Palo Alto

Sea Level Rise Vulnerability Assessment

Prepared for:

City of Palo Alto

June 2022

CITY OF PALO ALTO

Palo Alto

Sea Level Rise Vulnerability Assessment

Prepared for:

City of Palo Alto
Public Works–Watershed Protection
Regional Water Quality Control Plant
2501 Embarcadero Way
Palo Alto, CA 94303

Contact:

Julie Weiss
Acting Watershed Protection Program Manager
650.329.2117

Prepared by:

AECOM

300 Lakeside Drive Suite 400
Oakland, CA 94612

Contact:

Diana Edwards
Project Manager
415.547.2592

pathways CLIMATE INSTITUTE

25 Taylor Street
San Francisco, CA 94102

CITY OF PALO ALTO

Table of Contents

Tables

Figures

Definitions, Abbreviations, and Acronyms

100-year storm tide	an abnormally high Bay water level that occurs when high astronomical tides are coupled with atmospheric and oceanographic conditions (e.g., storm surge) to elevate water levels above typical conditions
100-year storm	a storm event with a one percent chance of occurring during a given year
Adaptation Plan	Sea Level Rise Adaptation Plan
AECOM	AECOM Technical Services
ART	Adapting to Rising Tides (BCDC's sea level rise vulnerability and adaptation program)
Assessment	Sea Level Rise Vulnerability Assessment
Bay Area	San Francisco Bay Area
Bay	San Francisco Bay
BCDC	San Francisco Bay Conservation and Development Commission
California OES	California Office of Emergency Services
California OPC	California Ocean Protection Council
California OPR	California Governor's Office of Planning and Research
City	City of Palo Alto
contaminant	hazardous substances, pollutants, or contaminants that are present within an aquifer system
CoSMoS	Coastal Storm Modeling System (United States Geological Survey)
EG	emergent groundwater flooding
EIA	Economic Impact Area (a subregion used by the United States Army Corps of Engineers to evaluate the costs and benefits of implementing a flood protection project)
emergent groundwater	groundwater that rises to or above the surface of the ground and creates surface ponding
FEMA	Federal Emergency Management Agency (responsible for managing the National Flood Insurance Program and developing Flood Insurance Rate Maps)
GHG	greenhouse gas
GIS	geographic information system

GSI	green stormwater infrastructure
HG	high shallow groundwater table (within six feet of the surface)
HT	high-tide inundation
IPCC	United Nations Intergovernmental Panel on Climate Change
LiDAR	light detection and ranging (an airborne data collection technique to measure ground topography data at a high resolution over large spatial areas)
liquefaction	a soil condition in which water-logged sediments lose their strength in response to strong ground shaking (e.g., seismic events)
MHHW	mean higher high water (the average height of the higher of the two daily high tides at a given location, measured relative to a standard vertical datum over a standard 19-year period of time)
mm/year	millimeter(s) per year
OLU	Operational Landscape Unit (a geographic area with similar shoreline, hydrodynamic, and geomorphic characteristics used to identify regions where nature-based adaptation strategies may be applicable)
PG&E	Pacific Gas and Electric Company
RCP	Representative Concentration Pathway (a standard suite of atmospheric GHG concentration scenarios used by IPCC to represent different future climate conditions)
RWQCP	Palo Alto Regional Water Quality Control Plant
SAFER	Strategy to Advance Flood Control, Environmental Protection and Recreation
SCADA	Supervisory Control and Data Acquisition
SFCJPA	San Francisquito Creek Joint Powers Authority
SFEI	San Francisco Estuary Institute
SFPUC	San Francisco Public Utilities Commission
shallow groundwater	near-surface water found underground in the soil, either in the pores between soil particles or in crevices within rocks
Shoreline II	Also known as the South San Francisco Bay Shoreline Feasibility Study Phase II. This is a partnership between U.S. Army Corps of Engineers, Valley Water and the City of Palo Alto to rebuild Palo Alto levees to meet FEMA accreditation standards, provide flood mitigation and wetland restoration benefits for a portion of the South Bay, including the Palo Alto shoreline.
SLR	sea level rise
SPUR	San Francisco Planning and Urban Research Association

ST	100-year storm-tide flooding
State Guidance	State of California SLR Guidance, 2018 Update
subsidence	The gradual or sudden sinking of land due to factors such as groundwater pumping, oxidation of peat soils, oil and gas extraction, or regional tectonic processes
SWRCB	State Water Resources Control Board
US 101	United States Highway 101
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UV	Ultraviolet
Valley Water	The Santa Clara Valley Water District, which provides drinking water, flood protection, and stewardship of streams in Santa Clara County

Executive Summary

Executive Summary

This Sea Level Rise Vulnerability Assessment (Assessment) for the City of Palo Alto (City) documents potential sea level rise (SLR) hazards to City and community assets from 12, 24, 36, 48, 66, and 84 inches of SLR. Vulnerabilities for each scenario were evaluated for average high tide, 100-year storm tide, and wet-weather groundwater conditions. The SLR levels evaluated in this report are representative of what may occur through the year 2100 based on the recommended estimates of the California Ocean Protection Council Sea Level Rise guidance and in accordance with the California Adaptation Planning Guide. This Assessment will inform the subsequent development of a Sea Level Rise Adaptation Plan (Adaptation Plan) that will address the identified flood susceptibilities caused by SLR and rising shallow groundwater levels. The Adaptation Plan will serve as the Sea Level Rise chapter of the City of Palo Alto Sustainability and Climate Action Plan.

Sea levels in the San Francisco Bay Area (Bay Area) have increased by eight inches since the establishment of local tide records began in the mid-1850s, and the increase in sea levels has accelerated over the past several decades. As water levels rise in San Francisco Bay (Bay), the frequency and areal extent of flooding will increase. Areas once considered to be outside of the floodplain will begin to experience periodic coastal flooding or permanent inundation. SLR will also cause the surface of the shallow groundwater table in low-lying coastal communities to increase, damaging buried infrastructure, mobilizing subsurface contaminants, infiltrating below-grade structures, and emerging aboveground as an urban flood hazard, even before coastal floodwaters overtop the shoreline.

This Executive Summary and Section 8, Key Vulnerabilities, focus on SLR impacts from 36 inches of SLR, which represents a tipping point when widespread impacts could occur in Palo Alto if no protection measures are pursued. Details about all evaluated increments of SLR and related groundwater impacts are discussed in the vulnerability profiles listed in Section 8.2, Sea Level Rise and Shallow Groundwater Vulnerability Profiles. The approximate timing of SLR levels is listed in Table 1–Sea Level Rise Projections for San Francisco Bay, and in the vulnerability profiles discussed in Section 8.2.

The Assessment evaluates potential SLR hazards to the following assets and services: City and Community Facilities and Residential Parcels; Emergency Response; Natural Resources and Open Space; Transportation; and Utilities and Flood Management. The Assessment also discusses how SLR may influence shallow groundwater levels and exacerbate liquefaction, subsidence, and the expansion of contaminated groundwater areas. AECOM Technical Services (AECOM), the City's consultant for this project, worked with City staff to identify and collect asset information and related flood sensitivities. AECOM conducted a geographic information system (GIS) analysis for each asset category to identify the extent to which the assets are exposed to SLR and shallow groundwater hazards for each SLR scenario.

The Assessment assumes a "no action" scenario and evaluates SLR hazard impacts based on existing (year 2021) asset locations and shoreline elevations. This assumption allows the City to identify which assets and services are currently most at risk and provides essential information to inform future protection efforts that are not yet fully planned, funded, or approved.

Although the no action scenario has been assumed to capture existing vulnerabilities, the City and South Bay region have already completed projects that provide enhanced levels of flood protection for a subset of assets. In addition, several new projects are under way that will likely provide additional SLR and flood protection benefits once completed. The Assessment will provide additional information that will be instructive to these efforts.

Recently completed projects and efforts

- The San Francisquito Creek Downstream Project (formally known as San Francisquito Creek Flood Reduction, Ecosystem Restoration, Recreation Project from San Francisco Bay to Highway 101). Completed in 2019, this project widened sections of the creek channel and built new larger engineered levees along the creek to accommodate a 100-year storm tide and three feet of sea level rise;
- Iterative City infrastructure improvements such as raising equipment at the Regional Water Quality Control Plant as facility maintenance and upgrades are completed;
- The City adopted a Sea Level Rise Adaptation Policy in 2019, which provides guidance on developing sea level rise adaptation planning.

Projects that are currently underway

- The South San Francisco Bay Shoreline Feasibility Study Phase II, which consists of a partnership between the U.S. Army Corps of Engineers, Valley Water and the City of Palo Alto to rebuild Palo Alto levees to meet FEMA accreditation standards. This feasibility study leverages a previous study conducted by the San Francisquito Creek Joint Powers Authority known as SAFER (Strategy to Advance Flood Control, Environmental Protection and Recreation) which was completed in June 2019. Once completed, the proposed project would provide a primary defense system for the City and greater South Bay region against SLR. Based on planning and permitting requirements it is estimated that construction would begin in 2030 with all levee reaches completed by 2040 assuming funding is secured, and other significant delays do not occur. Levee improvements would not address secondary sea level rise hazards such as shallow groundwater rise and stormwater flooding that occurs landward of the levees. These hazards will be addressed through several existing projects including those funded by the Stormwater Management Fee in combination with additional measures that will be identified through the Sea Level Rise Adaptation Plan process;
- The Palo Alto Flood Basin Tide Gate Replacement Project (led by Valley Water). This structure regulates the flow of water between the flood basin and Bay. SLR will be incorporated into the new design to allow floodwaters within the basin to continue draining into the Bay. Construction is estimated to be complete in December 2026;
- Ongoing projects funded by the City of Palo Alto Stormwater Management Fee that provide improved stormwater drain capacity, pump stations, green stormwater infrastructure, maintenance, and related projects;
- Palo Alto Horizontal Levee Pilot Project. This pilot project evaluates the use of horizontal levees with gentle, vegetated slopes to attenuate waves and provide

transitional habitat between tidal wetlands and terrestrial uplands. Findings of the project will inform how additional horizontal levees might be used in conjunction with traditional levees and floodwalls along the Palo Alto shoreline and the greater Bay Area to maximize habitat benefits and SLR protection. Construction is estimated to be complete in 2024.

Although several sea level rise adaptation projects are underway, additional measures will be needed via the subsequent Sea Level Rise Adaptation Plan so that a holistic, integrated, adaptable, and phased protection is planned and built in advance of when it is needed.

Key Vulnerabilities due to 36 inches of SLR

The statements below summarize the key impacts of this assessment due to flooding from higher Bay and groundwater levels within the City for a future scenario with 36 inches of SLR.

City, Community and Residential Property Assets

- A 100-year storm tide could result in surface flooding of 4,400 residential parcels stretching south from approximately Channing and Greer Roads along Middlefield Road to San Antonio Road, two senior/disability centers (Palo Alto Housing Corporation and Alta Torre), two schools (Palo Verde and Ohlone), seven city facilities (Lucy Evans Baylands Nature Center, Animal Shelter, Municipal Services Center, Utility Control Center, Baylands Ranger Station, the former ITT property, and the boat launch), the Save the Bay Nursery, and the EcoCenter.
- A groundwater table within six feet of the surface could occur at 7,950 residential parcels near San Francisquito Creek past Channing Road approaching Middlefield Road and extending west toward Alma Road and to San Antonio Road. Three city facilities (Supervisory Control and Data Acquisition [SCADA], Mitchell Park Library, and the Baylands Ranger Station), eight schools (Duveneck, Greene, Jane Stanford, Fairmeadow, Palo Verde, Ohlone, Greendell, and Hoover), seven senior/disability centers (Achieve Kids, Abilities United/Gatepath, Ada's Café, Palo Alto Housing Corporation, Stevenson House, Alta Torre, and the Chinese Community Center at Avenidas), Cubberly Community Center, the Save the Bay Nursery, and the EcoCenter could be affected. The groundwater table could potentially impact the foundations of these structures.
- Approximately 770 residential parcels will be exposed to emergent groundwater, impacting the Palo Verde and Adobe Meadow/Meadow Park neighborhoods bordered by Matadero Creek, San Antonio Road, Middlefield Road and United States Highway 101 (US 101).

Emergency Response Assets

- A 100-year storm tide could expose an additional eight miles of evacuation routes (on US 101, Embarcadero Road, Oregon Expressway, San Antonio Road, Charleston Road, and Middlefield Road) beyond the six miles that are currently vulnerable to a 100-year storm tide. Although roadways are moderately sensitive to temporary flooding, evacuation routes are highly sensitive because they may not be usable if flood depths exceed thresholds for safe passage by vehicles.

- A high groundwater table within six feet of the surface will occur along 15 miles of evacuation routes. The shallow groundwater table is highest under Fire Station No. 4. Although this fire station does not have subgrade facilities, the foundation and regular structure inspections should be conducted to avoid risks of slow and chronic damage beginning with 12 inches of SLR. Additional monitoring wells may be required to better characterize site contaminant migration near these facilities to reduce the potential for impacts to human health and the environment from legacy contamination.
- Emergent groundwater could impact one mile of evacuation routes. Emergency response assets have a high consequence of flood impacts from delayed or impaired emergency response times.

Natural Resources, Parks, and Open Space Assets

- A 100-year storm tide could expose seven City parks (Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Nature Preserve, and Byxbee Park Hills) to flooding and expose 90% of the Baylands Golf Links and Athletic Center during a daily high tide or 100-year storm tide. Much of the Baylands marshes and estuarine habitats along the City's shoreline are already exposed to daily tidal fluctuations and a high shallow groundwater table, but 36 inches of SLR could transition some tidal marsh areas to a different habitat or inundate them completely.
- Approximately 6,900 City-maintained trees could be exposed to a temporary 100-year storm tide and approximately 4,700 City-maintained trees could be exposed to daily high-tide conditions. Tree species intolerant of flooding or saltwater conditions may experience increased stress.
- A high groundwater table within six feet of the surface will occur at seven parks (Hoover, Greer, Seale, Ramos, 40% of the Baylands Golf Links, Baylands Nature Preserve, and Mitchell Park) and 12,000 City-maintained trees. Changes in groundwater levels and salinity can cause increased stress to existing park and golf course vegetation species and City-maintained trees.
- Emergent groundwater could occur during daily high-tide conditions and could expose Byxbee Park Hills, 40% of the Baylands Golf Links, and 360 City-maintained trees. Similar to surface flooding caused by SLR, impact on tree health may depend on the groundwater quality and the species' sensitivity to salt or contaminants.

Transportation Assets

- A 100-year storm tide could expose key regional transportation routes, including US 101, all major roads on the bayside of Middlefield Road, and 36 miles of multi-use trails. Roadways are moderately sensitive to temporary surface flooding and can be damaged by repeated flooding events.
- A 100-year storm tide would inundate most of the Palo Alto Airport, including the runway and taxiway, limiting access to private planes and the Civic Air Patrol service.
- A high groundwater table would occur under approximately six miles of US 101 and approximately 73 miles of streets, including streets from Edgewood Drive, past Embarcadero Road, approaching Alma Street, and down to San Antonio Road.
- Groundwater within six feet of the surface can damage roadways when it meets the bottom of the roadbed underground. Overtime, the roadbed could deteriorate from below, increasing the likelihood of cracks, potholes, and sinkholes.

- Emergent groundwater could occur along four miles of multi-use trails and could cause impacts on commuters and disrupt emergency response service routes such as at the Oregon Expressway underpass, which is already subject to year-round emergent groundwater and seasonal flooding. Emergent groundwater could primarily occur along approximately one mile of US 101, East Bayshore Road, the Page Mill underpass approaching El Camino Real, segments of streets in neighborhoods along Matadero Creek and East Oregon Expressway, and portions of streets north of San Antonio Road in the Palo Verde and Adobe Meadow/Meadow Park neighborhood up to Loma Verde Street.

Utilities and Flood Management Assets

- A 100-year storm tide could expose several assets to flooding that are critical for day-to-day City operations, including the flood management levees, the Palo Alto Regional Water Quality Control Plant (RWQCP), four stormwater pump stations (Adobe, Matadero, Colorado, and Airport pump stations), two electrical substations, and the natural gas receiving station. Most utility assets are highly sensitive to surface flooding due to the presence of electrical/mechanical components and may be sensitive to rising groundwater if they were not designed for saturated soil conditions. If damaged, there is a high consequence of cascading impacts to the city's public health, safety, and the economy. Loss of power supply from flooded substations could interrupt electricity service to residents, hospitals, and businesses. Impacts to the RWQCP could impact ecological and human health from sewage backups or overflow.
- A high groundwater table within six feet of the surface could impact 17 miles of fiber optic cable and 64 miles of water pipelines and restrict access to more than 300 manholes and 1,000 access vaults. High groundwater could also result in pipe breaks from hydraulic uplift, corrosion, cracking, or displacement.
- Emergent groundwater could occur along two miles of water and sanitary sewer pipelines and impact one acre of green stormwater infrastructure.

Additional Findings:

Current Flooding Exposure

- One key finding is that portions of the City's shoreline may be exposed to flooding today from a 25-year storm tide (a storm with a four percent chance of occurring each year). This storm tide is equivalent to average high-tide conditions with 36 inches of SLR. If a storm of this magnitude occurs today, it has the potential to overtop nearly the entirety of Palo Alto's Bay shoreline. A 100-year storm tide (a storm with a one percent chance of occurring each year) could expose approximately four square miles of the City, including the Palo Alto Airport, RWQCP, the Baylands Golf Links, the Baylands Nature Preserve, and US 101, large sections of the residential neighborhoods of Duveneck/St. Francis, Midtown, Palo Verde, Adobe Meadows, and Meadow Park. With SLR, the frequency and magnitude of flooding will increase. If no action is taken, the assets and services will be compromised.

Flood Exposure Beyond 36 inches of SLR

- Although 36 inches of SLR represents a critical tipping point of flood vulnerability for the City, there are additional key assets that become impacted by SLR or experience large increases in network exposure at higher scenarios. For example, with 66 inches of SLR, the number of residential parcels inundated by average daily high tide nearly doubles, the first fire station is exposed to the 100-year storm tide, and the number of parks experiencing emergent groundwater increases from one to five locations. The portion of underground utility networks impacted by rising groundwater during the 66-inch SLR scenario also increases. The lengths of water and sanitary sewer pipelines exposed to high groundwater levels both increase by more than 20 miles. Similarly, the length of buried fiber optic cable exposed to emergent groundwater experiences an order of magnitude increase.

Liquefaction and Subsidence

- The rise of the groundwater table can affect liquefaction hazards during large earthquakes. Research examining the effect of SLR and groundwater suggests a substantial increase in liquefaction potential and infrastructure instability during earthquakes due to rising groundwater levels. Areas with the highest liquefaction susceptibility are along the bayside of US 101, including portions of San Francisquito Creek, the Baylands Golf Links, Embarcadero Road, US 101, and the Bay margins near the former salt pond complex and tidal marshes. The remainder of the low-lying areas within the City have moderate or low susceptibility to liquefaction.
- Human-caused subsidence in Santa Clara County has been halted or reversed due a combination of changes in groundwater management practices since 1970 and water imports by the San Francisco Public Utilities Commission (SFPUC) Regional Water System, which have reduced the need for local groundwater extraction. However, the ongoing natural subsidence of portions of the Bay's shoreline areas, including the filled portions of the City (such as the Baylands Golf Links, Palo Alto Airport, and the bayside Embarcadero Road corridor), will likely continue into the 21st century. The City currently experiences up to two millimeters per year (mm/year) of subsidence, which may result in enhanced rates of local SLR. As land subsides, higher relative sea level and increased flood risk result. Even small rates such as two mm/year can cause cumulative increases in flood risk over time as the level of the land relative to the level of the sea changes.

Mobilization of Contaminants

- The greatest safety concern related to rising groundwater is the potential mobilization of legacy contaminants found within shallow groundwater. Contaminants can mobilize horizontally as the groundwater flows slowly toward the Bay and vertically as it flows toward the ground surface as the groundwater table rises with SLR. When emergent groundwater occurs on contaminated sites, subsurface contaminants could be mobilized to the surface and pose health hazards to humans and wildlife.
- Of particular concern are volatile organic compounds, which can vaporize and impact indoor air quality. With 36 inches of SLR, the following two contaminant sites could mobilize from emergent groundwater flooding: Site #2 GOPOWER near Embarcadero Road and Embarcadero Way and Site #5 ARCO 2995 near Middlefield and Colorado. Site #1 Palo Alto Landfill is also likely to have emergent groundwater flooding around the perimeter of the landfill.

However, the landfill has a maintained leachate collection and removal system that is effective at removing fluids from the landfill area for treatment. The pumping needs for this system are likely to increase as sea levels and the surrounding groundwater table rise. If the leachate system is properly maintained and operated over time, this system should minimize the risk of contaminants leaking into the surrounding area as sea level rises.

With 84 inches of SLR, 10 contaminant sites and the Palo Alto Landfill may have emergent groundwater conditions. If the contaminants are still present at these locations when the groundwater becomes emergent, the contaminants could create human health and environmental risk. The largest contaminated site is along Page Mill Road and known as the Hewlett Packard and Varian Associates California-Olive-Emerson site. Active remediation efforts are ongoing and contaminant levels are likely to decrease before 84 inches of SLR occurs.

Most of the contaminated sites are in the process of being remediated (i.e., active measures are being taken to reduce the level of contamination in the soils and groundwater). However, residual contaminants often remain in the ground after remediation efforts are complete. As the groundwater table rises in response to SLR, residual contaminants could be re-mobilized and brought to the surface. In some cases, this re-mobilization could create a human health or environmental hazard. As awareness increases in the regulatory community, remediation methods and institutional controls may be revised to better consider a changing climate and related hazards. Facilities with a groundwater table within six feet of the ground surface, usually within approximately three miles of the shoreline, are at greatest risk. Additional monitoring wells may be required to better characterize contaminant migration near these facilities to reduce the potential for impacts to human health and environment from contamination.

1

Introduction

1 Introduction

1.1 Project Overview and Purpose

The City of Palo Alto (City) is developing a Sea Level Rise Adaptation Plan (Adaptation Plan) to address the City's risk from rising San Francisco Bay (Bay) water levels. Once completed, the Adaptation Plan will serve as a roadmap that will help prioritize adaptation strategies, land use decisions, and investments to protect the City's economic, social, and environmental assets and operations.

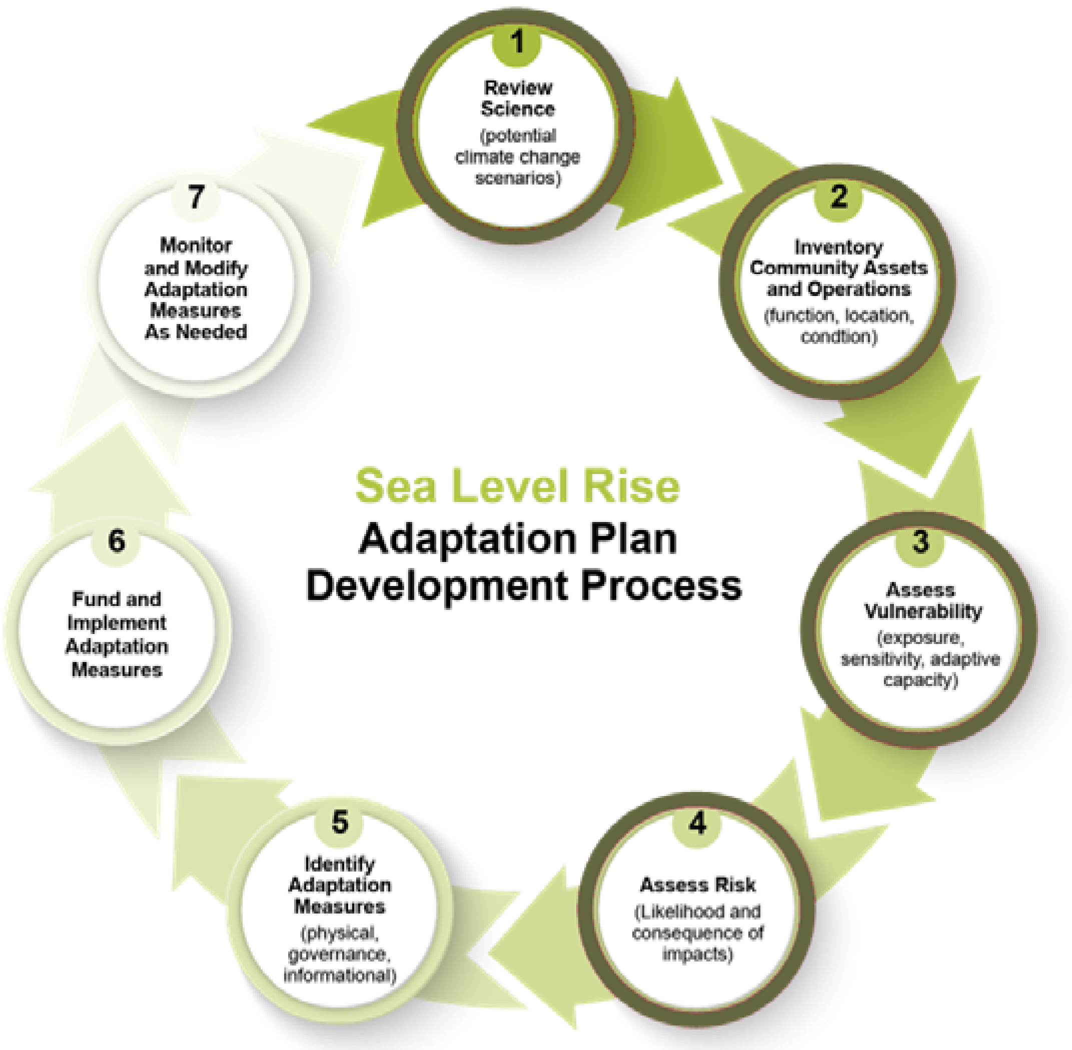
As a first step to the Adaptation Plan, AECOM worked with City staff to conduct a Sea Level Rise Vulnerability Assessment (Assessment) that identified existing infrastructure and services that could be jeopardized by sea level rise (SLR) and a rising shallow groundwater table. The Assessment will inform potential adaptation strategies to protect infrastructure and services and increase the long-term resilience of the City. Using the best-available science, the Assessment evaluates a suite of potential SLR scenarios that may occur over the next century and identifies:

- Which areas of the City are most vulnerable to SLR impacts
- Which sea level conditions create tipping points that may result in widespread flooding
- How SLR will affect specific types of assets and services across the City.

1.2 Conceptual Framework

The framework used for Palo Alto's Assessment process is shown on Figure 1, which leverages guidance from the California Governor's Office of Planning and Research (California OPR), the California Ocean Protection Council (California OPC), the Natural Resources Agency, and the California Office of Emergency Services (California OES). The Assessment consists of Steps 1 through 4: Step 1: Review Science (Sections 3–5); Step 2: Inventory Community Assets and Operations (Section 6); Step 3: Assess Vulnerability (Section 7); and Step 4: Assess Risk (Section 7). The subsequent City of Palo Alto Adaptation Plan will address Steps 5 through 7.

Figure 1. Sea Level Rise Vulnerability and Adaptation Conceptual Framework



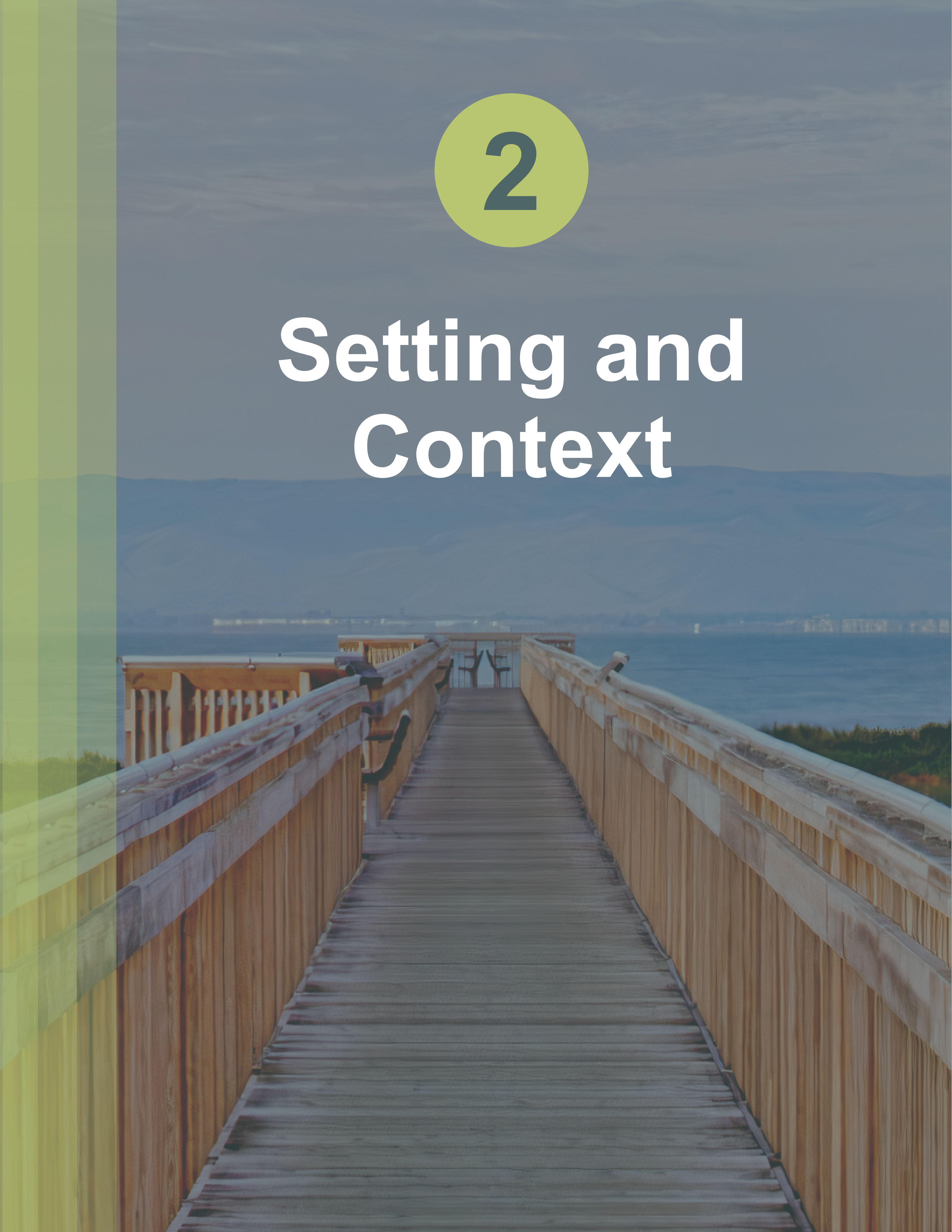
Dark green circles (1-4) indicate the contents of this assessment, light green circles (5-7) indicate future components of the City of Palo Alto Sea Level Rise Adaptation Plan Development Process

1.3 Organization of the Vulnerability Assessment

This report describes the approach to assessing vulnerability to SLR and related groundwater hazards and documents the key findings. The report is organized as follows:

- Section 1, Introduction: Provides an overview of the project scope, purpose, and report organization
- Section 2, Setting and Context: Describes the historical context of past development and the physical setting of the City of Palo Alto

- Section 3, Sea Level Rise Science: Reviews historical and projected trends of SLR
- Section 4, Building on Existing Policies and Studies: Summarizes existing state, regional, and local policies and studies related to SLR
- Section 5, Sea Level Rise Inundation and Shallow Groundwater Mapping: Describes the mapping process used to evaluate SLR and related shallow groundwater hazards
- Section 6, Asset Inventory: Details the identification of built and natural assets considered in the Assessment
- Section 7, Assessing Vulnerability and Risk: Describes the process used to assess the City's vulnerability to SLR and shallow groundwater hazards
- Section 8, Key Vulnerabilities: Presents key vulnerabilities identified and includes vulnerability profiles by asset type



2

Setting and Context

2 Setting and Context

Historically, the shoreline of Palo Alto was a tidal marsh and natural floodplain that experienced regular flooding from dynamic fluctuations in Bay water levels. During the 20th century, marsh areas were drained and filled to support urban development and changing land uses. Much of this area is still low lying, but it is now densely developed. This area is prone to coastal, riverine, and stormwater flooding caused when heavy rain events coincide with high tides. Together, these factors can temporarily elevate local water levels, cause floodwaters to overtop the shoreline and creek banks, and reduce the ability of the stormwater system to collect and drain urban runoff.

Today, the City is urban and supports approximately 67,000 residents. Community facilities are characterized by a contrast of old and new with a blend of historic buildings along tree-lined streets and new development, all of which supports the region's worldwide leadership in the Silicon Valley technology industry. In addition to the homes, businesses, schools, and parks that make up the City's built infrastructure, Palo Alto is also owns and maintains its own gas, electric, water, sewer, refuse, and stormwater management utilities, an airport, and the Palo Alto RWQCP, which provides wastewater treatment for six communities.

The City's natural environment has more than 1,940 acres of marsh and wetlands, mostly in the Baylands Nature Preserve. These natural areas support important ecological services for the region and provide habitat for a wide range of wildlife, including several threatened and endangered species such as the Ridgway's rail (Rallus longirostris obsoletus) and the salt marsh harvest mouse (Reithrodontomys raviventris). The City's marsh and wetlands also provide a natural buffer between the Bay and much of the City's upland developed areas.

Since the acceleration of urban development in the mid-1950s, the City has experienced multiple floods, with the largest occurring in February 1998. During that event, overtopping of the banks of the San Francisquito Creek and Bay shoreline caused an estimated $40 million in damages for the City and its residents (Anning 1998). In addition to economic impacts, the flood caused evacuation of 500 residents and closed US 101 and the Palo Alto Airport.

Although the City is no stranger to flooding from creeks, coastal storms, and seasonal high tides in summer and winter such as king tides, SLR poses a unique challenge. Encroachment of the Bay onto the shoreline will be permanent, widespread, and worsen over time. Much of the City's built and natural infrastructure was not designed to withstand increased frequency and magnitude of flooding due to rising sea levels and related rising shallow groundwater levels. Rising shallow groundwater may encroach on contaminated areas, change groundwater flow patterns, and reduce the efficacy of existing remediation measures. Without proactive action, widespread consequences could be experienced for much of the City's infrastructure, ecosystems, recreational spaces, and residences. SLR impacts could reduce the future competitiveness of the City in terms of jobs, tourism, and maintaining residents. These impact could also further exacerbate inequity, as some residents may experience a decline in quality of their lives, while others with means may retreat to areas outside of the SLR vulnerability zone.

Consideration of Proposed Bayfront Levee Projects in the Sea Level Rise Vulnerability Assessment

Palo Alto's existing coastal flood protection relies on a levee network that extends along the shoreline from San Francisquito Creek in the north to approximately San Antonio Road in Mountain View to the south. The City's creeks (San Francisquito, Barron, Adobe, and Matadero Creek) are highly altered and include channelized sections and riverine levees to reduce flood risk to developed areas. However, these bayfront and riverine levees were built decades ago and portions of the levees do not meet current FEMA accreditation standards for flood protection from a 100-year coastal or riverine flood event. They were also not originally designed to consider SLR. Thus, portions of the City are vulnerable to flooding today, and SLR will exacerbate the flood risk in the future.

The Palo Alto Flood Basin tide gate structure is one part of the levee system surrounding the City's Flood Control Basin. It is planned for replacement by 2026.

As part of a regional effort to provide flood protection to South Bay communities, the City is involved in several project partnerships with the San Francisquito Creek Joint Powers Authority (SFCJPA), Santa Clara Valley Water District (Valley Water), and the United States Army Corps of Engineers (USACE). Early efforts from the Strategy to Advance Flood Control, Environmental Protection and Recreation (SAFER) Bay project focused on eliminating pinch points in San Francisquito Creek where floodwater flows had historically been restricted. These projects installed steel sheet pile floodwalls along low-lying or eroding portions of the creek bank, widened the creek and created new marshland, excavated decades of sediment buildup within the channel, and added additional culverts to increase floodwater drainage capacity.

Currently the USACE is reviewing potential levee alignments along the Palo Alto shoreline, leveraging the 2019 SAFER Bay Project Draft Feasibility Report conducted by SFCJPA (SFCJPA 2019). The new levees would address existing and future coastal flood risks. Valley Water is also in the design phase of its plans to replace the existing Palo Alto Flood Basin tide gate, which would accommodate up to two feet of SLR (Valley Water 2020a). The tide gate's primary function is to regulate water discharge between the flood basin and the Bay. Rising tides in decades to come could limit the ability of floodwaters to be released to the Bay and pumping may be required to supplement gravity discharge through the tide gate.

Although the exact alignment, height, and timing of the construction of a bayfront levee project is unknown at this time, once designed, permitted, funded, and implemented, the levee and tide gate projects will serve as the City's primary line of defense against SLR inundation and coastal flooding over the coming decades. However, the bayfront levee alignments currently under consideration may not protect all City and community assets if they remain bayward of the constructed levee (e.g., Lucy Evans Baylands Nature Center, the Baylands, the sailing station). In addition, coastal levees do not address secondary SLR hazards such as impeded stormwater runoff due to higher Bay water levels, increased salinity exposures from rising shallow groundwater that could lead to subsurface infrastructure corrosion, impacts to the urban forest from prolonged root exposure to more saline water or excessively saline water, mobilization of subsurface contaminants, loss of recreational areas and access, changes to the environment triggered by warmer and drier weather, and declining habitat health.

To account for this uncertainty, the City's Assessment evaluates the vulnerability of City assets and services using a no action scenario. This approach evaluates hazards under current 2021 conditions but does not factor in potential protection benefits from any future protection efforts. The approach allows the City to evaluate which assets and services are most at risk and identify suitable adaptation strategies. By fully understanding the magnitude of City assets and services that may be exposed to future SLR hazards if no actions are taken, the City can plan appropriately.

In addition to the ongoing bayfront levee project, it is important to develop additional strategies to address assets that may still be exposed to coastal flooding on the bayside of the levee and other landside strategies to address secondary SLR hazards of groundwater rise and stormwater flooding. These strategies and their implementation timelines will be developed via the Adaptation Plan once the Assessment is completed.

3

Sea Level Rise Science

3 Sea Level Rise Science

SLR is caused by excessive greenhouse gases (GHGs) in the Earth's atmosphere, which have increased land and ocean temperatures from historical levels. More than 90 percent of the excess heat from excessive GHGs is being captured by the global ocean, leading to a subsequent increase in sea surface temperatures and ocean heat content (California OPC 2018). These temperature increases cause thermal expansion and melting land ice, which are the primary contributors to SLR.

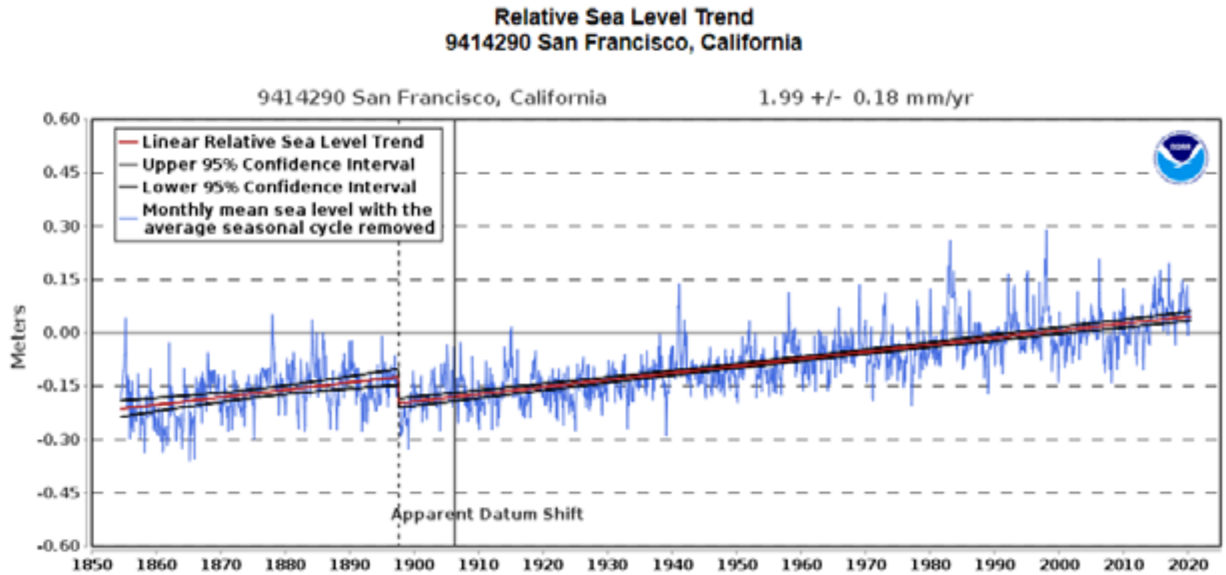
In 2017, the California OPC Science Advisory Team Working Group compiled, reviewed, and summarized the latest research on SLR (Griggs et al. 2017). The study's findings were incorporated into an updated SLR guidance documen for the State of California (State), which the Ocean Protection Council adopted in 2018 (California OPC 2018). The update presents the latest peer-reviewed projections of SLR, describes an extreme scenario for SLR caused by rapid ice sheet loss from the West Antarctica ice sheet, and scenario selections using a risk-based (probabilistic) framework. The 2018 update also lays out preferred approaches for planning for vulnerable assets, natural habitats, and public access.

This chapter discusses observed historical changes in local sea levels and future sea level projections and describes selections of the mapped SLR and storm-tide scenarios used for the Assessment and the Adaptation Plan.

3.1 Historical Sea Level Rise Trends

Since the installation of the San Francisco tide station at the Golden Gate in the mid-1850s, water levels have increased by eight inches in the Bay, equivalent to approximately two millimeters per year (mm/year) (Figure 2; NOAA 2020). Observations indicate that global sea level is not increasing linearly and has accelerated over the past couple decades, with the global rate more than doubling since 1990 to over three mm/year (Church and White 2011; Church et al. 2013; Hay et al. 2015; Ray and Douglas 2011; Thompson et al. 2016). Recent research also suggests that a period of relatively stable sea levels along the U.S. Pacific coast from 1990 to 2010 may be transitioning into a phase of accelerated SLR and that local rates may exceed the global average in the coming years (Hamlington et al. 2016; Buis 2020).

Figure 2. Sea Level Trends at the San Francisco Tide Station



Source: NOAA 2020.

Note: The dashed line vertical line an apparent datum shift (vertical movement of the land surface) that occurred in 1897, disrupting consistent measurements. NOAA researchers fit separate trendlines before and after that year to account for the datum shift. The solid vertical line represents the timing of the earthquake of 1906.

3.2 Sea Level Rise Projections

Over the next few decades, there is a relatively high degree of certainty regarding trends in potential future sea level changes. Beyond 2050, disparities between the projections increases (both in terms of amount and timing), depending on the amount of GHGs emitted into the atmosphere and the response of the global climate system (California OPC 2018). In 2014, the United Nations Intergovernmental Panel on Climate Change (IPCC) adopted a set of four GHG concentration trajectory scenarios known as Representative Concentration Pathways (RCPs) to model how changes in GHG emissions could affect future climate conditions (IPCC 2014). The four RCPs and their assumptions are described below:

- RCP 8.5: Sometimes referred to as a “business-as-usual” scenario, represents rapid economic growth through the end of the century, with no significant effort to reduce emissions.
- RCP 6.0: Assumes GHG emissions increase through the year 2080, followed by stabilization.
- RCP 4.5: Represents a more moderate scenario with GHG emissions rising until year 2040, reaching a concentration of 550 parts per million, followed by stabilization.
- RCP 2.6: Represents aspirational conditions for a sharp decline in GHG emissions by mid-century (70 percent reduction), with emissions dropping to zero by 2080.

Current State of California SLR Guidance, 2018 Update (State Guidance) (California OPC 2018) relies primarily on RCP 8.5 and RCP 2.6 to examine a range of possible sea level conditions that may be expected for planning into the coming century. Many municipalities and

State agencies adopt the SLR projections corresponding to RCP 8.5 to provide a sufficiently precautionary approach. To date, GHG concentrations continue to track on, or above, the RCP 8.5 projections, so many state and local planning efforts adopt projections based on this scenario. The State Guidance also includes an extreme scenario, referred to as H++, which represents a worst-case SLR scenario caused by rapid loss of the West Antarctic ice sheet over the 21st century. This scenario is associated with a high degree of uncertainty and is a topic of active research.

Table 1 shows SLR projections for the Bay. Based on the latest climate science, sea levels in the Bay Area are likely (67 percent probability) to rise between seven and 13 inches by the middle of the 21st century and between 12 and 41 inches by the end of the century. The State Guidance recommends using the upper limit of the likely range for projects with a high tolerance to flooding (e.g., park trails).

Table 1. Sea Level Rise Projections for San Francisco Bay (California OPC 2018)

Year	Emission Scenario	**Median** *(50% probability sea level rise meets or exceeds… [inches])*	**Likely Range** *66% probability sea-level rise is between… [inches])*	**1-in-20 chance** *5% probability sea-level rise meets or exceeds… [inches])*	**1-in-200 chance** *0.5% probability sea-level rise meets or exceeds… [inches])*	**H++** *(extreme risk aversion (no probability assigned) [inches])*
2030	High	5	4–7	7	10	12
2040	High	7	6–10	12	16	22
2050	High	11	7–13	17	23	32
2060	Low	12	7–16	19	29	-
2060	High	13	10–18	22	31	47
2070	Low	13	10–18	23	37	-
2070	High	17	12–23	29	42	62
2080	Low	16	11–22	28	47	-
2080	High	20	14–29	36	54	79
2090	Low	17	12–25	34	56	-
2090	High	25	17–35	43	67	100
2100	Low	19	12–29	38	68	-
2100	High	30	19–41	53	84	122

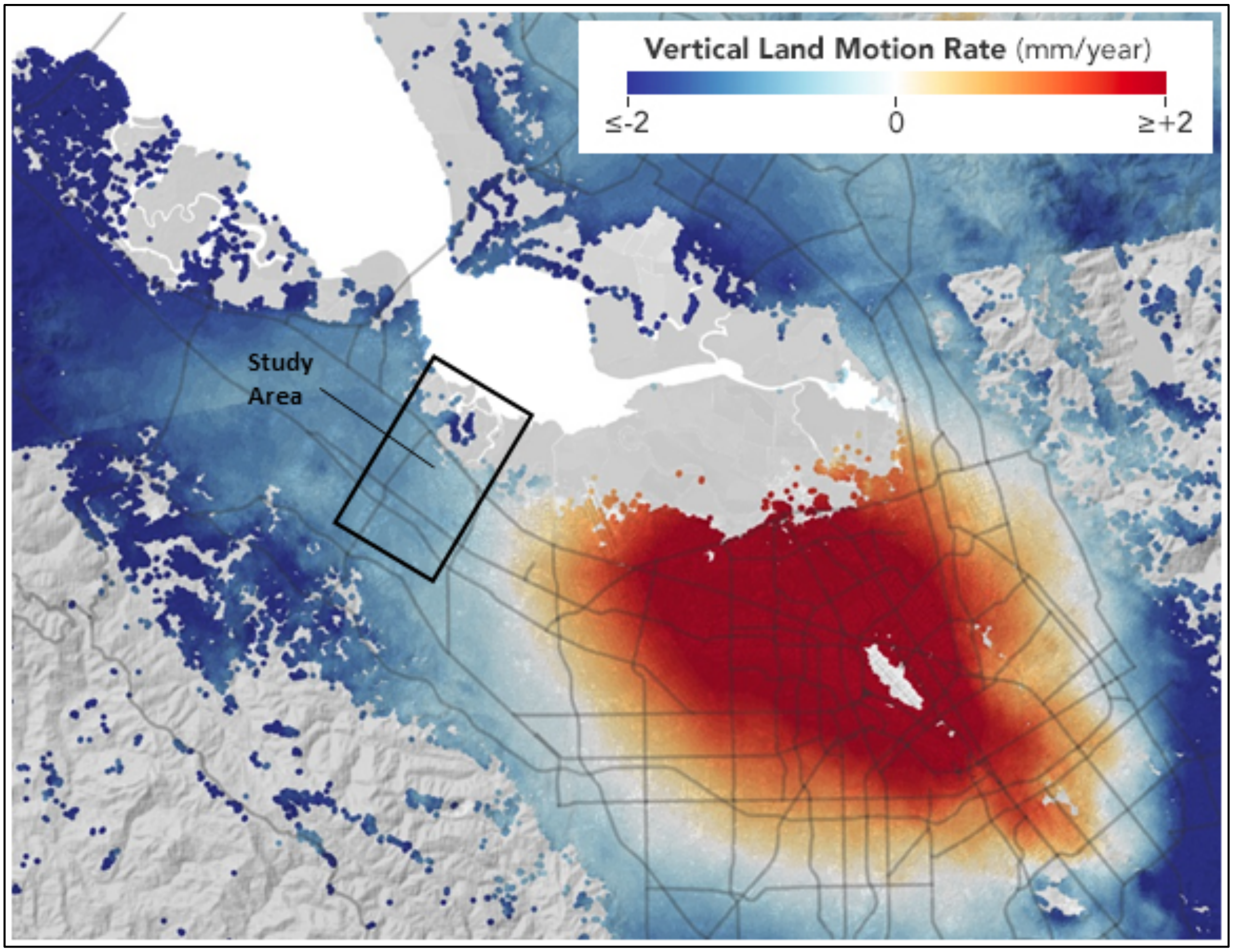
Notes:
Projections represent an SLR increase above the baseline year of 2000.
Low emissions correspond to RCP 2.6 (ambitious emissions reduction); high emissions correspond to RCP 8.5 (no emissions reduction).
Only the high emissions scenario is shown for the years leading up to mid-century conditions. Through the year 2050, the differences between emission scenarios are minor and the world is currently on the high emissions trajectory. Beyond 2050, different emission pathways may result in significantly different levels of SLR.

Because there is uncertainty regarding future GHG emissions and the global climate's response, SLR projections with a lower probability of occurring are also considered in adaptation planning. In the Bay Area, there is a 0.5 percent probability (1-in-200 chance) that SLR will reach or exceed 23 inches by the middle of the 21st century and 84 inches by the end of the century (California OPC 2018). The State Guidance recommends using the lower probability projections (particularly the 0.5 percent probability projections) when planning for assets with a lower tolerance to flooding, low adaptability, long lifespan, or high consequence of impact (such as water treatment facilities).

3.3 Subsidence

In addition to rising sea levels, land along much of the Bay shoreline has experienced subsidence (i.e., sinking) over much of the 20th century due to natural and man-made factors, including shifting of regional tectonic plates, compaction of shoreline fill areas, and extensive groundwater extraction, particularly in the Santa Clara Valley. Although human-caused subsidence in the Santa Clara Valley has been halted or reversed due to changes in groundwater management practices since 1970 (Valley Water 2020b) and due to SFPUC Regional Water System water imports by Palo Alto, which has reduced the need for local groundwater pumping, ongoing natural subsidence of portions of the Bay's shoreline areas, including filled portions of the City of Palo Alto (such as the Baylands Golf Links, Palo Alto Airport, and Embarcadero Road corridor), will likely continue into the 21st century. Recent monitoring of land surface elevation changes in the Bay Area by researchers (Blackwell et al. 2020; Shirzaei and Bürgmann 2018) has documented contemporary rates of subsidence along the shoreline. As shown by blue shading on Figure 3, the City of Palo Alto, indicated by the Study Area box, is currently experiencing up to two mm/year of subsidence. This combination of subsidence and rising sea levels may exacerbate local SLR rates and cause the City to experience an increase in the frequency and extent of flooding, especially when compared with other parts of the South Bay region that have a static or positive vertical land motion rate.

Figure 3. Observed Vertical Land Motion from 2007-2018



Source: Blackwell et al. 2020.
Note: Gray indicates areas where no vertical land motion data are available.

3.4 Shallow Groundwater Rise

As sea levels rise, the surface of the shallow groundwater table in low-lying coastal communities will also rise (Befus et al. 2017, 2020; May 2020; Plane et al. 2019). This slow but chronic rise in the shallow groundwater table can flood communities from below, damage buried infrastructure, mobilize subsurface contaminants, infiltrate below-grade structures, and emerge aboveground as an urban flood hazard, even before coastal floodwaters overtop the shoreline (May 2020). Failing to adequately consider this hazard could undermine adaptation success. For example, if coastal flood protection levees only consider coastal flooding and SLR and neglect the accompanying inland rise in the shallow groundwater table, the areas protected by levees could be flooded from below by emergent groundwater. This hazard could cause widespread consequences to infrastructure before the groundwater becomes emergent, such as higher rates of inflow and infiltration into flood control channels and stormwater pipelines, reduced effectiveness of green infrastructure installations that rely on infiltration, and reductions in the stormwater conveyance capacity during periods of heavy rainfall (May 2020).

San Francisco Bay Conservation and Development Commission's (BCDC) 2021 San Francisco Bay Plan Climate Change Policy Guidance recommends considering the rise in the shallow groundwater table in response to SLR in coastal Bay Area communities (BCDC 2021). In response to this recommendation, potential changes to Palo Alto's shallow groundwater table were evaluated in consideration of the SLR projections presented in Section 3.2.

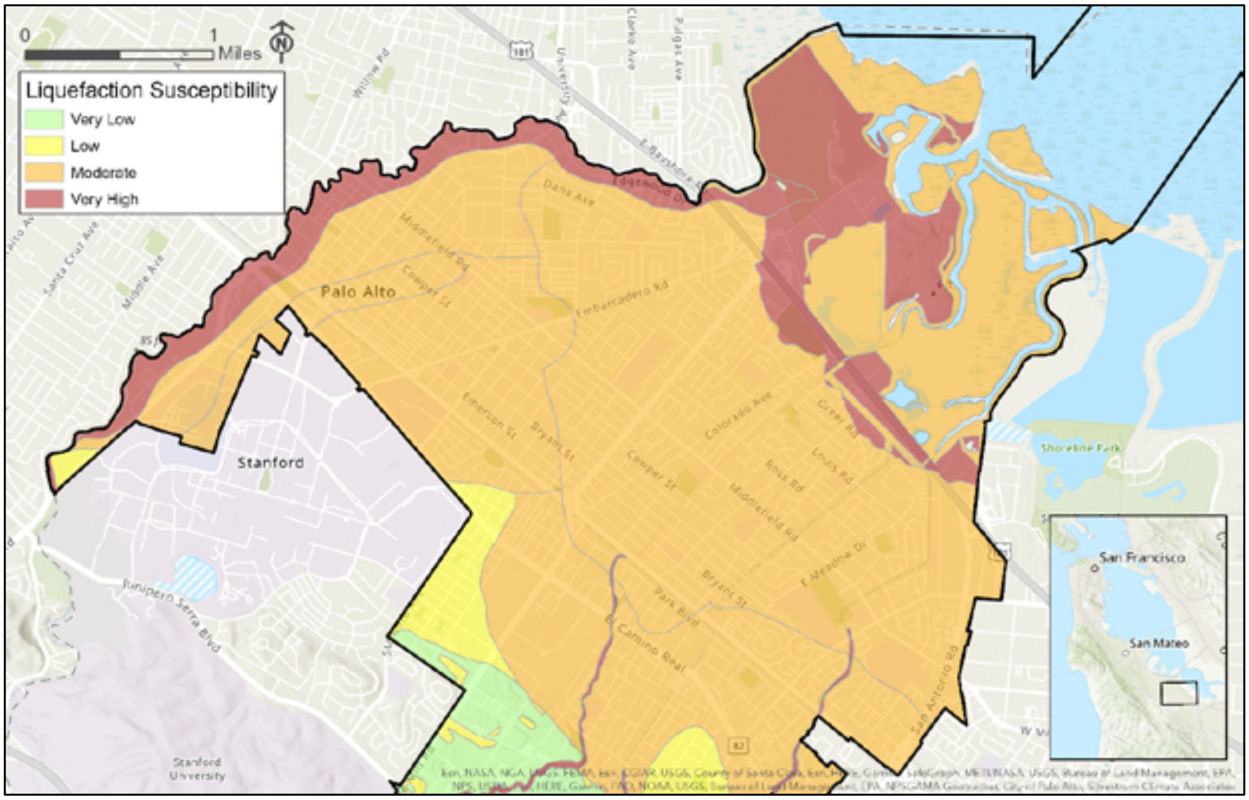
3.5 Liquefaction

The Bay Area is seismically vulnerable, with multiple active geologic plate-boundary fault lines that can move, resulting in an earthquake. There is an estimated 72 percent probability of a magnitude 6.7 or greater earthquake occurring in the Bay Area by the year 2043 (Aagaard et al. 2016). Soil liquefaction occurs when loosely packed and waterlogged sediments lose their strength in response to strong shaking and act more like a liquid than a solid. When this occurs beneath a building, structure, or other infrastructure, major damage can result.

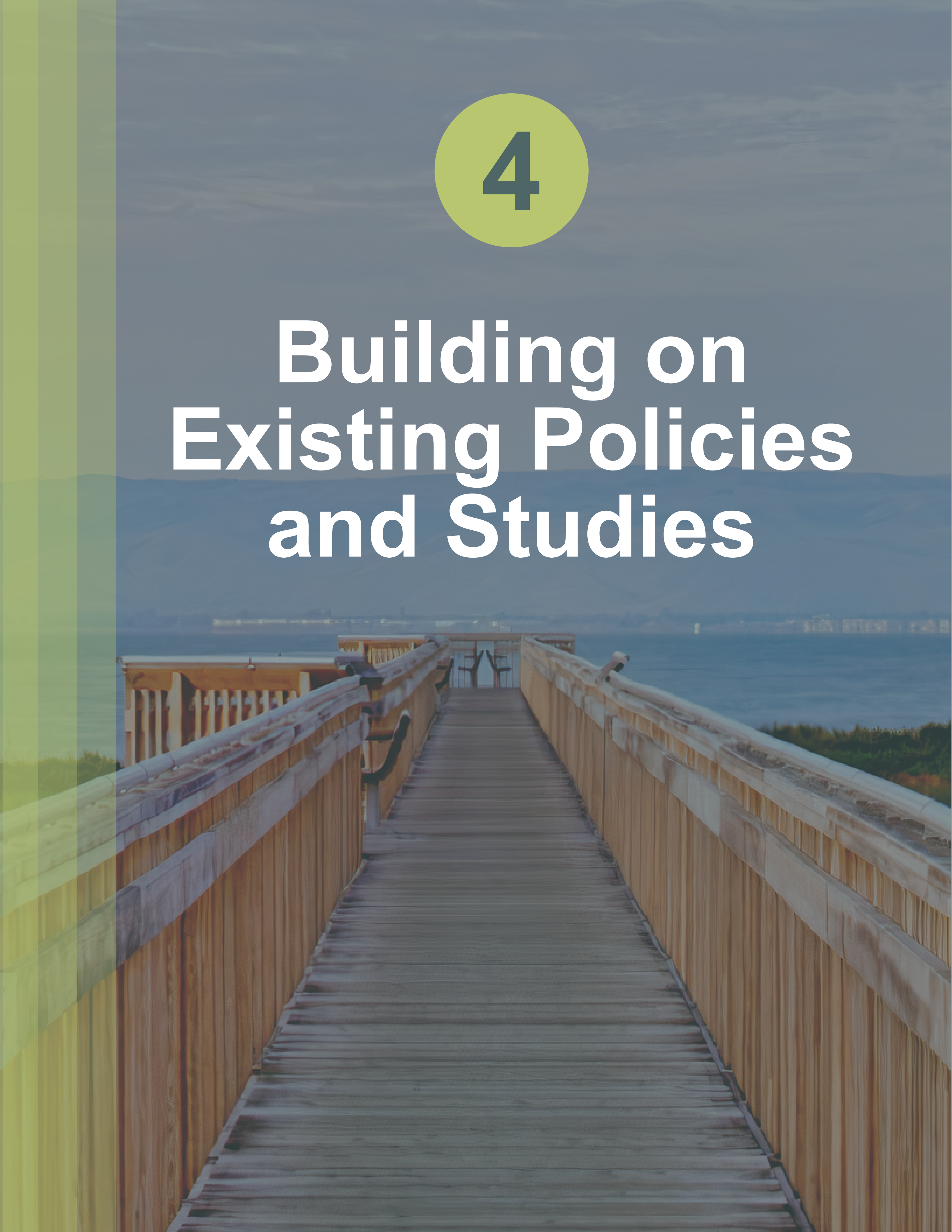
The elevation of the groundwater table can affect liquefaction hazards during large earthquakes. Research examining the effect of SLR and groundwater suggests a substantial increase in liquefaction potential and infrastructure instability during earthquakes due to rising groundwater levels (Quilter et al. 2015; Risken et al. 2015; Yasuhara et al. 2007).

Areas containing Bay fill (e.g., where former marshes and Baylands have been filled with silty-sandy soil or other materials to create new developable land) are generally the most prone to liquefaction during an earthquake. Figure 4 presents a map of liquefaction susceptibility in Palo Alto (Fowler 2012; Witter et al. 2006). The highest liquefaction susceptibility is along the bayside of US 101 portion of San Francisquito Creek, the Baylands Golf Links, Embarcadero Road, US 101, and along the Bay margins near the former salt pond complex and tidal marshes. The remainder of the low-lying areas within the City of Palo Alto have moderate susceptibility to liquefaction.

Figure 4. City of Palo Alto Liquefaction Suceptibility



Source: Witter et al 2006
Note: This study only evaluated impacts to Palo Alto and these maps are no indication of what may occur in adjacent communities.



4

Building on Existing Policies and Studies

4 Building on Existing Policies and Studies

In addition to local plans to adapt to future sea level conditions, the City is situated within a broader context of State and regional policies and regulations aimed at addressing potential SLR impacts. The City partners and coordinates with regional agencies or is the subject of numerous climate-change-related planning efforts. This chapter summarizes the regulations and studies that support the City's Assessment. This summary is not an exhaustive list of climate-related efforts that have been completed to date but represents a subset of the most relevant documents and projects that were reviewed for regulatory compliance and regional consistency for sea level flood protection.

4.1 Regulations and Guidance

Project planning and design along the shore often requires approval by local, regional, State, and federal agencies. Building partnerships with these stakeholders will be necessary to identify and enact cost-effective and proactive SLR solutions.

4.2 State

California has developed a series of guidance documents and studies to enhance understanding of SLR impacts on a regional scale and directly inform vulnerability assessments and adaptation strategies. To the extent possible, this Assessment relies on and adopts these State-published resources as best-available science for the Assessment. The following is a list of State regulations and resources that are considered in conducting the evaluation of potential SLR impacts for the City:

- California Executive Order B-30-15 (State of California 2015). This executive order requires that each State agency prioritize adaptation actions, prioritize natural infrastructure approaches, and protect the State's most vulnerable populations. The California Governor's Office of Planning and Research released a Guidebook for State Agencies (California OPR 2017) to assist State agencies in meeting these requirements by providing a process to determine how to integrate climate considerations into State planning and investment decisions. The guidance provides an introduction to climate hazards, common practices for analyzing risk, and principles to guide decision making in the context of climate change, social equity, and community resilience.
- Ocean Protection Council SLR Guidance (California OPC 2018). This State guidance update compiles, reviews, and summarizes the latest research on SLR and presents the latest peer-reviewed projections of SLR; describes an extreme scenario for SLR caused by rapid ice sheet loss from the West Antarctica ice sheet, and presents scenario selections using a risk-based (probabilistic) approach; and lays out preferred approaches to planning for vulnerable assets, natural habitats, and public access.
- California Natural Resources Agency et al. (CNRA et al. 2021). State agencies across California agreed to a set of seven principles to promote more resilient actions in response to SLR in the new guidance document: Making California's Coast Resilient to

Sea Level Rise: Principles for Aligned State Action (CNRA et al. 2021). These principles recommend that projects implemented by 2050 should consider, at a minimum, 3.5 feet of SLR to provide protection for the California OPC 2100 “likely” SLR projection associated with RCP 8.5.

- Assembly Bill 67 (2021). This bill, also referred to as the Sea Level Rise Preparedness Act of 2021, is currently making its way through the California Assembly. This bill would require projects that rely on State funds to use the SLR projections provided by California OPC for planning, designing, building, operating, maintaining, and investing in infrastructure in the coastal zone. This bill would further require that projects supported in whole or in part by State funds can only qualify for funding if the project is not anticipated to be vulnerable to SLR risks during the life of the project.

4.3 Regional

The BCDC has regulatory authority and jurisdiction over the 100-foot shoreline band around the edge of the Bay. BCDC’s policies related to consideration of climate change impacts occurring in the Bay are outlined in the San Francisco Bay Plan. Initiatives outlined in the plan include requiring SLR risk assessments, preserving public access, ecosystem restoration, preservation of undeveloped areas, and encouragement for regional strategies. In July 2021, BCDC released San Francisco Bay Plan Climate Change Policy Guidance to communicate the application of its Climate Change policies more widely and consistently (BCDC 2021).

4.4 City

To plan for rising tides that could impact the City’s neighborhoods, economy, and Baylands habitat, the City has adopted Sea Level Rise Adaptation Policy (City of Palo Alto 2019), a policy to encourage consideration of SLR in advance of development decisions. The plan includes integrating SLR language into the City’s key planning documents, establishing interdepartmental SLR planning responsibilities, and coordinating SLR projects with neighboring communities, counties, public agencies, and utilities, as needed.

4.5 Sea Level Rise Studies

A review of previous and ongoing studies and initiatives relevant to SLR adaptation efforts in Palo Alto was conducted to identify synergies, common goals, and key findings that may inform and guide development of the City’s Assessment and Adaptation Plan. Table 2 provides a summary of each document. In addition to these studies, the City also continues to iteratively improve (e.g., elevating equipment, upgrade facilities, increase drainage capacity) their infrastructure to account for future climate conditions through capital improvement and maintenance programs. The Assessment will provide additional information that will be instructive to these efforts.

Table 2. Summary of Relevant Sea Level Rise Studies

Study/Lead Agency	Summary
Regional	
Adapting to Rising Tides: Bay Area Sea Level Rise Analysis and Mapping Project (BCDC 2017) *Bay Conservation and Development Commission Metropolitan Transportation Commission and Bay Area Toll Authority*	▪ Provides consistent inundation data and mapping products for all nine Bay Area counties to help determine actions and interventions that preserve infrastructure functionality, public safety, and mobility for the Bay Area. ▪ Created mapping products for 10 scenarios (12 to 108 inches of SLR) and include shoreline overtopping potential layers to identify potential flood pathways and timing of tipping points of widespread overtopping.
Coastal Storm Modeling System (CoSMoS), 2016–present (Barnard 2014) *United States Geological Survey (USGS)*	▪ Numerical modeling system to predict coastal flooding and erosion due to climate change-driven SLR and storms. ▪ Version 2.1 is focused on the Bay Area
San Francisco Bay Shoreline Adaptation Atlas (SFEI and SPUR 2019) *San Francisco Estuary Institute (SFEI)* *San Francisco Planning and Urban Research Association (SPUR)*	▪ Presents nature-based coastal climate resilience strategies for the Bay region ▪ The region is divided into 30 Operational Landscape Units (OLUs) based on similar characteristics to represent "nature jurisdictions" to help identify tailored strategies for each area.
Bay Adapt, 2021-present *Bay Conservation and Development Commission*	▪ Initiative for regional collaboration on proactive adaptation to SLR in the Bay Area. ▪ Includes guiding principles and priority actions for local governments to take for a collective plan for SLR preparation.
Silicon Valley 2.0 *County of Santa Clara*	▪ Santa Clara County-wide effort to understand and minimize impacts of climate change. ▪ Includes a guidebook, Climate Change Preparedness Decision Support Tool, to evaluate the potential climate change impacts and associated financial cost, and strategies for climate change adaptation.
Local	
SAFER Bay: Palo Alto Public Draft Feasibility Report (SFCJPA 2019) *San Francisquito Creek Joint Powers Authority*	▪ A multijurisdictional effort to provide flood protection for the cities of East Palo Alto, Menlo Park, and Palo Alto from up to 10 feet of SLR above today's daily high tide. ▪ Includes evaluation of physical strategy alternatives for the shoreline, and feasibility scoring criteria to rank alternatives.

Study/Lead Agency	Summary
	▪ Reach 10 and 11 of the feasibility study include the City of Palo Alto shoreline.
South San Francisco Bay Shoreline Study (Valley Water 2021) *Santa Clara Valley Water District* *California State Coastal Conservancy* *United States Army Corps of Engineers (USACE)*	▪ Focused on identifying the National Economic Development alternative that provides flood protection at the best benefit-to-cost ratio. Recognizing that restoration will be required during permitting, the study is also looking at options that could provide restoration opportunities to meet permitting requirements and possibly incorporate them into the flood protection options to meet all communities' needs. ▪ Economic Impact Areas (EIAs) 1 to 3 include the Palo Alto shoreline.
Palo Alto Flood Basin Tide Gate Structure Replacement Project Planning Study Report (Valley Water 2020a) *Valley Water*	▪ This project informs the replacement of the aging Palo Alto Flood Basin Tide Gate, which will be designed to accommodate up to two feet of SLR. The tide gate prevents Bay water from entering into creeks and holds stormwater runoff until it can be discharged at low tide. The flood basin provides wetland habitat and flood protection for homes, businesses, and US 101. ▪ Six conceptual design alternatives, ranging from no action, replacement of tide gate in new strategic locations, and removal of the tide gate structure, were evaluated. ▪ Construction is estimated to be complete by December 2026.
Palo Alto Horizontal Levee Pilot Project, ongoing Preliminary Design Report (ESA 2020) *City of Palo Alto* *San Francisco Estuary Partnership*	▪ Preliminary design for a horizontal levee pilot project within the Palo Alto Baylands to provide flood protection from rising tides and enhance existing habitat. ▪ Pilot study findings may be used to inform design of other large-scale flood protection projects. ▪ Construction is estimated to be complete in 2024.
RWQCP New Outfall Pipe Project, 2016–ongoing City of Palo Alto	▪ Provides installation of a new outfall pipe, maintenance for the City's existing 56-year-old outfall pipe, pump replacement for effluent discharged to Renzel Marsh, and reliable transport of treated wastewater effluent under projected climate change and SLR scenarios. ▪ Project will be rescheduled to accommodate airport adaptations in anticipation of levee improvements.
Climate Change and Sea Level Rise at the Palo Alto Baylands (AECOM 2019) City of Palo Alto	▪ Describes the potential impacts of SLR on physical assets and habitats in the Baylands and high-level measures that the City can take to adapt. ▪ Findings of the study were used to inform the Baylands Comprehensive Conservation Plan, a framework for management of the Baylands over the next 15 years and beyond.

4.6 Shallow Groundwater Rise Studies

Assessments of the response of the shallow groundwater layer to SLR are not as widely available as assessments of SLR itself. However, the Bay Area has been leading the research in this area in response to a landmark USGS publication in 2012 that documented this hazard on the east coast (Bjerklie et al. 2012). The available studies that the project team reviewed to support Palo Alto and identify synergies, common goals, and key findings that could inform the City's Assessment and Adaptation Plan are presented in Table 3.

Table 3. Summary of Relevant Shallow Groundwater Studies

Study/Lead Agency	Summary
Regional	
California statewide shallow groundwater modeling, 2020 *USGS* *University of Wyoming*	▪ Numerical modeling of the long-term average shallow groundwater table elevation in response to SLR using three (state-wide) homogenous values of soil hydraulic conductivity.
San Francisco Bay regional estimate of highest annual shallow groundwater table elevation, 2019	▪ Empirical analysis using well monitoring observations to approximate the shallow groundwater table for the nine Bay Area counties within 500 meters of known wells. ▪ Response to one meter of SLR estimated
Sea Level Rise and Shallow Groundwater Response, 2020–ongoing *San Francisco Estuary Institute* *Silvestrum Climate Associates* *UC Berkeley*	▪ Developing a series of shallow groundwater maps to consider response to eight SLR scenarios ranging from 12 to 108 inches) for four Bay Area counties ▪ Includes guidance on how to use future-condition shallow groundwater mapping and communicate risk
Local	
Groundwater Assessment, and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy (Northwest County Recycled Water Strategic Plan)	▪ Characterizes hydrogeologic conditions in Palo Alto and surrounding areas as they relate to expanded use of recycled water for indirect potable reuse, purified recycled water, and additional non-potable uses.
Evaluation of ocean tides on the shallow aquifer system adjacent to the southern portions of the Bay (Valley Water 2020b) *Valley Water*	▪ Examines the effects of present-day ocean tides on coastal aquifers; knowledge about these effects could provide insight into how groundwater in the Santa Clara subbasin may respond to SLR.

5

Sea Level Rise, Shallow Groundwater, and Contaminant Mapping

5 Sea Level Rise, Shallow Groundwater, and Contaminant Mapping

SLR inundation and groundwater maps are essential tools for evaluating potential asset exposure to future water-level conditions. The maps help estimate the timing and extent of flooding that may be experienced based on SLR projections. These maps also identify critical flooding thresholds where an entire area may be compromised.

The sections below describe the selection of SLR scenarios evaluated as a part of the Assessment, leveraged SLR mapping layers, groundwater and contaminant mapping methodology, and mapping assumptions.

5.1 Sea Level Rise Inundation Mapping

The SLR inundation mapping effort leveraged existing SLR layers prepared as a part of the BCDC Adapting to Rising Tides (ART) program (BCDC 2017). The ART mapping depicts the geographical extent of inundation for the Bay Area's nine counties using a combination of 10 SLR scenarios, tidal datums, and extreme tides modeled to represent local conditions along the shoreline. Also included in the ART mapping dataset are overtopping potential maps for all 10 scenarios that depict where the Bay may overtop the shoreline. The data sources and inundation mapping methodology used to create the maps are presented in the ART report (BCDC 2017).

To evaluate future flood impacts for the City, six SLR levels were selected for the flood exposure analysis: 12, 24, 36, 48, 66, and 84 inches. Selected SLR projections align with the planning time horizons of 2030, 2050, 2070, and 2100, and are in accordance with State Guidance recommendations. All selected scenarios have a 1-in-200 chance (0.5% probability) of being exceeded at each planning time horizon. To account for the range of uncertainty of GHG emissions at the end of the century, two scenarios were included for 2070 (36 and 48 inches) and 2100 (66 and 84 inches) planning based on low and high-emission scenarios. Table 4 shows how each SLR projection aligns with the State guidance (California OPC 2018).

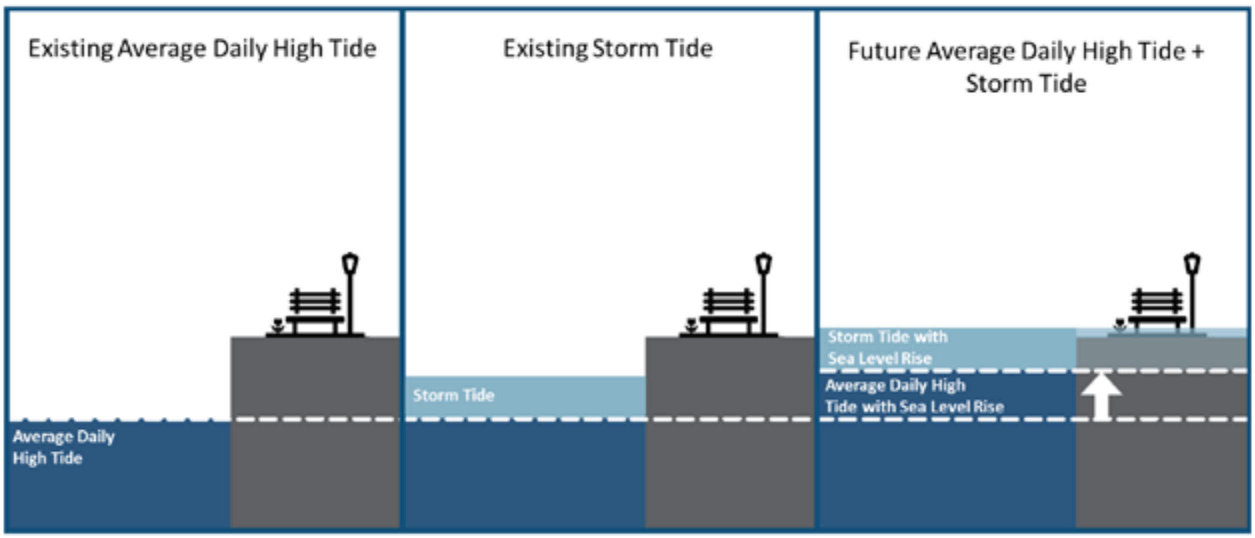
Future sea levels considered in the Assessment were evaluated under two tide conditions: (1) daily high tide and (2) a 100-year storm tide (Figure 5). In this report, inundation refers to permanent submersion that would occur from daily high tides if no adaptive action is taken by the City. Flooding refers to temporary flood exposure that only occurs during elevated water levels associated with coastal storms such as the 100-year storm tide. Flooding is temporary and less frequent but is associated with high water levels.

Table 4. Sea Level Rise Projection Alignment with Ocean Protection Council State Guidance

Year	GHG Emission Scenario	Daily High Tide	Storm Tide
2030	High	12-inch SLR + MHHW	12-inch SLR + 100-year storm tide
2050	High	24-inch SLR + MHHW	24-inch SLR + 100-year storm tide
2070	Low High	36-inch SLR + MHHW 48-inch SLR + MHHW	36-inch SLR + 100-year storm tide 48-inch SLR + 100-year storm tide
2100	Low High	66-inch SLR + MHHW 84-inch SLR + MHHW	66-inch SLR + 100-year storm tide 84-inch SLR + 100-year storm tide

Source: California OPC 2018.
MHHW = mean higher high water

Figure 5. Graphical Representation of Sea Level Rise Mapping Scenarios



The water level evaluated for daily tidal inundation is the MHHW tidal datum, which represents the long-term average of the higher of two high tides each day. The water level evaluated for the 100-year storm tide is a statistically derived water elevation that has a one percent chance of occurring in any given year. The 100-year storm tide includes the combined effects of astronomical tides and storm surge conditions due to atmospheric pressure and metrological effects that temporarily elevate water levels above typical conditions. It is a commonly used water design criteria for coastal development and flood protection.

5.1.1 Assumptions and Caveats

The SLR inundation maps, which are presented in Attachment B, are a screening-level tool to assess exposure to future SLR and 100-year storms. These maps represent a "do nothing" approach, where future mitigation and potential flood protection efforts are not made. These maps are prepared so that the City can understand the extent of adaptations that are needed for the future. Although they rely on the best-available information and data sources, they are still associated with a series of assumptions and caveats, as described below. To account for these caveats, a more sophisticated modeling effort would be required. However, given the uncertainties associated with SLR and future land use changes, development, and the geomorphic changes that will occur over the next century, a more sophisticated modeling effort may not necessarily provide more accurate results. The following assumptions and caveats apply to the inundation maps:

- The inundation maps do not account for storm waves, rainfall, or other potential variations in conditions that could affect the depth of inundation at any given location.
- Storm factors such as the frequency and intensity of storms, shifts in storm tracks, the magnitude of storm tides, and wave heights were not considered in this analysis. There is consensus among scientists that climate change will affect aspects of storm characteristics; however, a clear consensus has not emerged on the nature of these changes in the Bay Area due to the limitations of capturing the complex topography within the resolution of global climate models. Research is in progress to fill this data gap by other agencies and regional efforts.
- Shoreline elevations and the height of other topographic features that may affect floodwater conveyance are derived from a combined-source light detection and ranging (LiDAR) dataset (California OPC 2010) and are accounted for in the BCDC flood and inundation layers. The data have not been extensively ground-truthed, and elevations may be overrepresented or underrepresented by the LiDAR data.
- The inundation maps do not account for localized flooding associated with rainfall events or any changes to rainfall patterns, frequency, or intensity.
- Rates of historical or future land subsidence due to consolidation of Bay muds and regional tectonic processes (Shirzaei and Bürgmann 2018) were not directly incorporated into the Assessment; however, the inundation mapping and overtopping analysis developed for this Assessment incorporates the most up-to-date topographic LiDAR data available in the study area and therefore captures any historical subsidence that has occurred to date. Although rates of future subsidence will be low compared to future projected rates of SLR, continued land subsidence would add to the impacts of locally observed SLR.
- The methodology is GIS-based and does not consider the complex physics of overland flow, dissipation, drainage, or potential shoreline or levee erosion associated with extreme water levels and waves.
- The durations of storms is not accounted for in the modeling of temporary flood conditions, but potential flooding can be assumed to persist for several hours, which is typical of a large storm.

5.1.2 Sea Level Rise Map Interpretation

An example of the SLR inundation maps is shown on Figure 6, and the complete map book is presented in Attachment B for the baseline (existing) and for SLR scenarios of 12, 24, 36, 48, 66, and 84 inches. The maps are not intended to provide the precise locations and extents of flooding, but rather are useful for evaluating the timing of impacts and identification of areas that may be exposed to future inundation and flooding. The scenarios represent the potential extent of inundation for average daily high tide (dark blue) and 100-year storm tides (light blue), as noted on each map. Portions of the shoreline exposed to overtopping by Bay waters are also shown in yellow for average daily high tide and red for 100-year storm conditions. Shoreline overtopping provides information on potential flood pathways for Bay floodwaters to inundate low-lying inland areas and this information will be used in the adaptation phase of the project to identify locations to implement flooding-related adaptation strategies.

Figure 6. City of Palo Alto Sea Level Rise Inundation Map for 36 inches of Sea Level Rise

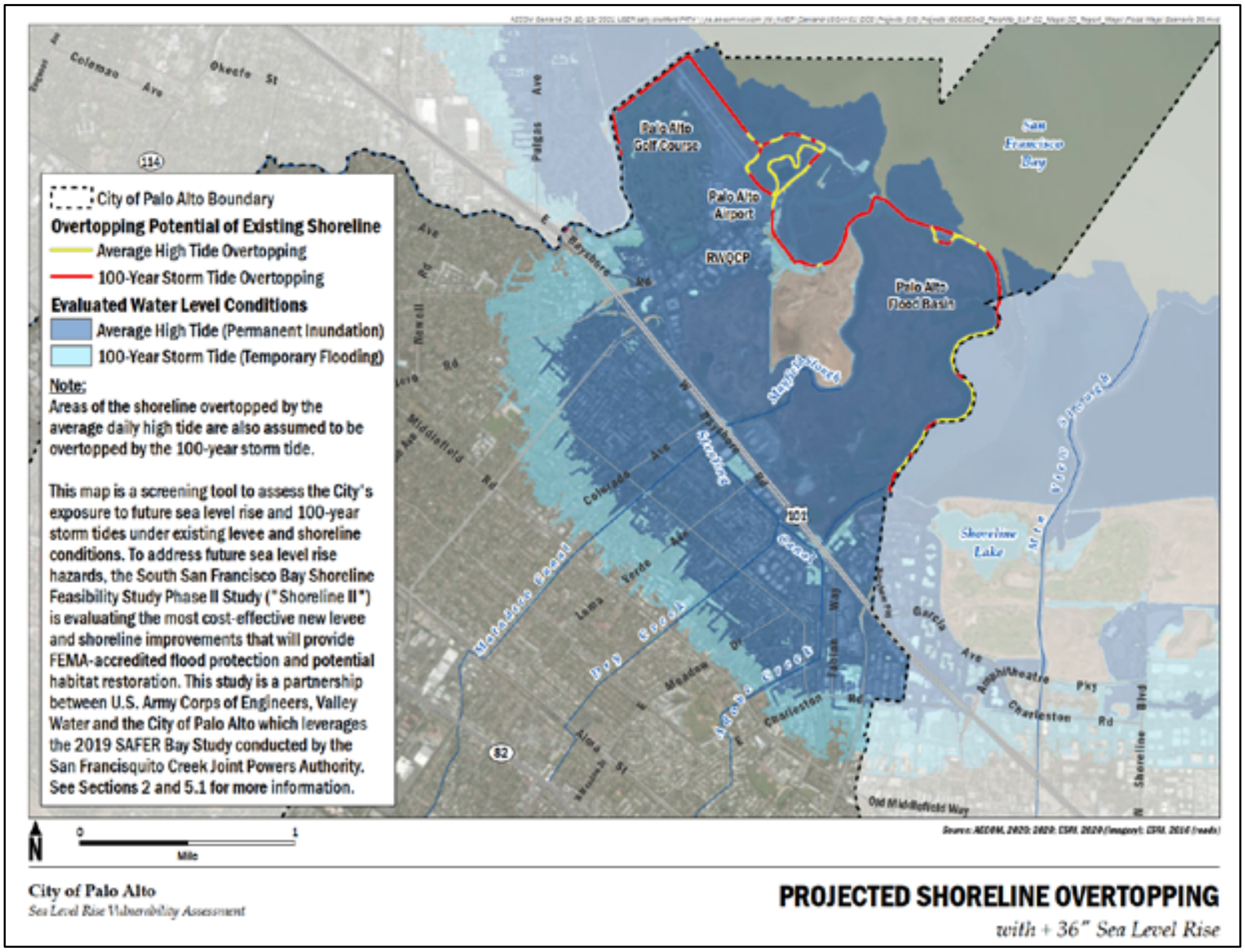


Figure 6 shows that the average high tide with 36 inches of SLR is a tipping point for potential widespread inundation of the City. Under existing conditions without levee improvements, flooding during the 36-inch SLR scenario has the potential to overtop nearly the entire shoreline, exposing most of the City's assets bayward of Middlefield Road. This is equivalent to a 25-year storm occurring today, with no SLR. This means that under today's sea level conditions, there is at least a four percent chance the City may experience coastal flooding in any given year.

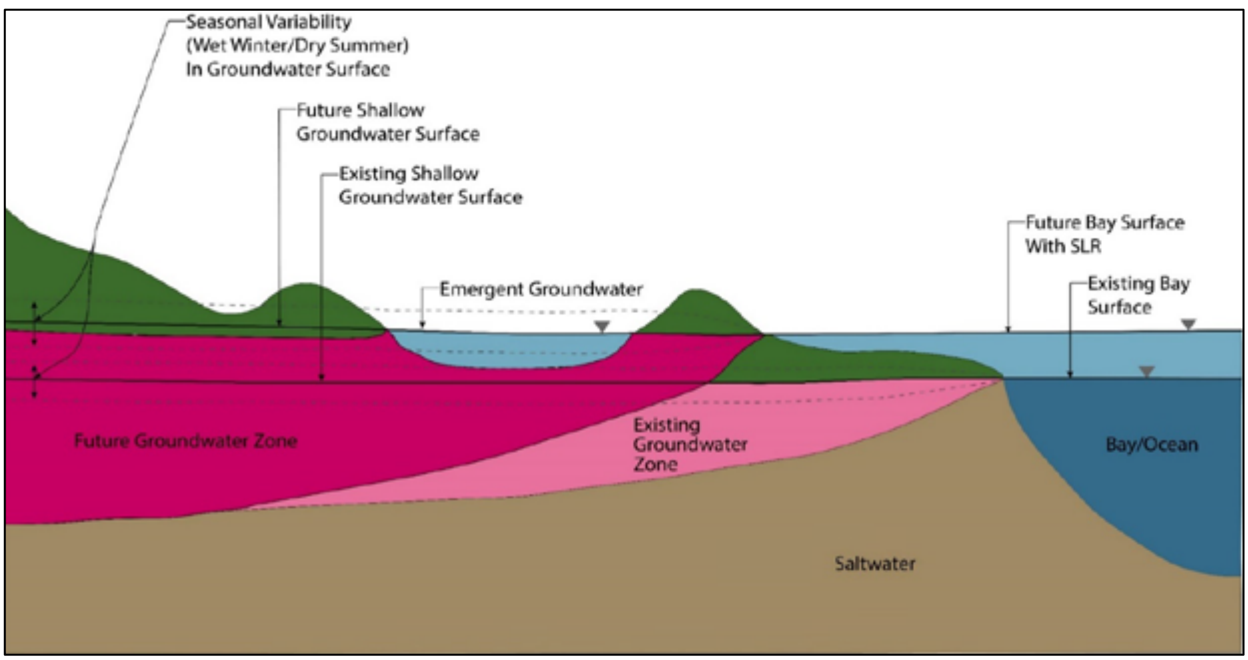
The maps in Attachment B also show that a proposed bayfront levee project (such as SAFER Bay) would provide coastal flood protection through average high-tide conditions with 84 inches of SLR. However, a 100-year storm tide could overtop the upgraded levees with 60 inches of

SLR, which may occur as early as 2090 based on current State SLR guidance (California OPC 2018).

5.2 Shallow Groundwater Mapping

The response of the shallow groundwater layer to SLR is a critical data gap associated with SLR and climate change adaptation planning (Michael et al. 2017). This study assessed and mapped the response of the shallow groundwater layer to SLR, with an emphasis on the highest annual groundwater surface, which generally occurs in the late winter or early spring in response to winter rainfall events. The groundwater surface is highest (i.e., closest to the ground surface) in wet years when total precipitation is generally much higher than in drought years. This high groundwater surface could emerge aboveground during or after a wet winter season, creating sporadic and localized flooding (referred to as "emergent groundwater flooding" in this Assessment). Over time, as sea levels and the shallow groundwater table rise, the impacts associated with a high and/or emergent groundwater table will become more widespread, as seen on Source: May 2020

Figure 7. Shallow Groundwater Surface Response to Sea Level Rise



Source: May 2020

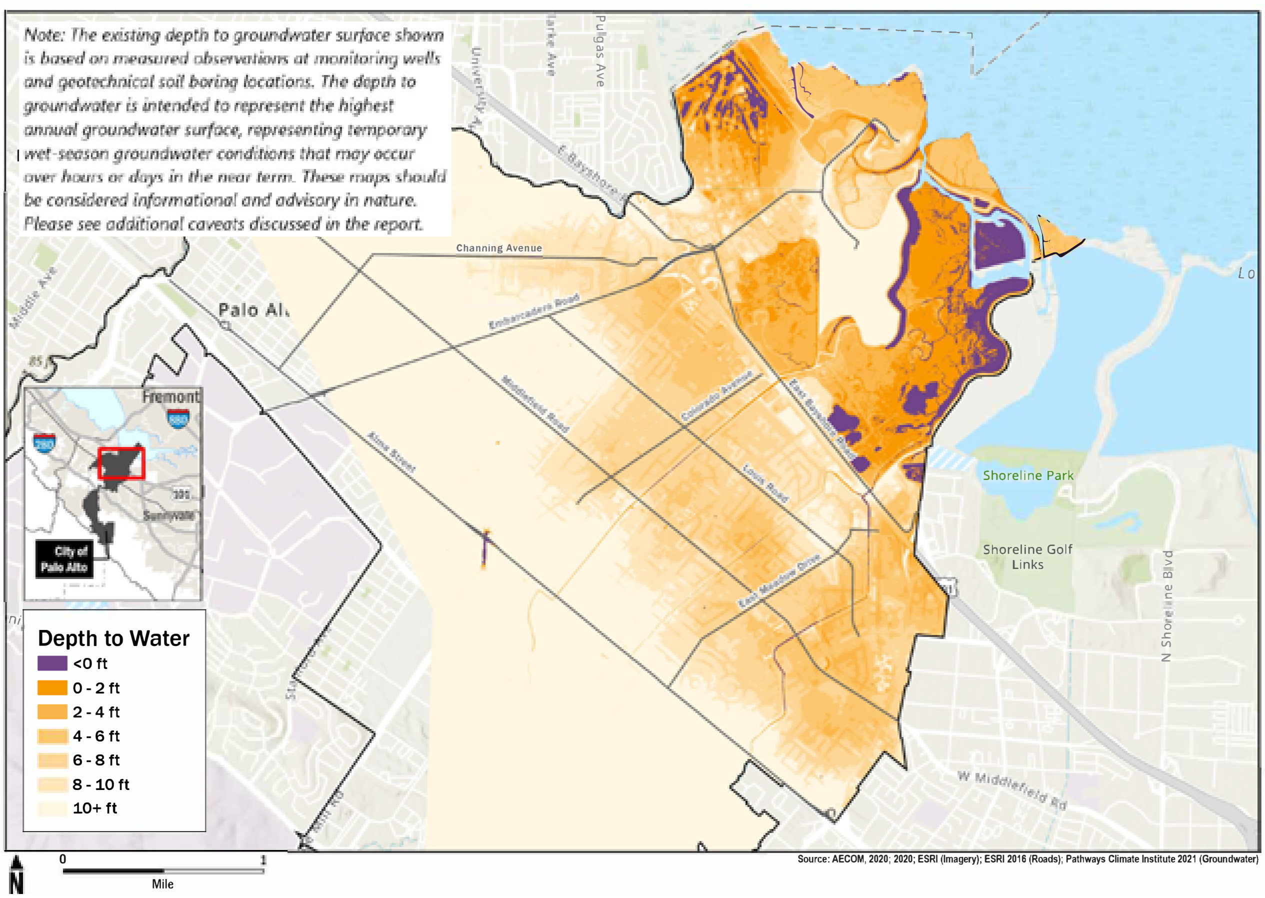
Similar to the SLR inundation maps, the existing and future condition groundwater maps are helpful for evaluating the timing and extent of subsurface and emergent groundwater flooding that may be experienced in the future as sea levels rise. The maps can help identify areas where the shallow groundwater table may rise into areas where underground utilities are buried.

This is particularly important if those utilities were not designed for saturated soil conditions or to withstand a fluctuating groundwater table. The maps can also help identify where transportation infrastructure or structures could be impacted by the rising groundwater table long before the groundwater emerges above the surface. As the groundwater table emerges above the ground surface, it can become a flood hazard with the potential to mobilize legacy contaminants and impact human health and the environment. The maps can also help identify the SLR scenarios under which emergent groundwater can impact a broad area, such as a neighborhood.
A summary of the groundwater mapping methods for existing and future conditions, their assumptions and caveats, and groundwater map interpretation are summarized below. Detailed discussion of the groundwater analysis methods is provided in Attachment A.

5.2.1 Existing Conditions

The existing shallow groundwater surface was characterized using groundwater monitoring well data submitted to the State Water Resources Control Board (SWRCB) and geotechnical reports provided by the City (Figure 8). The SWRCB data were the primary data source. Monitoring well records were reviewed and analyzed to develop a subset of wells to use to characterize the shallow groundwater table (as opposed to the deeper aquifers). The well records were subsampled to only select wells with measurements collected during or shortly after the wet winter seasons when rainfall resulted in the highest annual shallow groundwater table elevation. This elevation is often used as a design criterion for buried infrastructure, such as utilities, foundations, and subsurface structures.

Figure 8. Existing Groundwater Surface in Response to Precipitation



In areas with limited numbers of monitoring wells, the SWRCB data were augmented with geotechnical soil borings collected during or shortly after wet winters. The geotechnical reports include soil boring information collected between 2010 and the present to better characterize the depth to groundwater in data gap areas where no SWRCB monitoring wells were located. The soil boring logs include information on the soil characteristics and the location of the water table at the time the soil borings were extracted from the ground. To connect the shallow groundwater surface with sea level in the Bay, tidal water elevations from the Bay Tidal Datums and Extreme Tides Study (AECOM 2016) were used. In areas with limited monitoring well information near the shoreline, the data from this study helped approximate the natural slope of the shallow groundwater surface toward the Bay.

The final collection of well observations, soil boring logs, and tidal water elevations was used to approximate the highest annual shallow groundwater surface for existing conditions (see Figure 8).

5.2.2 Future Conditions

SLR will result in a landward migration of the saltwater groundwater wedge near the Bay. As the wedge pushes inland, it will cause the overlying fresh groundwater layer to rise (Figure 7). The amount of rise in the shallow groundwater surface depends on many factors, including the tide range, salinity, aquifer geology, soil characteristics, distance from the shoreline, and shore slope. As a conservative approximation, a 1:1 correlation between SLR and shallow groundwater rise was assumed to adjust the existing shallow groundwater surface to future conditions. The existing shallow groundwater surface was raised to account for SLR by applying future scenarios of 12, 24, 36, 48, 52, 66, and 84 inches of SLR. For each future SLR scenario, the depth to the shallow groundwater surface was calculated based on existing topography by subtracting the elevation of the groundwater surface from the ground elevation. Areas of emergent groundwater flooding were identified in areas where the groundwater surface was projected to rise above the existing ground surface. Maps showing future depth to groundwater and areas of emergent groundwater flooding are included in Attachment A.

5.2.3 Assumptions and Caveats

Groundwater flow is incredibly complex, and the approaches used in this assessment are considered approximate but reasonable. Flow dynamics vary with soil characteristics such as soil porosity (soil volume relative to pore space, i.e., how much space there is between the soil particles for water to flow through) and hydraulic conductivity (the ability of saturated soil to convey water, i.e., the ease with which water can move through saturated soil) and can also be driven by connections to surface water bodies, tributaries, marshes, and the Bay. Although the mapping relies on the best available information and data sources, it is associated with a series of assumptions. To account for these caveats, a more sophisticated hydrogeological modeling effort accompanied with additional monitoring and soil characterization would be required. The cost and data requirements to develop and calibrate such a model would both be high, and this more sophisticated modeling effort may not necessarily provide more accurate results.

- The existing condition mapping represents the highest annual groundwater surface elevation measured at the SWRCB monitoring wells. Although measurements are recorded during late winter / early spring when the highest groundwater surface is expected to occur in response to winter precipitation, it cannot be assured that the highest groundwater surface elevation was captured. A more detailed monitoring effort would be required, such as recording hourly depth to water measurements over an entire season across multiple wells, during a very wet year.
- Precipitation is often the primary driver of seasonal fluctuations in groundwater table elevation. However, near the Bay shoreline, the rise and fall of the Bay tides can affect the elevation of the groundwater table on a daily (tidal) and monthly (spring-neap) cycle. The fluctuations in the groundwater table are generally muted compared to the tidal variations (i.e., the tidal range in the south Bay can exceed eight feet from mean lower low water to mean higher high water, and this range may translate to fluctuations in the groundwater table of less than one foot depending on the soil characteristics and distance from the Bay). A more detailed monitoring effort would be required to capture the influence of the Bay tides on the elevation of the groundwater table, such as recording sub-hourly depth to water measurements for a minimum of 14 days, and preferably a minimum of 28 days to evaluate spring-neap tidal variations. Long-term groundwater table elevations are dominated by sea level rise, climate change effects on recharge, and human interventions such as groundwater pumping, placing streamflows in underground pipes and culverts, and the use of concrete-lined drainage channels.
- The methodology is empirical and GIS-based and does not consider the complex physics of groundwater flow, nor does it consider the considerable heterogeneity in soil conditions that could result in a higher, or lower, groundwater surface in between monitoring well or geotechnical soil boring log observations.
- The well measurements may not accurately represent the depth to water locations adjacent to the well. Although the wells have been in place long enough to reach equilibrium conditions, the depth to water within the well may be slightly higher, or lower, than the depth to water in the surrounding areas.
- The depth to water measurements from the geotechnical soil borings are considered approximate. Depending on the soil boring collection method and the geotechnical contractor, the notation of the depth to water location for the soil boring may vary. If the geotechnical reports included information or a citation relative to a higher annual groundwater surface (i.e., a smaller depth to water) that differs from the boring log estimate(s), the higher annual groundwater surface elevation was used in place of the boring log. In general, the depth to water locations reviewed for this study were reasonable when compared with the SWRCB monitoring well measurements.
- This assessment does not consider the influence of future green stormwater infrastructure that may be installed by the City of Palo Alto. Green stormwater infrastructure can be designed to either increase precipitation infiltration into the soil or retain runoff in the upper watershed during storm events to reduce or mitigate the potential for downstream flooding.

- This assessment does not consider localized groundwater pumping for basement drainage which occurs at some locations that were installed prior to 2006, or the temporary construction-related dewatering which occurs where the groundwater is shallow. The City of Palo Alto issues permits for short-term construction-related dewatering which typically ends before projects are completed. Basement drainage systems were prohibited in 2006, but some of those remaining systems contribute to localized long-term (> one year) groundwater pumping due to the soil collapse that can occur between longer drought periods and more extreme wet periods and due to increased groundwater pumping.

5.2.4 Shallow Groundwater Map Interpretation

An example of the future condition groundwater surface for the City of Palo Alto is shown on Figure 9 for the 36-inch SLR scenario. Areas of emergent groundwater flooding (i.e., where the groundwater surface has emerged above the surface) are shown in purple. Orange shading indicates depth to groundwater (for wet season conditions approximating the highest annual groundwater table elevation, as described above). In general, areas close to the Bay shoreline (and former wetland areas) are more likely to experience emergent groundwater flooding. These areas include areas east of US 101 such as the Baylands Nature Preserve and Palo Alto Airport. The area of emergent groundwater expands inland with higher SLR scenarios; maps for each SLR scenario evaluated (12, 24, 36, 48, 66, and 84 inches of SLR) are presented in Attachment A.

5.3 Shallow Groundwater and Contamination

The shallow groundwater layer contains various contaminants from legacy industrial land uses and from more recent commercial and industrial land uses (e.g., gas stations, dry cleaners, machine shops). As the shallow groundwater table rises in response to SLR, the natural rise and fall of the layer could enhance contaminant mobilization, including into enclosed subgrade spaces such as basements. In addition, the contaminants could emerge above ground creating an environmental and human health hazard. If vapor-forming chemicals (e.g., petroleum hydrocarbons, chlorinated solvents) are mobilized upward in areas with sewers, drainpipes, subgrade enclosed spaces, or above-grade structures, these chemicals could pose threats to indoor air quality. Depending on the concentration, these vapors can be harmful to humans.

The City and Valley Water completed an assessment in 2018 that identified contaminated areas within the City (City of Palo Alto and Santa Clara Valley Water District 2018). The wells with identified contaminants of concern are shown on Figure 10.

Figure 9. Future Groundwater in Response to Precipitation and 36" of Sea Level Rise

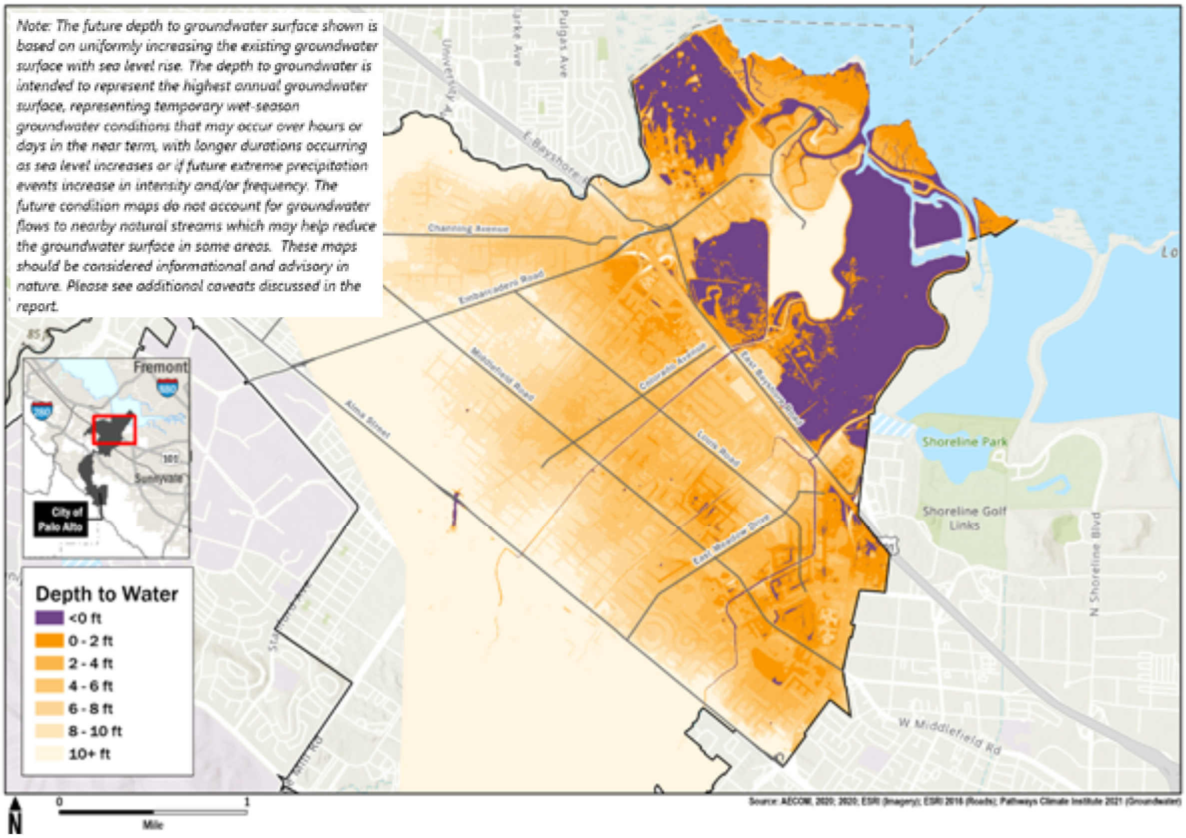
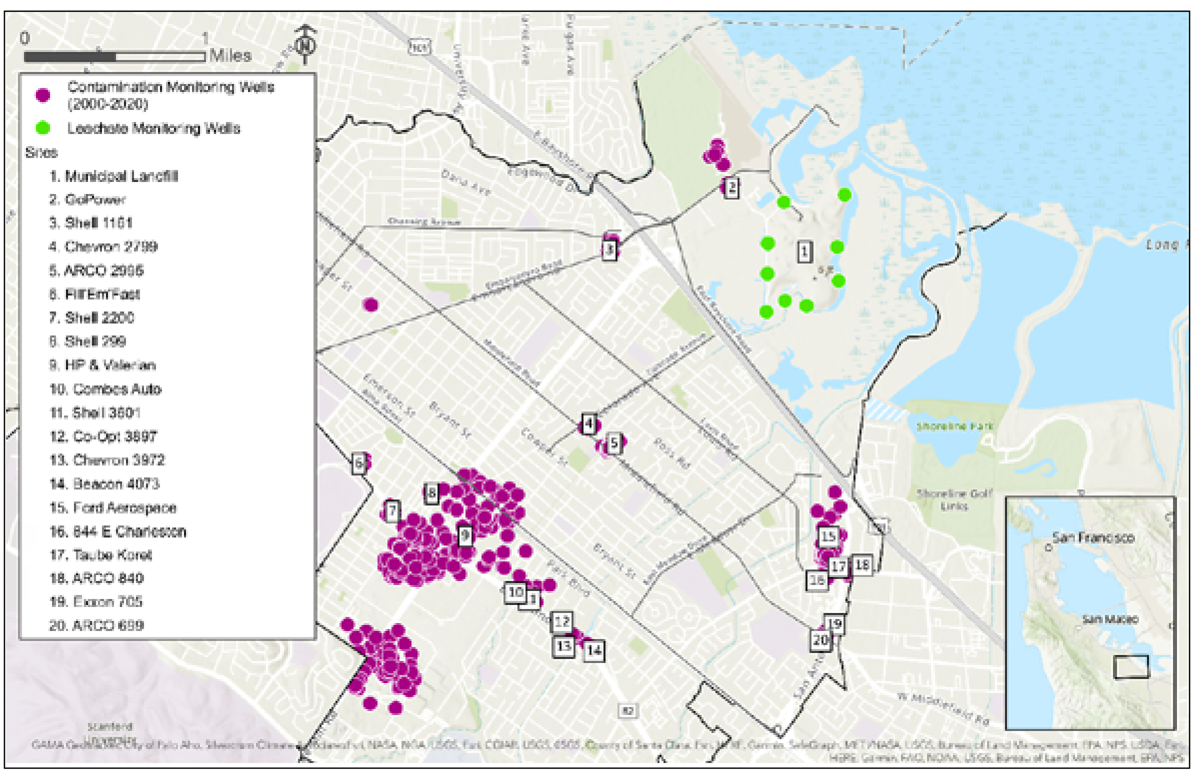


Figure 10. Groundwater Monitoring Well Locations



Source: (City of Palo Alto and Santa Clara Valley Water District 2018, SWRCB 2020)

Emergent groundwater flooding layers were overlain on the contaminant well points shown on Figure 10 to evaluate the potential for rising groundwater to mobilize contaminants to the surface. Based on this analysis, 36 inches would result in surface mobilization of two contaminant sites by emergent groundwater flooding (Site #2 GOPOWER near Embarcadero Road and Embarcadero Way; and Site #5 ARCO 2995 near Middlefield and Colorado). Site #1 Palo Alto Landfill is also likely to have emergent groundwater flooding around the perimeter of the landfill. However, the landfill has a maintained leachate collection and removal system that is effective at removing fluids from the landfill area for treatment. The pumping needs for this system are likely to increase as sea level and the surrounding groundwater table rise. If the leachate system is properly maintained and operated over time, this system should minimize the risk of contaminants leaking into the surrounding area as sea level rises.

A high-range end-of-century SLR projection of 84 inches would result in surface mobilization of 10 contaminated sites and the Palo Alto Landfill, which may have emergent groundwater conditions. If the contaminants are still present at these locations when the groundwater becomes emergent, this could create human health and environmental risk. The largest contaminated site is along Page Mill Road and known as the Hewlett Packard and Varian Associates California-Olive-Emerson site. Active remediation efforts are ongoing and contaminant levels are likely to decrease before 84 inches of SLR occurs. See Figure 10 and Attachment A for additional details on contaminants and their current remediation status. Most of the contaminated sites are in the process of being remediated (i.e., active measures are being taken to reduce the level of contamination in the soils and groundwater).

6

Asset Inventory

6 Asset Inventory

This chapter describes the development of a comprehensive inventory of built and natural assets within the City of Palo. Included assets are selected based on their significance to the City's operations and the services the City provides. All assets included as a part of the inventory were evaluated for vulnerability to SLR and shallow groundwater impacts.

The sections below describe the development and organization of the City's assets that were considered in the Assessment.

6.1 Data Collection

An inventory was developed to identify and organize the assets within the City that may be vulnerable to SLR. It is not possible or necessary to evaluate the climate vulnerability of all individual assets within the City's jurisdictional boundary. Therefore, assets included in the inventory list were prioritized for evaluation of potential flood impacts and protection through adaptation strategies based on their significance to the City's provided services and their significance to the community. Inventoried assets were evaluated for exposure, sensitivity, and adaptive capacity to SLR during the Assessment, as discussed in Chapter 7.

The inventory was developed using extensive City-maintained geospatial data (i.e., GIS data) for asset locations and through review and discussions between AECOM and City staff. The inventory is organized by the following asset categories:

- City and Community Facilities and Residential Parcels (e.g., key City-owned buildings and facilities, community centers, residential properties, senior centers)
- Emergency Response (e.g., fire and police stations, hospitals)
- Natural Resources and Open Space (e.g., Baylands marshes, parks, City-maintained trees)
- Transportation (e.g., Palo Alto Airport, US 101, primary roadways, bicycle/pedestrian trails, city parking lots)
- Utilities and Flood Management (e.g., wastewater system, recycled water pipelines, stormwater infrastructure, electrical substations, potable water network, flood protection levees, tide gate)

6.2 Asset Inventory Table

The inventoried City assets that were evaluated by the Assessment are presented in Table 5.

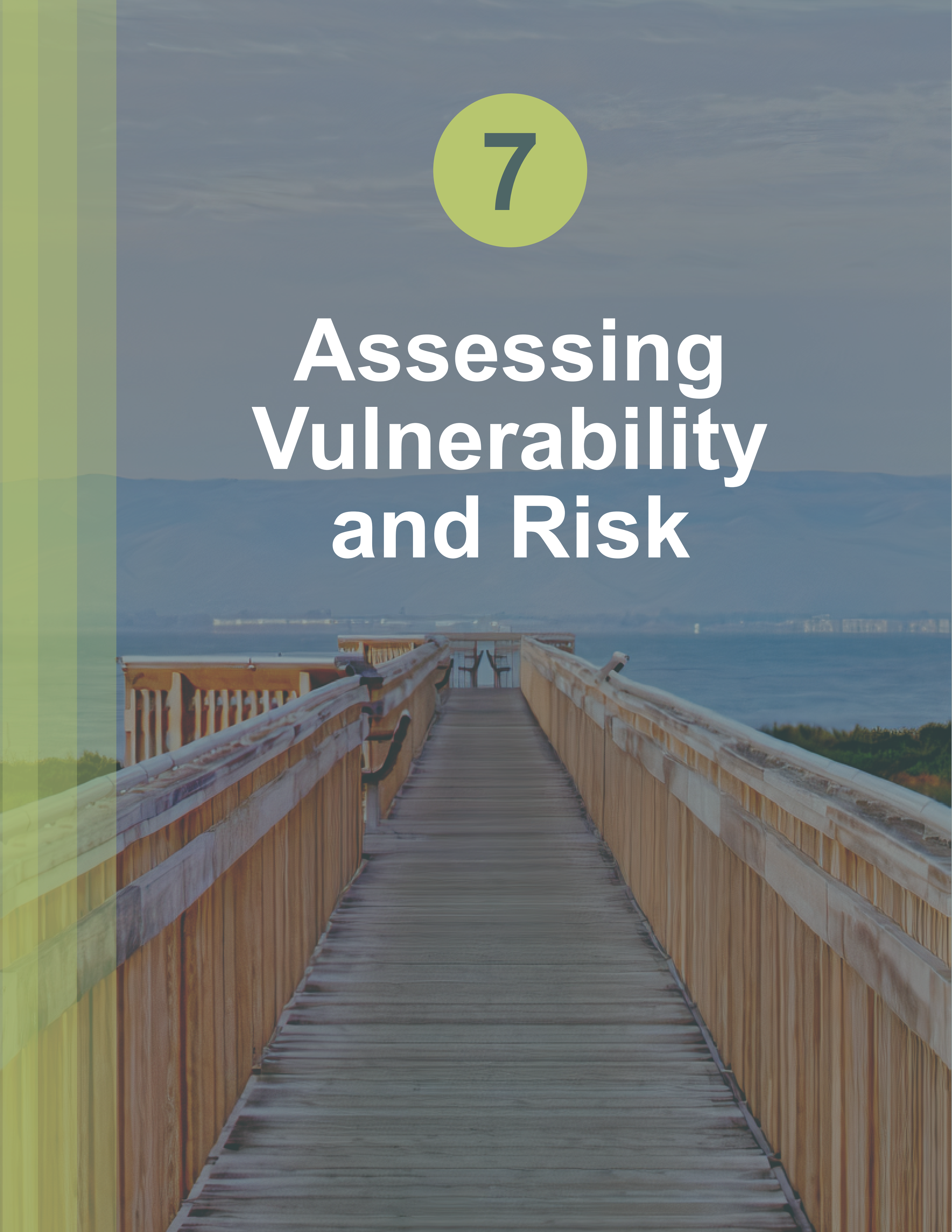
Table 5. Inventory of City Asset Types, Subtypes, and Individual Assets Included in the Sea Level Rise Vulnerability Assessment

Type	Asset Subtype	Asset
City and Community Facilities and Residential Parcels	City Facilities	▪ Animal Shelter ▪ Baylands Ranger Station ▪ Boat Launch ▪ City Hall ▪ Community Centers (5) ▪ Development Center ▪ Lucy Evans Baylands Nature Center ▪ Former ITT Property ▪ Libraries (5) ▪ Municipal Services Center ▪ Roth Building ▪ Utility Control Center ▪ Utilities Engineering Building
	Community Facilities and Residential Parcels	▪ Environmental Volunteers EcoCenter ▪ Save the Bay Nursery ▪ Schools (18 total) ▪ Residential Parcels
Emergency Response	Facilities	▪ Emergency Evacuation Route ▪ Fire Stations (7) ▪ Hospitals (4) ▪ Police Station and Substation (2)
Natural Resources and Open Space	Open Space	▪ City Parks (45) ▪ City Maintained Trees (owned or maintained for line clearing)
	Natural Resources	▪ Baylands marshes
	Baylands Golf Links and Athletic Center	▪ Baylands Golf Links ▪ Athletic Center
Transportation	Transportation Infrastructure	▪ Bike/Pedestrian Access Trails ▪ City Parking Lots (122) ▪ City Parking Garages (15) ▪ Highways ▪ Streets ▪ CalTrain stations and bus routes

Type	Asset Subtype	Asset
	Airport	▪ Landside/Airside Facilities ▪ Runways/Taxiways ▪ Parking
Utilities and Flood Management	Drinking Water	▪ Potable Water Pipelines
	Wastewater	▪ Recycled Water Pipelines ▪ Regional Water Quality Control Plant ▪ Sanitary Sewer Pipelines
	Stormwater	▪ Green Stormwater Infrastructure Locations (12) ▪ Stormwater Inlets (80) ▪ Stormwater Pipelines ▪ Stormwater Manholes (602) ▪ Stormwater Outfalls (280) ▪ Stormwater Pump Stations (12)
	Electrical	▪ Electrical Substations (10) ▪ Access Vaults
	Telecommunications	▪ Fiber Optic Cable
	Natural Gas	▪ Receiving Station
	Flood Management	▪ Flood Control Basin and Tide Gate ▪ Flood Protection Levees and Tide Gate

7

Assessing Vulnerability and Risk



7 Assessing Vulnerability and Risk

Vulnerability and risk assessments help determine which of the City's physical assets and services will potentially be impacted by future climate change conditions. This Assessment also provides information about the potential timing, extent, and consequence of climate hazard impacts. Overall, the process serves as a prioritization exercise for identifying the City assets that are the most at risk from climate change and informing the development of strategies to integrate climate considerations into City planning, design, and operations. This chapter describes key susceptibilities identified for each sector of the City's assets and operations.

7.1 Methodology and Approach

A vulnerability and risk assessment determine which physical assets and City operations may be potentially impacted by future sea level and shallow groundwater conditions. It also provides information about the potential timing, extent, and consequences of impacts. Overall, the process serves as a prioritization exercise to help identify City assets and infrastructure most at risk from SLR and informs the development of strategies to integrate adaptation into city planning, design, and operations.

Vulnerability is expressed in terms of exposure, sensitivity, and adaptive capacity:

- Exposure: The nature and degree to which an asset or system is introduced to the hazard
- Sensitivity: The degree to which the physical conditions and functionality of an asset, population, or system are affected by hazard exposure
- Adaptive capacity: The ability of an asset system to evolve in response to, or cope with, the impacts of SLR

Although exposure can be the greatest indicator of an asset's susceptibility to SLR or shallow groundwater, evaluating sensitivity and adaptive capacity provides valuable information on the degree to which an asset would be impaired once exposed and the inherent characteristics that would allow the asset to readily respond or adapt. Assets are considered more vulnerable if they are exposed to a hazard, are highly sensitive, and have limited to no adaptive capacity.

A high-level risk assessment was also completed by analyzing the potential consequences that could occur due to exposure to SLR and shallow groundwater hazards. Risk was evaluated in terms of the potential consequences that could occur to the individual asset, the surrounding environment, and the greater community. Understanding the consequences of inaction is useful in prioritizing assets for potential adaptation planning.

Results of the analysis are summarized in this chapter to highlight the primary vulnerabilities and risks of each of the following asset types:

- City and Community Facilities and Residential Parcels
- Emergency Response
- Natural Resources and Open Space
- Transportation
- Utilities and Flood Management

7.1.1 Exposure

Exposure describes the degree to which an asset or system is introduced to SLR hazards. To complete the exposure assessment, SLR inundation and shallow groundwater mapping layers were overlaid on the locations of the inventoried assets using GIS to estimate the timing and extent of future flooding.

The exposure assessment provides information about when SLR hazards may begin to affect an asset and serves as an initial screening to prioritize assets or asset categories that will receive additional evaluation for sensitivity and adaptive capacity. However, am exposure assessment does not provide information about the degree to which the asset will experience damage or loss, as it does not consider site-specific conditions (e.g., flood-proofed buildings, elevated electrical equipment) that may limit or prevent impacts. Sensitivity and adaptive capacity consider these additional aspects of vulnerability.

The exposure assessment varied based on the type of asset analyzed. Assets represented as points, such as electrical substations, pump stations, and smaller facilities were analyzed as in or out of the inundated area. Assets represented as linear features, such a pipelines, roadways, or public transportation routes, were analyzed by calculating the inundated length of the asset. Assets represented as polygons, such as larger facilities, were analyzed by calculating the percentage of each asset within the inundation area. This approach allows City managers and staff to assess the scale and progression of potential SLR exposure.

7.1.2 Sensitivity

Assets that are exposed to SLR and shallow groundwater hazards were analyzed for sensitivity, the degree to which an asset's physical features or functionality is affected by exposure to the hazard. For each asset in the inventory, sensitivity was assessed qualitatively based on a set of considerations unique to each asset type. The following characteristics would affect an asset's sensitivity to SLR hazards:

- Electrical equipment: Flooding or inundation of electrical equipment may lead to operation malfunction or damage to an asset.
- Corrosive material: Flood exposure may cause building material to corrode prematurely or experience structural damage.
- Susceptibility to increased frequency, duration, or depth of saltwater inundation: Some assets and/or habitats may have a narrow tolerance for water depth changes and may experience damage or complete loss of function.
- Susceptible to erosion or scour events: Flood events may be associated with high velocity flows that could cause erosion/scour under the asset.
- Buried equipment or system components: Subsurface structures required for the conveyance of water, sewer, natural gas, and electrical utilities may not be properly flood-proofed or designed for longer-term submergence within soils saturated by groundwater, particularly if they were not originally designed to sit within the saturated groundwater layer.

AECOM evaluated how susceptible City assets would be to potential exposure to flood and shallow groundwater hazards based on a combination of professional judgment, staff input, and asset characteristics that could increase sensitivity to SLR. Sensitivity levels considered for each asset type include not sensitive, low, moderate, and high, as described in Table 6.

Table 6. Sensitivity Rating Descriptions

Rating	Description
Not Sensitive	No impact to asset function
Low	Short-term, minor, or reversible damage to asset or function
Moderate	Significant but reversible damage to asset or function
High	Irreversible damage to asset and permanent loss of function

7.1.3 Adaptive Capacity

Adaptive capacity refers to an asset's ability to adjust to future climate conditions to maintain its primary function or service. Adaptive capacity was assessed qualitatively based on a set of considerations that are applicable to each asset type. The following characteristics would contribute to a greater adaptive capacity for an asset:

- Ability to elevate infrastructure: Existing asset can easily be raised to reduce its vulnerability to flooding or have electrical components raised out of the reach of temporary flooding.
- Ability to relocate: Existing asset can be easily moved to higher elevation or outside of floodplain to protect it from flood damage.
- Redundancy: There are multiple access paths to the existing asset, a backup generator or other means that could provide asset substitution is present, or (for natural resources) a similar habitat area that could support refugial communities is nearby.
- Ability to retrofit/upgrade: Existing asset can be easily retrofitted with flood-proofing material.

AECOM evaluated where adaptation was feasible based on cost and level of effort. Each asset type was evaluated and assigned an adaptive capacity rating of none, low, moderate, or high, as described in Table 7.

Table 7. Adaptive Capacity Rating Descriptions

Rating	Description
None	No ability to adapt asset or possible adaptations do not mitigate impacts
Low	Ability to adapt asset to partially mitigate impacts or full mitigation is possible but extremely costly or difficult
Moderate	Ability to adapt asset with moderate level of effort or advanced budget planning
High	Ability to adapt asset to fully mitigate impacts; full mitigation is possible at reasonable cost and effort

7.1.4 Consequence

Consequence considers the magnitude of the impact that may occur if an asset is damaged or inoperable due to SLR or shallow groundwater exposure. As many of the City's assets and operations are interconnected, it is also likely that there will be cascading or cumulative consequences that threaten the City's economy, health, or well-being of communities and the natural environment. By understanding the cascading nature of SLR impacts, the City will be better able to plan, adapt, and manage risks. For each asset type, the consequence was assessed qualitatively based on the following set of considerations:

- Economic: Potential effects to infrastructure, services, local businesses, tourism, or private property values
- Social: Potential impacts to the well-being of City residents, workforce, and visitors with regard to public health, safety, and culture
- Environmental: Potential impacts that alter natural resources, damage native habitats and green space, contaminate water, or harm wildlife

AECOM assigned ratings of negligible, minor, moderate, major, or catastrophic impacts, as described in Table 8.

Table 8. Consequence Rating Descriptions

Rating	Description
Negligible	Asset is resilient
Minor	Inconvenient or temporary effects; easy and not costly to restore
Moderate	Widespread impacts resulting in loss or setback of asset or system; costly, but possible to restore
Major	Significant and long-lasting loss or setback; very costly to restore
Catastrophic	Extensive loss likely; irreversible/not cost-effective to restore

8

Identified Vulnerabilities

8 Identified Vulnerabilities

This chapter summarizes the key findings of the Assessment. The described impacts presented in Section 8.1 focus on the 100-year storm or shallow groundwater rise impacts with 36 inches of SLR (shown on Figure 6 and Figure 9, respectively), which represent potential conditions that could occur by the end of the century. This scenario was selected to provide an overview of the wide-ranging impacts the City may experience over the coming decades. Flood and shallow groundwater exposure for all evaluated SLR scenarios and a detailed discussion of identified vulnerabilities for each asset type can be found in the Section 8.2. The key vulnerabilities summarized below reflect potential SLR and shallow groundwater impacts under a “no action” scenario (as described in callout box in Chapter 2).

8.1 Key Sea Level Rise Vulnerabilities

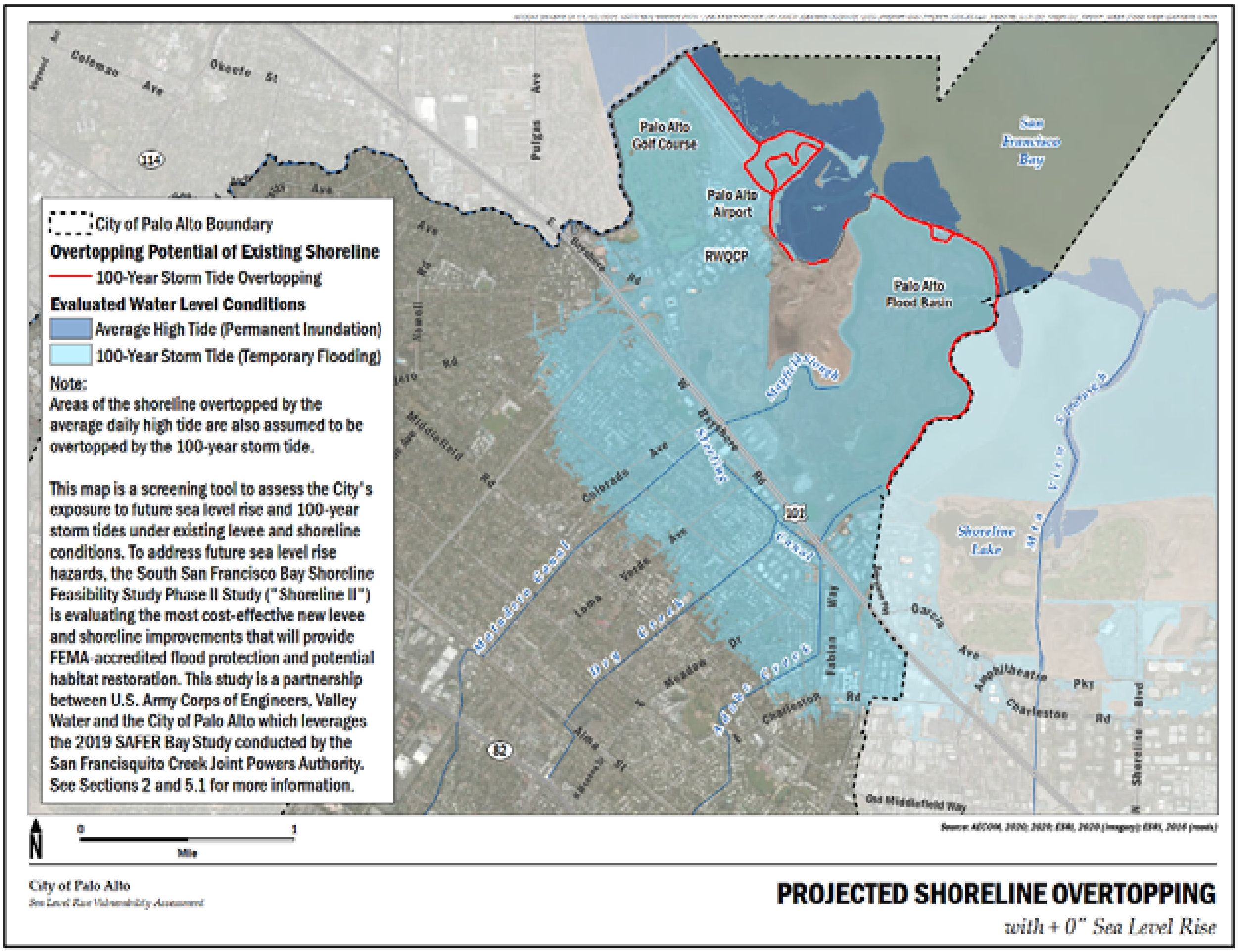
8.1.1 Sea Level Rise Vulnerabilities Under No Action Scenario

Many of the City’s built and natural assets near the shoreline are already at risk of temporary flood impacts from a 100-year storm tide were it to occur today. A 100-year storm tide could overtop nearly the entire length of Palo Alto’s existing flood management levees, exposing approximately four square miles of the City, including the Palo Alto Airport, RWQCP, the Baylands Golf Links, the Baylands Nature Preserve, and US 101 (Figure 11). Areas vulnerable to flooding under existing conditions extend inland approximately 0.7 mile southwest of US 101, and include commercial areas on the bayside of US 101 and large sections of the residential neighborhoods of Duveneck/St. Francis, Midtown, Palo Verde, Adobe Meadows, and Meadow Park.

In the near term, the effects of SLR will be felt during occasional storm events, but by the end of the century, even daily high tides could adversely affect the City. The SLR inundation maps (Attachment B) show that the average daily high tide with 36 inches of SLR is a tipping point when many areas of the City become vulnerable to permanent inundation. With 36 inches of SLR, daily high tides are projected to be high enough to overtop nearly the entire length of the City’s shoreline and could inundate a portion of Palo Alto.

Although permanent inundation from average daily high tides will likely challenge the long-term sustainability of existing land uses in the areas at risk (in the absence of adaptation actions), even exposure to temporary storm events may cause impacts that are severe and far-reaching. Due to the critical linkages between many of the City’s assets and critical services, loss of functionality at one site can trigger a cascade of effects throughout the City. These secondary impacts are particularly common for assets dependent on an uninterrupted power supply, such as pump stations, the RWQCP, and City and community facilities.

Figure 11. Existing Conditions Sea Level Rise Inundation Map (0-inch Scenario)



A summary of the key assets vulnerable to SLR, 100-year storm tide, and shallow groundwater is provided below. The asset exposure due to 36 inches of SLR is categorized by asset type. The 36-inch SLR scenario represents a tipping point when widespread flooding is anticipated to occur. The discussion of flood exposure is followed by a table summarizing ratings for each vulnerability component (sensitivity and adaptive capacity) and risk (consequence) for each asset type. The ratings were assigned to each asset type based on the characteristics that may increase its vulnerability to flooding (Table 9). In general, most asset types exhibit moderate to high sensitivity, moderate adaptive capacity, and high consequence due to exposure to flooding or high shallow groundwater levels. A more detailed evaluation of the vulnerability for each asset type is presented in the Vulnerability Summary Profiles (Section 8.2).

Table 9. Summary of Sensitivity, Adaptive Capacity, and Consequence Ratings for Sea Level Rise Impacts by Asset Type

Asset Type	Asset Subtype (if applicable)	Sensitivity	Adaptive Capacity	Consequence
City and Community Facilities and Residential Parcels	—	Moderate	Moderate	High
Emergency Response	—	High	Moderate	High
Natural Resources and Open Space	Natural Resources	Moderate	Moderate	High
	Parks and Open Space	Low	High	Moderate
Transportation	Transportation Infrastructure	Moderate	Moderate	High
	Airport	High	Moderate	High
Utilities and Flood Management	Drinking Water	Low	Moderate	High
	Wastewater	High	Moderate	High
	Stormwater	High	Moderate	High
	Electrical	High	Moderate	High
	Telecommunications	Moderate	High	High
	Natural Gas	High	Moderate	High
	Levees and Tide Gate	High	Moderate	High

Note: See Vulnerability Profiles in Section 8.2 for detailed discussion of asset type exposure, sensitivity, adaptive capacity, and consequence.

8.1.1.1 City and Community Facilities and Residential Parcels

With 36 inches of SLR:

- A 100-year storm tide could result in surface flooding of 4,400 residential parcels stretching south from approximately Channing and Greer Roads along Middlefield Road to San Antonio Road, two senior/disability centers (Palo Alto Housing Corporation and Alta Torre), two schools (Palo Verde and Ohlone), seven city facilities (Lucy Evans Baylands Nature Center, Animal Shelter, Municipal Services Center, Utility Control Center, Baylands Ranger Station, the former ITT property, and the boat launch), the Save the Bay Nursery, and the Ecocenter.
- A high groundwater table within six feet of the surface could occur at 7,950 residential parcels near San Francisquito Creek past Channing Road approaching Middlefield Road and extending west toward Alma Road down to San Antonio Road. Three city facilities (SCADA, Mitchell Park Library, and the Baylands Ranger Station), eight schools (Duveneck, Greene, Jane Stanford, Fairmeadow, Palo Verde, Ohlone, Greendell, and Hoover), seven senior/disability centers (Achieve Kids, Abilities United/ Gatepath, Ada's Café, Palo Alto Housing Corporation, Stevenson House, Alta Torre, and the Chinese Community Center at Avenidas), Cubberly Community Center, the Save the Bay Nursery, and the EcoCenter. The groundwater table could potentially impact the foundations of these structures.

- Approximately 770 residential parcels would begin to be exposed to emergent groundwater in the Palo Verde and Adobe Meadow/Meadow Park neighborhoods bordered by Matadero Creek, San Antonio Road, Middlefield Road, and US 101.

These hazards could collectively result in high-consequence flooding of the City and community assets that compromises the safety of occupants and causes a loss of services until access to the buildings can be restored.

8.1.1.2 Emergency Response

With 36 inches of SLR:

- A 100-year storm tide could expose approximately eight miles of evacuation routes (on US 101, Embarcadero Road, Oregon Expressway, San Antonio Road, Charleston Road, and Middlefield Road). Although roadways are moderately sensitive to temporary flooding, evacuation routes are highly sensitive because they may not be usable if flood depths exceed thresholds for safe passage of vehicles.
- A high groundwater table within six feet of the surface would expose 15 miles of evacuation routes. The shallow groundwater table is highest under Fire Station No. 4, and the highest annual groundwater table is projected to rise to just below the ground surface with 84 inches of SLR. Although this fire station does not have subgrade facilities, foundation and regular structure inspections should be conducted to avoid risks of slow and chronic damage, beginning with 12 inches of SLR. Additional monitoring wells may be required to better characterize contaminant migration near these facilities to reduce the potential for impacts to human health and environment from legacy contamination.
- Emergent groundwater could impact one mile of evacuation routes. Emergency response assets have a high consequence from flood impacts because of delayed or impaired emergency response times.

8.1.1.3 Natural Resources and Open Space:

With 36 inches of SLR:

- A 100-year storm tide could expose seven City parks (Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Nature Preserve, and Byxbee Park Hills) to flooding and expose 90 percent of the Baylands Golf Links and Athletic Center during a daily high tide or a 100-year storm tide. Much of the Baylands marshes and estuarine habitats along the City's shoreline are already exposed to daily tidal fluctuations and a high shallow groundwater table, but 36 inches of SLR could transition some tidal marsh areas to a different habitat or inundate them completely.
- Approximately 6,900 City-maintained trees could be exposed to temporary flooding by a 100-year storm tide, and approximately 4,700 City-maintained trees could be exposed to daily high-tide conditions. Tree species intolerant of flooding or saltwater conditions may experience increased stress.
- A high groundwater table within six feet of the surface would occur at seven parks (Hoover, Greer, Seale, Ramos, 40 percent of the Baylands Golf Links, the Baylands Nature Preserve, and Mitchell Park) and 12,000 City-maintained trees. Changes in

groundwater levels and salinity can cause increased stress to existing park and golf course vegetation species and City-maintained trees.

- Emergent groundwater could expose Byxbee Park Hills, 40 percent of the Baylands Golf Links, and 360 City-maintained trees. Similar to surface flooding caused by SLR, the impact on tree health may depend on the groundwater quality and the species' sensitivity to salt or contaminants; impact on tree health may depend on the groundwater quality and the species' sensitivity to salt or contaminants.

8.1.1.4 Transportation

With 36 inches of SLR:

- A 100-year storm tide could expose key regional transportation routes, including US 101, all major roads on the bayside of Middlefield Road, and 36 miles of multi-use trails. Roadways are moderately sensitive to temporary surface flooding but can be damaged by repeated flooding events.
- A 100-year storm tide would also inundate most of the Palo Alto Airport, including the runway and taxiway, limiting access to private planes and the Civic Air Patrol service.
- A high groundwater table would occur under approximately six miles of US 101 and approximately 73 miles of streets, including streets from Edgewood Drive, past Embarcadero Road approaching Alma Street, and down to San Antonio Road.
- Groundwater within six feet of the surface can damage roadways when it meets the bottom of the roadbed underground. Over time, the roadbed could deteriorate from below, increasing the likelihood of cracks, potholes, and sinkholes.
- Emergent groundwater could occur over four miles of multi-use trails, which could cause impacts on commuters, and disrupt emergency response service routes such as at the Oregon Expressway underpass, which is already subject to year-round emergent groundwater and seasonal flooding. Emergent groundwater could primarily occur along approximately one mile of US 101, East Bayshore Road, the Page Mill underpass approaching El Camino Real, segments of streets in neighborhoods along Matadero Creek and East Oregon Expressway, and portions of streets north of San Antonio Road in the Palo Verde and Adobe Meadow/Meadow Park neighborhood up to Loma Verde Street.

8.1.1.5 Utilities and Flood Management

With 36 inches of SLR:

- A 100-year storm tide could expose several assets that are critical for day-to-day operations, including the flood management levees, the RWQCP, four stormwater pump stations (Adobe, Matadero, Colorado, and Airport pump stations), two electrical substations, and the natural gas receiving station. Most utility assets are highly sensitive to surface flooding due to the presence of electrical/mechanical components and may be sensitive to rising groundwater if they were not designed for saturated soil conditions. If damaged, there is a high consequence of cascading impacts to the City's public health, safety, and economy. Loss of power supply from flooded substations could interrupt electricity service to residents, hospitals, and businesses. Impacts to the RWQCP could impact ecological and human health from sewage backups or overflow.

- A high groundwater table within six feet of the surface could impact 17 miles of fiber optic cable and 64 miles of water pipelines and restrict access into more than 300 manholes and 1,000 access vaults. High groundwater could also result in pipe breaks from hydraulic uplift, corrosion, cracking, or displacement.
- Emergent groundwater could occur over two miles of water and sanitary sewer pipelines, and impact one acre of green stormwater infrastructure.

8.1.1.6 Flood Exposure Beyond 36 inches of Sea Level Rise

Although 36 inches of SLR represents a critical tipping point for flood vulnerability of the City, there are additional key assets that become initially impacted by SLR or experience large increases in network exposure at higher scenarios. For example, with 66 inches of SLR, the number of residential parcels inundated by average daily high tide nearly doubles, the first fire station is exposed to the 100-year storm tide, and the number of parks experiencing emergent groundwater increases from one to five locations. The portion of underground utility networks impacted by rising groundwater during the 66-inch SLR scenario also increases. The lengths of water and sanitary sewer pipelines exposed to high groundwater levels increase by more than 20 miles. Similarly, the length of buried fiber optic cable exposed to emergent groundwater experiences an order of magnitude increase.

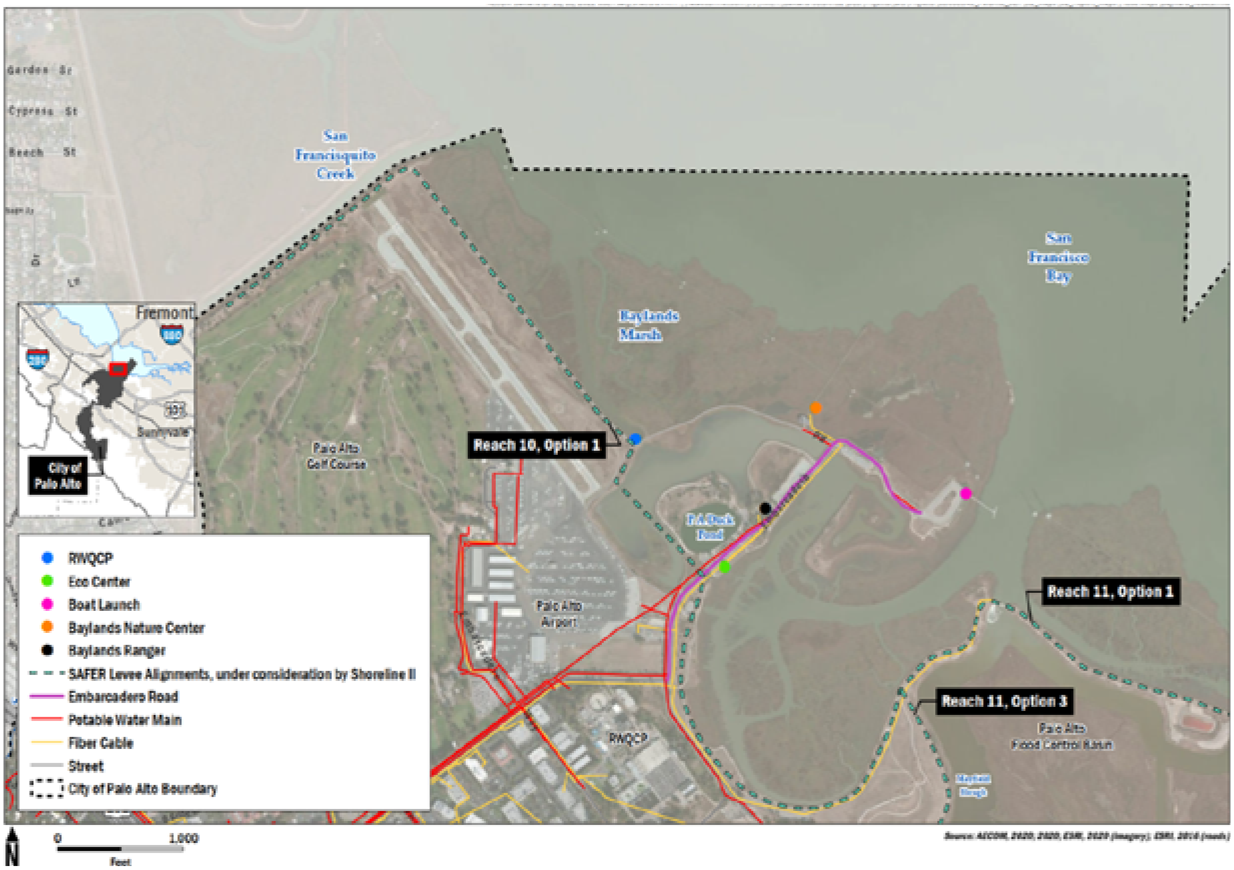
8.1.2 Sea Level Rise Vulnerabilities if a Bayfront Levee is Constructed

Implementation of the SAFER Bay or Shoreline II bayfront levee projects would provide coastal flood protection for the City and assets landward of the levee. The SAFER Bay Feasibility Study (SFCJPA 2019) assumed a levee design that would provide protection up to a 100-year storm tide with 36 inches of SLR (plus additional freeboard that may provide some level of additional protection for SLR above 36 inches). However, assets located bayward of the proposed levee alignment may require additional asset-specific adaptation strategies or relocation to accommodate future SLR and higher shallow groundwater levels in areas protected by levees.

Depending on the levee alignment, the following assets may be located bayward of the levee and potentially exposed to flooding without further asset-specific adaptation actions (see Figure 12).

- RWQCP outfall
- Baylands marshes
- Boat launch
- Lucy Evans Baylands Nature Center
- Baylands Ranger Station
- EcoCenter
- Embarcadero/Harbor Road
- Fiber optic telecommunication cable along Embarcadero Road
- Potable water pipeline

Figure 12. Assets Located Bayward of Proposed Bayfront Levee Alignment



Although a bayfront flood protection levee would be designed to provide protection against SLR and storms, it would not address flood risks posed by rising groundwater levels or localized urban flooding due to heavy rainfall events. This highlights the importance of evaluating these potential impacts and implementing adaptation strategies to address these vulnerabilities even if a bayfront levee project is constructed. Key groundwater-related vulnerabilities are presented in Section 8.2.

8.2 Sea Level Rise and Shallow Groundwater Vulnerability Summary Profiles

Vulnerability profiles were developed for each asset type evaluated as a part of the Assessment, including profiles for City and community facilities and residential parcels, emergency response, natural resources and open space, transportation, and utilities and flood management. The profiles summarize identified vulnerabilities of the inventoried assets, providing more depth and detail to support the SLR inundation maps and the discussion of key vulnerabilities above. For example, although the inundation maps show the areas of the City that may be exposed to flood hazards for each SLR scenario, the vulnerability profiles list the projected timing of asset exposure and describe how specific assets may be vulnerable to SLR hazards.

How to read these vulnerability profiles

Each profile summarizes vulnerability and risk considerations for assets in the City as a result of SLR and related shallow groundwater impacts. The profile consists of an Asset Category Overview and a Vulnerability and Risk Summary. Together, they provide detailed information about the key vulnerabilities and risks from SLR. Vulnerability considers exposure, sensitivity, and adaptive capacity. The SLR exposure summary tables indicate the amount of SLR at which each asset is exposed to daily high-tide inundation, 100-year storm-tide flooding, or emergent groundwater or high shallow groundwater flooding. For some asset categories, summary statistics such as number of assets exposed or length of the asset that is exposed are tabulated and presented in the tables. The Vulnerability and Risk Summary then discusses the sensitivity and adaptive capacity of each asset. "Sensitivity" refers the degree to which an asset's physical features or functionality is affected by exposure to SLR tides/flooding and shallow groundwater hazards, and "adaptive capacity" is the degree to which an asset can adapt to hazards and maintain its function or service. "Risk" is the consequence or magnitude of the impact that may occur if an asset is rendered inoperable due to exposure to SLR tides/flooding or shallow groundwater hazards.

8.2.1 City and Community Facilities and Residential Parcels

8.2.1.1 City and Community Facilities and Residential Parcels Asset Category Overview

To maintain daily operations and services, the City is dependent on access to City- and partner organization-owned facilities and buildings across the City's jurisdiction. Many of these faciliites serve as places of business for the City, including offices, public services, and storage areas. They are also places that support the daily well-being of residents through their public programs. The following sections summarize how key assets supporting each of these services may be vulnerable to flood hazards from SLR changes that impact daily high tides, 100-year storm tides, and rising groundwater. Findings are based on present-day built conditions and consider potential impacts under a no action scenario.

8.2.1.2 City and Community Facilities and Residential Parcels Sea Level Rise Exposure Summary

This section summarizes the exposure of city and community facilities and residential parcels to SLR (Table 10) and groundwater (Table 11). Table 10 indicates the amount of SLR at which each asset is exposed to either daily high-tide inundation (HT) or 100-year storm-tide flooding (ST). Table 11 indicates the amount of SLR at which each asset is exposed to either emergent groundwater flooding (EG) (shallow groundwater that rises above the surface of the ground and creates surface ponding) or a high shallow groundwater table (within six feet of the surface) (HG).

Table 10. City and Community Facilities and Residential Parcels: Sea Level Rise Exposure Summary from Daily High-Tide Inundation or 100-Year Storm-Tide Flooding

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
CITY FACILITIES								
Lucy Evans Baylands Nature Center	HT	—	✓	✓	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Animal Shelter	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Municipal Services Center	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Utility Control Center	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Baylands Ranger Station	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Former ITT Property	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Libraries	HT	—	—	—	—	—	—	—
	ST	—	—	—	—	—	Mitchell Park	Mitchell Park
Boat Launch	HT	—	—	—	—	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
COMMUNITY FACILITIES AND RESIDENTIAL PARCELS								
Save the Bay Nursery	HT	—	✓	✓	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Schools	HT	—	—	—	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde & Ohlone
	ST	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde & Ohlone	Palo Verde, Ohlone & Duveneck	Palo Verde, Ohlone & Duveneck
Senior/ Disability Centers	HT	—	—	—	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre
	ST	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp & Alta Torre	Palo Alto Housing Corp, Alta Torre & Ada's Café	Palo Alto Housing Corp, Alta Torre, Ada's Café & Achieve Kids
EcoCenter	HT	—	✓	✓	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Residential Parcels	HT	—	25 total	30 total	2,630 total	3,090 total	3,990 total	4,600 total
	ST	3,090 total	3,260 total	3,990 total	4,370 total	4,600 total	5,380 total	6,050 total

Note: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high-tide inundation or storm-tide flooding include City Hall, the Development Center, and the Roth Building.

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
CITY FACILITIES								
Lucy Evans Baylands Nature Center	EG	—	—	—	—	—	✓	✓
	HG	✓	✓	✓	✓	✓	—	—
Animal Shelter	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	✓	✓	✓
Municipal Services Center	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	✓	✓	✓
Utility Control Center	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	✓	✓	✓
Baylands Ranger Station	EG	—	—	—	—	—	—	✓
	HG	—	✓	✓	✓	✓	✓	—
Former ITT Property	EG	—	—	—	✓	✓	✓	✓
	HG	—	✓	✓	—	—	—	—
Libraries	EG	—	—	—	—	Mitchell Park	Mitchell Park	Mitchell Park
	HG	—	Mitchell Park Library	Mitchell Park Library	Mitchell Park Library	—	—	—
Cubberley Community Center	EG	—	—	—	—	—	—	✓
	HG	—	✓	✓	✓	✓	✓	—
Boat Launch	EG	—	—	—	—	—	—	—
	HG	—	—	✓	✓	✓	✓	✓

Table 11. City and Community Facilities and Residential Parcels: Sea Level Rise Exposure Summary from Emergent Groundwater Flooding or a High Shallow Groundwater Table

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
COMMUNITY FACILITIES AND RESIDENTIAL PARCELS								
Residential Parcels	EG	N/A	260 total	360 total	770 total	1,680 total	3,570 total	6,050 total
	HG	N/A	6,050 total	7,030 total	7,950 total	8,720 total	9,880 total	10,720 total
Schools	EG	—	—	—	—	—	Palo Verde and Greendell	Jane Stanford, Fair-meadow, Palo Verde, Ohlone and Greendell
	HG	—	Jane Stanford, Fair-meadow, Palo Verde, Ohlone, and Greendell	Jane Stanford, Fair-meadow, Palo Verde, Ohlone, Greendell, and Hoover	Jane Stanford, Fair-meadow, Palo Verde, Ohlone, Greendell, Hoover, Duveneck, and Greene	Jane Stanford, Fair-meadow, Palo Verde, Ohlone, Greendell, Hoover, Duveneck, and Greene	Duveneck, Greene, Jane Stanford, Fair-meadow, El Carmelo, Ohlone, and Hoover	Duveneck, Walter Hays, Greene, and El Carmelo
Senior/Disability Centers	EG	—	—	—	—	—	Ada's Café, Stevenson House, Alta Torre, and Chinese Community Center (Avenidas)	Ada's Café, Stevenson House, Alta Torre, Chinese Community Center (Avenidas), Achieve Kids, and

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
								Abilities United/ Gatepath
	HG	—	Achieve Kids, Abilities United/ Gatepath, Ada's Café, Stevenson House, Alta Torre, and Chinese Community Center (Avenidas)	Achieve Kids, Abilities United/ Gatepath, Ada's Café, Stevenson House, Alta Torre, Chinese Community Center (Avenidas) and Palo Alto Housing Corporation	Achieve Kids, Abilities United/ Gatepath, Ada's Café, Stevenson House, Alta Torre, Chinese Community Center (Avenidas) and Palo Alto Housing Corporation	Achieve Kids, Abilities United/ Gatepath, Ada's Café, Stevenson House, Alta Torre, Chinese Community Center (Avenidas) and Palo Alto Housing Corporation	Achieve Kids, Abilities United/ Gatepath, and Palo Alto Housing Corp.	Palo Alto Housing Corp.
Save the Bay Nursery	EG	—	—	—	—	—	—	✓
	HG	✓	✓	✓	✓	✓	✓	—

Note: A checkmark indicates that an asset is exposed to groundwater hazards at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high groundwater hazards include City Hall, Development Center, and Roth Building.

8.2.1.3 City and Community Facilities and Residential Parcel Vulnerability and Risk Summary

This section describes the identified characteristics of City and Community Facility and Residential Parcels that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 12.

Table 12. City and Community Facility and Residential Parcel Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
Moderate	Moderate	High

Modeling of shallow groundwater changes from sea level rise indicate that Mitchell Park Library will be exposed to shallow groundwater within six feet of ground surface with 36 inches of sea level rise.

City and community facilites located on the bayside of US 101 are most likely to experience the earliest flood and shallow groundwater impacts due to SLR. Facilities such as the Lucy Evans Baylands Nature Center and the EcoCenter, which are built on former marshlands, are already exposed to temporary flooding by a 100-year storm tide under existing conditions and may be exposed to permanent inundation by daily high tides with 12 inches of SLR. Other facilities located inland of US 101, including several City-owned buildings, two schools (Palo Verde Elementary and Ohlone Elementary), and two senior/disability centers (Palo Alto Housing Corporation and Alta Torre) are also already exposed to flooding by a 100-year storm tide under existing conditions. These buildings are first exposed to permanent inundation by daily high tides with 36 inches of SLR.

City and community facility exposure to emergent groundwater and/or a high groundwater table (within six feet of the ground surface) is reduced due to the prevalence of long-term groundwater pumping related to contaminant remediation. However, the Lucy Evans Baylands Nature Center, the Baylands Ranger Station, the Former ITT Property, Mitchell Park Library, and Cubberley Community Center could all experience impacts from a rising groundwater table in the near term, as the existing groundwater surface is already within six feet of the ground during wet season conditions. If these facilities have subgrade features or foundations, the impacts could begin to occur in the near term. In addition, the Save the Bay Nursery, seven schools, seven senior/disability centers, and the EcoCenter could all experience impacts related to the rising groundwater table in the near term, particularly during and after winter seasons with heavy precipitation.

Asset Sensitivity

Facilities are **moderately sensitive** to exposure to flooding and rising groundwater. The buildings contain materials and electrical equipment on the first floor (and potentially in basements or subterranean areas) that are easily damaged if exposed to floodwaters. The extent and degree of damage is dependent on flood depths, duration, conformity of the structure with modern building codes, and the degree of floodproofing and site drainage. Older buildings may be more sensitive to exposure to floodwaters and high groundwater due to deteriorated condition. Even if building damage is not sustained, flooding may limit access to building entrances and limit use of the facility until floodwaters recede. Smaller, lighter structures are more sensitive to hydraulic uplift from rising groundwater than larger, heavier structures, if groundwater is not properly accounted for in design and construction.

Asset Adaptive Capacity

Facilities have **moderate adaptive capacity**, particularly in response to temporary flooding (but not permanent inundation). Floodproofing at building entryways, erecting perimeter floodwalls, and elevating electrical equipment can prevent damage from temporary flooding events. Most facilities have moderate adaptive capacity to a rising groundwater table as well. Floodproofing can lessen or eliminate seepage into below-grade areas, and drainage improvements and other measures can reduce the hydraulic uplift forces on structures. However, facilities are not easily adaptable or relocated to provide relief from frequent flood exposure (such as king tides), permanent inundation, or shallow groundwater impacts.

Asset Consequence

City and community facilities have a **high consequence** from flood impacts and damage caused by high groundwater. Beyond the direct impacts to infrastructure, which may require costly repairs or replacement, damage to the facilities could cause widespread and catastrophic impacts to the community. The greatest concern is for the safety of community members or staff occupying the facilities during a flood event. Floodwaters would likely force schools and senior/disability centers to close until floodwaters recede and repairs could be made to the building to ensure safe occupancy. Damage to City-owned or community service buildings may cause a delay of operations that are dependent on access to the facility. Also, damage to City facilities may result in a temporary loss of City-facilitated programs until access to the building can be restored. Damage related to rising groundwater is more likely to be slow and chronic, although if damage is undetected, partial structural collapse could occur without warning, putting lives at risk.

The greatest safety concern related to rising groundwater is the potential mobilization of legacy contaminants, particularly volatile organic compounds, which can vaporize and impact indoor air quality (see Attachment A). Facilities with below-grade basements or crawl spaces near a contaminated site and with an existing groundwater table within six feet of the ground surface are at greatest risk for potential contaminant concerns. Additional monitoring wells may be required to better characterize contaminant migration near these facilities to reduce the potential for impacts to human health and the environment from legacy contamination. Thirty-six inches of SLR could create emergent groundwater conditions at or near two contaminated sites: Site #2 (GOPOWER plume, near Embarcadero Road and Embarcadero Way) and Site #5 (ARCO 2995, near Middlefield and Colorado) (see Figure 10). Site #1 (Palo

Alto Landfill) is also likely to have emergent groundwater flooding around the perimeter of the landfill. However, the landfill has a maintained leachate collection and removal system that is effective at removing fluids from the landfill area for treatment. The pumping needs for this system are likely to increase as sea levels and the surrounding groundwater table rise. If the leachate system is properly maintained and operated over time, this system should minimize the risk of contaminants leaking into the surrounding area as sea level rises.

With 84 inches of SLR, 10 contaminant sites as well as the Palo Alto Landfill may have emergent groundwater conditions. If contaminants are still present at these locations when the groundwater becomes emergent, a human health and environmental risk could be created. The largest contaminated site is along Page Mill Road (the Hewlett Packard and Varian Associates California-Olive-Emerson site). Remediation efforts are ongoing and contaminant levels are likely to decrease before 84 inches of SLR occurs. Attachment A provides additional details on the contaminated sites and the remediation methods used to date.

8.2.2 Emergency Response

8.2.2.1 Emergency Response Asset Category Overview

A key service of the City is to create a safe and secure environment for residents, businesses, and visitors. The City operates police and fire facilities and assets to serve the area, including seven fire stations, one police station, and one police substation. The emergency response capabilities of the City are also supported by four hospitals. To provide ongoing services, the Emergency Response structures and staff must remain operational, even during extreme events. The following summarizes how key assets supporting each of these services may be vulnerable to flood hazards from SLR changes that impact daily high tides, 100-year storm tides, and rising groundwater. Findings are based on present-day built conditions and consider potential impacts under a no action scenario.

8.2.2.2 Emergency Response Sea Level Rise Exposure Summary

This section summarizes the exposure of Emergency Response assets to SLR (Table 13) and groundwater (Table 14). Table 13 indicates the amount of SLR at which each asset is exposed to either daily high-tide inundation (HT) or 100-year storm-tide flooding (ST). Table 14 indicates the amount of SLR at which each asset is exposed to either emergent groundwater flooding (EG) (shallow groundwater that rises above the surface of the ground and creates surface ponding) or a high shallow groundwater table (within six feet of the surface) (HG).

Table 13. Emergency Response: Sea Level Rise Exposure Summary from Daily High-Tide Inundation or 100-Year Storm-Tide Flooding

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
Emergency Response Facilities								
Evacuation Route	HT	—	—	—	5 miles	6 miles	7 miles	8 miles
	ST	6 miles	7 miles	7 miles	8 miles	8 miles	10 miles	14 miles
Fire Stations	HT	—	—	—	—	—	—	—
	ST	—	—	—	—	—	Fire Station No. 4	Fire Station No. 4

Note: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high-tide inundation or storm-tide flooding include police stations and hospitals.

Table 14. Emergency Response: Sea Level Rise Exposure Summary from Emergent Groundwater Flooding or a High Shallow Groundwater Table

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
Evacuation Route	EG	—	1 mile	1 mile	1 mile	1 mile	4 miles	9 miles
	HG	6 miles	9 miles	12 miles	15 miles	17 miles	19 miles	22 miles
Fire Stations	EG	—	—	—	—	—	—	Fire Station No. 4
	HG	—	Fire Station No. 4	Fire Station No. 4	Fire Station No. 4	Fire Station No. 4	Fire Station No. 4	Fire Station No. 3

Note: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high-tide inundation or storm-tide flooding include police stations and hospitals.

8.2.2.3 Emergency Response Vulnerability and Risk Summary

This section describes the identified characteristics of City and Community Facility and Residential Parcels that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 16.

Table 15. City and Community Facility and Residential Parcel Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

Regular foundation and structural inspections should begin at Fire Station #4 with 12 inches of sea level rise to avoid structural risks from rising shallow groundwater.

The City's evacuation routes are the most vulnerable Emergency Response asset. Six miles of evacuation routes are already exposed to temporary flooding by a 100-year storm tide during existing conditions, and five miles would be exposed to emergent groundwater during wet winters (i.e., late winter and spring conditions after a winter with heavy precipitation) if the current groundwater pumping efforts for contaminant remediation were discontinued. The emergency evacuation routes exposed include US 101, Embarcadero Road, San Antonio Road, Oregon Expressway, Charleston Road, and Greer Road. Groundwater pumping at underpasses, such as near the Oregon Expressway and University Avenue, already occurs to reduce the presence of emergent groundwater.

Five miles of evacuation routes are initially exposed to permanent inundation by daily high tides with 36 inches of SLR. Fire stations, police stations, and hospitals are not expected to be impacted by flooding until the end of the century, when Fire Station No. 4 is exposed by 66 inches of SLR and a 100-year storm tide. The shallow groundwater table is also highest under Fire Station No. 4, and the highest annual groundwater table is projected to rise to just below the ground surface with 84 inches of SLR. Although this fire station does not have subgrade facilities, foundation inspections and groundwater monitoring should begin at Fire Station No. 4 with 12 inches of SLR to avoid structural risks from rising shallow groundwater.

Asset Sensitivity

Emergency response facilities have **high sensitivity** to flood exposure and rising groundwater. Buildings typically contain materials and electrical equipment on the first floor that are easily damaged if exposed to flooding. Some buildings have below-grade spaces that are at risk to both floods and rising groundwater levels. The extent and degree of damage is dependent on flood depths and the conformity of the structure with modern building codes. Even if building damage is not sustained, flooding may limit access to building entrances and limit use of the facility. Evacuation routes have a **high sensitivity** to flooding because even if the route is submerged by just a few inches, it may be impassable until floodwaters recede. High-velocity flows or repeated flooding can cause degradation of roadway features and subsurface materials, increasing the need for maintenance and repair. Rising groundwater can also increase the saturation frequency of subsurface road materials, which may not be designed for saturated conditions. This situation can result in degradation of the roadway from below, increasing the likelihood of cracks, potholes, and sinkholes.

Asset Adaptive Capacity

Emergency response assets have **moderate adaptive capacity**. Floodproofing at building entryways or perimeter walls can prevent damage from temporary flooding. Floodproofing of below-grade structures and drainage improvements could mitigate some of the risks associated with rising groundwater. Elevating or waterproofing electrical and mechanical equipment, installing backup power sources, and relocating emergency vehicles and gear before flood events can reduce operational vulnerabilities. However, emergency response operations are also dependent on clear access routes from the ground floor entrance and connections to the region's transportation network. It is possible to elevate evacuation routes above projected flood elevations to maintain access; however, this is likely to be associated with a high cost due to the extensive ancillary reconstruction required for the connected roadway network.

Asset Consequence

Emergency response assets have a **high consequence** from flood impacts. Flood impacts to the fire station or evacuation routes could delay or impair emergency response times, affecting the long-term health and safety of the community.

8.2.3 Natural Resources and Open Space

8.2.3.1 Natural Resource and Open Space Asset Category Overview

Although Palo Alto is largely developed, much of the City's shoreline consists of the Palo Alto Baylands Nature Preserve (Baylands), an approximately 1,976-acre open space. The Baylands has multiple habitats, including marshes and uplands that provide important habitat for imperiled species such as the salt marsh harvest mouse (Reithrodontomys raviventris), Ridgway's rail (Rallus obsoletus), and the western burrowing owl (Athene cunicularia). Fifteen miles of multi-use trails provide access to a unique mixture of tidal and freshwater habitats. It serves as an important habitat for migratory shorebirds and is considered one of the best birdwatching areas on the U.S. West Coast.

Founded in the 1950s, the Palo Alto Municipal Golf Course, now known as the Baylands Golf Links, is part of the Baylands Nature Preserve District and was reconfigured in 2018 to complement the look of the surrounding area and to allow the conveyance of flood flows in San Francisquito Creek to the Bay. The golf course features 55 acres of native Baylands vegetation and wetland areas. The Baylands Athletic Center offers an additional six acres of recreational space.

The City also maintains 32 parks, four open space preserves, 36,000 City-owned and maintained trees along streets and in parks and facilities, and an additional 30,000 private trees that are maintained for electric line clearance. The trees that constitute the City's urban forest enhance the quality of life for Palo Alto through their many community, environmental, and economic benefits.

The following section summarizes how key assets supporting each of these services may be vulnerable to flood hazards from SLR changes that impact daily high tides, 100-year storm tides, and rising groundwater. Findings are based on present-day built conditions and consider potential impacts under a no action scenario.

Table 16 lists the exposure summary for Natural Resources and Open Space from 0 (current situation) to 84 inches of SLR from daily high tides and 100-year storm tides.Table 17 lists the exposure summary for Natural Resources and Open Space from 0 (current situation) to 84 inches of SLR from emergent groundwater flooding or a high shallow groundwater table.

8.2.3.2 Natural Resource and Open Space Sea Level Rise Exposure Summary

This section summarizes the exposure of Natural Resources and Open Space to SLR (Table 16) and groundwater (Table 17). Table 16 indicates the amount of SLR at which each asset is exposed to either daily high-tide inundation (HT) or 100-year storm-tide flooding (ST). Table 17 indicates the amount of SLR at which each asset is exposed to either emergent groundwater flooding (EG) (shallow groundwater that rises above the surface of the ground and creates surface ponding) or a high shallow groundwater table (within six feet of the surface) (HG).

Table 16. Natural Resources and Open Space: Sea Level Rise Exposure Summary from Daily High-Tide Inundation or 100-Year Storm-Tide Flooding

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
NATURAL RESOURCES								
Marshes	HT	✓	✓	✓	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
OPEN SPACE								
Parks	HT	—	Baylands Preserve	Baylands Preserve	Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills
	ST	Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, and Byxbee Park Hills	Baylands Athletic Fields, Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, Byxbee Park Hills, and Mitchell Park
City-Maintained Trees	HT	—	—	—	4,700	5,300	5,500	6,400
	ST	5,300	5,500	6,400	6,900	7,200	8,400	9,700
BAYLANDS GOLF LINKS AND ATHLETIC CENTER								
Bayland Golf Links	HT	—	—	—	90%	95%	100%	100%
	ST	—	—	—	90%	95%	100%	100%
Baylands Athletic Center	HT	—	—	—	25%	50%	90%	100%
	ST	—	—	—	25%	50%	90%	100%

Notes: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For area assets, the percentage of land exposed is listed.

Table 17. Natural Resources, Parks and Open Space: Sea Level Rise Exposure Summary from Emergent Groundwater Flooding or a High Shallow Groundwater Table

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
NATURAL RESOURCES								
Marshes	EG	✓	✓	✓	✓	✓	✓	✓
	HG	✓	✓	✓	✓	✓	✓	✓
OPEN SPACE								
Parks	EG	—	Byxbee Park Hills	Byxbee Park Hills	Byxbee Park Hills	Byxbee Park Hills and Ramos Park	Byxbee Park Hills, Ramos Park, Baylands Golf Links, Baylands Nature Preserve and Mitchell Park	Byxbee Park Hills, Ramos Park, Baylands Golf Links, Baylands Nature Preserve, Mitchell Park and Greer Park
	HG	—	Greer, Ramos, Baylands Golf Links, Baylands Preserve, and Mitchell	Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, and Mitchell	Hoover, Greer, Seale, Ramos, Baylands Golf Links, Baylands Preserve, and Mitchell	Hoover, Greer, Seale, Baylands Golf Links, Baylands Preserve, and Mitchell	Baylands Athletic Fields, Hoover, Greer and Seale	Baylands Athletic Fields, Rinconada, Pardee, Hoover, and Seale
City-Maintained Trees	EG	—	11	45	360	1,300	4,300	8,500l
	HG	—	8,500	10,500	12,000	14,000	16,600	18,800
BAYLANDS GOLF LINKS AND ATHLETIC CENTER								
Baylands Golf Links	EG	—	10%	25%	40%	50%	70%	85%
	HG	75%	85%	90%	90%	95%	100%	100%
Baylands Athletic Center	EG	—	—	—	—	—	—	<1%
	HG	—	< 1%	4%	20%	45%	90%	100%

Notes: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For area assets, the percentage of land exposed is listed.

8.2.3.3 Natural Resources Vulnerability and Risk Summary

This section describes the identified characteristics of Natural Resources that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 18.

Table 18. Natural Resources Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

Endangered species such as the salt marsh harvest mouse reside in the Palo Alto Baylands.

Asset Sensitivity

The City's natural resources are **highly sensitive** to SLR. Although habitats may be able to withstand occasional temporary flooding during extreme storm events, many plant and animal species in the marshes fronting the City's shoreline are dependent on existing habitats and have a narrow tolerance for long-term changing conditions.

Asset Adaptive Capacity

Marshes are resilient to temporary changes in water levels and can recover from temporary storm events. They have **moderate adaptive capacity** to SLR, if adequate sediment supply is available. Marshes trap sediment, and the combination of sediment and organic matter deposition helps marshes increase in elevation over time. However, if sufficient sediment is not available or if the rate of SLR accelerates beyond the marsh's ability to increase in elevation, the marsh may slowly drown, degrade, or disappear.

Analysis completed as a part of the Climate Change and Sea Level Rise at the Baylands study showed that under a no-management scenario—a scenario in which the landscape is not managed through levees, pumps, routine maintenance, or other management actions—deposition of sediment and organic material at the Baylands would likely keep pace with SLR through the late 21st century (City of Palo Alto 2018). However, the rate at which this accretion will occur depends on the amount of available sediment and organic material. The results show that by 2050, Harriet Mundy Marsh and Faber-Laumeister tract (the eastern and northern portions of the Palo Alto Baylands respectively north of Embarcadero Road), which are on the bayside of future levee alignments could maintain a mid-marsh habitat, but that much of the other Baylands habitat types may convert to lower elevation habitat types (e.g., mudflat to mid-marsh). If sediment accredition rates do not keep pace with SLR, lower-lying marshes could convert to mudflats and would provide different habitat benefits than they do today. Baylands marshes have limited ability to migrate landward with SLR due to the presence of fixed urban areas along the landward edge.

Asset Consequence

Impacts to natural resources due to SLR would have **high consequence**. The natural resources provide unique ecosystem services to the City and the greater Bay region that could not be easily replaced or replicated once lost. Marshes may experience habitat conversion or a complete loss due to inundation (marsh drowning), resulting in habitat loss for shorebirds, mammals, and fish nurseries, including threatened and endangered species. Loss of marshes may also adversely affect local water quality and result in the loss of a large local carbon sink and wave attenuation during coastal storm events. The loss of natural resources may also affect local recreational opportunities such as birding, paddling, and fishing.

8.2.3.4 Open Space Vulnerability and Risk Summary

This section describes the identified characteristics of Open Spaces that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 19.

Table 19. Open Space Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
Low to Moderate	High	Moderate

Much of the City's waterfront is at a low elevation, making it prone to flooding during king tide events under existing conditions. In addition to the Baylands, Greer Park, Seale Park, Ramos Park, and the Baylands Golf Links may be exposed to temporary flooding by a 100-year storm tide under existing conditions. These assets are first exposed to permanent inundation by daily high tides with 36 inches of SLR.

A portion of Byxbee Park near the Baylands and Mitchell Park could experience a small amount of emergent groundwater with 12 to 24 inches of SLR. With 84 inches of SLR, emergent groundwater could be found over 75 percent of Mitchell Park, Greer Park, and Seale Park. Over 50 percent of Ramos Park could have emergent groundwater at the 84 inch scenario.

Asset Sensitivity

Parks and open space have a **low to moderate sensitivity** to SLR, depending on the degree of flood exposure. For example, minor flooding may only require temporary closure and cleanup of debris after floodwater recedes; however, regular or major flooding may completely erode or wash out trails or damage park/golf course facilities, making future use impossible until repairs are made.

City-maintained trees have a **moderate sensitivity** to flood exposure and rising groundwater levels. Currently 5,300 City-maintained trees are exposed to temporary flooding by a 100-year storm tide. Although most species have moderate adaptive capacity to tolerate temporary and infrequent flooding, they are unlikely to withstand regular or chronic inundation or saline groundwater conditions. Approximately 4,700 City-maintained trees are exposed to permanent inundation by daily high tides with 36 inches of SLR. Approximately 360 City-maintained trees are in locations where emergent groundwater could occur with 36 inches of SLR, and more than 8,500 City-maintained trees will have their root systems located in areas saturated by groundwater.

A King Tide at Palo Alto Baylands Nature Preserve coverse the trail, January 20, 2019

Asset Adaptive Capacity

Parks and open space have **high adaptive capacity**, particularly when compared to other built City infrastructure. It is relatively easy to relocate or elevate trails or transition a recreation area to adopt different activities based on the changing climate. There are many examples worldwide where parks and open spaces areas are designed to accommodate flooding and reduce flood impacts to adjacent developed areas. Areas with emergent groundwater may convert from grasslands and maintained park areas to freshwater or brackish marshes, helping to replace marsh habitat that is lost due to SLR. However, marsh connectivity is essential for many species that rely on this habitat type. Although existing trees are likely not able to accommodate frequent flooding, the City can transition trees located in flood-prone or groundwater intrusion areas to species that are more tolerant to saturated or saline conditions.

Asset Consequence

Damage to parks and open space will have **moderate consequences** for the City. Flooding of City parks and open space could limit public access to recreational facilities such as trails, courts, fields, bike routes, and opportunities such as hiking, paddling, and birdwatching. Impacts to tree health may depend on the groundwater quality and the species' sensitivity to salt or contaminants.There are high consequnces of tree mortality at end-of-century without adaptation strategies. The urban forest provides shade, habitat, and contributes to carbon sequestion. As a designated Tree City USA Community, Palo Alto places a high value on its urban canopy and will need to plan for additional protections for its urban forest.

8.2.4 Transportation

8.2.4.1 Transportation Asset Category Overview

The City's transportation network links residents and visitors with community facilities, services, jobs, recreational sites, and neighborhoods throughout the area. The City maintains approximately 257 miles of roads and 56 miles of bike lanes. Several major highways and a Caltrain commuter railway also traverse the City, serving as major connections to the greater region and state. In addition to ground transport, the City also owns and operates the tenth-busiest single-runway airport in California. The following discussion summarizes how key assets supporting each of these services may be vulnerable to flood hazards from SLR changes that impact daily high tides, 100-year storm tides, and rising groundwater. Findings are based on present-day built conditions and consider potential impacts under a no action scenario.
Table 19 lists the exposure summary for Transportation from 0 (current situation) to 84 inches of SLR from daily high tides and 100-year storm tides. Table 20 lists the exposure summary for Transportation from 0 (current situation) to 84 inches of SLR from emergent groundwater flooding or a high shallow groundwater table.

8.2.4.2 Transportation Sea Level Rise Exposure Summary

This section summarizes the exposure of Transportation assets to SLR (Table 20) and groundwater (Table 21). Table 20 indicates the amount of SLR at which each asset is exposed to either daily high-tide inundation (HT) or 100-year storm-tide flooding (ST). Table 21 indicates the amount of SLR at which each asset is exposed to either emergent groundwater flooding (EG) (shallow groundwater that rises above the surface of the ground and creates surface ponding) or a high shallow groundwater table (within six feet of the surface) (HG).

Table 20. Transportation: Sea Level Rise Exposure Summary from Daily High-Tide Inundation or 100-Year Storm-Tide Flooding

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
TRANSPORTATION INFRASTRUCTURE								
Streets	HT	—	<1 mile	<1 mile	30 miles	35 miles	42 miles	47 miles
	ST	35 miles	37 miles	42 miles	45 miles	47 miles	53 miles	61 miles
Trails	HT	—	<1 mile	<1 mile	23 miles	30 miles	35 miles	37 miles
	ST	30 miles	32 miles	35 miles	36 miles	37 miles	40 miles	45 miles
US 101	HT	—	—	—	5 miles	6 miles	7 miles	7 miles
	ST	6 miles	6 miles	7 miles	7 miles	7 miles	8 miles	8 miles
AC Transit Routes	HT	—	—	—	2 miles	2 miles	3 miles	4 miles
	ST	2 miles	2 miles	3 miles	3 miles	4 miles	4 miles	5 miles
Valley Trantis Authority Routes	HT	—	—	—	12 miles	15 miles	16 miles	17 miles
	ST	15 miles	15 miles	15 miles	16 miles	17 miles	23 miles	30 miles
Caltrain Routes	HT	—	—	—	—	—	—	—
	ST	—	—	—	—	—	—	<1 mile
AIRPORT								
Airport (all assets)	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
Runway/ Taxiways	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓

Note: Notes: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high-tide inundation or storm-tide flooding include parking garages, parking lots, Highway 280, SamTrans routes, and Caltrain stations.

Additional information regarding the extent of exposure is also summarized by the following:

- A checkmark indicates that an asset is exposed to groundwater hazards at a given amount of SLR and a dash indicates that the asset is not exposed.
- For network assets, the linear footage or number of individual assets exposed is listed.
- For area assets, the percentage of land exposed is listed.

Table 21. Transportation: Sea Level Rise Exposure Summary from Emergent Groundwater Flooding or a High Shallow Groundwater Table

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
TRANSPORTATION INFRASTRUCTURE								
Streets	EG	—	<1 mile	<1 mile	3 miles	9 miles	24 miles	44 miles
	HG	—	51 miles	62 miles	73 miles	82 miles	94 miles	102 miles
Trails	EG	—	1 mile	2 miles	4 miles	5 miles	9 miles	15 miles
	HG	—	16 miles	21 miles	28 miles	33 miles	40 miles	44 miles
US 101	EG	—	<1 mile	<1 mile	<1 mile	<1 mile	1 mile	2 miles
	HG	—	2 miles	4 miles	6 miles	7 miles	7 miles	8 miles
AC Transit Routes	EG	—	<1 mile	<1 mile	<1 mile	<1 mile	1 mile	2 miles
	HG	—	2 miles	3 miles	4 miles	5 miles	6 miles	7 miles
VTA Routes	EG	—	<1 mile	<1 mile	1 mile	3 miles	14 miles	28 miles
	HG	—	28 miles	34 miles	37 miles	40 miles	41 miles	44 miles
Caltrain Routes	EG	—	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile
	HG	—	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile
SamTrans Routes	EG	—	—	—	<1 mile	<1 mile	<1 mile	<1 mile
	HG	—	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile	<1 mile
AIRPORT								
Airport multi-purpose building (includes Civil Air Patrol)	EG	—	—	2%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Wash Rack	EG	—	—	3%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Pollution Control Facility	EG	—	< 1%	90%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Air Control Tower	EG	—	—	3%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Fuel Island	EG	—	—	10%	100%	100%	100%	100%

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building D	EG	—	<1%	100%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building E	EG	—	—	<1%	80%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building F	EG	—	—	<1%	60%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building G	EG	—	—	<1%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Fixed Base Operator (FBO) Hangar Building C	EG	—	—	< 1%	50%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building H	EG	—	—	2%	100%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building B	EG	—	—	-	25%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Hangar Building I	EG	—	—	—	—	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
FBO Hangar Building A	EG	—	—	—	10%	100%	100%	100%
	HG	—	100%	100%	100%	100%	100%	100%
Fuel Island	EG	—	—	—	—	—	<1%	100%
	HG	—	100%	100%	100%	100%	100%	100%
FBO Hangar	EG	—	—	—	—	—	2%	100%
	HG	—	100%	100%	100%	100%	100%	100%

Note: For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed Assets not exposed to high groundwater levels (within six feet of the ground surface) or emergent groundwater flooding include parking garages, parking lots, and Highway 280. Exposure to existing conditions high and emergent groundwater hazards not evaluated as part of this Assessment.

8.2.4.3 Transportation Infrastructure Vulnerability and Risk Summary

This section describes the identified characteristics of Transportation that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 22.

Table 22. Transportation Infrastructure Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
Moderate	Moderate	High

Embarcadero and Middlefield Roads are exposed to permanent daily high tide inundation with 36 inches of sea level rise.

SLR impacts to transportation assets are likely to be first experienced along Embarcadero Road and the trails that provide access to and throughout the Baylands. Most transportation infrastructure east of Middlefield Road could be exposed to temporary flooding by a 100-year storm tide under existing conditions. Transportation assets in these areas are first exposed to permanent inundation by daily high tide with 36 inches of SLR.

Asset Sensitivity

The pavement and substructure of roadways, rail lines, trails, bridges, and parking lots can be damaged by intermittent flooding or high groundwater levels, making them **moderately sensitive**, depending on factors such as flood depth, velocity, frequency of flooding, and structural characteristics. For example, if these features are submerged by more than a few inches, it may temporarily limit their use, but they should be able to be used quickly after floodwaters have receded. However, high-velocity flows or repeated flooding can cause degradation of these surface features and subsurface materials, increasing the need for maintenance and repair. Rising groundwater can also increase the saturation frequency of subsurface materials that were not designed for permanent inundation. Emergent groundwater effects could also occur before coastal floodwaters overtop the shoreline and inundate inland areas.

Asset Adaptive Capacity

Transportation infrastructure has **moderate adaptive capacity** because there may be built-in system redundancy, allowing traffic to use alternate routes, parking areas, or trails during flood events. It is also possible to elevate transportation infrastructure above projected flood elevations to maintain access; however, for network features, such as roads, trails, and railways, this action is likely to be associated with a high cost due to the extensive ancillary reconstruction required for the connected facilities.

Asset Consequence

Transportation infrastructure has a high consequence from flooding. Beyond the direct impacts to infrastructure, flooding can cause widespread access issues, affecting critical access routes, the ability to respond to emergencies, the movement of goods, and everyday life for City residents. Flooding of US 101, which provides a key transportation corridor to the greater region and state, would likely result in significant economic impacts. Flooded bike and pedestrian paths, which serve as both a source of recreation and corridors for non-automotive transportation, will affect the use of human-powered transit for employment, retail, dining, businesses, and neighborhoods in the City. Public transit routes experiencing flooding are also likely to affect disadvantaged populations that rely on these services for transportation throughout the City and greater area.

8.2.4.4 Airport Vulnerability and Risk Summary

This section describes the identified characteristics of Airports that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 23.

Table 23. Airport Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

The Palo Alto Airport would be exposed to permanent daily high tide inundation with 36 inches of sea level rise.

The Palo Alto Airport is a general aviation field owned and operated by the City of Palo Alto. The airport provides overflow or emergency relief for three international Bay Area airports (San Francisco, Oakland, and San Jose) and therefore has regional importance. The airport is adjacent to the Bay shoreline, and its low-lying elevation and proximity to the Bay make it vulnerable to coastal storm events, SLR, and rising groundwater levels. The airport includes multiple individual assets that could be impacted by SLR and rising groundwater, including the air control tower, runway, pollution control facility, fueling stations, and hangars.

With 24 inches of SLR, emergent groundwater flooding may impact portions of the airport, including the runway, Pollution Control Facility, and Hangar Buildings D and H. Emergent groundwater flooding is projected to expand to impact other facilities as sea level rises. All airport assets could be exposed to temporary flooding by a 100-year storm tide under existing conditions. The airport would be first exposed to permanent inundation by daily high tides with 36 inches of SLR. All airport assets are also located within the existing high groundwater zone where wet season groundwater levels can rise to within six feet of the ground surface.

Asset Sensitivity

The airport includes a variety of different asset types that have a **high sensitivity** to saltwater flooding. Runways, taxiways, and adjacent navigational aids contain electrical light fixtures that may be obstructed or damaged if exposed to floodwaters. Standing water on the runway and/or taxiways may prevent aircraft from landing or taking off and require rerouting flights. The airport's power system could lose functionality if flooded, halting operations until power is restored. Airports also have many supporting facilities (e.g., hangars, office buildings, terminals, airport- and tenant-owned buildings, car rental centers) that are sensitive to flooding and may sustain structural damage if exposed to floodwater.

It is anticipated that implementation of the SAFER/Shoreline II bayfront levee would provide protection from SLR inundation through late-century and possibly longer. However, if regional shoreline flood protection, such as a bayfront levee project, is not completed, the airport has limited ability to adapt to long-term inundation of the site and may require costly site-specific flood protection measures, rebuilding or realignment, or relocation. It is also possible that the facility could be affected by local stormwater or groundwater flooding. Facilities with basements or subterranean areas may experience seepage or damage by high groundwater levels, and smaller, lighter structures may be sensitive to hydraulic uplift forces. Rising shallow groundwater levels may also contribute to degradation of runway and taxiways due to saturation of subgrade materials or surface flooding by emergent groundwater.

Asset Adaptive Capacity

The airport has **low to moderate adaptive capacity** to SLR inundation, flooding, and groundwater rise. Temporary measures, such as deployable flood barriers and pumps could be used to prevent flooding of critical features in the near term. Flights could also be redirected to other airport locations across the Bay Area if the site is flooded, providing service redundancy. Diesel power generators can also be used to maintain power to the stormwater pumps, airfield lighting, and key facilities necessary for operations in case of power outage. Floodproofing buildings, drainage improvements, and pumping could mitigate groundwater hazards to airport facilities. However, long-term adaptability of the airport will be difficult due to restrictions on raising the shoreline levees located within lateral and end-of-runway safety zones. City staff are currently coordinating with the airport and Federal Aviation Administration to better understand these constraints as they relate to other ongoing projects in the area.

Asset Consequence

With 36 inches of SLR, flood impacts would result in **high consequences** to the airport and region if flood prevention is not in place. Damage could include saltwater exposure to runway surfaces, lighting, and other electrical structures, which may require complete replacement.

Overflow relief services to surrounding airports could be impacted, more than 350 aircraft owners could lose access to their aircraft, and the Civil Air Patrol would be unable to perform emergency missions. This information is based on a current assessment using standard industry assumptions provided by C&S Engineers Inc., the Airport's consultant drafting the Airport Layout Plan, which includes considerations for SLR. According to the Transportation Research Board's Airport Cooperative Research Program Report 199 "Climate Resilience and Benefit-Cost Analysis: A Handbook for Airports," the physical damage costs to the airport navigational infrastructure (including the navigational instruments surrounding the runway) would range from approximately $500,000 with three to four inches of SLR to $10 million with seven to eight inches of SLR.

Depending on the extent of the flooding and remnant soil conditions, it would also cost the City up to $100 million to reconstruct paved airport surfaces such as the runway, taxiway, and apron if SLR hazards are not sufficiently addressed. In addition, a yet-unknown amount of tax revenue would be lost annually and an estimated $2.7 million per day could be lost in wages and services according to the Transportation Research Board's Airport Cooperative Research Program Report 224 "Understanding Impacts to Airports from Temporary Flight Restrictions." The final Airport Layout Plan scheduled for completion in 2023 will provide more detailed information about operational and cost impacts from SLR, including potential tax revenue impact.

8.2.5 Utilities and Flood Management

8.2.5.1 Utilities Asset Category Overview

The City owns and manages a network of utility and flood management infrastructure to provide basic services to residents and industrial and commercial businesses. Services include water distribution, emergency groundwater supply wells, wastewater collection and treatment, recycled water production and distribution, natural gas distribution, electricity distribution, telecommunication services, and stormwater/flood management. The following sections summarize how key assets supporting each of these services may be vulnerable to flood hazards from SLR changes that impact daily high tides, 100-year storm tides, and rising groundwater. Findings are based on present-day built conditions and consider potential impacts under a no action scenario.

8.2.5.2 Utilities Sea Level Rise Exposure Summary

This section summarizes the exposure of Utility assets to SLR (Table 24) and groundwater (Table 25). Table 24 indicates the amount of SLR at which each asset is exposed to either daily high-tide inundation (HT) or 100-year storm-tide flooding (ST). Table 25 indicates the amount of SLR at which each asset is exposed to either emergent groundwater flooding (EG) (shallow groundwater that rises above the surface of the ground and creates surface ponding) or a high shallow groundwater table (within six feet of the surface) (HG).

Table 24. Utilities and Flood Management: Sea Level Rise Exposure Summary from Daily High-Tide Inundation or 100-Year Storm-Tide Flooding

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
DRINKING WATER								
Water Pipeline	HT	—	—	—	35 miles	41 miles	48 miles	53 miles
	ST	41 miles	43 miles	48 miles	51 miles	53 miles	61 miles	68 miles
WASTEWATER								
RWQCP	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	□	✓	✓	✓	✓
Sanitary Sewer Pipeline	HT	—	—	—	37 miles	41 miles	49 miles	53 miles
	ST	41 miles	43 miles	49 miles	51 miles	54 miles	60 miles	68 miles
Recycled Water	HT	—	—	—	3 miles	3 miles	3 miles	3 miles
	ST	3 miles	3 miles	3 miles	3 miles	3 miles	3 miles	3 miles
STORMWATER								
Outfalls	HT	—	1 total	1 total	18 total	18 total	18 total	18 total
	ST	18 total	18 total	18 total	19 total	19 total	19 total	19 total
Green Stormwater Infrastructure Locations	HT	—	San Francis-quito Pump Station	San Francis-quito Pump Station	Matadero Pump Station and San Francis-quito Pump Station	Matadero Pump Station, San Francis-quito Pump Station, and Ross Road Bike-Ped Improve-ments	Matadero Pump Station, San Francis-quito Pump Station, and Ross Road Bike-Ped Improve-ments	Matadero Pump Station, San Francis-quito Pump Station, and Ross Road Bike-Ped Improve-ments
	ST	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments, Mitchell Park Library and	San Francis-quito Pump Station, Matadero Pump Station, Ross Road Bike-Ped Improve-ments, Mitchell Park Library and

Asset	Water Level	+0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
							Community Center	Commun-ity Center, Hoover Park Rainwater Harvesting
Pump Stations	HT	—	—	—	Adobe, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport
	ST	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado and Airport	Adobe, Matadero, Colorado, Airport, San Francis-quito Creek
Manholes	HT	—	—	—	226 total	258 total	290 total	316 total
	ST	258 total	268 total	290 total	302 total	316 total	357 total	401 total
Pipeline	HT	—	—	—	18 miles	21 miles	23 miles	25 miles
	ST	21 miles	21 miles	23 miles	24 miles	24 miles	26 miles	29 miles
Inlets	HT	—	—	—	49 total	50 total	56 total	57 total
	ST	50 total	52 total	56 total	57 total	57 total	58 total	69 total
ELECTRICAL								
Access Vaults	HT	—	2 total	3 total	469 total	548 total	609 total	804 total
	ST	548 total	578 total	697 total	770 total	804 total	1,066 total	1,324 total
Substations	HT	—	—	—	2 total	2 total	2 total	2 total
	ST	2 total	2 total	2 total	2 total	2 total	3 total	3 total
TELECOMMUNICATIONS								
Fiber Optic Network	HT	—	<1 miles	<1 miles	14 miles	15 miles	16 miles	17 miles
	ST	15 miles	16 miles	16 miles	17 miles	17 miles	20 miles	24 miles
NATURAL GAS								
Receiving Station	HT	—	—	—	✓	✓	✓	✓
	ST	✓	✓	✓	✓	✓	✓	✓
FLOOD MANAGEMENT								
Flood Protection Levees	HT	—	—	—	2.3 miles	4.4 miles	5.0 miles	6.0 miles
	ST	4.7 miles	4.7 miles	5.0 miles	5.7 miles	6.1 miles	6.3 miles	6.3 miles

Note: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Assets not exposed to high-tide inundation or storm-tide flooding include water pumps and water wells.

Table 25. Utilities and Flood Management: Sea Level Rise Exposure Summary from Emergent Groundwater Flooding or a High Shallo Groundwater Table

The exposure summary table below indicates the amount of SLR at which each asset is exposed to either EG or HG. A checkmark indicates that an asset is exposed to groundwater hazards at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For areas assets, the percentage of land exposed is listed.

Asset	Water Level	0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
DRINKING WATER								
Water Pipeline	EG	—	<1 mi	<1 mi	2 mi	6 mi	18 mi	40 mi
	HG	—	40 mi	54 mi	64 mi	74 mi	92 mi	109 mi
WASTEWATER								
Sanitary Sewer Pipeline	EG	—	<1 mi	1 mi	2 mi	7 mi	20 mi	41 mi
	HG	—	41 mi	55 mi	66 mi	73 mi	85 mi	94 mi
Recycled Water Pipeline	EG	—	<0.1 mi	<0.1 mi	<0.1 mi	0.2 mi	0.7 mi	1.7 mi
	HG	—	1.7 mi	2.3 mi	2.6 mi	2.7 mi	2.8 mi	3.0 mi
Wastewater - RWQCP								
New Pumping Plant	EG	—	—	—	—	—	—	—
	HG	—	—	1%	25%	90%	100%	100%
Old Chlorine Contact Tank	EG	—	1%	5%	20%	30%	40%	90%
	HG	—	98%	100%	100%	100%	100%	100%
Maintenance Building and Warehouse	EG	—	—	—	—	—	—	—
	HG	—	—	—	3%	100%	100%	100%
Ops Tank	EG	—	—	—	—	—	—	—
	HG	—	3%	100%	100%	100%	100%	100%

Asset	Water Level	0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
Influent Junction Box / Diesel Storage	EG	—	—	—	—	—	—	20%
	HG	—	20%	100%	100%	100%	100%	100%
Oil Storage / RW Filters	EG	—	—	—	—	—	—	80%
	HG	—	80%	100%	100%	100%	100%	100%
Chemical Storage Tanks	EG	—	1%	2%	2%	2%	3%	75%
	HG	—	75%	100%	100%	100%	100%	100%
Recycled Water UV Channel/ Chlorination Station	EG	—	—	—	—	—	—	—
	HG	—	< 1%	20%	100%	100%	100%	100%
UV Disinfection	EG	—	—	—	—	—	—	—
	HG	—	40%	90%	100%	100%	100%	100%
RW Storage Tank #3 / Flocculation	EG	—	—	—	—	—	—	20%
	HG	—	20%	90%	100%	100%	100%	100%
Paint Storage	EG	—	—	—	—	—	—	100%
	HG	—	100%	100%	100%	100%	100%	100%
Admin Building	EG	—	—	—	—	—	—	—
	HG	—	—	3%	50%	95%	100%	100%
RW Chlorine Contact Basin	EG	—	—	—	—	—	—	—
	HG	—	—	—	55%	100%	100%	100%
Incineration Building	EG	—	—	—	—	—	—	—
	HG	—	—	5%	15%	55%	100%	100%

Asset	Water Level	0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
Tunnel 2	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	60%	100%	100%
Operations Building	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	30%	100%	100%
Grit Handling Building	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	100%	100%
Primary Sedimentation Tanks	EG	—	—	—	—	—	—	—
	HG	—	—	< 1%	2%	30%	75%	90%
Trickling Filter 1	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	< 1%	5%	40%
Trickling Filter 2	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	1%	30%
Secondary Clarifiers 1, 2, 3, 4	EG	—	—	—	—	—	5%	15%
	HG	—	15%	25%	60%	90%	100%	100%
Aeration Tanks	EG	—	—	—	—	—	—	—
	HG	—	—	—	1%	10%	40%	75%
Secondary Clarifiers 6	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	100%	100%
RAS Pump Station (MCC Room)	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	100%	100%

Asset	Water Level	0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
Secondary Clarifier 5	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	< 1%	75	100
Dual Media Filters	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	< 1%	40%
Landfill Maintenance	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	—	55%
Landfill Maintenance	EG	—	—	—	—	—	—	—
	HG	—	—	—	—	—	—	30%
STORMWATER								
Outfalls	EG	—	6 total	10 total	12 total	16 total	19 total	22 total
	HG	—	16 total	12 total	12 total	9 total	10 total	9 total
GSI Measures	EG	—	<1 acre	<1 acre	1 acre	2 acres	3 acres	6 acres
	HG	—	6 acres	10 acres	12 acres	17 acres	21 acres	25 acres
Pump Stations	EG	—	—	—	—	Airport	Airport	Airport, Colorado
	HG	—	Colorado, Airport	Colorado, Airport	Airport, Colorado, Adobe	Colorado, Adobe	Colorado, Adobe, Matadero	Adobe, Matadero
Manholes	EG	—	1 total	4 total	9 total	35 total	114 total	248 total
	HG	—	247 total	325 total	367 total	393 total	376 total	304 total
Pipeline	EG	—	<1 mi	1 mi	2 mi	4 mi	14 mi	29 mi
	HG	—	29 mi	37 mi	42 mi	47 mi	54 mi	60 mi
Inlets	EG	—	6 total	8 total	11 total	18 total	40 total	52 total

Asset	Water Level	0-inch SLR	+12-inch SLR	+24-inch SLR	+36-inch SLR	+ 48-inch SLR	+66-inch SLR	+84-inch SLR
	HG	—	46 total	54 total	53 total	49 total	28 total	25 total
ELECTRICAL								
Access Vaults	EG	—	5 total	14 total	42 total	106 total	346 total	722 total
	HG	—	717 total	960 total	1,111 total	1,226 total	1,301 total	1,300 total
Substations	EG	—	—	1 total	1 total	1 total	1 total	2 total
	HG	—	2 total	2 total	2 total	2 total	2 total	1 total
TELECOMMUNICATIONS								
Fiber Optics Cable	EG	—	0.2 mi	0.3 mi	0.7 mi	1.6 mi	5 mi	11 mi
	HG	—	11 mi	15 mi	17 mi	20 mi	23 mi	26 mi
NATURAL GAS								
Receiving Station	EG	—	—	—	—	—	—	—
	HG	—	—	✓	✓	✓	✓	✓

Note: Note: A checkmark indicates that an individual asset is exposed to inundation or flooding at a given amount of SLR and a dash indicates that the asset is not exposed. For network assets, the linear footage or number of individual assets exposed is listed. For area assets, the percentage of land exposed is listed. Exposure to existing high and emergent groundwater hazards was not evaluated as part of this Assessment.

8.2.5.3 Drinking Water Vulnerability and Risk Summary

This section describes the identified characteristics of Drinking Water assets that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 26.

Table 26. Drinking Water Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
Low	Moderate to Low	High

Asset Sensitivity

Water wells and pumps are not likely to be exposed to future 100-year storm-tide flooding or average high-tide conditions. Although over 60 miles of water pipelines could be exposed to temporary flooding due to 100-year storm-tide conditions by the end of the century, this type of pipeline has a **low sensitivity** to flooding due to its nature as a closed piping system without features that could allow floodwater to enter and contaminate the water being distributed. As long as power to the water pumps is maintained, the pipes are pressurized, which prevents inflow and infiltration into water pipelines. However, potential impacts from groundwater may occur in the near term. With 12 inches of SLR, 40 miles of potable water pipelines could be in areas with high groundwater within six feet of the surface during wet season conditions. High groundwater levels surrounding buried pipes could saturate surrounding soils or create unanticipated uplift forces.

Palo Alto's 235 miles of water main lines are resilient to flooding, but high shallow groundwater could cause uplift forces that are problematic for pipes.

Asset Adaptive Capacity

Water assets have **moderate to low adaptability** to SLR impacts, depending on the individual asset features of the system. Electrical components at wells and pumps can be elevated to be above flood levels relatively easily; however, modifications or relocation of pipeline infrastructure is difficult and costly.

Asset Consequence

Damage to the water distribution system or a loss in power to the water pumps would have direct impacts to residents and businesses across the City, causing low water pressure and boil orders. Therefore, such impacts are associated with a high consequence of damage.

8.2.5.4 Wastewater Vulnerability and Risk Summary

This section describes the identified characteristics of Wastewater assets that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 27.

Table 27. Wastewater Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate to Low	High

The City of Palo Alto Regional Water Quality Control Plant treats 17 million gallons of wastewater each day from Palo Alto and its five partner communities.

Asset Sensitivity

The wastewater collection and treatment system is highly vulnerable to changes in sea level, with the RWQCP being the most critical and at-risk feature of the network. The RWQCP is highly sensitive to SLR and emergent groundwater flooding because it is a complex facility with many electrical and mechanical components that are susceptible to flood damage. Eighty-six percent of the facility's area could be exposed to temporary flooding by a 100-year storm tide during existing conditions. The treatment facility is first exposed to permanent inundation by daily high tide at 36 inches of SLR.

Detailed groundwater exposure information is presented in the Table 24, below, showing exposure to high and emergent groundwater conditions at each individual facility at the RWQCP. In the near term (12 inches of SLR), emergent groundwater flooding is not projected to be a major issue at the plant; however, some facilities are projected to be in areas of high groundwater (within six feet of the surface) during wet season conditions, including the Old Chlorine Contact tank, Influent Junction Box/Diesel Storage, Oil Storage/RW Filters, Chemical Storage Tank, UV Disinfection, RW Storage Tank #3/Flocculation, Paint Storage, and Secondary Clarifiers 1–4. If any of these facilities have basements or subterranean structures, they may be susceptible to seepage or uplift forces from high groundwater levels. The New Pumping Plant is approximately 20 to 25 feet below grade and is likely already exposed to groundwater; however, it was installed with waterproofing over thick concrete walls and does not have a history of leakage. In addition, if cracks or leakage is detected, it could be injected with foam to stop leakage to prevent damage and preserve structural integrity.

Although the sanitary sewer pipeline infrastructure itself has **low sensitivity** to SLR inundation, the pipe network is a key vulnerability because it is a direct pathway for floodwater to enter the RWQCP via surface utility manholes or through inflow and infiltration of aging pipelines. Introduction of floodwaters to the sanitary sewer system could stress the capacity or operations of the RWQCP or compromise the wastewater biological treatment process due to the increased influent salinity associated with intrusion of saline Bay waters. Treated wastewater discharge points also represent a key vulnerability of the RWQCP. The functionality of the discharge points may be limited during flood events when Bay levels are higher than discharge elevations. This concern is a main driver of a New Effluent Outfall Pipe project that is currently under evaluation by the City.

Although three miles of recycled water pipeline could be exposed to temporary flooding by a 100-year storm tide during existing conditions, it is a closed piping system without features that could allow a pathway for floodwater, reducing its sensitivity to flooding. The recycled water pipeline is first exposed to permanent inundation by daily high tides at 36 inches of SLR. The pipes are also pressurized, preventing inflow and infiltration of water pipelines.

Asset Adaptive Capacity

It is anticipated that implementation of a bayfront levee project would provide SLR protection to the RWQCP through late-century and possibly longer. Some individual features of the system are being adapted to provide redundancy or to reduce sensitivity to stormwater or groundwater flooding, with modifications such as elevating the foundations for electrical and mechanical equipment, floodproofing entry doorways at the RWQCP, and rehabilitating/replacing aging pipelines. These mitigation measures will be considered for upcoming capital improvement projects at the RWQCP. However, if regional shoreline flood protection, such as a bayfront levee project, is not completed, the RWQCP has **low to moderate adaptive capacity** to long-term inundation posed for the site and may require costly site-specific flood protection measures or relocation (which is even more cost prohibitive). Although the proposed bayfront levee project would offer long-term flood protection from surface flooding by rising tide levels and coastal storm events, the facility may still be affected by local stormwater or groundwater flooding.

Asset Consequence

Wastewater collection and treatment is a critical service provided by the City, resulting in **high consequence** from SLR impacts. In addition to the significant repair and replacement costs posed by direct flood exposure of infrastructure, failure of the system could cause sewage backups and overflow events across the City. Such events could result in the spread of water-borne pathogens, creating health hazards for communities and wildlife and degrading the quality of adjacent water bodies.

8.2.5.5 Stormwater Vulnerability and Risk Summary

This section describes the identified characteristics of Natural Resources and Open Space that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 28.

Table 28. Stormwater Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate to High	High

Stormwater assets are located throughout the City, including in low-lying areas in close proximity to the Bay and high groundwater levels. The Flood Basin, a 585-acre retention basin that receives inflow from the Matedero, Adobe, and Barron Creeks and nine pump stations, currently protects the city from flooding from a 10-year storm event. Two of these pump stations (the San Francisquito Creek and Matadero Creek stations) can pump 300 cubic feet per second each. SLR and increasing storm intensity may expose many of the stormwater system components and reduce the overall capacity of the system to provide continuous flood protection.

Asset Sensitivity

The Flood Basin is **highly sensitive** to sea level because it was designed to accommodate a particular set of historical Bay water level conditions. Incoming riverine floodwaters are stored in the basin and released to the Bay through a gravity-driven tide gate structure when water levels in the Flood Basin exceed the Bay's tidal elevation. Rising sea levels may reduce the ability to efficiently drain floodwater by gravity and create upstream backups. The Flood Basin's earthen walls are also sensitive to potential scouring and levee failure during overtopping events if Bay water levels exceed the levee crest elevation.

Pump stations are **highly sensitive** to flooding because they depend on an electrical and fiber optic services that can be interrupted by storm events and damaged by marine floodwaters. The City's pump stations, motors, and electrical cabinets have already been elevated above the existing base flood elevation but may be exposed if water levels exceed this elevation due to rising sea levels.

Green stormwater infrastructure (GSI) is sensitive to high groundwater levels, as they can limit infiltration into surrounding soils. With 12 inches of SLR, approximately six acres of public GSI measures are projected to be located in areas with high groundwater levels within six feet of the surface during wet season conditions. By the end of the century, the area of impacted GSI could quadruple to 25 acres.

Although outfalls, inlets, manholes, and pipelines are not structurally susceptible to flood damage, their functionality at a sub-basin-level scale may be sensitive and could result in localized flooding. Most of the stormwater system throughout the City is gravity drained, toward either the creeks or pump stations that discharge flows directly into one of the City's four major creeks, with the outfalls being the lowest point of discharge. Outfall functionality in the future may be limited due to rising Bay waters exceeding the outfall elevations that drain by gravity. Flooded inlets that are overwhelmed beyond their design capacity will not drain runoff efficiently. Manholes, although not designed to receive floodwaters, can also provide a pathway for floodwaters to enter the stormwater system, reducing the overall capacity of the network.

Similarly, floodwaters and rising groundwater levels can infiltrate stormwater pipelines through cracks in aging infrastructure and in doing so reduce the capacity of the system to convey stormwater. Some GSI relies on vegetation and landscaped bioretention areas to collect and treat stormwater on-site, making it sensitive to SLR flooding. Rising groundwater levels can also reduce the effectiveness of infiltration from GSI installations. Many of the features and plant species used in the GSI design may have a narrow tolerance for saltwater exposure. GSI measures are also designed to retain and treat a limited quantity of water, which may be quickly overwhelmed from flooding due to extreme storms or high-tide events.

Asset Adaptive Capacity

The Flood Basin has **moderate adaptive capacity**. Over time, it can be modified to increase the height of the basin perimeter levees and tide gate features to accommodate future Bay water-level conditions. At higher levels of SLR, pumps could be installed to help discharge floodwaters from the Flood Basin; however, the costs are likely to be significant, and any projects would require coordination with Valley Water (flood control agency for Santa Clara County). Valley Water is currently evaluating the feasibility of replacing the aging tide gate, and the anticipated SLR will be incorporated into the design. This project is scheduled to begin in 2023 and will take up to four years to complete. Elevation of the Flood Basin features was also considered in the SAFER Bay study, which would include designs to provide flood protection for a 100-year coastal storm event with three feet of SLR.

Individual features of the stormwater system have a **moderate to high adaptive capacity**, with modifications such as elevating sensitive mechanical or electrical equipment and floodproofing entry doorways at pump stations, replacement or lining of aging pipelines, and installation of backflow valves on outfalls can be altered to adapt to the changing environment with permits and funding. However, other features, such as inlets, have limited adaptive capacity because modifications would require major reconstruction of the stormwater system and the potential network they're integrated into (e.g., roadways or sidewalks). Similarly, gravity discharge under conditions with moderate to high SLR may not be possible. GSI features may be modified, depending on the unique needs of the project site, to accommodate greater inflows and be planted with salt-tolerant species; however, rising groundwater levels may reduce capacity for infiltration and retention.

Asset Consequence

A functioning stormwater system plays a large role in providing flood protection throughout the city and protecting local water quality, giving it a **high consequence** for damage or reduction of services. Loss of any asset functionality may increase flood damage to public and private property and affect access across the City. Reductions in stormwater system functionality and the flooding of adjacent properties could also allow excess sediment and contaminants to flow into surrounding waterways and the Bay.

8.2.5.6 Electric Vulnerability and Risk Summary

This section describes the identified characteristics of Natural Resources and Open Space that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 29.

Table 29. Electric Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

The City of Palo Alto owns and operates the City's electrical distribution system.

The electrical distribution system is highly vulnerable to SLR inundation. Two major substations, including the Pacific Gas and Electric Company (PG&E) power source line for the City, are vulnerable to temporary flooding by a 100-year storm tide during existing conditions. Substations are first exposed to permanent inundation by daily high tides at 36 inches of SLR. With 24 inches of SLR, one substation could be impacted by emergent groundwater flooding during wet season conditions.

Asset Sensitivity

Substations contain **highly sensitive** components, including circuit breakers, switches, electrical panels, and transformers that could be quickly damaged if exposed. The City's electrical transmission grid also includes a network of below-grade access vaults where lateral lines are tied into the primary network. These vaults have vents and the boxes are not watertight. Although the housed connectors and equipment inside the vault may be capable of withstanding temporary exposure to water, they are not designed to be submerged for long periods of time and would need to be de-energized once flooding occurs. In addition to subgrade electrical vaults, the City has aboveground pad-mounted equipment (transformers, switches, and load breaks) that sits four inches above the adjacent grade. In most cases, this equipment could operate without damage with up to 16 inches of above-grade flooding. Once floodwaters exceed this height, there is risk of equipment damage.

Asset Adaptive Capacity

Substations have **moderate adaptive capacity** and can be modified to resist flooding by raising electrical components or hardened by floodproofing or erecting floodwalls around their perimeter. Access points are also adaptable through floodproofing with water-tight housing capable of withstanding long durations of water exposure.

Asset Consequence

Substations have a **high consequence** from damage, as they are a key component of the City's electricity infrastructure, performing a variety of functions as part of the generation, transmission, and distribution systems. Flood impacts to substations generally only have direct impacts on customers receiving power distributed by each substation. However, the Adobe Creek Station, which is connected to the PG&E power source line, is vulnerable to SLR inundation. Damage to this substation would have widespread impacts across the city, affecting all utilities, critical services, residents, and businesses. The second substation vulnerable to flood exposure provides power supply to several residential and industrial areas in the City, potentially affecting about 1,200 customers. Although on a smaller scale, exposure of access points can also cause power outages for downstream customers of the exposed box.

8.2.5.7 Telecommunications Vulnerability and Risk Summary

This section describes the identified characteristics of Telecommunication assets that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 30.

Table 30. Telecommunications Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
Moderate	High	High

Palo Alto's fiber optic network monitors all Palo Alto electric substations and creek levels and supports general and emergency telecommunications.

The City's fiber optic cable network, which is critical to telecommunications, is moderately vulnerable to SLR inundation. The fiber optic cable could already be exposed to temporary flooding by a 100-year storm tide during existing conditions. Although most of the fiber optic cable could be exposed to permanent inundation by daily high tides with 36 inches of SLR, less than a mile of the cable that supplies telecommunication services east of East Bayshore Road is initially exposed by 12 inches of SLR.

Asset Sensitivity

Most of the City's fiber optic network is underground and, even though it is tolerant of some temporary flooding, most of the deployed conduits are not designed to be submerged for prolonged periods, making the fiber optic network **moderately sensitive** to SLR. Depending on the depth of burial, cable could be exposed to high groundwater conditions and saturated soils in the near term. With 12 inches of SLR, 11 miles of cable is projected to be located in areas of high groundwater levels (within six feet of the surface during wet season conditions).

Asset Adaptive Capacity

Fiber optic cables have the ability to be modified to accommodate more frequent flooding and rising groundwater levels through floodproofing techniques, giving them a **high adaptive capacity**. Cables located in coastal areas can be replaced with water-tight cable housing options that are designed to be submerged in saltwater conditions.

Asset Consequence

Telecommunications serve a vital role in the everyday life and safety of the City's residents. Impacts from SLR could have **high consequence**. Damage to sections of the fiber optic cable could create isolated internet outages across the City, particularly for areas east of East Bayshore Road, and affect the availability of efficient communications for emergency response and other critical City services. The Baylands includes commercial customers and City-owned facilities that rely on the fiber optic network. If water exposes the splice enclosures for these locations, it will likely cause damage and require a new line. However, silt deposits from past floods in this area has made it increasingly difficult to run new subgrade cables.

8.2.5.8 Natural Gas Vulnerability and Risk Summary

This section describes the identified characteristics of Natural Gas assets that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 31.

Table 31. Natural Gas Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

The City of Palo Alto natural gas distribution system is sensitive to flood hazards.

The City of Palo Alto Gas Engineering Division is responsible for planning, designing, budgeting, and constructing major capital improvements to the City's gas distribution system. The natural gas receiving station, which connects PG&E's natural gas line into the City's distribution network, may be exposed to temporary flooding by a 100-year storm tide during existing conditions. The receiving station is first exposed to permanent inundation by daily high tides by 36 inches of SLR. With 24 inches of SLR, the receiving station is projected to be located in an area of high groundwater levels within six feet of the surface during wet season conditions.

Asset Sensitivity

The receiving station is composed of a complex system of valves, meters, pressure reduction devices, and electrical control panels, making it **highly sensitive** to flood exposure. Even temporary flooding of the site would require replacement of the regulator and the diaphragm area to prevent corrosion. The receiving station is also connected to a network of underground distribution pipelines.

Asset Adaptive Capacity

The system has a **moderate adaptive capacity** to future water level conditions, as electrical panels and sensitive equipment can be elevated. Alternatively, the receiving station may be floodproofed to prevent water from impacting sensitive equipment.

Asset Consequence

Loss of functionality of the receiving station and pipeline network would directly affect the ability to supply natural gas to the City's residents and businesses, giving this system a **high consequence** from damage. Corrosion or storm sediment build-up on regulator components can affect the pressure of distributed gas to customer appliances, causing potential damage or leaks. As a part of the City's emission reduction goals in the Sustainability/Climate Action Plan, the city is currently transitioning to electrification, thereby decreasing the number of homes relying on natural gas sources.

8.2.5.9 Flood Management Vulnerability and Risk Summary

This section describes the identified characteristics of Flood Management assets that contribute to their overall vulnerability and risk to SLR. Results for each component of the vulnerability and risk assessment are summarized in Table 32.

Table 32. Flood Management Vulnerability and Risk Summary

Sensitivity	Adaptive Capacity	Consequence
High	Moderate	High

The Palo Alto Flood Basin tide gate regulates water between San Francisco Bay and a flood detention basin to protect urban areas from flooding.

The City's existing coastal flood protection levee begins near the intersection of US 101 and San Francisquito Creek, traces the border with the Bay waterfront and the Palo Alto Flood Basin, and ends near the intersection of Adobe Creek and US 101. The levee and its associated tide gate feature at the Flood Basin are currently at a lower elevation than a 100-year storm tide during existing conditions. Thus, 4.7 miles of the levee may be exposed or overtopped by temporary flooding today. The levee and tide gate are first exposed to permanent inundation by daily high tides at 36 inches of SLR.

Asset Sensitivity

The levee itself is **highly sensitive** to flooding and inundation. Although it was designed to withstand high-water conditions, its elevation is lower than the existing 100-year storm-tide base flood event. Once Bay water levels exceed the levee height, the asset would no longer perform its primary function of providing flood protection for the City. In addition, the levee was constructed with earthen materials that could experience scour or breaching during storm events.

Asset Adaptive Capacity

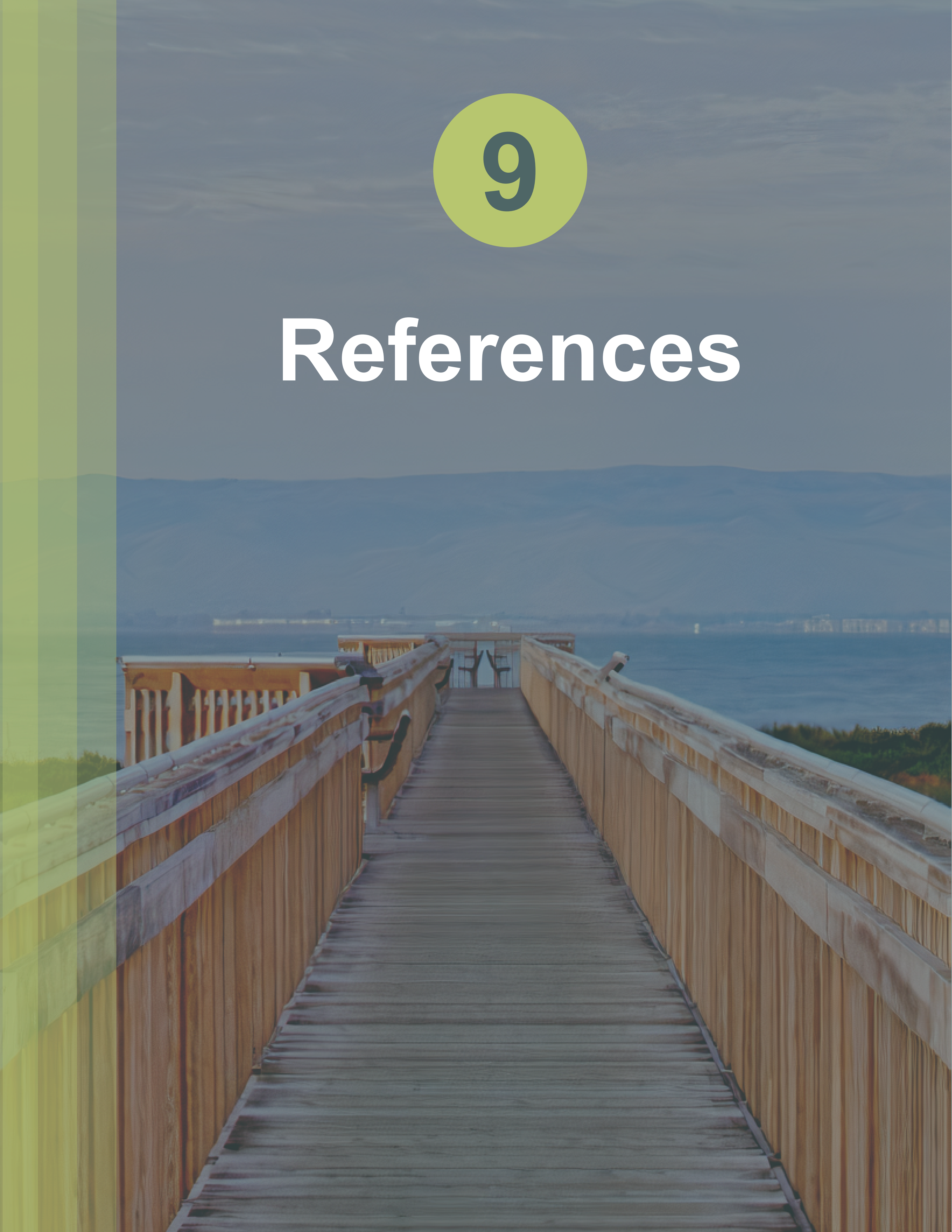
The levee has **moderate adaptive capacity** to future water-level conditions. Although it is possible to elevate the levee to consistently provide flood protection for a 100-year storm-tide event with SLR, this possibility is associated with a high cost and would require significant collaboration with regional stakeholders and regulatory agencies.

Asset Consequence

Damage or failure of the levee would have very **high consequences** for the City because it is the primary form of flood protection for the City. Levee failure during a storm with high water level conditions could result in catastrophic damages to property, infrastructure, and life safety. In addition to direct damages, impacts to the levee's functionality could cause flooding of many high-risk assets, including the RWQCP, Palo Alto Airport, and US 101, which will have long-term impacts to City operations, services, and day-to-day life for residents and businesses.

9

References



9 References

Aagaard, B.T., J.L. Blair, J. Boatwright, S.H. Garcia, R.A. Harris, A.J. Micheal, D.P. Schwartz, and J.S. DiLeo. 2016. Earthquake Outlook for the San Francisco Bay Region 2014. 2043:6. DOI:10.3133/fs20163020.

AECOM. 2016. San Francisco Bay Tidal Datums and Extreme Tides Study. Prepared for the Federal Emergency Management Agency Region IX and the San Francisco Bay Conservation and Development Commission.

———. 2019. Climate Change and Sea Level Rise at the Palo Alto Baylands. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/67887.

Anning, Vicky. 1998. Flood of ’98: Flood cost may top $40 million. Palo Alto Online. Available: https://www.paloaltoonline.com/weekly/morgue/news/1998_Jun_3.CREEK.html.

Barnard, P.L., M. van Ormondt, L. Erikson, J. Eshleman, C. Hapke, P. Ruggiero, P. Adams, and A. Foxgrover. 2014. Development of the Coastal Storm Modeling System (CoSMoS) for Predicting the Impact of Storms on High-Energy, Active-Margin Coasts. Natural Hazards 74, 1095–1125.

BCDC (San Francisco Bay Conservation and Development Commission). 2017. Adapting to Rising Tides: Bay Area Sea Level Rise Analysis and Mapping Project. Prepared for the San Francisco Bay Conservation and Development Commission, the Metropolitan Transportation Commission, and the Bay Area Toll Authority. San Francisco, CA: AECOM. http://www.adaptingtorisingtides.org/wp-content/uploads/2018/07/BATA-ART-SLR-Analysis-and-Mapping-Report-Final-20170908.pdf.

———. 2021. San Francisco Bay Plan Climate Change Policy Guidance. https://www.bcdc.ca.gov/bpacc/San-Francisco-Bay-Plan-Climate-Change-Policy-Guidance.pdf https://www.bcdc.ca.gov/bpacc/San-Francisco-Bay-Plan-Climate-Change-Policy-Guidance.pdf.

Befus, K.M., P.L. Barnard, D.J. Hoover, J.A. Finzi-Hart, and C.I. Voss. 2017. Quantifying the Increasing Threat of Coastal Groundwater Hazards Resulting from Sea-Level Rise. Nature Climate Change.

———. 2020. Increasing threat of coastal groundwater hazards from sea-level rise. Nature Climate Change. DOI:10.1038/s41558-020-0874-1.

Bjerklie, D.M., J.R. Mullaney, J.R. Stone, B.J. Skinner, and M.A. Ramlow. 2012. Preliminary Investigation of the Effects of Sea-Level Rise on Groundwater Levels in New Haven, Connecticut. Reston, VA: Open File Report 2012-1025, United States Geological Survey, United States Department of the Interior, and Yale University. https://pubs.usgs.gov/of/2012/1025/.

Blackwell, E., M. Shirzaei, C. Ojha, and S. Werth. 2020. Tracking California's Sinking Coast from Space: Implications for Relative Sea-Level Rise. Science Advances 6 (31).

Buis, Alan. 2020. Changing Pacific Conditions Raise Sea Level Along U.S. West Coast. https://climate.nasa.gov/news/3039/changing-pacific-conditions-raise-sea-level-along-us-west-coast/.

California OPC (California Ocean Protection Council). 2010. California Coastal LiDAR Project. Available at: https://opc.ca.gov/webmaster/ftp/pdf/opc_cclp_report_final.pdf.

———. 2018. State of California Sea-Level Rise Guidance. 2018 Update. Available at: https://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/.

California OPR (California Governor's Office of Planning and Research). 2017. Planning and Investing for a Resilient California: A Guidebook for State Agencies. Accessed January 1, 2021. Available at: https://opr.ca.gov/docs/20180313-Building_a_Resilient_CA.pdf.

Church, J.A., and N.J. White. 2011. Sea Level Rise from the Late 19th to the Early 21st Century. Surv. Geophys. 32, 585–602.

Church J.A., P.U. Clark, A. Cazenave, J.M. Gregory. 2013. Sea level change. Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge Univ Press, Cambridge, UK), pp 1137–1215.

City of Palo Alto. 2018. Palo Alto Baylands: Climate Change and Sea Level Rise at the Baylands. Palo Alto, CA: City of Palo Alto, November. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/67887.

———. 2019. Sea Level Rise Adaptation Policy. Available at: https://www.cityofpaloalto.org/civicax/filebank/blobdload.aspx?t=71340.78&BlobID=70115.

City of Palo Alto and Santa Clara Valley Water District. 2018. Groundwater Assessment and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy.

CNRA et al. (California Natural Resources Agency and 17 other State of California agencies). 2021. Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action. Seventeen State of California agencies endorsed these principles. http://www.opc.ca.gov/webmaster/_media_library/2020/05/State-SLR-Principles_FINAL_April-2020.pdf.

ESA. 2020. Palo Alto Horizontal Levee Pilot Project: Preliminary Design Report. Available at: https://www.sfestuary.org/wp-content/uploads/2020/04/PAHL_Final-PDR_191231-and_Appendices.pdf.

Fowler, C.M.R. 2012. The Modified Mercalli Intensity Scale (abridged version). In: The Solid Earth, 654. DOI:10.1017/cbo9780511819643.023. https://www.usgs.gov/natural-hazards/earthquake-hazards/science/modified-mercalli-intensity-scale?qt-science_center_objects=0#qt-science_center_objects.

Griggs, G., J. Árvai, D. Cayan, R. DeConto, J. Fox, H.A. Fricker, R.E. Kopp, C. Tebaldi, and E.A. Whiteman. 2017. Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Protection Council Science Advisory Team Working Group. April.

Hamlington, B.D., S.H. Cheon, P.R. Thompson, M.A. Merrifield, R.S. Nerem, R.R. Leben, and K.-Y. Kim. 2016. An Ongoing Shift in Pacific Ocean Sea Level. J. Geophys. Res. Oceans, 121, 5084–5097. DOI:10.1002/2016JC011815.

Hay, C., E. Morrow, R. Kopp, and J. Mitrovica. 2015. Probabilistic Reanalysis of Twentieth-Century Sea-Level Rise. Nature 517, 481–484. Available at: https://doi.org/10.1038/nature14093.

Holzer, T.L., M.J. Bennett, T.E. Noce, A.C. Padovani, and J.C. Tinsley. 2002. Liquefaction Hazard and Shaking Amplification Maps of Alameda, Berkeley, Emeryville, Oakland, and Piedmont, California: A Digital Database. Open-file Report 2002-296. Reston, VA: U.S. Geological Survey.

IPCC (United Nations Intergovernmental Panel on Climate Change). 2014. AR5 Synthesis Report: Climate Change, 2014.

Lamjiri, M.A., M.D. Dettinger, F.M. Ralph, N.S. Oakley, and J.J. Rutz. 2018. Hourly Analyses of the Large Storms and Atmospheric Rivers that Provide Most of California's Precipitation in Only 10 to 100 Hours per Year. San Francisco Estuary and Watershed Science 16:1–17. DOI:10.15447/sfews.2018v16iss4art1.

May, C.L. 2020. Rising Groundwater and Sea-Level Rise. Nature Climate Change. DOI:10.1038/s41558-020-0886-x.

Michael, H., V. Post, A. Wilson, and A. Werner. 2017. Science, Society, and the Coastal Groundwater Squeeze. Water Resources Research 53: 2610–2617. DOI:10.1002/2017WR020851.

NOAA (National Oceanic and Atmospheric Administration). 2020. Sea Level Trends. Available at: https://tidesandcurrents.noaa.gov/sltrends.

Plane, E., K. Hill, and C.L. May. 2019. A Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Driven by Sea Level Rise in Coastal Cities. Water 2228: 8–10. DOI:10.3390/w11112228.

Polade, S.D., A. Gershunov, D.R. Cayan, M.D. Dettinger, and D.W. Pierce. 2017. Precipitation in a Warming World: Assessing Projected Hydro-Climate Changes in California and Other Mediterranean Climate Regions. Nature Scientific Reports 7. DOI:10.1038/s41598-017-11285-y.

Quilter, P.W., S. Van Ballegooy, and M. Russ. 2015. The Effect of Sea Level Rise on Liquefaction Vulnerability: A Case Study for Consideration of Development on Coastal Plains and Reclamations, 1–9. In: 6th International Conference on Earthquake Geotechnical Engineering. Christchurch, New Zealand. https://secure.tcc.co.nz/ei/images/ICEGE15%20Papers/Quilter_480.00.pdf.

Ralph, F.M., T. Coleman, P.J. Neiman, R.J. Zamora, and M.D. Dettinger. 2012. Observed Impacts of Duration and Seasonality of Atmospheric-River Landfalls on Soil Moisture and Runoff in Coastal Northern California. Journal of Hydrometeorology 14: 443–459. DOI:10.1175/jhm-d-12-076.1.

Ray, R.D., and B.C. Douglas. 2011. Experiments in Reconstructing Twentieth-Century Sea Levels. Progress in Oceanography 91: 496–515.

Risken, J.L., J.G. Fraser, H. Rutter, and M. Gadsby. 2015. Implications of Sea Level Rise on Liquefaction Vulnerability in Christchurch, 1–8. In: 6th International Conference on Earthquake Geotechnical Engineering. Christchurch, New Zealand. https://secure.tcc.co.nz/ei/images/ICEGE15%20Papers/Fraser%20109.00_.pdf.

SFCJPA (San Francisquito Creek Joint Powers Authority). 2019. SAFER Bay: Strategy to Advance Flood Protection, Ecosystems and Recreation along San Francisco Bay. Public Draft Feasibility Report. Accessed December 15, 2020. Available at: https://static1.squarespace.com/static/5f21f9097be3cf17ef8a9984/t/5f28a20bc7611279210cb475/1596498607751/SAFER-Bay-Palo-Alto-Public-Draft-Feasibility-Report-June-2019.pdf.

SFEI and SPUR (San Francisco Estuary Institute and San Francisco Planning and Urban Research Association). 2019. San Francisco Bay Shoreline Adaptation Atlas. Accessed December 1, 2020. Available at: https://www.sfei.org/sites/default/files/toolbox/SFEI%20SF%20Bay%20Shoreline%20Adaptation%20Atlas%20April%202019_highres.pdf.

Shirzaei, M., and R. Bürgmann. 2018. Global Climate Change and Local Land Subsidence Exacerbate Inundation Risk to the San Francisco Bay Area. Sci. Adv. 4. eaap9234.

State of California. 2015. California Executive Order B-30-15. Available at: https://www.library.ca.gov/Content/pdf/GovernmentPublications/executive-order-proclamation/39-B-30-15.pdf.

Thompson, P.R., B.D. Hamlington, F.W. Landerer, and S. Adhikari. 2016. Are Long Tide Gauge Records in the Wrong Place to Measure Global Mean Sea Level Rise? Geophysical Research Letters 43(19): 10403–10411.

Valley Water (Santa Clara Valley Water District). 2020a. Palo Alto Flood Basin Tide Gate Structure Replacement Project Planning Study Report. Project No. 10394001. Available at: https://s3.us-west-

2.amazonaws.com/assets.valleywater.org/PAFB_Tide_Gate_Structure_Replacement_-_Planning_Study_Report.pdf.

———. 2020b. Santa Clara Valley Water District Annual Groundwater Report 2019. Available at: https://www.valleywater.org/sites/default/files/2020-09/2019_Annual_Groundwater_Report_Web_Version.pdf.

———. 2021. South San Francisco Bay Shoreline Study. Available at: https://www.valleywater.org/project-updates/creek-river-projects/E7-san-francisco-bay-shoreline-protection.

Witter, R.C., K. Knudsen, J.M. Sowers, C.M. Wentworth, R.D. Koehler, C.E. Randolph, S.K. Brooks, and K.D. Gans. 2006. Maps of Quaternary Deposits and Liquefaction Susceptibility in the Central San Francisco Bay Region, California. U.S. Geological Survey Open-File Report 06-1037. Page Database. U.S. Geological Society. http://pubs.usgs.gov/of/2006/1037/.

Yasuhara, K., S. Murakami, N. Mimura, H. Komine, and J. Recio. 2007. Influence of Global Warming on Coastal Infrastructural Instability. Sustainability Science 2: 13–25.

City of Palo Alto

Sea Level Rise Vulnerability Assessment

Appendix A

Shallow Groundwater Assessment and Maps

Prepared for:
City of Palo Alto
Public Works–Watershed Protection
Regional Water Quality Control Plant 2501
Embarcadero Way
Palo Alto, CA 94303

Contact:
Julie Weiss
Watershed Protection Program Manager
650.329.2117

Prepared by:

pathways
CLIMATE INSTITUTE

Contact:
Kris May, PhD, PE
Principal, Pathways Climate Institute
510.289.5705

Peer reviewed by Professor Kristina Hill, PhD

May 2022

Executive Summary

As many coastal communities are developing adaptations to growing flood hazards from rising sea levels and increasing extreme storm and flood events, they tend to focus on flooding from shoreline overtopping and usually fail to account for the flood hazard from the shallow groundwater table. Yet, the unconfined groundwater surface will also rise with sea levels and storm events and can create flooding hazards from below even *before* a shoreline is overtopped. Impacts can include roads buckling from water pressure, inflow and infiltration into buried pipes and infrastructure, and damage to basements and buildings below ground. This appendix explores the link between the shallow groundwater surface, sea level rise, and precipitation for the City of Palo Alto.

In addition to the physical damage rising groundwater can cause to the environment and infrastructure, in Palo Alto, like most Bay Area shorelines, there is another problem: the shallow groundwater can contain contaminants in some areas due to historical land uses or leaking underground storage tanks. Areas of known contamination are closely monitored and remediated, although remediation of some contaminants is challenging using current remediation methods. If contamination is still present at unacceptable levels when shallow groundwater reaches belowgrade facilities (e.g., basements, stormwater infrastructure), or the shallow groundwater emerges above ground, this could cause health hazards to humans, especially vulnerable populations like children and the elderly, as well as pets and wildlife.

Thus, this study uses monitoring well data to estimate the existing shallow groundwater surface and evaluate the existing concentrations of contaminants in groundwater plumes (which were identified in 2018 and which exceed human health benchmarks). The study further evaluates the response of the existing shallow groundwater surface to seven sea level rise scenarios (i.e., 12, 24, 36, 48, 52, 66, and 84 inches), and maps the areas with emergent groundwater. This study does not consider the potential for partial or full contaminant remediation before the groundwater reaches belowgrade infrastructure or becomes emergent.

In Palo Alto, and in the Bay Area, most precipitation occurs between November and April, resulting in the highest annual groundwater surface in the spring in the low-lying areas near the San Francisco Bay shoreline. Beyond sea level rise, the rise and fall of the groundwater surface in response to precipitation events (and groundwater extraction) can impact utilities, foundations, and other infrastructure, particularly if the groundwater surface is within ten feet of the ground surface where most subgrade infrastructure is located. The rise and fall of the groundwater layer can cause sewer collapse, small sinkholes, and roadway damage. Most infrastructure is designed to consider the existing groundwater table variations and the highest annual groundwater elevation on record. However, as the groundwater table rises in response to sea level rise, the variability in the groundwater surface and the highest annual groundwater elevation are likely to change. Current design standards do not account for these changing conditions.

In summary, there are several recommendations to support mitigating or reducing this potential future hazard: larger-scale mitigation and adaptation measures could include increasing pumping to help reduce the groundwater surface, increasing stormwater pumping capabilities, and wetproofing below-grade utilities. In the longer-term, additional measures such as filling low-lying neighborhoods, raising structures, and managed retreat could be necessary to ameliorate the longer-term effects of sea level rise and an elevated shallow groundwater surface. In addition, continued groundwater water quality monitoring and remediation (where necessary) is recommended because the plumes could migrate and move with the flow of groundwater.

Definitions, Abbreviations and Acronyms

Act	Groundwater Quality Monitoring Act of 2001
ART	Adapting to Rising Tides
Bay	San Francisco Bay
BCDC	San Francisco Bay Conservation and Development Commission
CADWR	California Department of Water Resources
City	City of Palo Alto
COE	California - Olive - Emerson (plume named after the local streets)
CoSMoS	USGS Coastal Storm Modeling System
DTSC	Department of Toxic Substances Control
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GAMA	Groundwater Ambient Monitoring and Assessment Program
GHG	greenhouse gas
GIS	geographic information system
LiDAR	Light Detection and Ranging
MCL	maximum contaminant level
MSL	mean sea level
MHHW	mean higher high water
MODFLOW	USGS modular hydrologic model
MTBE	Methyl tert-butyl ether
NAVD88	North American Vertical Datum of 1988
NL	notification level
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
OCOF	Our Coast, Our Future
OPC	Ocean Protection Council
PCE	Tetrachloroethene
PDSI	Palmer Drought Severity Index
RCP	Representative concentration pathway
RWQCB	San Francisco Regional Water Quality Control Board
RWQCP	Palo Alto Regional Water Quality Control Plant
SLR	sea level rise
SMCL	secondary maximum contaminant level
SWRCB	California State Water Resources Control Board
TBA	Tert-butyl alcohol
TCA	Trichloroethene
TDS	total dissolved solids
USGS	United States Geological Survey
VOC	volatile organic compounds

Table of Contents

Tables

Figures

A.1 Introduction

As sea levels rise and extreme storms become more frequent, communities are developing climate adaptation plans to protect communities from flooding. The City of Palo Alto is being pro-active in their planning efforts and incorporating the response of the shallow groundwater layer to sea level rise and precipitation events. This slow but chronic rise in the shallow groundwater table can flood communities from below, damaging buried infrastructure, flooding below grade structures, and emerging aboveground as an urban flood hazard, even before coastal floodwaters overtop the shoreline (May 2020).

As sea levels rise, the surface of the shallow groundwater table in low-lying coastal communities will also rise (see Figure A-1). Failing to adequately consider this hazard could undermine adaptation success of fortifying the shoreline. For example, if coastal flood protection levees only consider coastal flooding and sea level rise and neglect the accompanying inland rise in the shallow groundwater table, the areas protected by levees could be flooded from below by emergent groundwater. This hazard could cause widespread consequences to infrastructure before the groundwater becomes emergent, such as higher rates of inflow and infiltration into flood control channels and stormwater pipelines and reductions in the stormwater conveyance capacity during periods of heavy rainfall (May et al. 2020).

This study assesses and maps the response of the shallow groundwater layer to sea level rise and seasonal rainfall events within the City of Palo Alto, with an emphasis on the highest annual groundwater surface, which generally occurs in the late winter or early spring after winter rainfall events. The groundwater surface is highest (i.e., closest to the ground surface) in wet years when total precipitation is generally a lot higher than in drought years. This high groundwater surface could emerge aboveground during or after a wet winter season, creating sporadic and localized flooding. Over time, as sea levels and the groundwater table rise, the impacts associated with a high and/or emergent groundwater table will become more widespread in coastal communities such as Palo Alto.

This study assesses and maps the reaction of the shallow groundwater layer to sea level rise and seasonal rainfall events within the City of Palo Alto … which could emerge aboveground during or after a wet winter season.

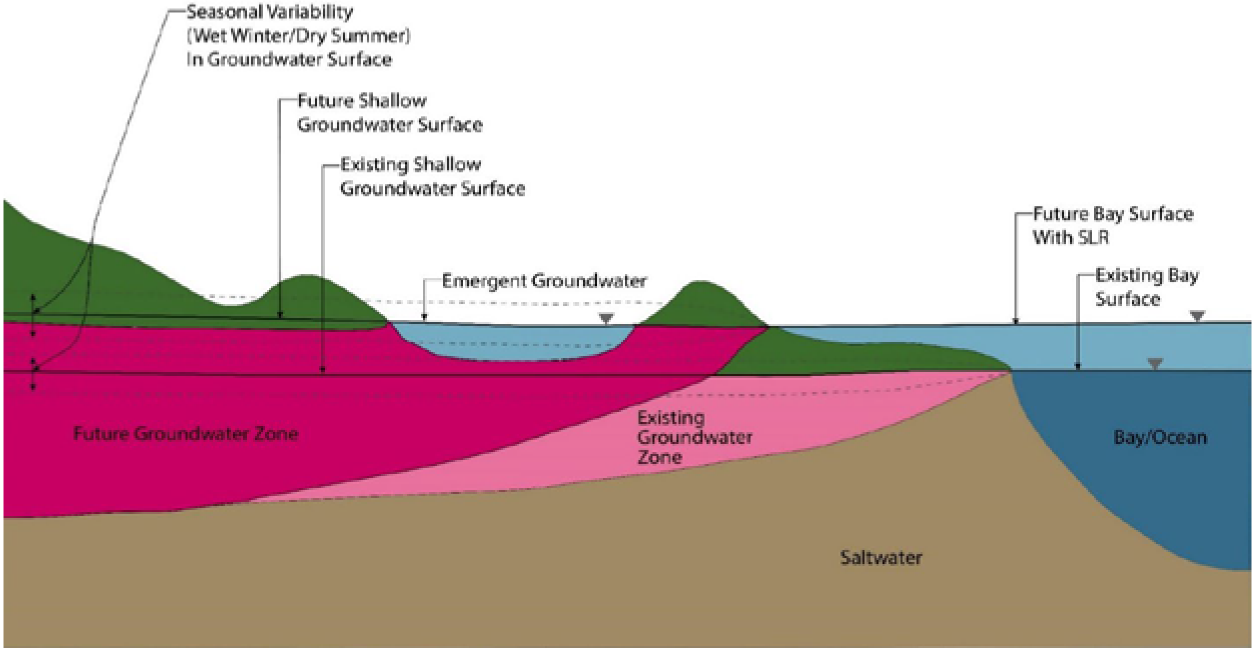
The results of this assessment are incorporated within the City's Sea Level Rise Vulnerability report. To aid the City in their efforts, the groundwater water analysis and mapping used sea level rise scenarios consistent with the Adapting to Rising Tides (ART) program[1], by the San Francisco Bay Conservation and Development Commission (BCDC). The response of the shallow groundwater layer was evaluated in response to seven sea level rise scenarios: 12, 24, 36, 48, 52, 66, and 84 inches (Vandever et al. 2017).

---

[1] http://www.adaptingtorisingtides.org/

This appendix documents the methodology used to characterize the existing groundwater surface, the future groundwater surfaces in response to sea level rise and considers how the rising groundwater water table could affect contaminants found underground adsorbed to soils or within shallow groundwater. Additional results, including the exposure assessment of City-owned asset and major facilities, are presented in the Sea Level Rise Vulnerability Assessment report.

This appendix underwent external peer review, and the document includes revisions to address peer-review comments and feedback.



Source: May et al. 2020

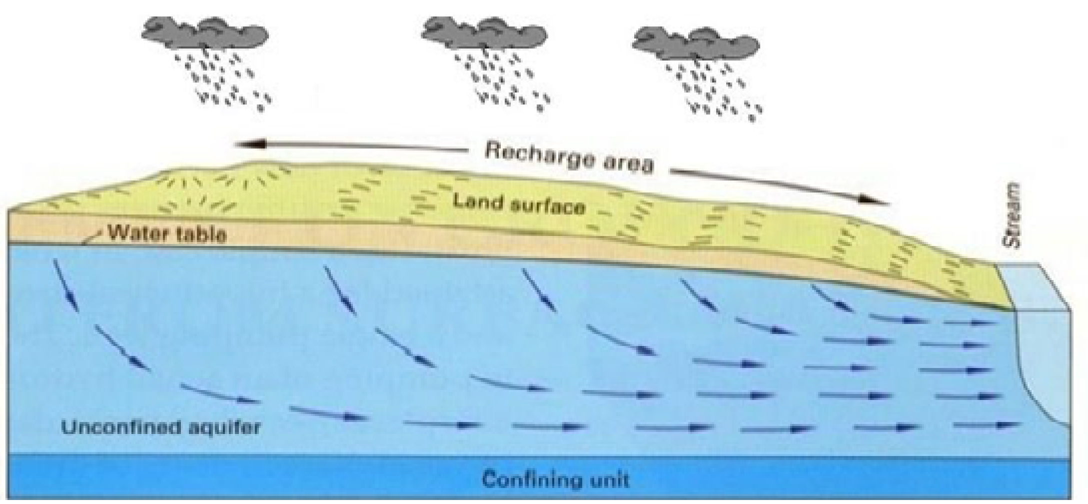
Figure A-1 Shallow Groundwater Surface Response to Sea Level Rise

A.2 Shallow Groundwater

Groundwater is water found underground in the soil, either in the pores between soil particles or in crevices within rocks. The groundwater layers found in the Bay Area are complex, with multiple porous layers of soil separated by impervious layers often comprised of clay. The shallow groundwater layer of interest in this assessment is the uppermost groundwater layer that is unconstrained at the surface. Because this layer is unconstrained, it can emerge above the surface of the ground and create surface flooding. To differentiate this flooding source from other flooding sources (e.g., coastal, riverine, urban stormwater), this flood hazard is called "emergent groundwater" flooding. Understanding the variability of the existing shallow groundwater layer below the ground surface, and how it responds to precipitation and sea level rise, can inform more than future emergent groundwater hazards. It can inform how soil and groundwater contamination may migrate over time, and how susceptible soils may be to liquefaction during a large earthquake.

A.2.1 Precipitation

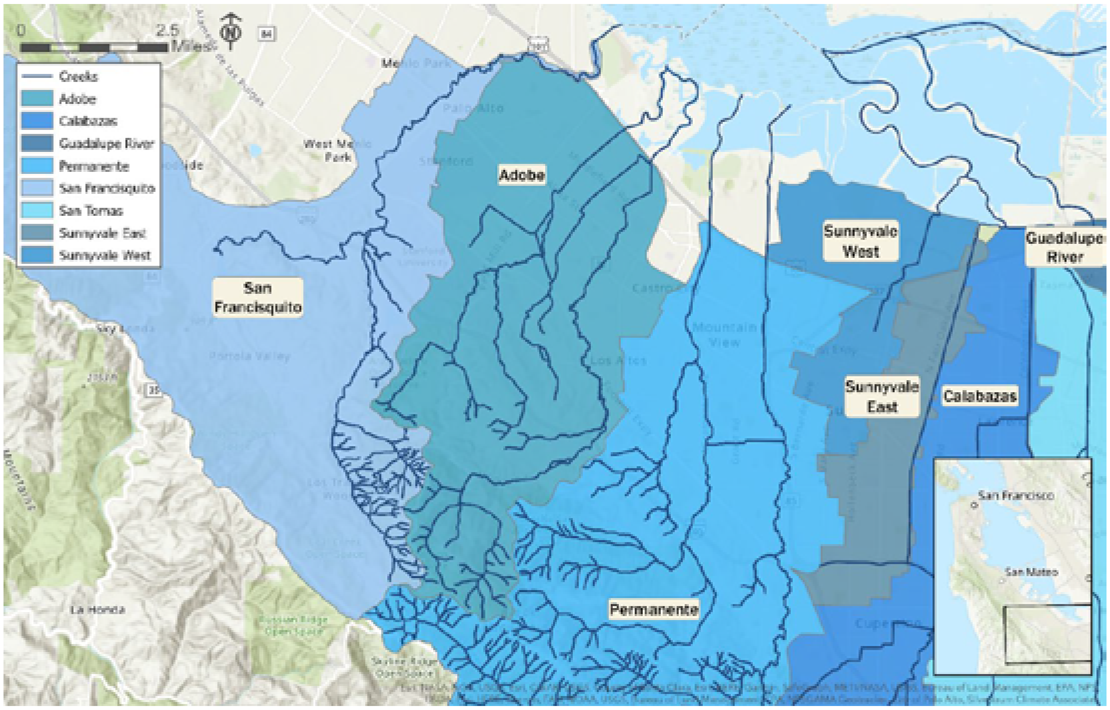
As precipitation falls, the rainwater can infiltrate into the ground, pond, and runoff on impervious surfaces, and/or be captured within the City's storm sewer system. Precipitation that infiltrates the ground surface can elevate the shallow groundwater table and increase the flow of the groundwater layer towards and into nearby natural streams and the Bay (see Figure A-2). Channelized streams and drainage canals hardened with concrete do not influence groundwater flow in the same manner as natural streams. Depending on the overall size of the watersheds, and the hydraulic conductivity of the soils, it can take days, weeks, or months for the shallow groundwater table in the low-lying downstream, coastal areas to reach its annual maximum elevation during wet years (i.e., years with above average precipitation). As sea level rise increases the average, or steady state groundwater table elevation, it may also increase the groundwater flow towards nearby natural streams (Befus et al. 2020). Many of the natural (and channelized) streams carry little streamflow outside of the rainy seasons, and when streamflows are reduced, the groundwater flowing towards natural streams can discharge into the stream for direct conveyance towards the Bay. This mechanism can help reduce the high groundwater table between rain events and during the summer months.



Source: USGS

Figure A-2 Precipitation and Shallow Groundwater Flow

The City of Palo Alto is within the San Francisquito and Adobe watersheds located between San Francisco Bay (Bay) and the Santa Cruz Mountains (see Figure A-3). The bedrock hills slope downward towards the Bay, and the groundwater flows towards the creeks and the Bay, recharging both the shallow and deep groundwater aquifers (City of Palo Alto and Santa Clara Valley Water District 2018).



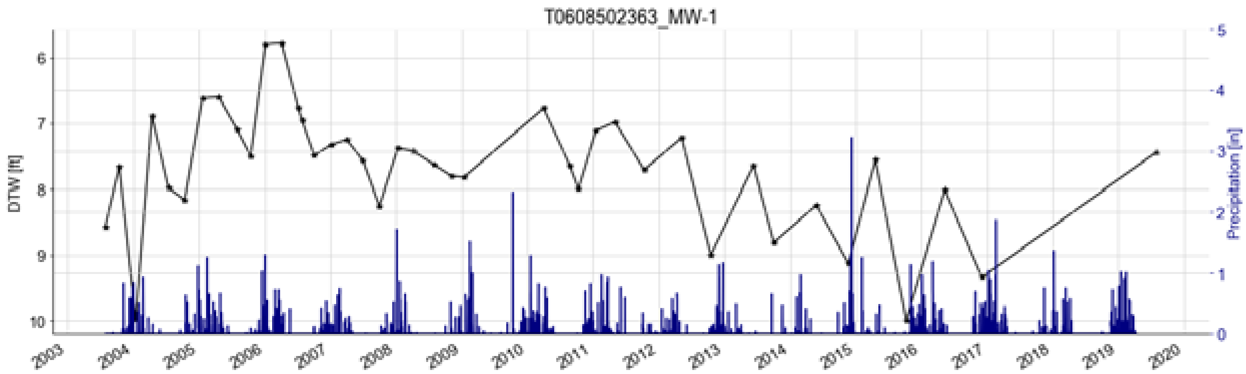
Source: Santa Clara Valley Water District 2017

Figure A-3 Creeks and Watersheds of Palo Alto

Figure A-4 presents a snapshot of how the shallow groundwater surface can vary in response to precipitation. In general, in late winter and early spring the depth to water measures smaller (i.e., the groundwater surface is closer to the ground surface) than the rest of the year. The depth to water increases (i.e., falls deeper below the ground surface) in the fall at the end of the dry season. However, groundwater dewatering (e.g., groundwater extraction pumping) efforts have been associated with numerous contaminated sites in the City of Palo Alto over the past several decades. Groundwater pumping can alter the natural rise and fall of the shallow groundwater surface observed in the monitoring wells near the extraction locations, with the area of influence varying based on the pumping rate and the surrounding soil characteristics.

In Palo Alto, and in the Bay Area, most precipitation occurs between November and April, resulting in the highest annual groundwater surface in the spring. It should be noted that measurements are recorded at each monitoring well approximately two to four times per year depending on the monitoring requirements and the status of ongoing contaminant remediation efforts; therefore, it is possible that the highest and lowest elevations of the water table surface may not be captured. However, measurements are usually collected in the fall and late winter / early spring when the lowest and highest water table elevations are most likely to occur.

The rise and fall of the groundwater surface in response to precipitation events (and groundwater extraction) can impact utilities, foundations, and other infrastructure, particularly within six feet of the ground surface where most subgrade infrastructure is located. The rise (i.e., wetting) and fall (i.e., drying) of soils can create instabilities around pipelines, under roadways, and under foundations. Over time, these instabilities can cause sewer collapse, small sinkholes, and roadway damage. Most infrastructure is designed to consider the existing groundwater table variations and the highest annual groundwater elevation on record. However, as the groundwater table rises in response to sea level rise, the variability in the groundwater surface and the highest annual groundwater elevation are likely to change. Current design standards do not account for these changing conditions.



Source: SWRCB 2020

Figure A-4 Shallow Groundwater Table Response to Precipitation

A.2.2 Contamination

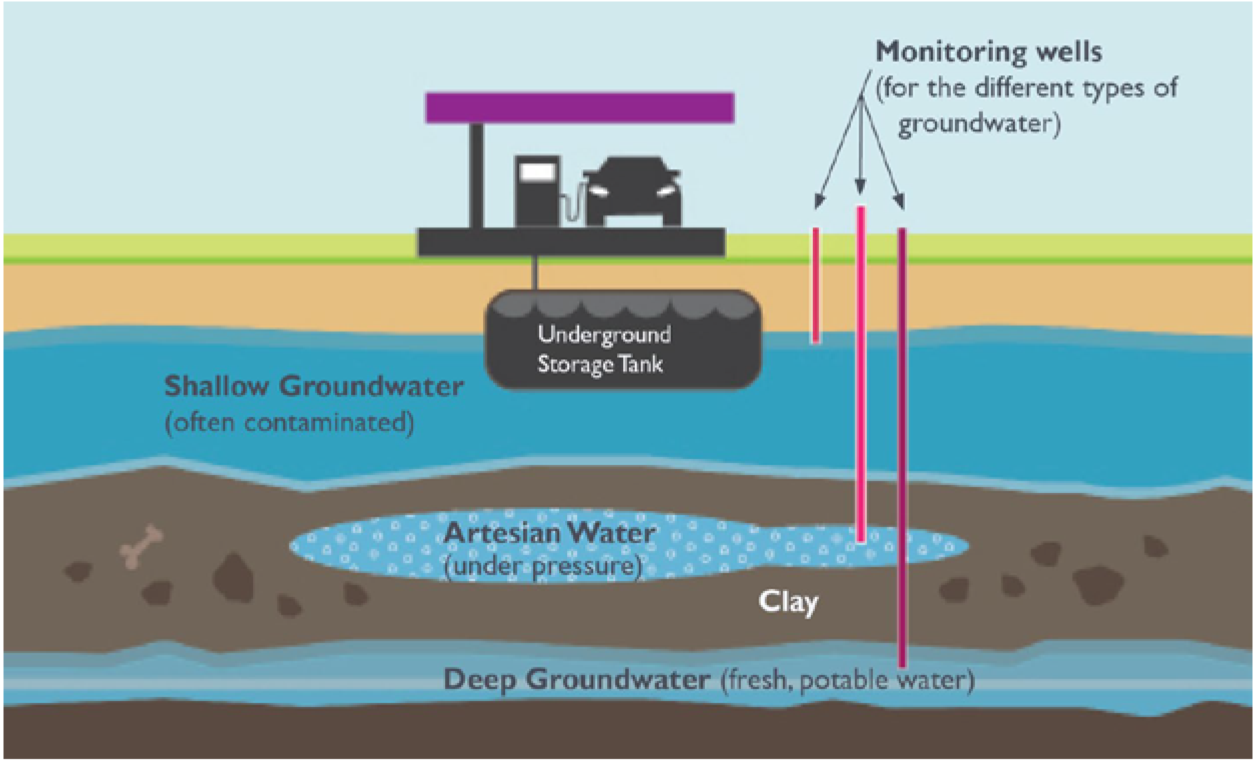
The shallow groundwater layer contains various contaminants from legacy industrial land uses and from more recent commercial and industrial activities (e.g., gas stations, dry cleaners, machine shops, etc.). These contaminants could pose health risks to humans, pets, and wildlife once the groundwater becomes emergent, either above ground or within subterranean structures such as basements and below ground living or working spaces. Some contaminants vaporize as they encounter the air (i.e., vapor-forming or volatile compounds). High concentrations can collect in indoor spaces impacting air quality and creating hazardous health conditions.

The California State Water Resources Control Board (SWRCB) and the local San Francisco Bay Regional Water Quality Control Board (RWQCB) have a mission to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment and public health. In the Bay Area, their jurisdiction includes San Francisco Bay, its tributaries, and all groundwater resources, including the shallow groundwater layer. The SWRCB and RWQCB regulate discharges into these waters, as well as the cleanup of unplanned, unauthorized, or illegal discharges that impact these waters.

The California Department of Toxic Substances Control (DTSC), part of the California Environmental Protection Agency (EPA), also has a mission of protecting public health and the environment from toxic harm. The DTSC regulates hazardous waste treatment and storage facilities and the cleanup of unplanned hazardous waste spills and legacy contamination. Additional contaminated sites, such as leaks from small underground storage tanks (e.g., residential oil tanks), fall under the jurisdiction of the local enforcement agencies. Contamination records from DTSC and local enforcement agencies were not reviewed for this assessment. This assessment is focused on sites regulated by the RWQCB.

The groundwater and contaminant mapping relied on monitoring data submitted to the SWRCB. SWRCB maintains a data management system for public and private well data called GeoTracker Groundwater Ambient Monitoring and Assessment Program (GAMA) (SWRCB 2019) in support the Groundwater Quality Monitoring Act (Act) of 2001 (AB 599 2001, Belitz et al. 2003). The Act identifies the importance of maintaining and monitoring groundwater resources in the state. Thousands of groundwater monitoring wells are located throughout the Bay Area, typically near potential water quality hazards such as underground storage tanks containing chemicals (e.g., gas stations), facilities where chemicals are used or stored (e.g., dry cleaners, manufacturing industries), or locations of previous known spills (see Figure A-5). The SWRCB and RWQCB oversee the remediation and monitoring of these sites.

Regular monitoring observations of each active well include the depth to groundwater, relevant contaminant concentrations, and other factors based on each facility's permit requirements. In many cases, monitoring wells are sampled multiple times a year, providing an extensive data set to monitor changes in the groundwater surface elevation and water quality. Observation data from over 270,000 individual wells throughout California, monitoring more than 260 different chemicals, are included in the GAMA database. Between 2000 and 2020, more than 337,000 measurements were recorded at monitoring wells within the City of Palo Alto.



Source: May et al. 2020

Figure A-5 Example Groundwater Monitoring Wells

This assessment does not include an exhaustive review of all contaminants currently monitored within the city. Only the contaminants within known contaminated areas documented by the City were reviewed (City of Palo Alto and Santa Clara Valley Water District 2018), as shown in Table A-1.

Table A-1 Monitored Contaminants and Human Health Benchmarks

Contaminant	Abbreviation	Human Health Benchmark	Highest Measurement (2018-2020)
Methyl tert-butyl ether	MTBE	> 13 µg/L	2.7
Tert- butyl alcohol	TBA	> 12 µg/L	0
1,1,1-Trichloroethane	1,1,1 TCA	> 200 µg/L	12,000
Trichloroethene	TCE	> 5 µg/L	32,000
Tetrachloroethene	PCE	> 5 µg/L	89,000
Benzene	Benzene	> 1 µg/L	1,000
Gasoline	Gasoline	> 5 µg/L	12,000
Arsenic	Arsenic	> 10 µg/L	140
Toluene	Toluene	> 150 µg/L	420
Total Dissolved Solids	TDS	> 1000 mg/L	56,000

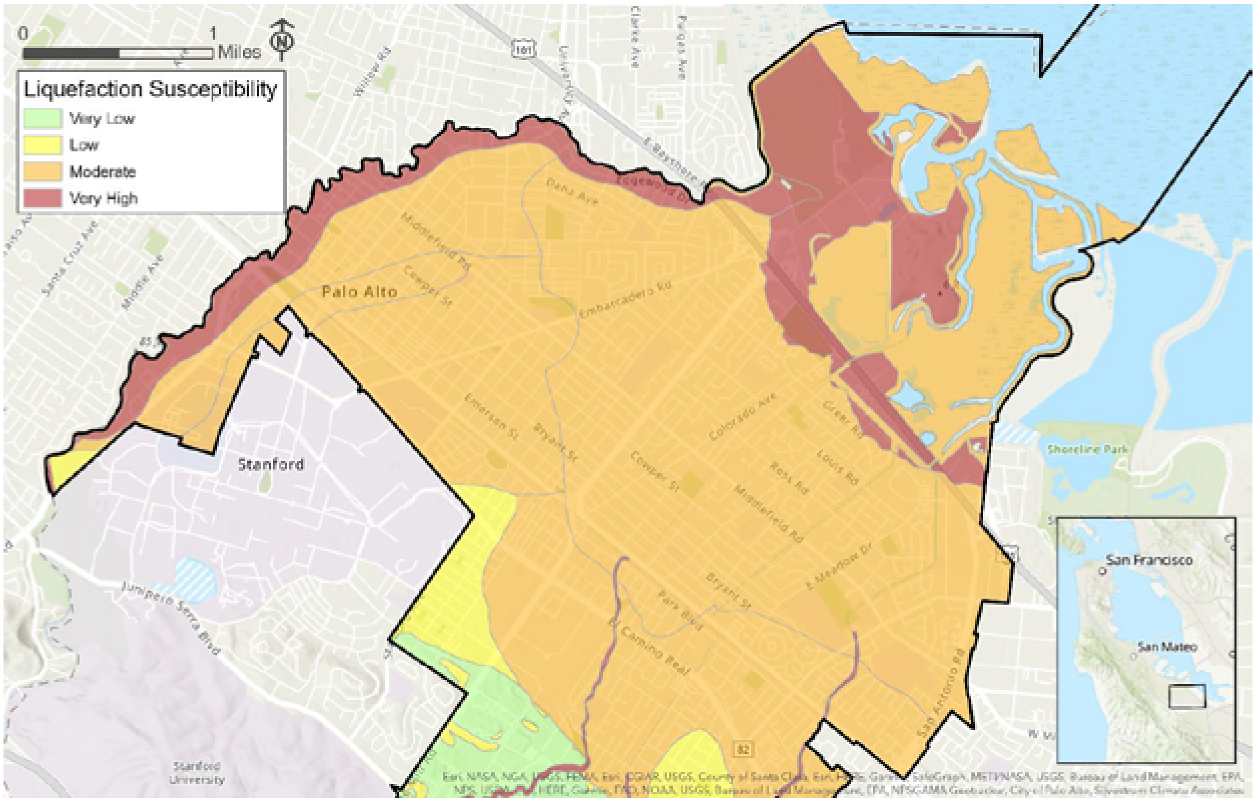
Source: SWRCB 2020

A.2.3 Liquefaction

The Bay Area is seismically vulnerable, with multiple active geologic plate-boundary fault lines that can move, resulting in an earthquake. There is an estimated 72-percent probability of a magnitude 6.7 or greater earthquake occurring in the Bay Area by the year 2043 (Aagaard et al. 2016).

The elevation of the groundwater table will likely impact liquefaction hazards during a large earthquake (Quilter et al. 2015, Risken et al. 2015, Grant et al. 2021). Liquefaction occurs when loosely packed and waterlogged sediments lose their strength in response to strong shaking and act more like a liquid than a solid land surface. When this occurs beneath a building, structure, or other infrastructure, major damage can result. The USGS Western Geographic Science Center is evaluating how rising groundwater may influence, and potentially increase, liquefaction susceptibility across the Bay Area (Grant et al. 2021). This research is ongoing.

Figure A-6 presents the liquefaction susceptibility in Palo Alto using a rating scale delineated in five units from “very high” to “very low” (Holzer et al. 2005, Witter et al. 2006, Fowler 2012). Areas rated as very high contain soils that could liquify with only modest earthquake shaking. These are often historical stream channels, natural levee and beach deposits, and areas of former Baylands and wetlands that were filled to create new lands for development. In Palo Alto, the areas rated very high are along the former San Francisquito Creek floodplain and along the Bay margins near the former salt pond complex and tidal marshes. The remainder of the low-lying areas within the City of Palo Alto have moderate susceptibility to liquefaction. Much stronger earthquake shaking is required to liquify the soils in area rated as moderate; therefore, these areas have a lower liquefaction risk. There are many other scales that describe earthquake shaking and damage risks, the most common being the Modified Mercalli Intensity Scale which correlates earthquake shaking to the potential for people to feel the ground shaking inside vs. outside, the movement of furniture, and the potential for damage to a variety of structures. The Modified Mercalli Intensity Scale considers many factors beyond liquefaction risk.



Source: Witter et al. 2006

Figure A-6 Liquefaction Susceptibility

A.3 Existing Condition Mapping

The existing shallow groundwater surface was characterized using the SWRCB groundwater monitoring well data and geotechnical reports provided by the City of Palo Alto. The monitoring wells observations include the depth to the groundwater table surface. The SWRCB data was supplemented with geotechnical soil boring logs. Geotechnical reports were collected in areas with limited monitoring wells to help better characterize the existing groundwater surface. The soil borings logs include information on the soil characteristics, as well as the location of the water table at the time the soil boring was extracted from the ground. Soil borings that were collected in late winter and early spring were preferred to support the assessment of the highest annual groundwater surface that could occur in response to precipitation. This approach was developed to create a San Francisco Bay Area-wide map of the shallow groundwater layer to support a rapid assessment of potential emergent groundwater hotspots (Plane et al. 2017, 2019), and further refined for the City of Alameda to support climate adaptation and resilience planning (May et al. 2020).

The well data were filtered to use measurements collected between 2000 and 2020 (i.e., focusing on the most recent time period) for wells with depths to water less than 50 feet (i.e., to capture the shallow groundwater layer as opposed to the deeper aquifer). Wells with negative depths to water were removed (i.e., wells with a depth to water above the ground surface are usually associated with artesian wells).

Some depth to water measurements were reported relative to a well riser height. Most wells are flush with the ground surface, as most monitoring wells are in developed (and paved) areas, such as near existing or former gas stations. However, some wells are in grassy fields, wetlands, and undeveloped areas to characterize the potential migration of contaminants away from the original source. These wells often have an elevated riser to aid in finding the well in tall, unmaintained vegetation, and to prevent inadvertent damage to the well riser from lawn mowers and other equipment and vehicles. The riser height was accounted in the analysis so that the depth to water measurements were all used relative to the ground surface.

In areas with well clusters (i.e., areas with five or more wells closely spaced together), the well data were carefully reviewed. In areas with numerous wells and a lengthy remediation history, wells may be closed and replaced with new wells over time to improve the accuracy of the measurements. In these locations, only the most recent measurements from currently active wells were retained.

The well data was subsampled to only select wells with measurements collected during or shortly after wet winters (generally December thru May) between 2000 and 2020. Although this subsampling reduces the number of wells available for interpolation, it removes potential bias from wells that were only sampled during the dry summer seasons, and wells with short-term data collection that did not include a measurement collected after a precipitation event. Between 2000 and 2018, California experienced more drought years than wet years, based on the National Oceanic and Atmospheric Administration's Palmer Drought Severity Index (PDSI), with the four-year drought occurring between 2011 – 2015 estimated as the worst drought in over a century at the time (CADWR 2015). Although 2015 and 2017 were both considered wet winters with above average rainfall, nearly all the Bay Area is under severe to exceptional drought conditions. The prolonged drought conditions may be responsible for the longer-term trend of a declining shallow groundwater surface observed in many of the well records (as shown in Figure A-4).

From this filtered data set, the minimum depth to water measurement for each well was extracted. Selecting the minimum depth to water measurement is a proxy for the highest observed groundwater surface elevation. The depth to water measurements were translated to the NAVD88[2] topographic datum using a digital elevation model developed by the USGS and

[2] The North American Vertical Datum of 1988 (NAVD88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian Mexican United States leveling observations.

refined for the Adapting to Rising Tides program using LiDAR[3] data collected in 2010 and 2011 (OPC 2010, Vandever et al. 2017). Updated topographic data for the Palo Alto golf course was used to update the digital elevation model to account for the recent grade changes.

To connect the shallow groundwater surface with the Bay, tidal water elevations from the San Francisco Bay Extreme Tide and Tidal Datum Study prepared by the Federal Emergency Management Agency (FEMA) were used (May et al. 2016). The FEMA study provides tidal datum information at over 900 points along the complex Bay shoreline. In areas with limited monitoring well information near the shoreline, this data helped approximate the natural slope of the shallow groundwater surface towards the Bay. The tides within the Bay rise and fall twice per day in a semi-diurnal cycle, and a Bay water level elevation approximately one foot above mean tide level was selected because fresh groundwater is usually found just above the mean tide line inland of coastal estuaries (Moss 2016).

Figure A-7 presents the SWRCB well locations, FEMA Tidal Datum points, and the digitized soil boring locations used to develop the existing condition shallow groundwater surface using a multi-quadratic radial basis interpolation technique in ArcGIS[4]. Figure A-8 presents the resulting existing (i.e., present day) shallow groundwater surface in response to precipitation. This condition is representative of the highest existing annual shallow groundwater table elevation, relative to the ground surface, as it can occur during a wet year.

[3] Light Detection and Ranging (LiDAR) is a surveying method that measures distance to a target by illuminating the ground with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the ground surface.

[4] ArcGIS is a geographic information system for working with maps and geographic information.

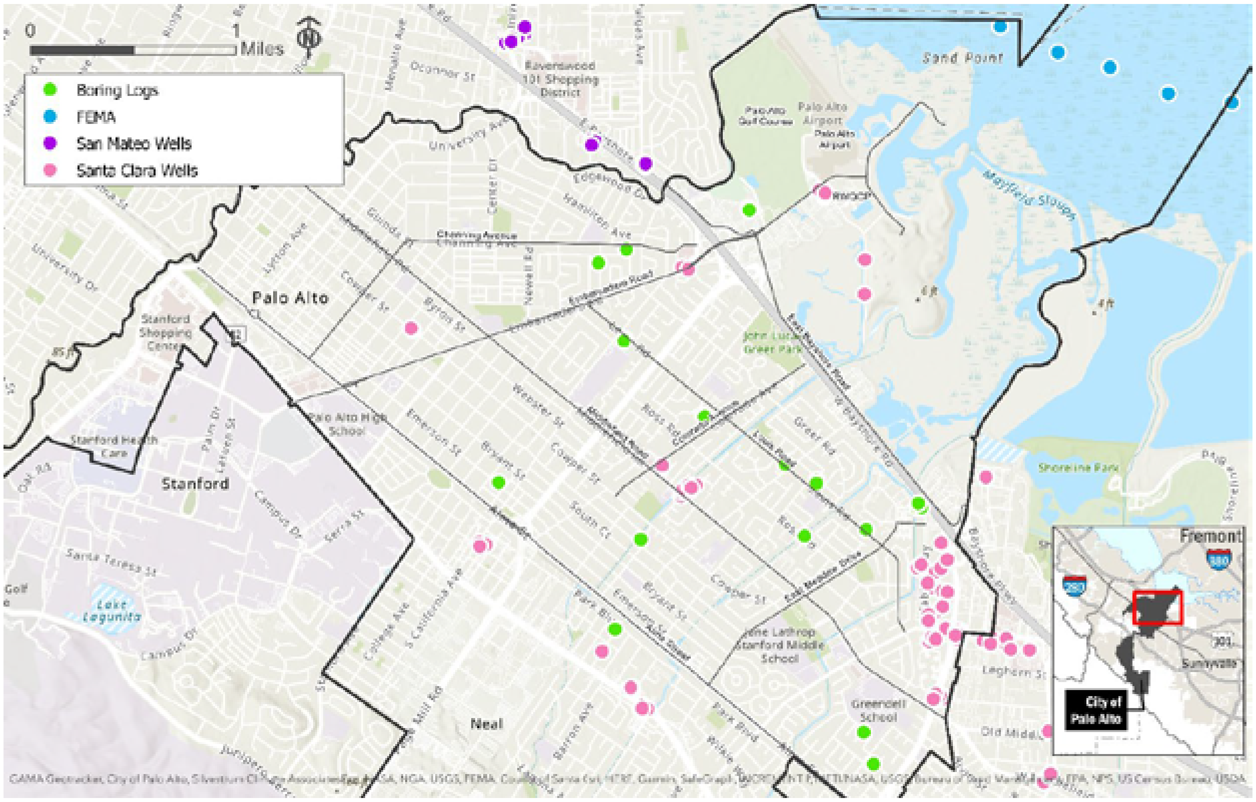


Figure A-7 SWRCB Wells, FEMA Tidal Datums and Soil Boring Log Locations

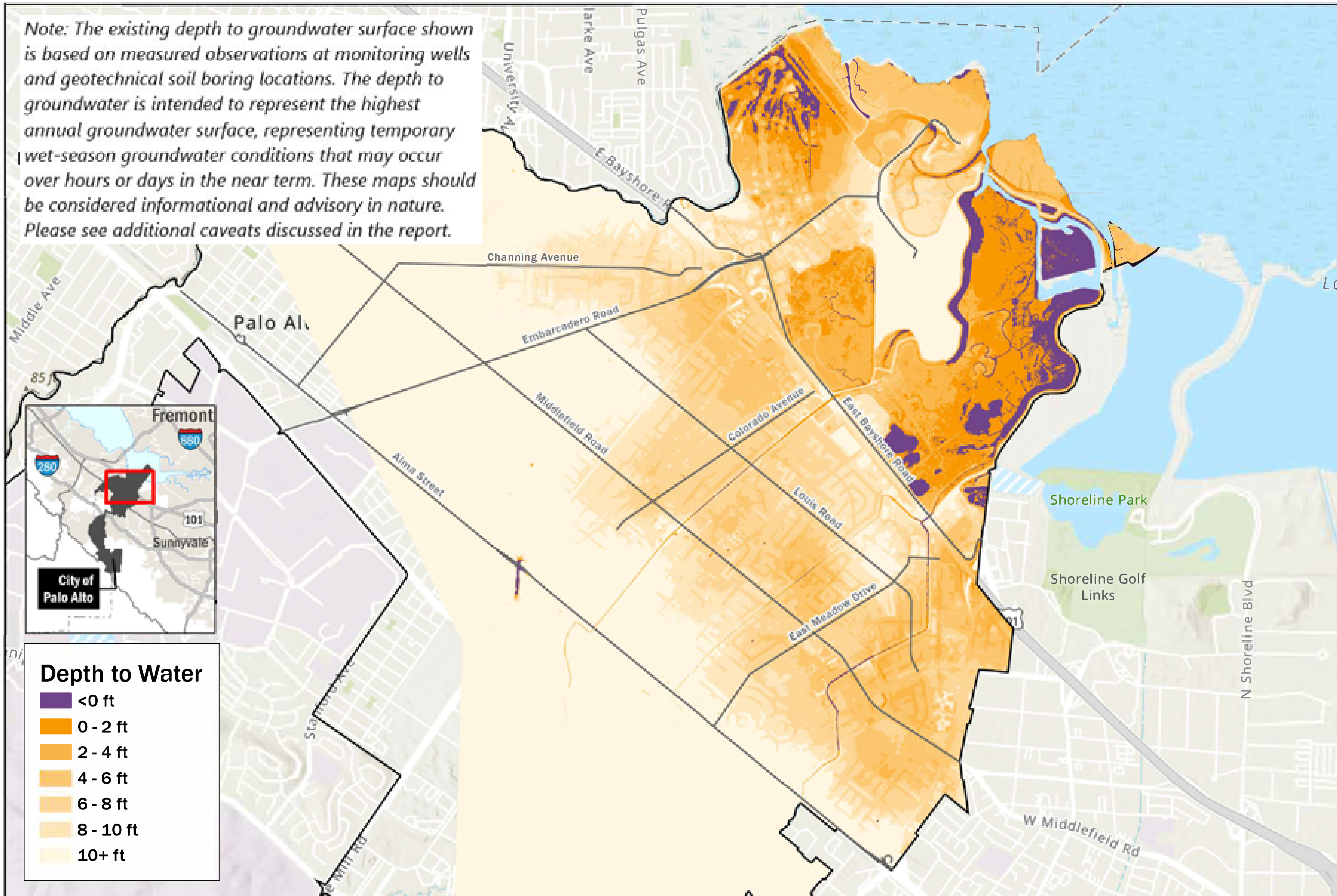
A.3.1 Assumptions and Caveats

Groundwater flow is incredibly complex, and the approaches used in this assessment are considered approximate but reasonable. Flow dynamics vary with soil characteristics such as soil porosity (soil volume relative to pore space, i.e., how much space there is between the soil particles for water to flow through) and hydraulic conductivity (the ability of saturated soil to convey water, i.e., the ease with which water can move through saturated soil) and can also be driven by connections to surface water bodies, tributaries, marshes, and the Bay. Although the mapping relies on the best available information and data sources, it is associated with a series of assumptions. To account for these caveats, a more sophisticated hydrogeological modeling effort accompanied with additional monitoring and soil characterization would be required. The cost and data requirements to develop and calibrate such a model would both be high, and this more sophisticated modeling effort may not necessarily provide more accurate results.

- The existing condition mapping represents the highest annual groundwater surface elevation measured at the SWRCB monitoring wells. Although measurements are recorded during late winter / early spring when the highest groundwater surface is expected to occur in response to winter precipitation, it cannot be assured that the highest groundwater surface elevation was captured. A more detailed monitoring effort would be required, such as recording hourly depth to water measurements over an entire season across multiple wells, during a very wet year.

- Precipitation is often the primary driver of seasonal fluctuations in groundwater table elevation. However, near the Bay shoreline, the rise and fall of the Bay tides can affect the elevation of the groundwater table on a daily (tidal) and monthly (spring-neap) cycle. The fluctuations in the groundwater table are generally muted compared to the tidal variations (i.e., the tidal range in the south Bay can exceed eight feet from mean lower low water to mean higher high water, and this range may translate to fluctuations in the groundwater table of less than one foot depending on the soil characteristics and distance from the Bay). A more detailed monitoring effort would be required to capture the influence of the Bay tides on the elevation of the groundwater table, such as recording sub-hourly depth to water measurements for a minimum of 14 days, and preferably a minimum of 28 days to evaluate spring-neap tidal variations. Long-term groundwater table elevations are dominated by sea level rise, climate change effects on recharge, and human interventions such as groundwater pumping, placing streamflows in underground pipes and culverts, and the use of concrete-lined drainage channels.
- The methodology is empirical and GIS-based and does not consider the complex physics of groundwater flow, nor does it consider the considerable heterogeneity in soil conditions that could result in a higher, or lower, groundwater surface in between monitoring well or geotechnical soil boring log observations.
- The well measurements may not accurately represent the depth to water locations adjacent to the well. Although the wells have been in place long enough to reach equilibrium conditions, the depth to water within the well may be slightly higher, or lower, than the depth to water in the surrounding areas.
- The depth to water measurements from the geotechnical soil borings are considered approximate. Depending on the soil boring collection method and the geotechnical contractor, the notation of the depth to water location for the soil boring may vary. If the geotechnical reports included information or a citation relative to a higher annual groundwater surface (i.e., a smaller depth to water) that differs from the boring log estimate(s), the higher annual groundwater surface elevation was used in place of the boring log. In general, the depth to water locations reviewed for this study were reasonable when compared with the SWRCB monitoring well measurements.
- This assessment does not consider the influence of future green stormwater infrastructure that may be installed by the City of Palo Alto. Green stormwater infrastructure can be designed to either increase precipitation infiltration into the soil or retain runoff in the upper watershed during storm events to reduce or mitigate the potential for downstream flooding.
- This assessment does not consider localized groundwater pumping for basement drainage which occurs at some locations that were installed prior to 2006, or the temporary construction-related dewatering which occurs where the groundwater is shallow. The City of Palo Alto issues permits for short-term construction-related dewatering which typically ends before projects are completed. Basement drainage systems were prohibited in 2006, but some of those remaining systems contribute to localized long-term (> one year) groundwater pumping due to a rise in shallow groundwater levels since the projects were completed.

- At present, some construction sites require dewatering (i.e., groundwater pumping to lower the groundwater surface sufficiently belowgrade during construction). The pumped groundwater is tested for the presence of contamination. If required, the pumped groundwater is treated before discharge into the City’s stormwater conveyance system. For many construction sites, only a settling tank is needed to reduce the fine sediment load before discharge into stormwater conveyance system. As the groundwater table rises over time, the need for dewatering of construction sites will increase (in area, volume, and frequency). Although the City limits some construction activities during wet weather, additional limitations or changes in dewatering policies may be required in the future to avoid adding excess flows to the City’s stormwater conveyance system during wet winters or a heavy precipitation event.
- This study only evaluated impacts to Palo Alto and the mapping is not intended to represent conditions in adjacent communities. The interpolation uses wells observations from the adjacent communities to best characterize the existing groundwater surface across the entire city and avoid boundary effects and challenges. The same level of analysis was applied across all wells, both within Palo Alto and within the adjacent communities. However, boring log information was not collected for the adjacent communities, and the ground truthing process did not extend into these communities. For these reasons, the figures within this report are not displayed beyond the City of Palo’s geographic boundaries. The City of Palo Alto will continue to work with neighboring communities towards creating regional solutions. There are concurrent groundwater studies underway in the county of San Mateo.



Source: AECOM, 2020; 2020; ESRI (Imagery); ESRI 2016 (Roads); Pathways Climate Institute 2021 (Groundwater)

FIGURE A-8

EXISTING GROUNDWATER *in Response to Precipitation*

A.4 Future Condition Mapping

The response of the shallow groundwater table to sea level rise can vary based on the topography of the area and the number of natural streams, tributaries, and man-made drainage canals that help convey stormwater runoff within the watershed towards the Bay. In areas with a limited number of natural streams and tributaries, groundwater rise is approximately unform (i.e., one-to-one) with sea level rise. These areas are “flux-controlled” systems where the rate of groundwater discharge towards the Bay is constant as sea level rises. Sea level rise causes landward migration of the saltwater toe, otherwise known as saltwater intrusion (Werner and Simmons 2009, Chesnaux 2016). This saltwater intrusion causes the overlying fresh groundwater layer to rise (Chang et al. 2011). Therefore, sea level rise causes an increase in the height of the shallow groundwater table, or a decrease in the measured or modeled depth to water (Nuttle and Portnoy 1992, Masterson and Garabedian 2007, Chang et al. 2011, Rotzoll and Fletcher 2013, Wehner 2013, Chesnaux 2016, Befus et al. 2017).

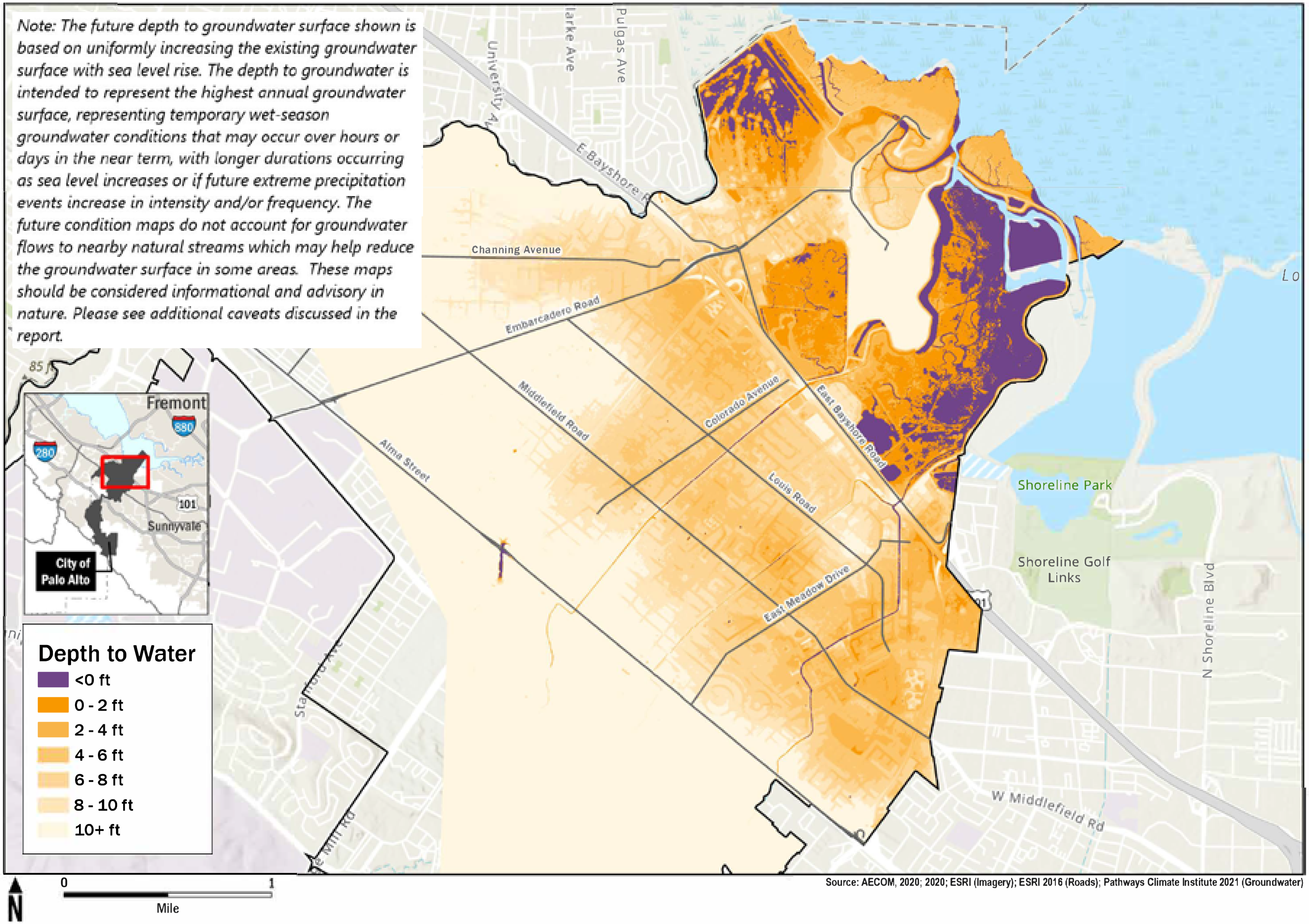
In areas with numerous natural streams, tributaries, and drainage canals that can aid the conveyance of stormwater runoff towards the Bay, the relationship between sea level rise and water table rise is unlikely to be exactly uniform, especially near the tributaries, natural streams, and rivers (Nuttle and Portnoy 1992, Masterson and Garabedian 2007, Befus et al. 2020). As the groundwater table rises, the rate of groundwater flow towards natural streams and tributaries may increase, and the groundwater discharged into these streams and tributaries can be conveyed more swiftly towards to the Bay. This mechanism can help mitigate (i.e., reduce) the rise in the groundwater table in response to sea level rise. During the wet season when natural (and channelized) streams are actively conveying stormwater runoff from the upper watershed towards the Bay, the discharge of groundwater into natural streams may be minimal. However, as the wet seasons ends and natural streams and tributaries have increased conveyance capacity, the groundwater table elevation may slowly decrease due to discharge into natural streams and tributaries, direct discharge into the Bay, and other mechanisms.

The rate of rise in the groundwater surface is also affected by many other factors, including the tidal range, salinity, aquifer geology, soil characteristics, coastline change, shore slope, surface permeability, and precipitation (Rotzoll and Fletcher 2013, Chesnaux 2016, Hoover et al. 2017). For the purposes of this study, and as a conservative approximation, a one-to-one correlation between sea level rise and water table rise can be assumed within the study area (Nuttle and Portnoy 1992). This approximation is most applicable in the zone where sea level and tidal fluctuations have an influence on the shallow groundwater aquifer; therefore, this study focuses on the nearshore areas within approximately three miles of the shoreline (Rotzoll and Fletcher 2013, Knott et al. 2019, May et al. 2020).

Understanding when and where shallow groundwater could become emergent over time is important for developing plans to mitigate and reduce potential risks. The existing shallow groundwater surface was modified to account for sea level rise using seven of the ten sea level rise scenarios mapped as part of the Adapting to Rising Tides (ART) program: 12, 24, 36, 48, 52, 66, 84 inches of sea level rise (Vandever et al. 2017). The ART program scenarios were selected for consistency with the Palo Alto Sea Level Rise Vulnerability Assessment. The use of the ART program sea level rise scenarios also support consistency with the regional groundwater study currently underway in Alameda, San Mateo, San Francisco, and Marin counties.

For the purposes of this study, only the response of the shallow groundwater layer to sea level rise (as opposed to coastal storm surge events) is of concern. The groundwater layer responds slowly to changes in Bay water levels; therefore, it is not anticipated to rise significantly in response to storm surge conditions. Based on best available science, 84 inches is an upper-end estimate of future sea level rise by 2100, and is the highest scenario evaluated in this assessment (NRC 2012, Griggs et al. 2017, CCC 2018). For the mapped future condition scenarios, the areas where groundwater could become emergent was highlighted (See Figure A-9 through Figure A-15).

As with the existing condition mapping, the future condition mapping represents the shallow groundwater surface in response to winter precipitation during wet years. This condition is not representative of the daily, or average, shallow groundwater elevation. As shown in Figure A-4, the groundwater elevation will rise and fall in response to winter precipitation. In the near term, emergent groundwater flooding would occur sporadically during wetter winters or after extreme precipitation events. This flooding hazard could occur with higher frequency and longer durations as the sea level rises and extreme precipitation events become more intense.

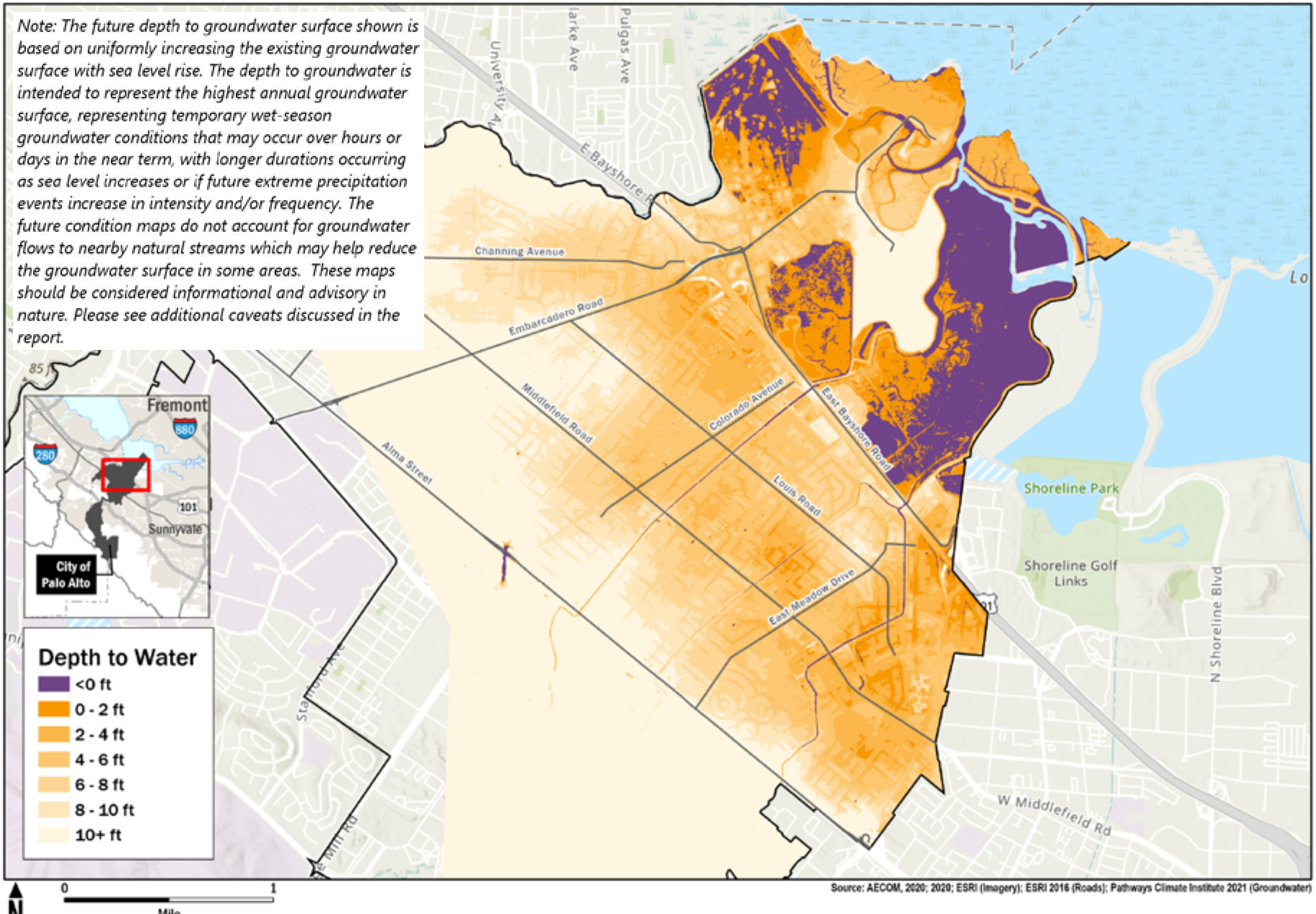


Source: AECOM, 2020; 2020; ESRI (Imagery); ESRI 2016 (Roads); Pathways Climate Institute 2021 (Groundwater)

City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-9

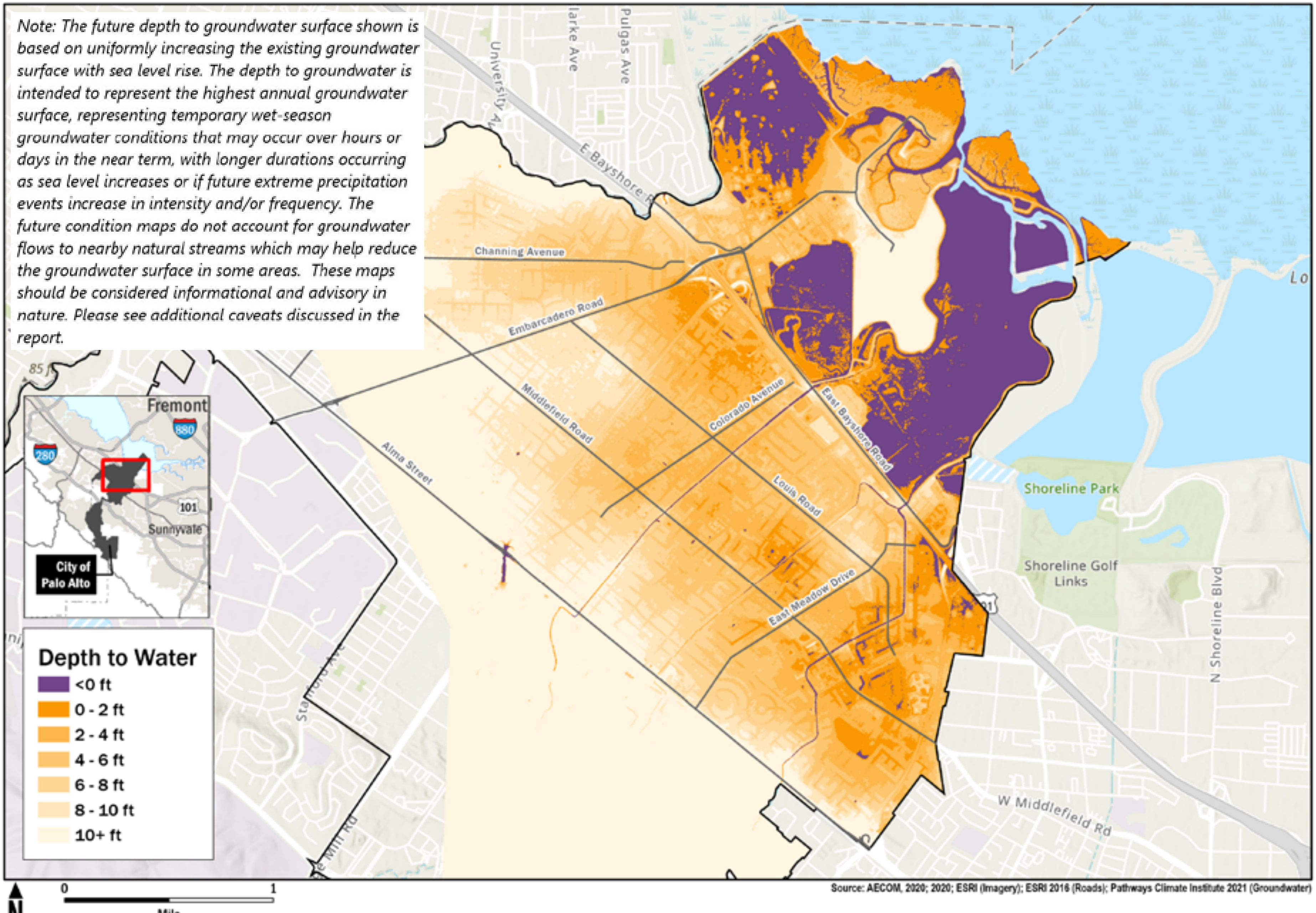
FUTURE GROUNDWATER *in Response to Precipitation and 12" of Sea Level Rise*



City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-10

FUTURE GROUNDWATER *in Response to Precipitation and 24" of Sea Level Rise*

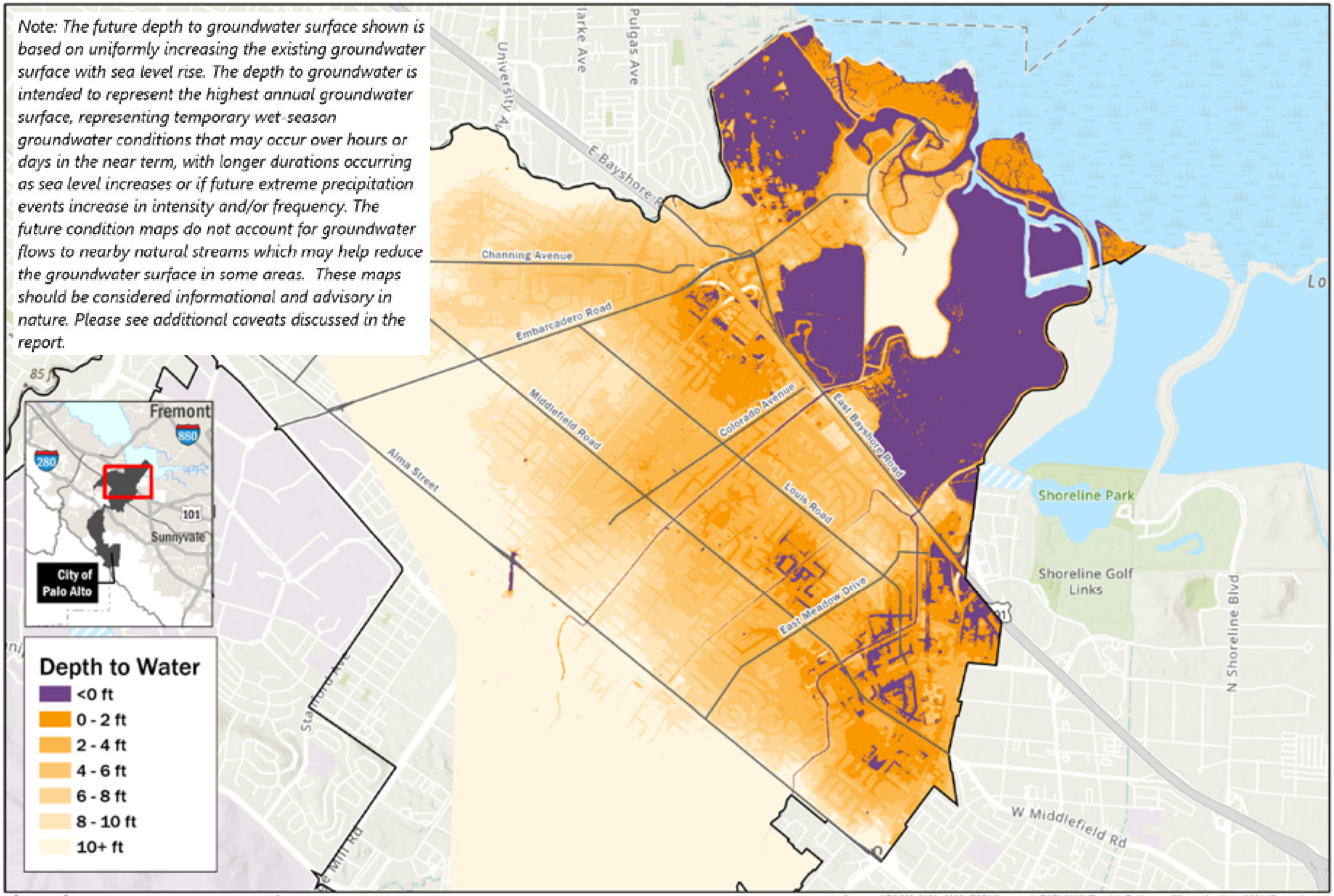


City of Palo Alto

Sea Level Rise Vulnerability Assessment

FIGURE A-11

FUTURE GROUNDWATER *in Response to Precipitation and 36" of Sea Level Rise*

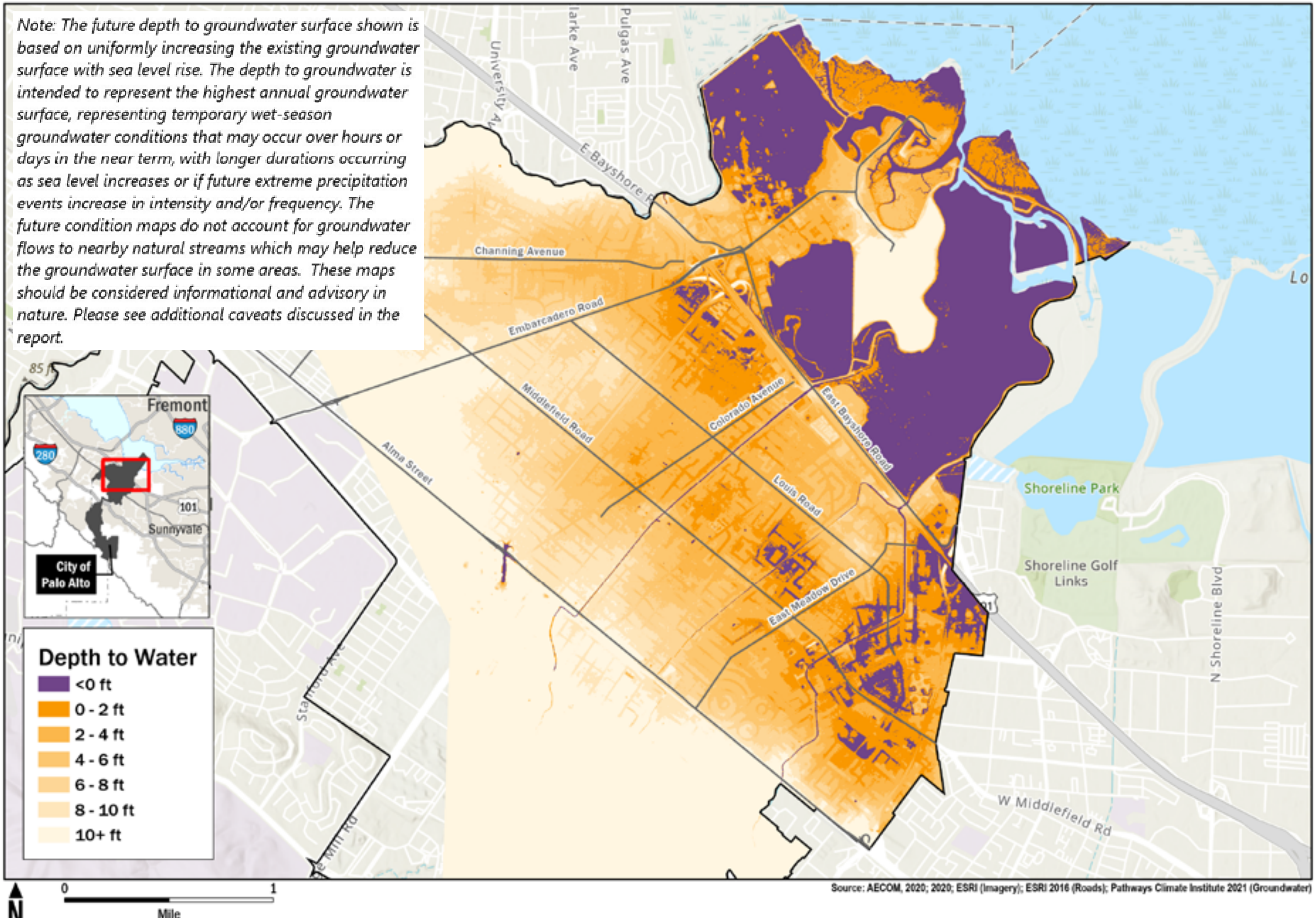


Source: AECOM, 2020; 2020; ESRI (Imagery); ESRI 2016 (Roads); Pathways Climate Institute 2021 (Groundwater)

City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-12

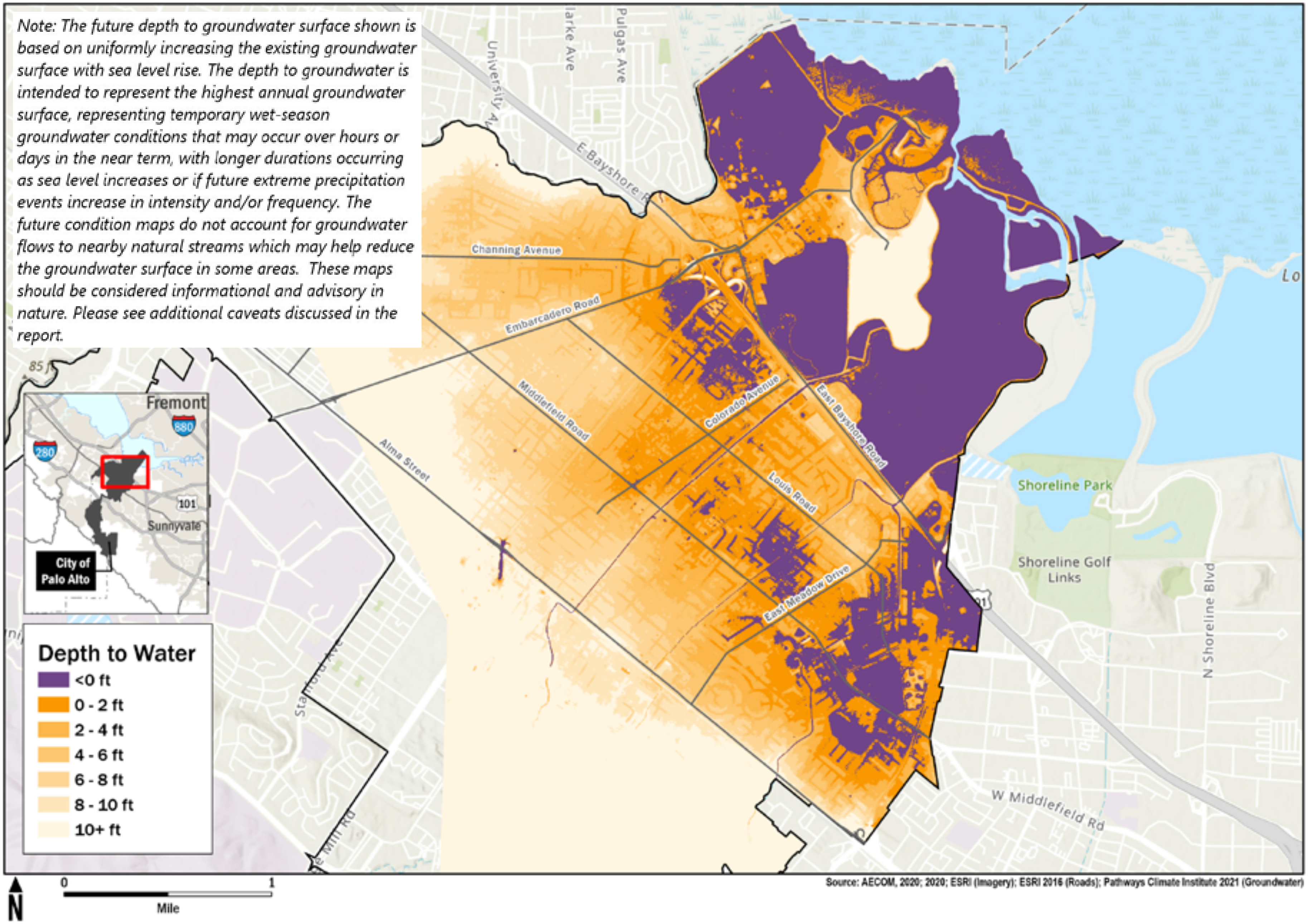
FUTURE GROUNDWATER *in Response to Precipitation and 48" of Sea Level Rise*



City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-13

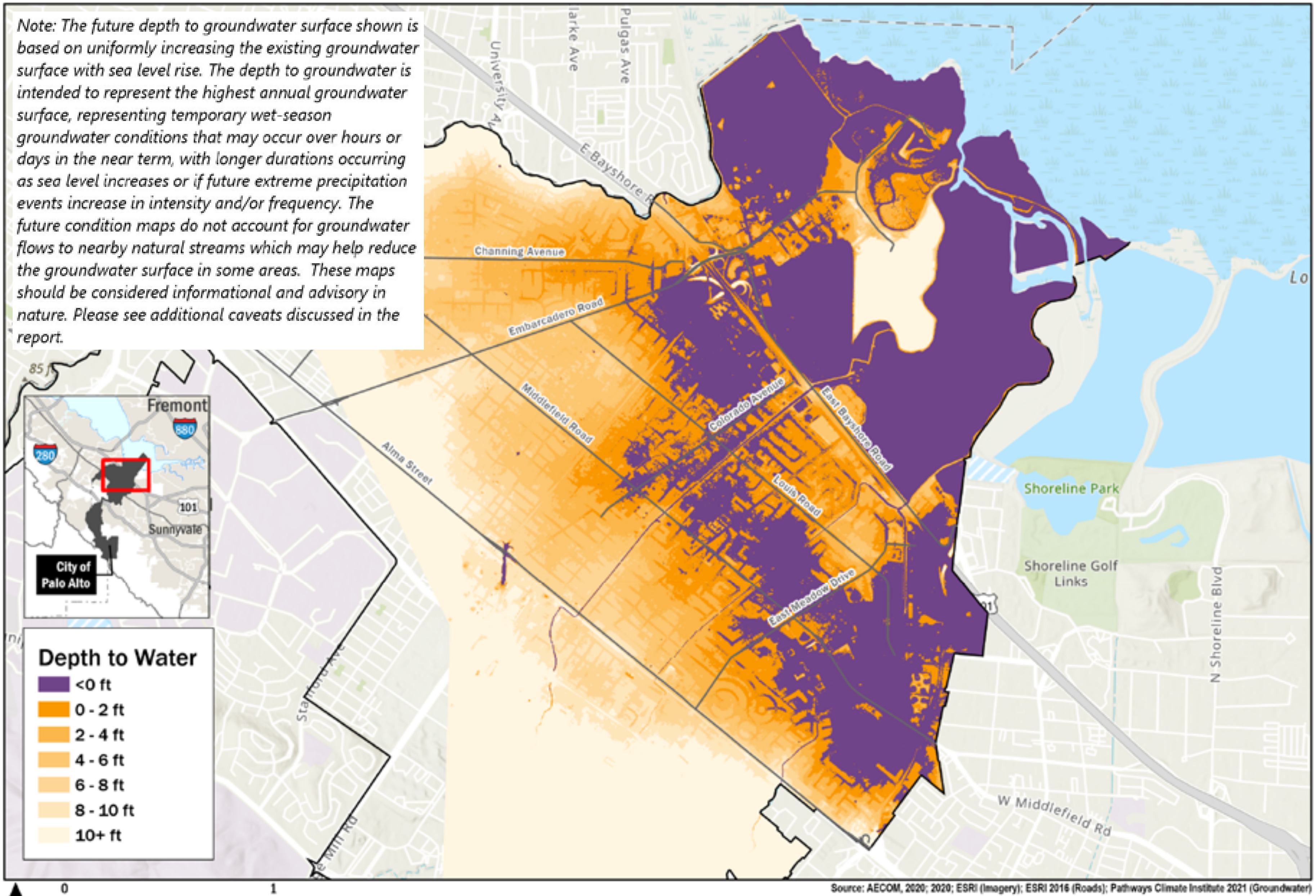
FUTURE GROUNDWATER *in Response to Precipitation and 52" of Sea Level Rise*



City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-14

FUTURE GROUNDWATER *in Response to Precipitation and 66" of Sea Level Rise*



Source: AECOM, 2020; 2020; ESRI (Imagery); ESRI 2016 (Roads); Pathways Climate Institute 2021 (Groundwater)

City of Palo Alto
Sea Level Rise Vulnerability Assessment

FIGURE A-15

FUTURE GROUNDWATER *in Response to Precipitation and 84" of Sea Level Rise*

A.4.1 Comparison with USGS Shallow Groundwater Mapping

To address to the need for better information on the response of shallow groundwater to sea level rise, two approaches were developed for the Bay Area. An in-depth comparison of the two approaches is available on the ART program website[5]. The City of Palo Alto's assessment relies on the regional rapid assessment approach developed by Plane et al. (2019), refined to better account for local conditions by May et al. (2020). This approach aligns the ART program and the sea level rise and coastal storm mapping presented within the ART Shoreline Flood Explorer (Vandever et al. 2017) and the Bay Adapt Platform[6] for supporting faster, better, and more equitable adaptation to a rising Bay. The May et al. (2020) approach focuses on characterizing the shallow groundwater table at its highest elevation in response to wet years when emergent groundwater is first likely to occur. This approach is data driven, or empirical, based on a large network of monitoring well observation, geotechnical soil borings, and local knowledge. The resultant mapping represents a temporary or episodic condition that would occur sporadically in response to heavy precipitation during wet years (as opposed to drought years when the shallow groundwater table is generally farther below the ground surface) for a duration of hours to days in the near term, and increasing in duration over time to days, weeks, and months.

A.4.2 Assumptions and Caveats

As noted in Section A.3.1 for existing conditions, groundwater flow is incredibly complex, and the conservative approaches used in this assessment are considered approximate but reasonable. All the caveats in Section A.3.1 apply for the future condition mapping. Additional caveats include:

- The assessment does not consider potential increases in future extreme precipitation that are likely to occur as the climate changes. Bay Area precipitation is likely to remain extremely variable, with periods of prolonged droughts and periods with extreme wet winters. Future condition atmospheric river events coupled with extratropical cyclones, which generally bring the bulk of California's rainfall, are likely to become more extreme (Ralph et al. 2012, Polade et al. 2017, Lamjiri et al. 2018, Zhang et al. 2019, Patricola et al. 2022), and would therefore result in a higher wet season groundwater table elevation than projected in this assessment.
- This assessment does not consider the potential for groundwater discharge into natural streams and tributaries (during drier periods when they have conveyance capacity) which could mitigate a portion the rise in the groundwater table in response to sea level rise.
- The assessment does not consider land subsidence that could increase in low-lying coastal areas due to the soil collapse that can occur between longer drought periods and more extreme wet periods, and due to increased groundwater pumping. Shirzaei and Bürgmann (2018) have characterized historical rates of subsidence, and this is captured

---

[5] https://www.adaptingtorisingtides.org/wp-content/uploads/2020/03/GW_ModelComparison_Compendium_ADA.pdf

[6] https://www.bayadapt.org/

within the digital elevation model for existing conditions. However, projected rates of future land subsidence have not been developed at this time. The digital elevation model used in the assessment is based on existing conditions. Future land use changes are likely to result in changes to ground surface elevations and groundwater flow that are not considered.

- Future mitigation and adaptation efforts to depress the high groundwater surface, such as additional groundwater pumping, dewatering, or other measures, are not considered.
- At present, pumped groundwater flow is treated in place and discharged into the City's stormwater conveyance system. As the need for dewatering increases over time (in area, volume, and frequency), groundwater treatment needs will increase, and the volume of treated groundwater could strain the City's stormwater conveyance system and further reduce its ability to convey stormwater during a heavy precipitation event, further exacerbating both emergent groundwater flooding and stormwater flooding during wet years.

A.5 Contaminants

The City of Palo Alto is underlain with a deep groundwater aquifer and a shallow unconfined layer of groundwater. The shallow layer slowly percolates through layers of clay and recharges the deep-water aquifer over time. As part of the Northwest County Recycled Water Strategic Plan, the City examined using recycled and treated water to intentionally recharge the deep-water aquifer to augment an emergency supply of water in the event the municipal supply is reduced due to drought or emergency conditions. This potable water may also be needed in the future to support the City's longer-term demand for municipal water If the water quality of the shallow groundwater layer is poor or contaminated, this could impact the water quality and/or treatments needs of water in the deeper aquifer.

The City completed an assessment in 2018 that identified contaminated areas to avoid for deep aquifer recharge purposes and recommended continued monitoring of the contaminated sites (City of Palo Alto and Santa Clara Valley Water District 2018). The locations where contaminants were measured underground, either in the existing soils or within shallow groundwater are shown in Figure A-16. Over 40 contaminants were reviewed, along with their respective concentrations relative to public drinking water standards established by the California Department of Public Health: primary maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and notification levels (NLs) (City of Palo Alto and Santa Clara Valley Water District 2018). These water quality standards were used for comparison purposes only, as the shallow groundwater layer is not an existing potable drinking water source. Ten of the 40 contaminants had concentrations above human health benchmarks (see Table A-1), and these contaminants are the focus of this assessment. The most recent (e.g., 2018 – 2020) monitoring well measurements are also shown in Table A-1.

Continued groundwater water quality monitoring is recommended because the contaminants may migrate and move with the flow of groundwater. The contaminants are generally tightly adsorbed to the soils, so the contaminants move more slowly than the flow of the groundwater layer itself. As the shallow groundwater table rises in response to sea level rise, the natural rise and fall of the layer could enhance mobilization of contaminants upwards, including into enclosed subgrade spaces such as basements, and the contaminants could emerge aboveground creating an environmental and human health hazard. When emergent groundwater ponds on the surface with a high concentration of contaminants, these chemicals could be ingested by pets and wildlife. The contaminants could remain in the upper layers of the soil as the groundwater table subsides in the summer months.

If vapor-forming anthropogenic chemicals (e.g., petroleum hydrocarbons and chlorinated solvents) are mobilized upwards in areas with sewers, drainpipes, subgrade enclosed spaces, or above grade structures, these chemicals could pose threats to indoor air quality via vapor intrusion pathways into an overlying building. An example of a vapor intrusion pathway is through connected sewer lines in areas with contaminated soil and/or groundwater (Beckley and McHugh 2020). Depending on the contaminant concentration, these vapors can be harmful to humans living and working in buildings experiencing vapor intrusion. Remediation methods, such as soil vapor extraction and/or air sparging[7], may be required (EPA 2018). For new construction, a soil vapor barrier and vent system would be required to support the release of the chemical vapors higher into the air column instead of at ground level. Vapor barrier and vent systems must be monitored frequently. A failed vapor barrier could rapidly lead to indoor air quality concerns.

Metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and persistent organic pollutants such as herbicides can also flow into wetlands at the bottom of the City's topographic slope. A groundwater rises, it is possible that more of these chemicals will be mobilized and flow towards the Bay. Rising groundwater may also mobilize more nutrients and carry them to the nearshore environment, potentially resulting in an increased frequency and size of harmful algal blooms in warming Bay waters. These concerns would impact Bay ecosystems and should be included in a future study of contamination risks related to sea level rise, flooding, and rising groundwater.

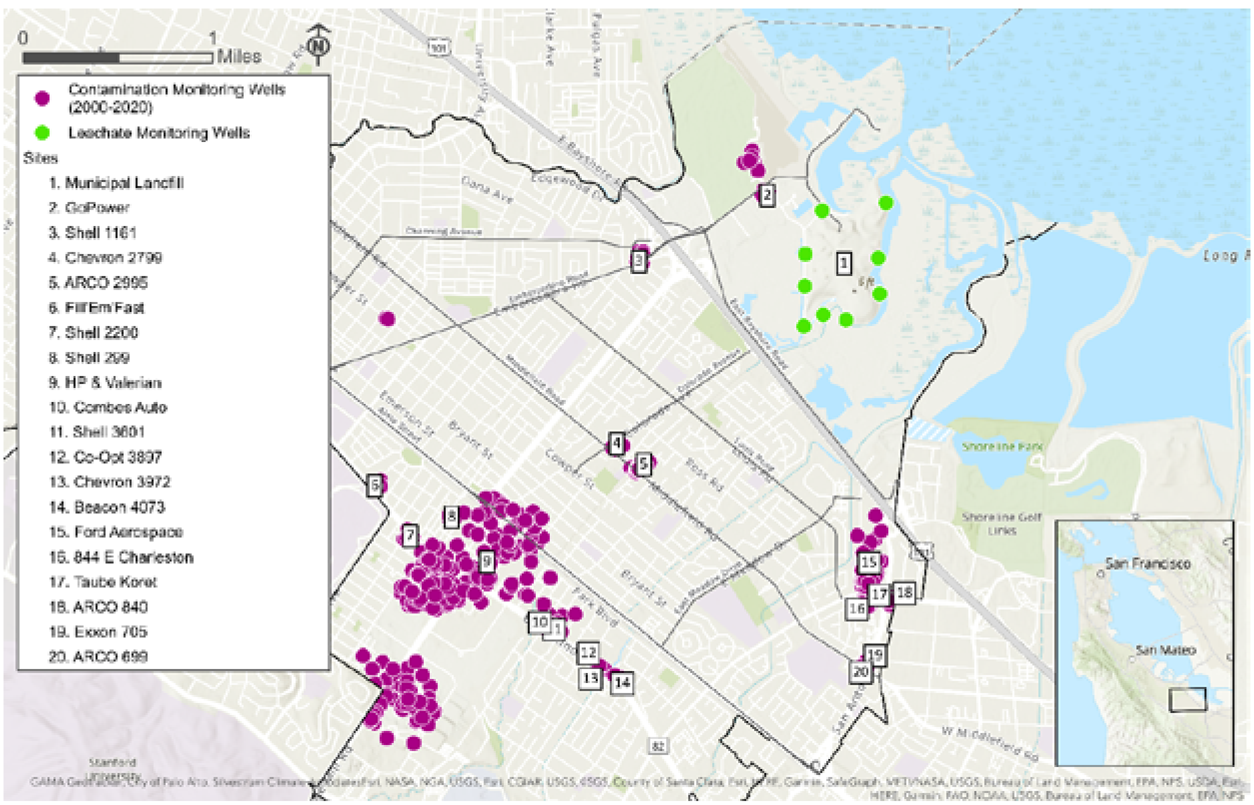
The active monitoring well locations and the associated sites are shown on Figure A-16. The information on the responsible facilities, contaminants of concern, contaminant concentrations, remediation methods, and RWQCB status (e.g., active or closed) presented in this section are from publicly available RWQCB reports.

Table A-2 identifies sites where the shallow groundwater table could become within six feet of the ground surface as sea level rises, and where groundwater could become emergent during a wet year in response to the sea level rise. Many contaminants could pose direct threats to human health if the contaminant reaches subgrade areas such as basements, sewer lines, or other potential underground pathways that could allow volatile contaminants to reach indoor inhabited spaces. Most subgrade infrastructure is within six to ten feet of the groundwater surface. Other non-volatile contaminants could pose threats to human health and wildlife if

[7] Air sparging is a technique to remediate contaminated soils by forcing air through the soil column and venting through a soil vapor extraction system to capture and vent contaminant (VOC) laden air as it rises to the unsaturated soil zone (McCann et al. 1994, Braida and Ong 2000, Reddy and Tekola 2004).

contaminated groundwater becomes emergent. Therefore, for each facility noted in Table A-2 both benchmark groundwater surface elevations should be considered.

Table A-3 identifies sites that could be directly inundated by sea level rise (in the absence of a levee or other sea level rise adaptation measure). The contaminants associated with the legacy Ford Aerospace properties as well as the adjacent Arco 840 site, present an interesting dynamic between Table A-2 (emergent groundwater) and Table A-3 (sea level rise inundation). In general, if an area is inundated by sea level rise (in the absence of a levee or other adaptation measure), it is expected that this area would also exhibit emergent groundwater. However, groundwater extraction has been occurring in this area at rates of 70 to 90 gallons per minute since the 1960s to address contaminated groundwater associated with legacy land uses. The effect of this pumping on the overall groundwater surface is captured in the existing and future conditions mapping since the mapping is based on observed groundwater surface measurements. The lack of emergent groundwater in this area at earlier sea level rise scenarios is a clear indication that the long-term pumping efforts at the Ford Aerospace properties have depressed the shallow groundwater surface.



Source: (City of Palo Alto and Santa Clara Valley Water District 2018, SWRCB 2020)

Figure A-16 Groundwater Monitoring Well Locations

It should also be noted that if a contaminated site becomes emergent *and* it is directly inundated by sea level rise, the contamination could be mobilized across a much wider area due to the natural rise and fall of the tides. However, it is possible that the contamination present within each site could be fully remediated or reduced below concentrations known to cause environmental and human health harm before these levels of sea level rise are reached. The following sections provide additional detail on the plumes and their current remediation status.

Table A-2 shows when each plume that could either have groundwater within six feet of the surface, or when groundwater can become emergent during a wet year in response to the sea level rise scenarios.

Table A-2 Sites with Emergent Groundwater

No	Facility		Sea Level Rise Scenario							
			12”	24”	36”	48”	52”	66”	77”	84”
1	Municipal Landfill	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	*	*	*	*	*	*	*
2	GOPOWER	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	Y	Y	Y	Y	Y	Y	Y
3	Shell 1161	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	Y	Y	Y	Y	Y
4	Chevron 2799	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	–	–	Y	Y	Y
5	ARCO 2995	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	*	*	*	*	*	Y	Y
6	Fill’Em Fast	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
7	Shell 2200	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
8	Shell 299	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
9	HP & Varian	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
10	Combes Auto	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
11	Shell 3601	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
12	Co-Opt 3897	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
13	Chevron 3972	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
14	Beacon 4073	GW within 6 ft	–	–	–	–	–	–	–	–
		Emergent GW	–	–	–	–	–	–	–	–
15	Ford Aerospace	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	Y	Y	Y	Y	Y
16	844 E Charleston	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	–	–	Y	Y	Y
	Taube Koret	GW within 6 ft	–	Y	Y	Y	Y	Y	Y	Y

Attachment A
Shallow Groundwater Assessment and Maps

No	Facility		Sea Level Rise Scenario							
			12"	24"	36"	48"	52"	66"	77"	84"
17		Emergent GW	–	–	–	–	–	–	–	Y
18	ARCO 840	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	–	–	Y	Y	Y
19	Exxon 705	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	–	–	Y	Y	Y
20	ARCO 699	GW within 6 ft	Y	Y	Y	Y	Y	Y	Y	Y
		Emergent GW	–	–	–	–	*	Y	Y	Y

* Less than 5% of the area near the well location could have emergent groundwater
Y = More than 5% of the site has emergent groundwater, the percentage increases with higher amounts of sea level rise

Table A-3 Sites Inundated by Sea Level Rise

No	Facility	Sea Level Rise Scenario							
		12"	24"	36"	48"	52"	66"	77"	84"
1	Municipal Landfill	–	–	Y	Y	Y	Y	Y	Y
2	GOPOWER	–	–	Y	Y	Y	Y	Y	Y
3	Shell 1161	–	–	Y	Y	Y	Y	Y	Y
4	Chevron 2799	–	–	–	–	–	–	–	*
5	ARCO 2995	–	–	Y	Y	Y	Y	Y	Y
6	Fill'Em Fast	–	–	–	–	–	–	–	–
7	Shell 2200	–	–	–	–	–	–	–	–
8	Shell 299	–	–	–	–	–	–	–	–
9	HP & Varian	–	–	–	–	–	–	–	–
10	Combes Auto	–	–	–	–	–	–	–	–
11	Shell 3601	–	–	–	–	–	–	–	–
12	Co-Opt 3897	–	–	–	–	–	–	–	–
13	Chevron 3972	–	–	–	–	–	–	–	–
14	Beacon 4073	–	–	–	–	–	–	–	–
15	Ford Aerospace	–	–	Y	Y	Y	Y	Y	Y
16	844 E Charleston	–	–	–	Y	Y	Y	Y	Y
17	Taube Koret	–	–	–	Y	Y	Y	Y	Y
18	ARCO 840	–	–	Y	Y	Y	Y	Y	Y
19	Exxon 705	–	–	–	–	–	–	–	–
20	ARCO 699	–	–	–	–	–	–	–	–

* Less than 5% of the area near the well locations could be inundated by sea level rise
Y = more than 5% of the site could inundated by sea level rise, the percentage increases with higher amounts of sea level rise

A.5.1 Palo Alto Municipal Waste Landfill

The Palo Alto Municipal Landfill is a 126-acre closed landfill bordering Mayfield Slough and tidal salt marsh habitat (see Figure A-17). This site was purchased for by the City of Palo Alto in 1904 for residential waste landfill, and in 1914 a garbage incinerator was built. The City operated the incinerator and used the incinerator waste as fill for the expansion of Embarcadero Road into the baylands until the 1930's when the incinerator was closed, and the airport and sewage treatment plant were built. The landfill was then operated as a Class III non-hazardous waste landfill from 1954 until it was closed in 2011.

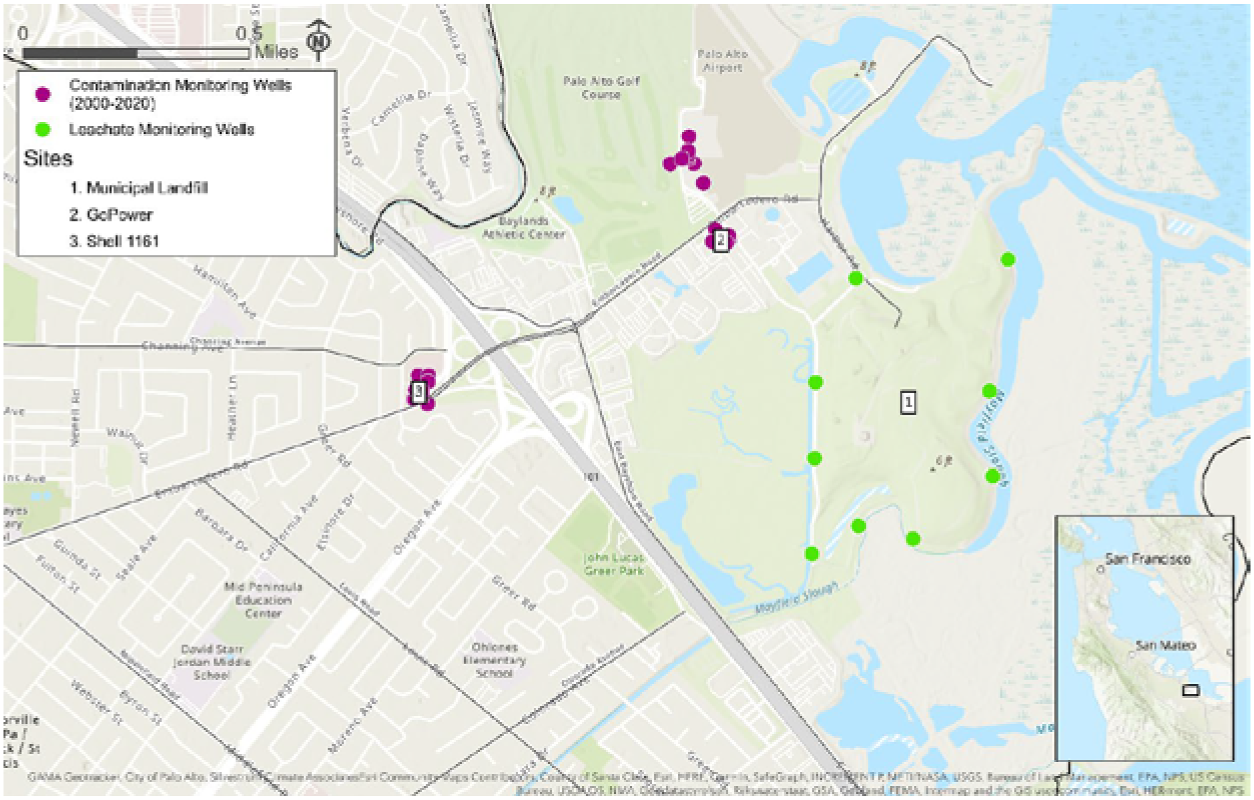


Figure A-17 Monitoring Wells and Contaminant Site Locations

Due to its age, this landfill was not designed using today's standards for landfill siting, design, and operations. In 1990, a leachate collection and removal system was installed to collect liquids from the waste mass within the landfill and convey liquids to the Regional Water Quality Control Plant for treatment. This system continues to operate, and in 2016, nearly 3.5 million gallons of leachate were extracted and treated (Golder Associates Inc. 2017). In 2015, an evapotranspiration cover was placed over the landfill to minimize the percolation of rainwater into the landfill. This cover stores rainwater until it is either transpired through vegetation or evaporated from the soil surface of the cover material.

The layer underneath the landfill is six to 16 feet of Younger Bay Mud, a soft unconsolidated deposit of silt and clay, which is underlain by Older Bay Mud, a very stiff to firm clay. Two zones of sand have been identified within the low-permeability Bay Mud, one at 20 feet below mean sea level (MSL) and one at 40 feet below MSL. Surface and shallow groundwater occur in the tidal marsh environment surrounding the landfill, therefore the Bay Mud is saturated within a few feet of the ground surface (Golder Associates Inc. 2017).

The landfill is surrounded by leachate monitoring wells that provide early detection of leachate leakage from the landfill into the surrounding areas. Currently, the only contaminant monitored that has exceeded human health benchmarks is arsenic. However, arsenic is a naturally occurring chemical that is often present in water and soils and background level of arsenic often exceed drinking water standards. The groundwater quality generally resembles nearby Bay waters. No leachate breakthrough or leakage has been observed within the leachate monitoring wells. The leachate collection and removal systems are effective at removing fluids from the area for treatment. However, the pumping needs for this system are likely to increase as sea levels rise. If properly maintained and operated, this system should continue to minimize the risk of contaminants leaking into the surrounding area from the landfill as sea levels rise.

Under existing conditions, the landfill is located in an area of limited wave hazards, and therefore there is minimal risk of wave-induced erosion along the landfill's perimeter. The existing FEMA Flood Insurance Rate maps place the landfill in an area with a FEMA special flood hazard designation of Zone AE (EL 11), which means the one-percent annual chance coastal flood elevation could reach an elevation of 11 feet NAVD88, and the AE designation means there is limited wave activity. However, most of the landfill is above an elevation of 11 feet NAVD88 and is unlikely to be inundated. The northern edge of the landfill is adjacent to a special flood hazard designation of Zone VE (El 11), where the VE designation is associated with a higher potential for wave hazards during a one-percent annual chance event. Although there is limited risk of wave-induced erosion today, if the surrounding wetlands do not keep pace with sea level rise (i.e., if the wetlands drown and the area becomes open water), there could be a future risk of wave-induced erosion along some portions of the landfill's perimeter. The presence or absence of wave hazard protection along the landfill perimeter was not assessed as part of this study.

Source: https://msc.fema.gov/

Figure A-18 Federal Emergency Management Agency Flood Insurance Rate Panel

A.5.2 GOPOWER 1890 Embarcadero Road

This small, contaminated site is associated with an underground storage tank that contained gasoline located at 1890 Embarcadero Road (see Figure A-17). This site has multiple contaminants of concern associated with gasoline, including Benzene, Toluene, and MTBE. Six monitoring wells are located around this site.

No remediation has been completed. The contaminants were allowed to dissipate via natural attenuation. The RWCQB closed the case in May 2008, and no monitoring has been reported to the RWQCB since 2007. In October 2007, all contaminants were reported as non-detectable except for MTBE and TDS. The last recorded measurement of MTBE was 170 µg/L in October 2007, above the human health benchmark of 13 µg/L. An adjacent well recorded 0.8 µg/L at the same time, and all other wells at this location did not detect MTBE. The last measurement of TDS reported to the RWQCB in 2007 was 26,200 mg/L, with the adjacent wells recording values in the range of 1,300 to 13,000 mg/L.

This site could become emergent during wet years with 24 inches of sea level rise, and groundwater is within six feet of the surface today. However, it is possible that limited contamination remains at this location. Additional monitoring is required to verify the current depth to groundwater and the presence of any remaining contamination remains.

A.5.3 Shell 1161 Embarcadero Road

This location has soil and groundwater contamination associated with underground storage tanks at the Shell gas station at 1161 Embarcadero Road (see Figure A-17). The contaminants of concern associated with gasoline at this location include Benzene, MTBE, PCE, TCE, and other petroleum hydrocarbons. Two remedial actions were completed. Groundwater was pumped and treated from 1993 to 2004 and from 1999 to 2001. Groundwater monitoring was last submitted to the RWCQB in June 2004, and the case was closed by the RWQCB in December 2004.

MTBE values above the human health benchmark (13 µg/L) were recorded at three of the seven wells in June 2004, with the highest measurement reported (110 µg/L) at a well across the street from the gas station, and two wells on the Shell facility reporting 19 and 57 µg/L. The remaining four wells did not detect the presence of MTBE. The presence of the highest contamination across the street indicates that the contaminants may have migrated, but additional site investigations and monitoring has not been completed.

A portion of this site could become emergent with 48 inches of sea level rise, with more of the site becoming emergent with 66 inches of sea level rise during wet years. However, the last groundwater measurements were collected during a period of active groundwater pumping, and it is possible that the groundwater elevation is higher today (i.e., the measurement may have been impacted by the groundwater extraction) and that the groundwater surface is within six feet of the surface today. This site could be inundated with 36 inches of sea level rise; therefore, it is possible that emergent groundwater could occur with 36 inches of sea level rise. It is possible that limited contamination remains at this location. Additional monitoring is recommended.

A.5.4 Chevron 2799 Middlefield Road

Thirteen groundwater monitoring wells and five soil vapor monitoring wells are located in and around the Chevron gas station near former underground storage tanks containing gasoline (see Figure A-19). The contaminants of concern associated with gasoline at this location include Benzene, Toluene, and MTBE.

Monitoring and remediation efforts began in 1998, and over time 19 soil borings have been collected to investigate contaminant migration. Soil vapor monitoring was expanded to include adjacent commercial properties. This site remains an open investigation site, although no remediation actions have been reported to date based on publicly available records.

Benzene concentrations above the human health benchmark (one µg/L) have been observed as recent as 2019 in three of the 13 monitoring wells, although concentrations are well below the maximum values observed between 2004 and 2006 in the range of 100 to 300 µg/L. MTBE and Toluene are currently not detected at any of the 13 monitoring wells.

This site could become emergent with 66 inches of sea level rise during wet years. However, it is possible that limited contamination remains at this location and groundwater is within six feet of the surface today. Site monitoring and evaluation is ongoing.

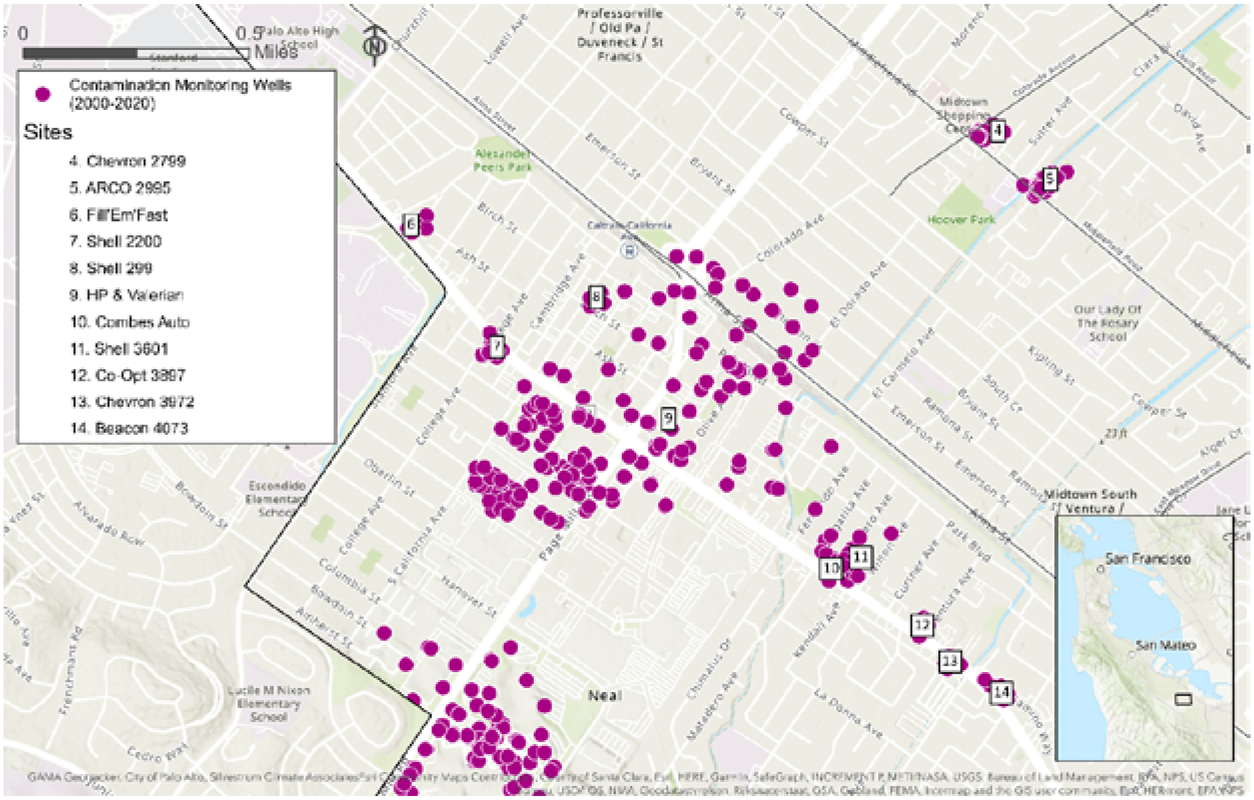


Figure A-19 Monitoring Wells and Contaminant Site Locations

A.5.5 ARCO 2995 Middlefield Road

This site is a former ARCO gas station (see Figure A-19). The contaminants of concern at this location associated with gasoline include Benzene, Toluene, and MTBE.

Extensive monitoring has occurred at this location with 22 groundwater monitoring wells. Multiple remediation efforts have been completed, including soil excavation and removal in 1988, free product removal between 1990 and 1992, groundwater pumping and treatment from 1992 to 1995, 2002 to 2004, and 2004 to 2005. The underground storage tanks and additional contaminated soil were removed in 2005.

High Benzene and MTBE concentrations were observed until 2006. All measurements in 2009 were either non detectable or below human health benchmarks. Groundwater monitoring ceased in 2009, and the RWQCB closed this case May 2011.

Although a small portion (less than one-percent by area) of this site could become emergent with 24 inches of sea level rise, most of this site is unlikely to become emergent until 77 to 84 inches of sea level rise during wet years. However, it is likely that limited contamination remains at this location and that groundwater is within six feet of the surface today.

A.5.6 Fill'Em Fast 1795 El Camino Real

A former Fill'Em Fast gas station was located at this site (see Figure A-19) and the underground storage tanks were removed in 1986. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Site investigations to characterize the potential soil and groundwater contamination began in 1988. Multiple remediation methods have occurred, including free product removal from 1993 to 1995; pumping and treating groundwater from 1995 to 2000, and 2001 to 2004; soil vapor extraction from 1995 to 2000, and 2002 to 2005; in situ physical and chemical treatment from 1997 to 1998, and 2004 to 2006; and dual phase vapor extraction in 2006.

Toluene and Benzene were last reported to the RWQCB in 2005. Groundwater monitoring for MTBE continued until 2009. No MTBE was detected in the monitoring wells in 2009, and the RWQCB closed this case in May 2010.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. However, it is likely that limited contamination remains at this location.

A.5.7 Shell 2200 El Camino Real

Twenty-one groundwater monitoring wells and numerous other monitoring activities have occurred on and around the Shell gas station located at 2200 El Camino Real (see Figure A-19) beginning in 1983. A 550-gallon underground storage stank was removed and replaced in 1987, and a second 550-gallon underground storage tank was removed in 2006. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

A groundwater pump and treat program was in place between 1992 and 2007, extracting and treating over 3.6 million gallons of groundwater and removing 55 pounds of petroleum hydrocarbons, 2.8 pounds of Benzene, and 20 pounds of MTBE. Soil vapor extraction was also performed.

Remediation efforts were completed in 2007, and groundwater monitoring continued until 2013. Two wells recorded MBTE concentrations of 15 and 17 µg/L in 2013, just above the human health benchmark of 13 µg/L. No Benzene was detected in 2013. The RWQCB closed this case in November 2014.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. Additional monitoring is recommended.

A.5.8 Shell 299 S California Ave

This location was occupied by a brewery between 1884 and 1935, and a Shell gas station between approximately 1939 to the early 1970s (see Figure A-19). The brewery reportedly had a 1,200-gallon oil underground storage tank, and Shell had three 1,000-gallon gasoline underground storage tanks. No information was found regarding the removal of the tanks; however, they were likely removed when the building at this location was constructed.

Subsurface explorations in 1998 detected high concentration of petroleum hydrocarbons, including Benzene and Toluene. MTBE was not detected. No remediation has occurred on site, and groundwater monitoring continued until 2014. Benzene concentrations of 4,300 µg/L and Toluene concentrations 3,700 µg/L were observed in September 2014 (the human health benchmarks are one µg/L and 150 µg/L, respectively). No measurements are reported after September 2014. The RWQCB closed the case in September 2016.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. However, additional monitoring of this location is recommended.

A.5.9 Hewlett Packard and Varian Associates COE Sites

A large, contaminated site is located on both sides of the Oregon Expressway (see Figure A-19) referred to as the California-Olive-Emerson (named for the local streets) or "COE" site. Hewlett Packard and Varian Associates are the responsible parties for the contamination dating back to their manufacturing facilities which began operation in the 1950s. Although the manufacturing facilities have been replaced with office buildings and other facilities, legacy contamination remains. The primary contaminants of concern are TCA, PCE, TCE, and other chlorinated hydrocarbons.

Portions of this site are on the EPA's Superfund National Priority list, while some portions of this site are below the Superfund threshold. The RWQCB is currently the regulatory agency for the entire location. Multiple remediation methods have been used to reduce and degrade the contaminants across this site over the past three decades, including enhanced reductive dechlorination and in situ chemical oxidation, groundwater pumping and treatment, and dual phase soil vapor extraction. Contaminated soil has also been excavated and disposed of offsite. Vapor intrusion barriers are required for new developments, and vapor intrusion monitoring has been performed in buildings and residences throughout and adjacent to the site area.

The COE site includes an extensive network of groundwater monitoring wells, soil vapor monitoring wells, and other monitoring activities. Although contamination concentrations have trended downward, numerous wells have recorded concentrations above human health benchmarks between 2018 and 2020. The extent of the contaminated area appears larger than characterized in 2018 based on recent RWQCB records and the location of additional monitoring wells, as shown on Figure A-19 (City of Palo Alto and Santa Clara Valley Water District 2018).

The COE site is not projected to become emergent until after 84 inches of sea level rise during wet winters. The status of the contamination is likely to change significantly before this level of sea level rise occurs. Monitoring and remediation efforts are ongoing.

A.5.10 Combes Auto Repair 3585 El Camino Real

This site contained a former auto repair service and gas station (see Figure A-19). The underground storage tanks were removed in 1986 and an unauthorized release of gasoline from the tanks was reported to the RWQCB. The contaminants of concern at this location are Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Contaminated soil was excavated to a depth of 12 feet below the ground surface and disposed of offsite in 1986. Soil vapor extraction and air sparging were completed from 1992 to 1996, 2002, and 2013 to 2014.

Maximum concentrations of MTBE of 31,000 µg/L were reported in 2001, and values decreased below human health benchmarks in 2014. Maximum concentrations of Toluene of 1,660 µg/L were recorded in 2011, and concentrations decreased below the human health benchmark (150 µg/L) in 2015. Maximum concentrations of Benzene of 4,100 µg/L were reported in 2007. The last reported measurements in 2015 were five to 150 µg/L, which remain over the human health benchmark of one µg/L. No monitoring records are publicly available after 2015. The RWQCB closed this case in August 2016.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. However, additional monitoring of this location is recommended to assess Benzene concentrations.

A.5.11 Shell 3601 El Camino Real

Four underground storage tanks were removed and replaced with three new tanks in 1985 at this Shell gas station (see Figure A-19). One if these tanks was replaced again in 2006. Subsurface investigations began in 1985 to characterize potential contaminated soil and groundwater. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Groundwater was pumped and treated from 1989 to 1996 and 2000 to 2004; soil vapor extraction was completed between 1992 and 1996; and in situ bioremediation was completed in 1997. Groundwater monitoring continued until December 2014. Toluene concentrations were below human health benchmarks in 2014. The last reported concentrations of Benzene ranged from two to 1,000 µg/L in December 2014 (above the human health benchmark of one µg/L); and the last reported concentrations of MTBE ranged from non-detectable levels to 40 µg/L in December 2014 (above the human health benchmark of 13 µg/L). This case was closed by the RWQCB in July 2016.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. Additional monitoring of this location is recommended to assess Benzene and MTBE concentrations.

A.5.12 Co-Opt Service Station 3897 El Camino Real

This location was occupied by a Co-Opt gas station until 1996 and is now operated as a Chevron gas station (see Figure A-19). An unauthorized release of gasoline was reported to the RWQCB in 1991. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Remediation actions completed include soil excavation, groundwater pumping and treatment, and soil vapor extraction beginning in 1996. RWQCB publicly available records do not report the duration of the remediation actions. Benzene concentrations were last reported to the RWQCB in 2005, with concentrations ranging from non-detectable to 53 µg/L (above the human health benchmark of one µg/L). Concentrations of Toluene were either non-detectable or below human health benchmarks in 2005, and concentrations of MTBE ranged from two to 99 µg/L. Four out of eleven monitoring wells reported MTBE concentrations above human health benchmarks in 2005. Groundwater monitoring was discontinued in 2005. The RWQCB closed this case in September 2007.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. Additional monitoring of this location is recommended to assess Benzene and MTBE concentrations.

A.5.13 Chevron 3972 El Camino Real

A Chevron gas station was previously located at this site, and it is currently operated as a Valero gas station (see Figure A-19). An unauthorized release of gasoline was reported to the RWQCB in 1987. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

No remediation actions are reported. Groundwater monitoring continued until 2004. One well in the median of El Camino Real reported MTBE concentrations of 41 µg/L in 2004, above the human health benchmark of 13 µg/L. Benzene and Toluene concentrations were not detected in 2004. The RWQCB closed this case in February 2006.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. Additional monitoring of this location is recommended to assess MTBE concentrations. Additional wells may be necessary to assess if the contaminants have migrated.

A.5.14 Beacon 4073 El Camino Real

A Beacon gas station was formerly located at this site (see Figure A-19). An unauthorized release of gasoline was reported to the RWQCB in 1988. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Multiple remediation actions were completed, including soil excavation between 1992 and 1993; groundwater pumping and treatment between 1995 and 1997; soil vapor extraction from 1995 to 1998; in situ physical and chemical treatment between 1997 and 2003; and ex situ physical and chemical treatment between 1998 and 2003.

Groundwater monitoring continued until 2003. Benzene concentrations of 27 µg/L were reported at one monitoring well in 2003. The remaining ten monitoring wells reported non-detectible levels of Benzene. MTBE and Toluene concentrations were below human health benchmarks. The RWQCB closed this case in November 2004.

This site is unlikely to become emergent until after 84 inches of sea level rise during wet years. Additional monitoring of this location is recommended to assess Benzene concentrations.

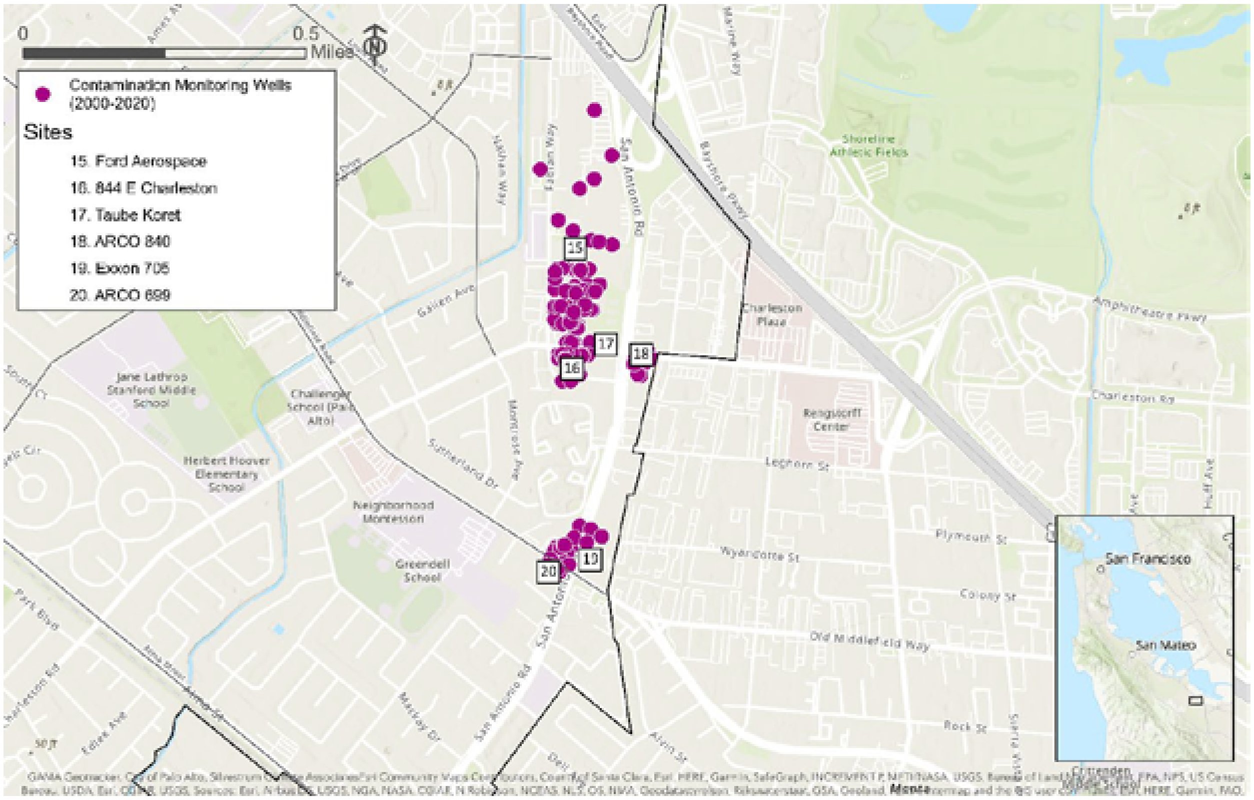


Figure A-20 Monitoring Wells and Contaminant Site Locations

A.5.15 Ford Aerospace 3825 Fabian Way

The Ford Aerospace Corporation leased this site from 1959 to 1990 and operated a research and development facility at this location (see Figure A-20). Space Systems / Loral Aerospace purchased the assets of the Ford Aerospace Corporation and continue to use the site for the research and development of communications equipment. However, the Ford Motor Company maintains the responsibility for site investigation and remediation efforts. The site is contaminated with chlorinated solvents, including TCE, PCE, and volatile organic compounds.

The maximum recent concentration of PCE observed on site was 27,000 µg/L (measured in 2006) and the maximum concentration of TCE observed was 110,000 µg/L (measured in 2008). Most of the monitoring wells on site are not active, and measurements have not been submitted to the RWCQB since 2014 (or the measurements are not publicly available), even though measurements above the human health benchmarks were recorded in 2014.

Voluntary remediation efforts, including groundwater pumping and treatment below Building Five have been ongoing since the mid-1960s to minimize the potential for contaminant migration towards the Bayshore Freeway. The extracted groundwater is treated with granular activated carbon absorption to remove PCE and discharged to Adobe Creek under a National Pollutant Discharge Elimination System (NPDES) permit. These efforts are expected to continue.

Soils contaminated with PCE along the eastern boundary of the site were excavated, treated, and replaced on site on 1996. In 2006, additional contaminated soils were removed and disposed of offsite. In situ bioremediation was used to treat the remaining contaminated soils and the groundwater to prevent offsite migration. Final site cleanup requirements were issued by the RWCB in 2003.

This site could begin to become emergent with 48 inches of sea level rise during wet years based on depth-to-water measurements collected through 2014. However, the active groundwater extraction efforts may be depressing the groundwater table at this location and there is groundwater within six feet of the surface present today. This site is projected to be almost fully inundated by Bay waters with 36 inches of sea level rise; therefore, it is possible that emergent groundwater could also occur with 36 inches of sea level rise if groundwater extraction is terminated. Remediation efforts are ongoing. More recent monitoring measurements should be collected at this location to assess if TCE and PCE are still above human health thresholds.

A.5.16 844 East Charleston Road

This location was once part of the Ford Aerospace property but is not part of the current Space Systems / Loral Aerospace campus (see Figure A-20). This site is contaminated with TCE, PCE, and volatile organic compounds. Groundwater pumping and treatment occurred between 1999 and 2002, treating nearly 14 million gallons of groundwater and removing approximately 490 pounds of volatile organic compounds. The treated groundwater was re-injected on site.

An enhanced in situ bioremediation program was performed between 2002 and 2007. Additional remediation actions, including soil excavation, may be necessary at this location. Monitoring is ongoing at this location. Measurements from six monitoring wells were submitted in February 2020. PCE was not detected in the six wells, but five of the six wells recoded concentrations of TCE above the human health benchmark, including a maximum concentration of 6,300 µg/L between Fabian Way and San Antonio Road near East Charleston Road.

This site could begin to become emergent with 52 inches of sea level rise during wet years and groundwater is present within six feet of the surface today. However, this site is projected to be nearly fully inundated by Bay waters with 48 inches of sea level rise. It is possible that the groundwater table at this site is depressed due to the ongoing groundwater extraction at the Ford Aerospace property, and emergent groundwater could occur under a lower sea level rise scenario if groundwater extraction is terminated. The status of remediation efforts is uncertain based on publicly available RWQCB records. As of 2007, the potential for vapor intrusion pathways to indoor air had not been evaluated at downgradient properties.

A.5.17 Taube Koret Campus 901 San Antonio Road

This location was part of the Ford Aerospace property from 1959 to 1988 (see Figure A-20). The property was purchased by Sun Microsystems in 1988, and then purchased by the Taube Koret Campus for Jewish Life in 2002. This site is contaminated with TCE, PCE, and volatile organic compounds.

The only remediation effort to date is the installation of a permeable reactive barrier downgradient of the site to mitigate the potential contaminant migration. TCE concentrations as high as 72,000 µg/L were reported in March 2004. To date, the full extent of TCE in the groundwater has not been determined. An upgradient contaminant has also migrated into this location, and Freon contamination has been reported on the Taube Koret Campus.

This site could become emergent with 84 inches of sea level rise during wet years and groundwater will be within six feet of the surface with 24 inches of sea level rise. However, this site is projected to be fully inundated by Bay waters with 48 inches of sea level rise. It is possible that the groundwater table at this site is depressed due to the ongoing groundwater extraction at the Ford Aerospace property, and emergent groundwater could occur under a lower sea level rise scenario if groundwater extraction is terminated. Additional site investigations and monitoring are warranted at this location. This site is still an open case with the RWQCB.

A.5.18 ARCO 840 San Antonio Road

An ARCO gas station is located at this site (see Figure A-20). In 1986, leak detection and monitoring problems were installed for the underground storage tanks. In 1988, one of the underground storage tanks was punctured and an unauthorized release was reported to the RWQCB. In December 1988, all underground storage tanks were removed and replaced. Site investigations and monitoring also began to characterize the extent of potential soil and groundwater contamination. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

In 1993, soil vapor extraction and air sparging tests were completed. These remediation efforts were determined to be infeasible at this site. In 1999, soil and pea gravel were excavated and disposed of offsite. This site is adjacent to the three properties with contaminated soil and groundwater associated with Ford Aerospace (see Section A.5.15, A.5.16, and A.5.17). Concern was raised about the ongoing groundwater extraction at the Ford Aerospace properties, as these activities could cause the contaminated groundwater associated with the gasoline spill to migrate offsite.

Groundwater pumping and treatment began in 2003 and continued through March 2006. Pumping and monitoring efforts were coordinated with the Ford Aerospace properties. Concentrations of Benzene, Toluene and MTBE in 2009 were either non-detectable or below human health thresholds. Groundwater monitoring continued until 2009. The RWQCB closed this case in August 2010.

This site could become emergent with 66 inches of sea level rise during wet years and groundwater is within six feet of the surface today. However, this site is projected to be inundated by Bay waters with 36 inches of sea level rise. It is possible that the groundwater table at this site is depressed due to the ongoing groundwater extraction at the Ford Aerospace property, and emergent groundwater could occur under a lower sea level rise scenario if groundwater extraction is terminated. Additional site investigations and monitoring may be warranted at this location due to its proximity to the Ford Aerospace contamination.

A.5.19 Exxon 705 San Antonio Road

An Exxon gas station was previously operated at this location and is currently operated by Union 76 (see Figure A-20). An unauthorized release of gasoline was reported to the RWQCB in 1988. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Remediation efforts include soil excavation in 1991 and groundwater pumping and treatment from 2000 to 2004. Monitoring wells were expanded to adjacent downgradient properties to assess potential contaminant migration. Toluene concentrations were either non-detectable or below human health benchmarks in 2007. MTBE concentrations were below human health thresholds on the gas station property in 2007, but concentrations exceeded this threshold across San Antonio Road near the location of Crossroads Specialty Foods. MTBE concentrations of 21 µg/L were reported at this location in 2007 (above the human health benchmark of 13 µg/L). Groundwater monitoring continued until 2007. The RWQCB closed this case in December 2008.

This site could become emergent with 66 inches of sea level rise during wet years and groundwater is within six feet of the surface today. Additional site investigations and monitoring are recommended at this location to assess MTBE concentrations, with emphasis on the parcels across the street to check for contaminant migration.

A.5.20 ARCO 699 San Antonio Road

An ARCO gas station is located at this site (see Figure A-20). An unauthorized release of gasoline was reported to the RWQCB in 1985. The contaminants of concern associated with gasoline at this location include Benzene, Toluene, MTBE, and other petroleum hydrocarbons.

Groundwater pumping and treatment from 1991 to 1996 is the only reported remediation effort. Groundwater monitoring continued until 2003. Two monitoring wells, one on the property and one in the median of Middlefield Road appear to have anomalous measurements reported to the RWCQB in 2003, including Benzene concentrations of 11,000 µg/L and 20,000 µg/L, MTBE concentrations of 57,000 µg/L and 55,000 µg/L, and Toluene concentrations of 1,200 and 1,800 µg/L. Other wells on the property reported concentrations that were either non-detectable or below the human health thresholds. The RWQCB closed this case in December 2004.

This site could become emergent with 66 inches of sea level rise during wet years, with a small portion of the site (approximately one percent) with emergent groundwater with 52 inches of sea level rise, groundwater is within six feet of the surface today. Additional site investigations and monitoring are recommended at this location to assess if the anomalous measurements reported in 2003 that were well above human health benchmarks.

A.6 References

Aagaard, B. T., J. L. Blair, J. Boatwright, S. H. Garcia, R. A. Harris, A. J. Micheal, D. P. Schwartz, and J. S. DiLeo. 2016. Earthquake Outlook for the San Francisco Bay Region 2014 – 2043:6. DOI:10.3133/fs20163020

Beckley, L., and T. McHugh. 2020. A conceptual model for vapor intrusion from groundwater through sewer lines. Science of the Total Environment 698:134283. DOI:10.1016/j.scitotenv.2019.134283 https://doi.org/10.1016/j.scitotenv.2019.134283

Befus, K. M., P. L. Barnard, D. J. Hoover, J. A. Finzi-Hart, and C. Voss. 2017. Quantifying the increasing threat of coastal groundwater hazards resulting from sea-level rise. Nature Climate Change

Befus, K. M., P. L. Barnard, D. J. Hoover, J. A. Finzi Hart, and C. I. Voss. 2020. Increasing threat of coastal groundwater hazards from sea-level rise in California. Nature Climate Change 10:946–952. DOI:10.1038/s41558-020-0874-1

Braida, W., and S. K. Ong. 2000. Modeling of air sparging of VOC-contaminated soil columns. Journal of Contaminant Hydrology 41:385–402. DOI:10.1016/S0169-7722(99)00075-3

CADWR. 2015. California's Most Significant Droughts: Comparing Historical and Recent Conditions. State of California Deaprtment of Water Resources

CCC. 2018. Sea Level Rise Policy Guidance Science Update 2018. California Coastal Commission, Sacramento,CA. https://www.coastal.ca.gov/climate/slrguidance.html

Chang, S. W., T. P. Clement, M. J. Simpson, and K. K. Lee. 2011. Does sea-level rise have an impact on saltwater intrusion? Advances in Water Resources 34:1283–1291. DOI:10.1016/j.advwatres.2011.06.006

Chesnaux, R. 2016. Closed-form analytical solutions for assessing the consequences of sea-level rise on groundwater resources in sloping coastal aquifers. Hydrogeology Journal 24:1325–1328. DOI:10.1007/s10040-016-1398-7

City of Palo Alto, and Santa Clara Valley Water District. 2018. Groundwater Assessment and Indirect Potable Reuse Feasibility Evaluation and Implementation Strategy. City of Palo Alto

EPA. 2018. EPA Region 4 Human Health Risk Assessment Supplemental Guidance. https://www.epa.gov/risk/region-4-risk-assessment-contacts

Fowler, C. M. R. 2012. The Modified Mercalli Intensity Scale (abridged version). Pages 654–654 The Solid Earth. DOI:10.1017/cbo9780511819643.023 https://www.usgs.gov/natural-hazards/earthquake-hazards/science/modified-mercalli-intensity-scale?qt-science_center_objects=0#qt-science_center_objects

Golder Associates Inc. 2017. Palo Alto Landfill Second Semi-Annual 2016 Monitoring Report and 2016 Annual Summary. Palo Alto

Grant, A. R. R., A. M. Wein, K. M. Befus, J. F. Hart, M. T. Frame, R. Volentine, P. Barnard, and K. L. Knudsen. 2021. Changes in Liquefaction Severity in the San Francisco Bay Area with Sea-Level Rise. Geo-Extreme 0:308–317. DOI:10.1061/9780784483695.030

Griggs, G., J. Arvai, D. Cayan, D. R, J. Fox, H. A. Fricker, R. E. Kopp, C. Tebaldi, and E. A. Whiteman. 2017. Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust, Sacramento, CA

Holzer, T. L., M. J. Bennett, T. E. Noce, A. C. Padovani, and J. C. Tinsley. 2005. Liquefaction Hazard and Shaking Amplification Maps of Alameda, Berkeley, Emeryville, Oakland, and

Piedmont, California: A Digital Database by Liquefaction Hazard and Shaking Amplification Maps of Alameda, Berkeley, Emeryville, Oakland, and Piedmont, Calif. Bay Area Association of Governments (ABAG) U.S. Geological Survey

Hoover, D. J., K. O. Odigie, P. W. Swarzenski, and P. L. Barnard. 2017. Sea-level rise and coastal groundwater inundation and shoaling at select sites in California, USA. Journal of Hydrology: Regional Studies 11:234–249. DOI:10.1016/j.ejrh.2015.12.055

Knott, J. F., J. M. Jacobs, J. S. Daniel, and P. Kirshen. 2019. Modeling Groundwater Rise Caused by Sea-Level Rise in Coastal New Hampshire. Journal of Coastal Research 35:143–157. DOI:10.2112/jcoastres-d-17-00153.1

Lamjiri, M. A., M. D. Dettinger, F. M. Ralph, N. S. Oakley, and J. J. Rutz. 2018. Hourly Analyses of the Large Storms and Atmospheric Rivers that Provide Most of California's Precipitation in Only 10 to 100 Hours per Year. San Francisco Estuary and Watershed Science 16:1–17. DOI:10.15447/sfews.2018v16iss4art1

Masterson, J. P., and S. P. Garabedian. 2007. Effects of sea-level rise on ground water flow in a coastal aquifer system. Ground Water 45:209–217. DOI:10.1111/j.1745-6584.2006.00279.x

May, C. L. 2020. Rising Groundwater and Sea-Level Rise. Nature Climate Change. DOI:10.1038/s41558-020-0886-x

May, C., M. Mak, E. Harris, M. Lightner, and J. Vandever. 2016. San Francisco Bay Tidal Datums and Extreme Tides Study. Prepared by AECOM for the Federal Emergency Management Agency Region IX and the San Francisco Bay Conservation and Development Commission

May, C., A. Mohan, O. Hoang, M. Mak, and Y. Badet. 2020. The Response of the Shallow Groundwater Layer and Contaminants to Sea Level Rise. Report by Silvestrum Climate Associates for the City of Alameda, California. City of Alameda. DOI:10.13140/RG.2.2.33390.69445

McCann, M., P. Boersma, J. Danko, and M. Guerriero. 1994. Remediation of a VOC-contaminated superfund site using soil vapor extraction, groundwater extraction, and treatment: A case study. Environmental Progress 13:208–213. DOI:10.1002/ep.670130319

NRC. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Academies Press

Nuttle, W. K., and J. W. Portnoy. 1992. Effect of rising sea level on runoff and groundwater discharge to coastal ecosystems. Estuarine, Coastal and Shelf Science 34:203–212. DOI:10.1016/S0272-7714(05)80106-4

OPC. 2010. California Coastal LiDAR Project. Page Data Management. Ocean Protection Council. http://www.opc.ca.gov/2010/01/mapping-californias-coastal-areas/

Patricola, C. M., M. F. Wehner, E. Bercos-Hickey, F. V. Maciel, C. May, M. Mak, O. Yip, A. Roche, and S. Leal. 2022. Future Changes in Extreme Precipitation over the San Francisco Bay Area: Dependence on Atmospheric River and Extratropical Cyclone Events. Weather and Climate Extremes 36. DOI:10.1016/j.wace.2022.100440

Plane, E., K. Hill, and C. L. May. 2017. Minimum Depth to Groundwater for the Coastal San Francisco Bay Area. DOI:10.6078/D1W01Q

Plane, E., K. Hill, and C. L. May. 2019. A Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Driven by Sea Levels Rise in Coastal Cities. Water 2228:8–10. DOI:10.3390/w11112228

Polade, S. D., A. Gershunov, D. R. Cayan, M. D. Dettinger, and D. W. Pierce. 2017. Precipitation in a warming world: Assessing projected hydro-climate changes in California and other Mediterranean climate regions. Nature Scientific Reports 7. DOI:10.1038/s41598-017-11285-y

Quilter, P. W., S. Van Ballegooy, and M. Russ. 2015. The effect of sea level rise on liquefaction vulnerability: A case study for consideration of development on coastal plains and reclamations. Pages 1–9 6th International Conference on Earthquake Geotechnical Engineering. Christchurch. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84973577803&partnerid=40&md5=1f88f50c894dd06e5c6227ec5393e39a

Ralph, F. M., T. Coleman, P. J. Neiman, R. J. Zamora, and M. D. Dettinger. 2012. Observed Impacts of Duration and Seasonality of Atmospheric-River Landfalls on Soil Moisture and Runoff in Coastal Northern California. Journal of Hydrometeorology 14:443–459. DOI:10.1175/jhm-d-12-076.1

Reddy, K. R., and L. Tekola. 2004. Remediation of DNAPL source zones in groundwater using air sparging. Land Contamination & Reclamation 12:67–83. DOI:10.2462/09670513.641

Risken, J. L., J. G. Fraser, H. Rutter, and M. Gadsby. 2015. Implications of Sea Level Rise on Liquefaction Vulnerability in Christchurch. Pages 1–8 6th International Conference on Earthquake Geotechnical Engineering. Christchurch. https://secure.tcc.co.nz/ei/images/icege15 papers/fraser 109.00_.pdf

Rotzoll, K., and C. H. Fletcher. 2013. Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change 3:477–481. DOI:10.1038/nclimate1725

Santa Clara Valley Water District. 2017. Santa Clara County Watersheds. https://gis.valleywater.org/arcgis/rest/services/public/mapserver/23

Shirzaei, M., and R. Bürgmann. 2018. Global climate change and local land subsidence exacerbate inundation risk to the San Francisco Bay Area. Science Advances 4:1–9. DOI:10.1126/sciadv.aap9234

SWRCB. 2020. Geotracker Survey XYZ, Well Data, and Site Map Guidelines & Restrictions. California State Water Resources Control Board, Sacramento,CA. http://www.geotracker.waterboards.ca.gov/

Vandever, J., M. Lightner, S. Kassem, J. Guyenet, M. Mak, and C. Bonham-Carter. 2017. Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project. Prepared by AECOM for the San Francisco Bay Conservation and Development Commission, the Metropolitan Transportation Commission, and the Bay Area Toll Authority, San Francisco, CA. http://www.adaptingtorisingtides.org/wp-content/uploads/2016/05/bata-art-slr-analysis-and-mapping-report-final-20170908.pdf

Wehner, M. F. 2013. Very extreme seasonal precipitation in the NARCCAP ensemble: Model performance and projections. Climate Dynamics 40:59–80. DOI:10.1007/s00382-012-

1393-1

Werner, A. D., and C. T. Simmons. 2009. Impact of sea-level rise on sea water intrusion in coastal aquifers. Ground Water 47:197–204. DOI:10.1111/j.1745-6584.2008.00535.x

Witter, R. C., K. . Knudsen, J. M. Sowers, C. M. Wentworth, R. D. Koehler, C. E. Randolph, S. K. Brooks, and K. D. Gans. 2006. Maps of Quaternary Deposits and Liquefaction Susceptibility in the Central San Francisco Bay Region, California U.S. Geological Survey Open-File Report 06-1037 (http://pubs.usgs.gov/of/2006/1037/). Page Database. U.S. Geological Society

Zhang, Z., F. M. Ralph, and M. Zheng. 2019. The Relationship Between Extratropical Cyclone Strength and Atmospheric River Intensity and Position. Geophysical Research Letters:10. DOI:10.1029/2018GL079071

Palo Alto

Sea Level Rise Vulnerability Assessment

Attachment B

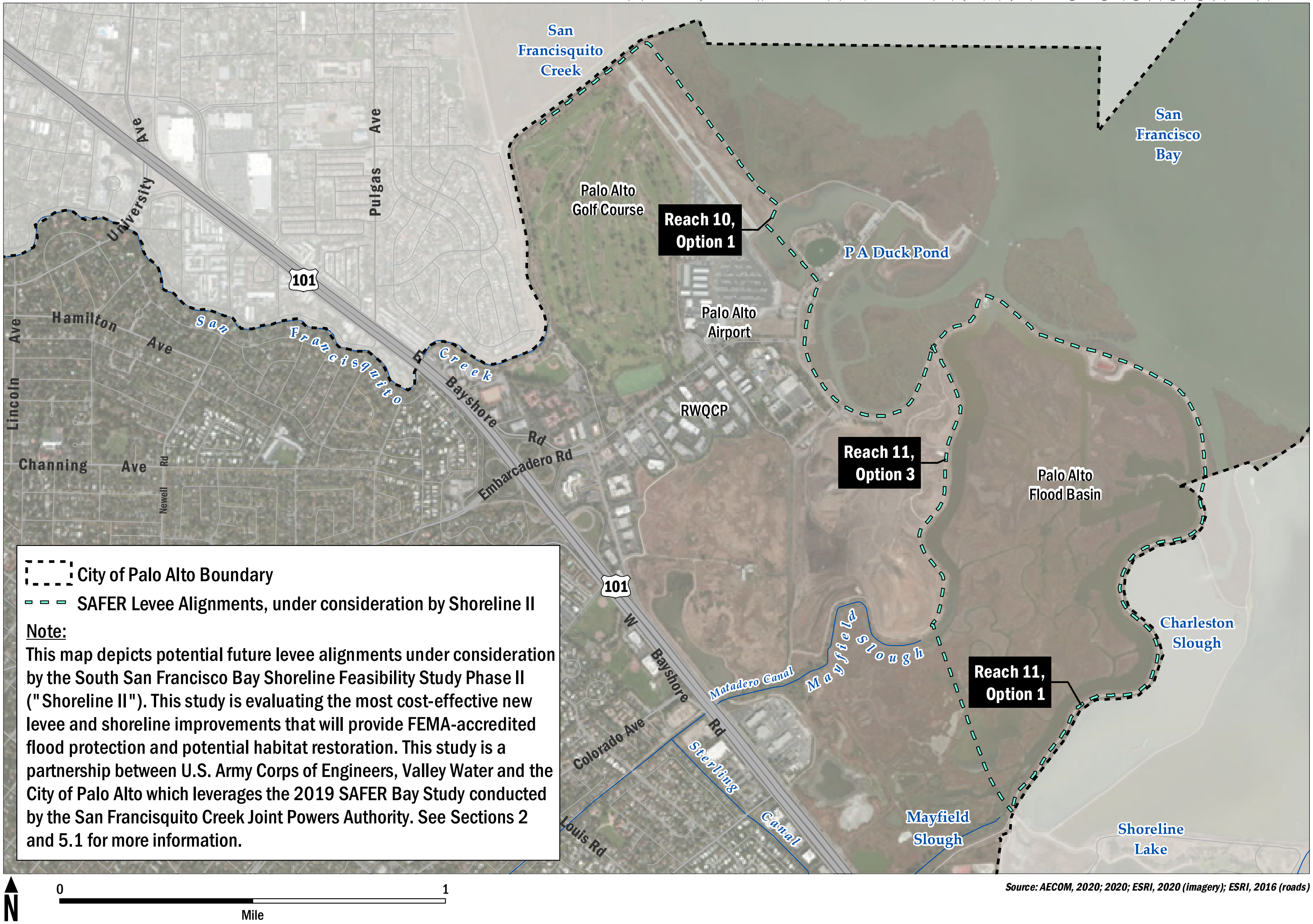
Sea Level Rise Figures

Prepared for:

City of Palo Alto

November 2021

AECOM Oakland CA 10/19/2021 USER sally.shatford PATH \\na.aecomnet.com\lfs\AMER\Oakland-USOAK01\DCS\Projects\GIS\Projects\60630343_PaloAlto_SLR\02_Maps\02_Report_Maps\Flood Maps\SAFER.mxd

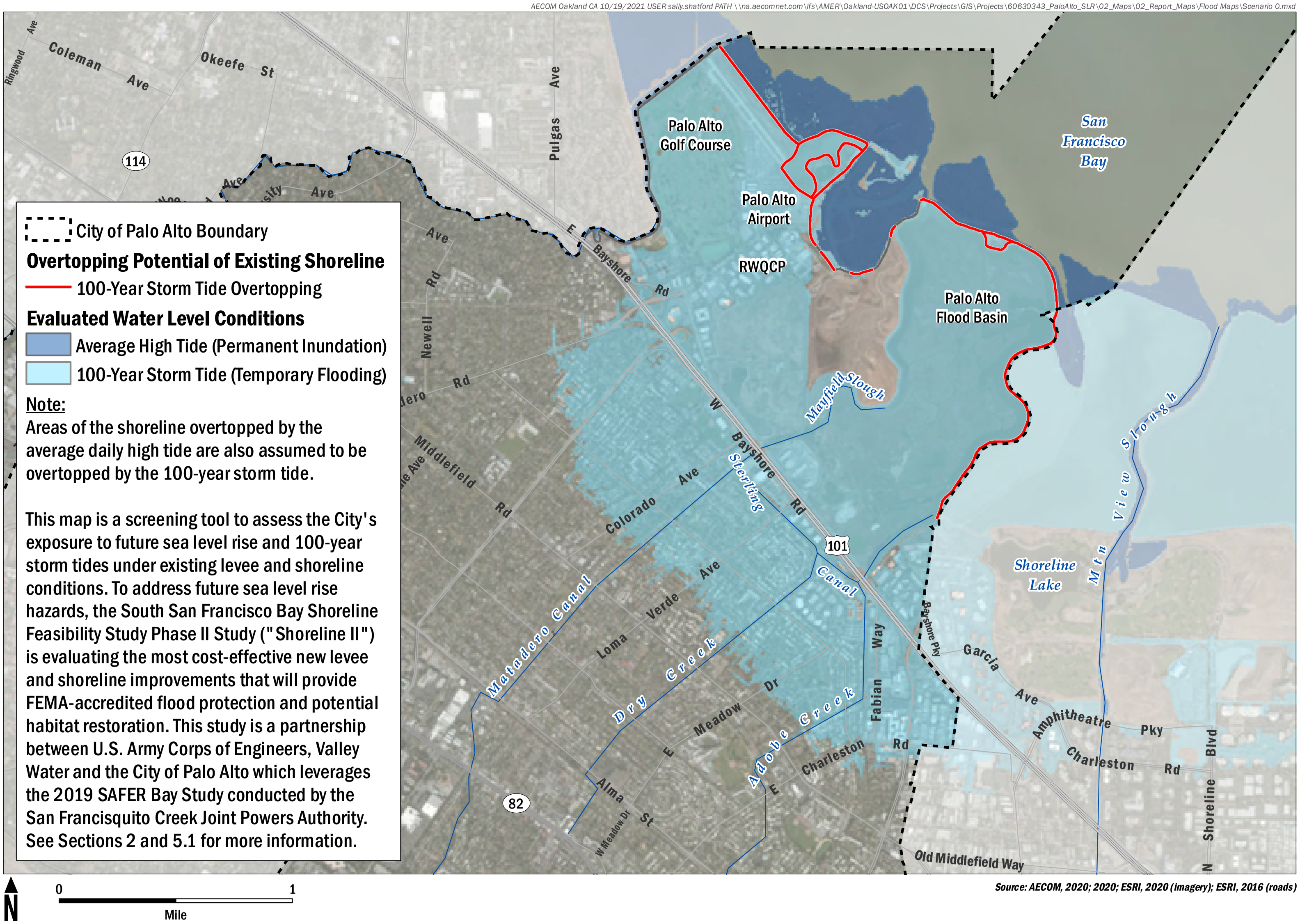


Note:
This map depicts potential future levee alignments under consideration by the South San Francisco Bay Shoreline Feasibility Study Phase II ("Shoreline II"). This study is evaluating the most cost-effective new levee and shoreline improvements that will provide FEMA-accredited flood protection and potential habitat restoration. This study is a partnership between U.S. Army Corps of Engineers, Valley Water and the City of Palo Alto which leverages the 2019 SAFER Bay Study conducted by the San Francisquito Creek Joint Powers Authority. See Sections 2 and 5.1 for more information.

Source: AECOM, 2020; 2020; ESRI, 2020 (imagery); ESRI, 2016 (roads)

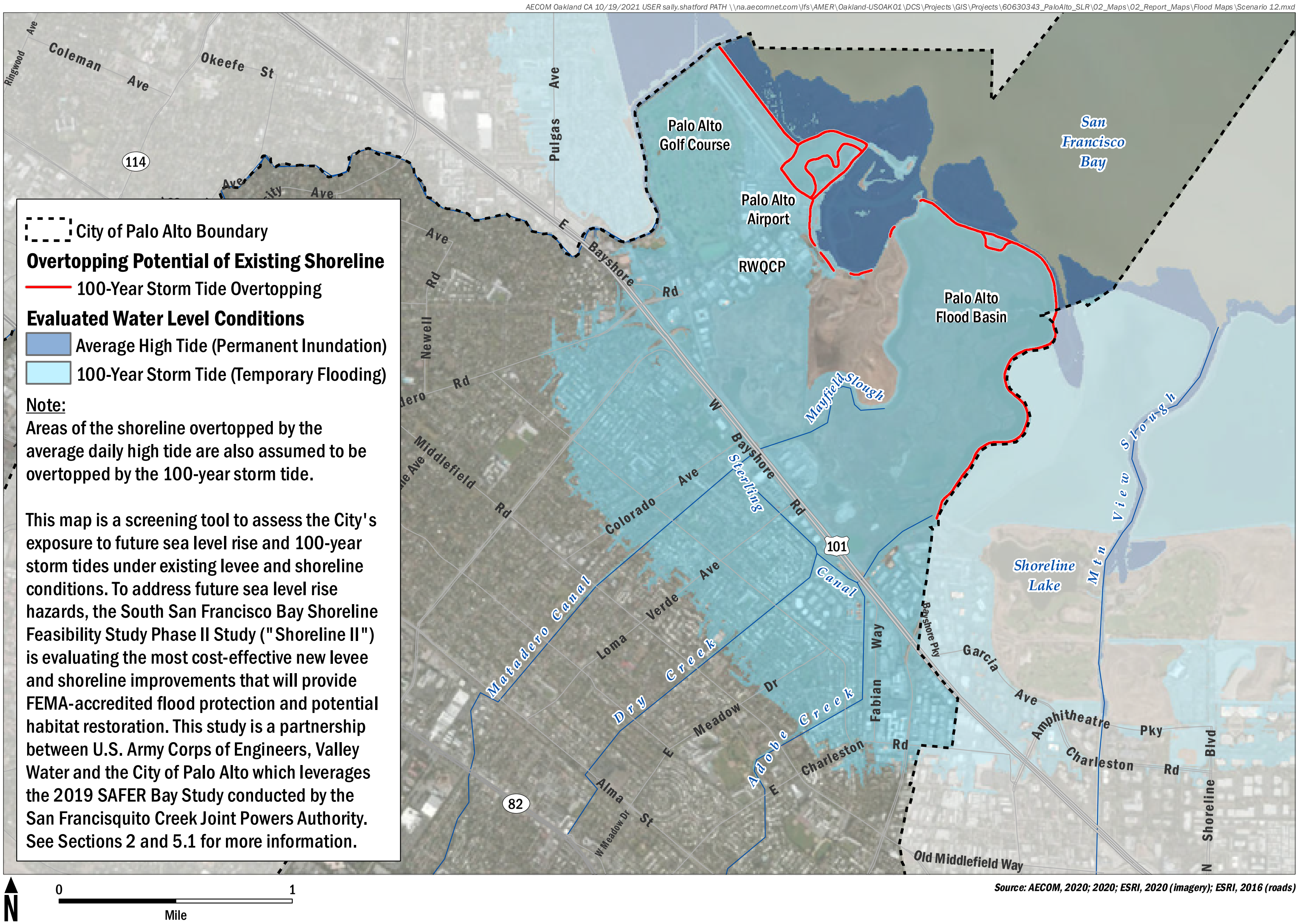
City of Palo Alto
Sea Level Rise Vulnerability Assessment

SAFER LEVEE ALIGNMENTS UNDER CONSIDERATION BY THE SHORELINE II STUDY



PROJECTED SHORELINE OVERTOPPING

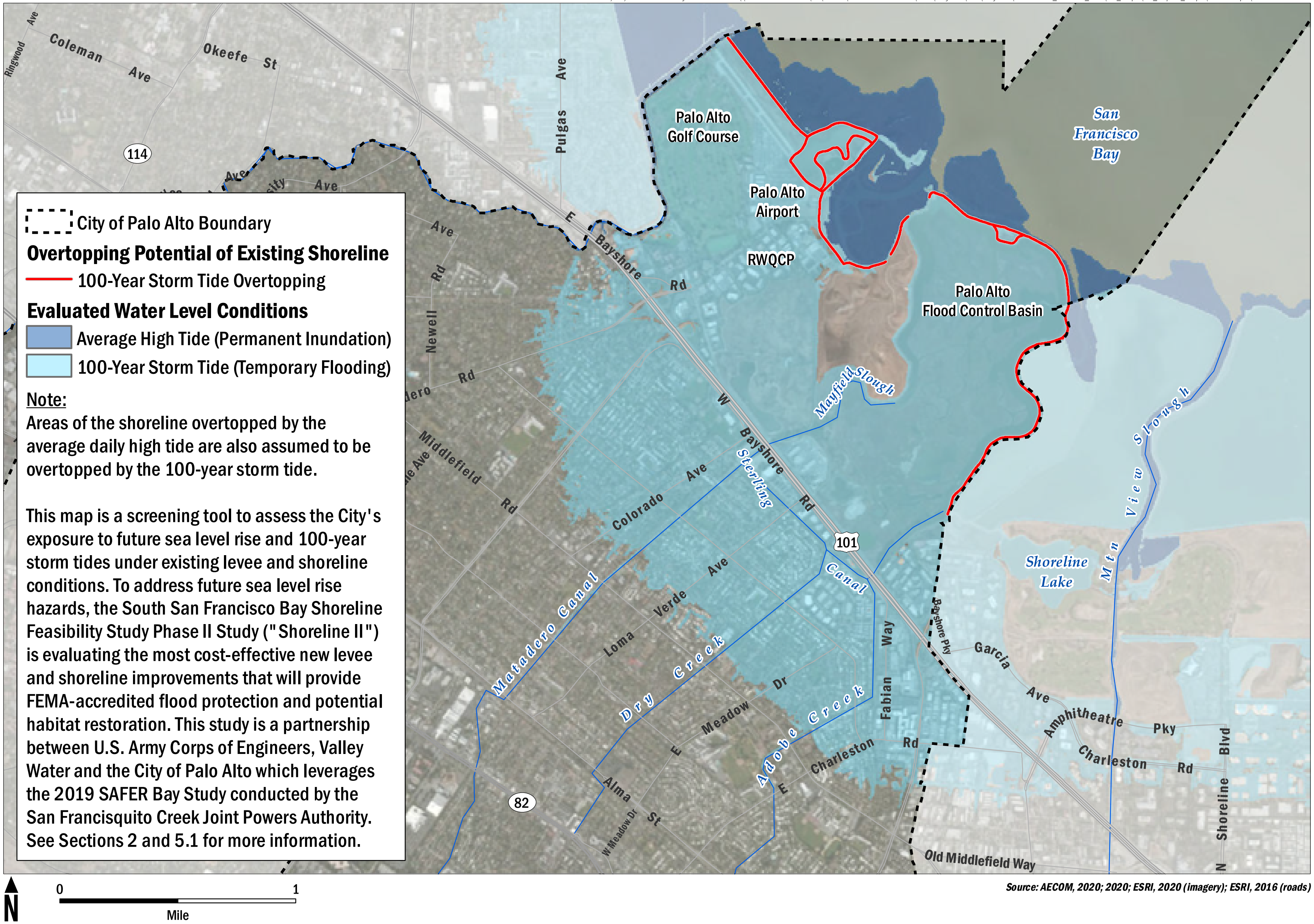
with + 0" Sea Level Rise



City of Palo Alto
Sea Level Rise Vulnerability Assessment

PROJECTED SHORELINE OVERTOPPING
with + 12" Sea Level Rise

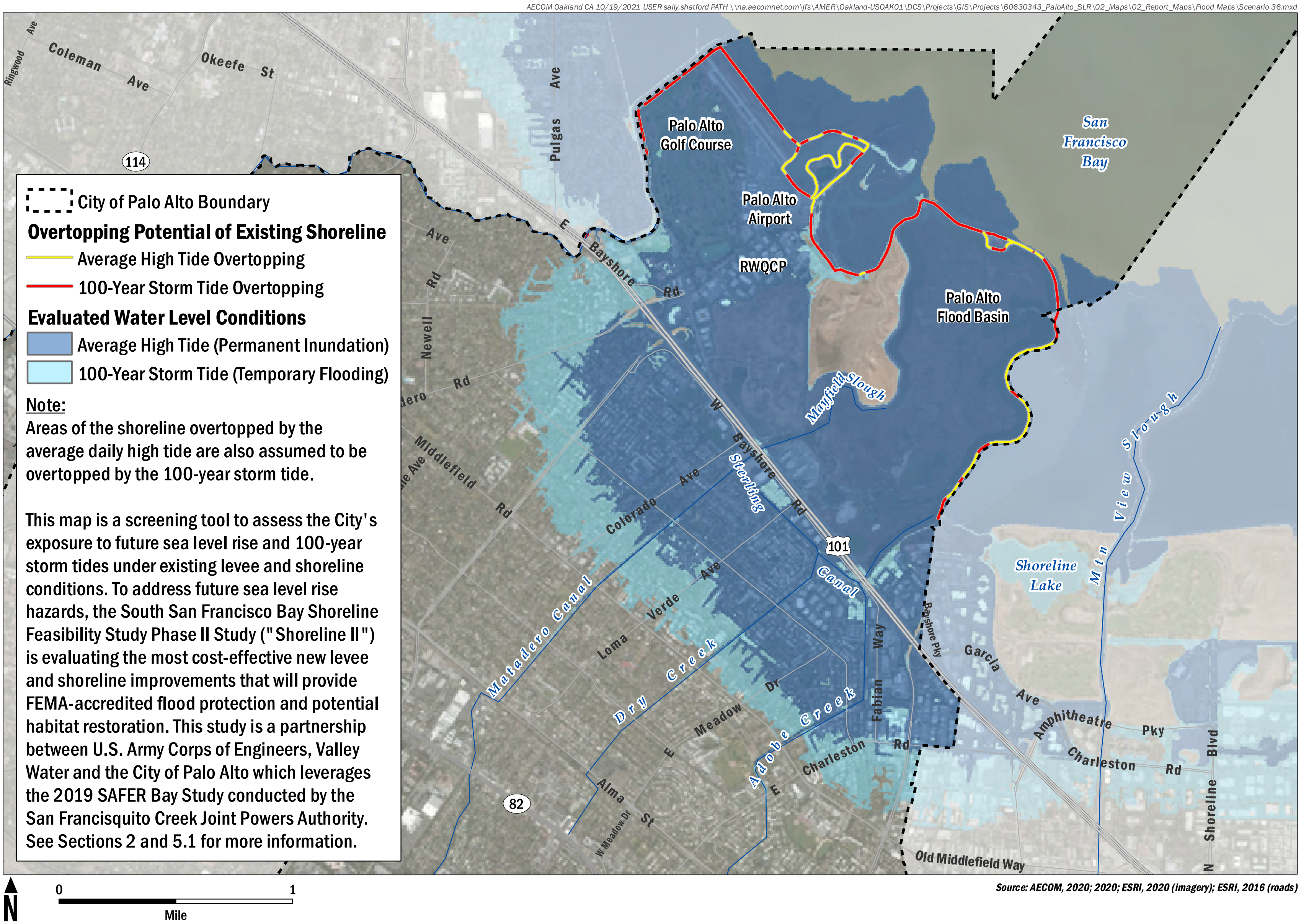
AECOM Oakland CA 10/19/2021 USER sally.shatford PATH \\na.aecomnet.com\lfs\AMER\Oakland-USOAK01\DCS\Projects\GIS\Projects\60630343_PaloAlto_SLR\02_Maps\02_Report_Maps\Flood Maps\Scenario 24.mxd



Source: AECOM, 2020; 2020; ESRI, 2020 (imagery); ESRI, 2016 (roads)

PROOJECTED SHORELINE OVERTOPPING

with + 24" Sea Level Rise

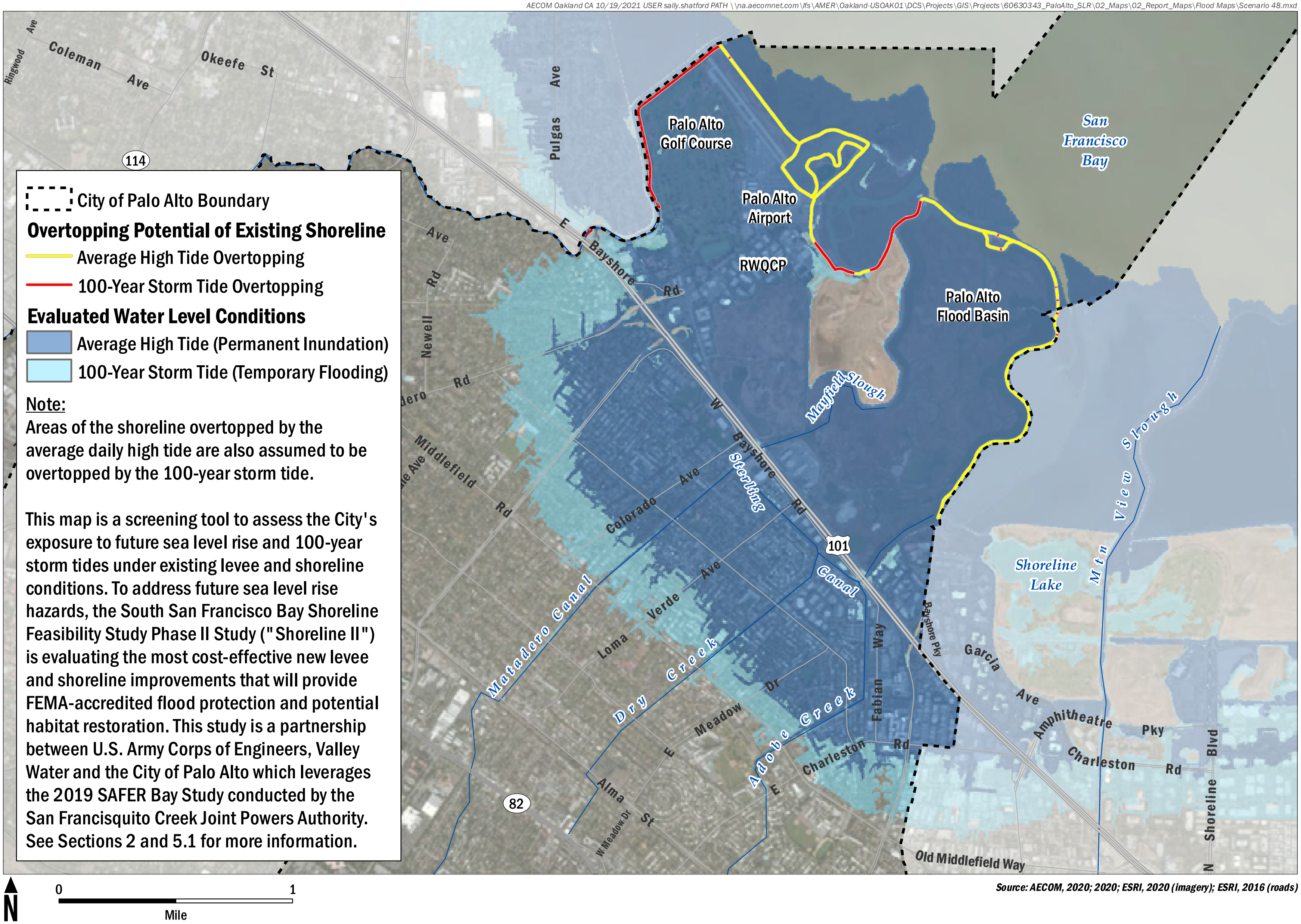


City of Palo Alto
Sea Level Rise Vulnerability Assessment

PROJECTED SHORELINE OVERTOPPING

with + 36" Sea Level Rise

AECOM Oakland CA 10/19/2021 USER sally.shatford PATH \\na.aecomnet.com\lfs\AMER\Oakland-USOAK01\DCS\Projects\GIS\Projects\60630343_PaloAlto_SLR\02_Maps\02_Report_Maps\Flood Maps\Scenario 48.mxd

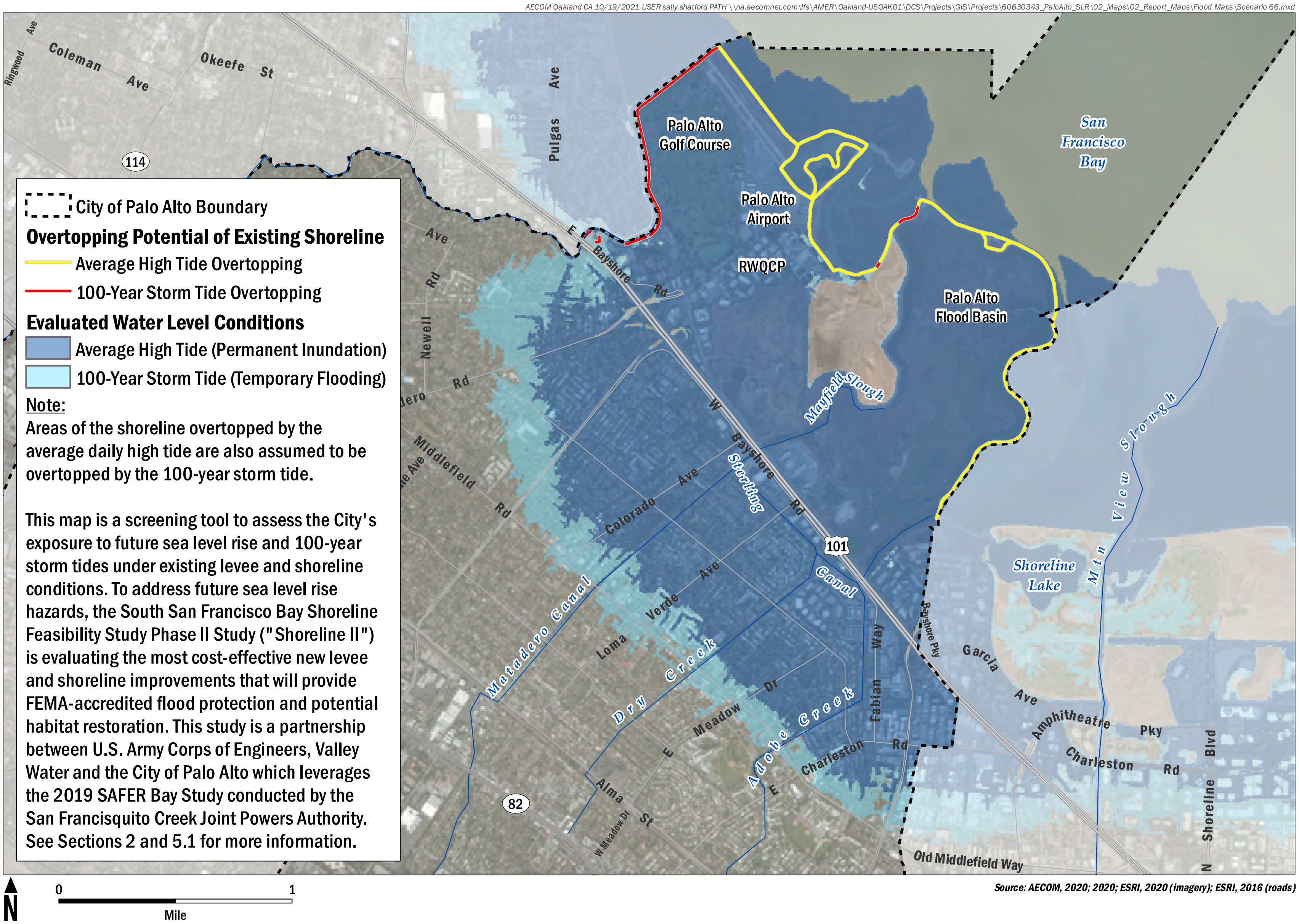


Source: AECOM, 2020; 2020; ESRI, 2020 (imagery); ESRI, 2016 (roads)

City of Palo Alto
Sea Level Rise Vulnerability Assessment

PROJECTED SHORELINE OVERTOPPING

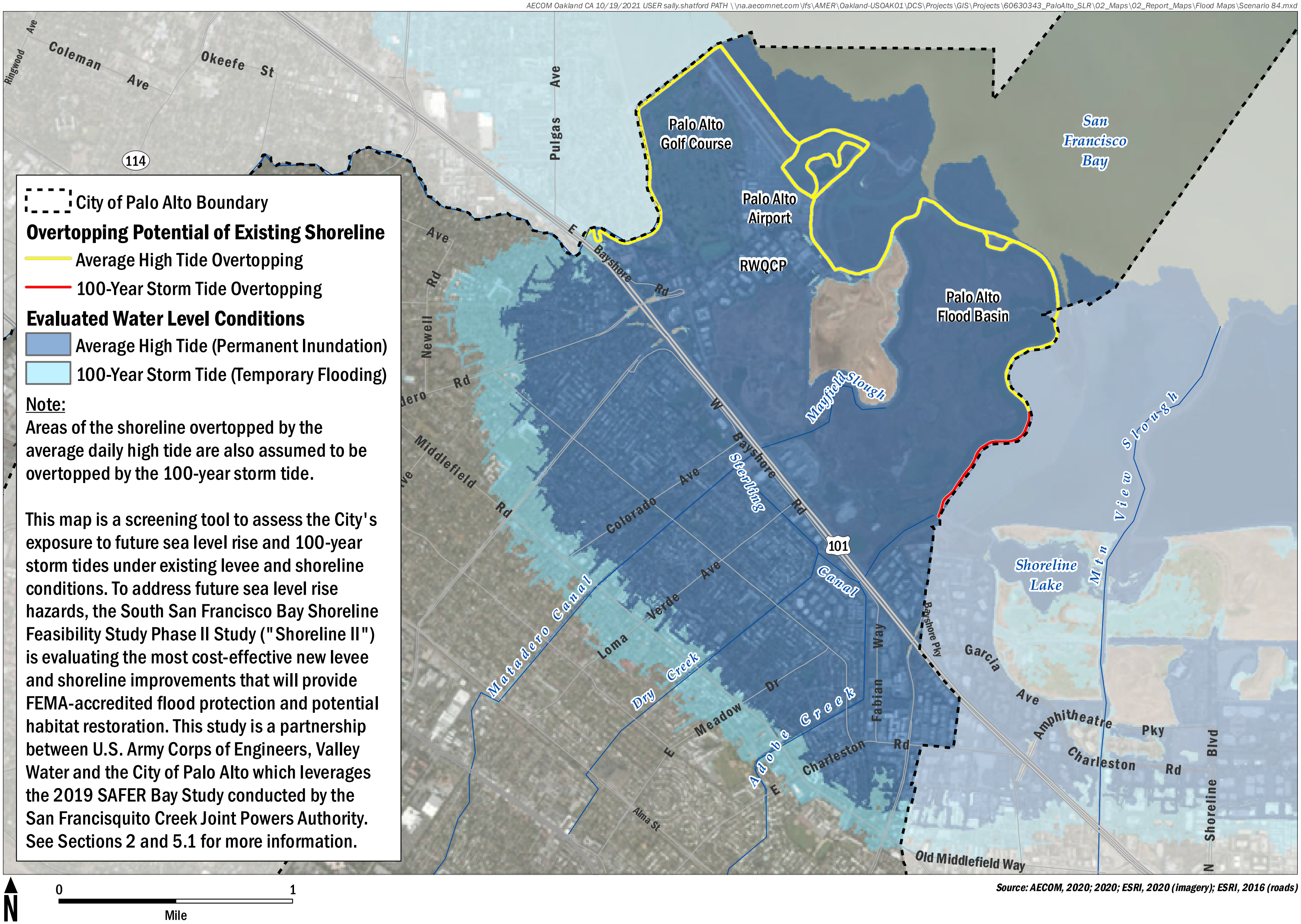
with + 48" Sea Level Rise



Source: AECOM, 2020; 2020; ESRI, 2020 (imagery); ESRI, 2016 (roads)

PROJECTED SHORELINE OVERTOPPING

with + 66" Sea Level Rise



PROJECTED SHORELINE OVERTOPPING

with + 84" Sea Level Rise