City of Seal Beach
Sea Level Rise Vulnerability Assessment

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Contents

Table of Figures

Table of Tables

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1. Introduction

1.1 Study Approach

The Sea Level Rise Vulnerability Assessment for the City of Seal Beach assesses potential impacts to coastal resources across multiple sea level rise (SLR) scenarios. An inventory of coastal resources within the City was compiled as an initial step of the Vulnerability Assessment. Analyses then focused on the extent to which local coastal hazards are influenced by multiple sea level rise scenarios. The overlap of projected future hazard zones and coastal resources is used to identify future vulnerabilities and the SLR thresholds at which critical coastal resources of the City are impacted. Key questions that guide the vulnerability assessment are illustrated in Figure 1-1. The Vulnerability Assessment is designed to inform policy and SLR adaptation strategy development as part of the City of Seal Beach Local Coastal Program update process.

For the purposes of this study a coastal resource is broadly defined as any natural or constructed feature that provides a benefit to the City. City coastal resources are grouped into the following categories: coastal development, utilities infrastructure, public safety facilities, transportation infrastructure, coastal access and recreation, and environmental resources. An inventory of those resources included in the Vulnerability Assessment can be found in Section 3.

The vulnerability of a coastal resource to SLR hazards is evaluated through an analysis of its exposure, sensitivity, and adaptive capacity. Within this study exposure refers to the type, duration, and frequency of coastal hazards a specific resource is subject to under a given SLR scenario. Sensitivity represents the degree to which a resource is impaired by exposure to coastal hazards, and adaptive capacity refers to the ability of a resource to cope with changes in coastal hazards over time. A discussion of the specific coastal hazard analysis methodologies used within the study can be found in Section 4.4.

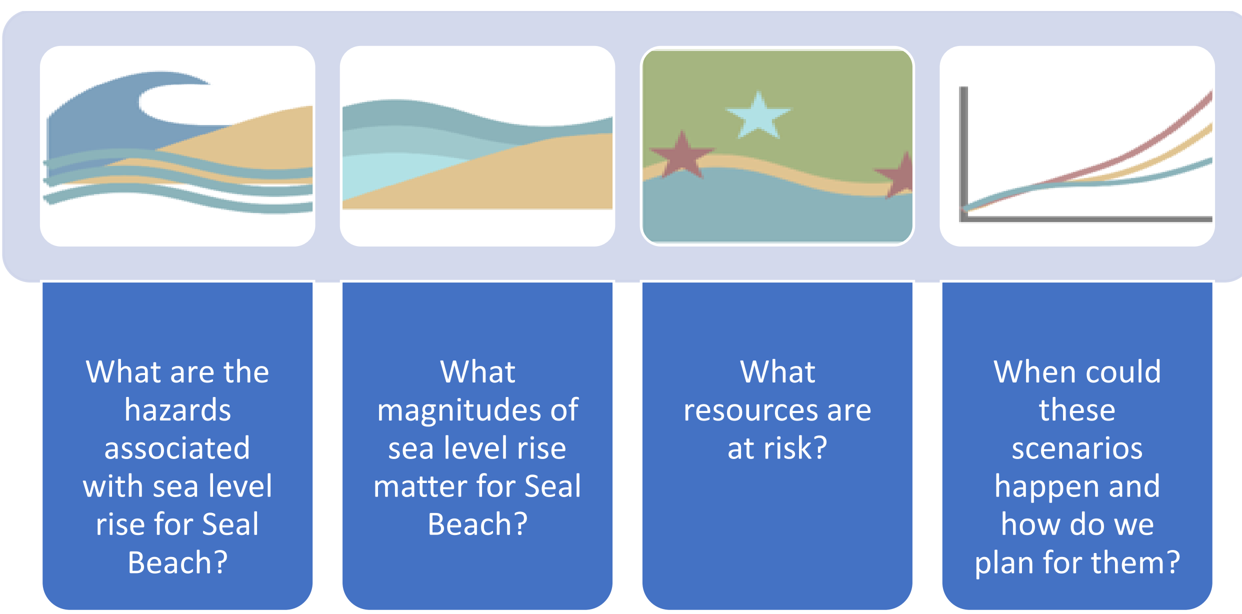


Figure 1-1: Key questions for a Vulnerability Assessment.

1.2 Coastal Setting

The City of Seal Beach is located within the northern portion of Orange County. The coastal setting within the City is defined by a number of major shoreline structures (Figure 1-2). The northwestern shoreline of the City is bordered by the San Gabriel River. The San Gabriel River mouth is defined by two jetty structures. The east jetty of the San Gabriel River extends approximately 200 feet beyond the City shoreline while the west jetty, which also forms part of the Alamitos Bay Entrance Channel, extends significantly further.

Immediately southeast of the San Gabriel River is the primary sandy beach area of the City. The sandy beach area is divided into western and eastern sections by the Seal Beach Municipal Pier (Figure 1-3). The western portion of the Municipal Pier is augmented with a concrete sheet pile groin. The western portion of the sandy beach is the larger of the two areas and generally varies from approximately 500 to 1000 feet in width. Beach width along the smaller eastern beach varies from 100 to 400 feet, occasionally narrowing further during episodic erosion events. This sandy beach area is backed by parking facilities and shoreline development including a small engineered wall bordering the Seal Beach Promenade.

The western jetty of Anaheim Bay forms the eastern barrier of the recreational beach area. This trapezoidal rubble mound jetty and a second eastern jetty downcoast make up the entrance to the Seal Beach Naval Weapons Station (SBNWS), providing significant wave protection to the interior of Anaheim Bay. Downcoast of the eastern Anaheim Bay jetty is the community of Surfside, a private development that lies seaward of the Pacific Coast Highway (Figure 1-4). The shoreline along the surfside community consists of an open coast sandy beach. Residential development lies immediately landward of the sandy beach area, with some areas of rock revetment fronting the far western structures of the community.

Figure 1-2: Coastal setting within the City of Seal Beach

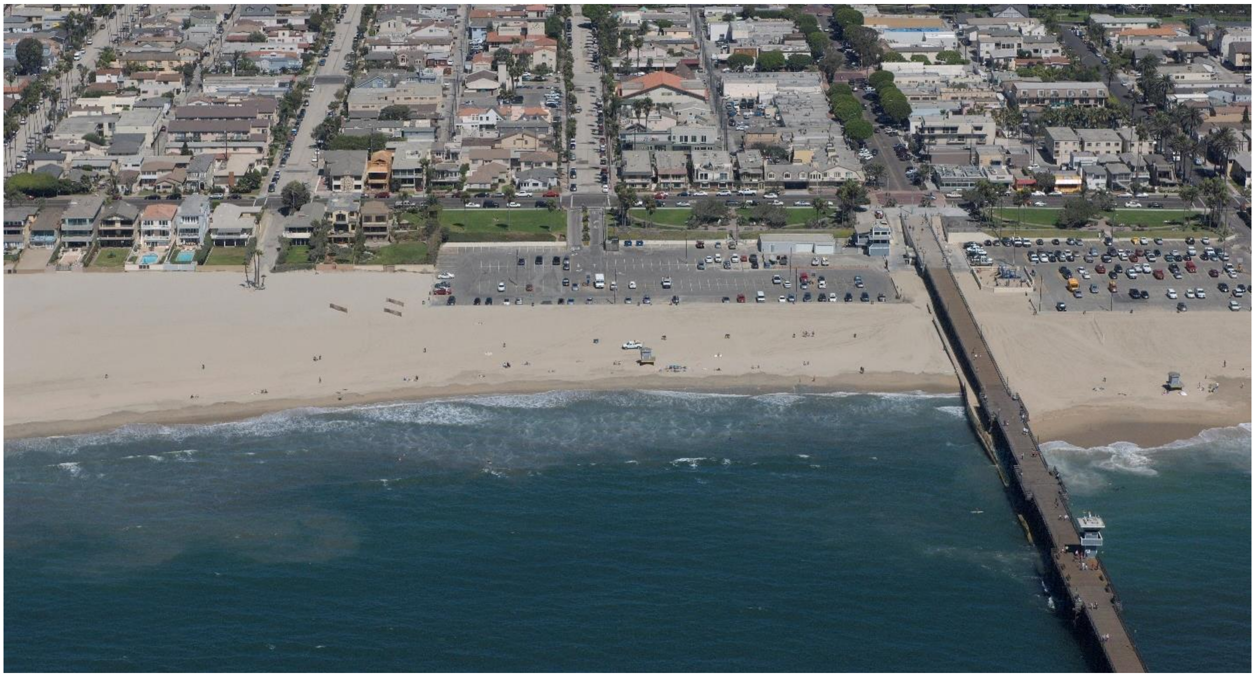


Figure 1-3: Seal Beach Municipal Pier and surrounding beach areas (Copyright © 2008. Kenneth and Gabriel Adelman, California Coastal Records Project).

Figure 1-4: Eastern Seal Beach coastline featuring the Anaheim Bay east jetty, Pacific Coast Highway, and western border of the Surfside community (Copyright © 2008. Kenneth and Gabriel Adelman, California Coastal Records Project).

1.3 Study Area

The study area for the Vulnerability Assessment encompasses the full extent of the City of Seal Beach shoreline and coastal zone. The study does not include specific analyses of resources that are outside of City jurisdiction such as the Seal Beach Naval Weapons Station. The study area extends landward as necessary to capture the full extent of coastal hazards present under each SLR scenario analyzed. There are three distinct regions where the combined effects of SLR, coastal and fluvial storms could result in flooding of the community. These regions are subject to unique hazards as discussed below.

1.3.1 Seal Beach - Open Coast

The coastal reach between the San Gabriel River and Anaheim Bay jetties encompasses West Beach, the Seal Beach Municipal Pier and East Beach. This is the center of beach-related activity in Seal Beach due to the accessibility and proximity to Main Street, residential development and visitor serving amenities. This area is currently exposed to coastal erosion, wave runup and flooding during extreme events. Sea level rise has the potential to increase these hazards impacting the recreational beach areas, amenities and residential development.

1.3.2 Surfside Community – Open Coast

The Surfside Community, south of Anaheim Bay, is also exposed to the open coast and associated process of coastal erosion, wave runup and flooding during extreme events. Located downcoast of complete littoral barrier formed by the Anaheim Bay jetties, this segment of shoreline is particularly vulnerable to erosion and dependent on regular nourishment from the United States Army Corps of Engineers (USACE) to maintain a sandy beach in front of residential development.

1.3.3 Inland low-lying areas

Inland low-lying areas of Seal Beach are also susceptible to potential flooding from sea level rise in combination with high tides and fluvial events from sources such as the San Gabriel River, Los Cerritos Wetlands and Anaheim Bay. The low-lying areas include portions the Electric Avenue corridor, commercial development adjacent to Westminster Boulevard and Leisure World.

2. Coastal Processes

Coastal processes refer to the waves, water levels, and sediment transport (including both long-shore and cross-shore) which shape the coastline of Seal Beach. These dynamic processes are largely driven by natural forces but have also been significantly modified by anthropogenic activities (i.e. development, coastal structures and beach nourishment). This section describes coastal processes and how they have affected the shoreline along Seal Beach. The influence of SLR on coastal processes is discussed in Section 4.

2.1 Water Levels

The tides in Southern California are semidiurnal, meaning there are two low waters and two high waters each lunar day, an approximately 25-hour time period. The National Oceanographic and Atmospheric Administration (NOAA) operates tide stations throughout southern California. The Los Angeles tide station (Station 9410660) provides a long-term sea level record near the City of Seal Beach. The station is located within Los Angeles Harbor and has been collecting data since 1923. Data from this station represents the most complete source of water elevation data relevant to the City of Seal Beach and can be used to characterize the variability in existing water levels (Figure 2-1).

Astronomical tides account for the most significant amount of variability in the total water level. Typical daily tides range from mean lower low water (MLLW) to mean higher high water (MHHW), a tidal range of about 5.5 feet. During spring tides, which occur twice per lunar month, the tide range increases to almost 7 ft due to the additive gravitational forces caused by alignment of the sun and moon. During neap tides, which also occur twice per lunar month, the forces of the sun and moon partially cancel out, resulting in a smaller tide range of about 4 ft. The largest spring tides of the year, which occur in the winter and summer, are sometimes referred to as “King” tides and result in high tides of 7 ft or more above MLLW and tidal ranges of more than 8 ft. King tides can lead to dry-weather or “nuisance” flooding in low-lying coastal areas even in the absence of a storm or swell event, though this is currently not an issue within the City of Seal Beach.

Ocean water levels typically vary within predictable ranges; however, it is not uncommon to experience sea level anomalies such as El Niño or storm surge that significantly increase the predicted water level above the normally-occurring astronomical tide. These events can increase the predicted tides over the course of several days to several months. SLR will cause these anomalous tidal elevations to become more commonplace as existing water levels rise across the entire tidal range.

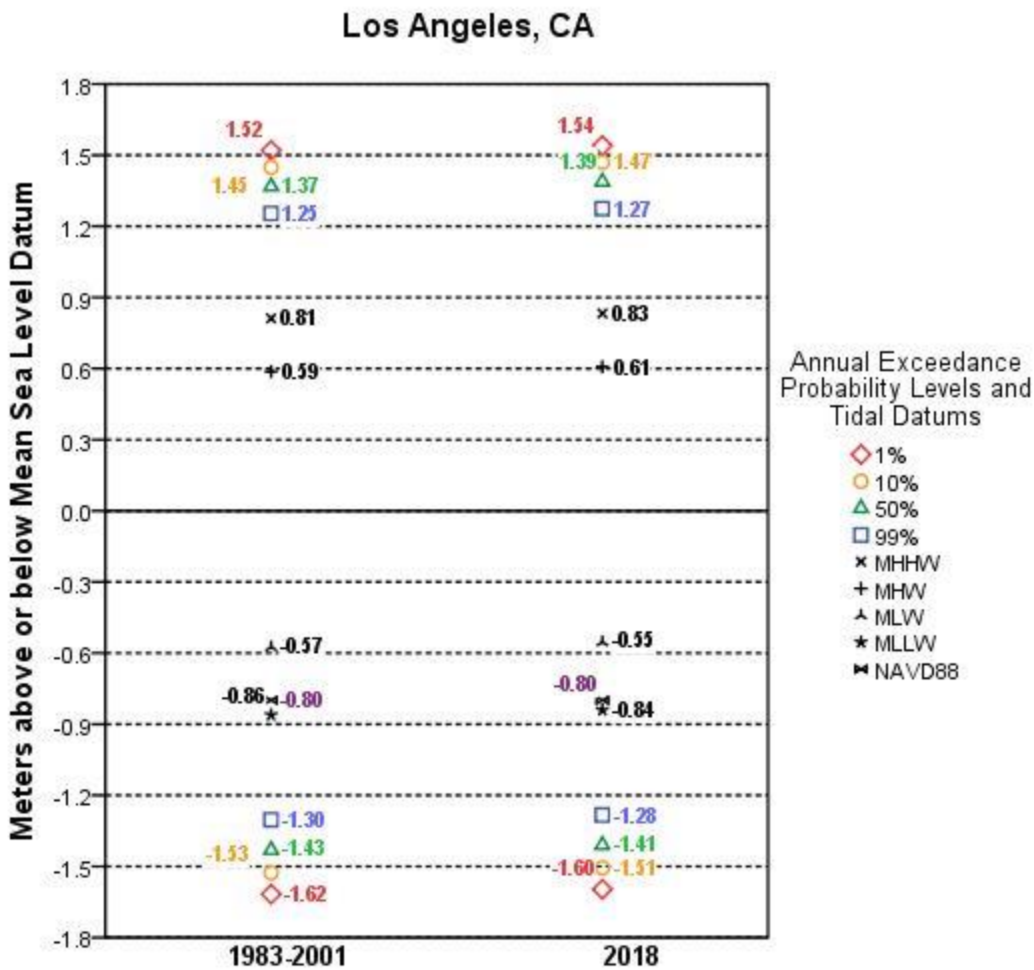


Figure 2-1: Los Angeles tidal datums and historic water elevations from NOAA station 9410660.

2.2 Wave Climate

The wave exposure within the City of Seal Beach is typical of the area. In summer months the City is exposed to southerly swells generated by tropical storm systems and other wave energy from the southern hemisphere. Swell events from the west and northwest become more prominent during winter months. Due to sheltering from the Palos Verdes Peninsula, the Port complex and the Channel Islands the predominant wave exposure windows are from the west and south directions as illustrated in Figure 2-2.

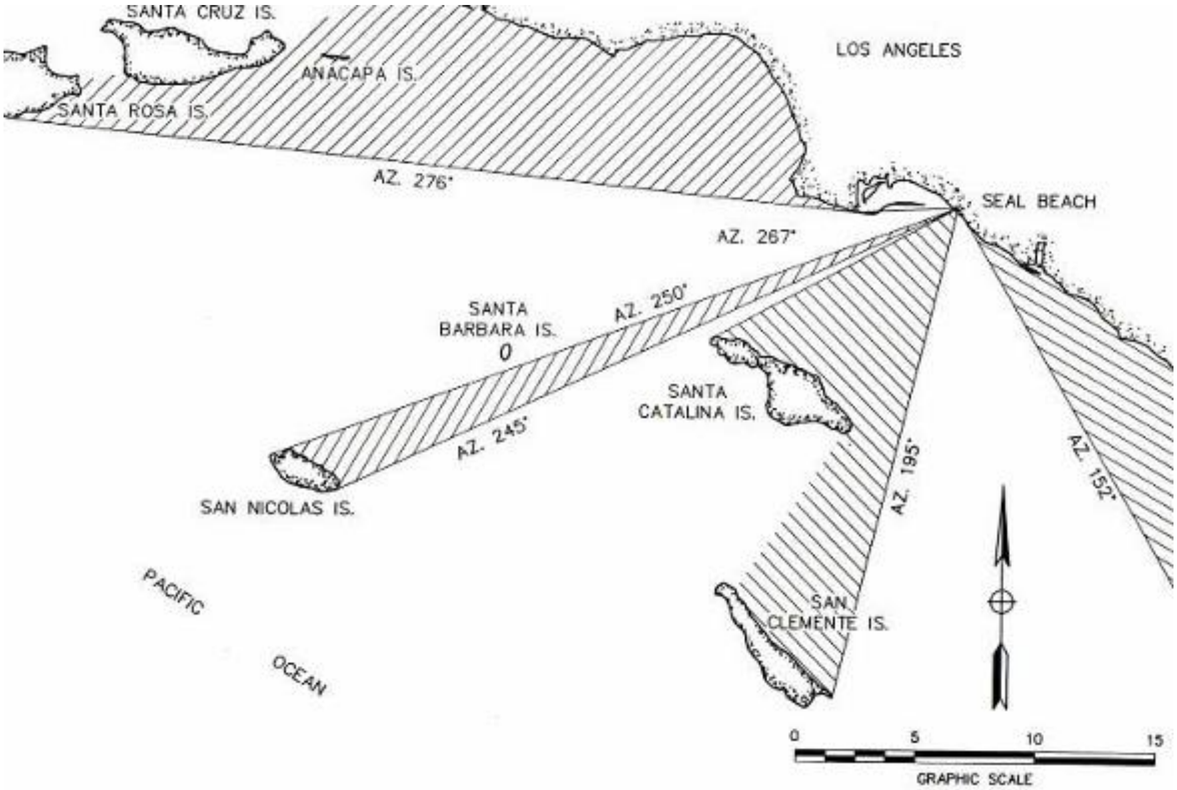


Figure 2-2: Wave exposure windows at Seal Beach.

A typical wave period for local, wind-driven seas in the region is 6 to 14 seconds, while the wave period for offshore swell events ranges from 12 to 22 seconds (Moffatt and Nichol, 2004). Breaking wave heights of 18 feet have been recorded along the shoreline during past storm events, representing a storm with an occurrence interval of approximately 10 years (Moffatt and Nichol, 2004). The larger wave heights (>15 feet) are associated with winter storm events from a westerly direction, typical during strong El Niño events.

During these winter swell events wave energy is reflected off of the Anaheim Bay west jetty. Wave energy is then amplified in the region of 13th Street to Dolphin Street due to constructive interference between incoming swells (Figure 2-3). This phenomenon results in significantly higher wave heights along east beach and a corresponding increase in erosion, wave runup and flooding of back beach areas. Most historic wave damage along east beach has occurred during periods of high wave energy combined with elevated water levels (Moffatt and Nichol, 1991). Past wave impacts include flooding of the shoreline promenade and damage to residences along the waterfront east of the Seal Beach Municipal Pier. Storms during the winter of 1983 represent a historic example of these wave hazards and prompted an evaluation of the shoreline protection strategies used throughout the City. Conditions during the winter 1983 storms were estimated to represent a storm with a 25 to 50-year recurrence interval and a high tide elevation approaching a 100 year recurrence interval (Moffatt and Nichol, 2004).

In the summer months the City is also exposed to long period swell form the southern hemisphere and occasionally large tropical swell events generated by tropical storms or hurricanes off the coast of Mexico. An example of this type of event is Hurricane Marie (August 2014) which generated 12 to 15 foot waves at Seal Beach resulting in flooding of the back beach development and damage to the

Anaheim Bay east jetty. South swells tend to focus more wave energy toward the western shoreline near the San Gabriel River jetties.

Figure 2-3: Wave reflection and amplification along the eastern Seal Beach waterfront.

2.3 Littoral Processes

The littoral process within the City of Seal Beach are heavily influenced by the jetty, groin, and pier structures located along the shoreline. The combination of the large jetty structures at the mouth of the San Gabriel River and the western border of Anaheim Bay isolates the City of Seal Beach from common upcoast and downcoast sand transport patterns, creating what amounts to a pocket beach along the waterfront (Moffatt and Nichol, 1984). The primary natural source of sediment to the waterfront is the San Gabriel River, which has shown a decrease in sediment supply over time as development has increased in the region.

Downcoast sand transport along the Seal Beach waterfront is limited by the Long Beach offshore breakwater and San Gabriel River jetties as these structures shelter the City from westerly wave action. Upcoast sand transport is increased by the Anaheim Bay west jetty due to the reflection of wave energy off of the jetty. This combination of restricted sand supply, reduced downcoast transport, and increased upcoast transport creates localized erosion in the vicinity of 13th Street and Dolphin Street where wave action is amplified (Moffatt and Nichol, 2004). The wave amplification process is evident from the ground level photos in Figure 2-3. The resulting sediment transport processes are shown in plan view in Figure 2-4.

Figure 2-4: Longshore sediment transport patterns along Seal Beach.

The concrete sheet pile groin along the Seal Beach Municipal Pier was initially constructed in 1959 to offset this effect and prevent undue loss of beach area east of the Pier. Without this structure in place it is estimated that erosion rates in the area would increase by approximately 50%. Despite this measure to conserve sand along the eastern shoreline, it is estimated that 1.75 to 3.25 feet of sandy beach areas is lost on an annual basis as a result of transport over the Municipal Pier groin and offshore over the Anaheim Bay west jetty (Moffatt and Nichol, 2004).

2.4 Sediment Management Activities

A sand management program is conducted along the City shoreline to address the chronic loss of beach area and reduce potential for flood damage due to strong winter storm events or large tropical swell events in the summer. The sediment management activities include backpassing, dike building and nourishment that date back to the 1950s after the west jetty was lengthened to its current configuration.

Backpassing refers to the movement of sediment from a downdrift location to an updrift location. Seal Beach is unique among most southern California beaches because the pre-dominant direction of longshore sediment transport is from south to north (or southeast to northwest). The City backpasses sediment from west beach to east beach on an annual basis for construction of the winter dike. The dike is typically constructed in October and removed in May and is located approximately 100 feet seaward of residential development (Figure 2-5). While this strategy has generally been effective in the past there have been instances where the dike is overtopped or flanked by large waves during high tides, resulting in flooding landward of the dike. The crest elevation of the dike varies from 20 to 23 feet (MLLW) with a top width of 14 feet and shown in the typical cross section (Figure 2-6).

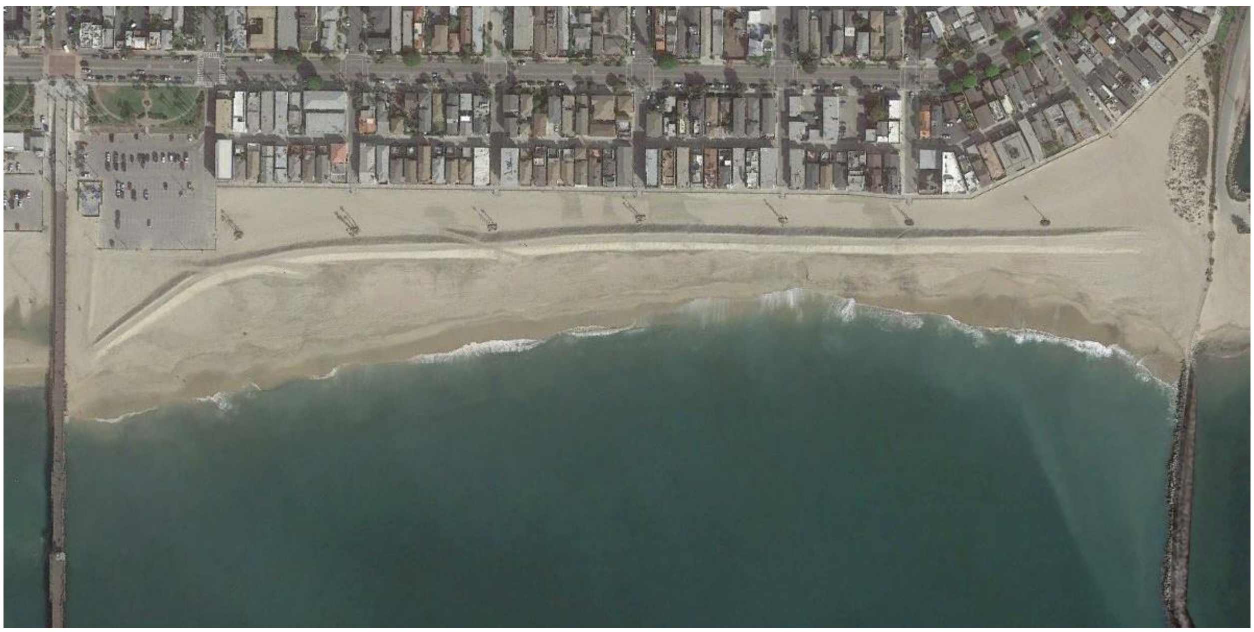


Figure 2-5: Satellite image of sand dike construction in winter 2017. (Photo credit Google Earth)

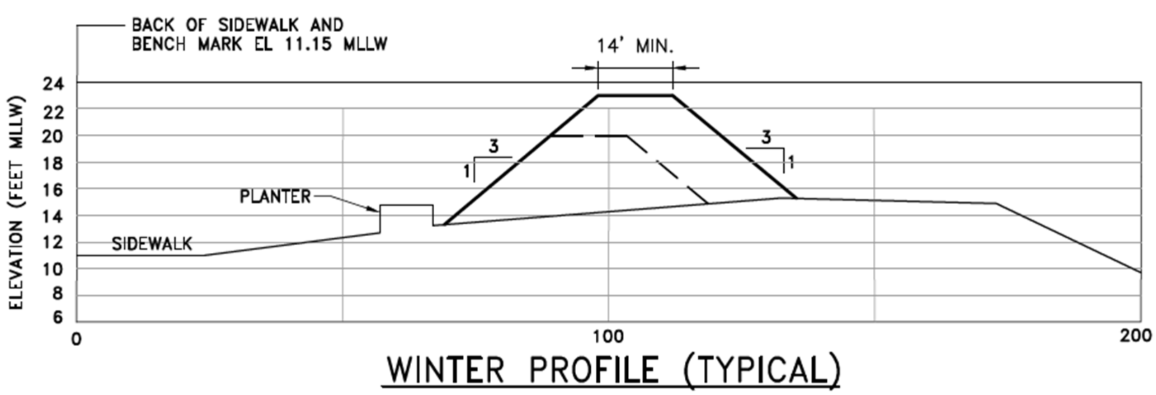


Figure 2-6: Typical cross section of winter dike.

Past sand nourishment events at Seal Beach have been sporadic and are generally supplied by dredge material from nearby projects, offshore sources or inland sources on an opportunistic basis. The placement of nourished material typically occurs along the east beach to widen the berm and provide a buffer for the winter dike.

The Surfside community is located downcoast of a complete littoral barrier formed by the Anaheim Bay jetties. These structures have cutoff the natural supply of sediment from beaches and rivers upcoast. The United States Army Corps of Engineers began regular beach nourishment cycles at Surfside-Sunset Beach in 1964 as mitigation for the downcoast shoreline impacts of the Anaheim Bay Jetties and to provide a feeder beach for the 13 miles of downdrift shoreline. Over 17 million cubic yards have been placed since 1964 (USACE, 2014). Recent nourishments have occurred at a frequency of about once every 5-7 years. Sand is placed immediately downcoast of the eastern Anaheim Bay jetty, dramatically increasing beach width (Figure 2-7). Downcoast sand transport is also exacerbated by wave energy reflected off the East Jetty resulting in an erosion signature (embayment) evident in many aerial images. The highest risk of coastal flooding occurs at the end of each nourishment cycle due to the reduced beach width fronting the west end of the Surfside community (Figure 2-8).

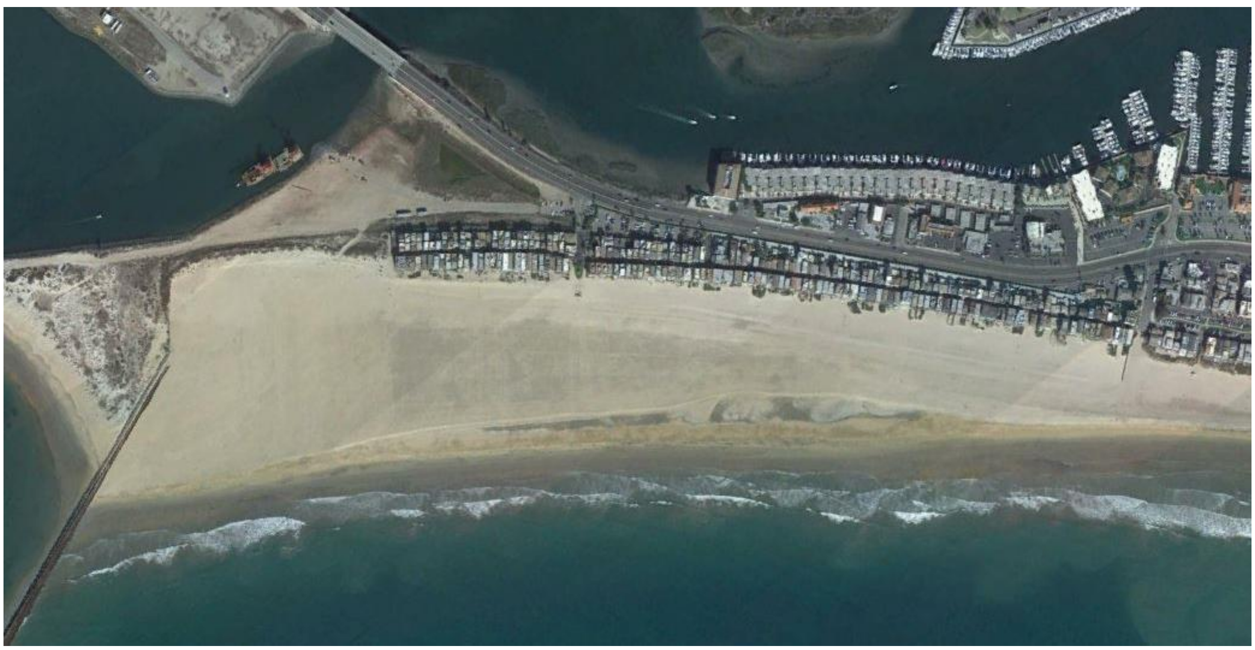


Figure 2-7: Shoreline downcoast of Anaheim Bay following a nourishment event in 2009.

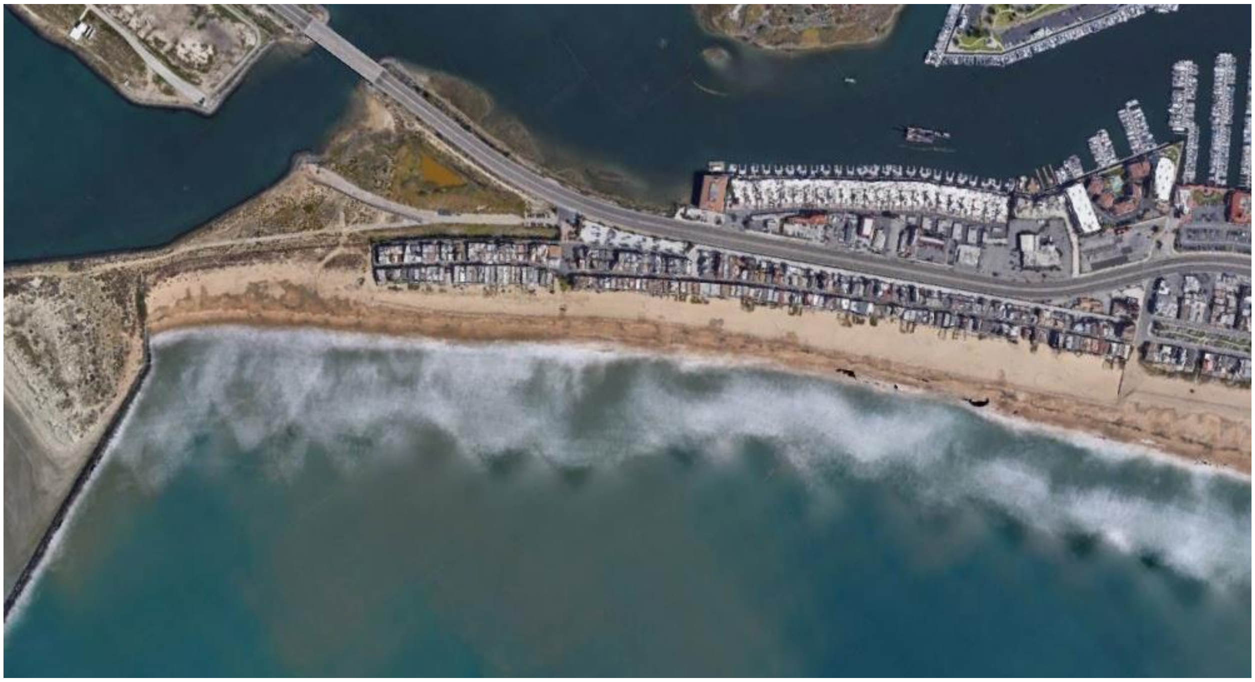


Figure 2-8: 2018 imagery of shoreline downcoast of Anaheim Bay showing significant loss of beach area from previous nourishment event.

3. City of Seal Beach Coastal Resource Inventory

Resource	Description
Coastal Development	All residential and commercial development within the City of Seal Beach subject to potential coastal hazards, including the Seal Beach waterfront, Surfside community, and inland areas surrounding coastal wetlands. Individual parcel and zoning information obtained from City staff.
Utilities Infrastructure	Water and electric infrastructure including electric substations, lift stations, pump stations, storm drains, gravity mains, force mains, and water lines. Data obtained from publicly available state and county datasets as well as City staff.
Public Safety Facilities	Safety facilities such as police stations, fire stations, and lifeguard stations located within the City. Data obtained from City staff.
Transportation Infrastructure	Local and major roadways within City limits. Critical local and regional roadways such as the Pacific Coast Highway are highlighted in analyses. Data obtained from public state and county datasets as well as City staff.
Coastal Access and Recreation	All coastal park areas, sandy beach areas, coastal access points, and parking facilities potentially subject to SLR hazards. Data obtained from City staff.
Environmental Resources	Coastal wetland areas including the Seal Beach National Wildlife Refuge and Los Cerritos Wetlands. Area boundaries based on zoning data provided by City staff.

4. Sea Level Rise

4.1 What is Sea Level Rise?

SLR science involves both global and local physical processes, as illustrated in Figure 4-1. Models are created based on science's best understanding of these processes on global and local scales, and, therefore, are dynamic and periodically updated to reflect these changes. On a global level, the most recent predictions come from the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) released in 2013. The AR5 projections for SLR were 50% higher than the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4) (released 2007) due to the addition of ice sheet dynamics on SLR. At the state level, the CCC recommends using the best available science, which is expected to be updated every 5 years.

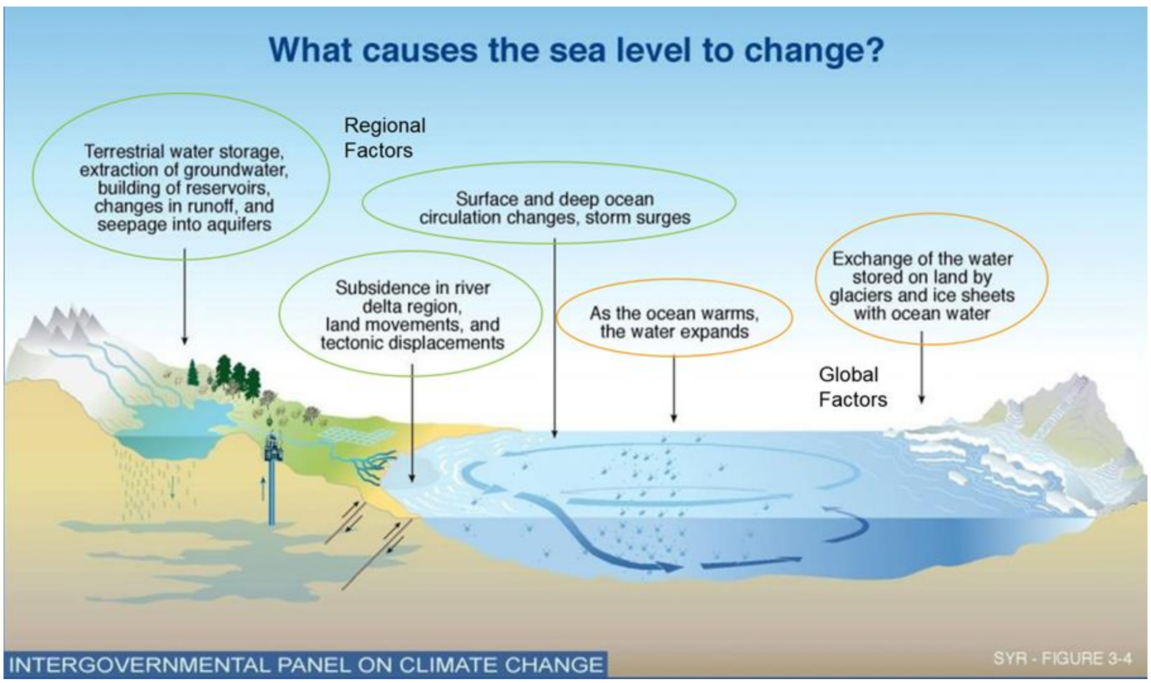


Figure 4-1: Regional and global factors that can contribute to changes in sea level (IPCC, 2013)

4.2 Projections and Probability

State of California Ocean Protection Council (OPC) Science Advisory Taskforce updated the best available science through the Rising Seas in California: An Update on Sea Level Rise Science report, released in April 2017. This report was then used to update the OPC's California State Guidance in 2018. The 2018 OPC SLR Guidance is now referenced as the best available science throughout the updated CCC SLR Policy Guidance document (2018).

The OPC (2018) Guidance projects SLR for multiple emissions scenarios and uses a probabilistic approach based on Kopp et al., 2014 to generate a range of projections at a given time horizon for 12 tide gauges along the California coast. The projections for the Los Angeles tide gauge are referenced in this section. CCC SLR Policy Guidance recommends using projections associated with a high emissions future given that worldwide emissions are currently following the high emissions trajectory. The 2018 California State Guidance Document lays out a risk decision framework that explains when to use low or high-risk aversion in the planning process. With this framework, the probabilistic projections inform a decision-making process rather than trying to estimate the exact rate or occurrence of SLR based on an individual scenario or projection.

For the 2050 time horizon the "likely range" of SLR is between 0.5 to 1.0 feet. Kopp et al. 2014 estimated there is a 66% probability that SLR will fall within this "likely range". The likely range of SLR at the 2100 time horizon is 1.3 – 3.2 feet for a high emissions scenario. The upper end of the "likely range" is recommended for low risk aversion situations where impacts from SLR greater than this amount would be insignificant, or easily mitigated. The state recommends this high-risk tolerance (low aversion) to be used when considering resources where the consequences of SLR are limited in scale and scope with minimum disruption and where there is low impact on communities, infrastructure, or natural systems. This "low risk aversion" curve is shown in orange in Figure 4-2. At any given time horizon there is a 17% chance that SLR will exceed this curve.

For medium-high risk aversion situations more conservative (lower probability) projections for SLR are recommended by the OPC Guidance. These projections have a 1-in-200 chance (0.5% probability) of occurring at a given time horizon and would be appropriate for use on projects where damage from coastal hazards would carry a higher consequence and/or a lower ability to adapt such as residential and commercial structures. A sea level rise of 1.8 feet is projected at the 2050 time horizon, 3.3 feet at 2070 and 6.7 feet at 2100. The "medium-high risk aversion" curve is shown in red in Figure 4-2 and is most applicable for the residential development along the City's shoreline.

The OPC guidance also includes a specific singular scenario (called H++), based on projections by Sweet et al., 2017 which incorporates findings of Pollard & Deconto, 2016 that predict Antarctic ice sheet instability could make extreme sea-level outcomes more likely than indicated by Kopp et al. 2014 (Griggs et al., 2017). Because the H++ scenario is not a result of probabilistic modeling the likelihood of this scenario cannot be determined. Due to the extreme and uncertain nature of the H++ scenario, it is most appropriate to consider when planning for development that poses a high risk to public health and safety, natural resources and critical infrastructure (OPC, 2018). The H++ extreme risk aversion curve is shown in purple in Figure 4-2.

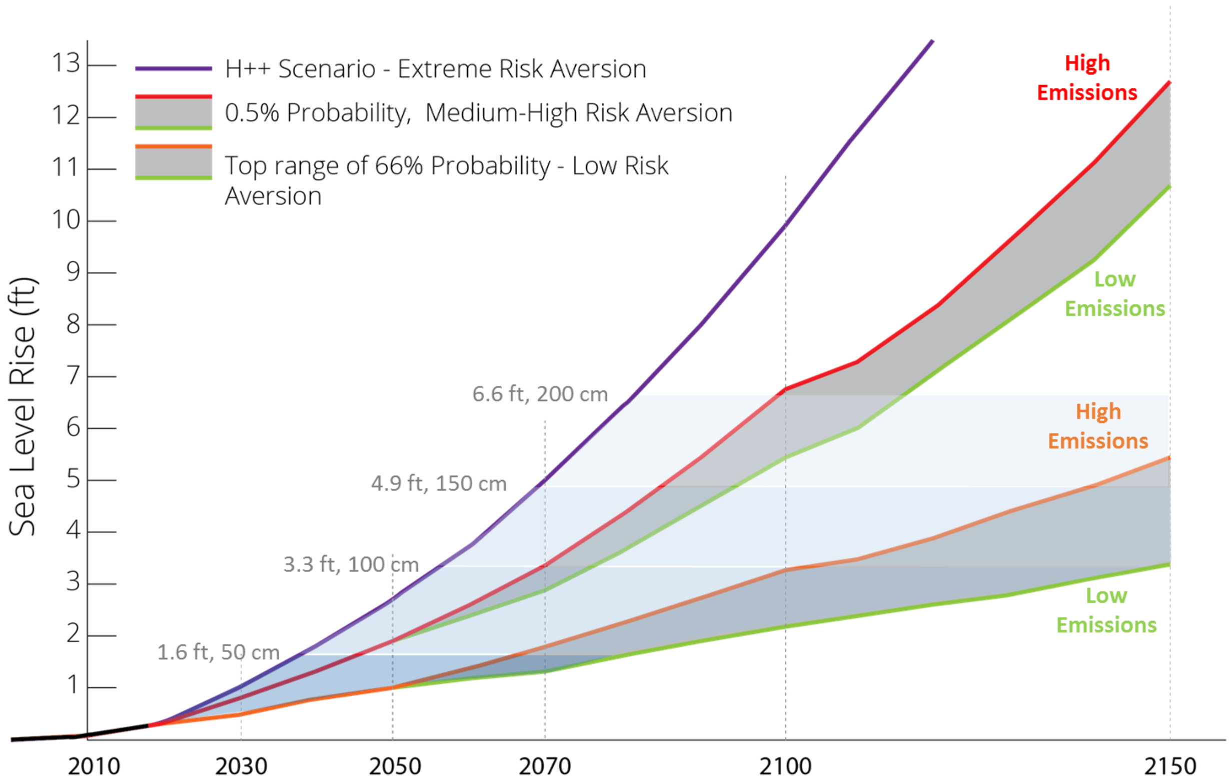


Figure 4-2: Approximate Sea Level Rise Projections for Three Risk Aversion Levels (OPC, 2018)

4.3 Selected SLR Scenarios

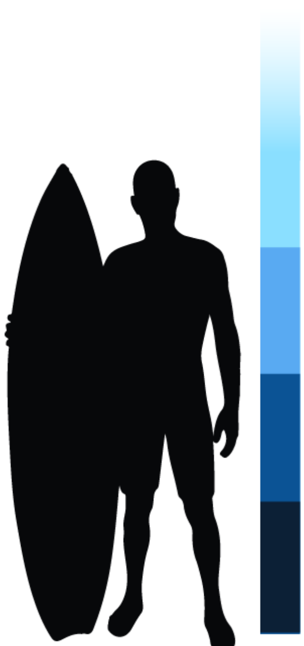
Climate science is a constantly changing field, often with high degrees of uncertainty. In the case of California's SLR, the OPC has high confidence in estimates for SLR to around year 2050, after which emissions scenarios cause predictions to diverge. Due to the high degree of uncertainty associated with predicting when and at what rate SLR will occur, this study looks at a range of SLR increments (scenarios) starting with present day conditions and including extreme SLR. Four scenarios have been selected for this study that consider increments of SLR between 1.6 and 6.6 ft, as shown in Figure 4-3, and based on available hazard data for the region discussed in Section 4.4. The probabilities that sea level rise will meet or exceed a particular height over a given time horizon are based on Kopp et al. 2014 and described below.

1. Sea level rise of 1.6 feet (50 cm) is representative of the low risk aversion projection for 2070 which means there is an 83% probability sea level rise will not exceed this amount over the next 50 years. There is less than a 5% probability that this amount of SLR will occur before 2060. Under a worst-case extreme SLR scenario (H++) this amount of SLR could occur by 2040.

2. Sea level rise of 3.3 feet (100 cm) is representative of the medium-high risk aversion projection for 2070 which means there is a 99.5% probability sea level rise will not exceed this amount over the next 50 years. However, under a worst-case extreme SLR scenario (H++) this amount of SLR could occur by 2060.

3. Sea level rise of 4.9 feet (150 cm) represents the medium-high risk aversion projection for the 2080-2090 time horizon. There is a ~95% probability that 4.9 feet of SLR does not occur until after 2100. However, under a worst-case extreme SLR scenario (H++) this amount of SLR could occur by 2070.

4. Sea level rise of 6.6 feet (200 cm) is representative of the medium-high risk aversion projection for 2100 which means there is a ~99.5% probability sea level rise of this magnitude will not occur this century. This scenario provides a conservative projection for SLR to be applied on projects with a longer design life (75-100 years) and subject to medium-high consequences if SLR is underestimated.



Sea level Rise above '91-'09 baseline	When might it occur?*
6.6 feet (200 cm)	2090 to 2100+
4.9 feet (150 cm)	2080 to 2100+
3.3 feet (100 cm)	2060 to 2100+
1.6 feet (50 cm)	2040 to 2080

* ranges are approximate and estimated from OPC State of CA SLR Guidance (2018)

Figure 4-3: SLR scenarios selected for vulnerability analysis and projected timing of impacts.

4.4 CoSMoS SLR Hazard Evaluation

The effects of SLR on storm and non-storm related flooding were evaluated using results of the Coastal Storm Modeling System (CoSMoS) Version 3.0, Phase 2, a multi-agency effort led by the United States Geological Survey (USGS) to make detailed predictions of coastal flooding and erosion based on existing and future climate scenarios for Southern California. Other SLR hazard viewers such as the NOAA Sea Level Rise Viewer are also available, but these tools lack the regional focus and depth of information provided in CoSMoS modeling efforts.

The CoSMoS modeling system incorporates state-of-the-art physical process models to enable prediction of currents, wave height, wave runup, and total water levels (Erikson et al., 2017). A total of 10 SLR scenarios are available, increasing in 0.8 ft (0.25 m) increments from 0 to 6.6 ft (0 to 2 m) and also including an extreme SLR scenario of 16.4 ft (5 m). CoSMoS modeling results provide predictions of shoreline erosion, cliff erosion, and coastal flooding under both average conditions and extreme events.

Hazard analyses for the City of Seal Beach focus primarily on shoreline erosion and coastal flood modeling results given the lack of erodible bluffs within the City coastal zone. The hazards depicted in this report are presented solely based on the assumptions and limitations accompanying the CoSMoS data available at the time of this study. No additional numerical modeling or independent verification of the CoSMoS data was performed.

4.4.1 Wave Modeling

Available CoSMoS storm scenarios include annual, 20-year, and 100-year return period storm events. Future storm conditions are downscaled from winds, sea-level pressures, and sea surface temperatures of an established global climate model (Erikson et al., 2017). Additional modeling was performed to translate projected deep water waves to shore, simulating additional regional and local wave growth. Due to the large geographical extent of CoSMoS modeling efforts, the same representative storm events are used across southern California to model wave impacts. Each of the selected representative storm events produces waves from a W-NW direction typical of winter storms (Table 4-1). CoSMoS Wave modeling results show nearshore wave heights of approximately 10ft along the coast of Seal Beach. Wave heights are diminished within areas shadowed by jetty structures. It should be noted that wave modeling immediately downcoast of Anaheim Bay does not fully extend to the current shoreline.

Table 4-1: Boundary conditions associated with each CoSMoS modeled storm scenario.

Scenario	**Hs (ft)**	**Tp (s)**	**Dp (degrees)**	**Maximum wind speed (m/s)**
Background	5.7	12	286	NA
1-year storm #1	14.4	16	284	22.8
20-year storm #1	19.2	18	281	22.3
20-year storm #2	20.1	18	292	28.7
100-year storm #1	20.3	16	264	26.6
100-year storm #2	22.3	18	287	30.3

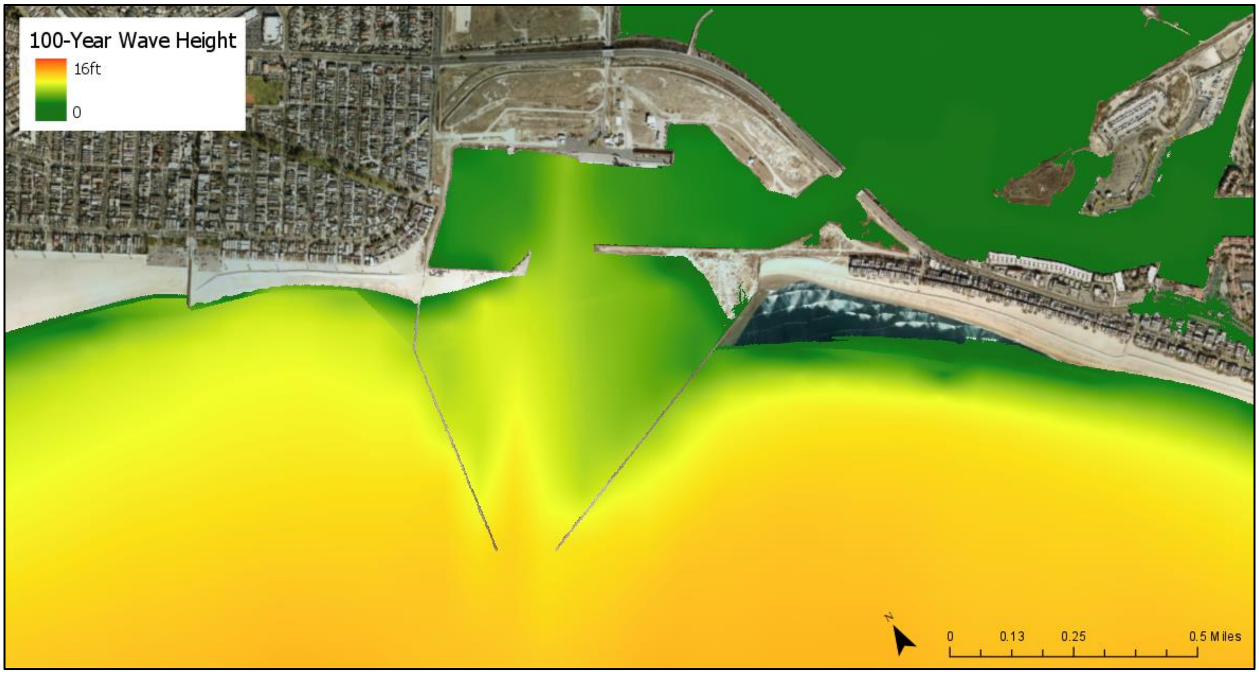


Figure 4-4: CoSMoS wave modeling results for a 100-year storm event under current conditions.

4.4.2 Coastal Flood Projections

CoSMoS coastal flooding projections simulate the effects of erosion, wave runup, and overtopping during storm events. Coastal flood extents are calculated and mapped at profiles spaced approximately 300 ft along the shoreline. The projected coastal water levels used in flood mapping consider future shoreline change, tides, sea level anomalies like El Niňo, storm surge, and SLR. Future wave conditions used in the model are based on forecasted conditions out to year 2100. All flood events are modeled in conjunction with a high spring tide, a tide height that occurs approximately twice a month, to represent a near worst-case scenario (Erikson et al., 2017).

CoSMoS coastal flood modeling results assume that future shoreline retreat will be halted at the existing development line and that no beach nourishment events will occur to maintain existing beach widths. These assumptions may have potential impacts on flood modeling results within the City of Seal Beach due to the recurring nourishment programs that take place along much of the shoreline. Projected coastal flood extents, unlike shoreline erosion, are permitted to extend beyond the line of development. Assumptions regarding the specific type, height, and shoreline profile of existing coastal protection structures are not immediately available for large-scale modeling efforts such as CoSMoS. These parameters are key in providing precise evaluations of the wave runup height and potential for flooding landward of specific structures, and thus it may be prudent to verify CoSMoS findings in a subsequent coastal flood modeling effort.

4.4.3 Shoreline Erosion Projections

CoSMoS shoreline erosion projections include long-term erosion resulting from SLR and projected wave conditions. Shoreline erosion projections are modeled with the CoSMoS Coastal Online Assimilated Simulation Tool (COAST), which includes a suite of models that consider historic erosion trends, longshore and cross-shore sediment transport, and shoreline changes due to increased water levels. These models were tuned with historic data to account for unresolved sediment transport processes and inputs such as sediment loading from rivers and streams, regional sediment supply including beach nourishment and bypassing, and long-term erosion.

The CoSMoS-COAST shoreline projections are based on an initial shoreline mapped from a 2009-2011 LIDAR data set (Erikson et al., 2017). Due to the dynamic nature of the shoreline in Seal Beach, the initial shoreline present in CoSMoS modeling efforts may not fully reflect the current shoreline position. In select locations the current shoreline is significantly landward of CoSMoS initial shoreline projections, particularly along Surfside Avenue where large beach nourishment events take place. This variation in shoreline width is shown in Figure 2-7 and Figure 2-8. Within these areas the shoreline erosion due to each SLR scenario may reach further inland than depicted in CoSMoS projections.

CoSMoS shoreline erosion projections for each level of SLR are based on four management scenarios. Management scenarios are defined by the presence or absence of shoreline armoring and beach nourishment. The use of shoreline armoring is referred to as a “Hold-the-Line” scenario, and shoreline erosion modeling under this scenario assumes that the existing boundary between sandy beach areas and development is maintained with coastal structures. The “No Hold-the-Line” scenario assumes no such armoring is in place and allows shoreline erosion projections to propagate inland to the maximum potential extent based solely on topography. In a similar manner to the shoreline armoring scenarios, the “Beach Nourishment” management scenario assumes that historical beach nourishment practices are continued into the future, whereas the “No Beach Nourishment” scenario assumes the beach is left in its current state. The No Hold-the-Line, No Beach Nourishment scenario is used for hazard analyses within this study in order to document the full suite of potential SLR hazards.

4.4.4 Limitations of CoSMoS Projections

The regional focus of the CoSMoS modeling effort results in certain limitations when applied at smaller scales or specific locations. The limitations are particularly evident at locations where wave action and littoral processes are heavily influenced by coastal structures and sediment management activities such as Seal Beach. Some limitations of the CoSMoS model and how they may influence the projected exposure of resources in Seal Beach are discussed in this section. The following section is based on our general understanding of the CoSMoS regional modeling approach compared with our local knowledge of coastal hazards in Seal Beach. An independent verification of their model was not performed because the site-specific details, assumptions and inner workings of the CoSMoS model are not publicly available.

Surfside Community

Perhaps the most significant limitation of the model results in Seal Beach is the starting shoreline used downcoast of the Anaheim Bay entrance. The CoSMoS shoreline projections and flood mapping are based on an initial shoreline mapped from a 2009-2011 LIDAR data set which represents a post-nourishment condition at Surfside/Sunset Beach where the beach is at its widest. Approximately 2 million cubic yards were placed immediately south of the Anaheim Bay east jetty in 2009/2010 nourishment. This segment of the study area is subject to significant variation over a typical nourishment cycle as illustrated in Figure 2-7 and Figure 2-8. Since the CoSMoS modeling of future shoreline position and flooding was applied to a nourished beach the results underestimate the potential for erosion and flooding of the Surfside Community in all SLR scenarios, especially the higher scenarios of 3.3 to 6.6 feet.

East Beach

It's uncertain the degree to which the unique wave dynamics and sediment management activities at east beach are reflected in the CoSMoS results. Since the flooding was evaluated based on one-dimensional transects it's unlikely the wave amplification effects described in Section 2.2 were incorporated into the flood modeling. This would result in an underestimate of the potential for flooding under each SLR scenario.

The winter dike constructed annually along east beach does not appear in the CoSMoS digital elevation model (DEM). Therefore, we assume this feature was not reflected in the one-dimensional transect modeling used to predict future flooding. If the modeling effort did not include the winter dike the results would provide a conservative estimate of the extent of flooding due to wave runup and overtopping of the beach berm.

Sediment management activities such as backpassing and nourishment provide an artificial source of sand to east beach which would influence future shoreline position. It's possible these are reflected in the CoSMoS-COAST shoreline projections since the model includes historic shoreline trends that were influenced by these sediment management activities.

San Gabriel River / Los Cerritos Wetlands / Anaheim Bay

The majority of flooding predicted by CoSMoS appears to be from tidally influenced water bodies such as the San Gabriel River, Los Cerritos Wetlands and Anaheim Bay. Since the CoSMoS model does not model extreme fluvial events the flooding appears to be a result of SLR in combination with high ocean water levels. However, the hydraulic connection (i.e. flood path) from these water bodies is not well defined or described in the CoSMoS data. It's uncertain if or how existing flood control measures such as levees, berms and walls were accounted for in the flood modeling. The DEM resolution used in the CoSMoS model may not adequately resolve the elevation of narrow features such as levees or flood walls. If a hydraulic connection does exist the amount of flooding is often limited by the volume of water conveyed through a particular connection over a period of time (i.e. high tide).

Given the various inland water bodies and potential for surface and below surface connections, it's difficult to diagnose the source of predicted flooding and what could be done to mitigate flooding form the CoSMoS results alone. A more detailed City-focused analysis would be required to identify any potential hydraulic connections that exist and evaluate the potential for flooding under each SLR scenario.

5. Vulnerability Assessment

5.1 Coastal Development

Short-term Vulnerability

Coastal development within the City of Seal Beach has a low vulnerability to non-storm flood hazards under short-term SLR projections. Non-storm flood projections under a 1.6ft SLR scenario do not approach any areas of the Seal Beach waterfront or Surfside community, resulting in minimal hazard exposure for these resources. Despite minimal direct exposure to tidal flood hazards, coastal development east of the Seal Beach Municipal Pier and within Surfside can still be considered sensitive to short-term SLR hazard projections due to the ongoing sand management practices within these areas. Even small reductions in beach width may alter these practices and lead to potentially undesirable outcomes, such as a loss of aesthetic value if winter berms are pushed further inland.

Coastal development is projected to be much more vulnerable to flooding during a 100-year storm event under short-term SLR scenarios. While storm flood hazard projections under current conditions do not overlap with any coastal development areas, projections under a 1.6ft SLR scenario cover a large, low-lying area immediately south of the Pacific Coast Highway stretching from the San Gabriel River to Anaheim Bay. Flooding within this inland area appears to stem from Anaheim Bay and the San Gabriel River rather than directly from the coast. Storm flood projections under this short-term scenario also extend inland from Anaheim Bay at the eastern and western ends of the Surfside community. As noted in Section 4.4.4, flood potential for development at the western end of Surfside may be underestimated due to changes in shoreline width following nourishment events.

Though the short-term hazard exposure of coastal development is limited to temporary flooding during extreme storm events, these hazards are still of concern due to the high sensitivity of affected areas. If flood mitigation measures are not in place, even minor flooding of the densely developed coastal areas within the Seal Beach waterfront and Surfside community can lead to extensive structural damages. While hazard sensitivity is high within these areas, overall short-term SLR hazard vulnerability is mitigated somewhat by potential adaptive capacity. A number of reliable options exist to mitigate temporary, storm-driven flood hazards projected under short-term SLR scenarios given that flood depths are <1 foot in the majority of affected areas. Potential adaptation measures include both wet and dry flood-proofing of threatened structures as well as incremental improvements to existing flood protection mechanisms. Such measures can typically be implemented more efficiently and at a lower cost than measures designed to address recurrent non-storm flooding or widespread flooding at depths exceeding 5 feet as projected under extreme SLR scenarios.

Long-term Vulnerability

Coastal development within Seal Beach is vulnerable to long-term SLR hazard projections under multiple scenarios. Specific impact projections including number of structures impacted and total estimated damages can be found in Section 6.1. Significant hazard exposure is projected for non-storm conditions under 3.3ft, 4.9ft, and 6.6ft SLR scenarios. Under the 3.3ft SLR scenario tidal flood projections become widespread within the low-lying area south of the Pacific Coast Highway, covering an area similar to that seen for 100-year storm conditions under a 1.6ft SLR scenario. Non-storm flood projections under a 4.9ft SLR scenario show further flooding in coastal areas between 4th and 7th Street and in areas inland of the

Pacific Coast Highway, including the entirety of Leisure World and portions of the commercial area along Westminster Boulevard. Beachfront property is also more exposed to flood hazards under this scenario, with areas along the eastern and western portions of the Seal Beach waterfront and Surfside community projected to experience recurrent tidal flooding. This is of particular concern in the eastern portion of Surfside, where shoreline projections show only a small amount of intact sandy beach area. While not shown specifically in CoSMoS hazard projections, this may also be the case along the entirety of the Surfside shoreline in the absence of a recent nourishment event. Non-storm flood projections under a 6.6ft SLR scenario extend across the entirety of beachfront property east of the Seal Beach Municipal Pier and within the Surfside community, covering the majority of development south of the Pacific Coast Highway. Incremental increases in inland flood extents are also seen under this scenario.

100-year storm flood projections show widespread flooding of coastal development under less extreme SLR scenarios. In addition to areas immediately south of the Pacific Coast Highway, storm flood projections under a 3.3ft SLR scenario cover significant portions of inland areas and beachfront property within the City, including the entirety of Leisure World and areas at the far western portion of the Seal Beach waterfront. Storm flood projections become more extensive with 4.9ft SLR, covering almost the entirety of development bordered by Main Street and the Pacific Coast Highway as well as all beachfront property within Surfside. Flood projections under this scenario also extend further into the Westminster Boulevard commercial area. Storm flood projections increase incrementally across all areas with 6.6ft SLR, notably within the Surfside community and eastern Seal Beach waterfront where flooding from the coastline joins flooding from surrounding bays over large areas.

Coastal development is highly sensitive to flood hazards projected under long-term SLR scenarios. While it is possible for limited structural damage due to temporary inundation to be repaired in a reasonable timeframe, the recurrent and widespread non-storm flooding projected under 3.3ft, 4.9ft, and 6.6ft SLR scenarios will likely prevent use of these areas due to ongoing damages and frequent loss of access if no adaptation measures are implemented. Storm flood hazard sensitivity also increases when considering long-term SLR scenarios due to the expanded area and increased severity of flood projections, especially within the Surfside community and beachfront areas. Adaptive capacity is also diminished when considering long-term flood projections. Many traditional flood mitigation practices such as structural elevation or retrofitting are not designed for the frequent inundation events or potential undermining from shoreline erosion projected under long-term SLR scenarios, and there are limited unoccupied areas at higher relief in the immediate vicinity of existing coastal development for use in alternative adaptation strategies.

5.2 Utilities Infrastructure

Short-term Vulnerability

Water and energy infrastructure within the City of Seal Beach is projected to experience minimal hazard exposure for non-storm conditions under short-term SLR scenarios. The only utilities resource exposed to non-storm flood hazards under a 1.6ft SLR scenario is the Aquatic Park lift station. Hazard exposure increases substantially when considering 100-year storm conditions under short-term SLR scenarios. Storm flood projections under a 1.6ft SLR scenario cover a number of water infrastructure resources in the area south of the Pacific Coast Highway. Affected resources include the 1st Street Lift Station, Pump

Station 35, the West End Pump Station, and a number of storm drains and catchment basins along the eastern end of Electric Avenue Median Park.

Pump and lift stations have the greatest sensitivity to SLR hazards among the utilities resources exposed under short-term SLR scenarios. The Aquatic Park lift station has the greatest degree of sensitivity due to the potential for recurrent non-storm flooding with 1.6ft SLR, which could severely disrupt the functioning of the station on a regular basis. Other utilities infrastructure exposed to storm-driven flooding is less sensitive to short-term SLR hazards. Structural damage to pump and lift stations may occur, but the temporary nature of flooding limits damage potential and provides opportunities for repair following extreme storm events. Storm flooding may also reduce the functionality of stormwater infrastructure, potentially causing upstream flooding if elevated water levels coincide with a major rain event, though once again these impacts would be temporary.

Though complex, water infrastructure has a relatively high adaptive capacity when considering projected short-term SLR hazards, helping to maintain low overall vulnerability. Elevation of small-scale utilities infrastructure is more feasible than larger residential or commercial infrastructure due to the lack of large engineered structures and reduced need for access. Utilities infrastructure within projected storm flood areas under a 1.6ft SLR scenario could likely employ this or other similar strategies to address temporary flood issues, though infrastructure subject to non-storm flooding such as the Aquatic Park lift station may require additional adaptation measures.

Long-term Vulnerability

The SLR hazard vulnerability of utilities infrastructure increases substantially when considering long-term SLR scenarios. Non-storm flood projections under a 3.3ft SLR scenario cover much of the water infrastructure south of the Pacific Coast Highway, including all pump and lift stations except those located on the Municipal Pier and 8th Street. Inland water infrastructure within Leisure World and surrounding areas is projected to become impacted by non-storm flooding with 4.9ft SLR, with flood extents also approaching the City electric substation. Non-storm flood projections increase incrementally with 6.6ft SLR, with additional flood areas encompassing the 8th Street pump station and the entirety of the electric substation.

Utilities infrastructure exposure to storm flooding occurs at lower long-term SLR thresholds. Storm flood projections with 3.3ft SLR cover all lift and pump stations with the exception of the Municipal Pier pump station. Upland water infrastructure within Leisure World is also impacted under this scenario. Storm flood projections with 4.9ft SLR additionally cover the electric substation. Incremental increases in flood projections with 6.6ft SLR do not extend over any additional major utilities infrastructure but will result in more frequent and more severe overall storm flood conditions in previously affected areas.

Utilities infrastructure can also be considered more sensitive to long-term SLR hazards due to the widespread nature of non-storm flooding. Water and electrical infrastructure may be able to accommodate and recover from localized, infrequent structural damage or system disruption due to temporary flooding during extreme storm events, but it is unlikely that systems will remain functional if a large portion of utilities resources become subject to recurring non-storm inundation, especially considering non-storm flood projections under 4.9ft and 6.6ft SLR scenarios. Storm flood projections under a 3.3ft SLR scenario are also likely to cause significant impacts to utilities infrastructure due to the city-wide nature of flooding. Any inundation of the electric substation, whether storm-driven or non-storm related, is also likely to result in impacts to the facility itself and disruption of critical services throughout the City.

The adaptive capacity of water and electric infrastructure is also reduced for long-term SLR hazard projections. While localized adaptation measures may be feasible when addressing short-term SLR flood hazards, long-term adaptation measures may require more extensive protection, redesign, or relocation of utilities resources due to the extent and magnitude of non-storm and storm-driven flood projections.

5.3 Public Safety Facilities

Short-term Vulnerability
Public safety facilities, within the City of Seal Beach, including fire stations, lifeguard stations, and the City Community Safety Building, have minimal vulnerability to short-term SLR hazards due to a lack of exposure. No major safety facility infrastructure is projected to be impacted by either non-storm or storm-driven flood hazards under a 1.6ft SLR scenario.

Long-term Vulnerability
The long-term SLR hazard vulnerability of public safety facilities is also limited due to relatively low hazard exposure. The only structures impacted under non-storm conditions are the Community Safety Building and Lifeguard Headquarters with 6.6ft SLR. These same structures are within 100-year storm flood projections under a 3.3ft SLR scenario. No additional public safety facilities are projected to be impacted with 4.9ft SLR, while 6.6ft SLR storm flood projections include Fire Station 48 in the northern portion of the City. In addition to direct exposure to flood hazards, the effectiveness of public safety initiatives within the City will likely be reduced as flooded transportation infrastructure surrounding facilities leads to increased response times.

The Community Safety Building and Lifeguard Headquarters are likely to experience the greatest impacts among public safety facilities. Non-storm flood conditions as projected under a 6.6ft SLR scenario would likely result in repeated structural damage and severe disruption of use. Storm flood projections also pose a significant risk under long-term SLR scenarios. Storm flooding projections with 3.3ft SLR show potential inundation of both facilities, and any impacts seen under this scenario will become more common under 4.9ft and 6.6ft SLR scenarios. Though storm-related flooding is temporary in nature, even infrequent damage to these structures could reduce emergency response capacity and lead to significant impacts to public use and safety of surrounding recreational areas including beaches.

Long-term adaptive capacity remains high for these resources. Traditional flood mitigation actions such as wet or dry floodproofing remain as options to address temporary, storm-driven flooding as projected under a 3.3ft SLR scenario. In the event that such measures are no longer sufficient to address coastal hazards under more extreme SLR scenarios, available land at higher relief exists immediately landward for potential relocation or realignment of resources.

5.4 Transportation Infrastructure

Short-term Vulnerability
Transportation infrastructure within the City of Seal Beach is potentially vulnerable to projected storm flood conditions under short-term SLR scenarios. No major transportation resources are exposed to

projected flood hazards for non-storm conditions under a 1.6ft SLR scenario. Storm flood projections under a 1.6ft SLR scenario cover several critical transportation routes, including select segments of the Pacific Coast Highway, Seal Beach Boulevard, and Marina Drive. A number of local roads south of the Pacific Coast Highway and north of Electric Avenue are also projected to experience flooding during extreme storm events with 1.6ft SLR.

Though short-term SLR hazard exposure is limited to temporary flooding during extreme storm conditions, major transportation infrastructure remains sensitive to projected hazards. While roads are generally resistant to structural damage during short-term inundation as projected under a 1.6ft SLR scenario, the disruption of major regional transportation corridors such as the Pacific Coast Highway and Seal Beach Boulevard, even on a limited basis, has the potential to impact critical services throughout the City and surrounding areas. This sensitivity is compounded by the likely need for emergency services in waterfront areas during major storm events when flooding will be most severe.

Adaptive capacity of transportation infrastructure is generally high when considering localized, temporary inundation during extreme storm events. Elevation, protection, or floodproofing of critical access routes can typically be employed to address these hazards without the need for significant reconfiguration of transportation resources.

Long-term Vulnerability

Transportation infrastructure is significantly more vulnerable to flood hazards projected under long-term SLR scenarios. Non-storm flood projections under a 3.3ft SLR scenario cover large segments of the Pacific Coast Highway, Marina Drive, and Seal Beach Boulevard within coastal areas. Under a 4.9ft SLR scenario non-storm flood projections extend continuously across the majority of local roads south of the Pacific Coast Highway and west of Seal Beach Boulevard. Inland portions of Seal Beach Boulevard and Westminster Boulevard are also impacted under this scenario. The incremental increase in non-storm flood projections under a 6.6ft SLR scenario does not impact any additional major transportation resources, but non-storm flooding projected under previous scenarios will become more frequent and severe.

Storm flood projections result in similar exposure but at less extreme SLR scenarios. Flood projections under a 3.3ft SLR scenario cover the majority of the Pacific Coast Highway west of Seal Beach Boulevard, extend continuously across local roads south of the Highway, and extend across large upland segments of Seal Beach Boulevard and Westminster Boulevard. Storm flood projections under a 4.9ft SLR scenario extend further along local roads north and south of the Pacific Coast Highway and along Westminster Boulevard east of Seal Beach Boulevard. A similar, incremental increase in flood extents is seen under a 6.6ft SLR scenario.

Along with increased exposure, transportation infrastructure is more sensitive to the types of hazards projected under long-term SLR scenarios. Extensive structural damage is more likely if transportation infrastructure is subject to repeated non-storm inundation, and frequent disruptions of use within non-storm flood areas is likely to significantly reduce the utility of any affected resources. Widespread inundation during extreme storm events as projected under 3.3ft and greater SLR scenarios is also likely to significantly disrupt transportation patterns throughout the City and surrounding areas until floodwaters subside.

The adaptive capacity of transportation infrastructure is also diminished for long-term SLR hazard projections. Mitigation beyond localized measures for critical infrastructure will likely be necessary to address the extensive nature of non-storm and storm flood projections under a 3.3ft SLR scenario. The city-wide extent of non-storm flood projections under SLR scenarios greater than 3.3ft also presents a significant challenge for adaptation, likely requiring significant redesign or realignment of transportation resources throughout the City.

5.5 Coastal Access and Recreation

Short-term Vulnerability
A number of coastal access and recreation resources are vulnerable to projected short-term SLR hazards. Non-storm flood projections under a 1.6ft SLR scenario show shoreline retreat of approximately 40ft along the Seal Beach waterfront. Approximately 100ft of shoreline retreat is projected within the Surfside community under this scenario. Storm flood projections under a 1.6ft SLR scenario cover multiple coastal access points and park areas at the western end of the Seal Beach waterfront, including the San Gabriel River Greenbelt and Windsurf Park. Storm flood projections extend further inland under this scenario, approaching the current location of seasonal sand berm construction along the eastern portion of the Seal Beach waterfront and Surfside community.

The eastern portion of the Seal Beach waterfront and Surfside community are highly sensitive to any loss of beach area due to continual erosion of the shoreline at these locations. Any loss of beach width in these areas has the potential to disrupt ongoing seasonal sand management practices necessary to maintain current beach width, including sand berm construction. Loss of beach width and higher water levels will also likely require higher berms placed closer to existing development to mitigate storm flood damage, potentially reducing the recreational and aesthetic value of beach areas while the berm is in place. Additional storm flood projections are also likely to increase the severity of episodic erosion events.

Adaptive capacity for coastal access and recreation resources is highest in the western portion of the Seal Beach waterfront where beach width and sediment supply are greatest. This area will likely be able to accommodate short-term shoreline retreat due to SLR, though increased storm flood hazard mitigation measures may be required to prevent damage to coastal parks in the area. Adaptive capacity is limited along the eastern portion of the Seal Beach waterfront and the Surfside community. In each of these areas the narrower sandy beach is backed by coastal development, preventing landward migration of beach areas over time with increased SLR and erosion.

Long-term Vulnerability
Coastal access and recreation resources within the City of Seal Beach are highly vulnerable to projected long-term SLR hazards. A more detailed discussion of the potential economic impacts of beach loss within the City can be found in Section 6.2. Non-storm flood projections under a 3.3ft SLR scenario show substantial shoreline retreat, covering the 1st Street coastal access point and surrounding coastal parks. In the eastern portion of the Seal Beach waterfront these projections cover approximately half of the current beach width at the narrowest locations, bordering existing sand berm placement locations. Non-storm flood projections under a 3.3ft SLR scenario also extend beyond current sand berm placement in the eastern portion of the Surfside community, ending approximately 100ft from existing development.

Storm flood projections with 3.3ft SLR extend across the majority of coastal access points within the City including Municipal Pier parking facilities and the eastern beach promenade.

Non-storm flood projections with 4.9ft SLR extend beyond current sand berm placement locations in the eastern Seal Beach waterfront, approaching parking areas and leaving minimal remaining beach width at select locations. Beach area in the far eastern portions of Surfside is eliminated entirely under these hazard projections. Storm flood projections with 4.9ft SLR extend further inland along the western Seal Beach waterfront and cover almost the entirety of the eastern waterfront, inundating all but two coastal access points. Storm flood projections increase incrementally within the Surfside community under this scenario, extending beyond current sand berm placement across approximately half of the shoreline.

Non-storm flood projections under a 6.6ft SLR scenario extend fully across portions of the eastern Seal Beach waterfront, dividing the current beach into two small, isolated areas and inundating all eastern coastal access points. Non-storm flood projections also leave minimal beach width in areas surrounding the Municipal Pier and fully inundate Pier parking facilities. Beach areas are also eliminated entirely across significant portions of the Surfside community. Storm flood projections under this scenario show marginal increases over non-storm flood projections with the exception of the western Seal Beach waterfront, where flooding extends inland from the San Gabriel River.

Coastal access and recreation resources remain highly sensitive to these hazard projections. The extensive shoreline retreat seen in long-term hazard projections is likely to significantly reduce or eliminate the utility of sandy beach areas within the eastern Seal Beach waterfront and eastern portions of Surfside. The SLR hazard sensitivity of these areas is again compounded by potential disruption of sand management practices needed to maintain beach width under current conditions. Use of the southern portions of the San Gabriel River Greenbelt, Windsurf Park, and 1st street parking facilities is also likely to be significantly disrupted due to repeated tidal inundation with 3.3ft or greater SLR. Other coastal access points and Municipal Pier Parking facilities may be unavailable for extended period following flooding during major storm events with 3.3ft SLR, or on a more frequent basis due to non-storm flood projections under more extreme SLR scenarios.

Adaptive capacity is once again limited due to the presence of coastal development immediately landward of beach areas. Without room for landward migration, additional sand placement measures or other similar actions will likely be needed to maintain usable beach width in areas surrounding the Municipal Pier, the eastern Seal Beach waterfront, and the Surfside community under 3.3ft and greater SLR scenarios. Adaptive capacity for coastal parking facilities is aided by the presence of open space landward of these resources and the relative ease of elevation or relocation due to the lack of large structures.

5.6 Seal Beach Municipal Pier

Like many timber piers along the coast of California, the Seal Beach Municipal Pier experienced significant damage during the severe winter storm events of 1983. During a series of large wave events at the end of January 1983 a ~300 foot segment of the pier collapsed adjacent to the concrete groin. Several months later, during another large swell event in March 1983, a much longer ~700 foot segment pier collapsed leaving only the base of the pier and the outer end of the pier standing. Photographs of the pier after these events are shown in Figure 5-1. The large wave heights, long wave periods (20-25 seconds) and westerly direction were factors in the extremely large waves impacting the Seal Beach area. The sequence of extreme storms during this season resulted in severe beach erosion and coastal flooding in addition to pier damage. The middle segment of the pier was re-built in 1985 with a deck elevation of 26 feet, MLLW (25.8 ft NAVD), three feet higher than the outer segment of the pier which remains at a deck elevation of 23 feet, MLLW (22.8 ft, NAVD).

Figure 5-1: Damage to Seal Beach Municipal Pier during the winter of 1983.

Water levels and wave heights from CoSMoS were used to evaluate the exposure of the Pier to damage from large wave events in combination with sea level rise. The pier is considered to be vulnerable to storm damage when the maximum wave crest elevation reaches the deck elevation. Most timber pier structures are sensitive to the dynamic loads resulting from a wave crest impacting the pier deck structure. Major damage experienced during the 1983 events was attributed to the combination of wave crests exceeding the pier deck, scour at the sea bed, excessive wave-induced forces on deteriorated piles, and debris from broken piles impacting other piles.

Short-term Vulnerability

For purposes of this analysis the significant wave height from the CoSMoS 100-year event was used to calculate a maximum wave crest elevation profile for each SLR scenario. The wave crest elevation profiles (solid lines) and water level profiles (dashed lines) are provided in Figure 5-2 in relation to the existing pier deck elevation. The results indicate that the vulnerability of the pier deck increases substantially for SLR scenarios of 3.3 feet and higher. However, due to the factors described below, the pier structure would likely be vulnerable to significant damage in an extreme event with any amount of SLR.

One factor not reflected in the CoSMoS wave heights is the amplification of wave height that occurs when an incident wave combines with a reflected wave (off of the Anaheim Bay west jetty) in the vicinity of the Pier. This amplification typically occurs in the surf zone which could explain why the outer segment of the pier survived the storms of 1983, but the middle segment experienced complete failure.

The significant wave height for the CoSMoS 100-year event (~10-12 feet) near the Seal Beach Municipal Pier is smaller than estimated in prior studies. Prior studies (USACE, 2002 and M&N, 1984) indicate a wave height of 10 feet is more representative of a 1-year to 5-year return period. The offshore wave parameters used in the CoSMoS model may be representative of a 100-year event for the greater southern California region but not for Seal Beach. The local wave exposure of Seal Beach is sensitive to the wave period and direction which is why the 1983 events were so problematic.

The Coast of California Storm and Tidal Waves Study (CCSTWS) for Orange County (USACE, 2002) estimated the 100-year wave height in Seal Beach to be about 18 feet (USACE, 2002). A prior study on coastal hazards in Seal Beach by Moffatt & Nichol (M&N, 1984) estimated the 100-year breaking wave height to be about 27 feet. Based on these larger wave heights, the pier would be vulnerable to an extreme storm today, especially if the event coincided with a high water level.

Long-term Vulnerability

This analysis indicates that any amount of SLR will increase the potential for damage during an extreme event. Assuming the CoSMoS wave heights are representative of a 1-5 year return period the higher SLR scenarios of 3.3 to 6.6 feet will significantly increase the frequency at which wave crest elevations exceed the pier deck. Two complicating factors that will also increase the vulnerability of the pier are long-term shoreline erosion which will shift the hazards further landward and the deterioration of the pier structure which could reduce the capacity of the structure to withstand additional wave impact forces.

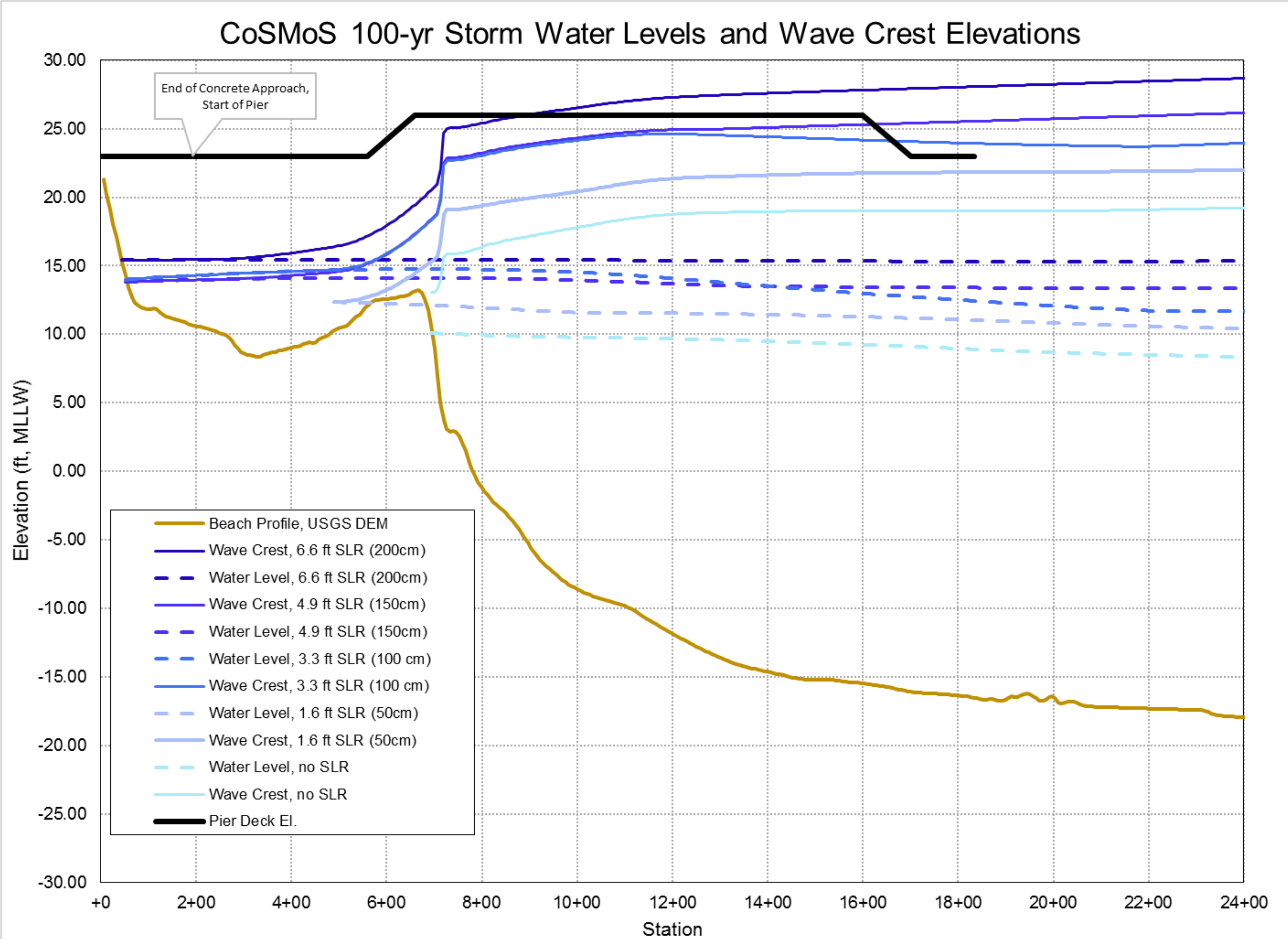


Figure 5-2: Wave crest profiles at Seal Beach Municipal Pier based on CoSMoS 100-year event.

5.7 Environmental Resources

Short-term Vulnerability

The Seal Beach National Wildlife Refuge is potentially vulnerable to short-term SLR hazards, while the Los Cerritos Wetlands have limited short-term vulnerability due to a lack of hazard exposure. Non-storm flood projections under a 1.6ft SLR scenario extend inland in the areas surrounding the Seal Beach National Wildlife Refuge, while no additional flooding is projected within the Los Cerritos Wetlands. Storm flood projections under a 1.6ft SLR scenario increase significantly in the region surrounding the Seal Beach National Wildlife Refuge. Flood projections are once again absent from the Los Cerritos Wetlands under this scenario.

Despite some degree of hazard exposure within the Seal Beach National Wildlife Refuge, overall hazard vulnerability is mitigated by potential adaptive capacity. Though wetlands are largely resistant to temporary inundation hazards, coastal wetlands can be sensitive to consistently elevated non-storm water levels if landward retreat or sediment accretion is prevented or inhibited. The ample open space landward of wetland areas within the Refuge reduces this concern when considering projected short-term SLR hazards, potentially allowing current coastal wetlands to migrate to higher ground over time. It should be noted that this potential adaptive capacity is highly dependent on a number of dynamic processes including rates of SLR, coastal sediment accretion, and the ability of wetland species to colonize new areas, and as such may require ongoing monitoring efforts to ensure preservation of ecological functions.

Long-term Vulnerability

Coastal wetlands are more vulnerable to flood hazards projected under long-term SLR scenarios. Non-storm flood projections increase significantly within the Seal Beach National Wildlife Refuge under a 3.3ft SLR scenario, extending more than 3,000ft inland from current Refuge boundaries in select locations. Non-storm flood projections under a 4.9ft SLR scenario extend further inland within the Seal Beach National Wildlife Refuge and also encompass the entirety of the Los Cerritos Wetlands area. Incremental increases in non-storm flood projections are seen in each area with 6.6ft SLR.

Storm flood projections under a 3.3ft SLR scenario cover almost the entirety of the Los Cerritos Wetlands and extend approximately 1000ft further inland than the 1.6ft SLR scenario in the areas surrounding the Seal Beach National Wildlife Refuge. Incremental increases in storm flood projections are seen in each area under 4.9ft and 6.6ft SLR scenarios.

Long-term increases in tidal elevations pose the greatest threat to coastal wetlands within the City of Seal Beach. The large increase in non-storm flood projections within the Seal Beach National Wildlife Refuge with 3.3ft SLR has the potential to significantly alter the structure and function of wetlands in the surrounding area, particularly if the inland migration of tidal floodwaters exceeds the landward migration rate of wetland areas. Despite increased non-storm flood projections, adaptive capacity for these resources is still present, as available space remains inland of current wetland areas within the Refuge even under extreme SLR scenarios. Other strategies such as thin-layer sediment placement may also mitigate SLR impacts by gradually elevating wetland areas as SLR increases. The Los Cerritos wetlands are generally more sensitive to long-term SLR hazards due to a lower of adaptive capacity. Non-storm flood projections under a 4.9ft SLR scenario become a major concern for the Los Cerritos wetlands where, unlike the Seal Beach National Wildlife Refuge, limited open space is available to facilitate landward migration. The potential for loss of these coastal wetland areas is further exacerbated under a 6.6ft SLR scenario.

6. Economic Impacts of SLR

6.1 Structural Damages

Potential structural damages to coastal structures within the City of Seal Beach are based on depth-damage relationships established through the USACE North Atlantic Coast Comprehensive Study (NACCS). These depth-damage relationships are specifically designed to better capture damage due to coastal storms as opposed to riverine flooding (U.S. Army Corps of Engineers, 2015b). The USACE functions provide estimates of minimum, most likely, and maximum damages to structures as a percentage of total structure value.

For the purposes of this analysis damage estimates throughout the City are based on inundation depth-damage relationships for USACE Prototype 5B: Two Story Residence, No Basement (Figure 6-1). Damage estimates were determined for each land parcel using flood depths from projected non-storm and 100-year storm conditions under each SLR scenario. Percent damages estimates were translated into dollar values using the current median Zillow Home Value Index for the City of Seal Beach. Results of this analysis are summarized in

Table 6-1 and Table 6-2. These estimates are not intended to be exact measurements of damage to structures within the city due to SLR hazards but are instead meant to provide information on the relative scale of potential damage under various SLR scenarios to inform adaptation planning initiatives.

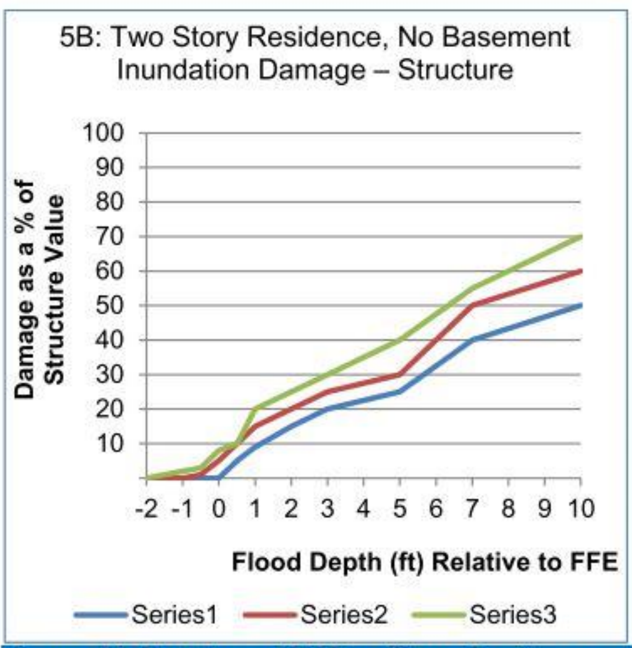


Figure 86. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Structure

Table 67. Prototype 5B: Two-Story Residence, No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-2.0	0	0	0
-1.0	0	0	2
-0.5	0	1	3
0.0	0	5	8
0.5	5	10	10
1.0	9	15	20
2.0	15	20	25
3.0	20	25	30
5.0	25	30	40
7.0	40	50	55
10.0	50	60	70

Figure 6-1: NACCS inundation depth-damage values for Prototype 5B: Two Story Residence, No Basement.

Table 6-1: Potential structural damage due to non-storm SLR hazards under multiple scenarios.

SLR (ft)	Conditions	Parcels Impacted	Damages ($)		
			Minimum	Most Likely	Maximum
1.6	Non-Storm	0	0	0	0
3.3	Non-Storm	800	81,000,000	122,000,000	148,000,000
4.9	Non-Storm	1350	181,000,000	251,000,000	313,000,000
6.6	Non-Storm	1900	321,000,000	425,000,000	526,000,000

Table 6-2: Potential structural damage due to 100-year storm SLR hazards under multiple scenarios.

SLR (ft)	Conditions	Parcels Impacted	Damages ($)		
			Minimum	Most Likely	Maximum
1.6	100-Year Storm	850	75,000,000	119,000,000	146,000,000
3.3	100-Year Storm	1450	167,000,000	241,000,000	296,000,000
4.9	100-Year Storm	1900	314,000,000	417,000,000	519,000,000
6.6	100-Year Storm	2000	487,000,000	617,000,000	738,000,000

Inundation damage estimates for non-storm conditions reflect SLR exposure thresholds seen in hazard analyses. No parcels were impacted under non-storm conditions for the 1.6ft SLR scenario, but likely damages under a 3.3ft SLR scenario exceed $120 million. Non-storm flood damage projections grow steadily under more extreme SLR scenarios, with likely damages exceeding $250 million for a 4.9ft SLR scenario and $420 million for a 6.6ft SLR scenario. Storm flood damage projections follow a similar trend but occur at less extreme SLR scenarios, reaching approximately $118 with 1.6ft SLR, $240 million with 3.3ft SLR, and $416 million with 4.9ft SLR. Likely storm damage projections increase substantially under a 6.6ft SLR scenario, exceeding $600 million. Refer to the maps in Appendix A for the CoSMoS flood zones predicted for each scenario.

6.2 Non-Market Value Loss

Non-market value refers to those goods and services that cannot be directly measured through a market price when bought or sold. The non-market value of coastal resources is defined in terms of recreation value and ecosystem services such as water quality improvements in wetlands or the provision of ecological diversity within coral reefs. Non-market values loss within the City of Seal Beach is likely due to projected significant losses of sandy beach area along the Seal Beach waterfront and Surfside community as SLR increases.

Beaches provide non-market value in a number of ways including recreation and storm buffering capacity (California Department of Boating and Waterways, 2011). These values can be quantified in terms of willingness to pay, or the amount that an individual consumer would be willing to consume the good or use the associated service (Raheem et al., 2009). Non-market beach value can be broken down further in terms of use. Direct use value consists of activities such as fishing or boating. Indirect use refers to benefits such as shoreline protection or groundwater discharge, and non-use values include cultural or existence values that do not rely on use or proximity to beaches.

Determination and quantification of non-market values associated with beaches remains challenging due to the inherent variability between locations. U.S. EPA estimates of the economic value of coastal ecosystems are used in this analysis to define beach value loss in a spatially explicit manner. U.S. EPA economic value estimates are based on a comprehensive review of past studies by economists, conservation biologists, and California Ocean Protection Council staff to provide policy-relevant ecosystem service values for the California coastline. The study considered over 30 categories of ecosystem services in total and provides quantitative estimates of erosion regulation, recreation and ecotourism, and cultural heritage values associated with beach ecosystems (Table 6-3).

Table 6-3: Non-market values of California beach ecosystems in 2008 U.S. dollars (Raheem et al., 2009)

Non-Market Service Category	Service Flow Per Acre Per Year
Recreation and Ecotourism	16,946
Erosion Regulation	31,131
Cultural Heritage Values	27
Total Value	48,104

The City of Seal Beach contains approximately 87 acres of sandy beach area, resulting in a total annual service flow of approximately $4,872,000 based on EPA non-market service valuations and adjustments to 2018 dollars using Consumer Price Index values. Sea level rise is projected to significantly reduce this sandy beach area over time. Estimates of beach loss based on CoSMoS shoreline projections under a no hold-the-line, no-nourishment scenario along with resulting loss in service flow per year are presented in Table 6-4.

Table 6-4: SLR impacts on non-market values for City beach areas (2018 $US)

SLR Scenario	Loss of Beach Area (Acres)	Service Flow Loss Per Year
0ft	0	0
1.6ft	8.8	492,800
3.3ft	18.8	1,052,800
4.9ft	28.5	1,596,000
6.6ft	38.3	2,144,800

7. Environmental Justice

Environmental justice components of future SLR hazards were evaluated using the 2016 Social Vulnerability Index (SOVI), published by the U.S. Center for Disease Control (CDC), and the results of CalEnviroScreen 3.0, an environmental health screening tool developed by the California Environmental Protection Agency (CalEPA) and the Office of Environmental Health Hazard Assessment (OEHHA). The SOVI program uses 15 socioeconomic and demographic factors at the census tract level to identify socially vulnerable areas where populations may be more adversely impacted during disaster events. These variables are organized around four themes: socioeconomic status, household composition and disability, minority status and language, and housing and transportation. Analyses presented within this study are based on summary variables for each theme, generated through percentile ranking of each variable for all census tracts within the state of California. Percentile ranking values range from 0 to 1, with higher values indicating greater vulnerability.

CalEnviroscreen data is also available at the census tract level. Pollution burden within each census tract is characterized using a suite of statewide indicators on pollution exposure and environmental effects. In a similar manner to the SOVI, percentiles are used to assign scores for each indicator in a given geographic area. Percentile scores are averaged and combined to produce an overall pollution burden score for each census tract relative to other tracts within California, scaled with a range of 0 to 10, with 10 representing the highest pollution burden. Specific variables included in pollution burden scoring and each SOVI theme are detailed below.

7.1 Socioeconomic Status

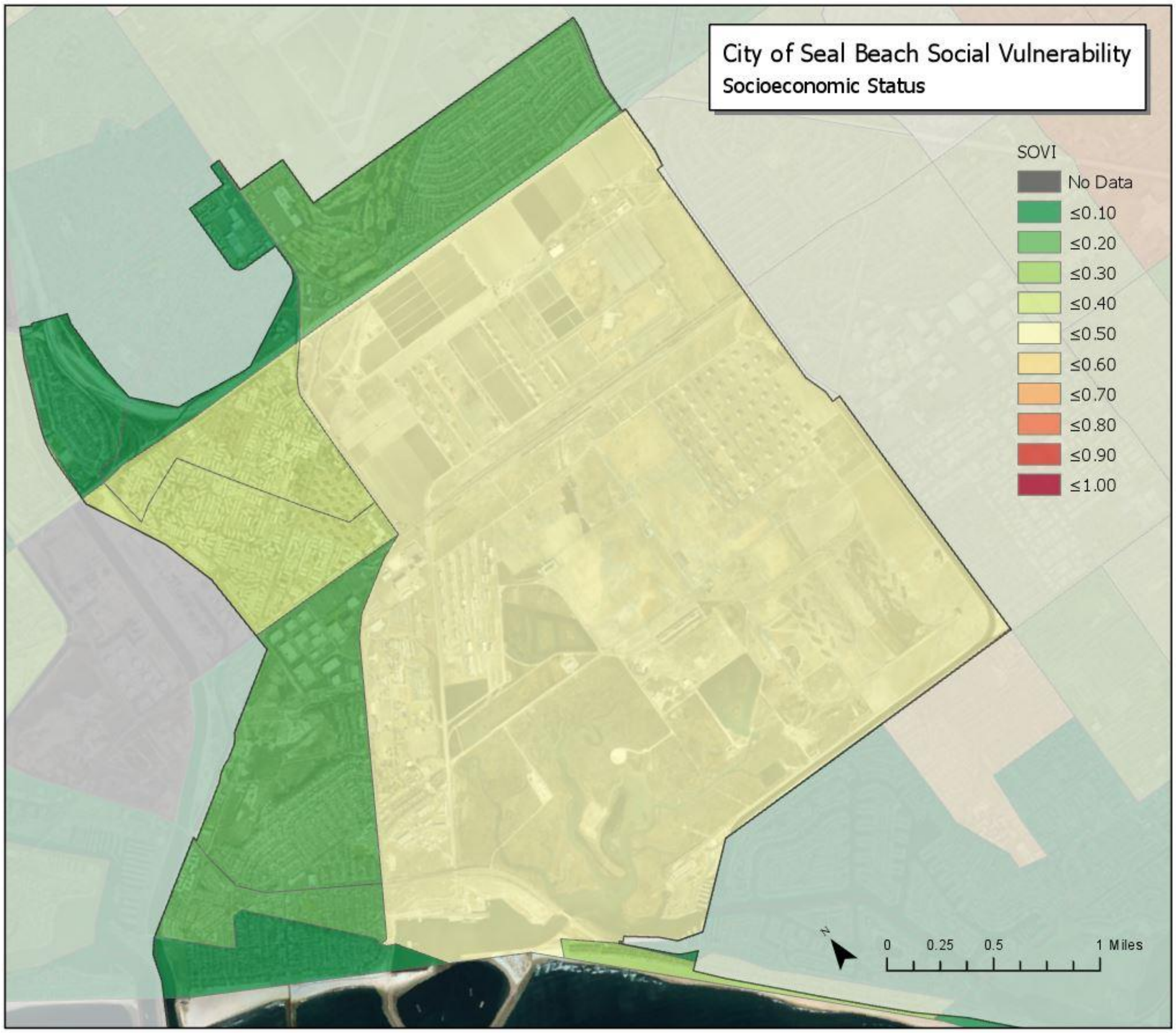


Figure 7-1: CDC SOVI socioeconomic status summary data within the City of Seal Beach.

The socioeconomic status summary variable is based on four factors: percentage of persons living below the poverty line, percentage of civilians age 16+ that are unemployed, per capita income, and the percentage of persons age 25+ with no high school diploma (Figure 7-1). Overall socioeconomic vulnerability is low within the City of Seal Beach, shown by the lack of census tracts in the upper half of percentile rankings. Waterfront areas in the City are among the least vulnerable in terms of socioeconomic status. Inland portions of the City such as Leisure World and military areas have greater socioeconomic vulnerability, though again their overall ranking within the state only approaches median values.

7.2 Household Composition and Disability

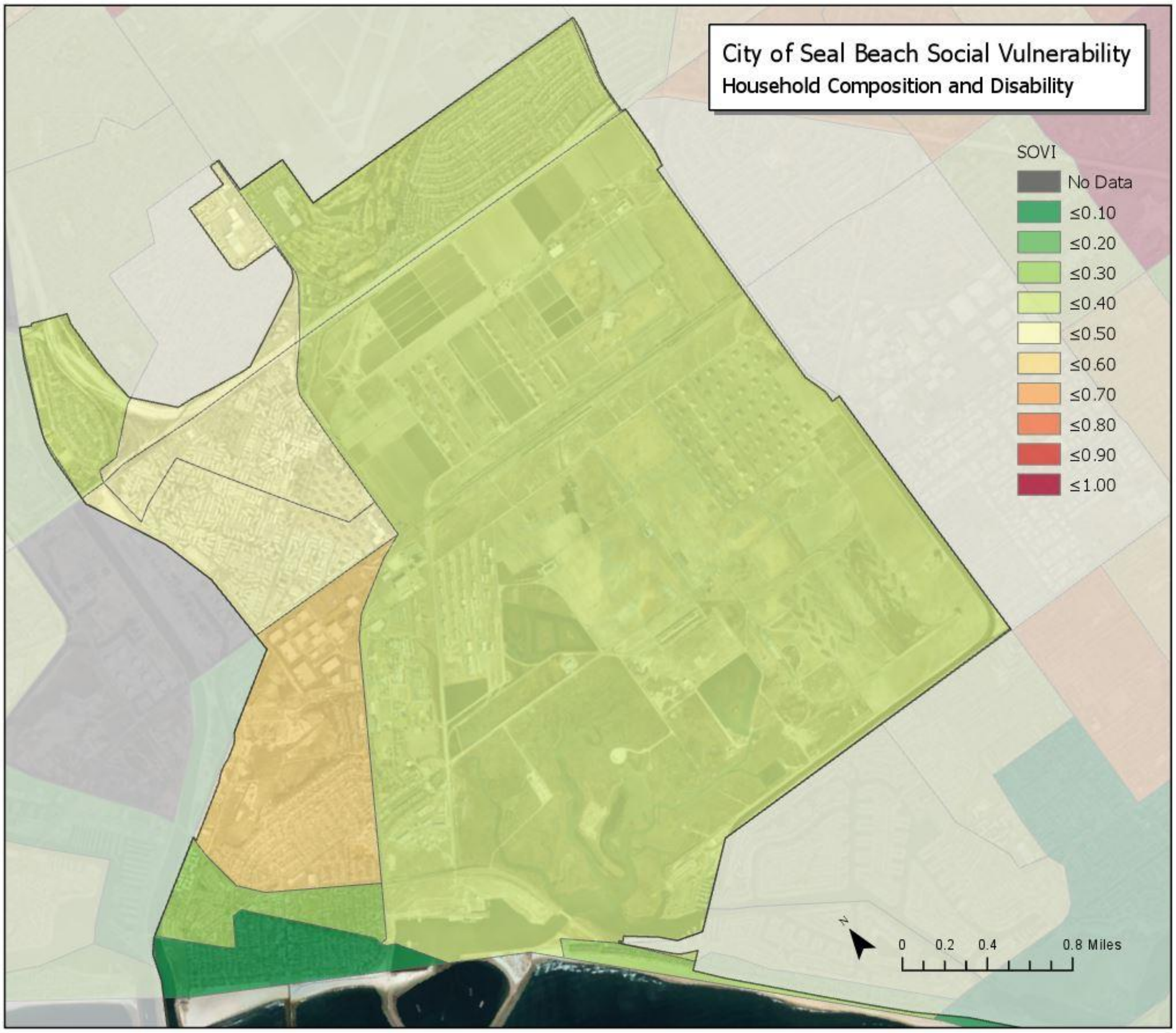


Figure 7-2: CDC SOVI household composition and disability summary data within the City of Seal Beach.

Disaster vulnerability due to household composition and disability is based on the following factors: percentage of persons aged 65 and older, percentage of persons aged 17 and younger, percentage of non-institutionalized civilians with a disability, and percentage of single parent households with children under 18 (Figure 7-2). Waterfront areas again show low social vulnerability when considering household composition and disability. Areas inland of the Pacific Coast Highway have the highest vulnerability based on household composition and disability. Leisure World remains below median values when considering a combination of all household composition and disability variables but ranks highly in terms of elderly population. Approximately 77% of the population within the two census tracts that make up Leisure World are over the age of 65 according to census estimates, a total of over 6,000 individuals.

This concentrated elderly population is likely to complicate SLR hazard adaptation and disaster response efforts. Inland flooding projected under long-term SLR scenarios covers the entirety of Leisure World and may require evacuation prior to major storms or significant response efforts afterwards. Planning for any such efforts must account for the additional needs and reduced capabilities of elderly populations.

7.3 Minority Status and Language

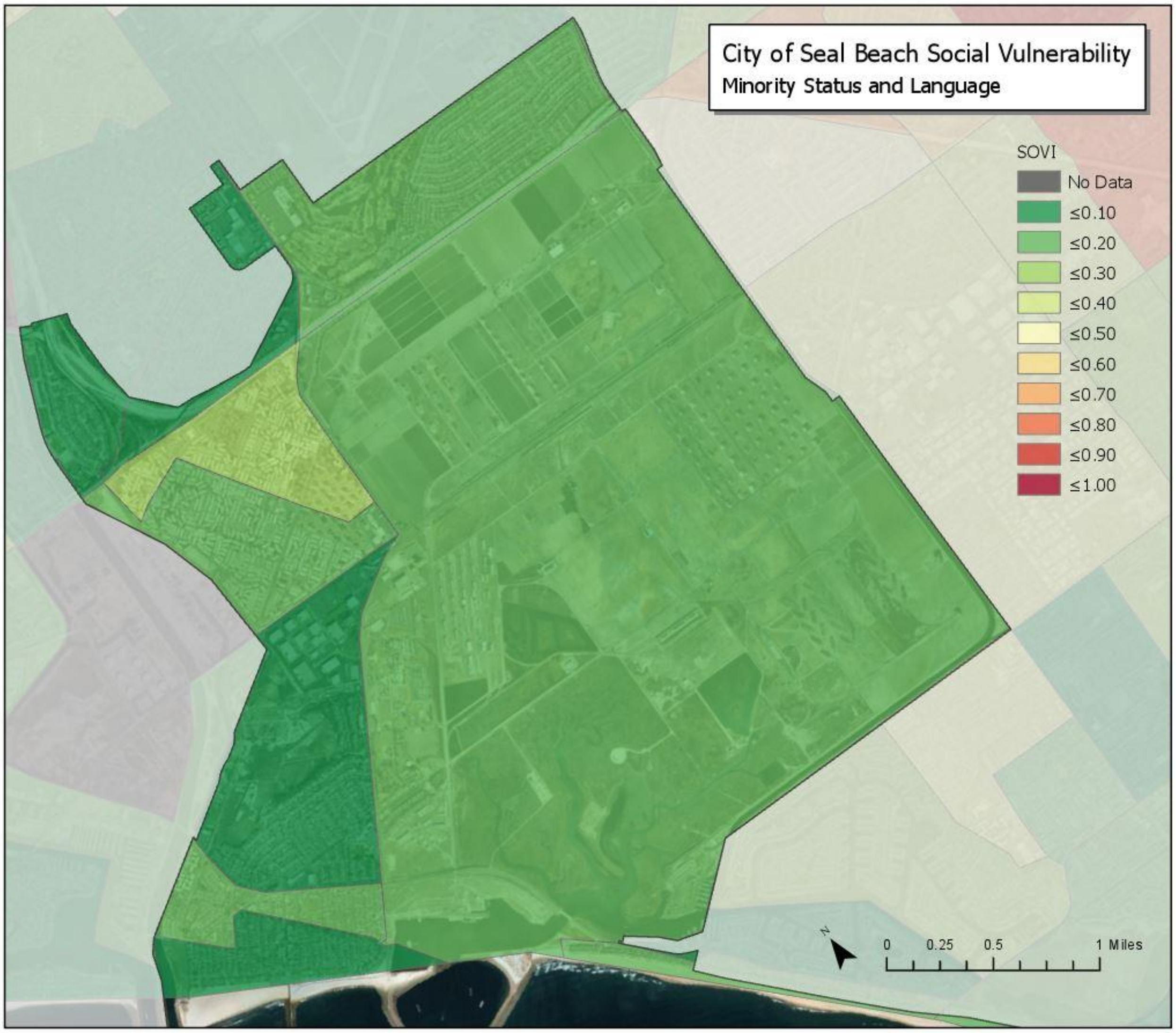


Figure 7-3: CDC SOVI minority status and language summary data within the City of Seal Beach.

Vulnerability due to minority status and language is based on two variables: the percentage of persons that do not identify as white, non-Hispanic, and the percentage of persons age 5+ who identify as speaking English "less than well" (Figure 7-3). Limited vulnerability due to minority status and language is seen within the City of Seal Beach. All census tracts within the City are well below median values. The highest vulnerability for these factors is seen in areas of Leisure World, though this tract remains in the lower third of overall rankings.

7.4 Housing and Transportation

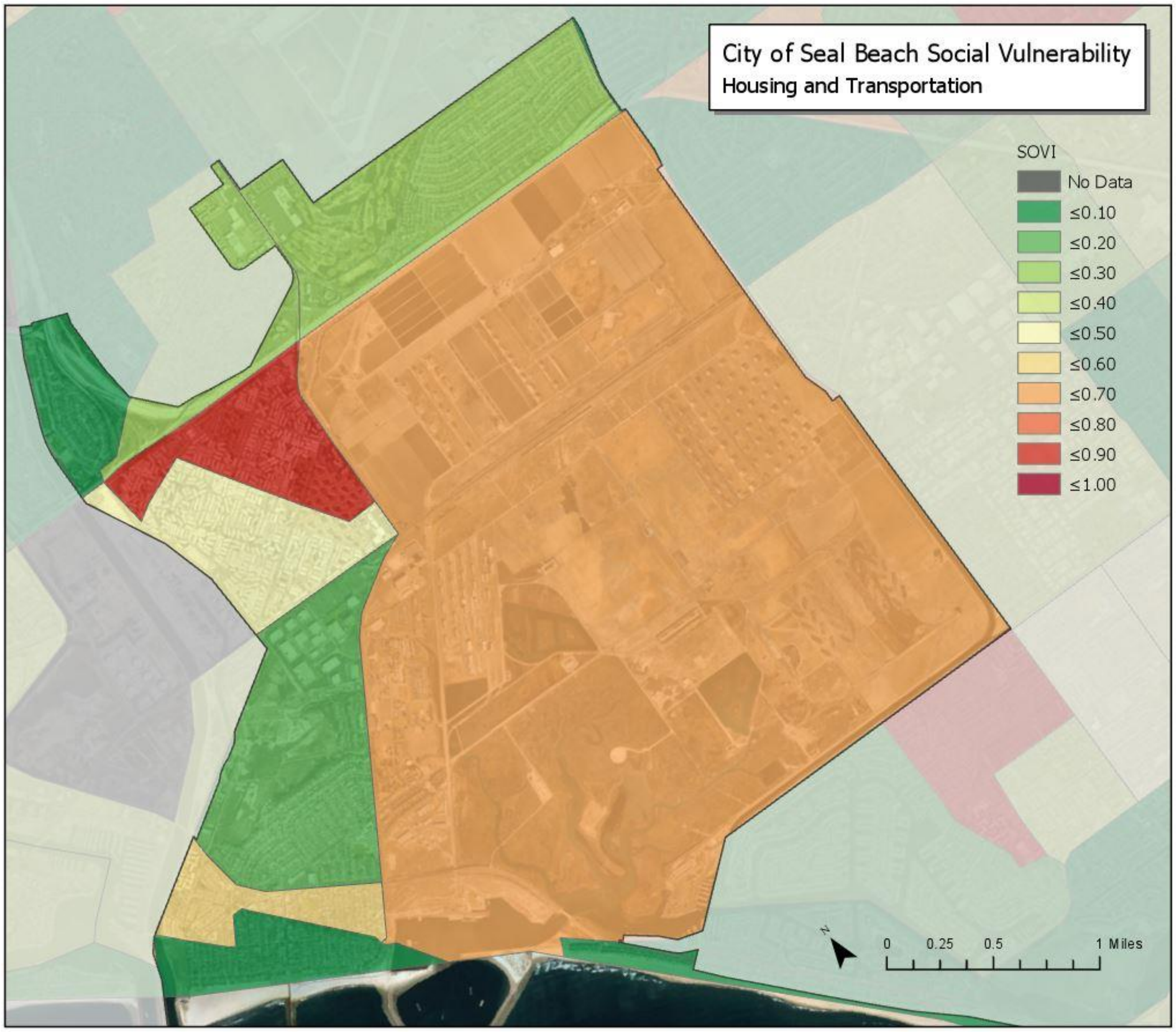


Figure 7-4: CDC SOVI housing and transportation summary data within the City of Seal Beach.

Social vulnerability due to housing and transportation is based on several factors including the percentage of housing structures with 10 or more units, the percentage of mobile homes, the percentage of household with more people than rooms, percentage of houses with no vehicles, and the percentage of persons in institutionalized group quarters (Figure 7-4). Vulnerability based on these factors varies throughout the City of Seal Beach. Waterfront areas show low vulnerability, but several inland portions of the City show high vulnerability in terms of housing and transportation. Areas immediately south of the Pacific Coast Highway and military areas are above median values, while a large portion of Leisure World ranks near the upper 10% of census tracts within California.

Flood projections cover large portions of the area south of the Pacific Coast Highway and Leisure World under multiple SLR scenarios. The scale of development, type of development, and lack of vehicle access each have the potential to hinder disaster response or recovery efforts for populations in these areas.

Leisure World is again an area of particular concern due the concentrated elderly population, compounding additional vulnerability due to housing and transportation resources. Planning for these factors in future response and adaptation efforts will greatly mitigate the potential impacts to human health and safety.

7.5 Coastal Access

Potential loss of coastal access is a major environmental justice consideration for the City of Seal Beach. Flood hazard projections under multiple SLR scenarios include local and regional transportation routes, several coastal access points, and parking facilities along the Seal Beach waterfront. Available beach area is also projected to decline significantly with SLR. Access points and parking facilities are detailed in Figure 7-5. Specific SLR thresholds and vulnerabilities for these resources are discussed in Section 5.5.

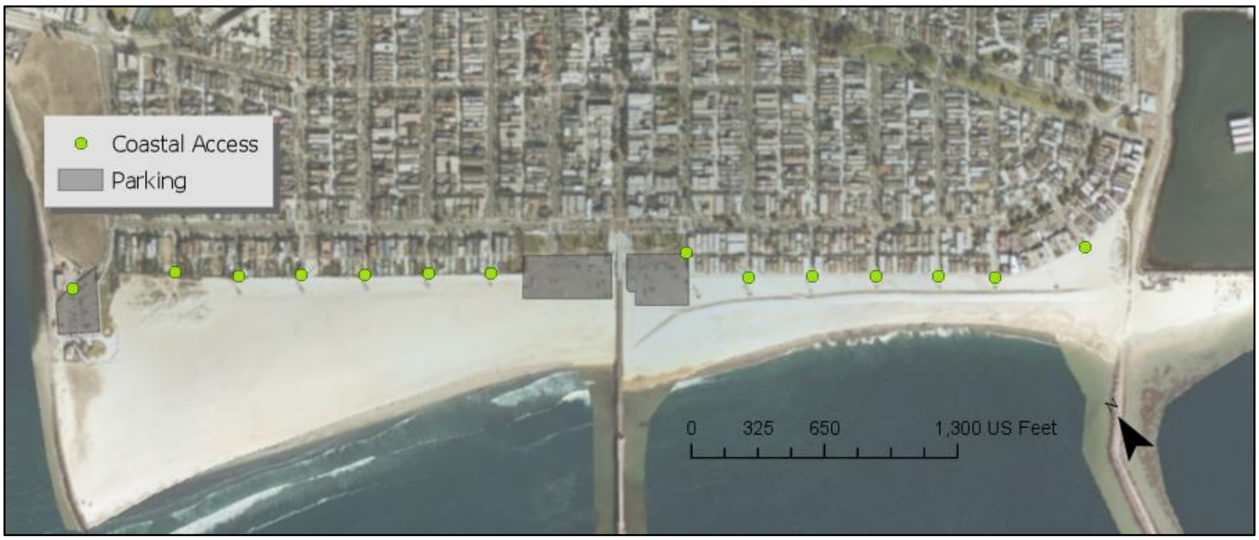


Figure 7-5: Coastal access points and parking facilities within the City of Seal Beach.

In the absence of mitigation actions, SLR hazard projections will significantly impede coastal access for both local and regional populations that do not live in the immediate vicinity of the waterfront as major coastal transportation routes such as the Pacific Coast Highway and Seal Beach Boulevard become unavailable due to flooding. Though limited data exists on specific communities that make use of the coastal resources within the City, it is highly likely that City beaches and access points serve as major recreational and cultural resources for a broad spectrum of communities within the City and surrounding areas due to the low cost of parking in the pier and jetty lots compared to other beach cities as well as available free street parking. Loss of low-cost public parking facilities at 1st Street and the Municipal Pier is of particular concern given their potential as an affordable access point for any disadvantaged communities in the region, as local street parking alone is unlikely to fully accommodate demand during peak beach visitation times. Adaptation efforts will also likely be required to maintain current levels of beach use along the eastern portion of the Seal Beach waterfront, where minimal beach width remains under severe long-term SLR scenarios. Loss of this area would greatly reduce available space for public use and could lead to regular congestion of western beach areas.

7.6 Environmental Pollution Burden

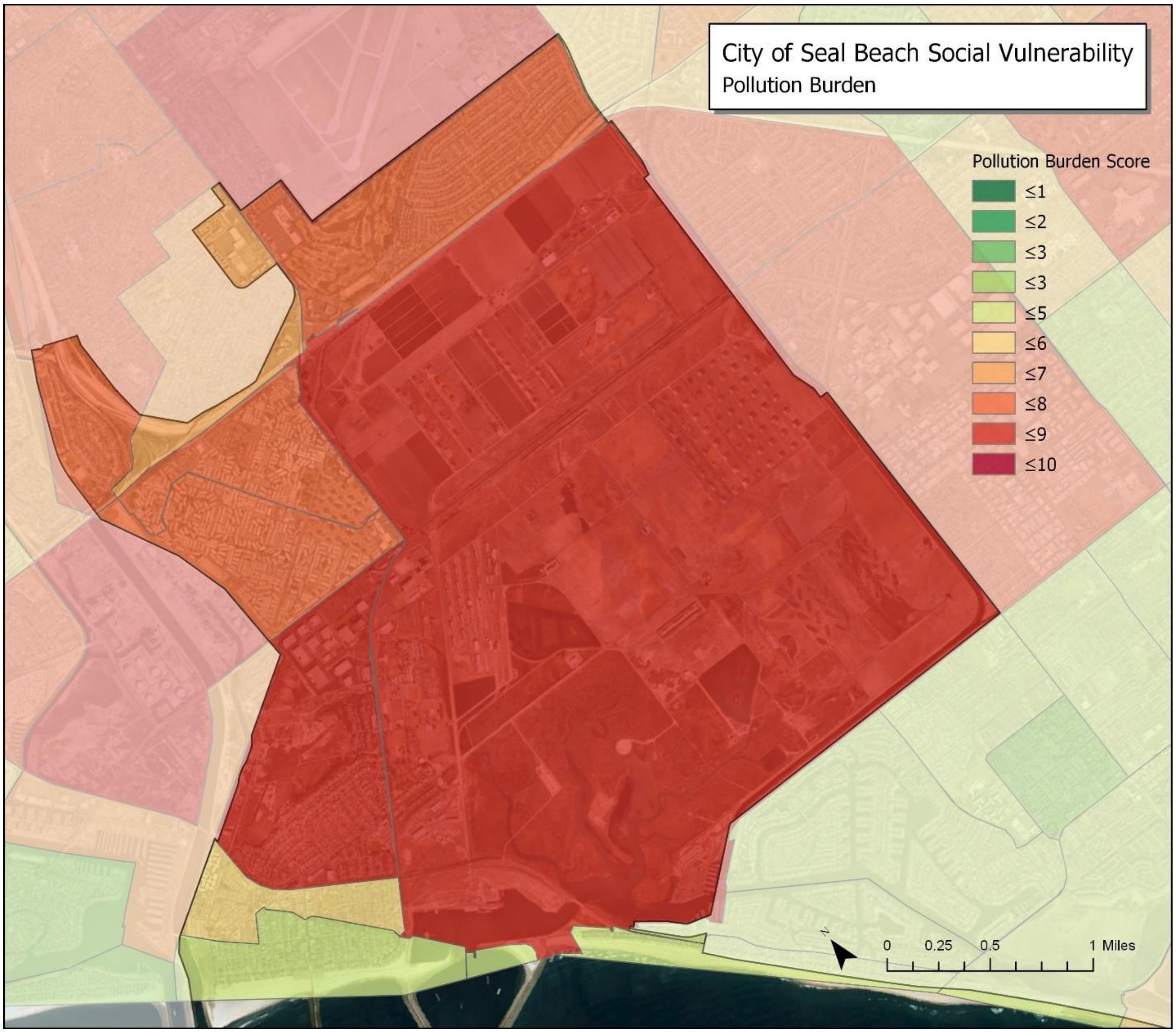


Figure 7-6: Environmental pollution burden within the City of Seal Beach per CalEnviroScreen 3.0

Environmental pollution burden indicators included in CalEnviroScreen assessments are divided into exposure indicators and environmental effects indicators. Exposure indicators include measurements of ozone, airborne particulate matter, drinking water contaminants, pesticide use, toxic releases from facilities, and traffic density. Environmental effects indicators include data relating to cleanup sites, groundwater threats, hazardous waste generators and facilities, impaired water bodies, and solid waste sites and facilities. When determining final environmental pollution burden scores for each census tract environmental effects indicators were given one-half weight and exposure indicators were fully weighted.

Overall environmental pollution burden is elevated throughout the majority of the City of Seal Beach, with the greatest exposure seen within inland portions of the City. Much of the environmental burden within the City can be attributed to dense traffic patterns, airborne particulate matter, and emissions from surrounding industrial facilities, each of which ranks highly when compared to other census tracts. These additional environmental burdens, particularly in inland areas, should be taken into consideration when forming future SLR adaptation planning strategies and efforts.

8. SLR Adaptation

The following outline of SLR adaptation strategies and policy objectives represents an initial step in the development of specific adaptation measures to reduce potential impacts identified in the SLR Vulnerability Assessment. Listed adaptation strategies and policy objectives build on work done by other municipalities that are updating their LCPs and are designed to be compatible with model adaptation measures included in CCC SLR guidance documents (California Coastal Commission, 2015, 2018). Listed adaptation strategies and policy objectives are not intended to be exhaustive or fully developed but are instead designed to be used as a high-level SLR adaptation planning framework for future adaptation measure development, analysis, and evaluation within the City of Seal Beach.

8.1 Adaptation Strategy Overview

Changing coastal hazards due to SLR can be addressed in a number of different ways. Though numerous adaptation methods are available, individual adaptation measures generally fall into one of three main categories: protection, accommodation, and retreat (Figure 8-1). In a SLR adaptation context protection refers to those strategies that employ hard or soft engineered measures to defend existing development from future SLR hazards without changes to the development itself. Accommodation refers to strategies that involve modifying existing development or designing new development in a way that reduces the potential future impacts of SLR. Adaptation strategies centered on retreat focus on measures to relocate or remove existing development from identified high-hazard areas while limiting the construction of any new development in such areas. In practice, SLR adaptation often relies on hybrid approaches that combine elements from multiple categories over different spatial and temporal scales.

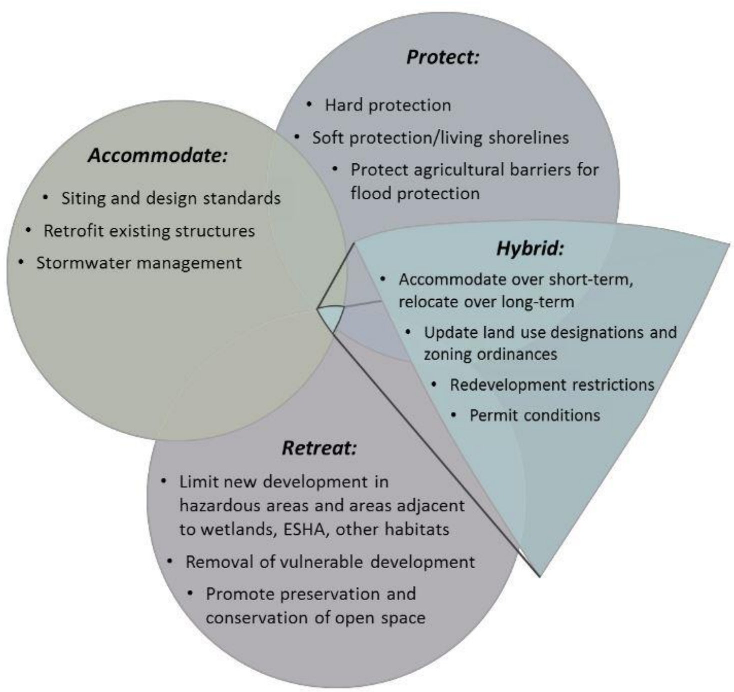


Figure 8-1: General SLR adaptation strategies and mechanisms (California Coastal Commission, 2015).

For the purposes of this study no individual adaptation strategy or category is to be considered a categorical “best” option for SLR adaptation planning within the City of Seal Beach. It is understood that a variety of adaptation strategies will be necessary to account for the different hazard vulnerabilities and coastal resources present at various locations within the City, and that adaptation strategies will need to be adjusted over time as their relative effectiveness changes.

8.1.1 Protection

Shoreline protection structures such as the San Gabriel River levees, Seal Beach Municipal Pier groin, and Anaheim Bay jetties have played a key role in the history of the City. As detailed in Section 2.3, these structures greatly influence the sandy beach areas along the Seal Beach waterfront and Surfside community. Due to the widespread presence and long history of shoreline protection structures within the City of Seal Beach, the continued maintenance and improvement of shoreline infrastructure will likely be an important component of near-term SLR adaptation efforts.

Protection strategies provide a means to minimize projected damage and disruption from higher water levels and wave events associated with low to moderate SLR scenarios. Protection strategies are generally most effective at mitigating periodic hazards due to flooding and wave overtopping associated with storm events. These strategies can also be employed to address localized high-risk areas or reinforce specific points of vulnerability to prevent flooding over a large area. Protection strategies may be less effective when considering frequent non-storm flooding projected within low-lying areas of the City under high to extreme SLR scenarios, especially in cases where future water levels are projected to consistently exceed current shoreline elevations. Given these limitations, protective structures alone are unlikely to form an effective long-term adaptation strategy for all highly vulnerable areas if SLR reaches the upper bounds of current projections. Long-term protection strategies may be appropriate if strategic reinforcement can reduce widespread flood potential, as is the case for inland portions of Seal Beach where flooding appears to originate from the San Gabriel River and Anaheim Bay rather than the coast. Protection strategies may also be employed as a potential first step to address current and near-term risk while long-term adaptation measures are developed and implemented.

An advantage of employing protection strategies within the City of Seal Beach is the ability to utilize existing infrastructure and sand management practices. Both hard and soft shoreline protection measures can be employed to enhance and maintain existing shoreline infrastructure within the City of Seal Beach. Hard protection measures include traditional engineered structures such as seawalls, revetments, and bulkheads, while soft protection measures involve the use of nature-based infrastructure such as beaches, reefs, or dune systems to reduce SLR hazards in coastal areas. Additional hard or soft protection measures within the City of Seal Beach can be used in high-risk areas where existing coastal structures are exposed to storm hazards, such as the eastern Seal Beach waterfront or the Surfside shoreline. Existing revetment structures in the interior of Anaheim Bay and along the San Gabriel River can also be enhanced to reduce the potential for inland flooding across a range of SLR scenarios (Figure 8-2). Each of these strategies can be accomplished in a manner that provides benefits to ecosystems. One such method would be to integrate environmentally sensitive materials such as ECOncrete into existing or enhanced revetment structures. Similar materials could also be used to create artificial reefs or additional hard-bottom habitat along the coastline in order to provide wave protection. Existing sand management practices can also potentially be leveraged in any construction of dune systems or living shorelines.

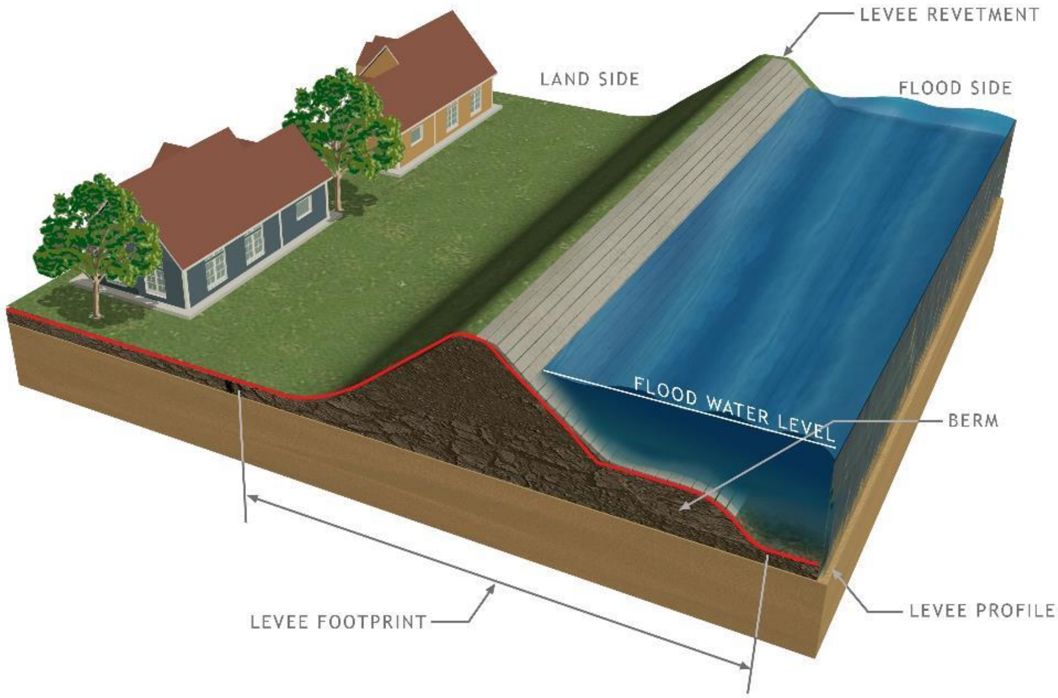


Figure 8-2: Example of additional levee reinforcement to prevent flooding within inland areas.

A key drawback of shoreline protection strategies is the potential disruption of natural littoral processes. The fixed barrier created by hard protections structures that run parallel to the coast prevents the inland migration of natural beaches and habitats over time as SLR increases. This phenomenon can already be seen along coastal development in the eastern waterfront of the City, where sandy beach areas require continued nourishment due to a lack of sand supply and increased erosion caused by the reflection of wave energy. If these coastal resources are unable to move inland, public beach recreational areas are projected to decline significantly over time in the absence of increased nourishment. Extreme protection measures extending significantly above the current shoreline may also result in negative visual impacts along the waterfront.

8.1.2 Accommodation

Accommodation strategies can be employed as alternative to or in conjunction with protective measures. These strategies are often employed for coastal structures or resources that rely on coastal access or proximity to the shoreline where it is not feasible to rely on shoreline protection. Depending on the characteristics of the coastal resource and type of accommodation employed, accommodation strategies can address coastal hazards across low, moderate, and severe SLR scenarios.

Coastal resources and structures can accommodate SLR hazards through both modification of existing development and design of new development. Accommodation strategies based on structural modification include actions such as structural elevation, retrofitting for flood resilience, and the use of flood resistant materials during construction (Figure 8-3, Figure 8-4). Accommodation strategies based on design can address SLR hazards by including potential relocation, redesign, or other form of adaptation in initial structural plans or by employing additional shoreline setbacks where possible. These strategies can be employed on an individual basis or on a community-wide scale through specific land-use designations, zoning ordinances, or other measures.

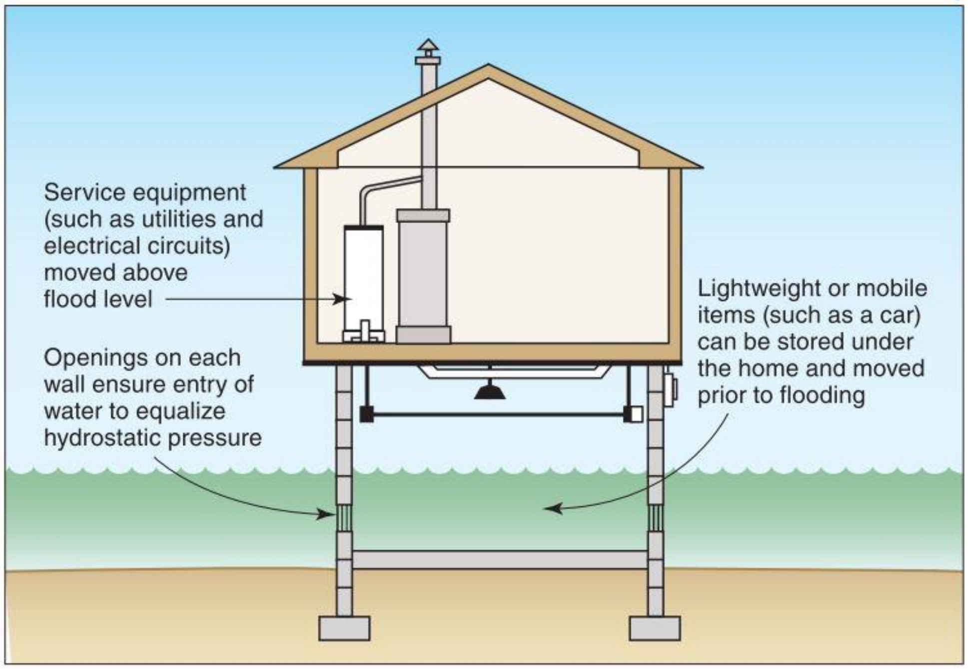


Figure 8-3: Example cross section of an elevated home using continuous foundation walls (FEMA, 2014).

Accommodation strategies can be implemented in a number of areas throughout the City of Seal Beach. Temporary or permanent floodproofing retrofits can be employed within current and projected future flood prone areas to reduce the impacts and recovery time flowing flood events. These measures are most appropriate in projected storm flood zones where flood events will not occur on a regular basis but must still be accounted for. An example would be the implementation of improved drainage infrastructure along low-lying waterfront roadways to collect and convey floodwaters, restoring critical transportation routes in a timely manner (Figure 8-5). Additional adaptation strategies may be necessary within projected non-storm flood zones along coastal and inland areas to accommodate future SLR hazards. Coastal-dependent structures such as lifeguard stations or coastal access facilities can be elevated to avoid repeated tidal flooding or wave damage. Elevation is also an option for other structures within low-lying areas, but the effectiveness of this strategy will be reduced if non-storm flooding prevents access to structures on a consistent basis.

While structural elevation can successfully mitigate coastal hazards driven by SLR, potential drawbacks are also present. If elevation of structures along a shoreline becomes widespread, elevated structures may reduce the aesthetic value of coastal areas or impact community character. Uncoordinated structural elevation initiatives, where only select structures are elevated in an area, can also result in a patchwork of different vulnerabilities within hazard zones, complicating future adaptation planning. Under high to extreme SLR scenarios, the continued elevation of structures in their current location can also result in a situation where structures unintentionally become elevated directly over tidelands, presenting access and maintenance challenges.

Figure 8-4: Example of elevated shoreline structures to prevent damage during flood events.

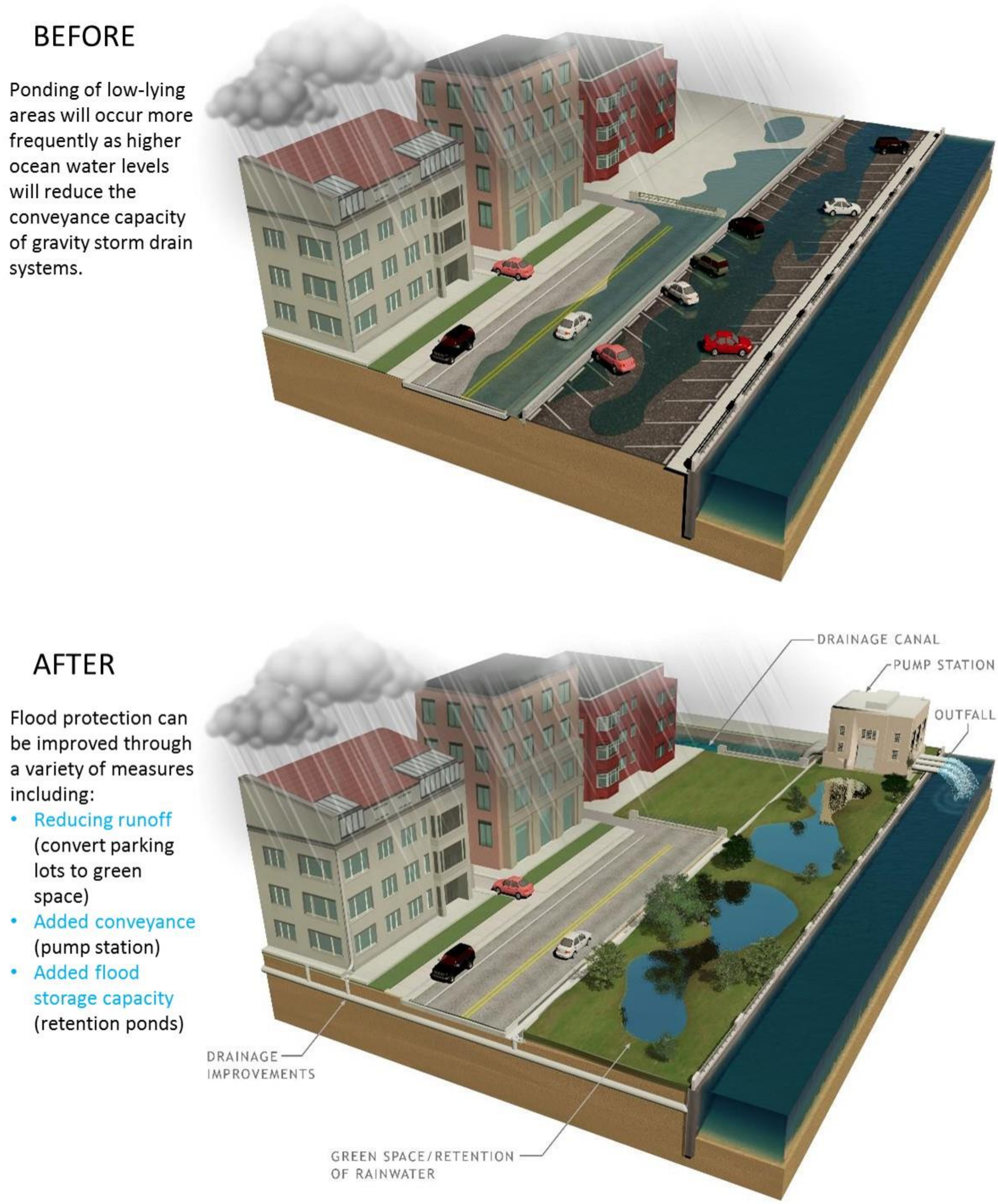


Figure 8-5: Example of drainage improvements to reduce flooding (U.S. Army Corps of Engineers, 2015a).

8.1.3 Retreat

Directly removing or relocating vulnerable structures away from hazard areas represents an effective long-term form of SLR adaptation under high to extreme SLR scenarios. Retreat strategies can be employed for cases in which any feasible protection or accommodation strategies become insufficient to address coastal hazards. Retreat strategies can be implemented in a variety of ways including land use designations or zoning ordinances designed to encourage new development within less vulnerable areas. Property acquisition programs, rolling easements, transfer of development rights programs, and permit conditions can additionally be used to gradually move highly vulnerable existing development away from current and future hazard areas.

Successful employment of retreat strategies often requires available areas located landward of vulnerable structures or resources. This is a complicating factor throughout much of the City of Seal Beach due to the high density of development in coastal areas. Available areas at higher elevations are also limited due to the relatively low relief within the City and extent of coastal wetlands, restricting potential retreat options. Despite these limitations retreat strategies can potentially result in greater resilience to SLR hazards at a lower cost than protecting structures in place under extreme SLR scenarios, while also avoiding recreation and coastal access issues that could result from additional shoreline protection. Retreat strategies can also be implemented in combination with protection or accommodation strategies as a method to plan for and address SLR hazards under a worst-case scenario.

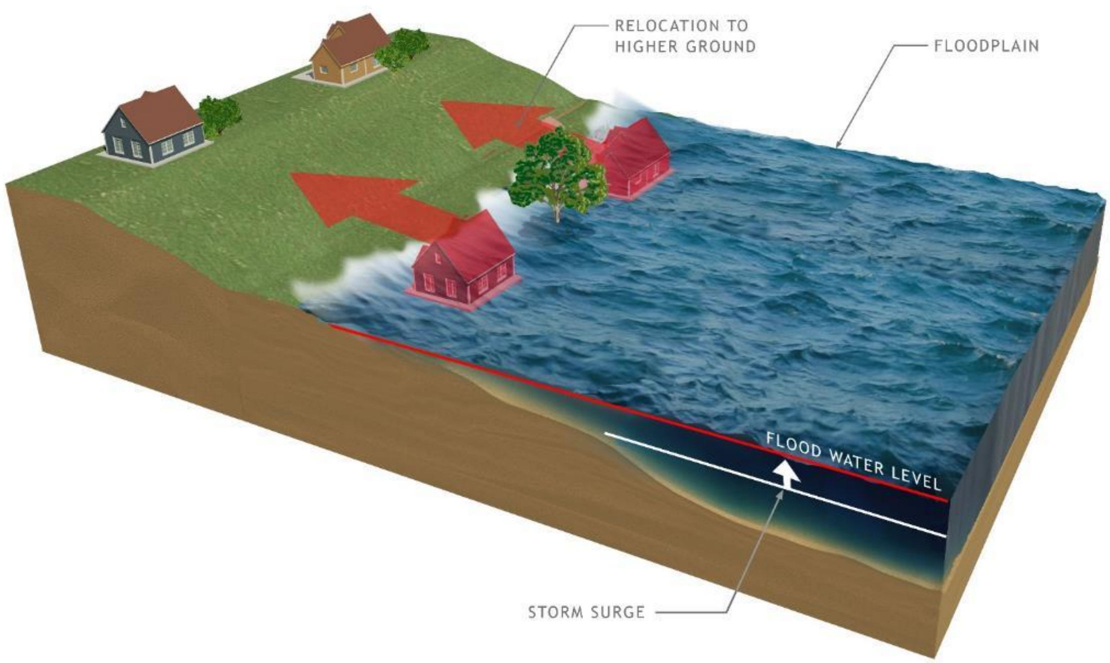


Figure 8-6: Example of retreat strategies within high-hazard areas.

8.2 SLR Adaptation Policy Objectives

8.2.1 Understand SLR Hazards

Knowledge of the timing, magnitude, and location of future SLR hazards is critical to SLR planning and adaptation efforts. Policies in pursuit of this goal will focus on ways to best obtain, utilize, and disseminate current and future SLR information to inform decision-making in coastal areas.

Ensuring the use of best-available climate science is a key component to achieving this goal. Policies to define best-available science will allow for the most accurate determination of potential future coastal hazards and the planning horizons associated with those hazards. Specifically defining best-available climate science will also provide a consistent standard for SLR adaptation planning, enabling the use of coordinated adaptation strategies within the City. Adaptation policies focused on continued hazard monitoring enable continual updates of SLR adaptation strategies and provide concrete information on when critical hazard thresholds have been exceeded. Hazard monitoring programs can take a number of forms including tracking regional SLR rates or documenting storm conditions that lead to localized coastal flooding.

Disseminating identified best-available science is also necessary to support public understanding and participation in SLR adaptation and planning. Policies designed to inform the general public of projected future hazards due to SLR encourage responsible decision-making at the individual level and can potentially increase public support for SLR adaptation initiatives within the City. Policies focused on disclosing risks to associated with new development can also provide an important mechanism for educating property owners about projected SLR hazards and their options for addressing them.

8.2.2 Manage Development in SLR Hazard Areas

Siting and construction standards for new coastal development or redevelopment projects represent key mechanisms to reduce SLR hazard impacts to new and existing development. Policies in pursuit of this goal will focus on reducing exposure to coastal hazards over the duration of new or proposed development.

Incorporating projected SLR hazards into the initial siting of new development is an important step in mitigating SLR hazards. Policies put in place to reduce new development within high-risk areas help prevent the growth of SLR vulnerability and the need for future adaptation measures. Policies focused on siting new development can also reduce the need for additional shoreline armoring, preserving natural shoreline processes that benefit coastal uses and resources.

Managing redevelopment is another method to control SLR vulnerability. Policies that establish limitations on continued redevelopment in hazard areas reduce future SLR vulnerability by restricting growth of high-risk structures and reducing ongoing repetitive losses. Policies focused on specific redevelopment thresholds also provide an opportunistic mechanism to implement SLR adaptation standards over time.

SLR hazard considerations can also be included in the design of new development or redevelopment. Policies that establish adaptive design requirements can reduce the initial SLR vulnerability of structures and facilitate additional long-term adaptation efforts as they become necessary. Due to their focus on adaptive flexibility over time, these policies can form an important component of phasing a response to SLR impacts.

8.2.3 Reduce Coastal Hazards

Enhancements and additions to existing coastal hazard reduction measures are often necessary to account for potential increases in hazard levels due to SLR. Policies in pursuit of this goal will focus on protection from and accommodation of current and future SLR hazards through both structural and nature-based means.

Managing the establishment and maintenance of shoreline protection measures can provide multiple benefits to SLR adaptation efforts. Policies that establish standards for the construction, evaluation, repair, and maintenance of existing shoreline protection measures enable the ongoing functionality of protective measures as coastal hazards change with rising water levels, reducing potential for failure under future conditions. Policies related to new or additional shoreline protection measures can reduce the potential for unwarranted or ineffective shoreline protection structures and can also help ensure that alternative, nature-based strategies are given appropriate consideration.

Standardizing approaches to structural floodproofing can also benefit adaptation efforts. Policies that establish appropriate situations and best practices for floodproofing retrofits or redesign allow for the consistent and effective application of these strategies within hazard areas. These types of policies can also improve awareness of available floodproofing mechanisms by providing a standardized reference for interested parties.

8.2.4 Use a Coordinated Approach to SLR Adaptation

Coastal processes that affect SLR hazards often extend beyond the parcel scale. Participating in coordinated regional SLR hazard mitigation planning efforts can substantially increase the efficiency and cost-effectiveness of SLR resilience measures. Policies in pursuit of this goal will focus on potential coordinated programs that could benefit coastal resources in the City of Seal Beach.

Developing a phased adaptation approach can provide a flexible implementation mechanism for future SLR adaptation efforts. Policies that establish appropriate SLR hazard mitigation trigger types, hazard thresholds, and responsive actions can substantially improve the implementation of SLR adaptation measures by providing clear standards for the timing and type of future SLR adaptation efforts. A key benefit of such an approach is that the timing of phases can be adjusted as new SLR hazard information becomes available. Including community participation provisions in the initial phased adaptation planning process can also increase clarity surrounding the potential timing and justification of future SLR adaptation measures.

Aligning planning documents within the City is another method to efficiently finance and implement SLR adaptation. Policies that address compatibility between the Local Hazard Management Plan and the Local Coastal Program help to ensure that proactive adaptation efforts are coordinated across City departments and that responses to damage from future coastal hazards are streamlined. These policies can also help secure additional SLR mitigation funding by identifying project types that meet the goals of both planning documents in order to fully leverage available federal and state funding opportunities.

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Appendix A Hazard Maps

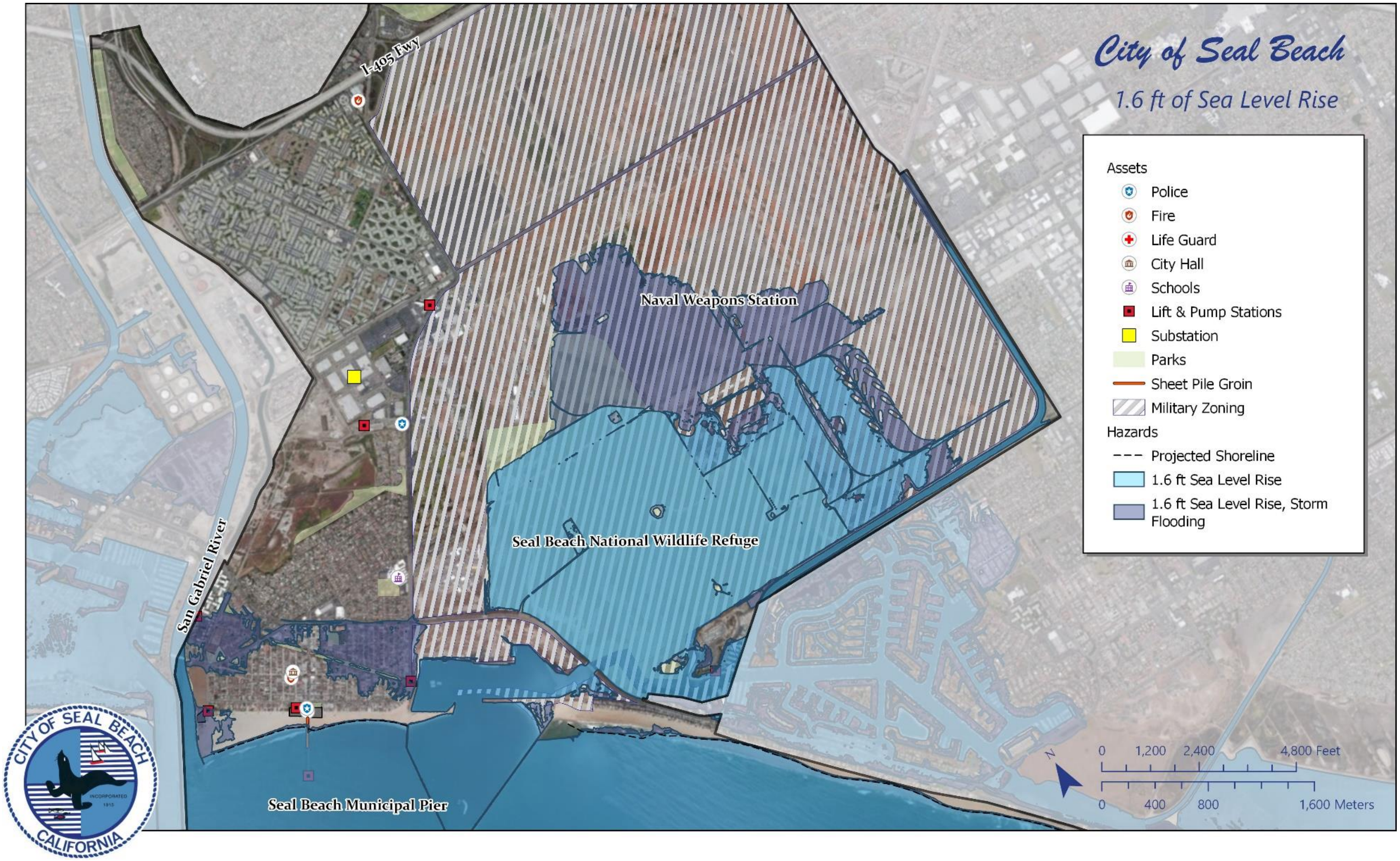

Figure A-9-1: 1.6ft SLR hazards, full City extent.

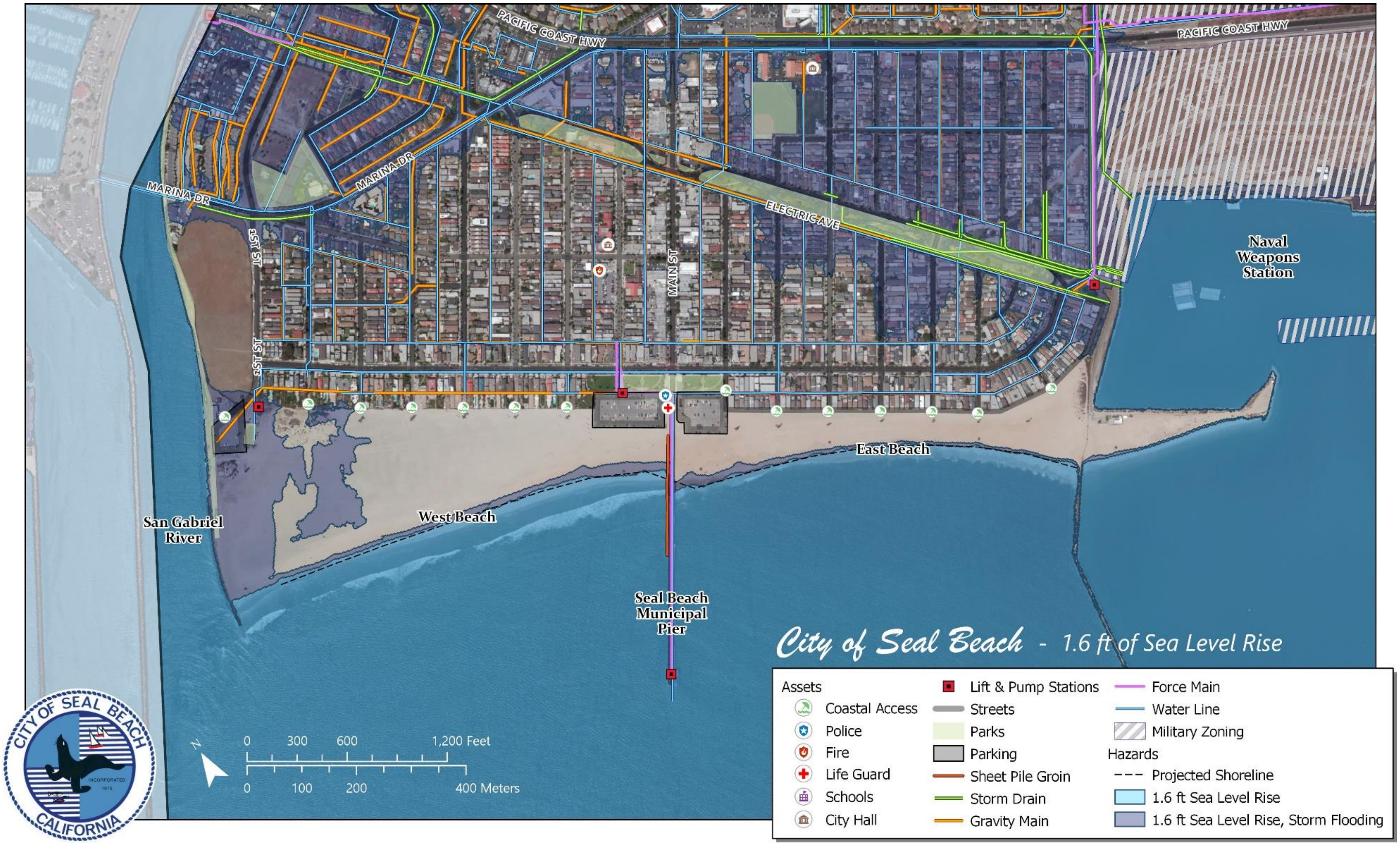

Figure A-9-2: 1.6ft SLR hazards, Seal Beach waterfront.

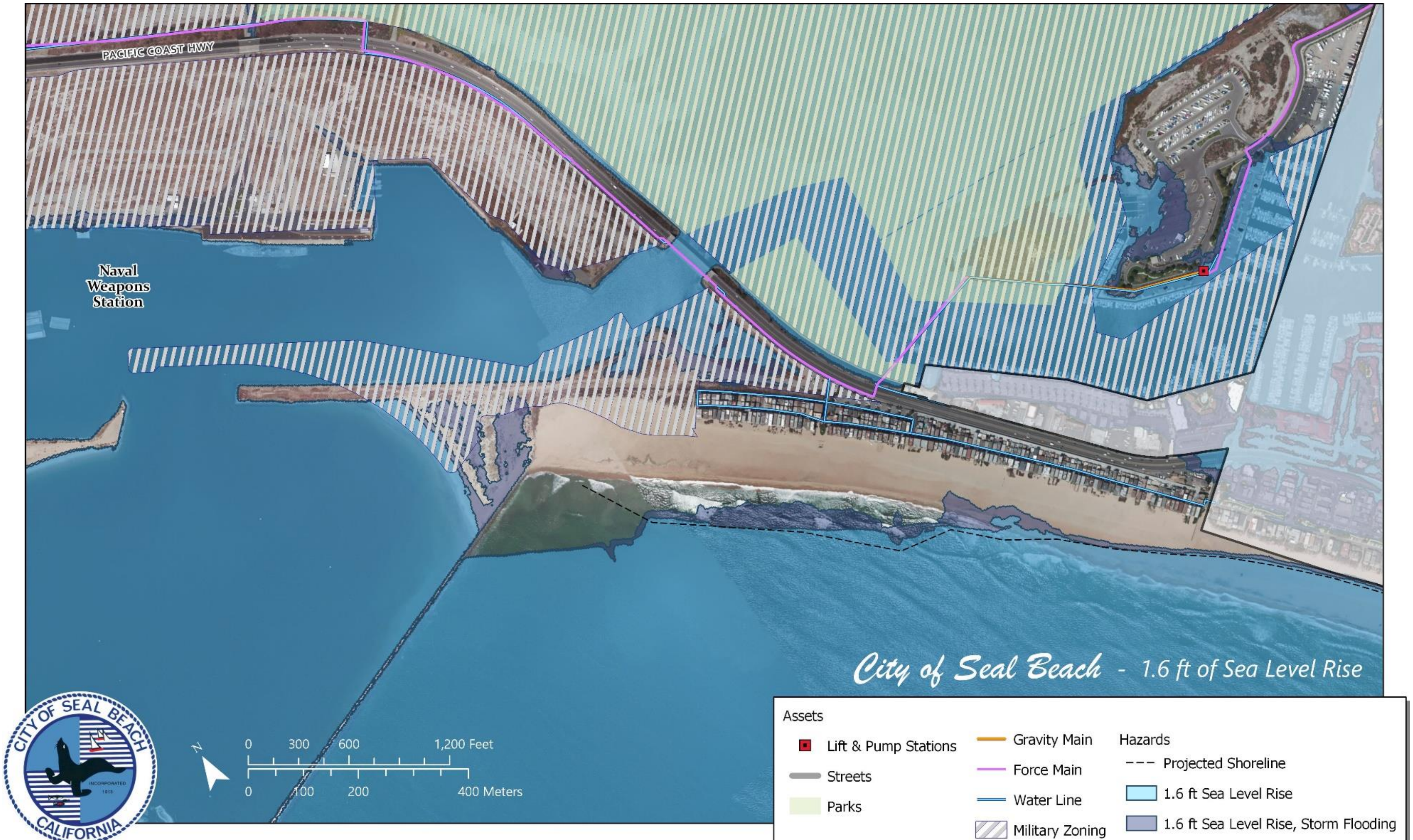

Figure A-9-3: 1.6ft SLR hazards, Surfside.

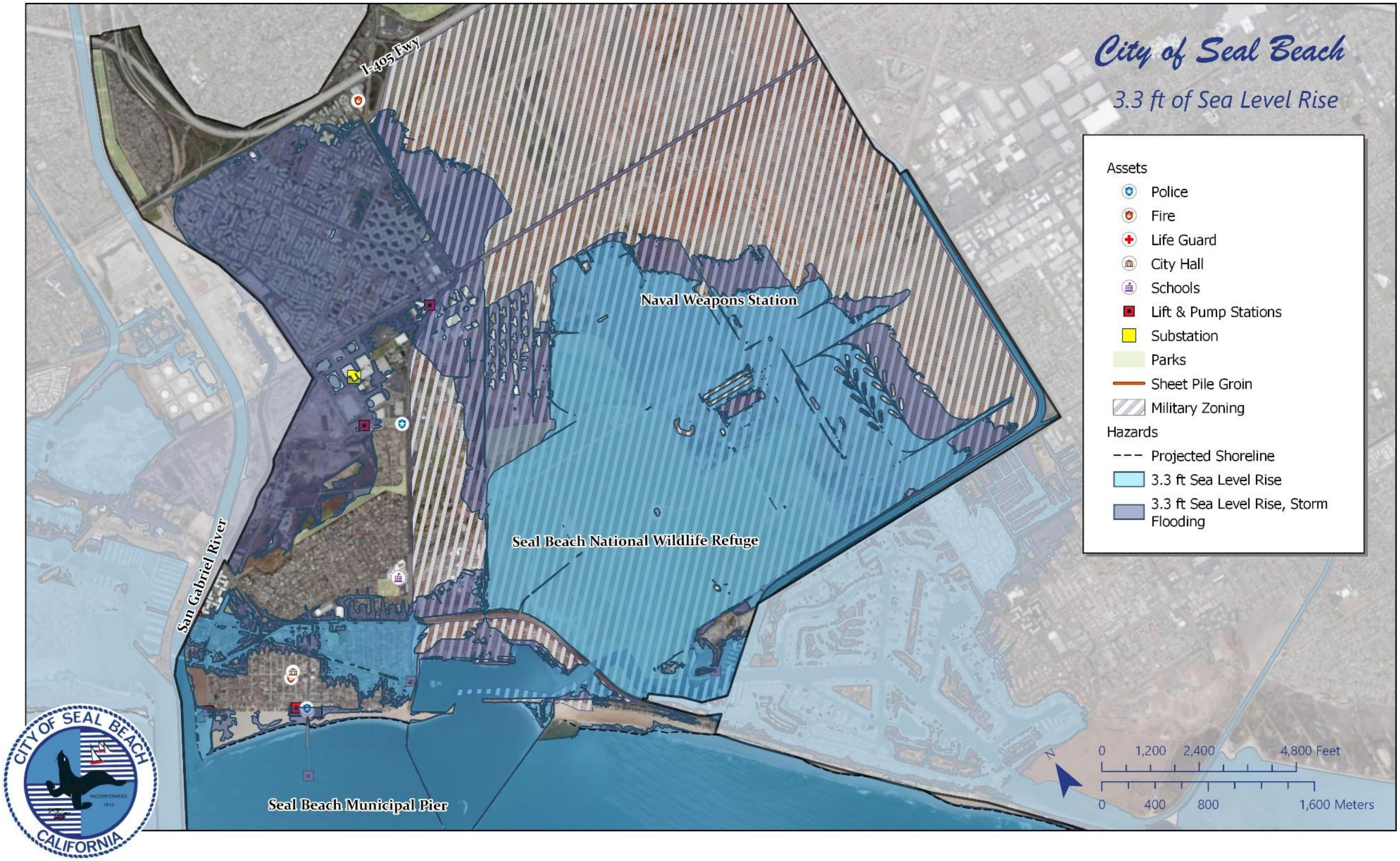

Figure A-9-4: 3.3ft SLR hazards, full City extent.

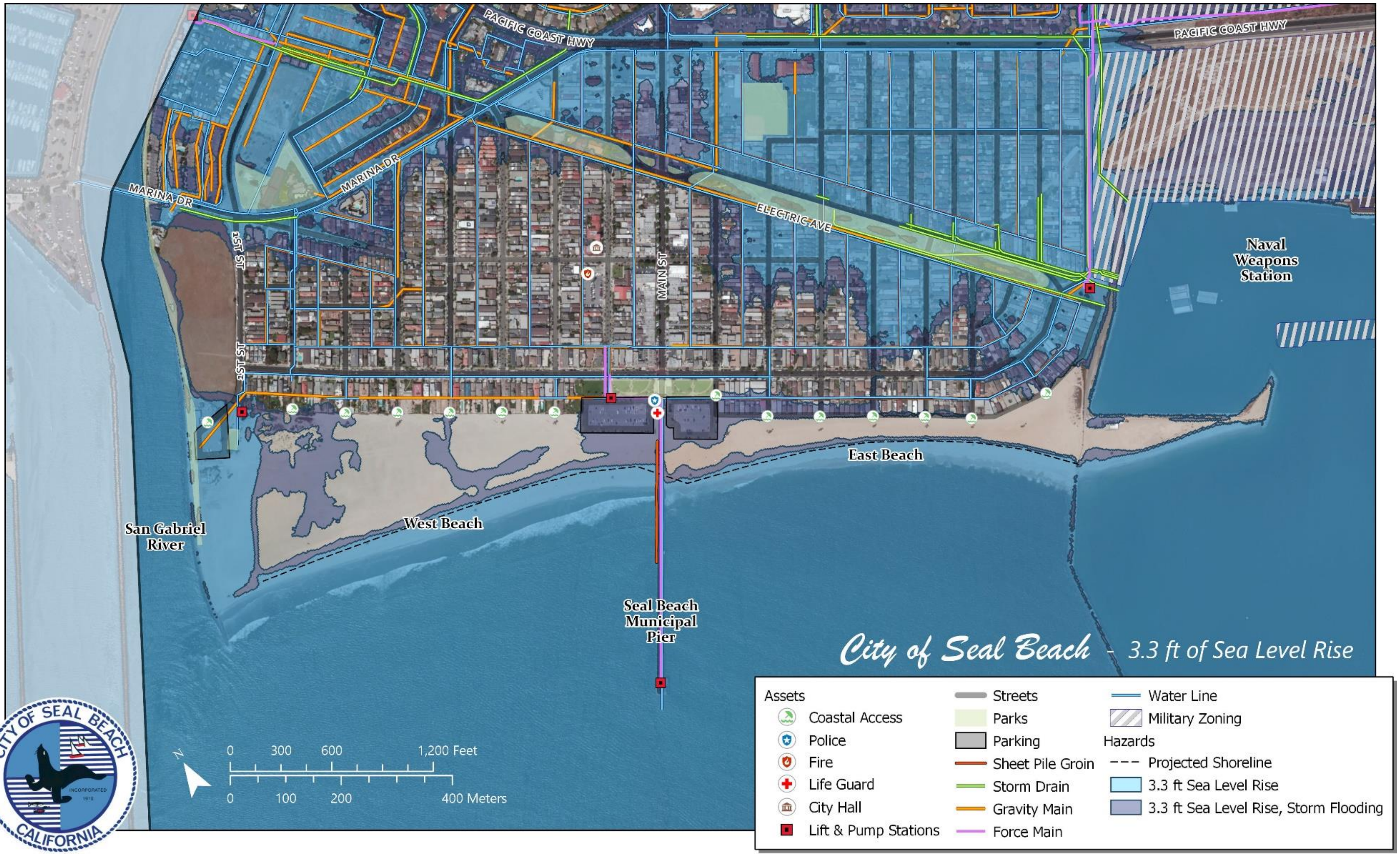

Figure A-9-5: 3.3ft SLR hazards, Seal Beach waterfront.

Figure A-9-6: 3.3ft SLR hazards, Surfside.

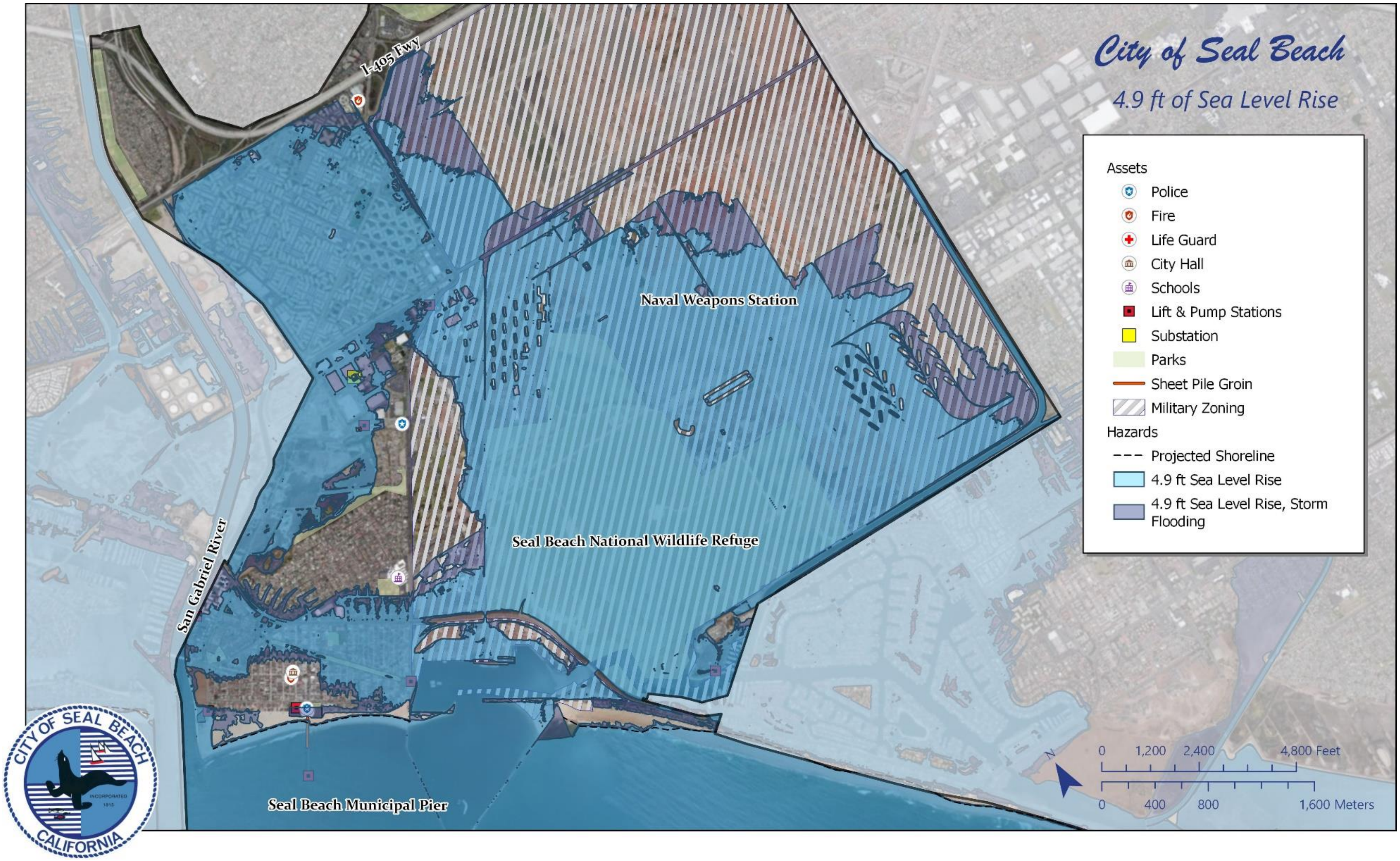

Figure A-9-7: 4.9ft SLR hazards, full City extent.

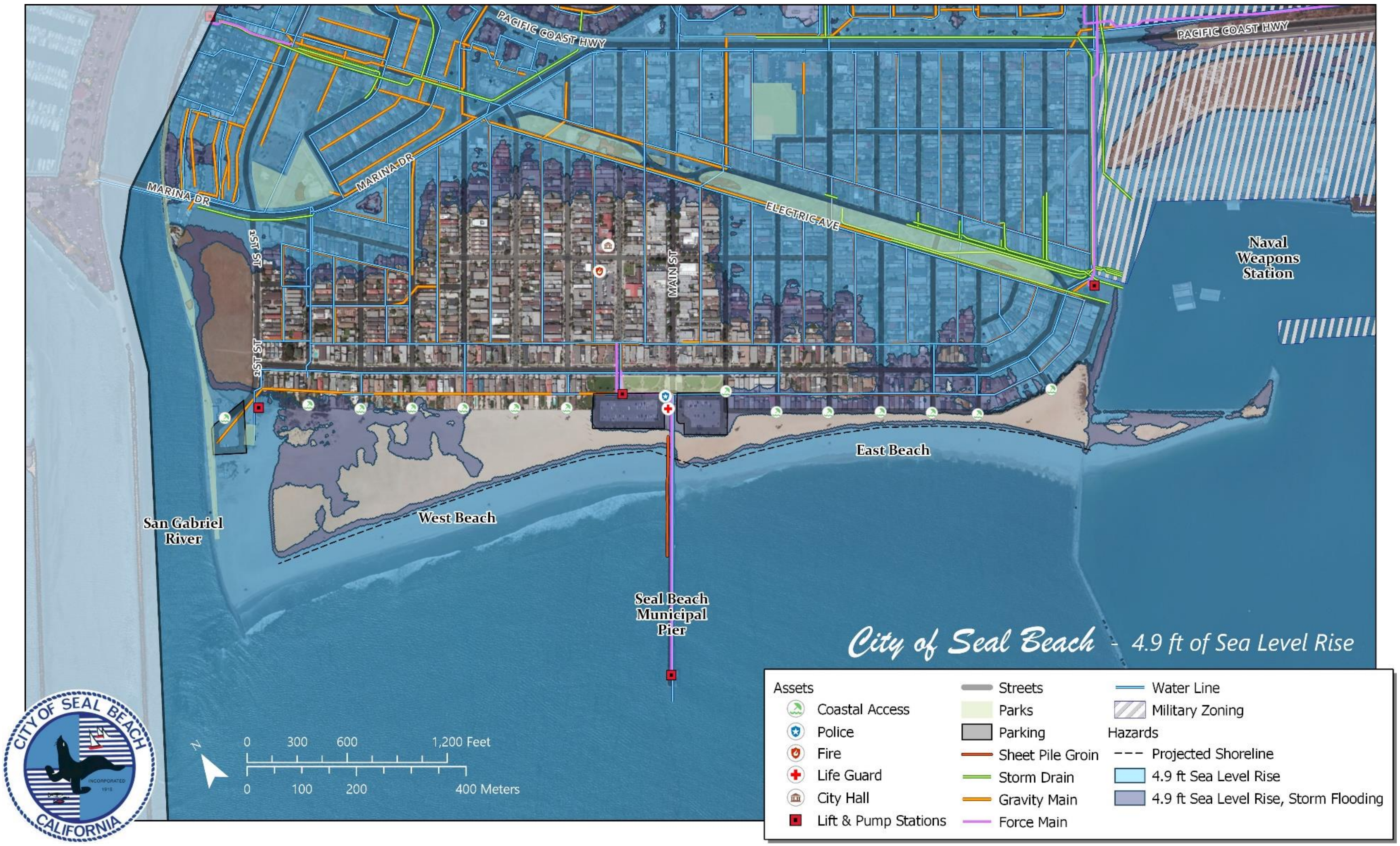

Figure A-9-8: 4.9ft SLR hazards, Seal Beach waterfront.

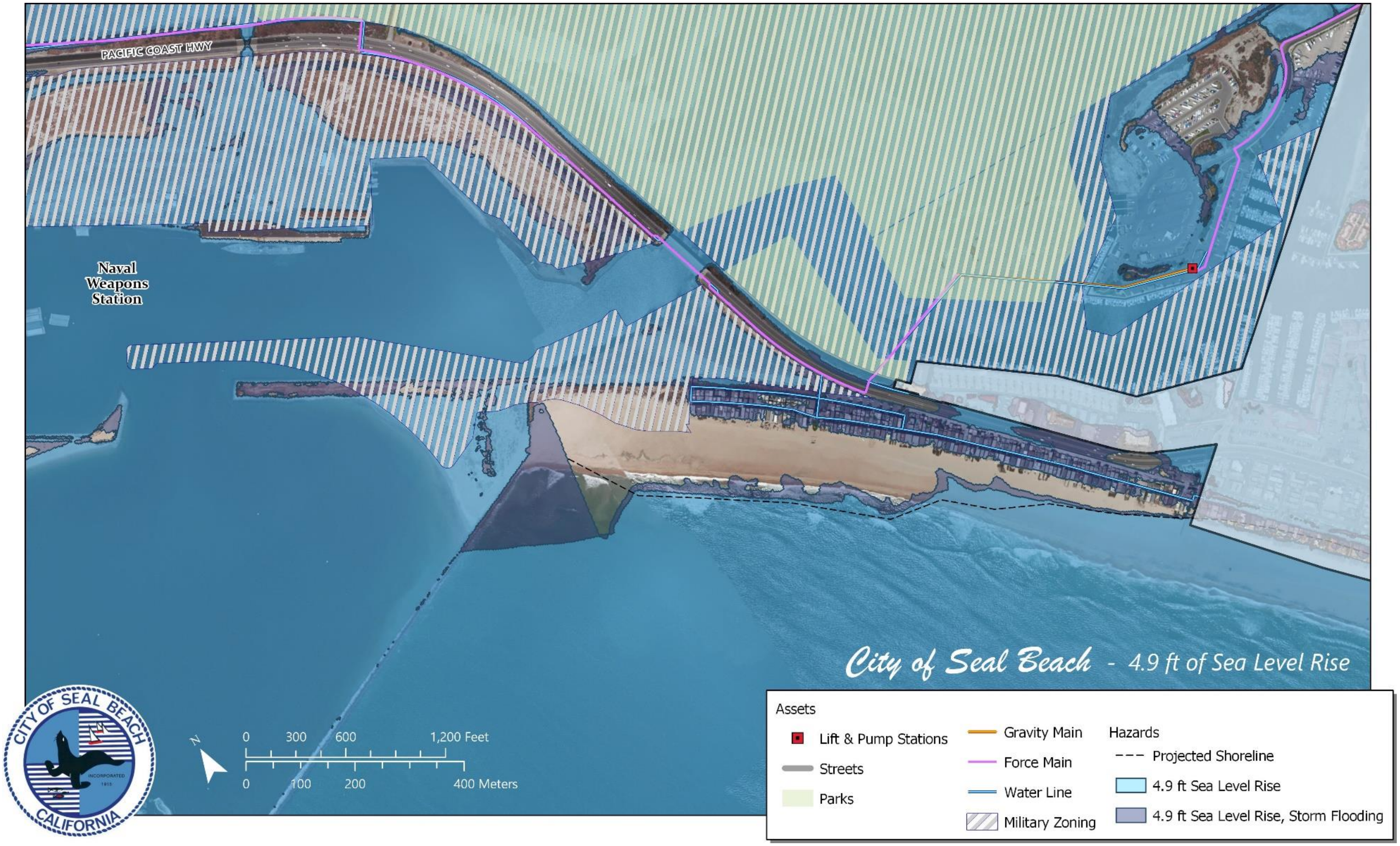

Figure A-9-9: 4.9ft SLR hazards, Surfside.

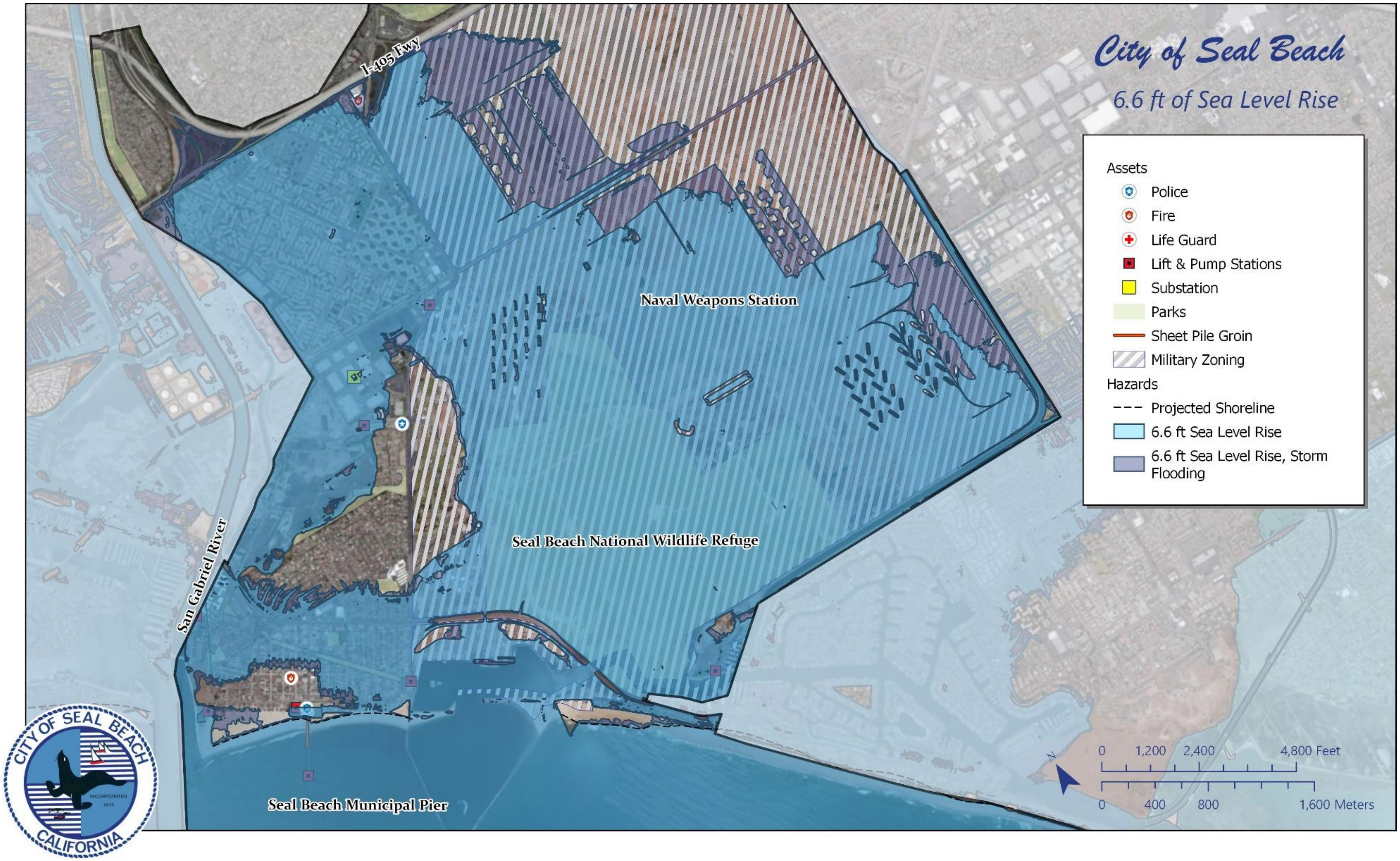

Figure A-9-10: 6.6ft SLR hazards, full City extent.

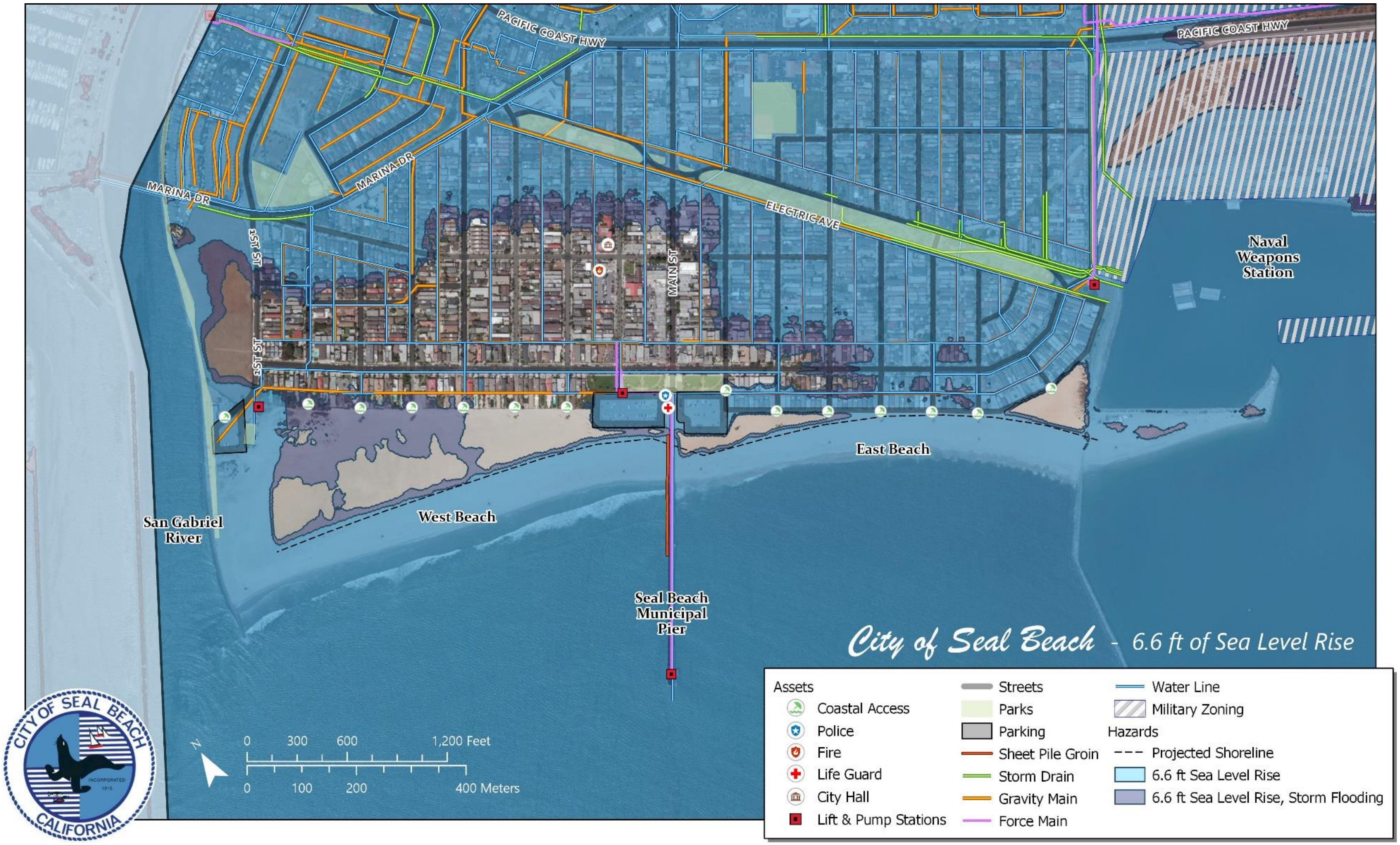

Figure A-9-11: 6.6ft SLR hazards, Seal Beach waterfront.

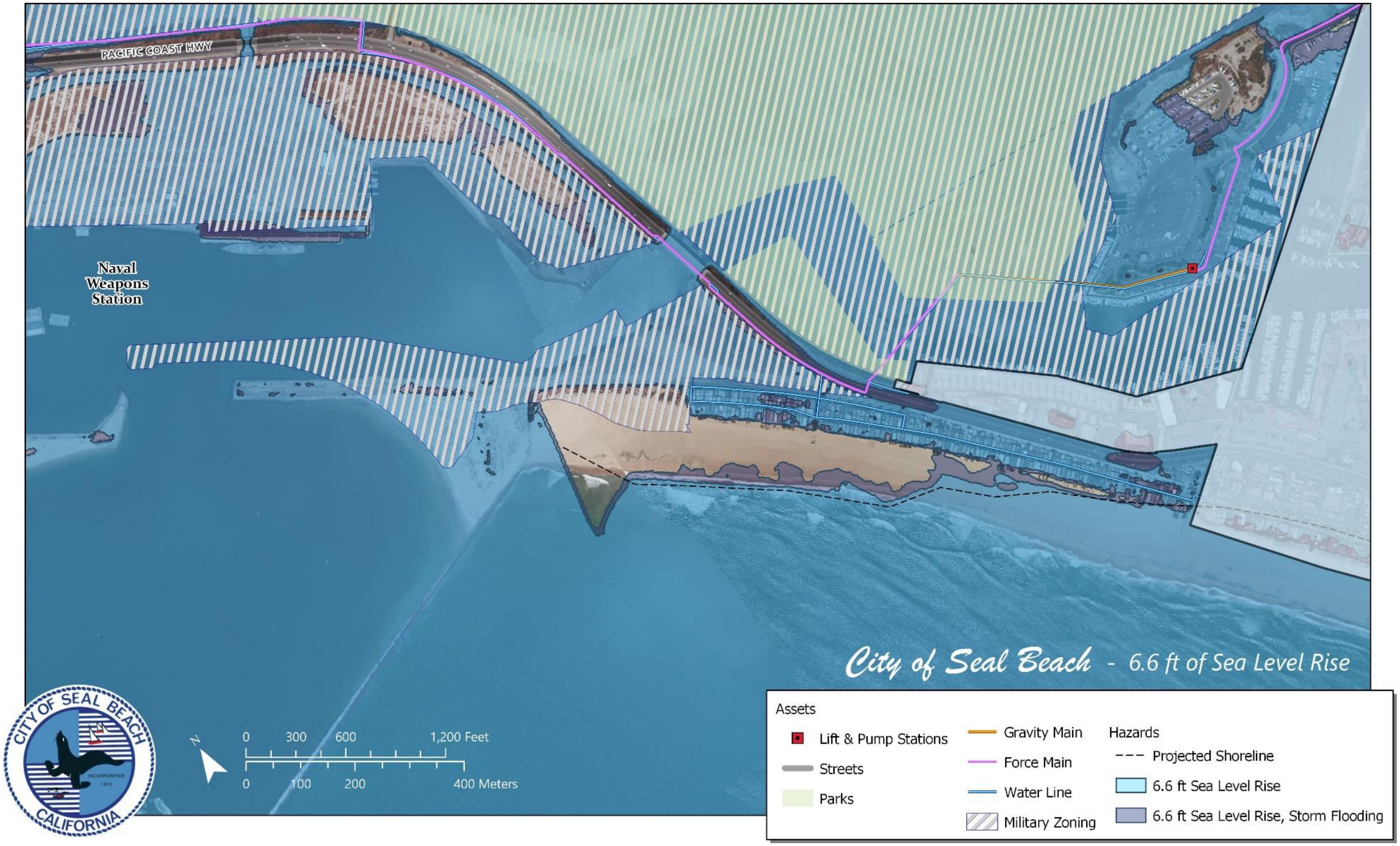

Figure A-9-12: 6.6ft SLR hazards, Surfside.