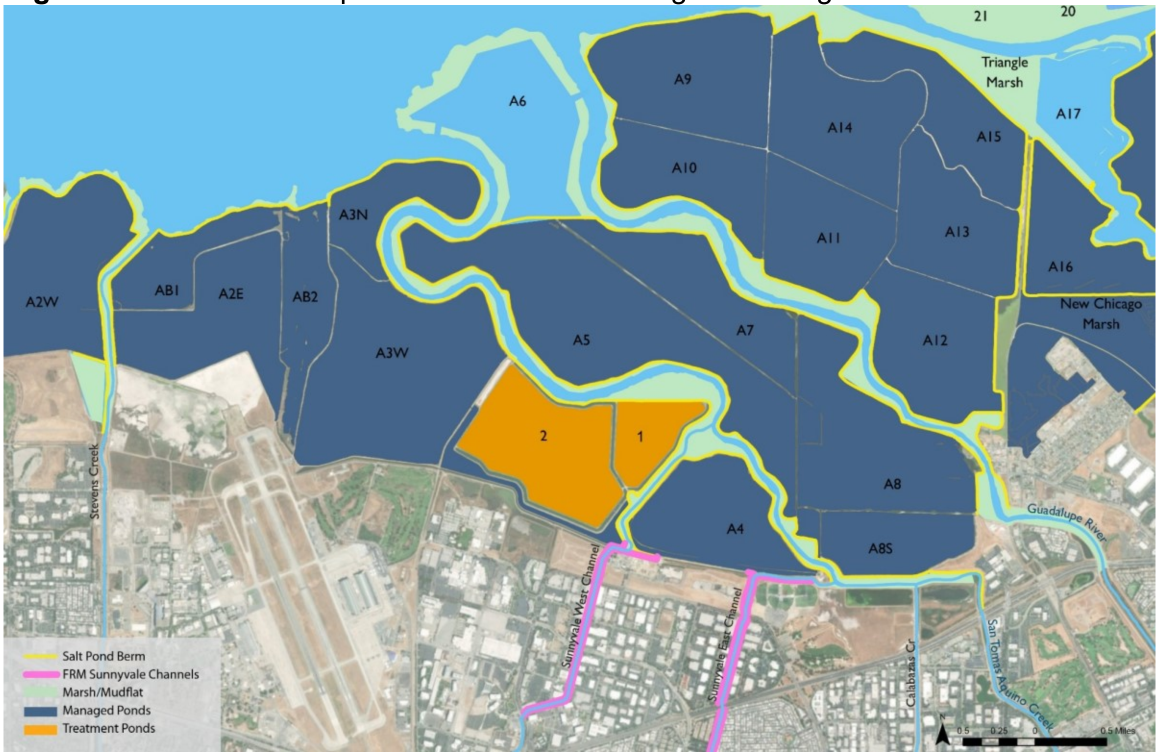
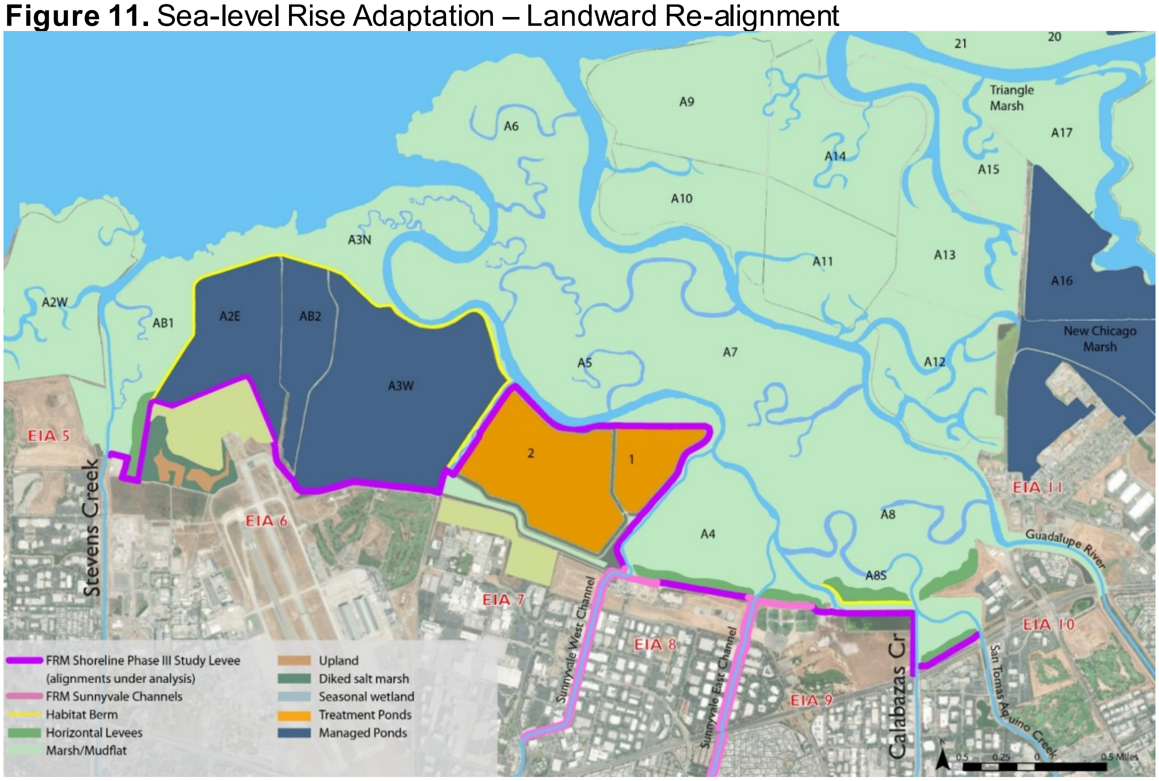


Figure 11. Sea-level Rise Adaptation – Landward Re-alignment



3.1.2.2 Protection

Landward of the realigned shoreline, the developed Plan Area will be protected from flooding by an improved system of levees and floodwalls. These flood protection barriers will follow along existing barrier footprints. Design conditions for these barriers are at least at the 100-year event with the addition of freeboard and additional elevation to adapt to sea-level rise. Although specific freeboard and sea-level rise criteria vary by project and flood source, the City's target for these projects is to improve the existing level of flood protection for at least 3 feet of sea-level rise as compared to existing conditions. Key protection projects for the Plan Area and other City infrastructure include the Shoreline Study levees to protect against coastal flooding from the Bay, the Sunnyvale East and West Channel Flood Protection Project to protect against fluvial flooding from precipitation runoff, and a floodwall surrounding the main area of City's Water Pollution Control Plant.

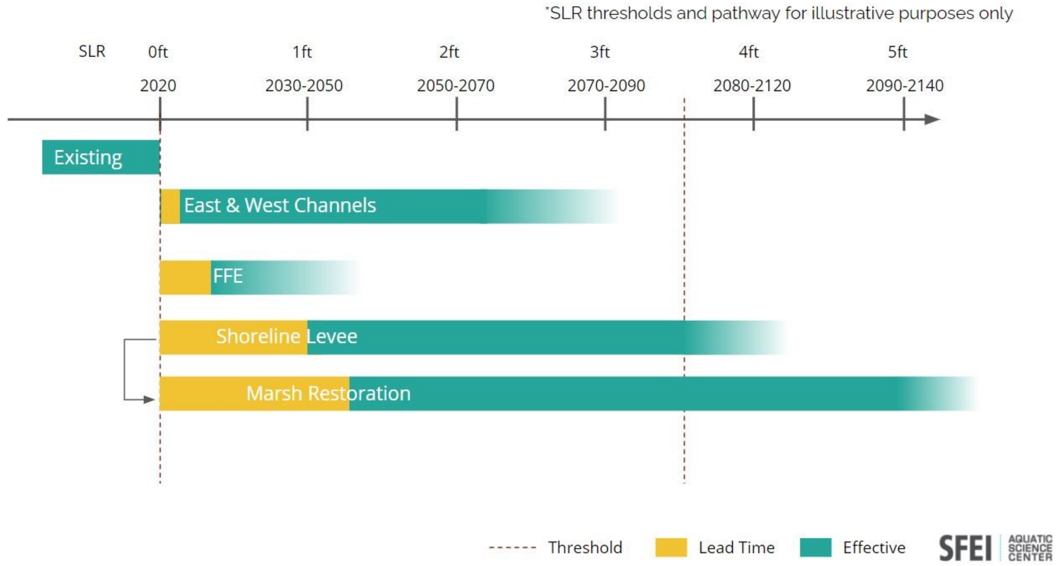
3.1.2.3 Accommodation

The third approach to adapting to sea-level rise, accommodation, will be employed to address several aspects of flood risk in the Plan Area. Buildings in the Plan Area must meet minimum finished floor elevations at or above the base flood elevation, to reduce damages in the event of flooding. The City is considering raising its finished floor elevation requirement for non-residential buildings by 1 foot, which would provide additional accommodation for higher floodwaters due to sea-level rise. The capacity of the stormwater system to collect and discharge runoff, will be evaluated for future sea-level rise and precipitation conditions. Expanding the use of wetlands to detain stormwater in the northwest portion of the Plan Area will be explored. Similarly, groundwater, which will rise in conjunction with sea level, will be assessed for increasing its potential for surface inundation as well as subsurface contamination and corrosion hazards. Surface inundation from groundwater will be addressed in coordination with the stormwater system. Contamination and corrosion hazards will be addressed through the building code's geotechnical investigation framework and construction materials requirements.

3.1.2.4 Timeline

Implementing all the measures in this strategy are anticipated to take a decade or more. The anticipated schedule for key components is shown in **Figure 12**. This timing is a function of lead time to secure funding, to design, and to permit these measures. In addition, measures may be dependent on one another. For example, breaching to restore the former ponds will raise floodwater levels within the ponds and along their boundary with the Plan Area, landward edge of the ponds, exacerbating flood hazard for the Plan Area. Hence, this levee realignment is scheduled for after completion of the Shoreline Project levees.

Figure 12. Sea-Level Rise Adaptation Timeline



3.1.2.5 Differences in Sea-level Rise Design Criteria

As described below, all of the measures composing the City's adaptation strategy do not use exactly 3 feet of sea-level rise in their design criteria. The different amounts of sea-level rise are indicative of the practices of different lead agencies and that the projects were started at different times while scientific projections of sea-level rise and adaptation guidance have evolved rapidly in the last decade. The key protective measures, the Shoreline Phase I Project and the East and West Channel project currently consider 2.6 feet and 2 feet of sea-level rise, respectively. However, both of these projects also include at least an additional 2 feet of freeboard, as required to achieve FEMA accreditation. This freeboard provides additional adaptive capacity for sea-level rise beyond the projects' design criteria. As future phases of these projects are initiated, the amount of sea-level rise used in their design could be reevaluated based on the most recent projections and guidance, including consideration of the latest state guidance (OPC, 2020) to adapt to 3.5 feet of sea-level rise.

3.1.2.6 Long-Term Planning for Sea-Level Rise Above 3 Feet

The adaptation measures above sea-level rise will reduce flood risk in the Plan Area for at least 3 feet of sea-level rise, or until at least 2070 and possibly to 2100 (OPC, 2018). Sea-level rise greater than 3 feet is possible toward the end of this century and likely to occur in the next century. To address this future risk, the City's strategy is to continue the long-term adaptation planning process exemplified in this study. This process will monitor sea-level rise rates, performance of the existing strategy measures, and what additional adaptation may be needed to maintain flood protection. Additional adaptation measures may include: landward realignment, raise levee and floodwall barrier elevations, raise building elevations, groundwater management, and stormwater improvements.

3.2 Overview of South San Francisco Bay Shoreline Study

The overall goal of the South San Francisco Bay Shoreline Study (Shoreline Study) is to safeguard and protect hundreds of homes, schools, and businesses along Santa Clara County's 18 miles of shoreline from the risk of coastal flooding. The Shoreline Study also aims to restore tidal marsh and related habitat that was lost due to former salt production activities, provide opportunities for continued recreational and public access along the Bay shoreline, and takes into consideration sea-level rise protection over a 50-year period.

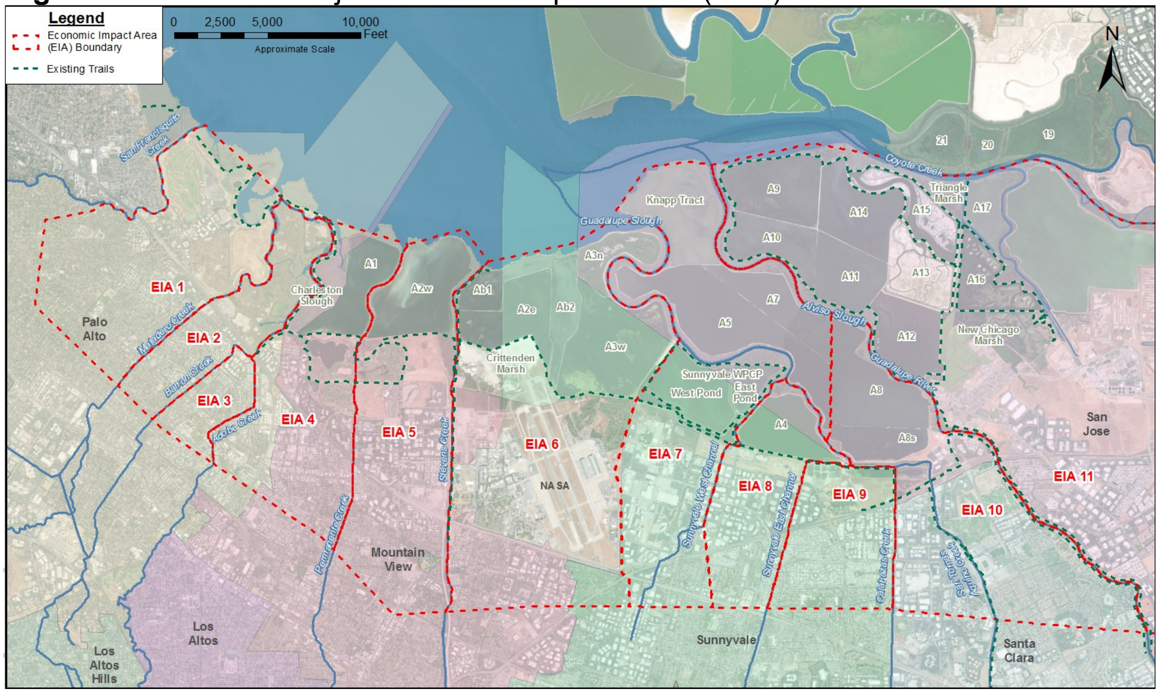
The Shoreline Study is being undertaken by USACE, Valley Water, and the California Coastal Conservancy. Authorization to conduct the Shoreline Study was granted by the Water Resources Development Act in 1976. Valley Water and the California Coastal Conservancy are the non-federal sponsors. The Shoreline Study efforts began in 2005 for all of Santa Clara County which was divided into 11 areas, called Economic Impact Areas (EIAs). EIAs are separated by creeks or land use boundaries (**Figure 13**). After gathering data for the entire County, Valley Water requested that USACE re-evaluate the Shoreline Study scope and conduct the Shoreline Study in phases beginning with the area that has the highest potential economic impacts. In 2011, the Shoreline Phase I Feasibility Study was thereafter refocused to EIA 11 located in north San José between the Alviso Slough and Coyote Creek.

The USACE authorized the South San Francisco Bay Shoreline Phase I Project in EIA 11 on December 18, 2015, when the USACE's Chief of Engineers signed the Chief's Report. The authorized project will provide 1-percent coastal flood risk management for the urban area of north San José, including the community of Alviso and the San José -Santa Clara Regional Wastewater Facility, and ecosystem restoration of approximately 2,900 acres of former salt ponds with recreational elements. Coastal flood risk management consists of 4 miles of new levee and structures at the Union Pacific Railroad and Artesian Slough crossings, with inclusion of protection for 2.6 feet of sea-level rise. Tidal marsh restoration will occur in Ponds A9-A15 and A18 pursuant to an adaptive management plan. In addition, an upland transition area (ecotone) will be constructed adjacent to the new levee in Ponds A12, A13 and A18 in order to provide habitat refugia for marsh species during high tides and storms.

The total design and construction cost of the Shoreline Phase I Project in EIA 11 is $177.2 million, which was authorized in the Water Infrastructure Improvements for the Nation (WIIN) Act. The WIIN Act was signed into law on December 16, 2016. On July 5, 2018, the Shoreline Phase I Project was awarded $177.2 million under the USACE Fiscal Year 2018 Disaster Supplemental Appropriations Bill. The non-federal sponsors' local cost share, to re-pay the initial outlay from the federal funding, is $103 million. Figure 13Construction bidding for Phase I is anticipated in 2021.

Concurrent with the Phase I effort, Valley Water conducted a preliminary feasibility study that included more detailed flood hazard mapping and benefit-cost analysis for EIAs 1-10 to inform the feasibility of implementing levee improvements, environmental enhancements, and recreation improvements and prepare for future phases of the Shoreline Study (Valley Water, 2017).

Figure 13. Shoreline Project Economic Impact Areas (EIAs)



To best conform to USACE's Feasibility Study policies and other federal requirements, EIAs 1-4 (from San Francisquito Creek in Palo Alto to Mountain View Slough in Mountain View) were selected to compose the Shoreline Phase II Feasibility Study area and EIAs 5-10 (from Mountain View Slough to Guadalupe River in San José) were selected to compose the Shoreline Phase III Feasibility Study area. The Shoreline Phase III's Feasibility Study may start at the end of 2021 depending on the receipt of federal funds.

Phase III of the Shoreline Study will determine the feasibility of providing improved coastal levees and habitat restoration in EIAs 5 through 10 that would protect the Plan Area. If the study receives congressional authorization and appropriation, the proposed coastal levees and habitat restoration resulting from the Shoreline Phase III Feasibility Study would be implemented. The Shoreline Phase III Feasibility Study will consider a wide range of potential levee alignments in the study area; however, the City's preliminary preferred levee alignment is shown in Figure 11. This alignment would also protect the WPCP, the WPCP's treatment ponds, the Sunnyvale Materials Recovery and Transfer (SMaRT) Station solid waste processing facility, and the landfill. The Shoreline Phase III Feasibility Study team will complete coastal hydraulic analysis to predict water levels for the 1% coastal flood and use the latest studies to determine the appropriate sea-level rise consideration for a 50-year period. The Shoreline Phase III Feasibility Study would consider preliminary designs of levees that meet USACE design criteria as well as FEMA accreditation criteria.

While constructing the Shoreline Study levees immediately north of the Plan Area will reduce flood risk in the Plan Area, improving these levee reaches alone will not address all of the coastal flood pathways threatening the Plan Area. To the west, low-lying topography that matches topography in the Plan Area continues uninterrupted until the east levee of Stevens Creek.

Therefore, Phase III of the Shoreline Project includes levee improvements as far west as the mouth of Stevens Creek (EIA 6) and as far east as the mouth of the Guadalupe River (EIA 10) to protect the Plan Area. The levees along the lower section of Stevens Creek and the lower section of Calabazas Creek are also not FEMA accredited, leaving coastal flooding and/or riverine flooding from the lower creeks as another potential pathway to be addressed.

The City should continue to collaborate on these regional levee reaches for EIAs 5-10 to support contiguous flood protection for the Plan Area and other areas of Sunnyvale outside the Plan Area. The amount of sea-level rise that will be used to set the levee's crest elevation, as well as the cost sharing between federal, state, and local sources remain part of ongoing decision-making for these levees.

3.3 South Bay Salt Pond Restoration Project

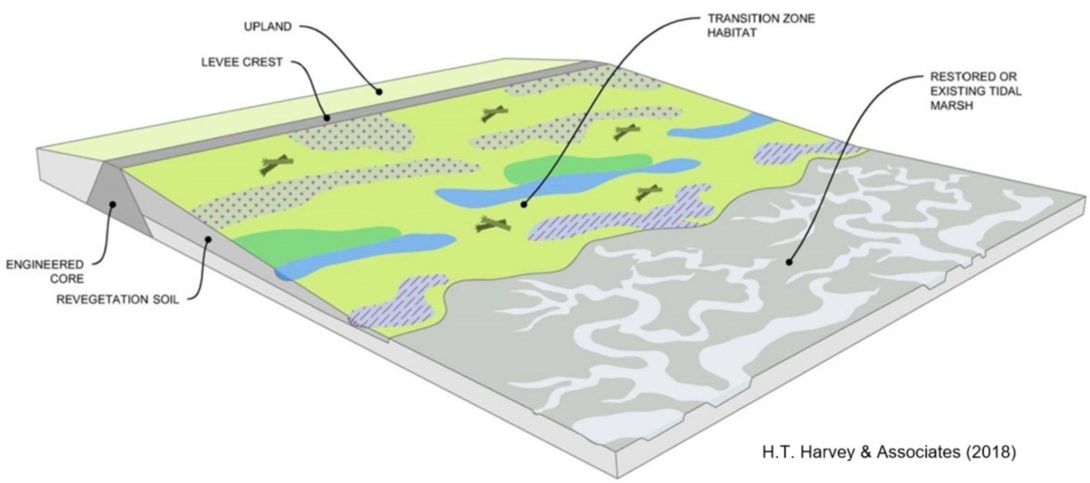
Nature-based measures to enhance the shoreline can complement the coastal levee improvements described above. As natural features, these measures can provide habitat, additional buffering against flooding and erosion that threatens levees, water quality management, and may evolve over time in response to sea-level rise.

The South Bay Salt Pond Restoration Project, a collaboration between the California Coastal Conservancy, the California Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service, manage many of the former salt ponds north of the Plan Area. Once the Shoreline Project provides improved flood protection between the former salt ponds and the Plan Area, then the former salt ponds' outboard levees can be breached, realigning the defended shoreline landward. This breaching will restore hydraulic and sediment connectivity between the ponds and the Bay. After sufficient sediment deposits in the ponds and raises their bed elevation, wetland vegetation will reestablish within the ponds and restore tidal marsh habitat to these ponds.

Habitat transition zones, also known as "horizontal levees" or "ecotones," are nature-based measures which also offers benefits to the Bayfront levees (**Figure 14**). This feature consists of a gently sloping berm on the outboard side of a levee. When combined with appropriate hydraulic connectivity, this configuration provides tidal wetland habitat and adjacent transitional uplands. By providing these habitats adjacent to one another, tidal wetland wildlife can use the uplands as refugia during high water events in the wetlands. The berm and vegetation also provide wave attenuation and scour protection for the levee itself. Because of its gentle slope, the habitats have adaptive capacity to shift upward and landward with sea-level rise, instead of being overwhelmed and lost to sea-level rise. These slopes could also be used to provide some additional treatment for treated wastewater and/or byproducts from drinking water treatment. Treating wastewater is currently being tested at the Oro Loma Sanitary District's horizontal levee.

Regional planning (e.g., USFWS and CDFG, 2007; SFEI and SPUR, 2019) and the Sunnyvale Shoreline Resilience Vision process (SFEI and ESA, 2019), as shown in Figure 11, has identified the southern shore of Pond A4 as a potential site for constructing habitat transition zones near the Plan Area, pending planning for the long-term use of this (Section 2.1.2.2). In addition, the southern end of the Pond A8 complex, and Ponds A2E, AB2, and A3W are nearby ponds owned and managed by the U.S. Fish and Wildlife Service, which are also considering habitat transition zones. Construction of these features requires a substantial source of imported soil to create the berms.

Figure 14. Habitat Transition Zone



3.4 Discharge Channels

As described in Section 2.2.2, the lower portions of the West Channel (north of Java Drive) and East Channel (north of State Route 237) do not currently meet FEMA freeboard requirements for levee accreditation for the 1% annual chance discharge. In addition, with sea-level rise, the design water surface elevation would be boosted higher in the channels' lower reaches, such that levees farther upstream that currently meet freeboard requirements could lose their accreditation.

Valley Water conceptualized, designed and permitted improvements to the discharge channels, for the Sunnyvale East and West Channels Flood Protection Project, which is designed to provide additional flood protection for the 100-year event as well as improve water quality. The project was initiated under the District's "Clean, Safe Creeks and Natural Flood Protection Plan". A preferred alternative was identified after evaluation of several conceptual alternatives and further refined through the environmental review process. Pending receipt of final permits, improvements to these two channels are scheduled for construction starting in 2021, with anticipated completion in 2023.

The improvements include a range of upgrades to the discharge channels. Major components of the improvements include the following (Valley Water, 2019a):

- Construction of vertical floodwalls along existing maintenance roads.
- Installation of flap gates to prevent backflow from the channels.
- Raising and/or widening existing levees.
- Raising and/or resurfacing maintenance roads.

- Increasing stream flow capacity at bridges/culverts.
- Stabilization of eroding stream banks with rock material.

Other proposed project components include stabilization of specific culvert outfalls removal of excessive sediment.

New floodwalls and existing levees were designed to comply with FEMA accreditation and the District's freeboard standards of four feet near bridges and three feet elsewhere (Valley Water, 2016). The project design assumes a sea-level rise amount of 2 feet by 2050, for planning consistency with the South San Francisco Bay Shoreline Project. Hydraulic modeling was conducted to develop the design water surface elevation for the 1% annual chance (100-year) conditions for coincident fluvial discharge, storm surge in the Bay, and 2 feet of sea-level rise (Valley Water, 2016). Proposed channel re-alignment of Calabazas Creek and salt pond levee breaching may further enhance channel conveyance, and thereby accommodate sea-level rise greater than two feet.

In addition to this base project to address flood hazards in the channels, Valley Water and Google, an adjacent property owner, are also partnering on complementary enhancement options for both channels, as described in the following sections.

3.4.1 West Channel Enhancement Project

Google is collaborating with Valley Water on the West Channel Enhancement Project. The proposed option would modify the Valley Water design for the 1,100 linear feet of the channel between Caribbean Drive and Caspian Court. Enhancements would include enlarging the channel's cross section, adding bridges over the channel, realigning storm drain pipes, planting additional native vegetation, and better integration with the adjacent open space (**Figure 15**). These modifications would still meet the hydraulic and flood protection design criteria of the original Valley Water project.

Figure 15. Channel Setback Option for West Channel

3.4.2 Interior Drainage Ditch Improvements

Just west of the Sunnyvale East Channel, Google has proposed a conceptual enhancement for an existing interior drainage ditch. The enhancement would realign the interior drainage ditch farther west and add mild, more natural sinuosity to the straight ditch.

By providing additional space between the ditch and the channel, the realignment also alleviates the space constraint that resulted in a floodwall in the Channel project's original design. Instead, the existing levee can be raised, which avoids the obstruction of a floodwall on the embankment while still providing the same level of flood protection and avoiding impacts to the flow capacity in the East Channel or City stormwater network.

The realignment design also provides expanded open space along this corridor for upland and riparian habitat. This open space would also be integrated with improved pedestrian and bicycle access along and across the realigned channel. Removing the floodwall makes the integration more complete and allows users greater connectivity to the open space.

In addition to these improvements to the west side of the East Channel, Google is also considering improvements to the east side of the East Channel as well. These would require coordination with other property owners and stakeholders (e.g., Pacific Gas and Electric Company for power line easements).

3.5 Finished Floor Elevation Requirements

Under its authority for floodplain management, the City building code specifies minimum finished floor elevations for residential and non-residential buildings. The "finished floor" refers to enclosed portions of buildings, but excludes areas used only for parking, storage, and building access. Higher finished floors better accommodate flooding because the building and any building occupants would be less susceptible to damage and inundation hazards.

At a minimum, the state and FEMA require finished floor elevations of at least one foot above the BFE for residential buildings and at least above the BFE for non-residential buildings. The City is considering raising the finished floor elevations for non-residential buildings by one foot, to also be at least one foot above the BFE. This could provide consistency between residential and non-residential requirements. The City could limit the region to which the higher finished floor standard applies by designating a sea-level rise overlay zone, similar to the approach proposed by the City of San Rafael (2020). Such an overlay zone would only apply to Moffett Park, the portion of the City facing increasing flood hazard from sea-level rise.

3.6 Stormwater Vulnerability Assessment

The City's pump stations that are located in, and pump water from, low-lying areas along the shoreline face greater flood hazard due to sea-level rise. The City should develop a protocol for assessing a pump station's capacity to meet its performance criteria in the face of climate change. Three key assessments are:

- What is the potential for increased inflow to the pump station due to more frequent levee overtopping due to sea-level rise, elevated groundwater levels caused by sea-level rise, and/or increased precipitation due to higher rainfall intensity and frequency?
- Can the pump station provide its design discharge capacity when pumping to open channels connected to the Bay when these channels' water levels are elevated by sea-level rise?
- Is the pump station itself and its supporting infrastructure (e.g., power supply, maintenance access) vulnerable to inundation from greater flood hazards due to sea-level rise?

Once the assessment protocol is developed, the protocol can either be applied across the City's entire stormwater system at once or on a case-by-case basis as individual pump stations are slated for substantial repair and upgrade.

Wetlands in the northwest Plan Area provide detention storage for stormwater before this stormwater is pumped to an outboard channel and then flows to the Bay. In conjunction with the pump station assessments described above, the City should also evaluate whether these wetlands can be enlarged or otherwise modified to improve performance of the stormwater system and/or the wetlands habitat. Because these wetlands are well-connected to groundwater, the potential effects of sea-level rise on groundwater should be considered as part of the stormwater and habitat assessments.

3.7 Groundwater Vulnerability Assessment

As per the groundwater hazard assessment (Section 2.3.3), most of Plan Area has at least 3 feet of minimum depth-to-water (Figure 5), and groundwater surface expression is not anticipated until 3 feet of sea-level rise. Because groundwater hazards are not expected to be become significant until at least 3 feet sea-level rise occurs, the recommended adaptations for groundwater start with monitoring and local hazard assessments, and then include some general guidance for portions of Moffett Park.

The study used for the initial assessment of increasing groundwater hazard due to sea-level rise, Plane et al. (2019), is a regional study and uses a method that assumes an unconfined aquifer. This study should be supplemented with existing local data from the Plan Area and ongoing monitoring of groundwater levels, possibly in conjunction with Valley Water, to characterize existing conditions. Establishing this baseline will make it easier to identify future changes due to sea-level rise. These local data can also be used for a local assessment of groundwater conditions, how these conditions are expected to change with sea-level rise, and what structures could be exposed to these changes. In particular, some structures lower than the surrounding grade may be affected earlier than with 3 feet of sea-level rise. For example, ditches incised below the adjacent ground surface or structures placed below ground (e.g., subterranean utilities and foundations) may be vulnerable to lower amounts of sea-level rise. In addition, changes to groundwater may alter the distribution and treatment of local ground and groundwater contamination. A local assessment of changes to groundwater flood and water quality hazards with sea-level rise would help identify the extent and timing of appropriate adaptation measures.

Once the vulnerability assessment is completed, possible adaptation measures to consider may include:

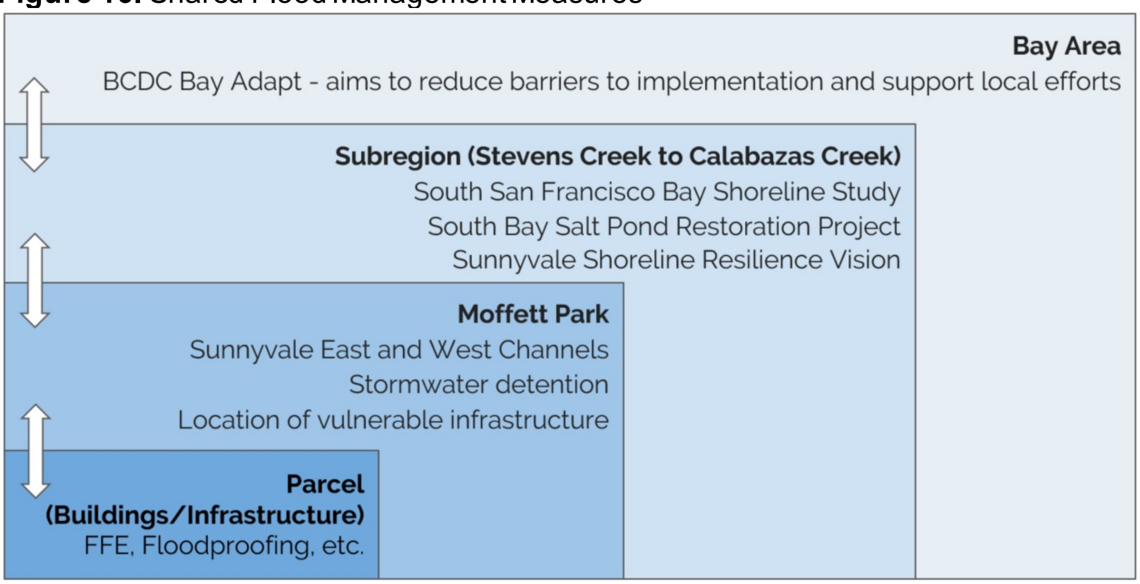
- **Pump station improvements—**Higher groundwater would likely first manifest as increased flows to the stormwater system, because many of this system's components are located below the typical ground surface elevation. As the City maintains this system, its planning and design should consider potential groundwater changes in parallel with the other climate change assessments mentioned in Section 3.6. For example, rising groundwater may increase low flow during the dry season, so pump stations may benefit from modifications to better handle dry season flows (e.g., more efficient low flow pumps in addition to large pumps designed for wet weather flows). If rising groundwater becomes an issue in the developed areas near drainage ditches, pumping capacity may need to be increased from that ditch. This could both reduce water levels in the ditch and lower groundwater levels in adjacent areas.
- **Wetlands management—**The portion of the northwest Plan Area with depths to groundwater less than 3 feet are undeveloped and already managed as seasonal wetlands. Thus, in these areas, raising groundwater would first manifest as increased extent and duration of surface water in these wetlands, which could modify the type and extend of wetland habitats. The potential for elevated groundwater levels to reduce detention storage volume available for stormwater and to cause more frequent and deeper inundation beyond the borders of the seasonal wetlands also should be considered for this area, as noted in Section 3.6.
- **Seepage cutoff wall—**Due to the lower minimum depth-to-water in the northeast portion of the Plan Area (Figure 5), this area may experience groundwater effects sooner than other developed parts of the Plan Area. In addition to managing surface-expressed groundwater by adding capacity to the stormwater system, as described above, this portion of the Plan Area may consider adaptation via a seepage cutoff wall. Further study of the feasibility for a seepage wall that restricts the influence of higher Bay water levels on groundwater in the Plan Area is recommended, with timing of this feasibility study dependent on the local groundwater hazard assessment.
- **Structure waterproofing and corrosion protection—**The California Building Code (California Code of Regulations Title 24, Chapter 18, *Soils and Foundations*, 2019), which is adopted by the City's code by reference, already requires geotechnical investigations of the existing groundwater table and soil corrosion potential, as well as waterproofing and corrosion-resistant materials. Once the groundwater vulnerability has been assessed, procedures to account for future geotechnical conditions of new and existing structures can be identified.

4. Next Steps

By definition, climate change is a moving target. Thus, as a complement to implementing the adaptation summarized in Table 1, the City will necessarily require monitoring of the evolving conditions. A host of state and federal agencies have been regularly updating global projections for sea-level rise and precipitation. In some instances, these groups are also providing regional or even local projections. These data should be reviewed regularly, as well as projections of future change, and used to update the City's understanding of how flood hazards will change in Sunnyvale. As the potential for sea-level rise beyond 3 feet becomes more likely, this strategy's long-term planning will need to be updated and expanded to accommodate that larger change in Bay water levels.

Because flooding extent is governed by topographic boundaries, not political boundaries, managing Sunnyvale's flood risk requires perimeter flood protection that extends outside the city's boundaries. As such, the City will need to continue to coordinate Bay area, subregional, Moffett Park, and parcel/building scale adaptation (**Figure 16**) with neighboring entities, including the City of Mountain View, Moffett Federal Airfield (operated by NASA), and the City of Santa Clara, as well as Santa Clara County (primarily via Valley Water) and USACE.

Figure 16. Shared Flood Management Measures



Costs to implement the adaptation strategy will be substantial, and dominated by costs for the two largest components of the strategy, the coastal and channel levees. A preliminary construction cost estimate at the feasibility stage for the Phase III portion (EIAs 5–10) of the Shoreline Study levees was $64 million. However, more detailed design and cost estimating for the Phase I of the Shoreline Project suggest that the actual cost of Phase III may be considerably higher. The Sunnyvale East and West Channels Flood Protection Project is estimated to be $69 million (total project cost for project nearing the contractor bid phase; Valley Water, 2019b). Funding for the channels project is largely from a county-wide bond measure. Funding for the rest of the strategy will likely be from a combination of city, county, state, and federal funds, accessed through a variety of funding streams such as grants, bonds, and community benefit contributions from private entities.

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