City of Avalon AB 691
Sea Level Rise Assessment
DRAFT

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October 2019

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Document Verification

Document Verification:	
Client	City of Avalon
Project Name	City of Avalon SLR/LCP Amendment
Document Title	City of Avalon AB691 Sea Level Rise Assessment
Document Sub-title	–
Status	Draft Report
Date	October 2, 2019
Project Number	10271
File Reference	Q:\LB\10271 City of Avalon LCP\8 Deliverables\Tidelands\Draft to City 10-02-2019

Revision	Description	Issued by	Date	Checked
00	Draft for submittal to SLC	JT	7/1/2019	AH
01	Revised draft for submittal to SLC	JT/AH	10/2/2019	TQ

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1. Introduction

As part of California Assembly Bill 691 (AB-691), the City of Avalon is required to perform a Sea Level Rise (SLR) Assessment for its granted public trust tidelands. The California State Lands Commission (CSLC) has jurisdiction over public lands, which include tidelands. Tidelands are a type of sovereign land held by the state of California where land is covered and uncovered by the ebb and flow of tides. The landward limit of tidelands is defined as the intersection of the mean high tide line with the shore. Tidelands can be granted to local trustees for purposes of commerce, navigation, fisheries, or other public trust purposes.

In 2013 the California legislature passed Assembly Bill 691, Chapter 592, which requires local trustees with average annual gross revenue greater than $250,000 from their public trust lands to prepare and submit an assessment of how they propose to address SLR to the CSLC by July 1, 2019.

In accordance with AB 691 assessment criteria this study includes the following: an assessment of SLR impacts over multiple scenarios relevant to 2030, 2050, and 2100 time horizons, maps of projected SLR impacts, estimates of the financial costs of SLR, and a description of potential SLR adaptation strategies to protect and preserve tideland resources and structures.

1.1 Study Approach

The AB 691 Sea Level Rise Assessment for the City of Avalon (City) analyzes potential impacts to coastal resources across multiple sea level rise (SLR) scenarios. SLR hazard analysis is accomplished through a phased approach. An inventory of tideland resources within the City was compiled as the first step of the Vulnerability Assessment. Analyses then focused on the extent to which local coastal hazards are influenced by incremental SLR, ultimately identifying the SLR thresholds at which tideland resources within the City are impacted.

For the purposes of this study, a tideland resource is broadly defined as any natural or constructed feature located within granted tidelands that provides a benefit to the City. City tideland resources are grouped into the following categories: recreation and coastal access, ecological resources, mooring and boating infrastructure, and tideland development and infrastructure. The Cabrillo Mole is also highlighted as a critical tidelands resource. An inventory of those resources included in the SLR assessment can be found in Section 3.

The vulnerability of a coastal resource to SLR hazards is assessed through an analysis of its exposure, sensitivity, and adaptive capacity. In this study, exposure refers to the type, duration, and severity of coastal hazards a resource is subject to under a given SLR scenario. Sensitivity is 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 used in the study may be found in Section 5.

1.2 Study Area

The City is located on the northeastern shoreline of Santa Catalina Island in Los Angeles County (Figure 1-1). Figure 1-2 details the coastal relief patterns within the City and the study area for the Sea Level Rise Assessment, encompassing the full extent of coastal tidelands granted to the City, extending from the Hamilton Cove area in the west through Descanso Bay, Avalon Bay, Lovers Cove, and select areas bordering Pebbly Beach Road to the east. The study area extends landward to the high water mark to capture the full extent of coastal tidelands granted to the City. Visualizations of City tidelands presented in hazard analyses within this study are not intended to be interpreted as exact legal boundaries but are instead used to identify major tideland assets and resources within the City. Official City tideland boundaries are presented in Figure 1-3.

1.3 Coastal Setting

Much of the Avalon coast is backed by cliffs and bluffs of varying height, with the exception of low-lying areas in portions of Descanso Bay and developed areas along the shoreline of Avalon Bay. The shoreline of the City northwest of Abalone Point is characterized by a series of embayments with primarily narrow, rocky beaches. The shoreline is fairly uniform southeast of Abalone Point, featuring a narrow to non-existent beach seaward of Pebbly Beach Road and backed by high-relief coastal bluffs. Specific shoreline characteristics present within tideland areas in each region of the City are detailed below.

1.3.1 Hamilton Cove

Hamilton Cove is the northwesternmost region of the Avalon shoreline. The northwestern portions of the cove are characterized by steep coastal bluffs with narrow rocky or sandy beach areas below. Private residential development is present along the blufftop, but no access is available to the shoreline below. A small sandy beach is also present in the central portion of the cove, with access provided by a local road. Southeast of this small beach area, the coastline within Hamilton Cove consists of an engineered rock revetment backed by a paved local access road, which provides access from boats moored offshore.

1.3.2 Descanso Bay

The next coastal region southeast of Hamilton Cove is Descanso Bay, which sits in a narrow low-lying area between two high-relief bluffs. The rocky bluff is exposed in northwestern portion of the bay with no beach area below. A sandy beach area sits in the central portion of the bay, representing one of the few public beach areas in the City. The sandy beach area is divided by a small seawall that runs the length of the bay. Sandy areas below the seawall are subject to natural littoral processes, whereas the larger sandy beach area above the seawall is artificially maintained. Southeast of the seawall, rock revetment once again becomes the dominant shoreline feature, backed by a coastal pedestrian pathway. Beyond the pathway the shoreline rises again to reach a coastal road. Development in Descanso Bay consists of tourism related services provided by the Descanso Beach Club such as a beach bar and restaurant, outdoor recreation park and other special events.

1.3.3 Casino Point

Casino Point lies at the northwesternmost point of Avalon Harbor. The areas surrounding the point are made up of a combination of rocky shoreline and seawall structures backed by paved coastal pathways which surround the Catalina Casino building. The northwestern breakwater of Avalon Harbor, an engineered rock structure, also extends off the tip of the point and is a popular destination for recreational diving at the Casino dive park.

1.3.4 Avalon Bay

Avalon Bay sits in the central portion of the City and is protected by a variety of coastal structures along its entire length. The shoreline along the northwestern portion of the bay consists of rock revetment backed by a small seawall and paved coastal pathway. The shoreline rises again beyond the pathway to meet a coastal road in a similar manner to other stretches of the Avalon coast. Rock revetment is absent in the central portion of the bay where a seawall retains a perched beach between the Tuna Club and Antonio's Pizzeria. Sandy beach areas are present in the vicinity of the Green Pleasure Pier, a large portion of which are artificially maintained and sit perched on top of the seawall. Rock revetment begins again along the southeastern portion of the bay, extending to the Cabrillo Mole. Similar to Casino Point, the Cabrillo Mole extends into Avalon Bay via an engineered rock breakwater.

1.3.5 Lovers Cove

Immediately southeast of the Cabrillo Mole is Lovers Cove. A rocky shoreline is present throughout the cove, backed by a concrete pedestrian pathway and paved coastal road which extends to the base of high relief coastal bluffs.

1.3.6 Pebbly Beach Road

Pebbly Beach Road continues southeast of Lovers Cove, leading towards an industrial area, again backed by high-relief coastal bluffs. This portion of Pebbly Beach Road sits at a lower elevation than areas in Lovers Cove, and the road alternates between rocky shoreline and narrow, more exposed sandy shoreline.

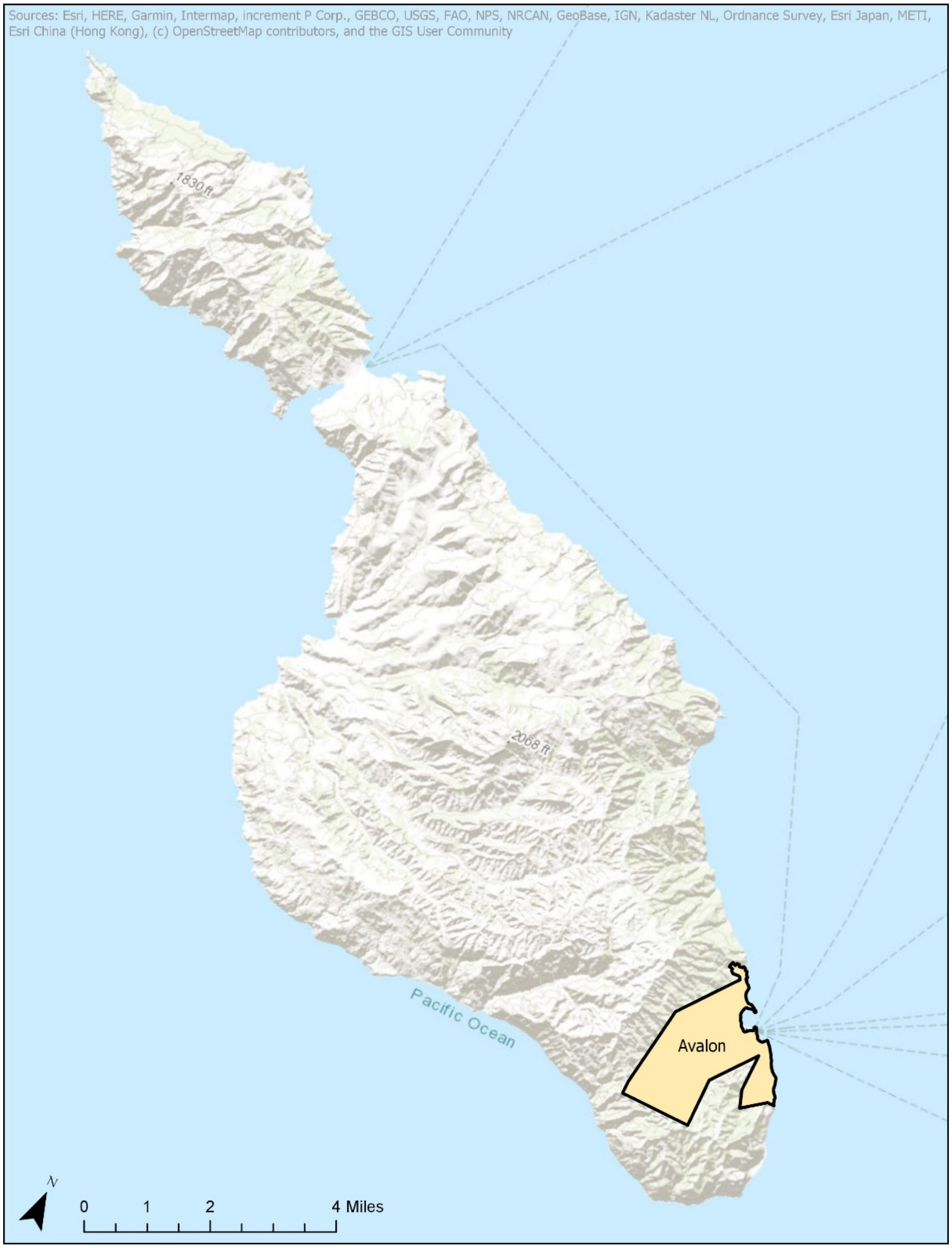

Figure 1-1: Santa Catalina Island and the City of Avalon.

Figure 1-2: Coastal elevation and tideland areas within the City of Avalon.

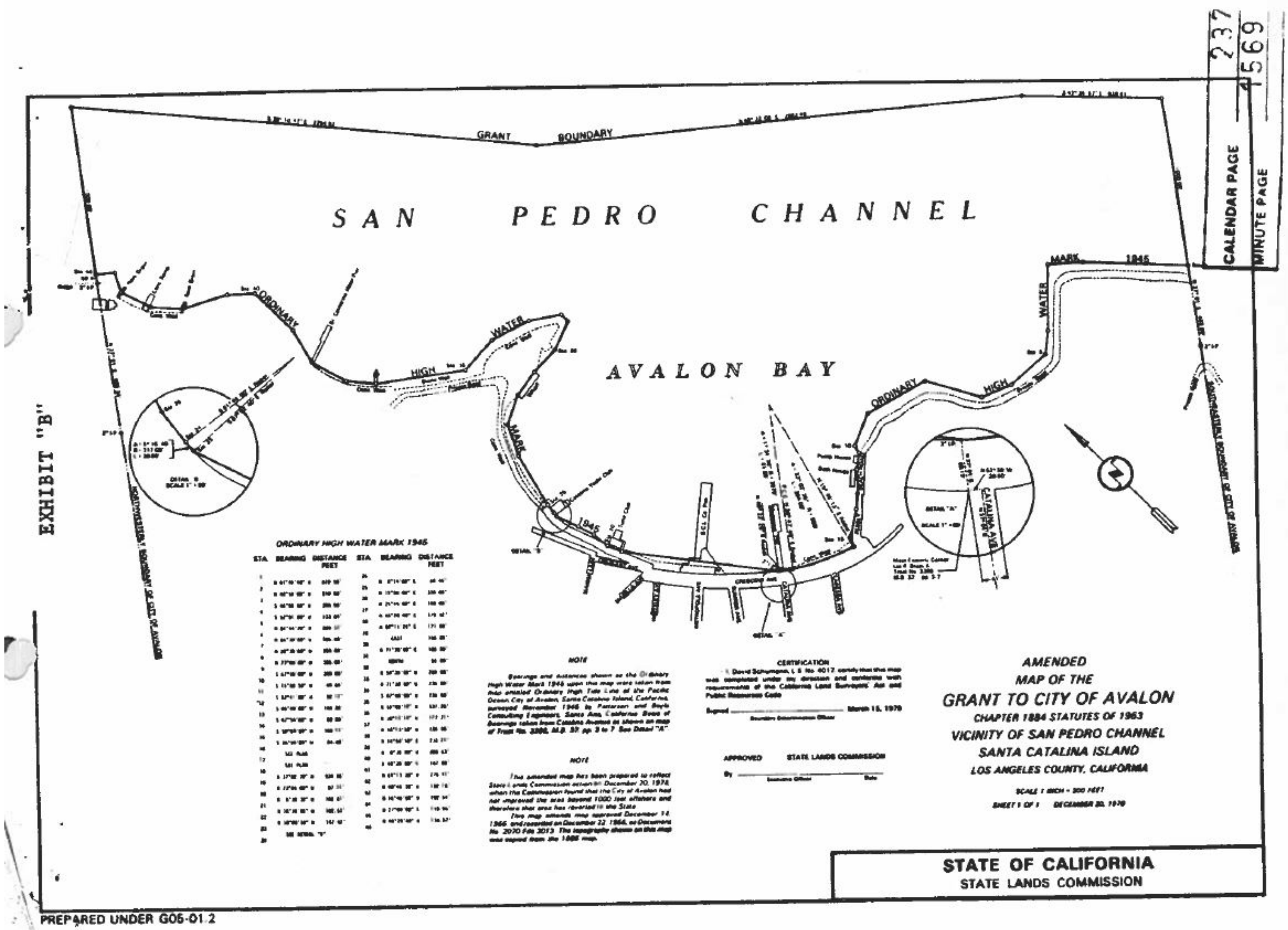

Figure 1-3: City tideland boundary as depicted in the 1988 CSLC Map Amendment.

2. Coastal Processes

Coastal processes refer to the waves, water levels, and transport of sediment that shape the coastline of Avalon. These dynamic processes are largely driven by natural forces but are also affected by anthropogenic activities (i.e., development, coastal structures, and beach nourishment). Coastal structures of various types line almost the entire shoreline of the study area. The interaction of coastal processes with these structures will largely influence the vulnerability of coastal tideland resources in Avalon for each SLR scenario evaluated.

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 Avalon. The station is located within Los Angeles Harbor and has collected data since 1923. Data from this station represents the most complete source of water elevation data relevant to the City of Avalon and can be used to characterize variability in existing water levels, which is illustrated in 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 (ft). 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, although this is currently not an issue within the City of Avalon.

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. An example of this occurred on November 25 and November 26, 2015, when a King Tide of about 6.7 ft above MLLW was predicted, but a water level of 7.5 ft was measured at NOAA station 9410660 in Los Angeles. The tide series from this event is shown in Figure 2-2. The predicted astronomical tide was elevated by 0.8 ft due to a sea level anomaly related to the strong El Niño and high ocean temperatures during the 2015-2016 winter season (Doherty 2015).

When considering the effects of SLR on coastal hazards, it is important to consider that SLR increases the entire range of existing water levels. To illustrate the range of potential flooding due to SLR, both mean higher high water (MHHW) and 100-year water levels were used to map future flood hazards, as described in Sections 5 and 6.

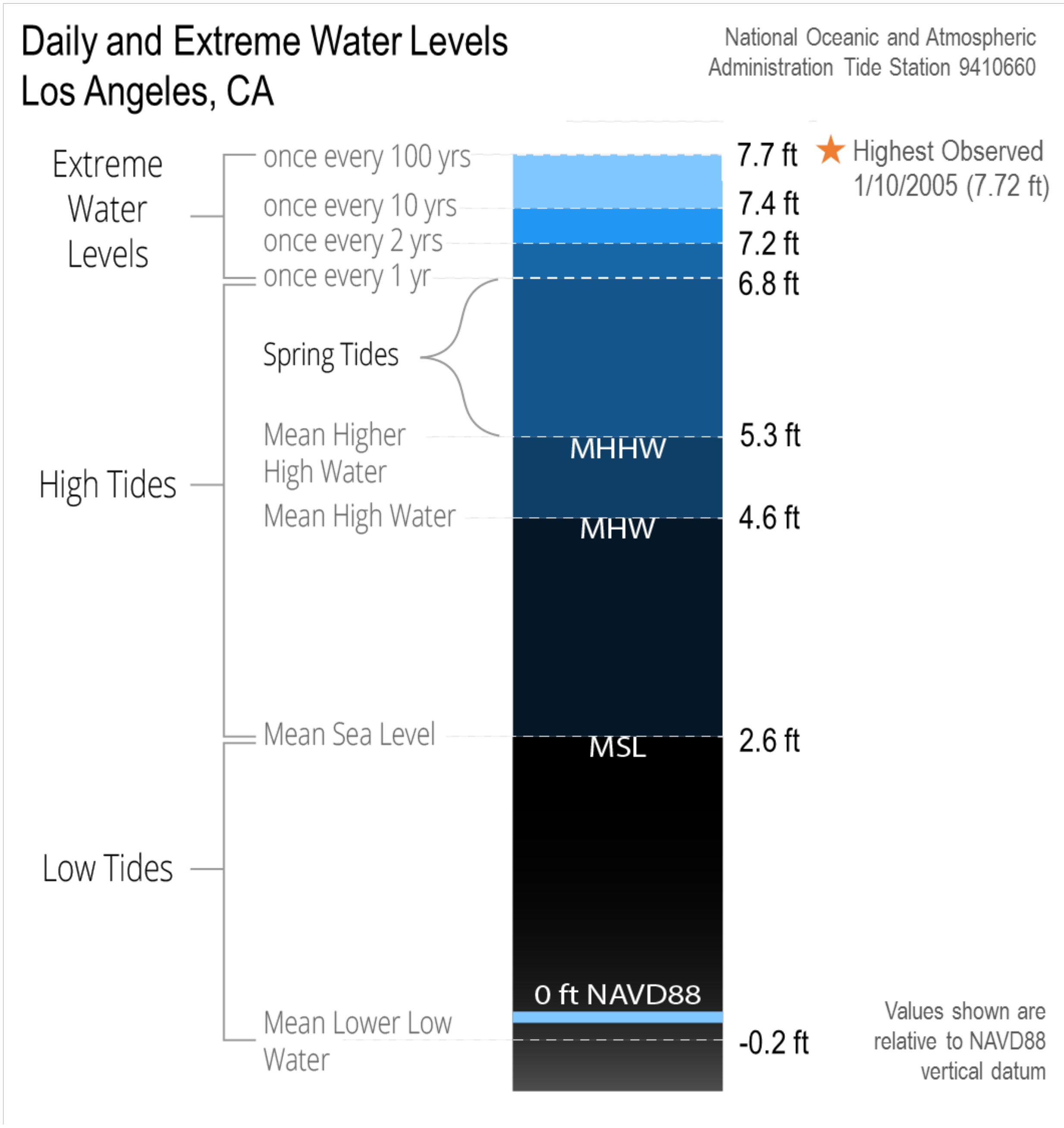

Figure 2-1: Daily and extreme water levels for NOAA Station 9410660.

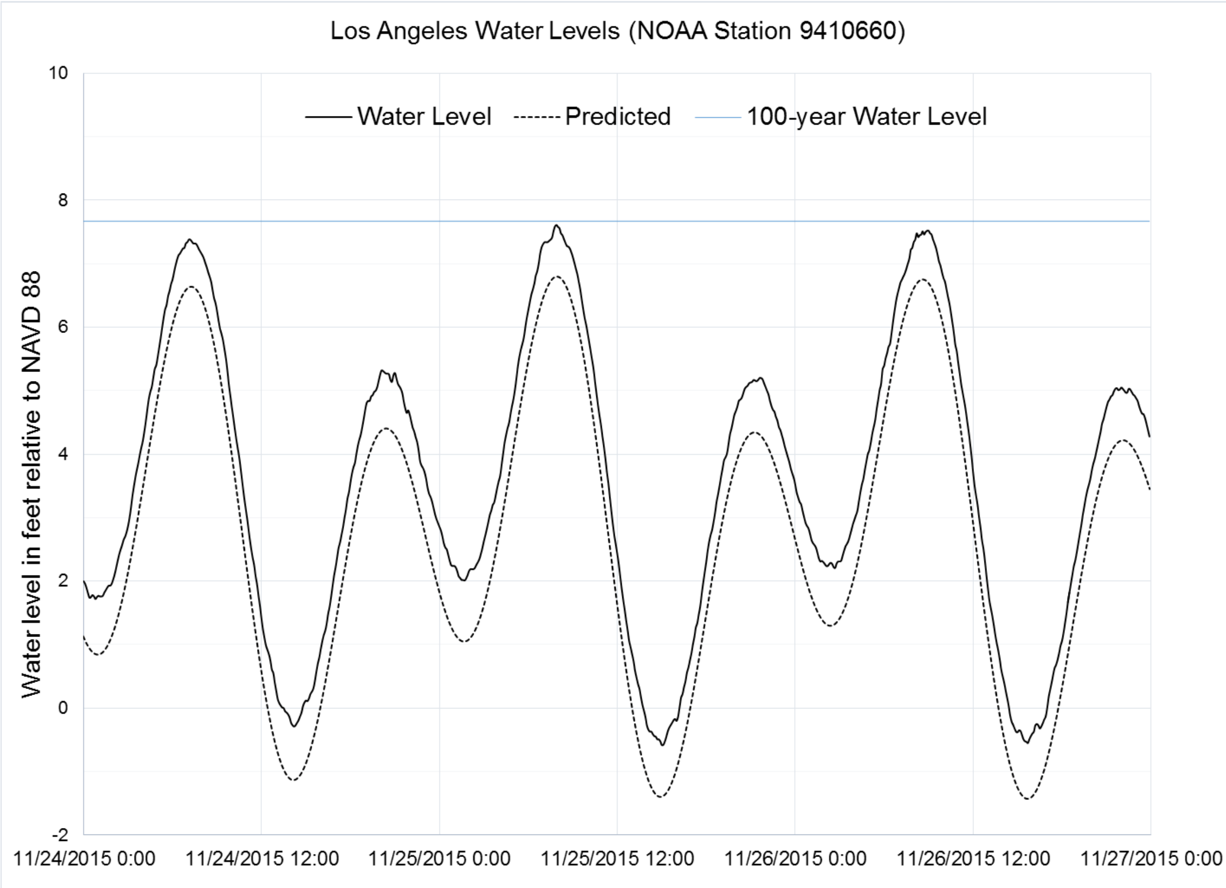

Figure 2-2: November 2015 Tide Series, Los Angeles Station 9410660.

2.2 Wave Climate

The City of Avalon's location on the eastern coast of Santa Catalina Island presents unique wave hazards compared to other areas of the California coast. Large west and northwest swell events associated with winter storms typically produce the most significant wave hazards in the region, but Avalon's location shields the city from such events. Avalon is instead exposed to wave hazards from southeasterly swells generated by tropical storm systems in the southern Pacific and seasonal northeast Santa Ana wind events, as illustrated in Figure 2-3. While long-period swells associated with offshore storms generally result in more severe wave hazards, sustained Santa Ana wind events are able to produce short-period, wind-driven wave hazards of sufficient magnitude to impact coastal infrastructure.

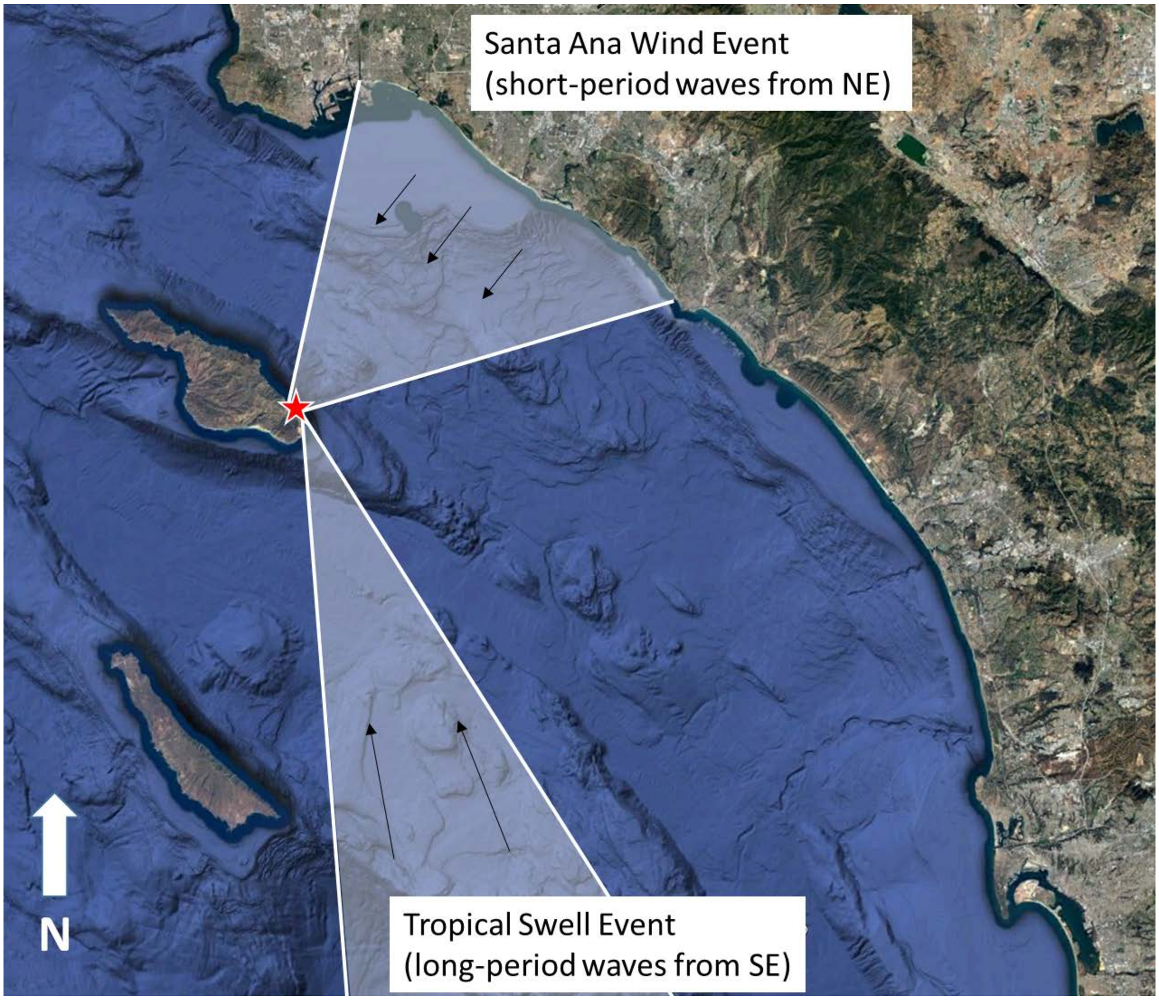

Figure 2-3: Primary wave exposure windows for Avalon.

Wave conditions associated with southeastern tropical swell and Santa Ana wind events have both been linked to past-documented wave damage to coastal resources within the City of Avalon. For example, a tropical swell event associated with Hurricane Marie in August 2014, with a reported significant wave height of 10.4 ft off the southeastern coast of Catalina Island (M&N, 2017), resulted in moderate damage to the Cabrillo Mole, including the dislodgement of grates due to wave uplift. This event caused damage and flooding within the Pebbly Beach Road industrial area (Figure 2-4) and resulted in wave runup and overtopping of the Avalon Harbor seawall (Figure 2-5).

In December 2014, a Santa Ana Wind event with an hourly wind speed of 22.5 knots resulted in severe damage to the Cabrillo Mole. Despite the relatively short wave period associated with wind events, Santa Ana winds can cause flooding and wave damage to City resources along the coastline and within Avalon Bay. Each of these types of wave events was used to inform a modeling study for strengthening and repair of the Cabrillo Mole (M&N, 2017). This wave modeling study and further discussions of wave hazards used in hazard analyses may be found in Section 5.

Figure 2-4: Hurricane Marie storm Damage at Pebbly Beach Road Industrial Area (Image: Los Angeles Times).

Figure 2-5: Hurricane Marie wave runup along Avalon Bay.

2.3 Littoral Processes

Littoral processes in Avalon consist of the movement of sediment in the cross-shore (i.e. perpendicular to the shoreline) and alongshore directions in response to waves, water levels, and currents. These processes are generally confined to individual pocket beaches in Avalon Bay and Descanso Bay. These narrow beaches are backed by seawalls and are sensitive to storm-induced sediment transport and long-term trends in shoreline change. Large wave events often result in a cross-shore sediment transport pattern in which sediment is eroded from the upper beach profile and carried offshore where it deposits in deeper water. Smaller and/or less steep waves during calm weather periods can transport some of this sediment back onto the beach resulting in seasonal patterns of beach loss and recovery. However, during very large wave events, some of the sediment can be lost to the littoral system if transported far enough offshore.

Wave refraction and reflection patterns in Avalon Bay can also induce currents, which result in movement of sediment in the alongshore direction. Based on a comparison of beach profiles, an estimated 5,000 cubic yards of sediment has been eroded from South Beach and deposited under the Pleasure Pier and along Middle Beach between 1994 and 2017 (MBI, 2017). Aerial images illustrating the localized erosion at the “corner” of South Beach are provided in Figure 2-6. The causes of this erosion were investigated by Michael Baker International (2017) in a study of sedimentation processes. The study focused on wave reflection off the seawall and prop-wash from Catalina Express boats as potential causes of this erosion trend. The study concluded that neither wave reflection from the seawall nor prop-wash alone could be responsible for this erosion trend, but the two processes in combination could explain the movement of sediment from South Beach toward the Pier.

Sediment-laden runoff from Avalon Canyon and other watersheds evaluated in the study provided the natural supply of sediment to these pocket beaches. However, this natural supply of sediment has been significantly reduced due to development within Avalon Canyon and channelization of the creek. With little or no natural sediment supply from Avalon Canyon and a net transport rate from South Beach to Middle Beach, it is very unlikely that South Beach will recover naturally. The City is in the process of evaluating sediment management options and various structural measures to mitigate this ongoing erosion. These options and other adaptation strategies are discussed in Section 8.

Figure 2-6: Localized erosion at South Beach between 1994 and 2013 (Image: Google Earth).

3. Coastal Resource Inventory

A number of resources are located within tideland areas that perform significant roles in coastal tourism and provide essential means of transportation for the City. Avalon Bay is the primary hub for commercial and recreational activity within the City of Avalon, including shopping, dining, fishing, diving, and tourism opportunities throughout the waterfront. The Cabrillo Mole also serves as the point of arrival for the majority of visitors to Catalina Island. Areas outside of Avalon Bay such as Lover's Cove and Descanso Bay also contain additional coastal recreation opportunities.

3.1 Catalina Island Yacht Club

The Catalina Island Yacht Club opened in 1924, making it one of the oldest yacht clubs in Southern California. The club currently has 180 members and hosts several events, including a Billfish Tournament, to raise funds for charity. The club is located in the northwestern portion of Avalon Bay. The club consists of a pile-supported structure that connects to the walkway along the seawall bordering Avalon Bay.

Figure 3-1: Catalina Island Yacht Club.

3.2 Tuna Club

The Tuna Club is a sportfishing club that hosts several events and tournaments throughout the year. Originally founded in 1898, the club is listed in both the National Register of Historic Places and as a California Historical Landmark. Like the nearby Catalina Island Yacht Club, the Tuna Club is a pile-supported structure connected to the seawall lining the pedestrian pathway in the northwestern portion of Avalon Bay.

Figure 3-2: Catalina Island Tuna Club.

3.3 Green Pleasure Pier

The Green Pleasure Pier serves as a hub for coastal tourism within Avalon Bay. In addition to hosting marine recreation activities such as boat tours and scuba diving, the pier also contains the Catalina Island Visitor Center and the City of Avalon Harbor Department. The structure itself is supported by pilings and connects to the walkway surrounding Avalon Bay.

Figure 3-3: Green Pleasure Pier.

3.4 Mooring and Boating Infrastructure

Waterfront access and mooring for recreational and commercial boating activities are key resources for residents and visitors to Avalon. The City of Avalon Harbor Department (Harbor Department) manages and maintains 264 moorings in Avalon Bay, 47 moorings in Descanso Bay, and 36 moorings at Hamilton Cove. Other supporting infrastructure include a pump-out facility, fuel station, and miscellaneous docks deployed on a seasonal basis for commercial vessels that offer ocean-based tourism activities.

3.5 Cabrillo Mole

The Cabrillo Mole Terminal, constructed in 1968, is the focal point for water-based transportation to and from Avalon. The mole provides shelter for the docking site for the high-speed Catalina Express ferries that carry the majority of visitors to and from the City of Avalon. Additional docks, sheltered by the mole, are used to ferry cruise ship passengers to and from shore. The mole is located at the southeastern tip of Avalon Bay and is a combination rubble mound breakwater and cast-in-place, reinforced concrete structure designed primarily to shield ferries from wave energy while docked.

Figure 3-4: Inner harbor view of the Cabrillo Mole and approaching ferry.

3.6 Public Access and Recreation

Coastal public access points are located along public beaches and pedestrian pathways within Descanso Bay, Avalon Bay, and Lover's Cove. Public beaches consist of sandy areas below seawall structures and beaches constructed atop seawalls. Access to the water is typically provided by stair cases over a coastal structure (seawall or revetment) to allow for safe entry and exit while swimming or diving.

Figure 3-5: Public beach and access structures in the eastern portion of Avalon Bay.

3.7 Ecological

SLR assessments within this study focus on marine ecosystems within tideland areas. Due to the steep topography of the island shoreline and presence of shoreline stabilization structures and development, there is only a limited area of intertidal habitat. The primary ecological resources in the study area consist of subtidal marine habitat.

The City of Avalon contains two designated State Marine Conservation Areas. The Casino Pont State Marine Conservation Area is located just west of Casino Point, and the Lover's Cove State Marine Conservation Area stretches from the Cabrillo Mole east along a portion of Pebbly Beach Road. These areas are home to submerged kelp forest and hard-bottom marine habitats that support a wide variety of marine life, making them popular destinations for local SCUBA divers and boat tours.

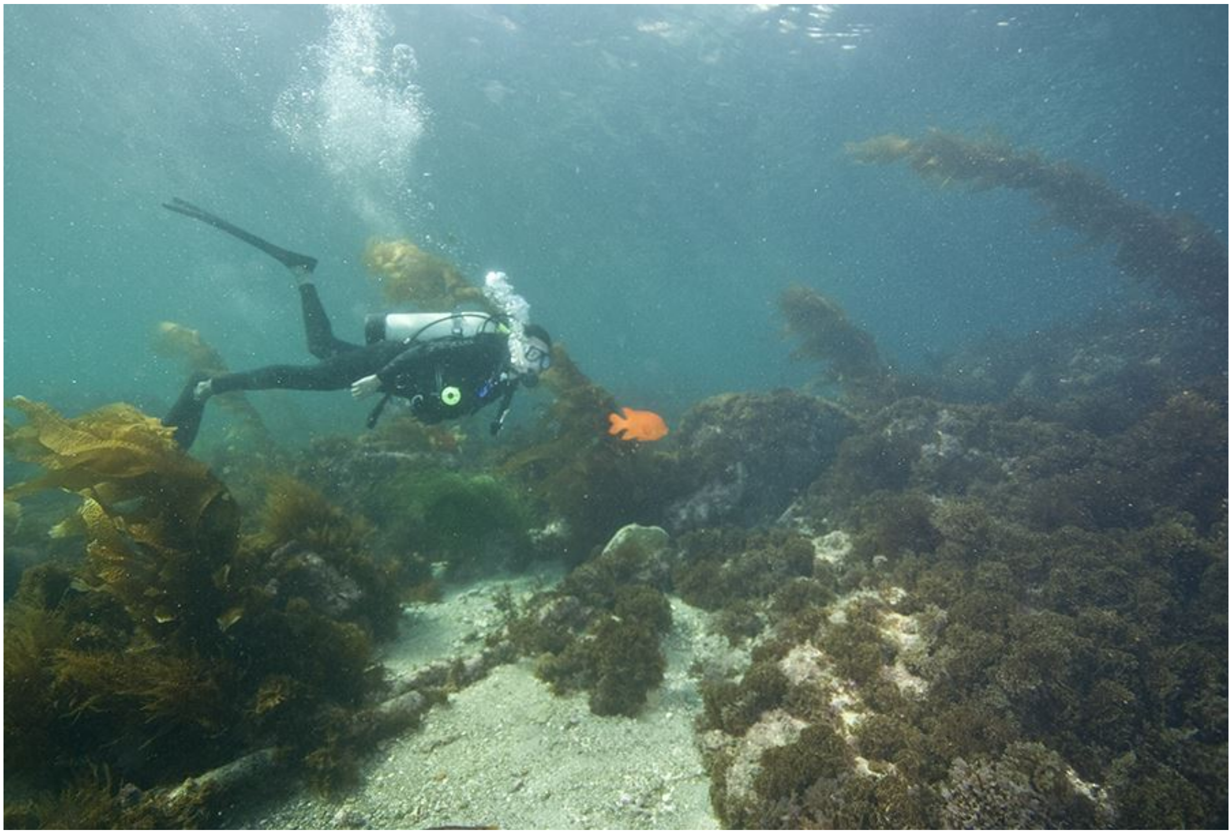

Figure 3-6: A diver within the kelp habitats offshore of the City of Avalon (Image: visitcatalinaisland.com.).

4. Sea Level Rise

4.1 What is Sea Level Rise?

Sea level rise (SLR) science involves both global and local physical processes, as illustrated in Figure 4-1. Models have been 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. AR5 projections for SLR were 50% higher than the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4), released 2007, due to the impacts of ice sheet dynamics on SLR. At the state level, the California Coastal Commission (CCC) recommends using the best available science, which is expected to be updated every five years.

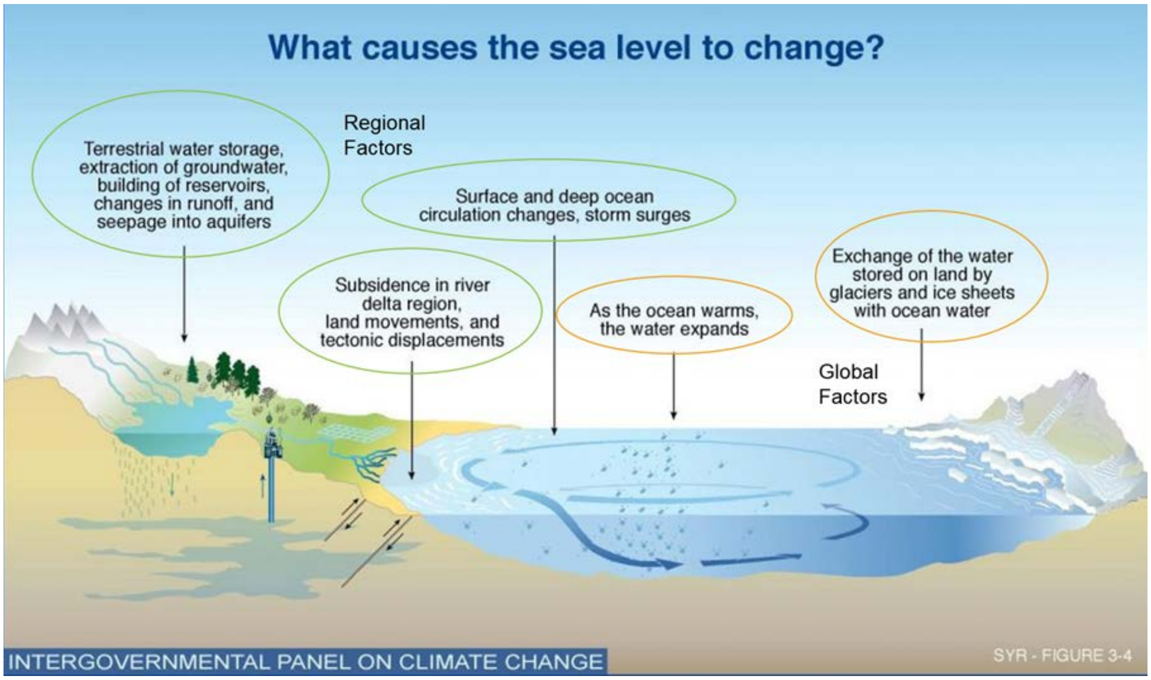

Figure 4-1: Regional and global factors that can contribute to changes in sea level (IPCC, 2013).

4.2 Projections and Probability

The State of California Ocean Protection Council (OPC) Science Advisory Taskforce updated the best available science through a report titled *Rising Seas in California: An Update on Sea Level Rise Science*, 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 0.5 to 1.0 ft. 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 to 3.2 ft 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. Under such assumptions SLR of 1.8 ft is projected at the 2050 time horizon, 3.3 ft at 2070, and 6.7 ft at 2100, shown in red in Figure 4-2.

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.

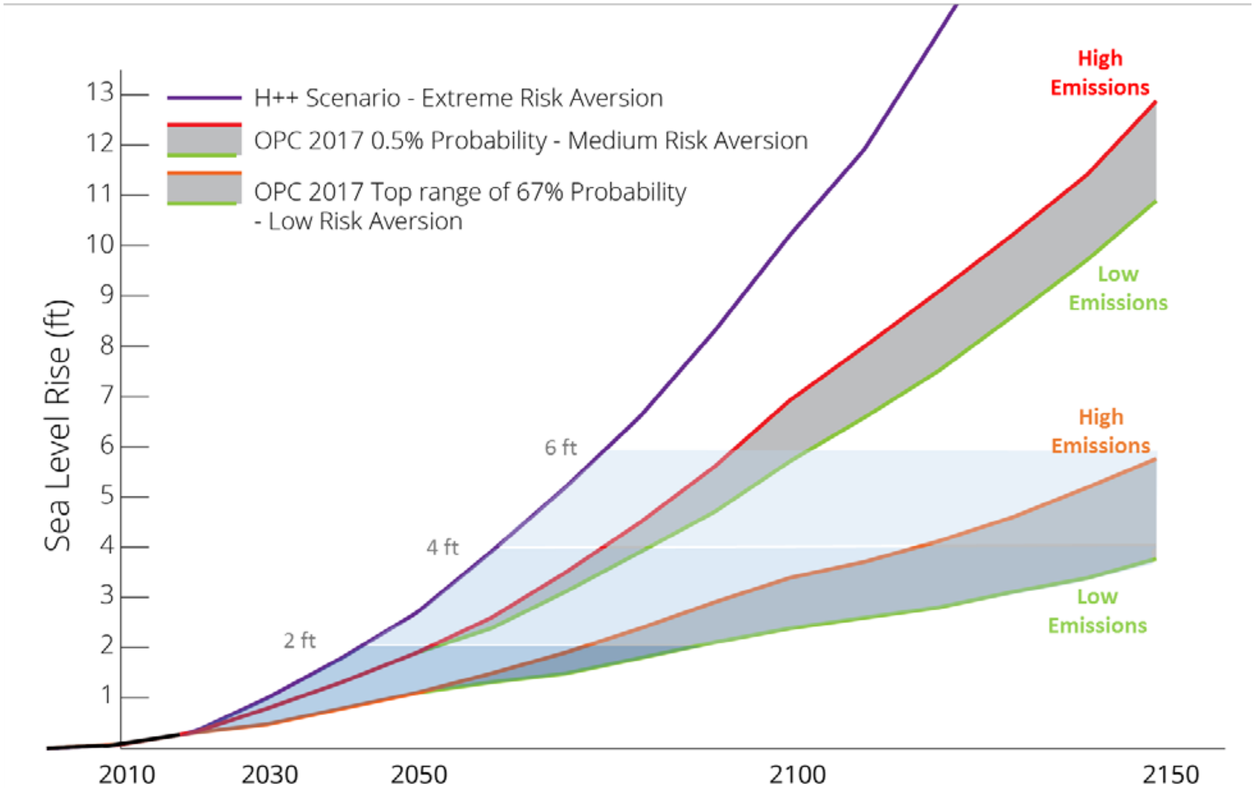

Figure 4-2: Approximate sea level rise projections for three risk aversion levels (OPC, 2018).

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 looked at a range of SLR increments (scenarios), starting with present day conditions and including extreme SLR. Three scenarios have been selected for this study at 2-foot increments of SLR up to 6 ft, as shown in Figure 4-2. The probabilities that SLR will meet or exceed a particular height over a given time horizon are based on projections provided in Kopp et al. 2014, described below.

1. SLR of 2 ft is representative of the low risk aversion projection for 2080, which means there is an 83% probability SLR will not exceed this amount over the next 60 years. There is less than a 2% probability that this amount of SLR will occur before 2060. Under a worst-case extreme SLR scenario (H++) this amount of SLR could occur between 2040 and 2050.

2. SLR of 4 ft is representative of the medium-high risk aversion projection for 2080. There is a 99% probability SLR will not exceed this amount over the next 60 years

and a 95% probability that this amount of SLR will not occur this century. However, under a worst-case extreme SLR scenario (H++) this amount of SLR could occur between 2060 and 2070.

3. SLR of 6 ft is representative of the medium-high risk aversion projection for 2090 – 2100. There is a 99% probability SLR 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.

5. SLR Hazard Evaluation

5.1 Assessment of Available Hazard Data

Assessments of available SLR hazard data for the City of Avalon focused on data provided through the Coastal Storm Modeling System (CoSMoS). CoSMoS, developed by the USGS, provides substantial information on future coastal flooding along the California coast associated with different SLR and storm scenarios (Erikson et al., 2017). As part of the City of Avalon Local Coastal Program update process, available CoSMoS data were reviewed to determine whether CoSMoS storm scenarios accounted for the unique hazards facing the City of Avalon, where Santa Ana winds and southeast swell events are of greater concern than the west-northwest winter storm swells seen in other areas of California. Data was obtained through the CosMoS website, displayed using GIS, and compared against flood events reported by City officials as well as prior Moffatt & Nichol studies in the area.

Available CoSMoS storm scenarios include annual, 20-year, and 100-year return period storm events. 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 west-northwest direction, typical of winter storms (Table 5-1). To simulate a worst-case scenario, all storms within CoSMoS were modeled as though they coincided with a high spring tide.

Table 5-1: Boundary conditions associated with each with each CoSMoS modeled storm scenario.

Scenario	Hs (ft)	Tp (s)	Dp (degrees)
Background	5.7	12	286
1-year storm #1	14.4	16	284
20-year storm #1	19.2	18	281
20-year storm #2	20.1	18	292
100-year storm #1	20.3	16	264
100-year storm #2	22.3	18	287

CoSMoS storm modeling does not capture the full extent of coastal hazards within the City of Avalon based on these representative storm events, as they do not capture the unique Santa Ana wind-driven wave hazards or southeast swells generated from Eastern Pacific hurricanes that impact Avalon (Figure 5-1). Recent storm hazard observations within Avalon also support this determination. CoSMoS models show minimal flooding in low-lying coastal areas of Avalon under current conditions combined with a 100-year storm; however, local officials have reported past storm damage due to wave overtopping in several areas, including the example cited earlier during the tropical swell event associated with Hurricane Marie.

Prior wave studies tailored to the City of Avalon also show greater wave hazards than those seen within CoSMoS modeling results. A 2017 Moffatt & Nichol wave study, performed to inform design of the Cabrillo Mole, a key wave energy protection structure within the City, determined 100-year wind-driven wave heights directly outside the mole to be 10+ ft (M&N, 2017). These values are significantly higher than those reported in CoSMoS wave hazard results, which show a wave height of approximately 2.6 ft in the same area under 100-year storm conditions.

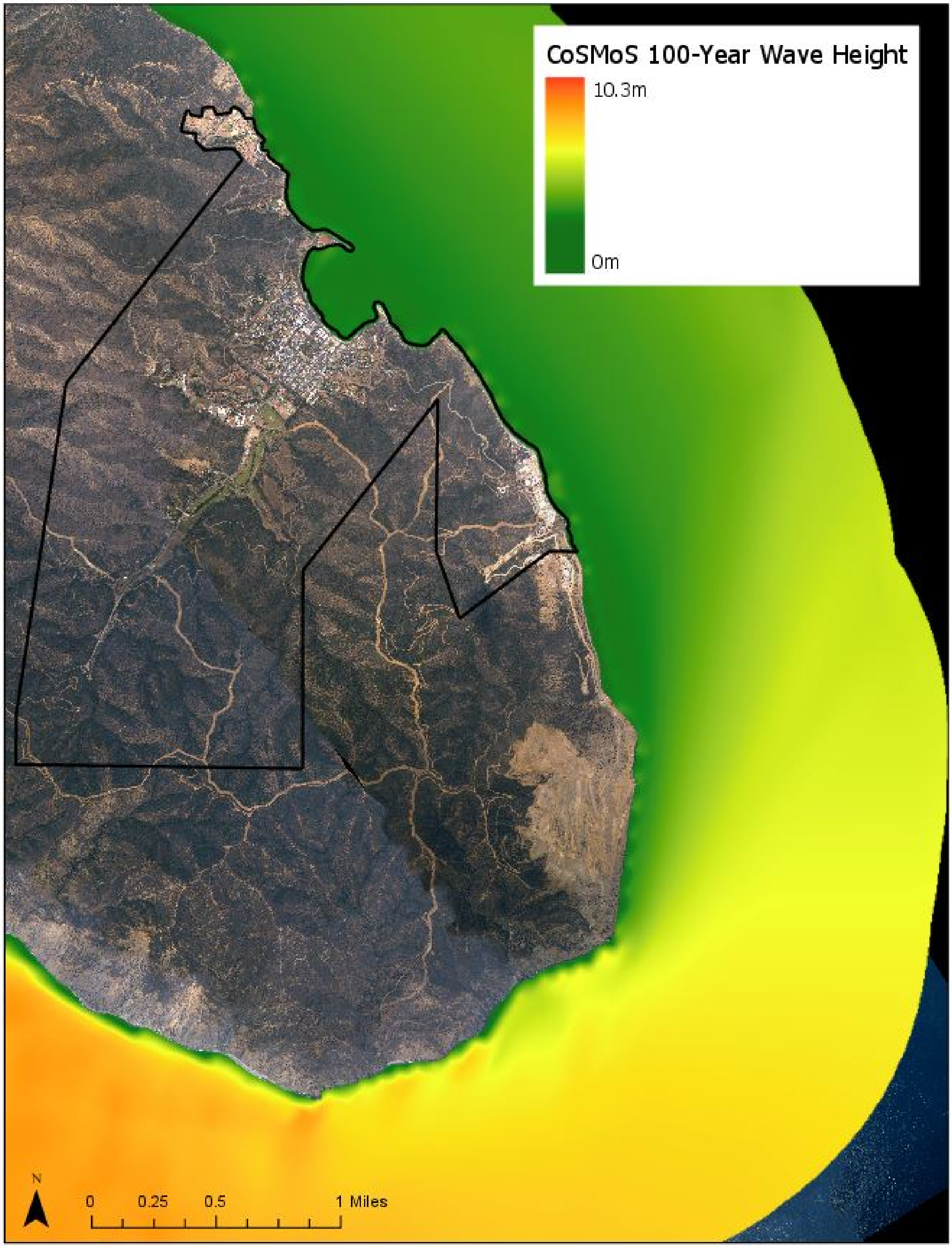

Figure 5-1: CoSMoS 100-year storm wave height projections, showing reduced impacts within the City of Avalon due to W-NW wave directions.

5.2 Coastal Hazard Modeling

Wave modeling and coastal hazard analysis specific to the City of Avalon was conducted due to concerns that hazards evaluated in CoSMoS modeling may underestimate the potential for storm-wave damage to coastal resources within the City. The representative storm events were based on the 2017 Moffatt & Nichol wave study to inform the design of the Cabrillo Mole (M&N, 2017).

The Cabrillo Mole study used wave conditions simulated via a numerical model based on offshore wind and wave data due to a lack of long-term wave measurement data within the coastal areas of the City. Offshore wave and wind data were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC). These data were compared to NOAA WAVEWATCH III (WW3), a third-generation wave model developed by the NOAA National Centers of Environmental Protection, to determine the adequacy of data to be applied in numerical modeling. Upon comparison and validation by NBDC measurement, the WW3 data was determined to be adequate to provide statistical analysis of wave events.

Two events were modeled in this study to capture the primary wave exposure windows for Avalon. One event, representing tropical swell hazards, was based on a tropical swell seen during August 2014 from Hurricane Marie that resulted in moderate damage to several resources in Avalon (Table 5-2). A second event, representing Santa Ana wind-driven wave hazards, was based on wind speed and duration during a February 1992 event (

Table 5-3).

Table 5-2: Representative tropical swell wave conditions

Date, Time	Significant Wave Height (ft)	Peak Wave Period (sec)	Mean Wave Direction (deg)
08/27/2014, 9:00	10.4	15	164 (SE)

Table 5-3: Representative Santa Ana wind event

Date, Time	Hourly Wind Speed (knot)	Wind Direction (deg)
02/06/1992, 18:00	29.5	110 (ESE)

A MIKE 21 Spectral Wave model was applied in the wave modeling to transform waves from offshore to nearshore and to simulate wind-generated waves at the site. MIKE 21 is a modeling suite developed by Danish Hydraulic Institute that can predict wave height, period, and directional spectrum by including the effects of wave diffraction, refraction, shoaling, wave breaking, wetting processes, and drying processes. The model grid applied in this study employed a 5-meter to 10-meter resolution in the areas surrounding the Cabrillo Mole, Green Pleasure Pier, Hamilton Cove, and Descanso Beach (Figure 5-2). A 30-meter resolution was used along the Pebbly Beach Road industrial area.

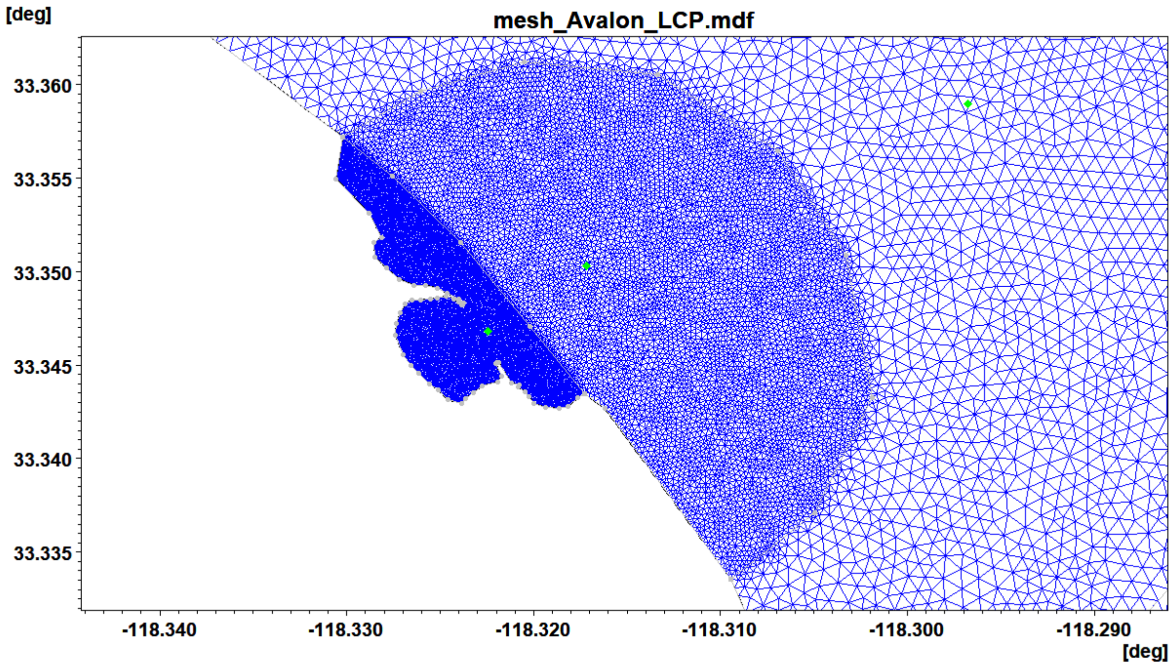

Figure 5-2: MIKE 21 spectral wave model grid used in vulnerability assessment wave modeling.

Modeled nearshore wave heights under representative extreme tropical swell conditions and wind conditions are shown in Figure 5-3 and Figure 5-4 respectively. Wave heights were modeled under current conditions as well as 6 ft of SLR. Minimal differences were seen when wave conditions were modeled with SLR; therefore, wave characteristics under existing conditions were applied to all SLR scenarios. All analyses used the USGS Coastal National Elevation Database integrated 2-meter topo-bathymetric elevation model for the Channel Islands, a high-resolution coastal elevation dataset that integrates over 25 different data sources.

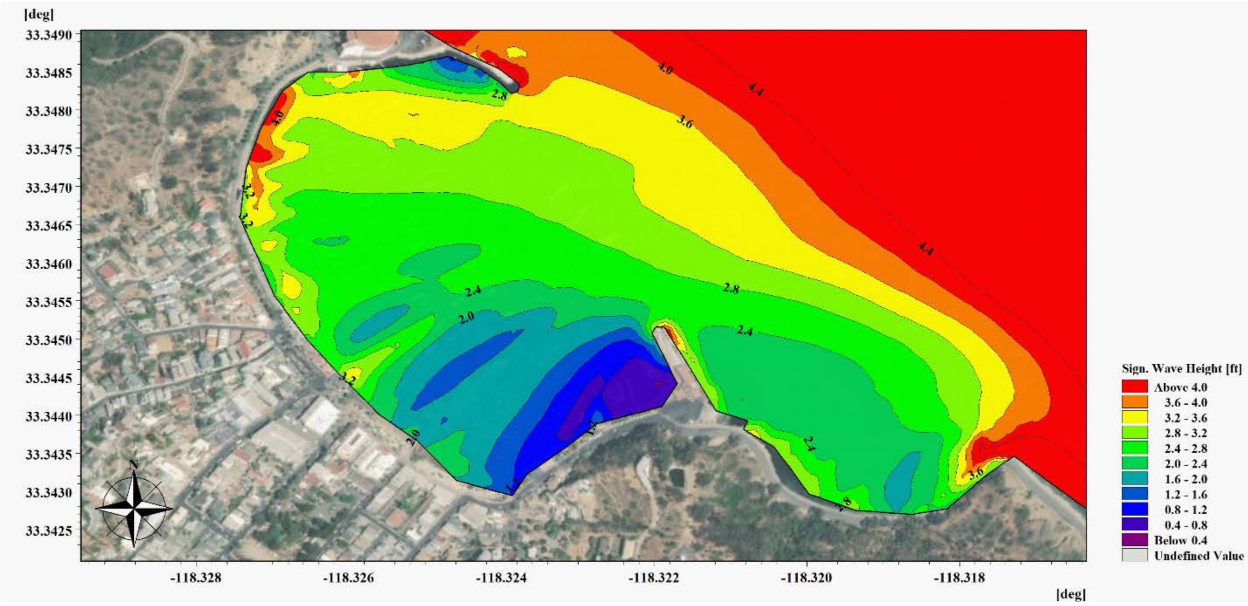

Figure 5-3: Nearshore wave heights associated with an extreme tropical swell event.

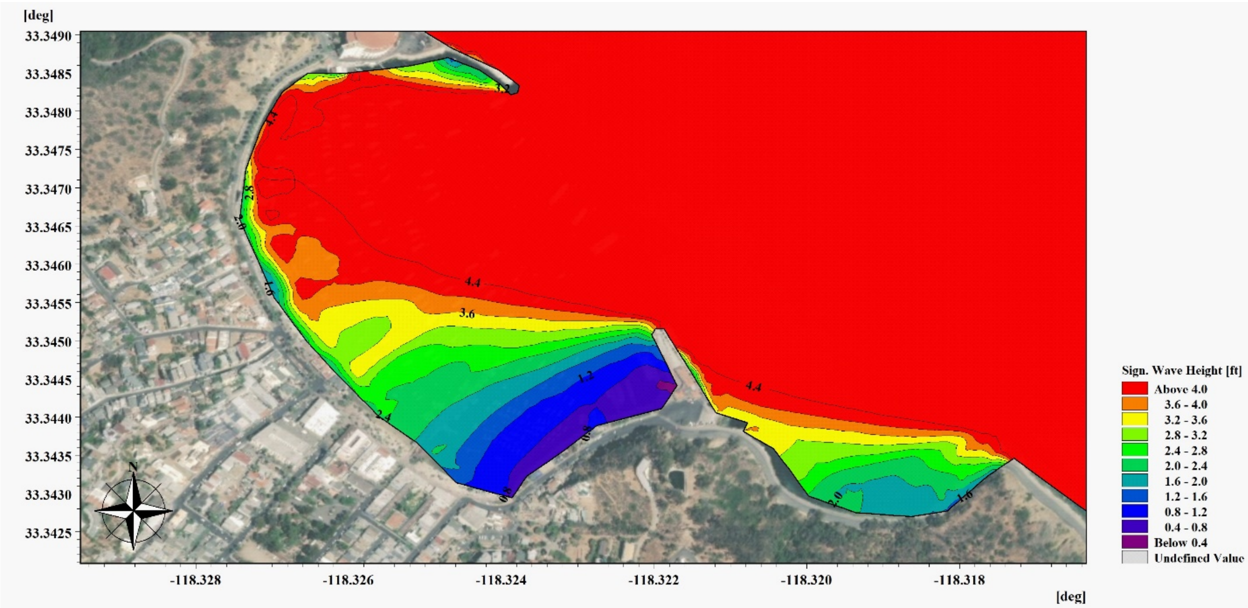

Figure 5-4: Nearshore wave heights associated with an extreme Santa Ana wind event.

5.3 Wave Runup and Overtopping

Nearshore wave conditions were translated into wave runup in coastal areas using a transect analysis. Twenty transects were generated along the Avalon coastline to capture variations in shoreline topography and wave energy (Figure 5-5). Final hazard projections for tideland areas within the City are based on results from transects 5 – 20. Nearshore slope, roughness, and crest height were determined for each transect to determine the magnitude of wave runup and the extent of coastal flooding due to overtopping. Slope and crest height were based on USGS topo-bathymetric data, while roughness was based on site observations and shoreline imagery.

Wave runup and wave overtopping hazard zones were calculated for each transect using FEMA methodology consistent with the *Los Angeles County FEMA Intermediate Data Submittal #3 Nearshore Hydraulics Report* (FEMA, 2014b), based on FEMA Pacific Coast Guidelines (FEMA, 2005). Overtopping hazard zones were estimated using FEMA methods for calculating the inland limit of high velocity hazard areas for transects that maintained positive freeboard with SLR. Total Water Level (TWL), including a water level setup component, was used to determine overtopping hazard zones for those transects and scenarios where SLR caused water elevations to rise above the current shoreline. All hazard calculations assume that wave events are concurrent with a mean higher high water level.

Figure 5-5: Transect locations.

Final flood extents included in SLR hazard maps incorporate the wave runup and overtopping hazard zones generated through numerical modeling as well as inundated areas based on the 100-year water level for Los Angeles, derived from NOAA NBDC tide station 9410660. Selected SLR values are added to the current 100-year water level to determine representative 100-year water level conditions under each SLR scenario. In order to generate hazard maps for each scenario, 100-year water levels are mapped against existing topography to provide a preliminary estimate of the potential flood zones. The flood extents were then moved landward as necessary to capture the additional wave overtopping hazard zones generated through empirical calculations applied at each transect.

5.4 Non-storm Flooding

Non-storm flood extents under selected SLR values were based on the Los Angeles Mean Higher High Water (MHHW) tidal datum provided by NOAA NBDC tide station 9410660, which represents the average higher high water height of each day. In the same manner as 100-year water levels, selected SLR values were added to the current MHHW datum to determine representative daily high tide conditions under each SLR scenario. All shoreline elevations used to determine coastal flood extents were based on USGS topo-bathymetric data.

5.5 SLR Hazard Overview

Tideland resources within the City of Avalon are projected to experience minimal flood hazards with 0 ft of SLR. Flood projections throughout tideland areas increase under 2 ft of SLR, reducing recreational beach area in the low-lying areas of Hamilton Cove, Descanso Bay, and Avalon Bay. Shorelines are reduced further under 4 ft of SLR, fully inundating the majority of tideland areas within the City. Non-storm flooding becomes substantial under 6 ft of SLR, with flood projections reaching well beyond existing tideland boundaries in a number of areas throughout the City. All current tideland areas become subject to multiple feet of flooding on a regular basis under such a scenario. An overview of non-storm SLR flood hazards under each scenario is presented in Figure 5-6 and Figure 5-7.

Flood impacts within tideland areas occur at less extreme SLR scenarios under 100-year storm conditions. Flood projections for a 100-year storm event with 0 ft of SLR extend across the vast majority of current tideland areas due to additional effects of storm surge and wave overtopping. In the 2-ft SLR scenario, flood projections increase noticeably along the low-lying Avalon Bay waterfront, resulting in the inundation of all current tideland areas. Storm flood projections increase further inland under the 4ft and 6ft SLR scenarios, resulting in more frequent and severe flooding within current tideland areas. An overview of storm-related SLR flood hazards within tideland areas is presented in Figure 5-8 and Figure 5-9.

Figure 5-6: SLR hazards under non-storm conditions for tideland areas within Descanso Bay and Hamilton Cove.

Figure 5-7: SLR hazards under non-storm conditions for tideland areas within Avalon Bay and Lover's Cove.

Figure 5-8: SLR hazards under 100-year storm conditions for tideland areas within Descanso Bay and Hamilton Cove.

Figure 5-9: SLR hazards under 100-year storm conditions for tideland areas within Avalon Bay and Lover's Cove.

6. Vulnerability Assessment

The vulnerability assessment provides a qualitative evaluation of coastal resources that could be impacted by future SLR hazards based on projections and methodologies discussed in Sections 4 and 5. The purpose of this assessment is to identify what resources are vulnerable at each increment of SLR to inform County planning efforts.

The intersection of potential SLR hazard zones and City tideland resources was determined using Geographic Information System (GIS) software. Methodology for assessing vulnerabilities and risk were based on guidelines published within the reports *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* (Snover et al., 2007) and *California Adaptation Planning Guide, Planning for Adaptive Communities* (California Emergency Management Agency & California Natural Resources Agency, 2012).

In accordance with these and other state SLR planning guidelines (California Coastal Commission, 2015), overall SLR vulnerability for each resource is assessed as a function of exposure, sensitivity, and adaptive capacity. These terms, in the context of how they are used within this vulnerability assessment, are defined as follows:

- **Exposure**: the degree to which a system or asset is exposed to SLR. In this Study, asset exposure to projected SLR was determined through numerical modeling and mapping and is defined in terms of flooding and inundation.
- **Sensitivity**: the degree an asset would be impaired by the impacts of SLR. Systems that are greatly impaired by small changes in SLR have a high sensitivity, while systems that are minimally impaired by the same small change in SLR have a low sensitivity.
- **Adaptive capacity**: the ability of an asset to respond to SLR, to moderate potential damages, to take advantage of opportunities, and to cope with the consequences. This does not mean that the system must look the same as before the impact, but it must provide comparable services and functions with minimum disruption or additional cost.

The vulnerability of an asset increases with both exposure and sensitivity, while adaptive capacity is inversely related to vulnerability, illustrated in Figure 6-1. As an example, pile-supported buildings typically have a high sensitivity to SLR hazards because even minor flooding or wave uplift forces can cause significant and costly damages. These structures also have a low adaptive capacity to SLR in that they cannot be easily relocated or raised to cope with consequences, compounding overall vulnerability. An alternative example would be structures such as floating docks, which are highly exposed to coastal hazards but often maintain a low vulnerability to SLR because they can easily adapt to increasing water levels.

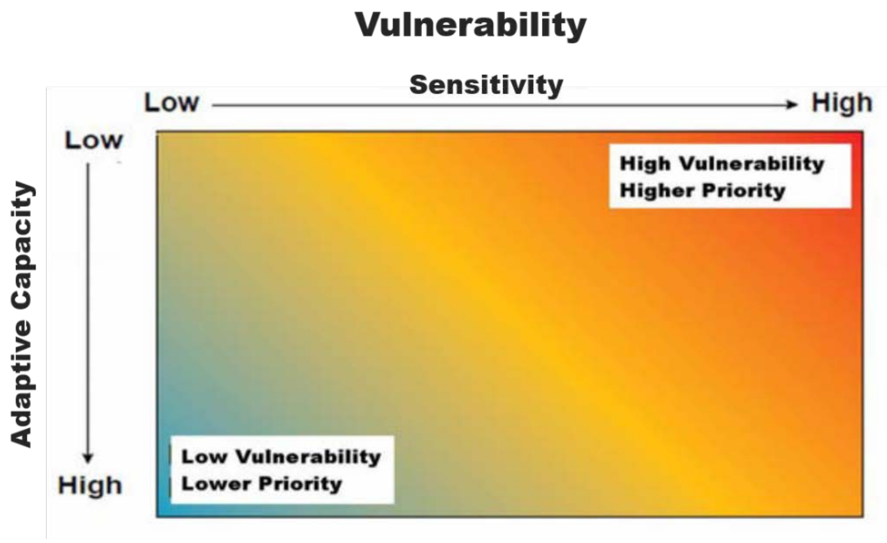

Figure 6-1: Relationship between sensitivity, adaptive capacity, and vulnerability (ICLEI, 2012)

6.1 Tideland Development and Infrastructure

6.1.1 Exposure

Pile-supported structures along the Avalon Bay waterfront such as the Catalina Island Yacht Club, Tuna Club, and Green Pleasure Pier have limited hazard exposure under non-storm conditions combined with 0ft and 2ft SLR (Figure 5-7). With more than 2 ft of SLR these pile-supported structures are projected to become subject to periodic tidal inundation, especially during elevated spring tides. With 6ft SLR, tidal inundation of pile-supported structures is projected and will likely require significant adaptation efforts to mitigate the potential for damage from regular wave impacts and inundation.

Hazard exposure for tideland structures increases substantially under 100-year storm conditions (Figure 5-9). Wave overtopping along the shoreline of Avalon Bay is projected under current conditions. Storm flood projections under 2ft SLR show potential flooding at the shoreline entryways of tideland structures, particularly those in the low-lying eastern portion of the Bay. SLR hazard exposure increases substantially under 4ft SLR combined with 100-year storm conditions. Under such a scenario, flood projections extend beyond seawalls within the Bay, and wave crests are likely to reach or surpass the finished floor elevations of tideland structures. Storm flooding is projected to become more severe with 6ft SLR, resulting in substantial inundation over the entirety of tideland structures.

In addition to storm flooding, tideland structures are also susceptible to increased wave action with SLR. Several structures currently experience damage during major storm events. These impacts are projected to become more severe as freeboard between the wave crest and first floor of structures is reduced with SLR. Under a 2ft SLR scenario storm conditions are projected to result in severe structural damages based on wave action alone, and storm conditions under a 4ft or 6ft SLR scenario are projected to result in complete loss of these structures.

6.1.2 Sensitivity

Pile-supported structures, such as those seen within the Avalon tidelands, have a high sensitivity to SLR hazards, given the relatively low freeboard between storm water levels and the finished floor elevation of these structures. Hazard sensitivity increases rapidly once the wave crest elevation approaches the deck of these structures, as illustrated in Figure 7-1. As such, these structures are likely to experience significant damage when water levels or wave heights approach first-floor elevations.

6.1.3 Adaptive Capacity

Tideland structures within Avalon Bay have a limited capacity for adaptation, given the nature of their construction and lack of available areas at higher elevations immediately landward. The water-dependent uses of the structures also limit options related to relocation or protection. The location over open water also creates construction challenges for structural accommodation or retrofitting related to SLR hazards.

6.2 Cabrillo Mole

6.2.1 Exposure

Non-storm tidal flood projections for the Cabrillo Mole indicate a low hazard exposure for the 0ft, 2ft, and 4ft SLR scenarios since the projected water levels would remain below the deck elevation of +15 ft MLLW (~14.8 ft NAVD). There would be roughly 4ft to 5ft of freeboard below the deck elevation during a spring tide plus 4ft of SLR. However, under a 6ft SLR scenario the freeboard of 2ft to 3ft would likely result in frequent wave uprush through the grates along the wharf and overtopping of the Cabrillo Mole, even during relatively calm weather conditions.

Under 100-year storm conditions flooding of the mole would be expected from wave uprush through the steel grates resulting in temporary impacts to access and operations at the mole. An example of this hazard is illustrated in Figure 6-2 during a December 2017 storm event. This type of flood event typically results in closure of the mole and some minor to moderate repairs and clean-up activities. In most cases, Catalina Express operations resume soon after the storm waves have subsided.

Each increment of SLR evaluated would increase the frequency and magnitude of these events. A 100-year wave event combined with 2ft of SLR would result in wave crest elevations approaching the deck of the mole, which would significantly increase the amount of flooding along with an increase in wave loads on the deck structure. The wave crest elevation was estimated to be 14.3ft NAVD under a 2ft SLR scenario based on the assumption the wave event coincided with a mean higher high water level (M&N, 2017).

If an extreme event coincides with a higher water level, as was the case on December 5, 2017, the wave crest elevations could reach higher.

100-year wave crest elevations were estimated to be 16.3ft and 18.3ft under the 4ft and 6ft SLR scenarios, respectively. These hazards would result in significantly more flooding of the deck and would likely result in major damage to the buildings and other amenities located on top of the mole. Wave loading would also increase significantly resulting in damage to the wharf structure, which was originally constructed in 1968. Based on the recent OPC guidance, 4ft to 6ft of SLR is unlikely to occur until the end of the century or beyond, which means these hazards would impact a wharf structure well past its current service life.

6.2.2 Sensitivity

The Cabrillo Mole structure itself has low sensitivity to hazards for SLR scenarios of less than 2ft. Although extreme events can temporarily impact access and operations at the mole, the structure itself is not sensitive to short duration flooding from wave uprush and overtopping of the deck. The structure has a higher sensitivity to SLR scenarios of 4ft and 6ft due to the significant increase in flooding and wave loads impacting the wharf.

The operations at the mole can be sensitive to flooding as it is the primary access point for passengers arriving via Catalina Express. Catalina Express typically cancels service during these extreme events due to rough conditions in the San Pedro Channel or difficulties tying up at the mole. This results in a direct economic impact to tourism-dependent businesses such as Catalina Express.

6.2.3 Adaptive Capacity

The Cabrillo Mole has a moderate adaptive capacity due to its original design as a storm protection structure and ability to accommodate 2ft of SLR without major impacts to the structure and current operations. However, significant structural improvements, a change in the mole operations, or a combination of the two would be required to withstand impacts from an extreme event in combination with 4ft to 6ft of SLR.

Figure 6-2: Cabrillo Mole flooding due to wave uprush and overtopping, December 5, 2017

6.3 Mooring and Boating Infrastructure

6.3.1 Exposure

All mooring and boating infrastructure located throughout Avalon Bay, Descanso Bay and Hamilton Cove is exposed to daily tidal fluctuations and extreme storm events. This exposure is not expected to change with SLR, except that the typical tidal range and extreme storm events will occur at higher elevations. Additional climate change impacts that could affect storm conditions at Avalon, such as changes in the frequency or intensity of Santa Ana wind events, were not evaluated as part of this study.

6.3.2 Sensitivity

Mooring and boating infrastructure has a low sensitivity to SLR hazards. These structures are designed to accommodate frequent changes in water levels, including tidal extremes and storm events. There is some sensitivity to harbor function during an extreme storm event since conditions are not safe for mooring and most vessels leave the harbor. However, there is greater risk of damage to individual vessels during these events than damage to the mooring infrastructure.

6.3.3 Adaptive Capacity

Some adaptive capacity is built into the mooring and boating infrastructure which may be sufficient to accommodate lower amounts of SLR (< 2ft). However, as sea levels rise, the mooring lines will need to be modified to account for higher water levels. This impact would occur slowly, allowing sufficient time to incorporate adaptation strategies into the maintenance cycle for this type of infrastructure. The adaptive capacity of pile-supported mooring infrastructure would depend on the freeboard above storm water levels and may require replacement when that threshold is reached. Higher SLR scenarios of 4ft to 6ft would also require modification to access points and gangways, which may need to be elevated to maintain accessibility under higher water level conditions.

6.4 Public Access and Recreation

6.4.1 Exposure

Tidal flood projections under the 2ft SLR scenario show loss of public beach area within Descanso Bay and Avalon Bay as water levels encroach upon the seawall and public stairways. Public beaches below the seawalls in Avalon Bay and Descanso Bay are projected to become completely submerged under high tide conditions with 4ft SLR, disrupting coastal access in these regions (Figure 5-6, Figure 5-7). Non-storm flood projections also show impacts to coastal access points within Lover's Cove and the Cabrillo Mole boat ramp under a 4ft SLR scenario. All public beaches and coastal access points within Avalon Bay are projected to become submerged with 6ft SLR, and projections show further beach loss above the coastal seawall in Descanso Bay.

100-year storm condition flood projections show significant hazard exposure for public access resources across all SLR scenarios examined. All public beaches below seawalls within Descanso Bay and Avalon Bay are projected to be submerged with 0ft SLR, along with coastal access points within Avalon Bay (Figure 5-8, Figure 5-9). Minimal beach area is projected to remain within Avalon Bay under a 2ft SLR scenario. Flood projections under this scenario also result in hazard exposure for all coastal access points within the City. All public beaches and access points are projected to become inundated under a 4ft SLR scenario, with more severe inundation projected under a 6ft SLR scenario.

6.4.2 Sensitivity

Public beaches and coastal access points have a high sensitivity to SLR hazards in terms of use. Beach area loss will occur with SLR due to both higher water elevations and increased erosion. Beaches located below seawalls are the most sensitive to these hazards as potential landward migration to higher elevations is limited by the coastal protection structures. The threshold for significant impacts to coastal access points is driven by frequent tidal flooding rather than temporary inundation during storm events. The opportunities for coastal access and recreation would be severely reduced if the beaches and access points are subject to frequent flooding during normal tidal cycles at the peak of the tourist season.

6.4.3 Adaptive Capacity

The adaptive capacity of public beaches and coastal access points is limited since most beach areas are backed by a shoreline protection structure and development. Beach nourishment is one option for maintaining a sandy beach area in front of this development. However, nourishment alone would not be sufficient to mitigate impacts from higher SLR scenarios of 4ft to 6ft. Comprehensive adaptation strategies for a re-configuration of the Avalon Bay waterfront would be required to balance the diversity of resources in this zone with the significant hazards associated with a 4ft to 6ft SLR scenario.

6.5 Ecological

6.5.1 Exposure

Marine ecological resources within the City are directly exposed to SLR. Although these resources are accustomed to frequently changing water levels, SLR will gradually alter the water depth and sunlight penetration of existing marine habitats. Additional climate change considerations such as water temperature, salinity and acidity levels could potentially pose much greater hazards to ecological resources than SLR. For example, kelp forests in southern California have traditionally experienced significant impacts during strong El Niño events due to stronger wave activity and warmer water temperatures.

6.5.2 Sensitivity

An ecological resources sensitivity to SLR hazards is expected to vary for different types of marine flora and fauna. Some habitat may be more adaptable to changes in water depth than others. Kelp forests may be less sensitive to depth but more sensitive to temperature increases. Eelgrass, on the other hand, is more sensitive to water depth and light penetration and may have to transition toward shallower water to keep pace with SLR.

6.5.3 Adaptive Capacity

Adaptive capacity for ecological resources within the City is also expected to vary for different types of marine flora and fauna. Offshore bathymetry may also influence the adaptive capacity for ecological resources. In some locations, like Avalon Bay, the gradual slope of the seafloor provides space for subtidal habitat to migrate as needed to adapt to higher water elevations. In other locations, the high relief of the shoreline and steeper offshore bathymetry provide less opportunity for habitat areas to migrate to higher elevations as SLR increases over time.

7. Financial Impacts of SLR

An economic analysis of Catalina Island tourism estimated that in 2016 approximately 910,800 visitors accounted for $166.7 million of direct spending, which generated $5.8 million in local tax revenue and supported 1,254 jobs (Lauren Schlau Consulting, 2017). The retail district of Avalon and the harbor were by far the most visited areas of the island. City tidelands also generate revenue directly through moorings in the form of nightly mooring fees, annual permit fees, and transfer fees. In 2018 the City operated 361 moorings resulting in over $2 million of generated revenue. Given that the City's tourism-dependent economy is focused on activities on or near the water, it is expected that adverse impacts to tideland resources could translate to significant direct and indirect financial impacts.

SLR is expected to increase the potential for damage to natural and built tideland resources during an extreme event, as described in Section 6. The damage from these increasing hazards will have direct and indirect financial impacts on the City. Direct financial impacts include the cost to repair storm-related damage to specific assets. Indirect financial impacts arise from the loss of use that a given resource provides to the City, its residents, and visitors. This section evaluates the potential financial impacts that may result from damage to tideland structures for a 100-year coastal storm event in combination with each SLR scenario as well as the potential non-market impacts of SLR on beach recreation value and ecosystem services. Further evaluation of all indirect impacts on the local economy due to SLR and associated impacts to tideland resources is beyond the scope of this study.

7.1 Tideland Structures

Potential financial impacts to tideland structures within the City of Avalon were evaluated using depth-damage relationships established through the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS), which were developed to better capture damage to structures during coastal storms as opposed to riverine flooding (USACE, 2015). Depth-damage relationships for inundation, erosion, and wave impacts were provided for 10 prototype structures incorporating data and information collected on coastal structures damaged by Hurricane Sandy. These updated depth-damage relationships are intended for use in cost-benefit analyses of Coastal Storm Risk Management (CRSM) projects.

These physical depth-damage functions were used to estimate a rough order of magnitude for potential storm damages under the future SLR scenarios evaluated in this study. The most vulnerable structures along the study area are the pile-supported structures along the Avalon Bay waterfront that are subject to increasing water levels and wave heights as sea level rises. The Catalina Island Yacht Club, Tuna Club, and Green Pleasure Pier are all supported on open timber pile foundations where the building footprint extends seaward of the mean high tide line.

For the purposes of this analysis, wave damage estimates are based on USACE Prototype 7A: Building on Open Pile Foundation and wave hazards used in the 100-year storm SLR analysis. The depth-damage functions for this type of structure (Figure 7-1) indicate that the potential for damage increases significantly as the wave crest elevation approaches the finished floor elevation (FFE) of a given structure.

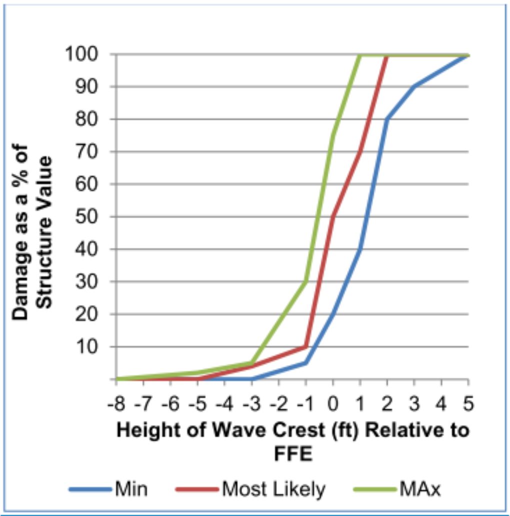

Figure 111. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Structure

Table 95. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Structure

Wave Crest	Min	Most Likely	Max
-8	0	0	0
-5	0	0	2
-3	0	4	5
-1	5	10	30
0	20	50	75
1	40	70	100
2	80	100	100
3	90	100	100
5	100	100	100

Figure 7-1: NACCS prototype 7A depth damage functions.

The USACE functions provide estimates of minimum, most likely, and maximum damages to structures as a percentage of total structure value. The range of expected damage is also a function of several building characteristics, including structure type, age, utility location, and condition of connections. The influence of these characteristics on damage potential are described in Table 7-1. For example, an older timber pile-supported structure with horizontal bracing below deck and corroded connections would experience a higher level of damage than a newer reinforced concrete pile-supported structure.

Table 7-1: Damage Potential based on Building Characteristics, Adapted from NACCS (USACE, 2015)

Building Characteristic	Minimum	Most Likely	Maximum
Type of structure	Reinforced Concrete	Reinforced Timber	Timber
Age (years)	0-10	15-30	>30
Condition of connections	Good	Fair	Poor
Utilities	Elevated	Elevated	Below deck

7.1.1 Catalina Island Yacht Club

The Catalina Island Yacht Club is a pile-supported structure in the western portion of Avalon Bay. Despite its location in the interior of Avalon Bay, wave modeling shows potential exposure during major storm events. Given the age and type of structure, the most likely or maximum damage estimates provide the most appropriate predictions of future damages. A 2ft SLR scenario represents a critical threshold for structural damages, as a 100-year storm event under such conditions would likely result in damages in excess of 50% of the value of the structure (Table 7-2). Potential damages increase further under the 4ft SLR scenario, likely resulting in a complete loss of the structure due to wave damage during an extreme event.

Table 7-2: 100-year storm structural damage projections for the Catalina Island Yacht Club under multiple SLR scenarios, expressed as a percentage of total structural value.

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	2	7	15
2	15	40	60
4	70	90	100
6	93	100	100

7.1.2 Tuna Club

The Tuna Club is another timber pile-supported structure in the western portion of Avalon Bay, with a slightly higher exposure to wave action than the Catalina Island Yacht Club, based on numerical modeling of an extreme wave event. It should be noted that the Tuna Club recently experienced damage to pilings during Hurricane Marie, although the peak wave height from this event coincided with a low to medium tide. If a wave event of this magnitude coincided with an MHHW level, the damage could have been much greater as indicated in

Table 7-3. Given the age and type of structure, the most likely or maximum damage estimates provide the most appropriate predictions of future damages under each SLR scenario. The results indicate this structure would likely experience greater than 50% damage under a 2ft SLR scenario in combination with an extreme event. It is unlikely the Tuna Club would be able to survive an extreme wave event combined with 4ft to 6ft of SLR.

Table 7-3: 100-year storm structural damage projections for the Tuna Club under multiple SLR scenarios, expressed as a percentage of total structural value.

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	3	8	18
2	20	50	75
4	80	100	100

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
6	95	100	100

7.1.3 Green Pleasure Pier

The Green Pleasure Pier is a pile-supported structure located in the eastern portion of Avalon Bay. This region experiences reduced wave exposure due to the sheltering influence of the Cabrillo Mole, and the pier structure itself is slightly elevated above the shoreline promenade. Due to these two factors, the pier is projected to experience less structural damage than other tideland structures under the 2-ft SLR scenario.

A 100-year storm under the 4ft SLR scenario is a critical threshold with estimated damage approaching 50% of the value of the structure (Table 7-4). Given the age and type of structure the potential damage under future SLR scenarios, especially over longer time frames, is largely dependent on the regular maintenance and repairs of aging piles and structural connections.

Table 7-4: 100-year storm structural damage projections for the Green Pleasure Pier under multiple SLR scenarios, expressed as a percentage of total structural value.

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	0	1	3
2	1	5	10
4	10	30	50
6	60	85	100

7.2 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 nearshore reefs. Non-market value loss within the City of Avalon is likely due to loss of sandy beach area throughout the City, resulting in significant impacts to recreational resources as sea levels rise.

Beaches such as those within Descanso Bay 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 of or proximity to beaches.

Determination and quantification of non-market values associated with beaches remains challenging due to the inherent variability between locations. Value can be expressed in a spatially explicit manner, such as a per-acre basis, and in terms of consumer surplus per activity day, which provides an estimate of the economic value of each beach attendee.

U.S. EPA estimates of the economic value of coastal ecosystems were used in this analysis to define beach value loss within the City of Avalon in a spatially explicit manner. Value estimates were also determined through a consumer surplus per activity day method, using a value of $40.00 per visitor per day, representing a median value of past studies (Pendelton & Kidlow, 2006).

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 7-5).

Table 7-5: Non-market values of California beach ecosystems in 2008 $U.S. (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 Avalon contains approximately 2.7 acres of recreational public sandy beach area, resulting in a total annual value of approximately $150,000 based on EPA non-market service valuations and adjustments to 2018 dollars using Consumer Price Index values. SLR is projected to significantly reduce this sandy beach area. While shoreline change projections were not conducted as part of this Sea Level Rise Assessment, estimates of beach loss can be made from changes in MHHW elevations, presented in Table 7-6.

Table 7-6: SLR impacts on non-market values for Avalon beaches using a spatially explicit method, 2018 $U.S.

SLR Scenario	Percent Loss of Beach Area	Service Flow Per Year	Loss in non-market value per year
0 ft	0%	$ 150,000	N/A
2 ft	18.5%	$ 122,250	$27,750
4 ft	34%	$ 99,000	$51,000
6 ft	71%	$ 43,500	$106,500

Non-market valuation estimates using consumer surplus per activity day provide additional information on recreational value. By incorporating beach attendance, these methods can account for the increased value of heavily trafficked beaches such as those within the City of Avalon as compared to methods that rely on available beach area alone. Considerable variability is still present in consumer surplus value estimates depending on individual beach characteristics, ranging from $15.66 (Leeworthy & Wiley, 1993) to $116.67 (Leeworthy, 1995). This analysis uses a value of $40 per person per day, consistent with median values of past studies (Pendelton & Kidlow, 2006) and recent CCC studies of beach value in southern California (California Coastal Commission, 2017).

City records have estimated the visitor volume for the City of Avalon at approximately 1,000,000 visitors annually. Past studies of tourism activity show that approximately 36% of visitors visit the beaches within the City (Lauren Schlau Consulting, 2017), resulting in an estimated annual beach attendance of 360,000. This estimate is combined with beach area loss estimates in Table 7-6 to determine SLR impacts to recreational values. Recreational value is assumed to decline directly based on loss in beach area due to the relatively small size of public beaches within the City of Avalon, limiting any excess recreational carrying capacity. The results of this analysis are presented in Table 7-7.

Table 7-7: SLR impacts on recreational values for Avalon beaches using consumer surplus estimates.

SLR Scenario	Percent Loss of Beach Area	Annual Recreational Value	Loss in Annual Recreational Value
0 ft	0	$ 14,400,000	N/A
2 ft	18.5	$ 11,736,000	$2.7 million
4 ft	34	$ 9,504,000	$4.9 million
6 ft	71	$ 4,176,000	$10.2 million

8. SLR Adaptation

Changing coastal hazards due to SLR can be addressed in a number of different ways. Though numerous adaptation methods are available, adaptation measures generally fall into one of three 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 resources from future SLR hazards without changes to the resource itself. Accommodation refers to strategies that involve modifying existing resources or designing new resources in a way that reduces the potential future impacts of SLR. Adaptation strategies centered on retreat focus on realignment, relocation, or removal of existing resources from identified high-hazard areas as well as limitations on the development of any new resources in hazardous areas. In practice, SLR adaptation often relies on hybrid approaches that combine elements from multiple categories over different spatial and temporal scales.

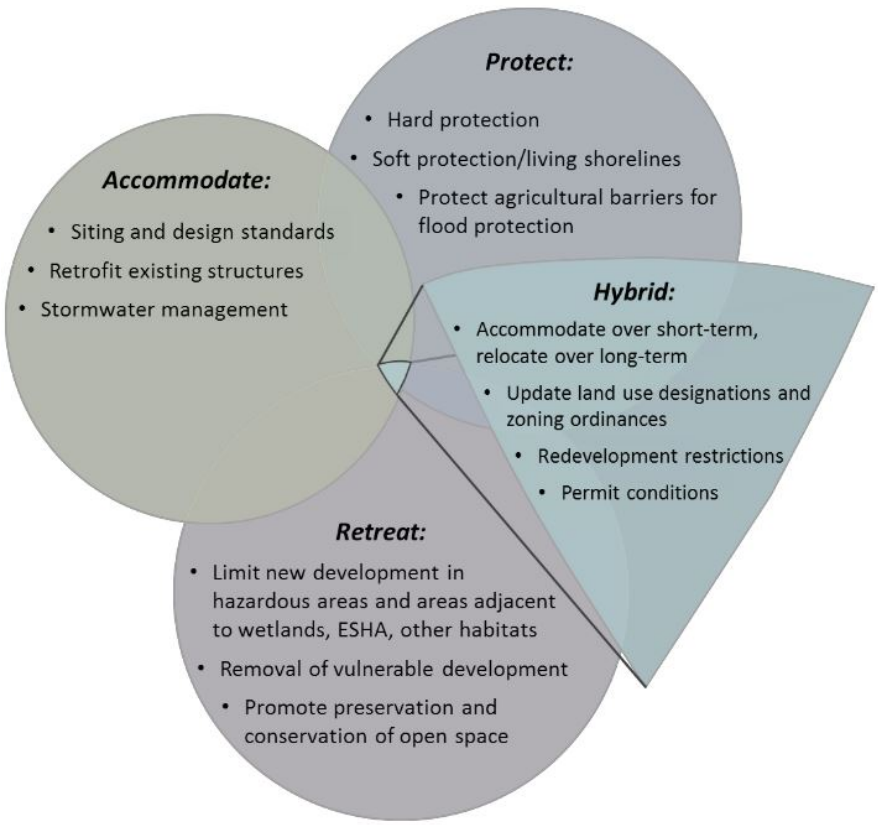

Figure 8-1: General SLR adaptation strategies and mechanisms (California Coastal Commission, 2015).

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 City of Avalon tidelands. It is understood that a variety of adaptation strategies will likely be necessary to account for the different hazard vulnerabilities and coastal resources present at various locations within the study area, and that adaptation strategies will likely need to be adjusted over time as their relative effectiveness changes. The following sections describe potential SLR adaptation strategies for each resource category included in the vulnerability assessment. Certain strategies, such as protection for ecological resources, are excluded for certain resources where appropriate due to a lack of applicable adaptation measures.

8.1 Tideland Development and Infrastructure

8.1.1 Accommodation

Accommodation strategies for tideland development, including any pile-supported structures, are linked to the structural design tolerance for high water levels. If current tideland development and infrastructure is not designed to withstand water levels outside the normal tide range, structures and piles can be elevated to accommodate projected future hazard conditions. A key consideration for these adaptation strategies is whether existing piles can remain in place or if new, higher piles will be needed to accommodate SLR over the design life of the development or infrastructure. Any planned tideland development or infrastructure redesign or replacement efforts within the study area provide an opportunity to increase adaptive capacity to match observed or projected rates of SLR.

8.1.2 Retreat

Because tideland development and infrastructure depend on proximity to the shoreline, retreat strategies may be necessary to account for potential shoreline migration over long-term SLR scenarios. This is a challenge for much of the tideland development within the City given the lack of available area landward of many resources. Retreat strategies may also require updates to tideland boundaries over time as the ordinary high water mark migrates landward. Due to the potential complexity of such strategies, any landward migration of tideland development and infrastructure should be coordinated with other retreat or realignment-based adaptation strategies throughout the study area.

8.2 Cabrillo Mole

8.2.1 Protection

Ongoing maintenance and enhancement of existing shoreline protection within the Cabrillo Mole will likely be necessary to account for changing coastal hazards with SLR. The existing shoreline protection system can be augmented with retrofits or replacement of existing infrastructure in order to keep pace with the projected increased height and frequency of flood events.

8.2.2 Accommodation

Additional accommodation strategies may be necessary within the Cabrillo Mole to mitigate impacts under severe storm and SLR scenarios. These strategies could include elevation of the mole to prevent loss of access and flooding of structures. Structures on the deck of the Cabrillo Mole can also employ wet or dry flood-proofing to reduce the impacts of extreme events. Potential floodproofing strategies such elevation of utilities infrastructure are illustrated in Figure 8-2.

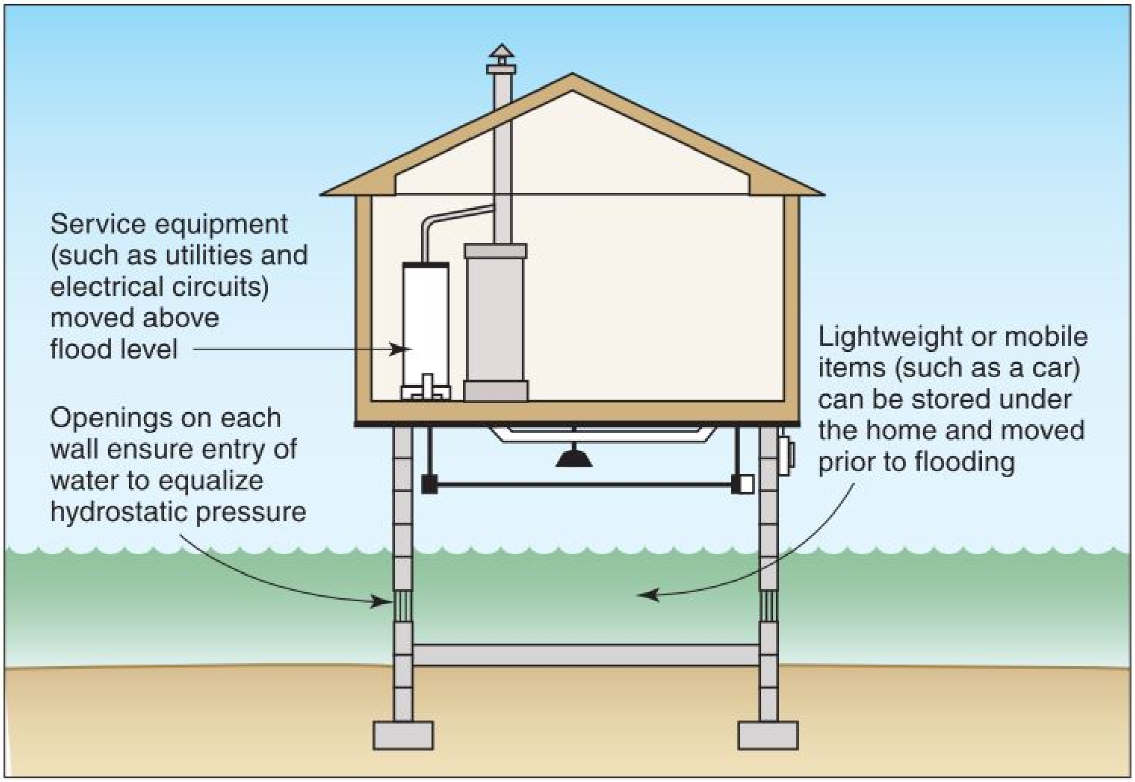

Figure 8-2: Example cross section of an elevated home using continuous foundation walls (FEMA, 2014a)

8.3 Mooring and Boating Infrastructure

8.3.1 Accommodation

Accommodation strategies will likely prove effective for mooring infrastructure. Limited effort may be required to preserve current use if mooring infrastructure is currently able to accommodate water elevations beyond the normal tide range. When necessary, mooring infrastructure can be adjusted accordingly as water elevations increase with SLR. Taking projected future water elevations into consideration when replacing mooring infrastructure represents a key opportunity to adapt infrastructure over time.

8.4 Public Access and Recreation

8.4.1 Accommodation

Recreation and coastal access resources can accommodate projected SLR impacts through elevation. Coastal access resources can be elevated through the use of fill or other methods in order to offset increased water elevations and maintain the current height of the shoreline relative to sea level. Beach area and height relative to sea level can also be maintained through periodic beach nourishment. Any planned elevation or beach nourishment event should be coordinated throughout the study area to avoid potential loss of aesthetic value or adverse impacts to other resources.

8.4.2 Retreat

Relocation or realignment of recreation and coastal access resources remain as options to address severe, long-term SLR impacts. Retreat measures are most feasible for resources that have open space located landward at higher elevation such as the southeastern portion of Avalon Bay. Sandy beach areas can also retreat landward through natural processes as water elevations rise if open space is made available (Figure 8-3). These measures may be complicated by the widespread presence of shoreline protection within the City, which can lead to loss of beach area over time through "coastal squeeze" (Figure 8-4), and the potential need to shift tideland designations landward over time to keep pace with any shoreline migration. Though retreat measures are likely to be employed only in long-term, severe SLR scenarios, it is important that they are considered throughout the SLR adaptation planning process to avoid precluding any potential adaptation actions necessary to preserve recreational opportunities and coastal access within the study area.

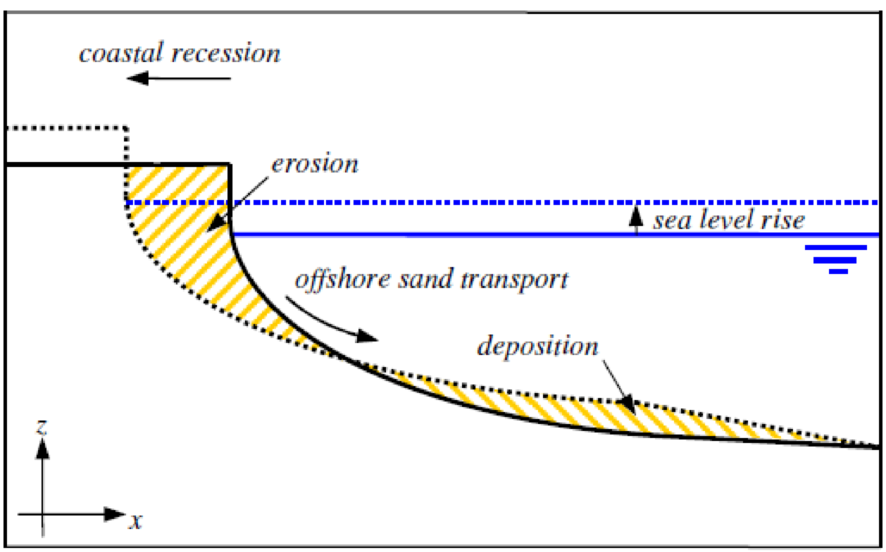

Figure 8-3: Potential beach area retreat over time with SLR.

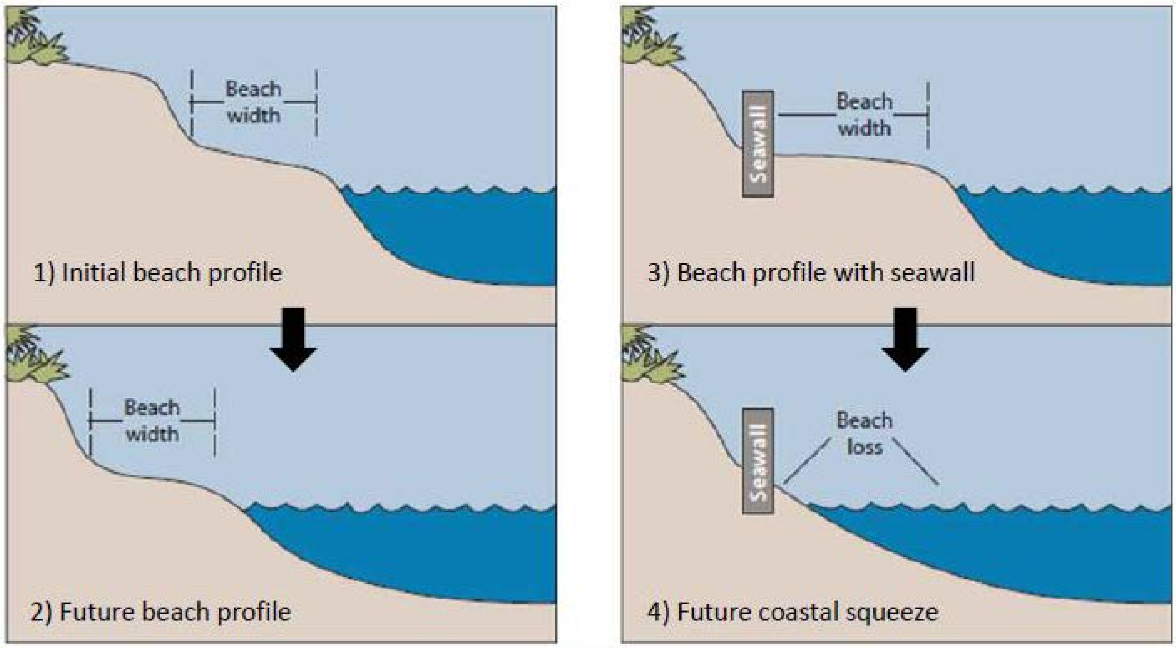

Figure 8-4: Potential coastal squeeze effect with the addition of hard shoreline protection (California Coastal Commission, 2018)

8.5 Ecological

8.5.1 Accommodation

Accommodation strategies for marine ecological resources within tidelands are primarily based on maintaining current depth levels relative to water surface elevations. The feasibility of accommodation strategies for marine ecological resources within the study area is largely dependent on the rate of SLR compared to habitat migration rates and the ability of current ecosystems to tolerate changes in depth over time. If ecological resources are able to migrate landward or tolerate increased depth without loss of ecological function these resources may be able to accommodate SLR with little outside intervention. Natural rates of ecosystem migration can also be supplemented through restoration efforts if necessary. Ecological monitoring will play a key role in the implementation of these adaptation strategies, including the identification of critical parameters that influence overall ecosystem resilience.

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