City and County of San Francisco

Planning Department

Local Coastal Program Amendment

FINAL

Sea Level Rise Existing Data and Analyses Technical Memorandum

May 6, 2016

Prepared For:

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1 Introduction

The City and County of San Francisco's (CCSF) existing Local Coastal Program (LCP) – the Western Shoreline Area Plan – was certified by the California Coastal Commission (CCC) in 1986. The San Francisco Planning Department recently received a grant from the CCC and the Ocean Protection Council to amend the Western Shoreline Area Plan to incorporate policies related to sea level rise (SLR). Sea levels have historically risen along the San Francisco coastline and will continue to rise over the 21st century. Erosion of the Ocean Beach shoreline south of Sloat Boulevard has damaged public recreational resources and threatens critical infrastructure. Sea level rise is expected to exacerbate these effects in the future. In response, CCSF proposes to amend its LCP to incorporate and implement policies developed through the Ocean Beach Master Plan to better manage coastal recreational facilities while protecting critical public infrastructure.

1.1 Purpose and Organization

The LCP is a policy document that guides development within the San Francisco LCP Planning Area (Coastal Zone). This technical memorandum summarizes existing data and analyses of SLR vulnerability within the Coastal Zone and lays the foundation for San Francisco's proposed LCP amendment. Because the LCP guides decisions related to both short- and long-term uses of coastal resources, it is important that the LCP consider SLR. By providing policy and adaptation recommendations based on state-of-the-art climate science, the amended LCP will improve the resilience of coastal infrastructure and coastal resources in light of a changing climate. This technical memorandum does not provide new SLR projections or modeling of the impacts of SLR. Instead, existing studies based on the best available science were leveraged to assess the vulnerability and risk of areas along San Francisco's Pacific coastline. Specifically, the goals of this technical memorandum are to:

1) Provide up-to-date local SLR projections.
2) Identify potential SLR impacts within the Coastal Zone.
3) Assess risks posed by SLR to coastal resources and development.
4) Inform coastal planning and policy decisions.

This memorandum is consistent with the CCC's Sea Level Rise Policy Guidance (Guidance) for California coastal communities (CCC 2015), reflects the CCC's direction, and fulfills CCC LCP amendment requirements. This memorandum is organized to reflect the CCC's Guidance (steps 1 through 3, as detailed in Chapter 5; CCC 2015):

- Step 1: *Determine relevant SLR projections*, addressed in Section 3 of this memorandum
- Step 2: *Identify potential SLR physical impacts*, addressed in Section 4
- Step 3: *Assess potential risks from SLR to coastal resources and development*, addressed in Section 5

Steps 4 through 6 of the Guidance (*identify adaptation strategies*, *develop draft LCP*, and *implement LCP*) will be addressed in subsequent stages of the San Francisco LCP Amendment.

1.2 List of Data Sources

AECOM identified the following studies, existing data, and analyses for evaluation as part of this technical memorandum. These sources were reviewed and incorporated, as appropriate, into the analysis of potential SLR impacts and risks to coastal resources and development within the Coastal Zone.

- **Existing and future conditions coastal flood hazards:** Federal Emergency Management Agency (FEMA) Preliminary Flood Insurance Study (FEMA 2015) and FEMA San Francisco SLR Pilot Study (BakerAECOM 2016), U.S. Geological Survey (USGS) modeling conducted as part of the Our Coast Our Future project, and San Francisco Public Utilities Commission (SFPUC) shoreline assessment and SLR inundation mapping (AECOM 2014a)
- **Historical and future shoreline change:** USGS National Assessment of Shoreline Change (Hapke et al. 2006; Hapke and Reid 2007), San Francisco Littoral Cell Coastal Regional Sediment Management Plan (Environmental Science and Associates [ESA] et al. 2016), Coastal Protection Measures & Management Strategy for South Ocean Beach (SPUR et al. 2015), and FEMA San Francisco SLR Pilot Study (BakerAECOM 2016)
- **SLR science and projections:** National Research Council (NRC) Sea-Level rise for the Coasts of California, Oregon, and Washington (NRC 2012) and SFPUC Climate Science Data Inventory (AECOM 2014b)
- **SLR policy and design guidance:** City and County of San Francisco Guidance for Incorporating SLR into Capital Planning (CCSF 2015), CCC SLR Policy Guidance (CCC 2015), and SFPUC San Francisco Design Tides and SLR Recommendations (AECOM 2015)
- **Climate change vulnerability and risk assessments:** SFPUC Sewer System Improvement Program Climate Change Vulnerability and Risk Assessment and Adaptation Plan (in progress)
- **Other studies:** SPUR Ocean Beach Master Plan (SPUR et al. 2012), and San Francisco Regional Groundwater Storage and Recovery Project Final Environmental Impact Report (San Francisco Planning Department 2014)

1.3 Key Findings

The San Francisco Coastal Zone has historically experienced coastal erosion issues, and SLR will exacerbate the extent and severity of these impacts in the future. The San Francisco Coastal Zone has a long history of human modification, which has increased the vulnerability of coastal resources and assets to future SLR. Efforts during the 20th century to push out the shoreline and stabilize it seaward of its historical position have resulted in substantial landward migration of the shoreline over time, particularly in the area along southern Ocean Beach. While there is little to no development directly on the beaches within the Coastal Zone, the backshore areas directly landward of the coastline are heavily developed and contain a range of transportation, wastewater, and residential assets. The high-level vulnerability and risk assessment conducted as part of this data summary identifies some of these vulnerable assets and discusses potential consequences of impacts for different SLR scenarios at 2050 and 2100 planning horizons.

A key finding of this assessment is the recognition that some segments of Ocean Beach are more susceptible than others to loss of the sandy beach in the future due to an increase in historical rates of shoreline retreat as a result of SLR and the presence of existing coastal armoring structures, which impede the natural landward migration of the shoreline over time. In these areas, beach nourishment may provide one alternative to maintain beach widths in the future, thereby preserving existing recreational and ecological benefits within the San Francisco Coastal Zone. In other areas, such as south of Sloat Boulevard, more comprehensive adaptation strategies, such as those identified in the Ocean Beach Master Plan, will be required to maintain the sandy beach and protect critical wastewater infrastructure.

2 The San Francisco Coastal Zone

The San Francisco Pacific coast encompasses approximately 9 miles of shoreline, beaches, rocky outcrops, and bluffs from the Golden Gate Bridge south to the San Mateo County line at Fort Funston (Figure 1). The Coastal Zone includes the portion of the coastline from Lands End in the north to Fort Funston in the south, including the Lake Merced area, the San Francisco Zoo, the Olympic Club, and the seashore and bluff area of Fort Funston. The Coastal Zone spans the Ocean Beach shoreline and includes Golden Gate Park west of 40th Avenue, the Great Highway Corridor, and the adjacent residential blocks in the Sunset and Richmond districts. The north end of the Coastal Zone includes the Cliff House and Sutro Baths area, Sutro Heights Park, and Lands End recreational area.

The northern section of shoreline at Lands End consists mostly of federal property (former military facilities or park lands) and is characterized by steep rocky cliffs. Smaller pocket beaches exist along the shoreline between rocky outcrops, but they are generally fronted by only a narrow sandy or cobble beach. The rocky cliffs are generally resistant to wave attack but are prone to terrestrial landslides and cliff retreat. The rocky section of coast along Lands End is generally undeveloped. This area includes the seaward portion of Lincoln Park and the remains of the Sutro Baths. A visitor center and lookout is located above Sutro Baths along Point Lobos Avenue, and trails provide public access to the Sutro Baths and coastal area.

The relatively straight section of coastline between the Cliff House and the bluffs of Fort Funston is known as Ocean Beach and consists of a relatively wide sandy beach backed by seawalls and dunes. The beach is publicly owned, and the backshore is heavily developed. The Cliff House is a restaurant built on top of the cliffs and operated by the National Park Service. The O'Shaughnessy Seawall and Esplanade were constructed in the 1920s and remain today. The seawall extends from the base of the Cliff House southward to Lincoln Way. South of the seawall is an area of active coastal foredunes that extends from Lincoln Way to Noriega Street. South of Noriega Street, the Great Highway Seawall was constructed between 1988 and 1993 and extends approximately from Noriega Street to Santiago Street. A relatively short and low seawall between Santiago and Taraval Streets was constructed in 1941 and is typically buried by sand.

The southern portion of Ocean Beach between Sloat Boulevard and the Oceanside Treatment Plant transitions from broad sandy beach backed by dunes to narrow sandy beach backed by artificial fill placed during construction of the Great Highway and wastewater treatment facilities. The section of the Great Highway immediately landward of the beach has been repeatedly threatened by undermining, and buried wastewater infrastructure in this area is also at risk. This area has a history of erosion control measures, including sand and rock placement along the back of the beach to protect existing parking lots, the roadway, and threatened infrastructure. Emergency revetments were constructed in 1997 and 2010 to halt erosion of two segments of the bluff. South of the treatment plant, the backshore transforms into steep, high, erodible sandy bluffs.

The southern portion of the Coastal Zone includes Lake Merced, Fort Funston, and the Olympic Club. Lake Merced, once a brackish lagoon that connected to the ocean, was developed and closed to tidal influence in the mid-1800s. It is now a freshwater lake providing a range of benefits including environmental, water supply, and recreation. Fort Funston is a former military installation on tall bluffs at the southern edge of San Francisco; it was transferred to the National Park Service in the 1960s and provides public access to the coast, including hang gliding, hiking, and horseback riding. The Olympic Club is a private athletic and social club adjacent to Fort Funston and Lake Merced; it maintains three golf courses on the coastal bluffs within San Francisco's Coastal Zone.

Figure 1. The San Francisco Coastline and Coastal Zone

3 Sea Level Rise Projections

The following sections summarize SLR projections relevant to the San Francisco Coastal Zone.

3.1 Planning Horizons and Range of SLR Projections

Potential SLR vulnerabilities and risks to coastal resources (discussed in Section 5) were evaluated for the 2050 and 2100 planning horizons.

All estimates of SLR impacts in this memorandum are based on current NRC (2012) projections and upper range scenarios, as listed in Table 1 and shown in Figure 1. Sea levels off the coast of San Francisco are expected to rise between 11 and 24 inches by mid-century, and 36 to 66 inches by 2100[1]. The SLR projections shown in represent a moderate greenhouse gas emissions scenario and extrapolation of continued accelerating land ice melt patterns. The upper range represents possible levels of SLR under a high greenhouse gas emissions scenario and includes significant land ice melt contributions.

Table 1. Sea Level Rise Projections at San Francisco Relative to the Year 2000

Year	Projection (inches)	Upper Range* (inches)
2030	6	12
2050	11**	24
2100	36	66

Source: NRC (2012)
* Lower range projections are excluded because they are not recommended for planning.
** For the purposes of the SLR impact assessment, a 2050 SLR projection of 12 inches was evaluated instead of 11 inches for consistency with available SLR hazard assessment data prepared by the Federal Emergency Management Agency.

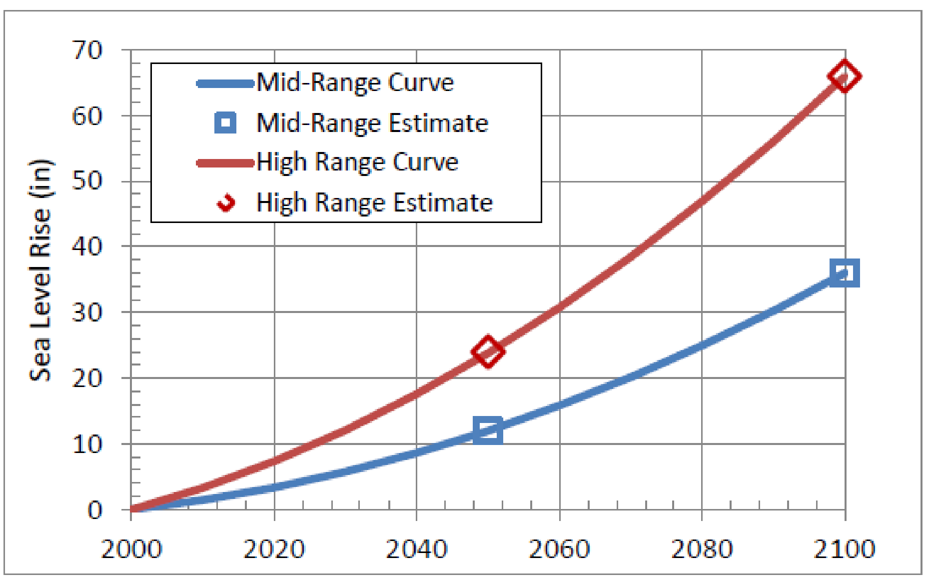

Figure 2. Sea Level Rise Projections for San Francisco

[1] Relative to mean sea level for the current National Tidal Datum Epoch, Section 4.1

These projections are consistent with:

- The NRC's Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past Present and Future (2012), which defines the most likely, lower, and upper ranges for SLR in the three states through the end of the century. This report has been identified by multiple state agencies as best available science.
- The California Coastal Commission's Sea-Level Rise Policy Guidance (2015)
- The City and County of San Francisco Guidance for Incorporating Sea Level Rise into Capital Planning (2015)
- The Intergovernmental Panel on Climate Change's Fifth Climate Assessment Report (2013), which generally agrees with the projections from NRC 2012 without quantifying upper end SLR scenarios

These projections are based on the best available science at this time and should be updated periodically as global conditions change and new data become available.

3.2 Sea Level Rise Scenarios

Four scenarios were selected to evaluate the impacts of SLR on coastal resources within the Coastal Zone: 12 inches (mid-century projection), 24 inches (mid-century upper range), 36 inches (end-of-century projection), and 66 inches (end-of-century upper range) of SLR. These four scenarios encompass the best available sea level rise projections and were derived considering local and regional processes and conditions.

3.3 Sea Level Rise Hazard Layers

FEMA recently completed an SLR pilot study along the Pacific coast of San Francisco (BakerAECOM 2016). The pilot study evaluated methods to incorporate the effect of SLR and shoreline change into FEMA's coastal hazards analysis framework. The study evaluated four SLR scenarios: 12 inches, 24 inches, 36 inches, and 66 inches – consistent with the SLR scenarios selected for the San Francisco LCP amendment. Data products from the pilot study include estimates of future wave runup elevations and the landward extent of the Special Flood Hazard Area[2], taking into account the effects of SLR and shoreline change. The layers represent areas that would be exposed to wave and erosion hazards during a future conditions 1-percent-annual-chance coastal storm event under each SLR planning scenario. These data layers are shown in Attachment A and referenced in Section 5 as part of the evaluation of the SLR vulnerability and risk of coastal resources within the San Francisco Coastal Zone.

[2] FEMA's Special Flood Hazard Area (SFHA) is the land area exposed to flooding during the 1-percent-annual-chance coastal flood event (commonly referred to as the "100-year" storm). The SFHA is the area where FEMA's National Flood Insurance Program's floodplain management regulations must be enforced and the area where mandatory purchase of flood insurance applies.

4 Potential Physical Sea Level Rise Impacts

The following sections discuss SLR impacts on physical hazards, such as local water level conditions, historical and future shoreline change, and water quality.

4.1 Local Water Level Conditions

Existing Conditions Tidal Datums

Coastal water levels fluctuate naturally throughout the day due to astronomical tides caused by the gravitational pull of the moon and sun. The coast of San Francisco experiences two high and two low tides each day, which vary in height over time. The highest annual tides typically occur during the summer (June-July) and winter months (December-January).

The largest annual tides, often referred to as king tides, occur approximately four or five days each year. King tides produce ocean levels typically 10 to 14 inches higher than the average high tides. Observations of flooding and wave impacts during king tides provide temporary insights into sea levels currently projected to occur between 2030 and 2050.

Datums

Tide elevations are measured relative to a datum – a baseline starting position against which other elevations may be related. There are two types of vertical datums: orthometric and tidal.

Tidal datums are elevations defined by a certain phase of the tide: e.g. mean sea level or mean higher high water (MHHW), which is the average daily high tide. Tidal datums are calculated by the National Oceanic and Atmospheric Administration over a recent 19-year period, called a National Tidal Datum Epoch. Current MHHW values are calculated for the present National Tidal Datum Epoch (1983 through 2001). Similarly, sea level projections presented in this document are also relative to this period.

An orthometric datum is a reference plane of zero elevation that historically attempted to approximate the average elevation of the surface of global oceans or “sea level.” The North American Vertical Datum of 1988 (NAVD88) is the current national standard reference datum. San Francisco has established its own vertical datum, the San Francisco City Datum (SFCD), and elevation values can be converted between the NAVD88 and SFCD vertical datums. This document uses NAVD88 throughout.

Figure 3 presents current tidal datum values at the Presidio Tide Station relative to the NAVD88 vertical datum.

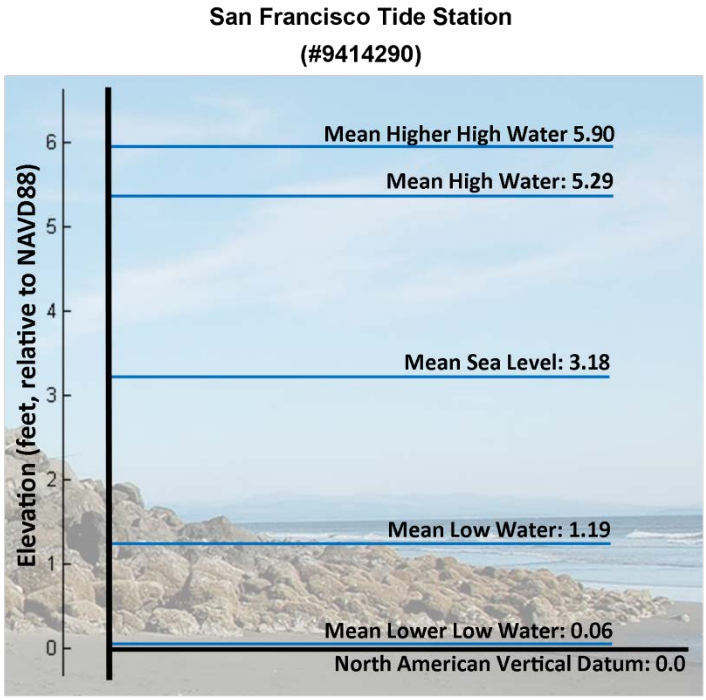

Figure 3. Tidal Datums at the Oceanic and Atmospheric Administration's Presidio Tide Station

Water Level Changes from Storms and Pacific Ocean Basin Phenomena

Many factors influence ocean levels, including storm surge, ocean swell, wind waves, El Niño–Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and tsunamis. Each of these factors can raise water levels independently, and two or more may combine to form exceptionally high coastal water levels.

El Niño–Southern Oscillation: California's water levels are strongly influenced by the large-scale changes in the ENSO cycle. Under normal conditions, global trade winds blow from east to west across the Pacific, moving warm surface water away from the Americas toward the western Equatorial Pacific. Every two to seven years, these winds weaken or reverse, pushing warm, equatorial water toward the Americas, and north to San Francisco. This warmer ocean water expands, and coastal waters during El Niño conditions are higher than typical. In addition, El Niño conditions in the Pacific Ocean frequently produce severe winter storms that impact the San Francisco shoreline because Pacific Ocean storms follow a more southerly route. Because the storm tracks are shifted farther south, waves approach from a more southerly direction, exposing normally protected reaches of shoreline to high water levels and wave hazards.

Pacific Decadal Oscillation: The PDO is a long-term (multi-decadal) ocean-atmosphere cycle of climate variability that shifts the locations of cold and warm water masses in the Pacific Ocean basin and alters the path of the jet stream. It is similar to ENSO, but it occurs over a longer time scale. The warm phase of the PDO is characterized by warmer than normal water temperatures in the eastern North Pacific and a more southerly jet stream. The cool phase of the PDO is characterized by cooler than normal water temperatures in the eastern North Pacific and a more northerly jet stream.

Coastal Storms: Large storm systems impact the San Francisco coastline every winter. These storms are typically characterized by low barometric pressure and strong winds, which produce storm surge, and are accompanied by large powerful waves. Storm characteristics such as wind speed, water level, and wave height are often described statistically using a concept referred to as the "return period" such as a "100-year wave runup elevation." It is important to note that a 100-year storm does not necessarily occur once every 100 years, but rather has a 1 percent chance of occurring in any given year. Therefore, it is possible to experience two 100-year storm events in a single year, or have a period of greater than 100 years without a 100-year storm.

Table 2 presents factors which may contribute to extreme water levels along the San Francisco Pacific coast.

Table 2. Processes That Temporarily Elevate Coastal Waters along the San Francisco Pacific Coast

Factors Affecting Water Level	Typical Range	Length of impact	Frequency
King tides	1 to 1.3 feet above MHHW	Hours	2 to 4 times each year
Storm surge	0.5 to 3 feet	Days	Several times each year
Storm waves	10 to 30 feet	Hours to days	Several times each year
El Niño	0.5 to 1 feet	Months	Every 2 to 7 years
Pacific Decadal Oscillation	Unknown	20 to 30 years	Decades

Existing Conditions Inundation and Wave Impacts

While local water level fluctuations exacerbate the effects of coastal flooding, along the open Pacific coast, wave processes dominate coastal hazards. Therefore, to understand shoreline risks, it is necessary to understand the effects of wave hazards and storm surge.

Wave hazards are typically characterized by the wave runup elevation[3], which is the elevation reached by waves breaking on the shoreline considering the combined effects of astronomical tides, storm surge, El Niño, and wave processes (Figure 4). In general, steeper shorelines experience higher wave runup than mild shorelines – for example, wave runup on the rocky bluffs of Lands End will be greater than on the flat sandy beaches of Ocean Beach.

[3] The wave runup elevation at the shoreline is typically referred to as the "total water level" (TWL) in FEMA Flood Insurance Studies. The 1-percent-annual-chance TWL is referred to as the "Base Flood Elevation" (BFE) and has important flood insurance implications and building standards for property owners whose property is within FEMA's Special Flood Hazard Area.

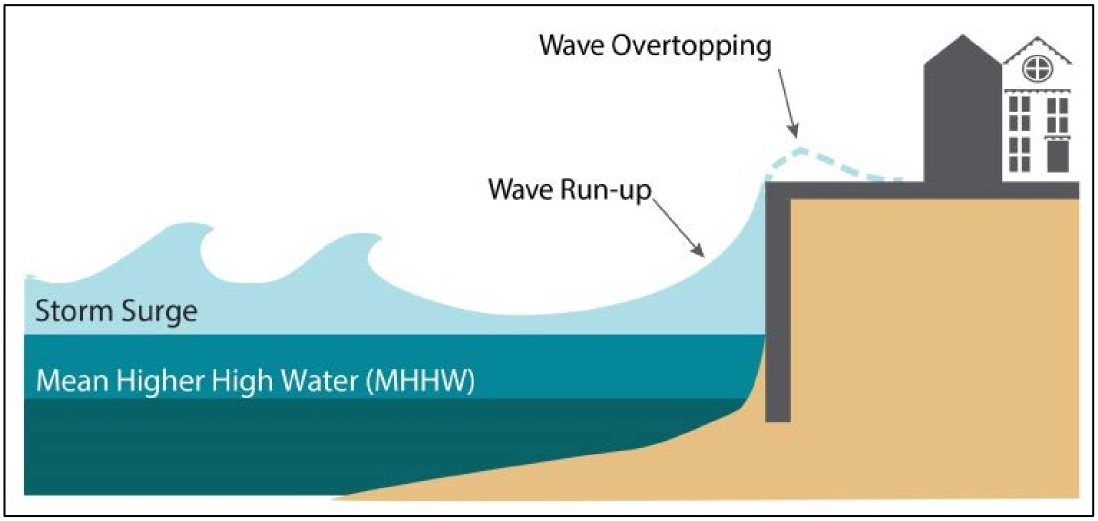

Figure 4. Conceptual Diagram of Wave Runup Processes at the Shoreline

Waves repeatedly impact and shape the coastline throughout the seasons. The waves observed at the shoreline are generated by wind and have traveled from distances ranging from a few to thousands of miles offshore. The combination of wind speed, storm duration, and storm size ultimately determines the wave characteristics. Although each incoming wave is responsible for incremental changes to the shoreline, large waves, usually generated by powerful offshore storm systems, can cause dramatic changes to the coast in a short time.

In San Francisco, the largest wave events typically occur in the winter (October–March) when Pacific Ocean storms near the Aleutian Islands of Alaska produce strong winds that blow across the ocean, generating large waves that can propagate to the central California coast. Typical impacts due to large storms include wave-induced erosion, flooding, and damage to coastal structures. These structures, such as seawalls and revetments, can be undermined and threatened if the storm waves exceed the existing capacity of the structure. Backshore inundation (i.e., flooding behind the protective structures) can occur when waves overtop the structures. Natural shorelines, and sections of the coast where protective structures are absent, can experience significant erosion, resulting in inland retreat of the shoreline. The San Francisco Coastal Zone has both natural and armored segments of shorelines that will respond differently to coastal storms, long-term shoreline change, and SLR. Depending on the intensity of the wave hazards, shoreline retreat may be gradual, or the shoreline could be dramatically reshaped by a single storm event, such as the recent bluff failures near Sloat Boulevard during the 2009–2010 and 2015–2016 El Niño winters.

FEMA's recently completed California Coastal Analysis and Mapping Project estimated the extent of flooding during the 1-percent-annual-chance coastal flood event along San Francisco's Pacific coastline. The Preliminary Flood Insurance Rate Map (FIRM), which depicts the landward extent of FEMA's SFHAs and estimated wave runup elevations, is available to CCSF and provides a reasonable estimate of existing conditions coastal flood hazards (FEMA 2015).

Future Conditions Inundation and Wave Impacts

Future coastal flood risks (e.g., extreme tides and wave hazards) will be magnified by the addition of SLR. As coastal waters rise, the frequency and magnitude of flooding from coastal storm events will increase.

The following coastal flood hazards will increase due to SLR:

- **Daily tidal inundation:** As sea level rises, the amount of land and infrastructure subjected to daily inundation by high tides will increase. The San Francisco Coastal Zone is relatively high compared to typical daily high tide elevations and currently does not experience adverse impacts of tidal flooding; however, as seas rise, previously dry or rarely inundated areas may be reached with increased frequency.
- **Annual high tide inundation (King Tides):** King Tides are abnormally high, but predictable, astronomical tides that occur approximately four to five times per year. As seas rise, the elevation of King Tides will rise concurrently. When King Tides coincide with storm waves, coastal flood and erosion impacts are more likely to occur.
- **Extreme tides:** Extreme tides can be thought of as any temporary ocean water level above the predicted (astronomical) daily high tide (not including wave effects). They occur as a combination of high astronomical tides, storm surge, and El Niño effects (see Table 2). As seas rise, the elevation of extreme tides will rise concurrently.
- **Storms and El Niño:** Climate change may affect the frequency and intensity of coastal storms, El Niño cycles, and related processes. A clear consensus has not yet fully emerged on the nature of these changes in the Pacific Ocean and this is an area of active research.
- **Shoreline change and coastal erosion:** The San Francisco Pacific coastline has undergone natural and manmade alterations over the past 150 years that have moved the shoreline either landward or seaward from its historical position. The long-term cumulative effects of tides, waves, and SLR generally results in the landward migration of the shoreline[4]; however, there is much variability, depending on location and time period. There is a general consensus among the scientific community that SLR will increase long-term rates of shoreline change, although the exact nature of that increase is not well understood and this is an area of active research.

Flooding from Other Extreme Events

The Coastal Zone is subject to flooding from other extreme events, such as a 500-year coastal storm event, tsunami runup and inundation from local and distant seismic events, and stormwater ponding from intense rainfall. Potential sources of existing conditions flooding due to other extreme events within the Coastal Zone are discussed below.

Extreme Coastal Storm Events: FEMA recently completed a coastal hazard analysis of the San Francisco coast as part of the California Coastal Analysis and Mapping Project (FEMA 2015). The primary purpose

[4] North Ocean Beach may be an exception to this general understanding. The beach in this area was very narrow prior to the mid-1970s, when it started to expand seaward. Despite SLR, this accretion pattern has continued and the beach is wider today than it has been in recorded history; however, future SLR may lessen or even reverse this widening trend in the future.

of FEMA's floodplain analysis and mapping was to estimate flood elevations associated with the 1-percent-annual-chance flood event – referred to as the "base flood" event (commonly referred to as the 100-year storm event); however, FEMA also developed estimates of flood elevations associated with the 0.2-percent-annual-chance coastal storm event (commonly referred to as the 500-year event). Wave runup elevations associated with the 0.2-percent-annual-chance event are reported in the Flood Insurance Study (FIS) documentation and are typically 1 to 3 feet higher than wave runup elevations associated with the 1-percent-annual-chance event along the San Francisco coast.

Tsunami Inundation: Tsunamis are ocean waves with very long wavelengths that are generated from geologic events such as earthquakes, landslides, and volcanic eruptions. The California coast is exposed to tsunami hazards from local sources such as the Point Reyes and San Gregorio Faults and distant sources such as the Pacific Northwest, Aleutian Islands, Japan, and Kuril Islands. The State of California (2009) evaluated potential tsunami inundation hazard zones along the California coast and developed exposure maps for emergency planning purposes. Tsunami hazard zones along the San Francisco Coastal Zone are depicted on the "San Francisco North/South" Quadrangle, available from the California Geological Survey. Worst-case tsunami runup elevations are projected to reach 26 feet above mean sea level along Lands End and 42 feet along the Richmond and Sunset Districts (CCSF 2011). Projected runup limits extend inland approximately to 48th Avenue in the Richmond District and 47th Avenue in the Sunset District.

Stormwater Ponding: Stormwater ponding occurs when surface runoff during intense rainfall events is too great to be captured and carried by the stormwater system. Operation of the stormwater system may also be disrupted when vegetation or debris block stormwater inlets or pipes. In these situations, runoff may pond in low-lying areas such as street intersections. Stormwater ponding is generally only a few inches deep, but ponding to depths of several feet can occur. The San Francisco Hazard Mitigation Plan (CCSF 2014) depicts areas of potential stormwater ponding. Potential stormwater ponding areas within the San Francisco Coastal Zone include the low-lying areas immediately east of the Great Highway between Lincoln Way and Sloat Boulevard, including a portion of the San Francisco Zoo.

4.2 Shoreline Change

The following sections provide an overview of historical shoreline change trends along the San Francisco Pacific coast and predicted future shoreline change distances within the Coastal Zone.

Historical Shoreline Change

Shoreline change is a complex process that can occur on a variety of time scales, ranging from individual storm events to multi-decadal climatic cycles, and can result in either retreating or advancing shorelines. Short-term shoreline change generally consists of episodic, storm-induced erosion or human alterations (e.g., beach nourishments or placement of coastal protection or sand retention structures). Long-term shoreline change is typically facilitated by natural or human-induced changes in sediment budget, longshore and cross-shore sediment transport, wave climate, SLR, surface runoff, and groundwater processes (Hapke et al. 2006). The sections below describe the historical shoreline change experienced by beaches and bluffs within the San Francisco Coastal Zone.

Sandy Beaches

The western shoreline of San Francisco is a complex environmental system with coastal processes influenced by regional geology, sediment dynamics, and hydrodynamic processes (e.g., waves and tidal currents). The largest stretch of sandy shoreline extends along Ocean Beach from the Cliff House in the north southward to Sloat Boulevard. San Francisco's coastline has been heavily influenced by human activity, including direct modifications to the shoreline (e.g., sand placement and construction of coastal armoring structures) and other anthropogenic activities that modify local hydrodynamics (e.g., navigation channel dredging and construction of submerged engineered structures, such as the Southwest Ocean Outfall).

In the late 19th and early 20th centuries, the Ocean Beach shoreline was pushed 200 feet seaward of its natural position to construct the Great Highway, which parallels the coast. Erosion soon followed, causing a need for much of the shoreline to be stabilized with armoring to protect inland infrastructure. Embankments of sand were placed along the beach using material excavated during construction of infrastructure associated with the Clean Water Program in the 1980s and subsequently vegetated with European beachgrass and native dune vegetation to allow protective dunes to form (SPUR et al. 2012). European beachgrass facilitates the formation of tall narrow foredunes, up to 65 feet in height, which are aligned parallel to the shoreline (Seabloom et al. 2013). In contrast, native west coast beach grasses typically form smaller, broad, low profile sand drifts called hillocks, which support increased biodiversity. While the tall foredunes along Ocean Beach have successfully buffered landward areas from wave overtopping and flooding, they have negative consequences on endangered species such as the snowy plover through loss of nesting areas. The response of dune systems vegetated by native vs. non-native vegetation to SLR is uncertain and is an area of active research. Observations tend to suggest that dunes stabilized with non-native vegetation such as European beachgrass and iceplant may be more stationary and less able to migrate landward in response to sea level changes.

Ongoing maintenance dredging of the San Francisco Bar navigation channel (approximately 5 to 7 miles offshore of the Golden Gate) has deposited substantial quantities of sediment in the nearshore area[5], which passively nourish the northern part of Ocean Beach as waves move the sediment onshore. At the same time, reduced sediment supply from the San Francisco Bay-Delta during the 20th century has resulted in a shrinking of the San Francisco Bar, which historically sheltered Ocean Beach from powerful storm waves. While offshore deposits of dredged material have allowed the northern portion of Ocean Beach to advance over the past few decades, southern Ocean Beach has been an erosional hotspot. The physical processes responsible for this erosion are an area of active research; however, recent research suggests the following primary factors: (1) artificial build out of the Ocean Beach shoreline during the 20th century, (2) reduction in overall sediment supply and shrinking of the San Francisco Bar, (3) changes to nearshore wave dynamics which focus wave energy in some areas, and (4) patterns of scour around the Southwest Ocean Outfall, which modifies nearshore circulation and increase shoreline erosion (Barnard et al. 2012).

[5] The U.S. Army Corps of Engineers (USACE) dredges approximately 400,000 cubic yards of sediment annually from the San Francisco Main Ship Channel and typically places the sediment onto the southern portion of the San Francisco Bar in 35- to 45-foot water depth. The USACE has also conducted nearshore placement of dredged material several times since 2005 to promote onshore movement of sand to nourish the shoreline at Ocean Beach.

Bluffs and Cliffs

Coastal bluff and cliff[6] retreat in California can occur through a variety of marine and terrestrial processes. Terrestrial processes include weathering by rain and wind, groundwater seepage, seismic shaking, animal burrowing, landslides, and human development. Marine processes are primarily driven by wave action, which can play an active role in bluff retreat by eroding the bluff toe and destabilizing the bluff or cliff face. Wave action can also take a more passive role by removing eroded material at the base of the bluff or cliff and steepening the slope, making it more prone to landsliding. The rate of bluff or cliff retreat strongly depends on the physical properties of the rock material. The hardness and consolidation of the bluff or cliff directly affect the potential exposure of internal weaknesses to physical and chemical weathering. Although all bluffs and cliffs along the California shoreline exhibit trends of chronic erosion, episodic mass block failures in the form of slumping, landslides, and rockfalls, all of which can quickly remove massive amounts of bluff material, also occur. Large-scale bluff and cliff failures most commonly take place after big storms due to heavy surf and rainfall. It is this complex combination of terrestrial and marine processes that makes it difficult to understand and quantify historical rates of bluff and cliff shoreline change.

The northern portion of the San Francisco Coastal Zone is characterized by high cliffs, composed of relatively erosion-resistant material such as serpentinite, graywacke (a type of sandstone), and large rocks and boulders. These rocky cliffs are generally resistant to wave attack but are prone to terrestrial landslides and cliff retreat. The southern portion of the Coastal Zone between the Oceanside Treatment Plant and Fort Funston is particularly vulnerable to erosion. In this reach, the unconsolidated sandy bluffs of the Merced and Colma formations are readily destabilized by marine and terrestrial processes. Some of the most dramatic evidence of this erosion occurs during large precipitation events when storm runoff rushes down the bluff face, cutting gullies in the soft rock material and depositing it onto the beach.

Estimates of Historical Shoreline Change

The USGS National Assessment of Shoreline Change (Hapke et al. 2006) estimated historical rates of change along sandy shorelines of the California coast over the past 150 years. The net average long-term shoreline change rate was estimated to be -0.7 feet/year in the region encompassing the San Francisco coastline. Ocean Beach exhibited strong alongshore variations in shoreline change rates, presumably because of variations in wave energy and a long history of anthropogenic modifications to the shoreline. The northern end of the beach was characterized as “relatively stable,” while the southern end of the beach was “strongly erosional.” USGS shoreline change rates for bluff and cliff shorelines were not available in San Francisco.

BakerAECOM (2016) estimated historical rates of sandy beach, bluff, and cliff shoreline change along the San Francisco coastline as part of the FEMA SLR Pilot Study. Historical shoreline change estimates for sandy beaches were based on the available USGS data. Because historical shoreline change rates were

[6] A distinction is made between bluffs and cliffs for the purposes of this memorandum. A cliff is considered to be a steep, rocky, erosion-resistant geologic feature composed of hard bedrock material. Cliffs along the California coast are typically composed of rocks such as granite, sandstone, siltstone, and limestone. A bluff is considered to be a milder sloped, erodible geologic feature composed of weakly consolidated sedimentary material. Bluffs along the California coast are typically composed of sand, silt, and pebble material.

extremely variable along the San Francisco coastline and because historical shoreline change data were not available everywhere in the study area, BakerAECOM (2016) categorized each segment of shoreline and assigned a representative rate derived from analysis of regional shoreline change rates within central California (Table 3). Each segment of coastline was assigned to a category based on available data, local knowledge of the study area, bluff and cliff characteristics, and inspection of aerial photographs. Shoreline change categories ranged from stable to low, moderate, or high rates of erosion.

Table 3. Historical Shoreline Change Rates Developed for the FEMA SLR Pilot Study

Reach	Shoreline Change Category	Representative Shoreline Change Rate (feet/year)	Shoretype
Lands End to Cliff House	Low Erosion	- 0.2	Bluff
North Ocean Beach from Cliff House to Fulton St.	Stable	± 0.0	Sandy Beach
North Ocean Beach at Golden Gate Park (Fulton St. to Lincoln Way)	Low Erosion	- 1.0	Sandy Beach
Middle Ocean Beach (Lincoln Way to Noriega St.)	Moderate Erosion	- 2.1	Sandy Beach
Middle Ocean Beach (Noriega St. to Pacheco St.)	High Erosion	- 4.4	Sandy Beach
Middle Ocean Beach (Pacheco St. to Sloat Blvd.)	Moderate Erosion	- 0.5	Bluff
South of Sloat Blvd. to Fort Funston	High Erosion	- 1.4	Bluff

Source: BakerAECOM (2016). Notes: Representative rates were derived from analysis of regional shoreline change rates within central California.

Future Shoreline Change

Projections of Future Shoreline Change

While historical rates of shoreline change can be estimated from careful measurements of aerial photographs and topography changes, no standard method exists to predict how these rates will evolve in the future. Coastal engineers apply a variety of methods and techniques to incorporate the effects of SLR on shoreline response. The simplest approach is to project historical rates of shoreline change into the future; however, there is broad consensus among scientists that SLR will increase the rate of shoreline retreat above historical values. FEMA's SLR Pilot Study developed estimates of future shoreline change for each segment of shoreline identified in Table 3 using a simplified method for sandy beaches, bluffs, and cliffs along the San Francisco coast. This method relied on an approach that increased a portion of the historical shoreline change rate (the portion assumed to have been caused by ongoing SLR over the past century) by an amount proportional to the relative increase in the future rate of SLR. The predicted increased rates of shoreline retreat were multiplied by the number of years elapsed at each planning horizon to estimate the total amount of predicted shoreline retreat. The predicted future shoreline change distances for each SLR scenario are shown in Table 4 and Table 5. These shoreline changes distances represent the projected natural, unimpeded shoreline retreat in the absence of coastal structures or future beach nourishment activities.

The predicted shoreline change distances are similar to estimates presented as part of the SPUR Ocean Beach Master Plan: Coastal Management Framework (SPUR et al. 2015), which estimated shoreline retreat distances for SLR scenarios of 14 inches at 2050 and 55 inches at 2100. These scenarios are similar to the 12 inches at 2050 and 66 inches at 2100 SLR scenarios evaluated as part of the FEMA SLR Pilot Study. A comparison of the predicted shoreline retreat distances is shown in Table 6, which shows good agreement between the studies despite differences in the applied methods[7].

Table 4. Predicted Future Shoreline Change Distances for Sandy Beaches Developed for the FEMA SLR Pilot Study

			SLR Scenario and Future Shoreline Change Distances (feet)			
Shoreline Change Category	**Sandy Beach Areas**	**Representative Historical Sandy Beach Shoreline Change Rate (feet/year)**	**12 inches at 2050**	**24 inches at 2050**	**36 inches at 2100**	**66 inches at 2100**
Stable	North Ocean Beach from Cliff House to Lincoln Way	± 0.0	- 25	- 65	- 110	- 220
Low Erosion	North Ocean Beach at Golden Gate Park (Fulton St. to Lincoln Way)	- 1.0	- 65	- 100	- 195	- 310
Moderate Erosion	Middle Ocean Beach from Lincoln Way to Noriega St. and from Pacheco St. to Sloat Blvd.	- 2.1	- 110	- 150	- 300	- 410
High Erosion	Middle Ocean Beach from Noriega St. to Pacheco St.	- 4.4	- 200	- 235	- 500	- 615

Source: BakerAECOM (2016)

[7] For the purposes of this evaluation, “good” agreement is a relative assessment of the alignment between the two studies that takes into consideration the large uncertainties in projecting future shoreline change as well as other differences between the applied methods (for example, the use of different SLR scenarios).

Table 5. Predicted Future Shoreline Change Distances for Bluffs and Cliffs Developed for the FEMA SLR Pilot Study

			SLR Scenario and Future Shoreline Change Distances (feet)			
Shoreline Change Category	**Bluff and Cliff Areas**	**Representative Historical Bluff and Cliff Shoreline Change Rate (feet/year)**	**12 inches at 2050**	**24 inches at 2050**	**36 inches at 2100**	**66 inches at 2100**
Low Erosion	Lands End and Cliff House	- 0.2	- 10	- 15	- 30	- 40
Moderate Erosion	None	- 0.5	- 35	- 50	- 95	- 125
High Erosion	Bluffs south of Sloat Blvd. to Fort Funston	- 1.4	- 90	- 130	- 260	- 350

Source: BakerAECOM (2016)

Table 6. Comparison of Predicted Shoreline Retreat Distances – Ocean Beach Master Plan and FEMA SLR Pilot Study

	Ocean Beach Master Plan		FEMA SLR Pilot Study	
Shoreline Segment	**14 inches at 2050 (feet)**	**55 inches at 2100 (feet)**	**12 inches at 2050 (feet)**	**66 inches at 2100 (feet)**
North Ocean Beach	- 30	- 185	- 25 to - 65	- 220 to - 310
Middle Ocean Beach	- 110	- 365	- 110	- 410
South Ocean Beach	- 150	- 405	- 90	- 350

Note: Predicted shoreline retreat distances are shown for a "no action" scenario, which does not take into account future management actions such as beach nourishment and projects natural shoreline retreat without consideration of the effects of coastal armoring structures, which would limit shoreline retreat along armored segments.
Source: SPUR et al. (2015); BakerAECOM (2016)

Challenges with Predicting Future Shoreline Change

Shoreline retreat in response to SLR is a natural process that results in establishment of a dynamic equilibrium as the shoreline adjusts to prevailing water level and wave conditions. As sea levels rise, beaches and bluffs naturally retreat to a new equilibrium position; however, construction of coastal armoring structures, such as seawalls and revetments, stop or slow this natural process. Coastal protection structures fix the shoreline in place along armored segments. These structures can contribute to loss of the sandy beach in cases where the coastal structure impedes the ability of the shoreline to migrate inland. Along unarmored shorelines, natural retreat processes may threaten public use areas, such as parking lots, trails, and bathrooms landward of the beach. The future shoreline projections provided above assume shoreline change would progress unimpeded in the future. They do not take into account the effect of coastal protection structures in halting or slowing down shoreline retreat or the shoreline adjustments that would occur in response to removal of existing armoring. SLR impacts presented in this memorandum are discussed in terms of "with armoring" and "without armoring," and SLR hazards zones for coastal segments protected by existing coastal armoring structures are symbolized differently in Attachment A to distinguish them from natural, unarmored segments[8].

4.3 Water Quality

Saltwater Intrusion

Saltwater intrusion into aquifers can occur when freshwater aquifers have a direct connection to the ocean. The extent of saltwater influence within freshwater aquifers depends on the balance between dense saltwater intruding from the ocean side and the characteristics of the freshwater aquifer, including subsurface geology, elevation of the water table, volume and rate of groundwater withdrawal, and rate of recharge. The San Francisco Regional Groundwater Storage and Recovery Project (San Francisco Planning Department 2014) evaluated the potential for saltwater intrusion into the Westside Groundwater Basin and concluded that saltwater intrusion is not currently occurring along the western boundary of the basin at its interface with the ocean; however, the shallow aquifer of the basin may be susceptible to saltwater intrusion under certain conditions.

The extent of saltwater intrusion into a freshwater aquifer is affected by the relative difference between water levels in the ocean and the aquifer. Typically, groundwater elevations are higher than mean sea level and groundwater flows toward the coast, effectively blocking intrusion of saltwater into the aquifer. When the relative difference between the ocean and the groundwater level decreases – either due to drawdown of the aquifer by pumping or raising of mean sea level due to SLR – the interface between saltwater and freshwater can move inland. Once saltwater intrudes into a freshwater aquifer, it can be very difficult and costly to remove.

The impact analysis conducted as part of the Regional Groundwater Storage and Recovery Project did not specifically address SLR impacts on potential saltwater intrusion into the Westside Groundwater Basin; however, the effects of long-term SLR are similar to the effects of long-term groundwater drawdown in terms of its influence on saltwater intrusion. Both SLR and long-term groundwater drawdown increase the potential for saltwater intrusion into the freshwater aquifer. CCSF continues to conduct regular monitoring of groundwater levels at multiple sites along the western edge of CCSF from Golden Gate Park to Fort Funston as well as groundwater modeling to develop a better understanding of conditions that may lead to increased saltwater intrusion in the future.

Coastal Water Pollution

Sea level rise may contribute to increased coastal water pollution issues in some coastal areas due to the inundation of toxic soils, rising water tables, and increases in non-point source pollution. These impacts are not expected to cause any issues in the San Francisco Coastal Zone because no such sources of pollution were identified; however, there may be an increased risk of coastal water pollution during

[8] In Attachment A, dashed lines indicate the potential landward limit of the Special Flood Hazard Area along reaches currently protected by coastal armoring structures such as seawalls and revetments. These areas would be exposed to wave and erosion hazards if existing coastal armoring structures were to be removed or fail in the future.

future combined coastal and precipitation storm events if the wastewater system is compromised by ongoing coastal erosion. The SFPUC is currently conducting a detailed assessment of system vulnerability to SLR as part of the Sewer System Improvement Program.

5 Potential Risks of Sea Level Rise to Coastal Resources and Development

In addition to direct exposure to coastal flooding and erosion, coastal communities may also be at risk of, and indirectly affected by, impairment of critical infrastructure and services. Within the San Francisco Coastal Zone, coastal retreat could directly damage, destroy, or temporarily interrupt critical infrastructure including transportation and wastewater. This section evaluates direct and indirect impacts to the following categories of coastal resources and assets as identified by the CCC's SLR policy guidance[9]:

- Existing and planned development, including public and private property
- Vulnerable public facilities, such as schools, post offices, libraries, or community centers
- Critical infrastructure, including transportation, water and wastewater, and power
- Public access, including parking, beaches, recreation areas, and coastal trails
- Environmentally sensitive habitats and sensitive marine species, such as seals and sea lions and sensitive bird species

AECOM reviewed the full list of asset categories identified in the CCC SLR Policy Guidance and screened out assets that did not fall within the highest SLR vulnerability zone (the 66-inch SLR scenario). The discussion presented below focuses on those assets that were within the Coastal Zone and potentially exposed to wave and erosion hazards under the SLR scenarios evaluated as part of this study.

5.1 Assets Impacted by Sea Level Rise and Potential Consequences

Existing and Planned Development

Existing and planned developments within the Coastal Zone may be exposed to coastal flooding and erosion hazards under future SLR scenarios. Table 7 presents the approximate total number of impacted buildings, the scenario at which they are directly impacted, and whether they are in an area currently protected by coastal armoring (e.g., seawall or revetment). Buildings are considered to be directly impacted when the impact zone reaches the building footprint; however, use of these structures may be disrupted at an earlier time due to loss of access, temporary flooding, or undermining of these structures. This estimate is based on an overlay of the FEMA SLR pilot study hazard layers and the CCSF building footprint layer[10].

[9] Note that not all asset categories listed in the CCC SLR Policy Guidance are present within the San Francisco Coastal Zone.

[10] Visual examination of the building footprint layer compared to aerial imagery indicated that some adjacent buildings may be merged into a single building footprint. Therefore, the estimate of impacted buildings shown in Table 7 may underestimate the total number of impacted buildings that would be obtained if each individual building was represented independently in the building footprint layer.

Table 7. Estimates of Existing Development Exposed to Future SLR Hazards within the San Francisco Coastal Zone

Coastal Armoring	Number Impacted at 12 inches	Number Impacted at 24 inches	Number Impacted at 36 inches	Number Impacted at 66 inches	Total Number of Buildings	Data Sources
Protected by existing coastal armoring*	0	7	55	39	101	FEMA SLR Pilot Study hazard layers; San Francisco building footprints
Not protected by existing coastal armoring	0	0	7	59	66	
Total	**0**	**7**	**62**	**98**	**167**	

*Note: Coastal armoring indicates that the area is currently protected by an existing structure such as a seawall or revetment. Future maintenance or performance of the structure under future SLR scenarios is unknown. Risk of impact to these structures is relatively low if existing coastal armoring structures are maintained. While these areas are currently protected, if the structure were to be removed or fail, these areas may be exposed to flood and erosion hazards in the future.

This estimate includes only existing buildings and does not account for any future development that may occur in the future. Approximately 167 buildings within the San Francisco Coastal Zone may be exposed to coastal flooding and erosion hazards under the analyzed scenarios, of which the majority are residential buildings: either single family residences or multi-unit. Of the 167 buildings impacted, 101 are in areas currently protected by coastal armoring structures and 66 are in areas currently unprotected by coastal armoring. Impacts on many of these structures could be avoided if existing coastal protection structures are maintained/improved over time; however, protecting developed areas will come at the expense of other impacts, such as the loss of sandy beach areas.

Included in this list of buildings are residential and commercial structures; restaurants, including the Cliff House Terrace Room and Beach Chalet Brewery and Restaurant; and the Great Highway Inn. The estimate may also include buildings not regularly occupied, such as parking garages. At least one nursery school, the Sunset Cooperative Nursery School, is within the impact area. This school, at Great Highway and Lawton Street, is first impacted by the 66-inch SLR scenario.

Coastal-Dependent Development

Coastal-dependent development refers to any development or use which requires a site on, or adjacent to, the sea to be able to function. Examples of such development include ports, harbors, piers, or docks, or offshore oil and gas development. There is no existing coastal-dependent development within the San Francisco Coastal Zone.

Critical Infrastructure and Public Facilities

Transportation

The San Francisco Pacific coast borders a vast network of transportation infrastructure and services. A series of interconnected highways, city streets, bus lines, and bike paths provides access from the neighborhoods throughout CCSF to nearby coastal resources. Transportation infrastructure alignments within the San Francisco Coastal Zone often traverse low-lying dunes and erodible bluffs, exposing this infrastructure to flood and erosion hazards.

The Great Highway parallels Ocean Beach and extends southward to Fort Funston and is the first transportation asset projected to be directly impacted by flood and erosion hazards under the 12-inch SLR scenario. This highway is the primary artery along the beach, connecting many intersecting neighborhood roadways and providing access to public facilities and parking areas. The unarmored portion of the highway south of Sloat Boulevard is particularly vulnerable due to a narrowing beach width and retreat of the coastal bluff. Planning efforts are currently underway to develop a resilient coastal protection strategy in this area (SPUR et al. 2015). Without maintenance of the seawall protecting much of Ocean Beach, the middle and south sections of the area will also experience direct impacts under the 12-inch SLR scenario. Loss (or reduction of width) of the Great Highway would also result in loss of the bike paths that parallel this section of the roadway.

Under the 36-inch SLR scenario, the coastal hazard area expands to include the western edge of Sloat Boulevard. Without maintenance of the Ocean Beach seawall, nearly all of the Great Highway is exposed to the direct effects of flooding and erosion under this scenario. Without maintenance of the seawall, shoreline erosion and coastal flooding would also affect the western portions of the following adjacent roadways: Ortega Street, Pacheco Street, Quintara Street, Rivera Street, Santiago Street, 8th Avenue, and Taraval Street. The 36-inch SLR scenario will directly impact the bus stop at the Great Highway and Sloat Boulevard. Without maintenance of the seawall, additional bus stops directly affected by this scenario include the Great Highway and Rivera Street, and the Great Highway at the Beach Chalet.

The 66-inch SLR scenario will further expand the coastal hazard area to include the western portion of the following roadways: Lincoln Way, Moraga Street, Noriega Street, Ulloa Street, Vincente Street, and Wawona Street. Additional transportation assets affected by this scenario include the MUNI terminal at the intersection of Judah and La Playa Street and the bus station at Noriega Street and 48th Avenue. Without maintenance of the seawall, the following bus stops will also be directly impacted: Rivera and 48th Avenue, Great Highway and Quintara Street, Great Highway and Fulton Street, Great Highway and Lincoln Way, and 48th Avenue and Ortega Street.

The majority of the transportation infrastructure is adjacent to low-lying sandy dunes along Ocean Beach, making it particularly sensitive to the impacts of flooding and erosion. Not preserving the existing transportation infrastructure would affect coastal access and routes connecting the Outer Sunset and Richmond neighborhoods.

Tsunami Evacuation Routes

The CCSF Tsunami Response Annex (CCSF 2011) identifies tsunami evacuation routes and evacuation assembly sites. Evacuation assembly sites include elementary, middle, and high schools in the Richmond and Sunset Districts. All evacuation assembly sites are outside the SLR vulnerability zone; however, the following evacuation and emergency bus routes are potentially impacted:

- Point Lobos Avenue: impacted south of the Cliff House at the 36-inch SLR scenario
- Fulton Street: intersection with Great Highway potentially impacted at the 36-inch SLR scenario (located behind seawall)

- Balboa Street: intersection with Great Highway potentially impacted at 66-inch SLR scenario (located behind seawall)
- Lincoln Boulevard: intersection with Great Highway impacted at 36-inch SLR scenario
- Noriega Street: intersection with Lower Great Highway impacted at 36-inch SLR scenario
- Taraval Street: intersection with Lower Great Highway impacted at 36-inch SLR scenario (located behind seawall)
- Sloat Boulevard: intersection with Great Highway impacted at 12-inch SLR scenario
- Planned evacuation bus route (westbound on Noriega Street, turn left on 48th Avenue, and left on Ortega Street) will be impacted at the 36-inch SLR scenario

SFPUC Facilities

The Oceanside Treatment Plant, a major wastewater treatment facility, is located at South Ocean Beach at the intersection of the Great Highway and Skyline Boulevard. In addition to the infrastructure in the immediate vicinity of the plant, there also exists a large network of stormwater and wastewater structures under the Great Highway and other nearby city streets. Several combined stormwater/sewage outfall pipes that discharge on the beach during large storm events are already exposed to coastal flooding and erosion hazards under existing conditions. Specific locations include Vicente Street outfall, Seacliff #2 outfall, Lincoln Way outfall, and the Vista Grande outfall. Flooding of wastewater outfalls may affect system operations. The SFPUC is currently conducting a detailed assessment of system vulnerability to SLR as part of the Sewer System Improvement Program.

Under the 12-inch SLR scenario, exposed wastewater assets expand to include large sections of sewer lines under the Great Highway, particularly those south of Sloat Boulevard such as the Lake Merced Tunnel (used for storage and transport of untreated stormwater and wastewater to the Oceanside Treatment Plant). Left unprotected, these structures could become exposed and damaged by erosion, causing a large sewage spill in coastal waters. The SFPUC is currently evaluating the feasibility of implementing a resilient coastal protection strategy for the area south of Sloat Boulevard that would provide coastal protection for the Lake Merced Tunnel while maintaining public access and ecological benefits to the beach (SPUR et al. 2015).

Under the 36-inch SLR scenario, additional exposed assets include the Westside Pump Station, large sections of sewer lines under the Great Highway north of Sloat Boulevard, the Westside Transport Box, and the Oceanside Treatment Plant. If exposed to flooding and erosion, the sewage lines and transport boxes may cause a large sewage spill into coastal waters. Exposure of the electrical components such as the pump station or treatment plant has the potential to disrupt operations of the treatment facilities on CCSF’s west side.

The 66-inch SLR scenario will further expand the coastal hazard area to include the sewer lines beneath 48th Avenue.

The majority of the wastewater infrastructure is in low-lying sandy dunes along Ocean Beach, making it particularly sensitive to the impacts of flooding and erosion. Although the initial impacts to this system may be temporary effects caused by large storms, long-term shoreline erosion and inundation due to SLR have the potential to damage many of the components, increasing future repair, relocation, and environmental clean-up costs.

Water Supply and Power Infrastructure

No critical water supply and power infrastructure were identified within the San Francisco Coastal Zone; however, coastal flooding and shoreline retreat along heavily urbanized and developed City blocks could potentially disrupt many services, including water supply and power.

Other Public Facilities

There were no other public facilities (e.g., post offices, libraries, community centers) directly exposed to coastal flooding and erosion under the evaluated SLR scenarios.

Public Access, Beaches, Recreation Areas, Coastal Trails, Cultural Sites

San Francisco's Pacific coastline accommodates a wide range of public uses. Its rugged and scenic beauty promotes recreational activities such as beach lounging, surfing, and hiking. Situated on the open coast just south of the gateway into the San Francisco Bay, this landscape has also served as a prime location for many cultural uses throughout CCSF's history. Many of these sites are now attractions preserved for public exploration and host a variety of educational programs. SLR and long-term shoreline change may impact many public access features within the San Francisco Coastal Zone in the future.

The examples below provide specific impacts to key public assets within the San Francisco Coastal Zone.

Golden Gate National Recreation Area

The San Francisco Pacific coastline, from Golden Gate Bridge to Fort Funston, consists mostly of Federal lands that are part of the Golden Gate National Recreation Area (GGNRA). The GGNRA is composed of wave-cut rocky cliffs and several stretches of sandy shorelines such as Ocean Beach. The GGNRA provides access to an abundance of outdoor recreation activities while also preserving many archeological, cultural, and historical sites. Based on analysis of existing conditions, areas currently at risk include the Sutro Baths at Lands End and many of the dune trails along Ocean Beach.

Without intervention, the areas affected by flooding and erosion under the 12-inch SLR scenario will expand to include parking and beach access to Ocean Beach (affected locations are the intersection of the Great Highway and Balboa Street, across from the Beach Chalet soccer fields, the intersection of the Great Highway and Sloat Boulevard, and the parking area just north of the Oceanside Wastewater Treatment Facility). Under the 24-inch SLR scenario, additional exposed assets will include the Funston Beach Trail. The 36-inch SLR scenario will expose the Cliff House at Ocean Beach, the Sunset Trail at Fort Funston, Battery Davis at Fort Funston, and the Fort Funston Observation Deck. The 66-inch SLR scenario will further expand the coastal hazard area to include parking at the Nike Missile Site near Fort Funston.

The extent of the impacts described above depends on future beach nourishment and management practices. Because GGNRA is made up of a variety of shoretypes, sensitivity of these assets will vary along the shore. Rocky cliff habitat at the northern end the GGNRA is less sensitive to SLR than beaches and dunes farther south. For this reason, the assets listed above located along rocky cliffs will mostly be affected by temporary flooding due to future storm events. Assets described above located along beaches and dunes in the central and south sections of the shoreline may be vulnerable to complete removal and loss of public use due to shoreline erosion and beach retreat. Failure to preserve park facilities would affect coastal access and recreation, result in loss of historic memorials, and increase maintenance and replacement costs of trails and access roads.

Golden Gate Park

Golden Gate Park, located between Fulton Street and Lincoln Way, is a large public urban greenspace within CCSF. The park is more than 3 miles long and 0.5 mile wide and serves as an iconic recreational area. It receives approximately 13 million annual visitors and is the fifth most-visited city park in the United States. The western edge of the park is bordered by Ocean Beach, exposing the western side of the park's facilities to future wave action and rising seas. Golden Gate Park is first projected to be impacted by flooding and erosion hazards under the 36-inch SLR scenario. Without maintenance of the seawall at Ocean Beach and continued beach nourishment, dune retreat and flooding will threaten assets such as the Beach Chalet Restaurant and trails west of the Beach Chalet soccer fields.

The extent of the impacts described above depends on future beach nourishment and management practices. The park is in an erodible dune setting, making it sensitive to the impacts of flooding and erosion. Encroachment of these hazards into the western boundary of the park will reduce the size of the park area as well as increase costs to maintain trails and roads on the park's west side.

The San Francisco Zoo

The Zoo is on a 100-acre plot between Sloat Boulevard and Lake Merced. The western edge of the property borders the Great Highway and Ocean Beach. The Zoo is first projected to be impacted by flooding and erosion hazards under the 36-inch SLR scenario; however, the majority of damage to the zoo property would not occur until the 66-inch SLR scenario. Without maintenance of the revetment south of Sloat Boulevard (or development of an alternative coastal protection strategy; see SPUR et al. 2015), it is anticipated that under the latter scenario, the Zoo will lose most of its customer parking area. Aside from the parking lot, the Zoo is not expected to experience direct impacts from coastal flooding and erosion related to the evaluated SLR scenarios.

The extent of the impacts described above depends on future beach nourishment and management practices. The Zoo is in a transitional area between dunes and erodible bluffs, making it sensitive to future effects of flooding and erosion.

Lake Merced

Lake Merced, a freshwater lake south of the San Francisco Zoo, is used as a natural resource and recreational area for San Francisco. Due to its setback distance from the coastline and high elevation, no direct impacts from coastal flooding and erosion are expected to occur under the evaluated SLR scenarios. Potential impacts on water quality from saltwater intrusion are discussed in Section 4.

Ocean Beach

At 3.5 miles long, Ocean Beach is the largest sandy beach in San Francisco. With over 300,000 visitors each year, it serves as an iconic, public, multi-use area for the city. The sandy beaches of Ocean Beach experience seasonal and inter-annual variations in beach width but generally offer year-round public access and recreational opportunities. As discussed in Section 4.2, SLR will increase historical rates of shoreline change in the future. As the shoreline retreats landward, sandy beach widths will decrease and in cases where the shoreline reaches a coastal protection structure (such as a seawall or revetment), the sandy beach will be lost. Projected impacts of long-term shoreline retreat on sandy beaches along Ocean Beach are presented in Table 8. In general, sandy beaches along Ocean Beach narrow but are maintained for the 12-inch and 24-inch SLR scenarios; however, substantial narrowing of sandy beaches at the 36-inch and 66-inch SLR scenarios is projected to occur. The shoreline change projections suggest that the sandy beach will be lost for some portions of Ocean Beach under the 36-inch and 66-inch SLR scenarios if coastal structures are maintained and natural retreat is impeded.

The extent of the impacts described above depends on future beach nourishment and management practices. The Draft San Francisco Littoral Cell Coastal Regional Sediment Management Plan (ESA et al. 2016) evaluated future shoreline retreat in response to various erosion mitigation alternatives, including no action, beach nourishment, complete armoring, and managed retreat. The management plan found that a nourishment of 1.5 million cubic yards every 20 years would be required to maintain beach widths along middle Ocean Beach and a nourishment of 500,000 cubic yards every 20 years would be required to maintain beach widths along south Ocean Beach.

Table 8. Projected Impacts of Long-Term Shoreline Retreat on Sandy Beaches along Ocean Beach

	Sea Level Rise Scenario and Impacts			
Shoreline Section	**12 inches**	**24 inches**	**36 inches**	**66 inches**
North Ocean Beach (Cliff House to Lincoln Way) (Seawall)	Sandy beach narrows but is maintained	Sandy beach narrows but is maintained	Sandy beach narrows but is maintained	Sandy beach narrows but is maintained
Middle Ocean Beach (Lincoln Way to Noriega St.) (Dunes)	Sandy beach narrows but is maintained	Sandy beach narrows but is maintained	Shoreline retreats to existing toe of dunes and beach narrows north of Noriega St.; erosion hotspot at Noriega St.	Shoreline retreats through existing dunes north of Noriega St., resulting in complete removal of dunes; erosion hotspot at Noriega St.
Middle Ocean Beach (Noriega St. to Santiago St.) (Seawall)	Sandy beach narrows but is maintained	Sandy beach narrows but is maintained	Shoreline retreats to seawall, resulting in loss of sandy beach	Shoreline retreats to seawall, resulting in loss of sandy beach
Middle Ocean Beach (Santiago St. to Sloat Blvd.) (Dunes)	Sandy beach narrows but is maintained	Shoreline retreats to existing toe of dunes and beach narrows	Shoreline retreats through dunes to Great Highway, resulting in loss of sandy beach	Shoreline retreats past Great Highway, resulting in loss of sandy beach
South of Sloat Blvd. (Artificial Fill and Erodible Bluff)	Shoreline retreats to existing toe of bluff, resulting in loss of sandy beach	Loss of sandy beach	Loss of sandy beach	Loss of sandy beach

Note: The “shoreline” is defined as the location of the mean high water line, which will migrate landward in response to SLR and other coastal processes. This analysis assumes that existing coastal armoring structures such as seawalls and revetments would be maintained, essentially fixing the backshore position of the beach.

Olympic Club

Located just southwest of Lake Merced, the Olympic Club operates a series of three private golf courses that overlook the bluffs at Fort Funston to the Pacific Ocean. Due to their setback distance from the coastline and high elevation, the Olympic Club golf courses are not anticipated to experience the impacts of coastal flooding and erosion under the SLR scenarios evaluated for this study.

The California Coastal Trail

The California Coastal Trail is a network of public trails extending 1,200 miles through 15 counties along the California coast. San Francisco has established 10.5 miles through the GGNRA, with an option of continuing south along Ocean Beach and connecting with the Fort Funston Coastal Trail. Based on analysis of existing conditions, Ocean Beach, currently a critical connection between the north California Coastal Trail and the Fort Funston Coastal Trail, is vulnerable to the effects of flooding and erosion. Without intervention, the areas affected by flooding and erosion under the 12-inch SLR scenario will expand to also include beach access to the Fort Funston Coastal Trail.

The extent of the impacts described above depends on future beach nourishment and management practices. Because the California Coastal Trail depends on scenic coastal views to attract the use of visitors, it often traverses low-lying beach areas and locations close to the shoreline. For this reason, this asset is sensitive to future flood and erosion events. Sections of the trail have already been damaged or eroded at South Ocean Beach due to ongoing coastal erosion. Not preserving the remaining portions of the trail will result in a further loss of visitor use and will increase costs for a future replacement trail.

Public Restrooms and Other Facilities

Several public restroom facilities are located along Ocean Beach. The Sloat Boulevard facility is the most exposed due to its location seaward of the Great Highway. It is first projected to be impacted by flooding and erosion hazards under the 12-inch SLR scenario. Under the 36-inch SLR scenario, restroom facilities at the intersection of the Great Highway and Taraval Street and the Great Highway and Wawona Street are also anticipated to be impacted by flood and erosion hazards. Without maintenance of the seawall, the 66-inch SLR scenario will expose restrooms located at the Beach Chalet. Also exposed at the 66-inch SLR scenario is the restroom facility at Judah Street and the intersection of the Great Highway. Facilities at the Great Highway and Judah Street location are within 100 feet of the area expected to be impacted by the 36-inch SLR scenario. Therefore, this location may experience indirect effects from hazards under this scenario.

The extent of the impacts described above depends on future beach nourishment and management practices. All public restroom facilities are in low-lying dune areas, making them sensitive to the effects of increased flooding and erosion. In addition to reducing or completely removing the ability for public use, not protecting these restroom facilities will increase future maintenance and reconstruction costs for CCSF.

Historic/Archeological Resources

Three historic districts are contained within the San Francisco Coastal Zone: (1) Golden Gate Park Historic District, (2) West Fort Miley Historic District, and (3) Veterans Affairs Medical Center Historic District. West Fort Miley and Veterans Affairs Medical Center Historic Districts are not impacted by flooding and erosion hazards for the evaluated SLR scenarios. Impacts on Golden Gate Park were discussed above.

The following National Register of Historic Places are also within the San Francisco Coastal Zone and may be exposed to coastal flooding and erosion hazards due to SLR:

- Moss Flats Building: located at Great Highway and Lawton St; impacted at 66-inch SLR scenario
- Point Lobos Archaeological Sites: located at Sutro Baths; impacted by wave runup under existing conditions; SLR will increase magnitude and frequency of wave impacts to Sutro Baths ruins
- Beach Chalet: located at Great Highway at Golden Gate Park; impacted at 66-inch SLR scenario
- Delia Fleishhacker Memorial Building Site (demolished) – located at San Francisco Zoo; impacted at 66-inch SLR scenario
- *King Philip* and *Reporter* shipwrecks: located at Ocean Beach between Noriega and Ortega Streets; typically submerged or covered in sand under existing conditions; SLR will increase submergence of shipwrecks in the future and may make access more difficult and less frequent
- Camera Obscura: located at North Ocean Beach at Point Lobos Avenue; impacted at 24-inch SLR scenario

Environmentally Sensitive Habitats, Coastal Habitats, and Sensitive Species

The Coastal Zone provides an important environmental corridor that includes several sensitive or scarce coastal habitats, from sandy intertidal to coastal bluff and dune habitats. Much of the Coastal Zone is highly manipulated, but these areas nevertheless provide necessary feeding, resting, and breeding habitat for protected bird species, intertidal fish, invertebrate species, and marine mammals that forage in nearshore waters. Sea level rise is not anticipated to directly affect fish or marine mammal species in the San Francisco Coastal Zone, although indirect effects on sensitive plant and animal species may occur. Other aspects of climate change such as warming ocean temperatures and ocean acidification may also have significant impacts but are beyond the scope of this evaluation.

Two threatened bird species are documented at Ocean Beach. The western snowy plover, a federally listed threatened species, inhabits the dry back beach, especially in the central part of Ocean Beach, from July to May. The plover uses the upper beach between the dunes or seawall and the high-tide line for roosting and the wet sand near the tide line for foraging. As a result of its reliance on back beaches, the number of plovers spotted in this area declines as beaches narrow.

The bank swallow, a state-listed threatened species, nests in exposed bluff faces, and a colony has been documented near Lake Merced at the south end of Ocean Beach.

Both the sandy beach habitat inhabited by plover and the coastal bluffs inhabited by bank swallows will be increasingly exposed to wave action as seas rise and beaches narrow due to coastal erosion. The total area of sandy beach habitat is expected to diminish due to future SLR, and ongoing bluff erosion is expected to accelerate. Sandy beaches are dynamic environments that change with shifting currents and winds, shrinking in response to winter storms and growing during summer and fall. Coastal bluffs erode in the face of large winter waves, depositing new sediment to augment the beaches below them. However, historical riverine depositional cycles have been altered, and the rate of deposition from bluff erosion is not expected to offset the rise sea level. Consequently, an overall decrease in sandy beach habitat is expected, and existing bank swallow nesting holes in coastal bluffs may be degraded or removed by waves and increased erosion or by the installation of coastal armoring. Habitat loss and degradation could affect local populations of both species. The extent of these impacts depends on future beach nourishment and management practices.

Rocky cliff habitat at the northern end of the San Francisco Coastal Zone is less sensitive to erosion than bluffs and dunes farther south. While high tide levels will increase along these habitats, expected impacts within the planning horizons are limited. Some portions of current rocky intertidal habitat would become subtidal, while other portions of rock cliff currently above the intertidal zone would become intertidal as a result of SLR.

Land Use Constraints

The San Francisco Coastal Zone is subject to several land use constraints that that may increase the vulnerability and risk of coastal resources and reduce the number and viability of various adaptation options, including:

- The San Francisco Coastal Zone is heavily developed, which leaves little room to relocate vulnerable assets.
- Critical infrastructure (such as wastewater infrastructure) is close to the coastline and within the SLR vulnerability zone. This infrastructure is costly to replace or relocate.
- Coastal areas serve multiple land uses such as transportation corridors, public access and recreation, and sensitive habitat. Balancing the competing needs of these resources makes climate change adaptation challenging[11].
- Coastal property and infrastructure is owned by many individual property owners (such as homeowners) and managed by multiple federal and CCSF agencies (such as the National Park Service, San Francisco Public Utilities Commission, Department of Public Works, and Municipal Transportation Agency). This makes development of integrated regional adaptation strategies challenging.

5.2 Identified Data Gaps

The following data gaps were identified through development of this existing data summary and SLR vulnerability and risk assessment:

- Effect of long-term SLR on the potential for saltwater intrusion into freshwater aquifer
- Effect of climate change on storm characteristics, offshore wave heights, and ENSO cycles
- Uncertainty in future management of coastal resources within the San Francisco Coastal Zone, including plans for maintenance and/or removal of existing coastal armoring structures and beach nourishment activities by the U.S. Army Corps of Engineers

[11] Much of the groundwork in balancing these competing interests was laid through development of the Ocean Beach Master Plan (SPUR et al. 2012), which provides a vision for future unified actions at Ocean Beach.

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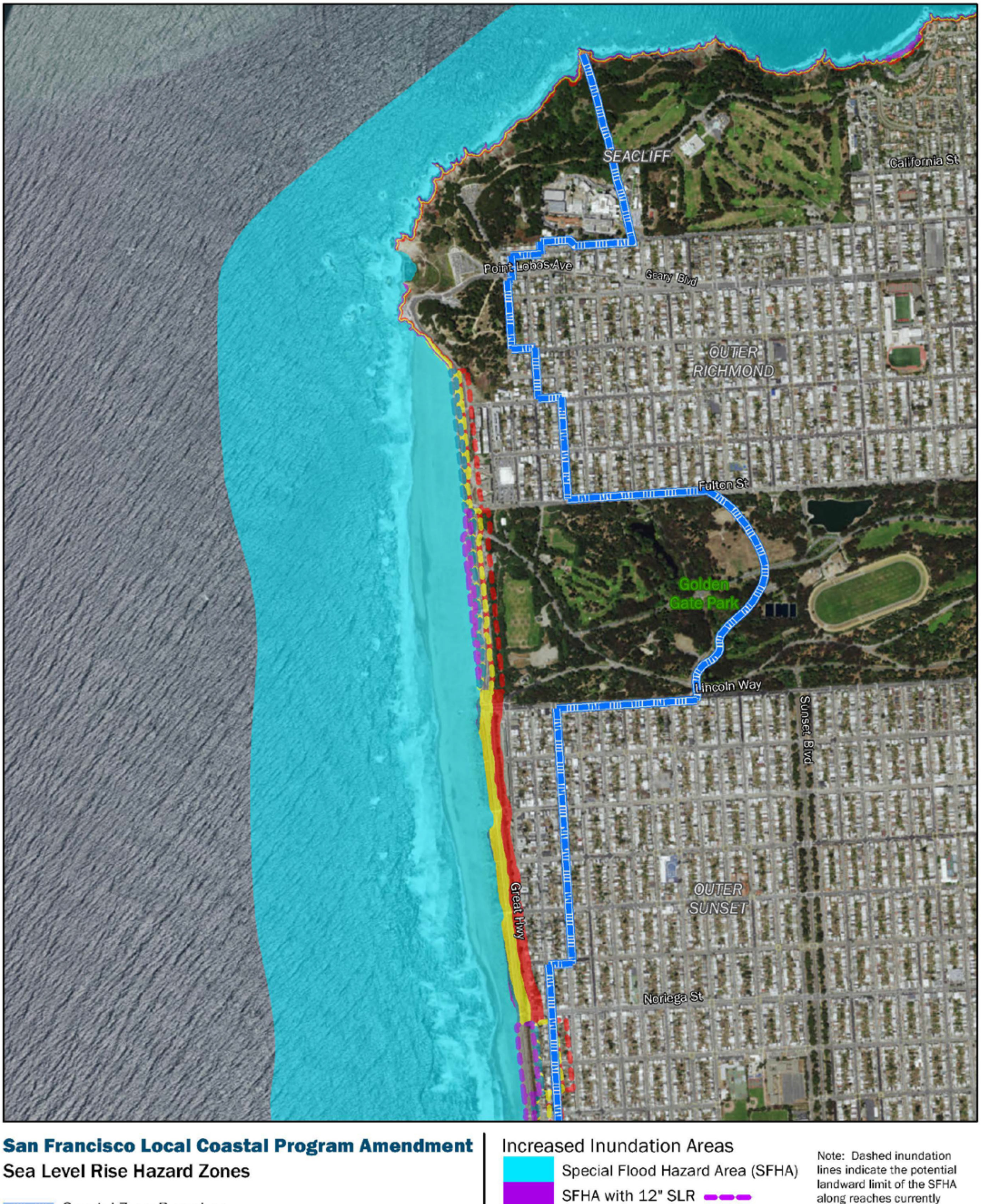
Attachments

Attachment A. FEMA Sea Level Rise Pilot Study Exposure Maps

Attachment A
FEMA Sea Level Rise Pilot Study Exposure Maps



San Francisco Local Coastal Program Amendment

Sea Level Rise Hazard Zones

Coastal Zone Boundary

0 1,000 2,000 3,000 Feet

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Increased Inundation Areas

Special Flood Hazard Area (SFHA)

SFHA with 12" SLR

SFHA with 24" SLR

SFHA with 36" SLR

SFHA with 66" SLR

Note: Dashed inundation lines indicate the potential landward limit of the SFHA along reaches currently protected by coastal armoring structures such as seawalls and revetments if the structures were to be removed or fail.

San Francisco Local Coastal Program Amendment

Sea Level Rise Hazard Zones

Coastal Zone Boundary

0 1,000 2,000 3,000 Feet

Page 2 of 2

Increased Inundation Areas

- Special Flood Hazard Area (SFHA)
- SFHA with 12" SLR
- SFHA with 24" SLR
- SFHA with 36" SLR
- SFHA with 66" SLR

Note: Dashed inundation lines indicate the potential landward limit of the SFHA along reaches currently protected by coastal armoring structures such as seawalls and revetments if the structures were to be removed or fail.