City of Avalon
Sea Level Rise Vulnerability Assessment

Prepared For:

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Table of Contents

Document Verification vi

Executive Summary vii

1. Introduction 1
   - 1.1 Study Approach 1
   - 1.2 Study Area 1
   - 1.3 Coastal Setting 1
2. Coastal Processes 6
   - 2.1 Water Levels 6
   - 2.2 Wave Climate 8
   - 2.3 Littoral Processes 11
3. Coastal Resource Inventory 13
   - 3.1 Hamilton Cove 13
   - 3.2 Descanso Bay 14
   - 3.3 Catalina Island Casino 14
   - 3.4 Catalina Island Yacht Club 15
   - 3.5 Tuna Club 15
   - 3.6 Green Pleasure Pier 16
   - 3.7 Mooring and Boating Infrastructure 17
   - 3.8 Cabrillo Mole 17
   - 3.9 Pebbly Beach Road Industrial Area 18
   - 3.10 Transportation and Utilities Infrastructure 18
   - 3.11 Public Access 19
   - 3.12 Ecological 20
4. Sea Level Rise 21
   - 4.1 What is Sea Level Rise? 21
   - 4.2 Projections and Probability 22
   - 4.3 Selected SLR Scenarios 23
5. SLR Hazard Evaluation 25
   - 5.1 Assessment of Available Hazard Data 25
   - 5.2 Coastal Hazard Modeling 28
   - 5.3 Wave Runup and Overtopping 32
   - 5.4 Non-storm Flooding 33
   - 5.5 SLR Flood Hazard Overview 33
   - 5.6 Additional SLR Hazards 34

6. Vulnerability Assessment 37
6.1 Hamilton Cove 38
6.2 Descanso Bay 39
6.3 Casino Point 43
6.4 Avalon Bay: Tidelands 44
6.5 Avalon Bay: Inland 45
6.6 Cabrillo Mole 49
6.7 Mooring and Boating Infrastructure 52
6.8 Pebbly Beach Road Industrial Area 52
6.9 Transportation and Utilities 56
6.10 Public Access 58
6.11 Ecological 59
7. Environmental Justice 61
7.1 Social Vulnerability 62
7.2 Environmental Pollution Burden 62
8. Financial Impacts of SLR 63
8.1 Tideland Structures 63
8.2 Land Parcel Impacts 66
8.3 Non-Market Value Loss 70
9. SLR Adaptation Strategies 73
9.1 Adaptation Strategy Overview 73
9.1.1 Protection 74
9.1.2 Accommodation 76
9.1.3 Retreat 80
9.2 SLR Adaptation Goals 81
9.2.1 Understand SLR Hazards 81
9.2.2 Manage Development in SLR Hazard Areas 82
9.2.3 Reduce Coastal Hazards 82
9.2.4 Use a Coordinated Approach to SLR Adaptation 83
9.2.5 Maximize Protection of Coastal Resources 83
10. References 85

TABLE OF FIGURES

Figure 1-1: Santa Catalina Island and the City of Avalon study area. 4
Figure 1-2: Coastal elevation within the City of Avalon. 5
Figure 2-1: Daily and extreme water levels for NOAA station 9410660. 7
Figure 2-2: November 2015 tide series, Los Angeles station 9410660. 8
Figure 2-3: Primary wave exposure windows for Avalon. 9

Figure 2-4: Hurricane Marie storm damage at Pebbly Beach Road Industrial Area (Image: Los Angeles Times). 10
Figure 2-5: Hurricane Marie wave runup along Avalon Bay. 10
Figure 2-6: Localized erosion at South Beach between 1994 and 2013 (Image: Google Earth). 12
Figure 3-1: Hamilton Cove aerial view (Image: Catalina Island Chamber of Commerce and Visitors Bureau). 13
Figure 3-2: View from the Descanso Beach Club looking toward the Casino (Image: Catalina Island Chamber of Commerce and Visitors Bureau). 14
Figure 3-3: View of Catalina Island Yacht Club from the shoreline pedestrian pathway. 15
Figure 3-4: View of the Catalina Island Tuna Club from the shoreline pedestrian pathway. 16
Figure 3-5: View of the Green Pleasure Pier from the shoreline pedestrian pathway. 16
Figure 3-6: Inner harbor view of the Cabrillo Mole and approaching ferry. 17
Figure 3-7: Aerial View of the industrial area along the southeastern portion of Pebbly Beach Road. 18
Figure 3-8: Pebbly Beach Road near the industrial area. 19
Figure 3-9: Public beach and access structures in the southeastern portion of Avalon Bay. 19
Figure 3-10: A diver within the kelp habitats offshore of the City of Avalon (Image: visitcatalinaisland.com.). 20
Figure 4-1: Regional and global factors that can contribute to changes in sea level (IPCC, 2013). 21
Figure 4-2: Approximate sea level rise projections for three risk aversion levels (OPC, 2018). 23
Figure 5-1: CoSMoS 100-year storm wave height projections, showing reduced impacts within the City of Avalon due to W-NW wave directions. 27
Figure 5-2: CoSMoS 0cm SLR + 100-year storm flood depth projections within the Pebbly Beach Road industrial area known to have experienced recent flooding. 28
Figure 5-3: MIKE 21 spectral wave model grid used in vulnerability assessment wave modeling. 30
Figure 5-4: Nearshore wave heights associated with an extreme tropical swell event. 31
Figure 5-5: Nearshore wave heights associated with an extreme Santa Ana wind event. 31
Figure 5-6: Transect locations used in wave runup and overtopping analyses. 32
Figure 5-7: Overview of SLR flood hazards within the City of Avalon under non-storm conditions including a H++ worst-case scenario. 35
Figure 5-8: Overview of SLR flood hazards within the City of Avalon under 100-year storm conditions. 36

Figure 6-1: Relationship between sensitivity, adaptive capacity, and vulnerability (ICLEI, 2012) 38
Figure 6-2: Flood hazards with SLR under non-storm conditions for Descanso Bay and Hamilton Cove. 41
Figure 6-3: Flood hazards with SLR under 100-year storm conditions for Descanso Bay and Hamilton Cove. 42
Figure 6-4: Flood hazards with SLR under non-storm conditions for Avalon Bay and Lover's Cove. 47
Figure 6-5: Flood hazards with SLR under 100-year storm conditions for Avalon Bay and Lover's Cove. 48
Figure 6-6: Cabrillo Mole flooding due to wave uprush and overtopping, December 5, 2017 51
Figure 6-7: Flood hazards with SLR under non-storm conditions for the Pebbly Beach Road Industrial Area. 54
Figure 6-8: Flood hazards with SLR under 100-year storm conditions for the Pebbly Beach Road Industrial Area. 55
Figure 6-9: Erosion damage to Pebbly Beach Road, February 1988. 56
Figure 7-1: Social and environmental vulnerability metrics for Avalon. 61
Figure 8-1: NACCS prototype 7A depth damage relationships. 64
Figure 8-2: Example of 4-ft SLR storm flood depths within parcels used in damage analyses. 67
Figure 9-1: General SLR adaptation strategies and mechanisms (California Coastal Commission, 2018a). 74
Figure 9-2: Examples of hard-bottom, nearshore habitat created with ECOncrete® (econcretetech.com). 76
Figure 9-3: Example cross-section of an elevated home using continuous foundation walls (FEMA, 2014a). 77
Figure 9-4: Example of drainage improvements to reduce flooding (U.S. Army Corps of Engineers, 2015a). 79
Figure 9-5: Example of a retreat project in which a parking lot was moved landward away from potential SLR hazard zones. Photo courtesy of Surfrider Foundation (California Coastal Commission, 2018a). 81

TABLE OF TABLES

Table E-1: SLR scenarios and potential timing based on various risk aversion levels. . viii
Table E-2: Summary of SLR thresholds and vulnerability across the Avalon coastline. x
Table 5-1: Boundary conditions associated with each with each CoSMoS modeled storm scenario, obtained from "CoSMoS v3.0 Phase 2 Southern California Bight: Summary of Methods". 25
Table 5-2: Representative tropical swell wave conditions 29
Table 5-3: Representative Santa Ana wind event 29

Table 6-1: Projected flood hazard exposure for transportation assets under each SLR scenario. 57
Table 8-1: Damage potential based on building characteristics, adapted from NACCS results (USACE, 2015). 64
Table 8-2: 100-year storm structural damage projections for the Catalina Island Yacht Club under multiple SLR scenarios, expressed as a percentage of total structural value. 65
Table 8-3: 100-year storm structural damage projections for the Tuna Club under multiple SLR scenarios, expressed as a percentage of total structural value. 65
Table 8-4: 100-year storm structural damage projections for the Green Pleasure Pier under multiple SLR scenarios, expressed as a percentage of total structural value. 66
Table 8-5: Financial impacts of SLR hazards in inland areas under non-storm conditions. Total value refers to combined land and improvement value. 69
Table 8-6: Financial impacts of SLR hazards in inland areas under storm conditions. Total value refers to combined land and improvement value. 69
Table 8-7: Non-market values of California beach ecosystems in 2008 $U.S. (Raheem et al., 2009) 71
Table 8-8: SLR impacts on non-market values for Avalon beaches using a spatially explicit method, 2018 $U.S. 71
Table 8-9: SLR impacts on recreational values for Avalon beaches using consumer surplus estimates. 72

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Executive Summary

The Sea Level Rise Vulnerability Assessment (Vulnerability Assessment) for the City of Avalon (City) analyzes potential impacts to coastal resources across multiple sea level rise (SLR) scenarios. A number of City resources that perform significant roles in tourism and provide critical services are located within coastal areas, including essential means of transportation. Understanding potential impacts to these resources as coastal hazards continue to evolve is a crucial step in enhancing the resilience of the City to future hazard conditions.

Coastal Processes

Much of the Avalon coast is backed by cliffs and bluffs of varying height except for low-lying areas in portions of Descanso Bay and along the shoreline of Avalon Bay. A typical tidal range for the City is approximately 5.5 ft. The largest tide events of the year, which occur in the winter and summer, can produce tidal ranges of more than 8 ft. Sea level anomalies such as El Niño or storm surge can also significantly increase the predicted water level above the normally occurring astronomical tide.

The City of Avalon is faced with unique wave hazards compared to other areas of the California coast. While westerly swells represent the greatest wave hazards for much of the California coastline, Avalon is exposed to wave hazards from southeasterly swells generated by tropical storm systems in the eastern Pacific Ocean and seasonal northeast Santa Ana wind events. Wave conditions associated with past tropical swell and Santa Ana wind events have both been linked to documented wave damage to coastal resources within the City of Avalon.

Sediment in coastal areas is transported in both the cross-shore and alongshore directions in response to waves, water levels, and currents. These processes are generally confined to small, sandy 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 due to offshore sediment transport. Wave refraction and reflection patterns in Avalon Bay also induce currents that transport sediment in the alongshore direction, reducing beach width south of the Green Pleasure Pier. Beach width is also affected by the natural supply of sediment, which has declined due to development within Avalon Canyon.

Sea Level Rise Projections

SLR values used within this study are based on the probabilistic SLR projections for Los Angeles included in the 2018 California Ocean Protection Council (OPC) SLR guidance, identified by the California Coastal Commission as the best-available science on the subject. The California Coastal Commission recommends use of high-emissions scenario projections based on current emissions trends. The OPC guidance provides further recommendations on appropriate levels of risk tolerance for coastal resources, grouping

projections into low, medium-high, and extreme risk aversion cases based on the probability associated with each projection.

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. At any given time horizon, there is a 17% chance that SLR will meet or exceed low risk aversion projections. For medium-high risk aversion situations more conservative projections for SLR are recommended by the OPC Guidance. These projections have a 1-in-200 (0.5%) chance of being exceeded at a given time horizon, making them appropriate for use on projects where damage from coastal hazards would carry a higher consequence.

The OPC guidance also includes a singular, extreme scenario (called H++), that incorporates potential Antarctic ice sheet instability that could lead to extreme sea level outcomes. 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. SLR scenarios evaluated within this study along with approximate timing based on OPC projections and risk aversion categories are presented in Table E-1.

Table E-1: SLR scenarios and potential timing based on various risk aversion levels.

SLR Scenario	**Low Risk Aversion** (17% probability)	**Medium-High Risk Aversion** (0.5% probability)	**Extreme Risk Aversion**
2 ft	2080	2060	2040-2050
4 ft	2100+	2080	2060-2070
6 ft	2100+	2090-2100	2070-2080

Sea Level Rise Vulnerability

Vulnerability to SLR hazards is evaluated based on a combination of hazard exposure, sensitivity, and adaptive capacity. Critical SLR thresholds and vulnerability within the City of Avalon are described below and summarized across different areas of the coastline in Table E-2.

A key component of SLR vulnerability within the City is the potential for increased hazard impacts at the Cabrillo Mole, the primary point of entry for visitors arriving by boat and

ferry. Under storm conditions flooding of the mole has occurred due to wave uprush through the steel grates resulting in temporary impacts to access and operations at the mole. This type of flood event typically results in closure of the mole and some minor to moderate repairs and clean-up activities. Each increment of SLR evaluated would increase the frequency and magnitude of these events. A 100-year wave event combined with 2 ft 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. 100-year wave crest elevations under the 4 ft and 6 ft SLR scenarios are projected to 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 under these higher SLR scenarios would also increase significantly and potentially damage the wharf structure, which was originally constructed in 1968. Based on OPC guidance, 4 ft to 6 ft of SLR is unlikely to occur until the end of the century or beyond. Given the age of the existing wharf structure and the low probability of these scenarios occurring over the next 50 years there would likely be a new or significantly modified wharf structure in place before sea level rise exceeds 4 feet.

Under non-storm conditions, other coastal resources within the City of Avalon are projected to experience minimal flood hazards with 0 ft of SLR. Non-storm flood projections remain minimal under 2 ft of SLR, although sandy beach area would be reduced in the low-lying areas of Descanso Bay, Avalon Bay, and Pebbly Beach Road. Shorelines retreat further landward under 4 ft of SLR, potentially encroaching on coastal resources in southeastern Avalon Bay and the Pebbly Beach Road utilities area. Non-storm flooding becomes substantial under 6 ft of SLR, impacting a number of structures and footpaths in low-lying areas of Avalon Bay and significantly intruding into the Pebbly Beach Road utilities area.

Flood impacts occur at less extreme SLR scenarios under 100-year storm conditions. A 100-year storm event with 0 ft of SLR results in flood projections along select coastal roads, footpaths, and low-lying coastal areas throughout the City primarily due to wave overtopping. In the 2 ft SLR scenario, flood projections increase noticeably along the low-lying Avalon Bay waterfront and Pebbly Beach Road utilities area. Flooding within Avalon Bay and the Pebbly Beach Road utilities area becomes extensive under the 4 ft SLR scenario. Substantial storm flooding is also projected along the Descanso Bay shoreline with 4 ft SLR, and projected flooding of coastal roads and footpaths becomes widespread under these conditions. The 6 ft SLR scenario in combination with 100-year storm conditions shows a substantial increase in flooding within Avalon Bay, Descanso Bay, and the Pebbly Beach Road utilities area, along with inundation of areas surrounding the Catalina Island Casino.

Pile supported structures such as the Catalina Island Yacht Club, Tuna Club, and Green Pleasure Pier 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 with 2 ft SLR as freeboard between the wave crest and first floor of structures is reduced. Under a 4 ft SLR scenario storm conditions are projected to result in severe structural damages based on wave action alone, and storm conditions under a 6 ft SLR scenario are projected to result in complete loss of these structures.

Table E-2: Summary of SLR thresholds and vulnerability across the Avalon coastline.

Area	SLR Thresholds and Vulnerability
Hamilton Cove and Descanso Bay	Loss of beach area, storm flooding along select coastal paths and roads with 2 ft SLR. Extensive storm flooding in area of Descanso Beach Club with 4 ft SLR. High topographic relief and available land at higher elevation provides additional adaptive capacity for severe SLR scenarios.
Avalon Bay	Loss of beach area below seawalls, storm flooding and more frequent damage to pile-supported structures with 2 ft SLR. Widespread storm flooding of waterfront and coastal pathways with 4 ft SLR. Widespread tidal flooding along waterfront, storm impacts at Casino Point with 6 ft SLR. Adaptation is complicated by density of development along waterfront. Improved protection and hazard accommodation potentially effective up to severe SLR scenarios.
Cabrillo Mole	Frequency and magnitude of flood impacts increase with 2 ft SLR. Storm flooding likely to cause major structural damage with 4 ft and greater SLR. Opportunities exist for ongoing improvements as part of regular maintenance and repair.
Pebbly Beach Road	Storm flooding along roads, additional storm flooding within industrial area with 2 ft SLR. Extensive storm flooding of roads, industrial area with 4 ft SLR. Tidal flood impacts with 6 ft SLR. Concentration of critical services increases hazard sensitivity. Accommodation of or protection from storm flooding possible for coastal-dependent uses and services.

Adaptation

SLR vulnerabilities can be addressed with a variety of adaptation strategies ranging from planning level policies and programs to specific project measures. The appropriate adaptation strategy often depends on the probability and timing of a potential vulnerability. Existing or near-term vulnerabilities may call for specific project level adaptation measures to mitigate impacts from coastal hazards. Vulnerabilities associated with longer time horizons, such as those identified for the 4 and 6 ft SLR scenarios, are less likely to occur this century and therefore can be addressed through planning and policy measures that can be implemented over the coming decades to reduce long-term vulnerabilities.

Project level adaptation measures generally fall into one of three main categories: protection, accommodation, and retreat. Protection refers to strategies that employ an engineered structure or other measure to defend existing development from future SLR hazards. Accommodation refers to strategies that involve modifying existing development or designing new developments in a way that reduces potential future impacts if exposed to SLR hazards. Retreat strategies focus on measures to relocate or remove existing development from identified high-hazard areas while limiting the construction of new development in such areas. In practice, it is likely that SLR adaptation with the City of Avalon will take a hybrid approach, combining elements from multiple adaptation categories over different spatial and temporal scales.

While the specific type and application of SLR adaptation strategies may vary, future planning efforts and adaptation measures within the City should align with the following goals:

- Improve understanding of SLR and coastal hazards.
- Manage development in SLR hazard areas.
- Reduce impacts of SLR hazards within the coastal zone.
- Use a coordinated approach to SLR adaptation.
- Maximize protection of coastal resources.

These adaptation planning goals and strategies will be evaluated in more detail and refined with input from the community to inform an Adaptation Plan that outlines specific policies, programs and projects that can be implemented to mitigate the impacts identified in this vulnerability assessment.

1. Introduction

1.1 Study Approach

The Sea Level Rise Vulnerability Assessment (Vulnerability 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 coastal 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 critical City coastal resources are impacted. For 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 categorized according to their location within one of the following regions: Hamilton Cove, Descanso Bay, Casino Point, Avalon Bay tidelands, Avalon Bay inland, and the Pebbly Beach Road industrial area. Additional categories of resources across the City are analyzed individually, including transportation, public access, ecologically sensitive areas and those that provide key functions. A full inventory of resources included in the Vulnerability Assessment may 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. The Vulnerability Assessment is designed to inform policy and SLR adaptation strategy development, as the City prepares to update its local coastal program.

1.2 Study Area

The City is located on the southeastern shoreline of Santa Catalina Island in Los Angeles County (Figure 1-1). Figure 1-2 shows the study area for the Vulnerability Assessment encompassing the full extent of the City's eastern shoreline, extending from the Hamilton Cove area in the northwest through Descanso Bay, Avalon Bay, Lovers Cove, and areas bordering Pebbly Beach Road to the southeast. The study area extends landward as necessary to capture the full extent of coastal hazards present under each SLR scenario analyzed.

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. This transitions to a mix of narrow, sandy beaches and rocky structures surrounding the industrial area located at the southeasternmost portion of Pebbly Beach Road. Specific shoreline characteristics present in each region of the City are detailed below.

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.

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.

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.

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 northern 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.

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.

Pebbly Beach Road and Industrial Area

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. A wider sandy shoreline is present in the northwestern portions of the industrial area, backed by a low seawall in some locations and intermittent rock revetment in others. The shoreline in the southeastern portion of the industrial area is made up of a more continuous rock revetment, including the engineered revetment in front of the Southern California Edison facilities, which sit at a higher elevation.

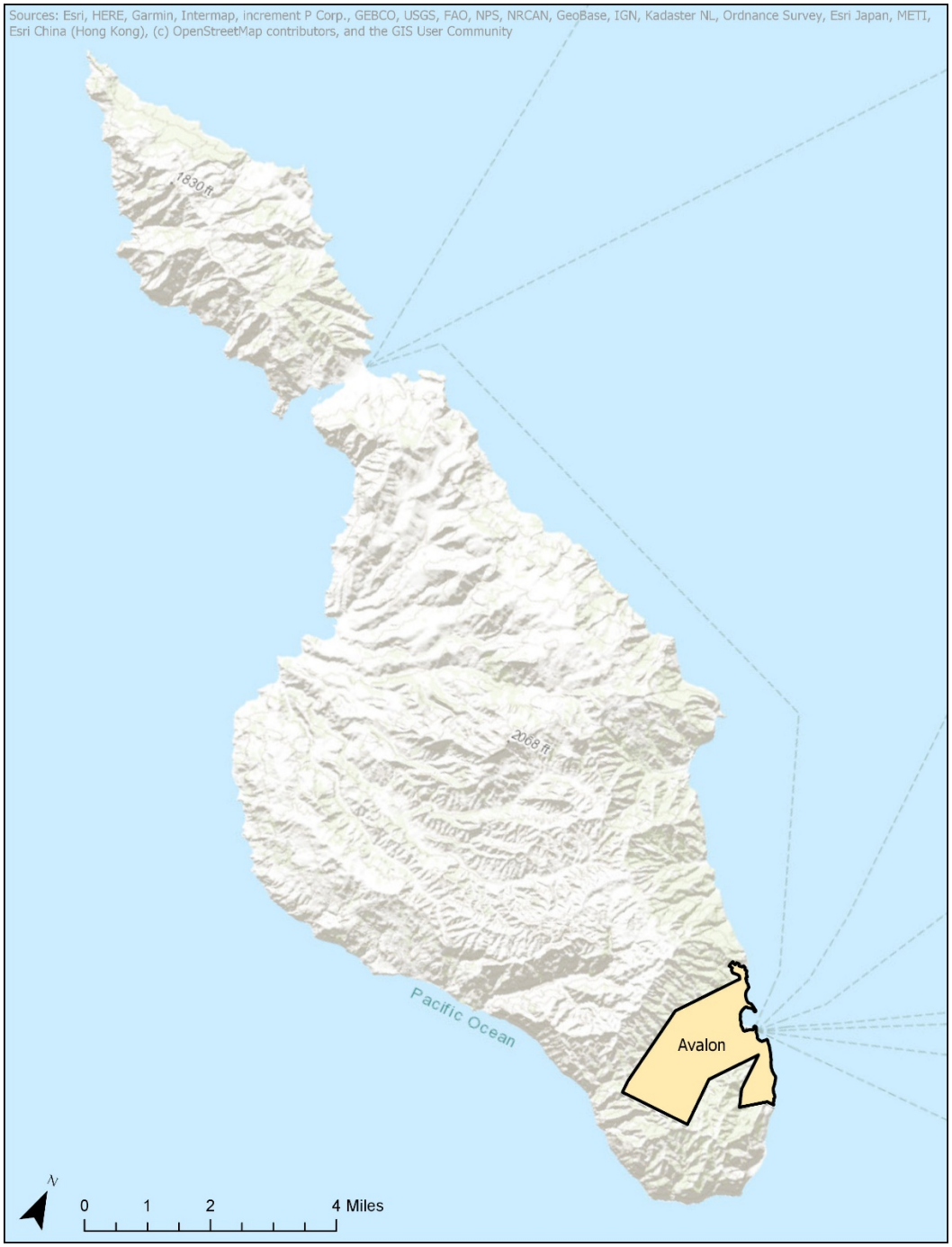

Figure 1-1: Santa Catalina Island and the City of Avalon study area.

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

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 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.

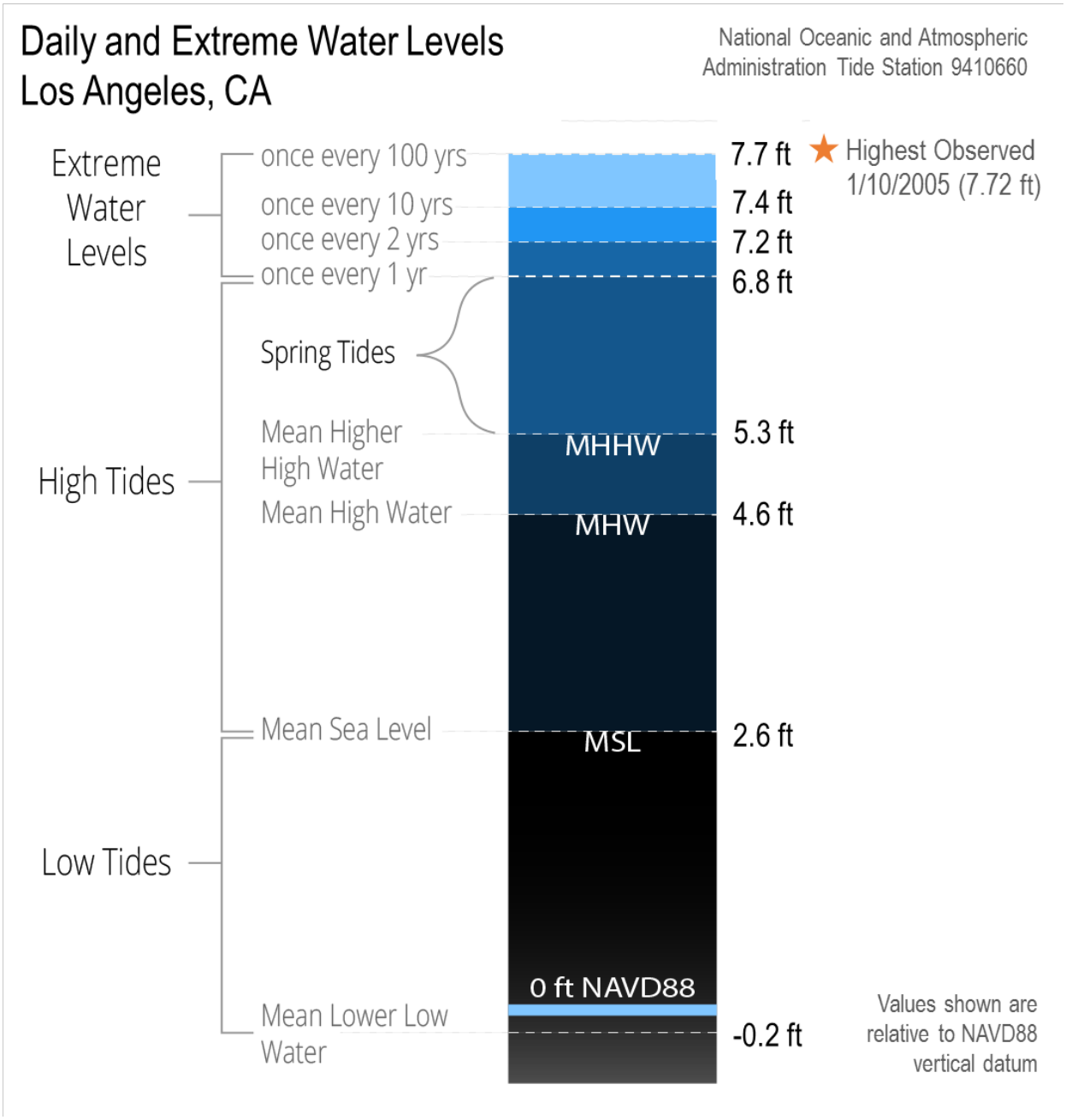

Figure 2-1: Daily and extreme water levels for NOAA station 9410660.

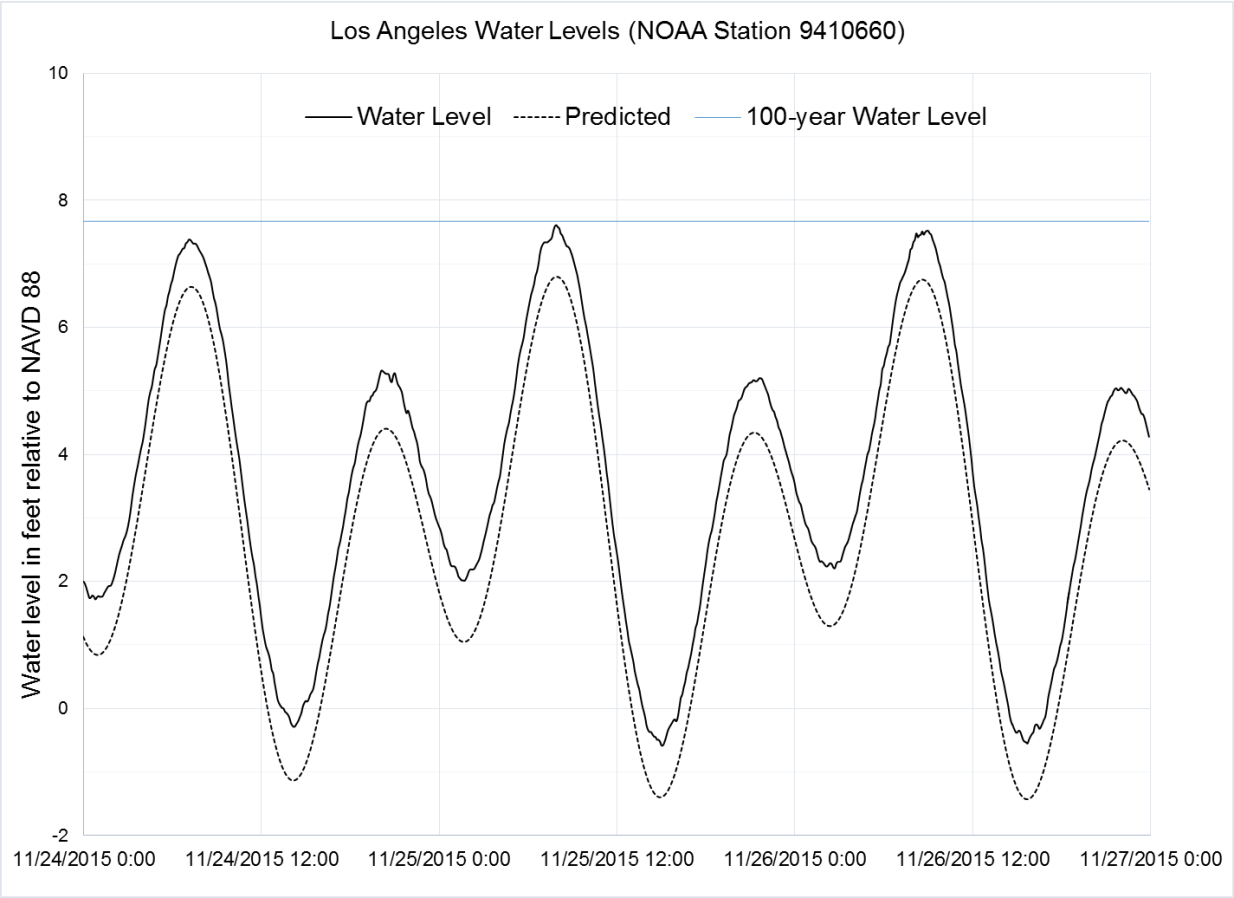

Figure 2-2: November 2015 tide series, Los Angeles station 9410660.

2.2 Wave Climate

The City of Avalon's location on the southeastern 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 and ferry service to and from Avalon.

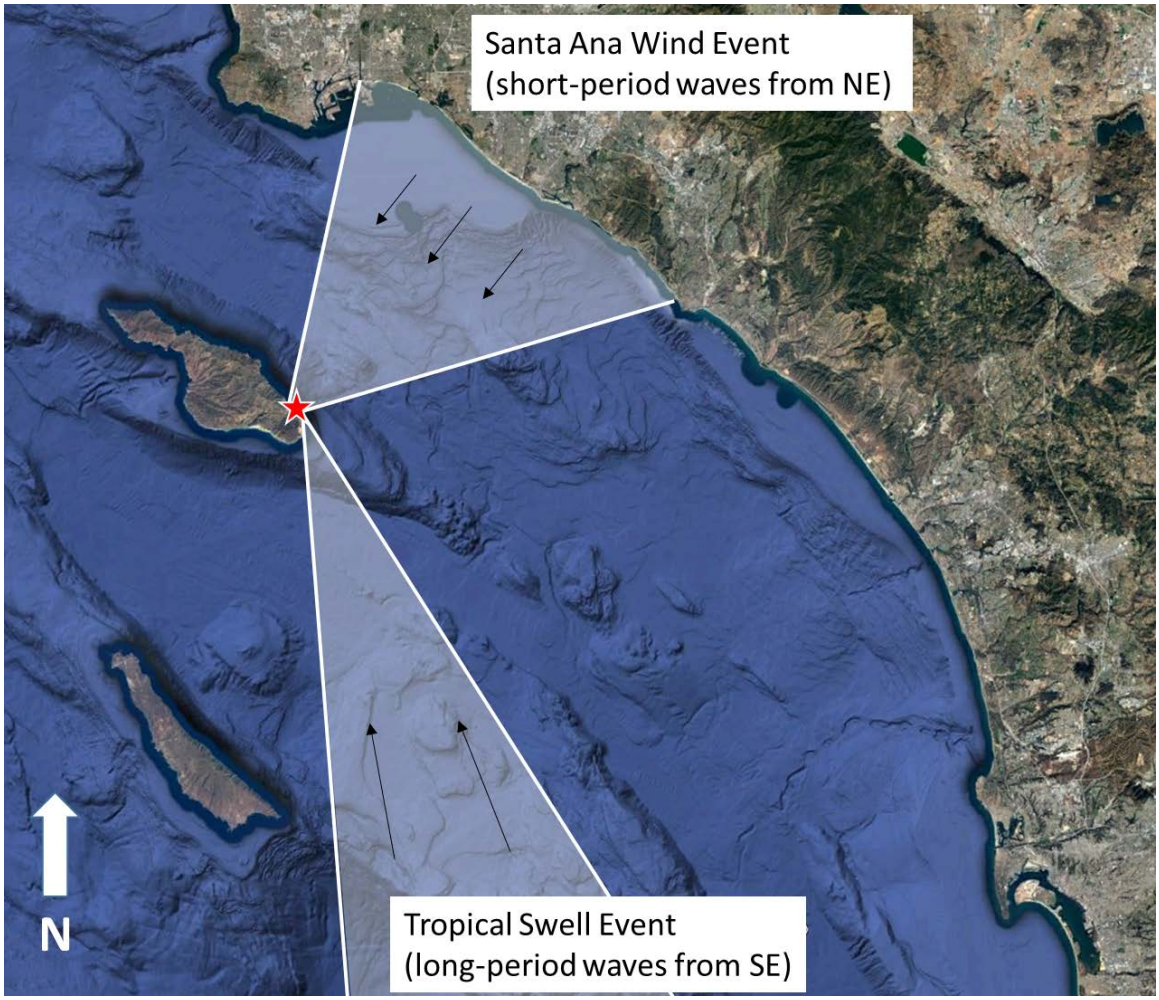

Figure 2-3: Primary wave exposure windows for Avalon.

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 9.

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

3. Coastal Resource Inventory

A number of City resources are located within coastal areas that perform significant waterfront roles in coastal tourism and provide essential means of transportation. The northwestern portion of Avalon contains Hamilton Cove, a private development, and Descanso Bay, home to the Descanso Beach Club. 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 bay serves as the point of arrival for the majority of visitors to Catalina Island, and the surrounding low-lying areas also contain much of the residential development within the City. Southeast of Avalon Bay are Lover's Cove, which contains additional coastal recreation opportunities, and the Pebbly Beach Road industrial area, where a number of critical freight and utility services are located.

3.1 Hamilton Cove

Hamilton Cove is a gated private residential community located along the coastal bluffs of the northwestern portion of the City. The area also contains a small portion of sandy beach and a pier structure for use by community residents.

Figure 3-1: Hamilton Cove aerial view (Image: Catalina Island Chamber of Commerce and Visitors Bureau).

3.2 Descanso Bay

Also located in the northwestern portion of the City, Descanso Bay sits on a low-lying stretch of land between surrounding coastal bluffs. The primary coastal resource in the area is the Descanso Beach Club, a private beach that allows for public access. The sandy beach and surrounding amenities within Descanso Bay are a major attraction for tourism and coastal recreation during the summer months.

Figure 3-2: View from the Descanso Beach Club looking toward the Casino (Image: Catalina Island Chamber of Commerce and Visitors Bureau).

3.3 Catalina Island Casino

The Catalina Casino, owned by the Santa Catalina Island Company, is a focal point for tourism in Avalon and a key structure in the City's history. Originally constructed in 1929, the circular structure stands 12 stories high and features a ballroom and theater. Tours are available daily, and the building also hosts major events such as the Catalina Film Festival and Catalina Jazz Festival. The Casino sits on the northwesternmost point of Avalon Bay on a spit of land protected by a combination of rock revetment and seawalls.

3.4 Catalina Island Yacht Club

The Catalina Island Yacht Club is a City-owned structure operated by a private entity. The 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 3-3: View of Catalina Island Yacht Club from the shoreline pedestrian pathway.

3.5 Tuna Club

Like the nearby Yacht Club, the Tuna Club is also operated by a private entity while under ownership of the City. The Tuna Club is a private 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 3-4: View of the Catalina Island Tuna Club from the shoreline pedestrian pathway.

3.6 Green Pleasure Pier

The Green Pleasure Pier is a City-owned structure that 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 3-5: View of the Green Pleasure Pier from the shoreline pedestrian pathway.

3.7 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.

3.8 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 high-speed ferries operated by Catalina Express and Newport Flyer 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. Other City-approved permit holders such as commercial tours and coastline camps also make use of the Mole to access services. 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 3-6: Inner harbor view of the Cabrillo Mole and approaching ferry.

3.9 Pebbly Beach Road Industrial Area

The southeastern portion of Pebbly Beach Road contains critical utility infrastructure for the City of Avalon, including Southern California Edison facilities that provide water, gas, and electric services as well as the City wastewater treatment plant. Utility structures are located in a low-lying coastal area bordered by a mix of engineered and non-engineered revetment, sand, and cobble beaches. The area additionally contains a heliport used for commercial flights and medical evacuations to mainland facilities. Freight deliveries are also made to the area, making Pebbly Beach Road a critical delivery route for supplies to the City as well as the main route to the City landfill.

Figure 3-7: Aerial View of the industrial area along the southeastern portion of Pebbly Beach Road.

3.10 Transportation and Utilities Infrastructure

In addition to the water-based transportation infrastructure discussed in Section 3.8, coastal roads and pedestrian pathways are located along most of the City's coastline, largely protected by a combination of seawall structures and rock revetment. Due to the large number of visitors that arrive by ferry, the pedestrian pathways that line coastal roads serve as key multi-modal transportation corridors, providing access to the variety of waterfront resources in Avalon. Alternative modes of transportation, such as golf carts and bicycles, are also common and make up the primary means of transportation for many residents and visitors. Analysis of impacts to utilities infrastructure is based on outfall locations along the City coastline, the majority of which are located within Avalon Harbor.

Figure 3-8: Pebbly Beach Road near the industrial area.

3.11 Public Access

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 3-9: Public beach and access structures in the southeastern portion of Avalon Bay.

3.12 Ecological

Ecological resources within the City include both terrestrial and marine ecosystems. To evaluate SLR impacts on ecological resources, this study focused on marine ecosystems. 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 north of Casino Point, and the Lover's Cove State Marine Conservation Area stretches from the Cabrillo Mole southeast 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.

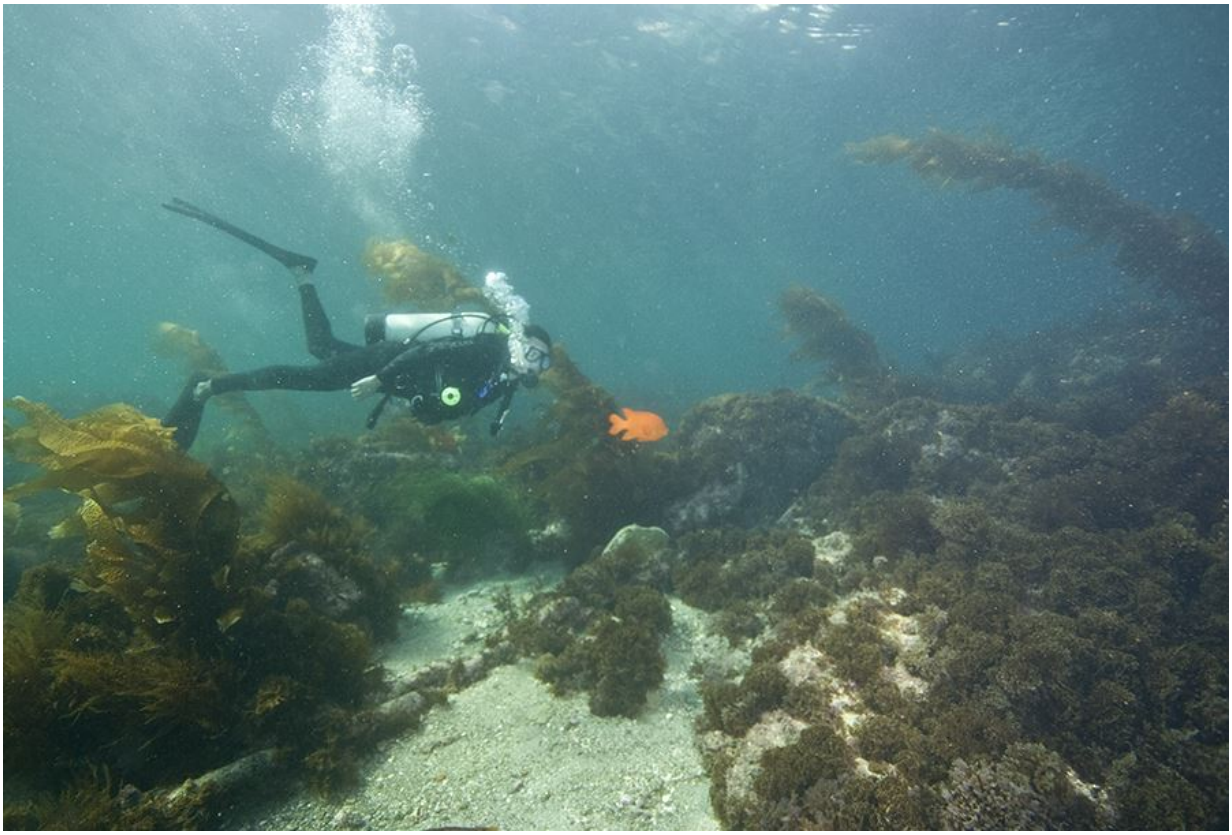

Figure 3-10: A diver within the kelp habitats offshore of the City of Avalon (Image: visitcatalinaisland.com.).

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. Per 2018 California Coastal Commission Sea Level Rise Policy Guidance, "Sea level can change, both globally and locally, due to (a) changes in the shape of the ocean basins, (b) changes in the total mass of water and (c) changes in water density. Factors leading to sea level rise under global warming include both increases in the total mass of water from the melting of land-based snow and ice, and changes in water density from an increase in ocean water temperatures and salinity changes. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence."

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.

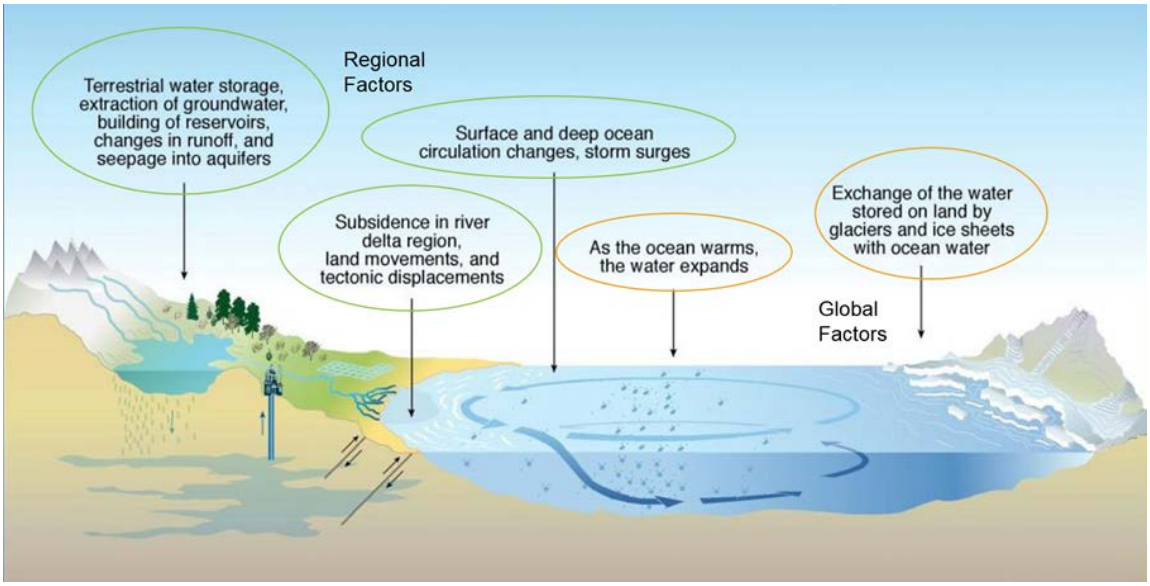

Figure 4-1: Regional and global factors that can contribute to changes in sea level (IPCC, 2013).

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 between 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. A SLR of 1.8 ft is projected at the 2050 time horizon, 3.3 ft at 2070, and 6.7 ft 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.

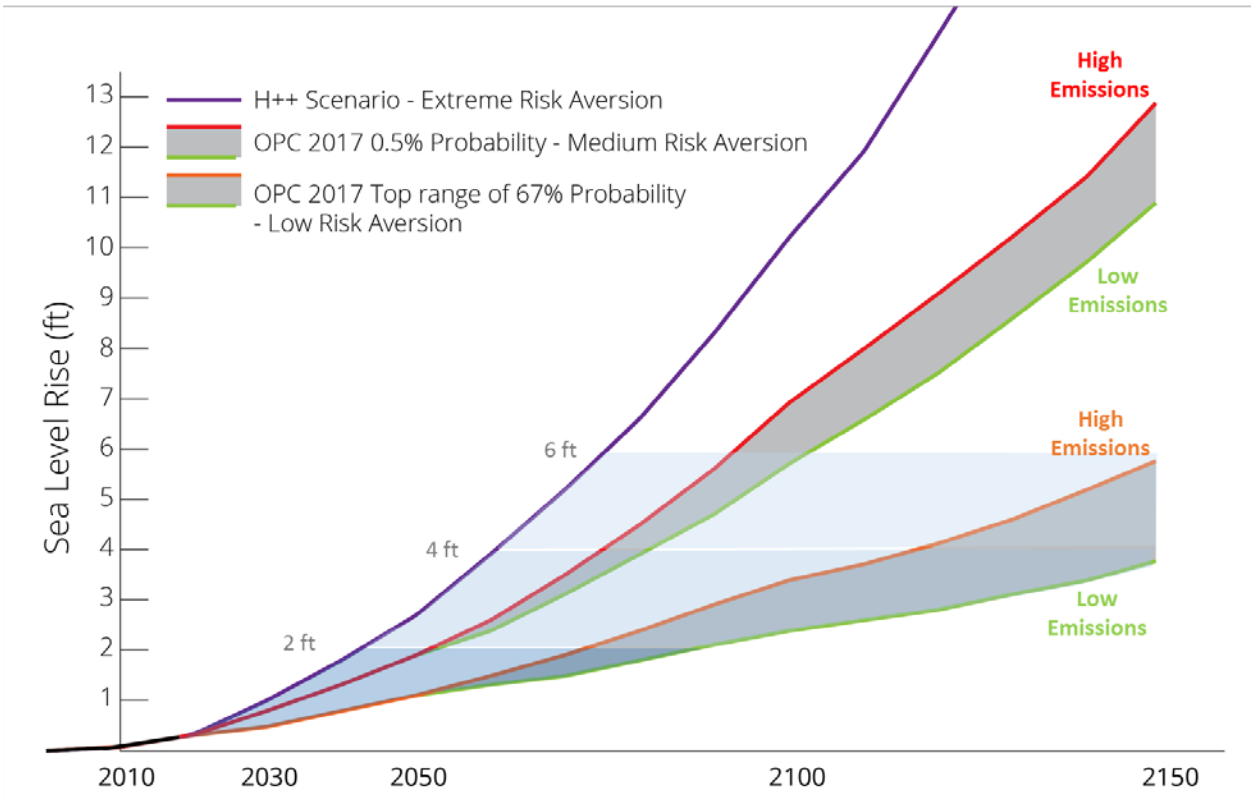

Figure 4-2: Approximate sea level rise projections for three risk aversion levels (OPC, 2018).

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 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 assessment also includes an initial analysis of potential non-storm conditions with 10-ft SLR in 2100 to account for a worst-case H++ scenario. This scenario is discussed briefly in Section 5.5. The probabilities that SLR will meet or exceed a particular height over a given time horizon are based on Kopp et al. 2014 and 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. Under the extreme H++ scenario this amount of SLR could occur between 2070 and 2080.

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, obtained from "CoSMoS v3.0 Phase 2 Southern California Bight: Summary of Methods".

Scenario	Significant Wave Height (ft)	Peak Wave Period (s)	Mean Wave Direction (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 (Figure 5-2).

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.

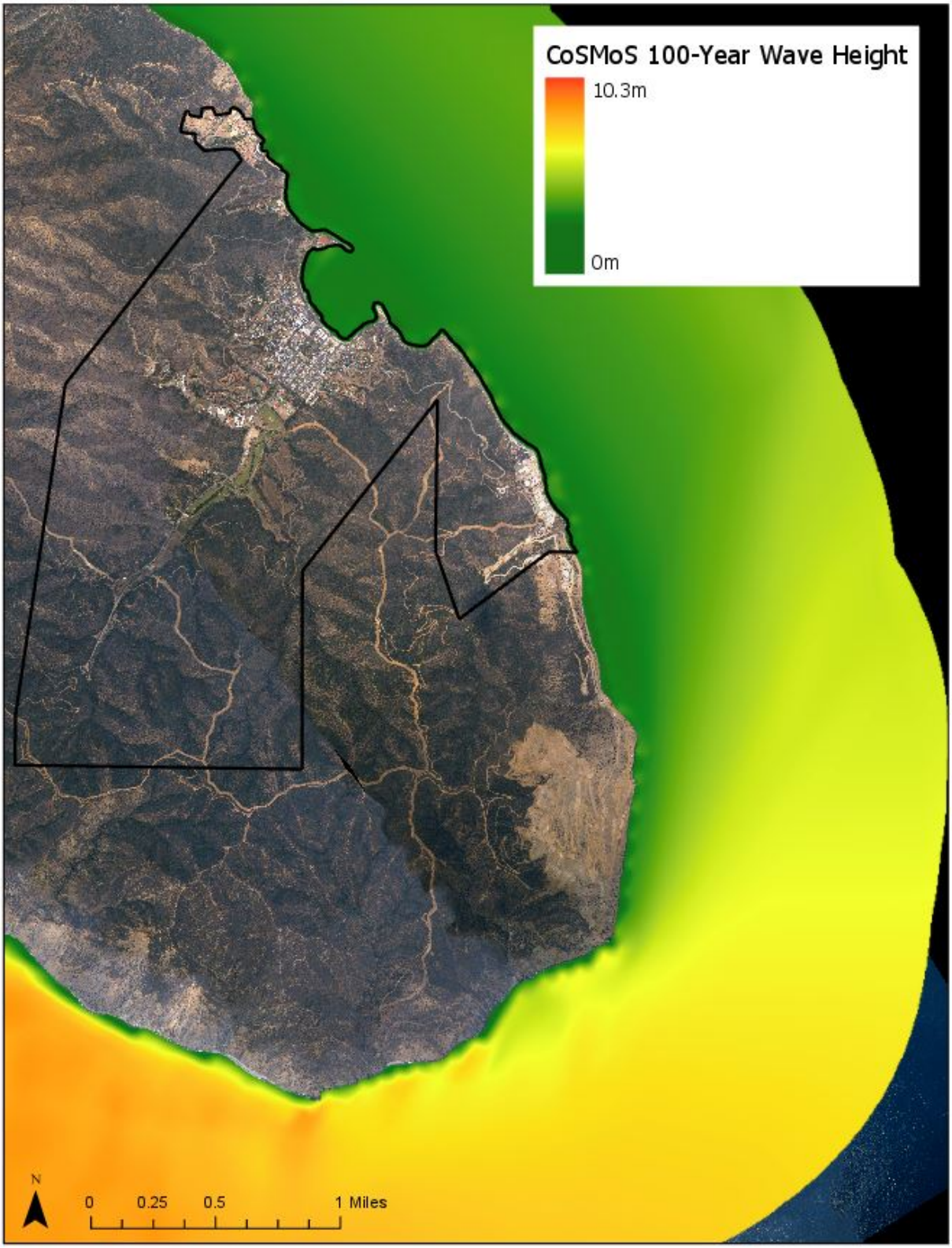

Figure 5-1: CoSMoS 100-year storm wave height projections, showing reduced impacts within the City of Avalon due to W-NW wave directions.

Figure 5-2: CoSMoS 0cm SLR + 100-year storm flood depth projections within the Pebbly Beach Road industrial area known to have experienced recent flooding.

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 5-3). A 30-meter resolution was used along the Pebbly Beach Road industrial area.

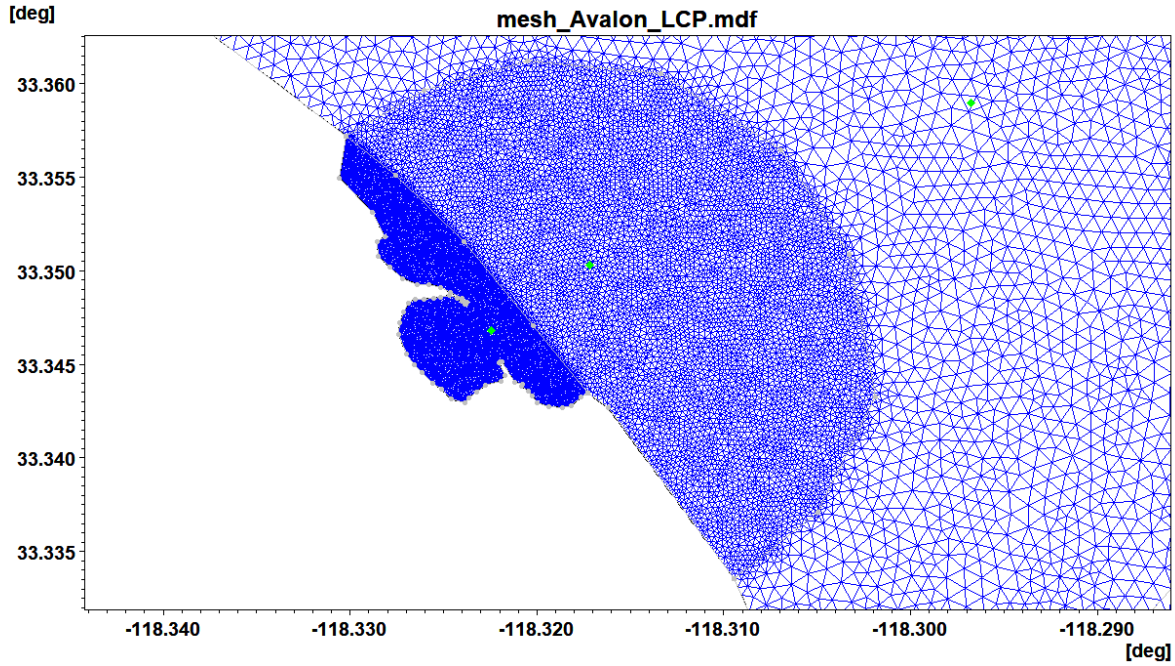

Figure 5-3: MIKE 21 spectral wave model grid used in vulnerability assessment wave modeling.

Modeled nearshore wave heights under representative extreme tropical swell conditions and wind conditions are shown in Figure 5-4 and Figure 5-5 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. This regional elevation model is based solely on the underlying topography and bathymetry within the City and does not include existing buildings. Due to the regional nature of the elevation model, assumptions regarding the specific height and flood protection capacity of narrow-footprint structures that extend above current topography are not immediately available, but the resolution appears sufficient to capture approximate elevations of existing seawalls, bulkheads, and revetments along the City shoreline. No changes to the elevation model were made to account for any potential future adaptation measures.

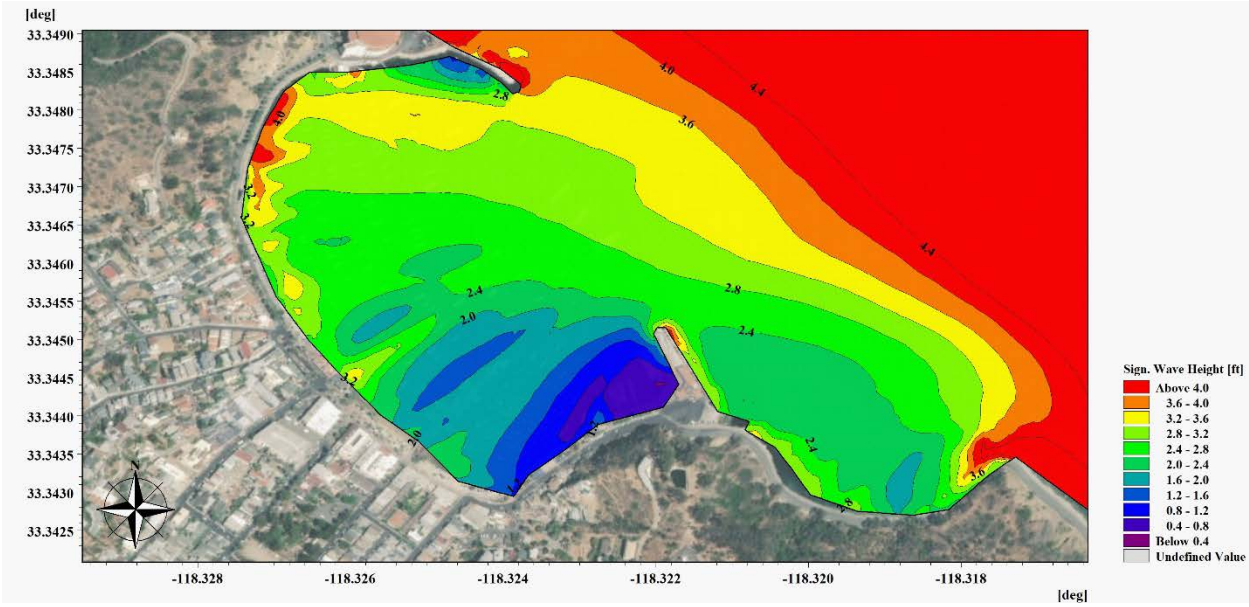

Figure 5-4: Nearshore wave heights associated with an extreme tropical swell event.

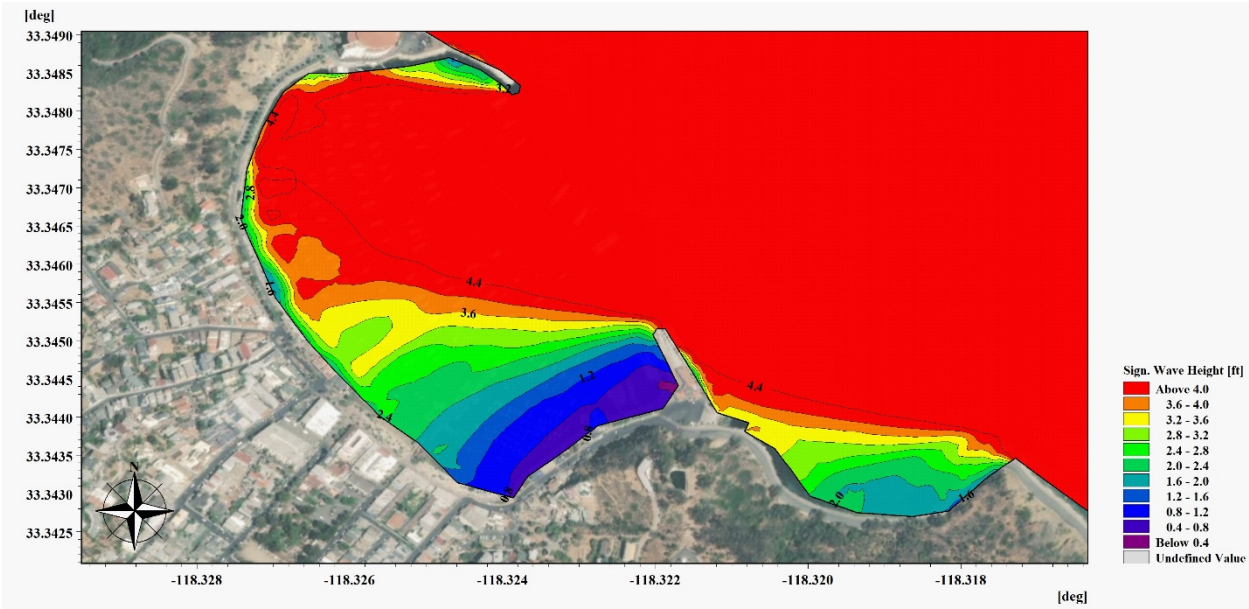

Figure 5-5: Nearshore wave heights associated with an extreme Santa Ana wind event.

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 5-6). 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.

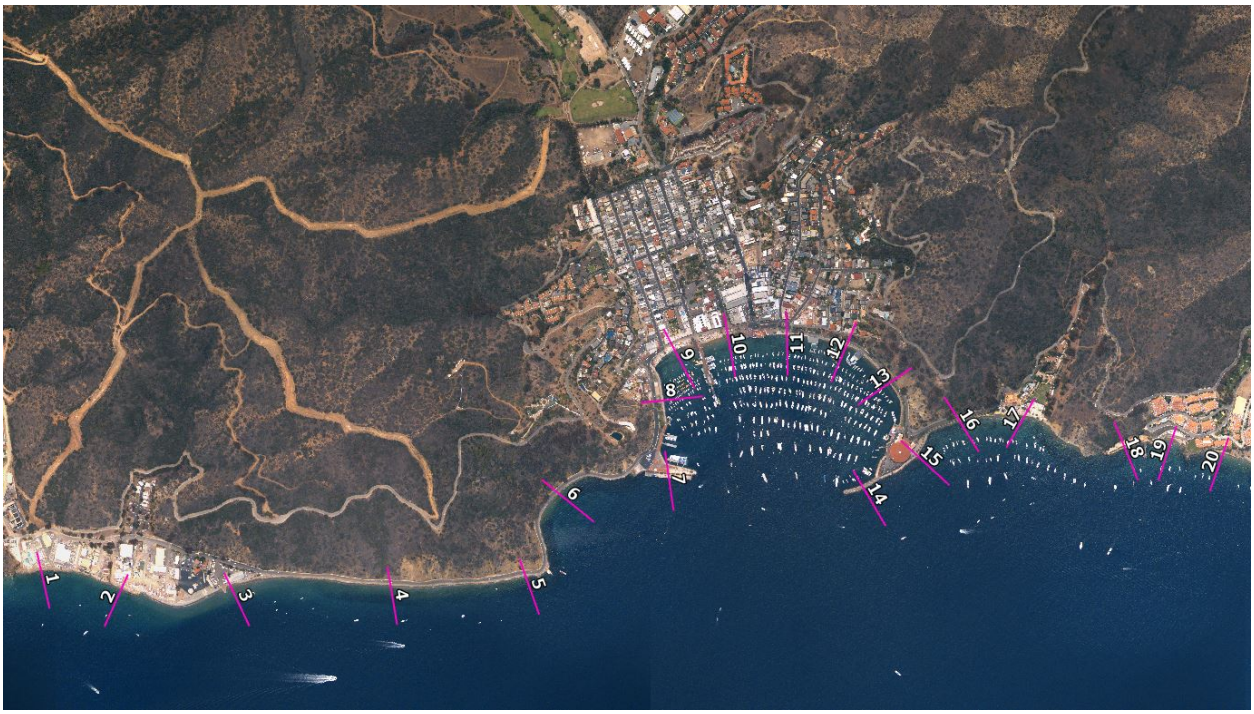

Figure 5-6: Transect locations used in wave runup and overtopping analyses.

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 Flood Hazard Overview

Under non-storm conditions, the City of Avalon is projected to experience minimal flood hazards with 0 ft of SLR. Flood projections remain minimal under 2 ft of SLR, although recreational beach area would be reduced in the low-lying areas of Descanso Bay, Avalon Bay, and Pebbly Beach Road. Shorelines are reduced further under 4 ft of SLR, potentially encroaching on coastal resources along the shoreline of Avalon Bay and the Pebbly Beach Road utilities area. Non-storm flooding becomes substantial under 6 ft of SLR, impacting a number of structures and footpaths in low-lying areas of Avalon Bay and intruding into the Pebbly Beach Road utilities area. Non-storm condition projections in 2100 under an H++ scenario significantly reshape the coastline of the City of Avalon, resulting in a substantial loss of land within the Pebbly Beach Road Industrial Area, Cabrillo Mole, Avalon Bay, and Casino Point. An overview on non-storm SLR flood hazards is presented in Figure 5-7.

Flood impacts occur at less extreme SLR scenarios under 100-year storm conditions. A 100-year storm event with 0 ft of SLR results in flood projections along select coastal roads, footpaths, and low-lying coastal areas primarily due to wave overtopping. In the 2-ft SLR scenario, flood projections increase noticeably along the low-lying Avalon Bay waterfront and Pebbly Beach Road utilities area. Flooding within Avalon Bay and the Pebbly Beach Road utilities area becomes extensive under the 4-ft SLR scenario, with Descanso Bay also showing substantial flood impacts. Flooding of coastal roads and footpaths also becomes widespread under this scenario. The 6-ft SLR scenario shows a substantial further increase in flooding within Avalon Bay, Descanso Bay, and the Pebbly

Beach Road utilities area, along with inundation in the areas surrounding the Catalina Island Casino. An overview of storm-related SLR flood hazards is presented in Figure 5-8.

5.6 Additional SLR Hazards

While flood hazards are the primary driver of coastal SLR vulnerability within the City of Avalon, additional hazards including erosion, shoreline migration, and changes in groundwater depth may also impact the City. Though this Assessment does not specifically quantify erosion or shoreline migration, these hazards can be approximated through non-storm flood hazards analyses that are based on changes in MHHW elevation. Erosion or shoreline migration beyond this extent is unlikely across the majority of the City shoreline due to the widespread presence of shoreline stabilization infrastructure. Assessment of potential vulnerability to changes in groundwater depth is hampered by the limited available data on shallow coastal aquifers within California. Initial studies have shown that impacts within southern California may not be significant due to the dry climate, whereas coastal plains along the northern California coast may be subject to more severe impacts due to the presence of shallow groundwater surfaces (Hoover, Odigie, Swarzenski, & Barnard, 2017). These hazards may be included in any updates to the Vulnerability Assessment as additional information becomes available.

Figure 5-7: Overview of SLR flood hazards within the City of Avalon under non-storm conditions including a H++ worst-case scenario.

Figure 5-8: Overview of SLR flood hazards within the City of Avalon under 100-year storm conditions.

6. Vulnerability Assessment

The vulnerability assessment provides a qualitative evaluation of coastal resources that could be impacted by the future hazards associated with the static and dynamic water levels described in Section 5. The purpose of this assessment is to identify what resources are vulnerable at each increment of SLR to inform planning efforts at the City.

A Geographic Information System (GIS) was used to compare hazard zones and coastal resources in the City. Methodology for assessing vulnerabilities and risk were based on the following guidelines:

- *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* published by ICLEI-Local Governments for Sustainability (Snover, A.K. et al, 2007).

- *California Adaptation Planning Guide, Planning for Adaptive Communities* prepared by CalEMA (now known as California Office of Emergency Services [CalOES]) and the California Natural Resources Agency (CalEMA, 2012).

The overall vulnerability was then assessed as a function of a resource's exposure, sensitivity, and adaptive capacity. These terms are defined as follows in the context of how they were used to develop this vulnerability assessment:

- **Exposure** is 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** is 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** is 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 as the sensitivity increases. Adaptive capacity is inversely related to vulnerability in that as the adaptive capacity increases, the vulnerability decreases. For example, Pebbly Beach Road has a high sensitivity because even minor damage from flooding or erosion can cause significant disruption in service. The roadway has a low adaptive capacity to SLR in that it cannot be easily relocated or raised to cope with consequences; thus, it would be classified as a highly vulnerable asset. The harbor moorings are highly exposed to coastal hazards but have a low sensitivity to SLR because they are easily adaptable to increasing water levels and will maintain their function even with a significant rise in sea level.

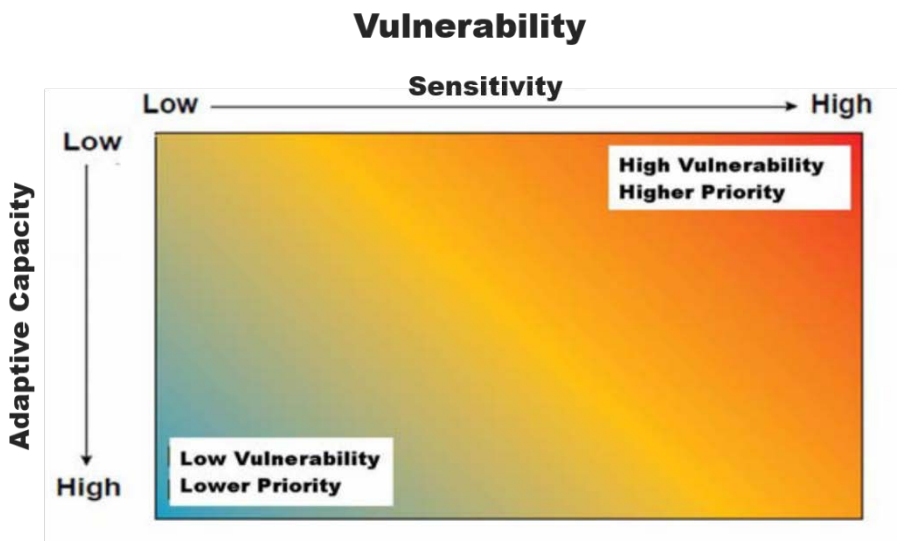

Figure 6-1: Relationship between sensitivity, adaptive capacity, and vulnerability (ICLEI, 2012)

6.1 Hamilton Cove

Exposure

Hamilton Cove has minimal hazard exposure under non-storm conditions for all SLR scenarios examined. The only appreciable impact of SLR under non-storm conditions is a loss of sandy beach area in the central portion of the region. Sandy beach area is limited under current conditions, and beach area is projected to be absent under high tide conditions with 2-ft SLR. Non-storm flood projections under 4-ft and 6-ft SLR scenarios extend further landward but do not surpass the current shoreline (Figure 6-2).

Minimal hazards are also projected under 100-year storm conditions for the 0-ft SLR scenario (Figure 6-3). A 2-ft SLR scenario combined with storm conditions shows potential flooding along select coastal paths and roads due to wave overtopping. Overtopping is projected to occur along the coastal road and pathways surrounding the central beach and coastal access areas. Additional overtopping of paths and roads along the coast are projected under the 4-ft SLR scenario, including the recreation area to the southeast of the pier structure. Flooded areas extend marginally further inland under the 6-ft SLR scenario largely due to the high relief of the coastline. While these flood extents are still confined to coastal paths and roads, flooding under the 6-ft SLR scenario is projected to fully cover sections of the primary coastal access road in the region.

Sensitivity

Hamilton Cove has a low overall sensitivity to SLR hazards. The resources subject to flooding are limited to coastal access roads and paths during an extreme event. Low-lying sandy beach areas will also experience impacts, but these areas are limited under current conditions and are unlikely to result in major loss of recreation value as areas decline with

SLR. Projected flooding under non-storm conditions is not likely to cause substantial damage to coastal roads and paved pathways, although erosion rates may increase along unprotected coastal bluffs. Under 100-year storm conditions, wave overtopping may cause periodic damage to limited stretches of coastal roads with 2 ft to 6ft SLR. Periodic damage to coastal access roads may result in locally impaired access but is unlikely to result in significant disruption.

Adaptive Capacity

Adaptive capacity within Hamilton Cove is generally high. Available land exists at higher elevations in the immediate vicinity of threatened coastal resources, enabling potential landward retreat of coastal pathways and roads over time as required to address SLR-driven coastal hazards. A lack of large structures within hazard exposure areas also makes hazard mitigation measures such as elevation of coastal resources more feasible.

6.2 Descanso Bay

Exposure

Coastal structures within Descanso Bay have limited hazard exposure under non-storm conditions, but sandy beach areas are projected to decline with SLR (Figure 6-2). The 2-ft, 4-ft, and 6-ft SLR scenarios each incrementally reduce sandy beach area. Projected high-tide conditions under the 2-ft SLR scenario will leave limited stretches of sandy beach below the coastal seawall, and the below-seawall beach is projected to become virtually absent under a high tide with 4-ft SLR. Under a 6-ft SLR scenario high-tide conditions are projected to extend above the small coastal seawall into the perched beach and recreational use area.

Descanso Bay is more exposed to coastal hazards under 100-year storm conditions due to the low-lying beachfront (Figure 6-3). Wave overtopping is projected to extend above the coastal seawall and into recreational use areas under all SLR scenarios examined. Flood projections under the 0-ft and 2-ft SLR scenarios extend a small distance beyond the seawall and do not reach any significant coastal structures. Storm flooding is projected to increase significantly under the 4-ft SLR scenario, covering the entirety of the sandy beach area above the seawall and impacting major coastal structures such as the Descanso Beach Club. Projected storm flooding extends further inland under the 6-ft SLR scenario, resulting in additional exposure to the Beach Club and surrounding structures.

Sensitivity

The moderate relief of Descanso Bay combined with the presence of a fairly wide sandy beach area reduces the sensitivity of the area to SLR. Under non-storm conditions SLR will lead to increased erosion and reduced sandy beach area, especially below the coastal seawall, but the majority of sandy beach area above the seawall is projected to remain under all SLR scenarios evaluated, providing opportunity for continued recreational use.

The lack of structures along the immediate shoreline also reduces the SLR hazard sensitivity of the area under non-storm conditions.

Structures exposed under the 4-ft and 6-ft storm conditions represent the most sensitive resources within Descanso Bay. Considerable structural damage is likely if storm flooding reaches major structures such as the Descanso Beach Club. The sensitivity of these structures is two-fold, given their value as coastal tourism and recreation attractions. The direct cost of damage from such an event could be significant. Also, a prolonged closure and recovery period could potentially result in significant economic losses in terms of visitation depending on how the timing of a flood event coincides with the tourism season.

Adaptive Capacity

Adaptive capacity is generally high for sandy beach areas within Descanso Bay, given the presence of available land at higher elevations. The unoccupied areas immediately landward of existing beaches provide opportunities to allow sandy areas to migrate landward as needed, while maintaining current levels of access and use. While beach areas have high adaptive capacity, the adaptive capacity of major coastal structures exposed to storm flooding under high SLR scenarios is limited. These structures will require more involved adaptation actions due to their size and location, likely requiring a significant investment.

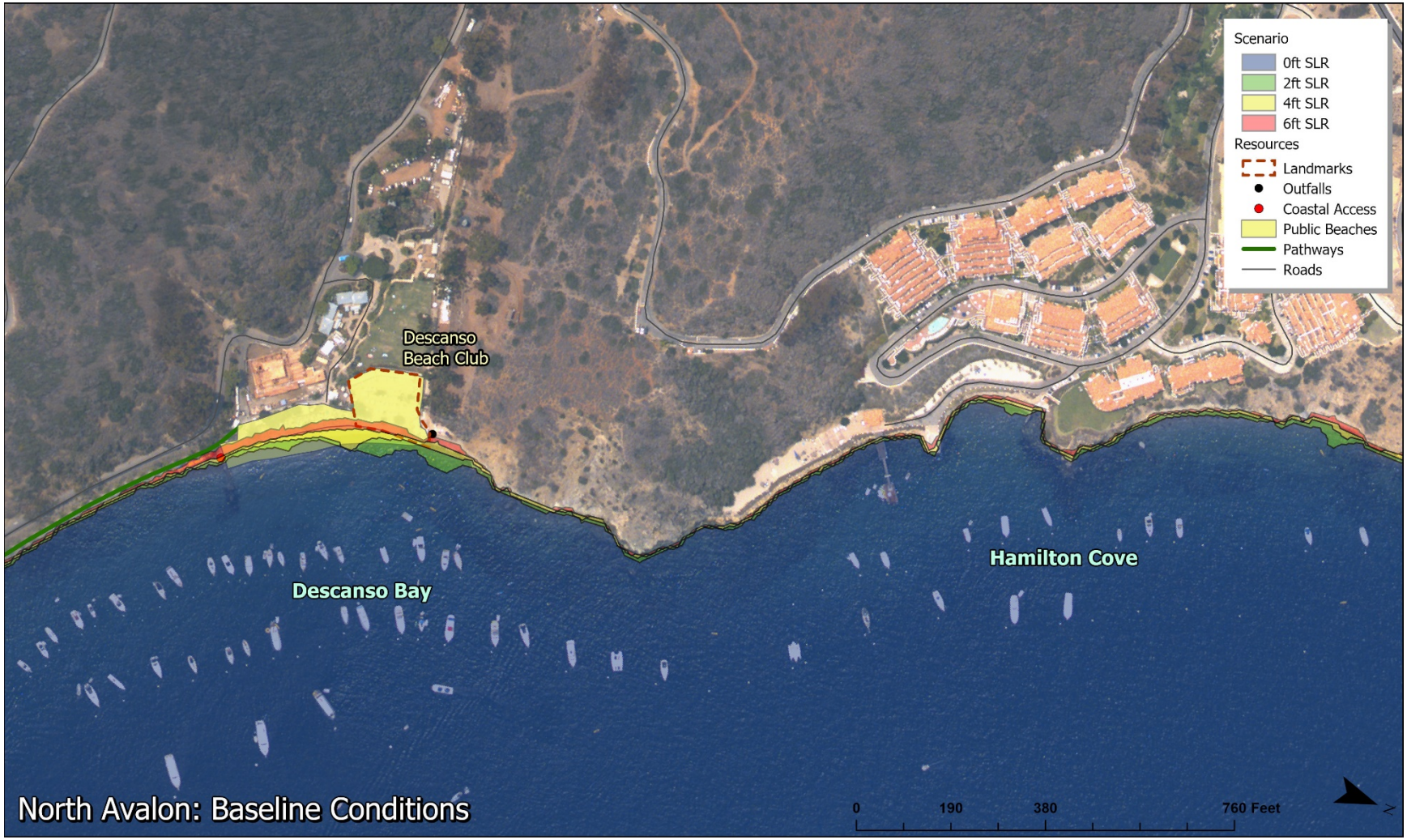

Figure 6-2: Flood hazards with SLR under non-storm conditions for Descanso Bay and Hamilton Cove.

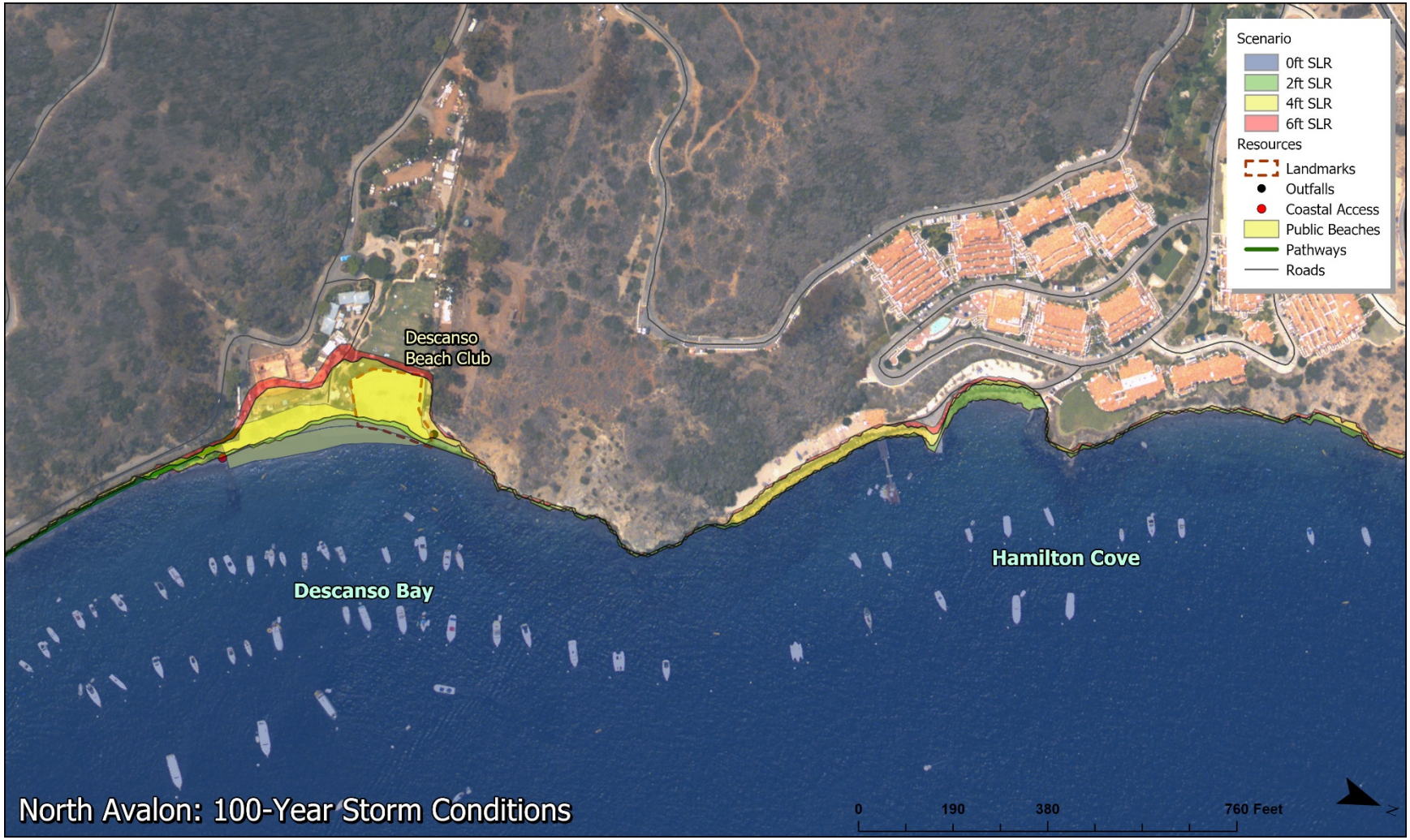

Figure 6-3: Flood hazards with SLR under 100-year storm conditions for Descanso Bay and Hamilton Cove.

6.3 Casino Point

Exposure

Non-storm flood projections show limited hazard exposure for the Catalina Island Casino under several SLR scenarios (Figure 6-4). Non-storm conditions for the 0-ft, 2-ft, and 4-ft SLR scenarios show no flooding that extends over the revetments and seawall structures surrounding Casino Point. Under the 6-ft SLR scenario tidal flooding increases along the southeastern shoreline of Casino Point, covering pedestrian pathways and extending into the Casino structure itself. The pile supported structures along the southeastern portion of the Point also become subject to tidal flood hazards under the 6-ft SLR scenario.

Under 100-year storm conditions flood projections show potential impacts along the northern shoreline of Casino Point (Figure 6-5). Wave overtopping during storm events can result in flooding within the Casino Point Dive Park under current conditions based on flood projections as well as local observations. Storm flood projections extend further inland under the 2-ft SLR scenario, potentially impacting the northwestern portion of the Casino and large portions of the Dive Park. Flood projections become extensive in the 4-ft SLR scenario along the northwestern and southeastern shorelines of Casino Point, including significant portions of the Catalina Island Casino, the majority of the Casino Point Dive Park, and the pile-supported structures along the southern portion of the Point. Severe flood hazard exposure is projected under the 6-ft SLR scenario. Under such conditions flood projections grow to encompass the entirety of the Dive Park and much of the Casino structure.

Sensitivity

The Catalina Island Casino has a high degree of sensitivity to SLR hazards, given the historic nature of the structure and its location on a narrow coastal point. Flood conditions such as those projected under 4-ft or 6-ft SLR combined with a 100-year storm event would likely result in significant structural damage, while non-storm 6-ft SLR conditions could lead to persistent flood damage along the southeastern portion of the structure. The pile-supported structures along the southern shoreline of the Point have a similar hazard sensitivity, as any flooding that extends above support structures is likely to result in extensive damage.

The Casino Point Dive Park is less sensitive to SLR hazards. Major structural damage to the paved park area and rocky shoreline is unlikely even when considering high SLR scenarios combined with 100-year storm conditions. Such conditions would limit use of the area, but dangerous dive conditions would already likely limit any demand for the park under storm conditions.

Adaptive Capacity

The adaptive Capacity of the Catalina Island Casino is limited due to the size of the structure and its location on a low-lying coastal point. Flood and wave protection

improvements or retrofits are potential adaptation options but there is little available land at higher elevations surrounding the structure. The lack of available area surrounding Casino Point and the coastal-dependent nature of the pile-supported structures and Dive Park also limits the adaptive capacity for these resources, though elevation or protection options remain feasible for the staging and access areas at the Dive Park.

6.4 Avalon Bay: Tidelands

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 6-4). 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 6-ft SLR, tidal inundation of pile-supported structures is projected and will likely require significant adaptation efforts to mitigate the potential for regular inundation.

Hazard exposure for tideland structures increases substantially under 100-year storm conditions (Figure 6-5). Wave overtopping along the shoreline of Avalon Bay is projected under current conditions. Storm flood projections under 2-ft SLR show potential flooding at the shoreline entryways of tideland structures, particularly those in the low-lying southeastern portion of the Bay. SLR hazard exposure increases substantially under 4-ft 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 6-ft 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 2-ft SLR scenario storm conditions are projected to result in severe structural damages based on wave action alone, and storm conditions under a 4-ft or 6-ft SLR scenario are projected to result in complete loss of these structures.

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 8-1. As such, these structures are likely to experience significant damage when water levels or wave heights approach first-floor elevations.

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.

6.5 Avalon Bay: Inland

Exposure

Commercial, recreational, and residential areas in the inland portion of Avalon Bay experience only a small degree of hazard exposure under non-storm conditions combined with 0 ft, 2 ft, and 4 ft of SLR (Figure 6-4). Tidal flood projections are limited to shoreline areas under these scenarios with no projected impacts to any major inland structures. SLR hazard exposure increases significantly under the non-storm condition 6-ft SLR scenario. With 6-ft SLR, tidal flooding is projected to extend inland in the southeastern portion of Avalon Bay between Sumner Avenue and Clarissa Avenue, inundating a number of structures extending back to 3rd Street.

While projected flood hazards within the normal tide range are limited under the 0-ft, 2-ft, and 4-ft SLR scenarios, it is important to note that tidal elevations seen during a King tide or other anomalous events may lead to further hazard exposure. As an example, tidal elevations, such as those illustrated in Figure 2-2, combined with 4-ft SLR would likely result in flooding along storefronts surrounding the Green Pleasure Pier. A similar tidal elevation combined with 2-ft SLR could result in overtopping at select portions of the seawall in Avalon Bay. Although modeling of these specific tidal scenarios is beyond the scope of this analysis, these potential risks should be considered as a part of future SLR adaptation planning efforts.

Inland structures within Avalon Bay are projected to experience hazard exposure under 100-year storm conditions for all SLR scenarios examined (Figure 6-5). Under 100-year storm conditions the 0-ft SLR scenario flood projection shows a small amount of wave overtopping along the shoreline in southeastern Avalon Bay, which has been observed during past storm events. Flood projections show more extensive shoreline flooding and wave overtopping under the 2-ft SLR scenario. Flood projections are generally limited to the immediate shoreline, save for the far southeastern portion of Avalon Bay where projections extend further along Clarissa Avenue. The 4-ft SLR scenario combined with 100-year storm conditions represents a critical impact threshold for a number of structures within Avalon Bay. Under these conditions, flood projections due to wave overtopping and storm surge extend inland across the southeastern half of Avalon Bay from Marilla Avenue to Pebbly Beach Road, reaching as far back as 500 ft from the shoreline. Flood projections under the 6-ft SLR scenario show additional hazard exposure for inland

structures, extending further inland primarily along Metropole, Sumner, and Clarissa Avenues.

Sensitivity

Structures in the inland portions of Avalon Bay have a high sensitivity to SLR hazards, particularly those structures with a first floor that sits at ground level. Storm flood impacts as projected under 4-ft and 6-ft SLR scenarios are likely to cause substantial damage to any inundated structures, potentially disrupting use of major coastal tourism and recreational resources for an extended amount of time as repairs are made. Tidal flood projections under a 6-ft SLR scenario are likely to frequently disrupt large areas of the Avalon waterfront, a hub for many visitors upon arrival. Inland open space commercial or recreational areas are less sensitive to SLR hazards unless inundation occurs on a regular basis.

Adaptive Capacity

The inland portion of Avalon Bay has a moderate capacity for adaptation. Multiple strategies may be feasibly employed to reduce SLR hazards in the area. Traditional flood hazard mitigation measures such as structure elevation, flood protection, or floodproofing remain options in the short to medium-term. When considering long-term adaptation, the presence of open space within landward areas situated at higher elevations provides additional options for accommodating hazards under severe SLR scenarios of 4 ft and 6 ft.

Figure 6-4: Flood hazards with SLR under non-storm conditions for Avalon Bay and Lover's Cove.

Figure 6-5: Flood hazards with SLR under 100-year storm conditions for Avalon Bay and Lover's Cove.

6.6 Cabrillo Mole

Exposure

Non-storm tidal flood projections for the Cabrillo Mole indicate a low hazard exposure for the 0-ft, 2-ft, and 4-ft 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 4 to 5 ft of freeboard below the deck elevation during a spring tide plus 4 ft of SLR. However, under a 6-ft SLR scenario the freeboard of 2 ft to 3 ft 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 6-6 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. However, the loss of potential visitors and disruption in access to the City result in adverse economic consequences.

Each increment of SLR evaluated would increase the frequency and magnitude of these events. A 100-year wave event combined with 2 ft 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 14.3 ft NAVD under a 2-ft 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 16.3 ft and 18.3 ft under the 4-ft and 6-ft 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, 4 ft to 6 ft 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 service life.

Sensitivity

The Cabrillo Mole structure itself has low sensitivity to hazards for SLR scenarios of less than 2 ft. 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 4 ft and 6 ft 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 throughout Avalon, in addition to Catalina Express.

Adaptive Capacity

The Cabrillo Mole has a moderate adaptive capacity due to its original design as a storm protection structure and ability to accommodate 2 ft 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 4 ft to 6 ft of SLR.

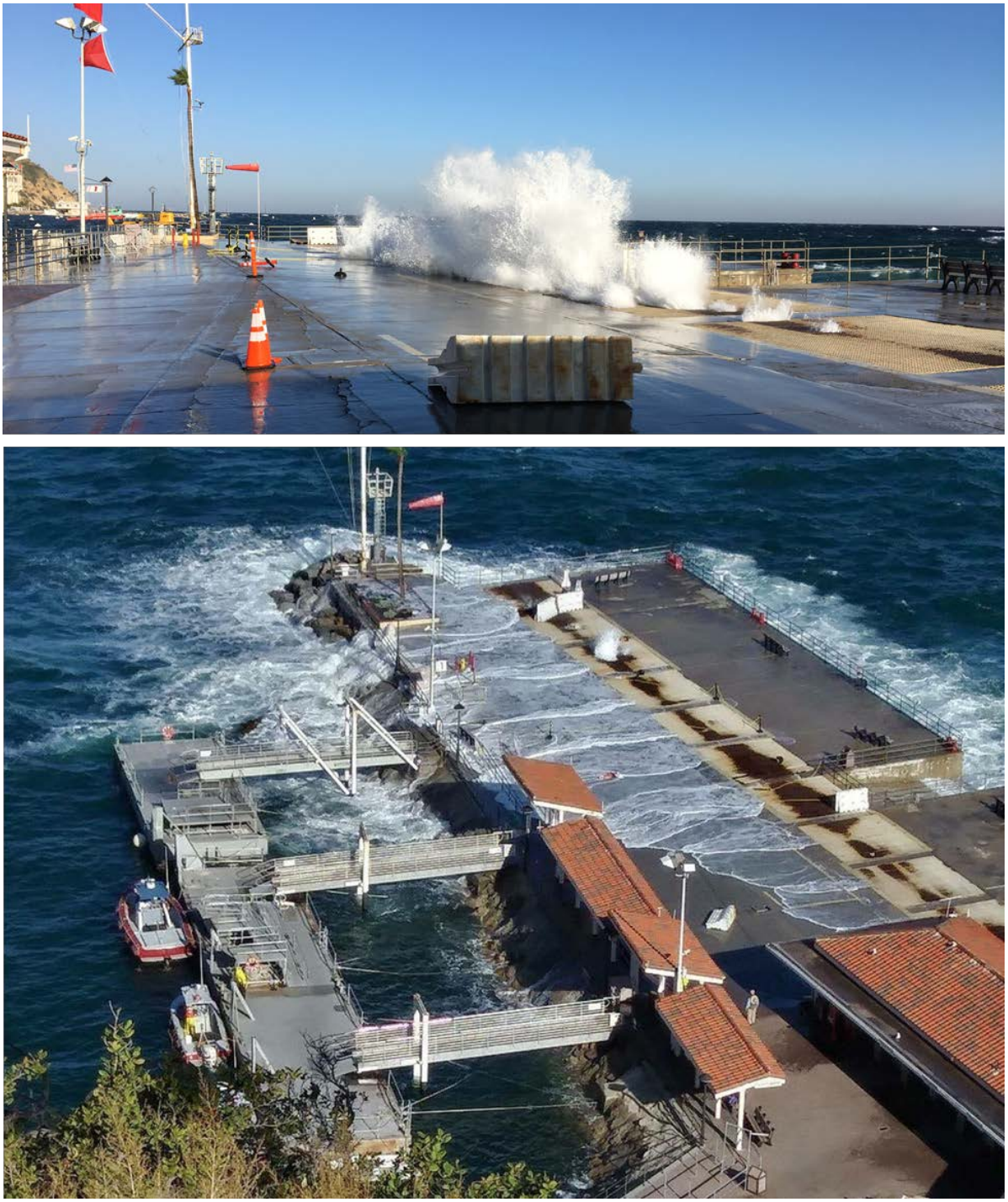

Figure 6-6: Cabrillo Mole flooding due to wave uprush and overtopping, December 5, 2017

6.7 Mooring and Boating Infrastructure

Exposure

All mooring and boating infrastructure located throughout Avalon Bay, Descanso Bay and Hamilton Cove are 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.

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.

Adaptive Capacity

Some adaptive capacity is built into the mooring and boating infrastructure which may be sufficient to accommodate lower amounts of SLR (< 2 ft). 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 4 ft to 6 ft would also require modification to access points and gangways, which may need to be elevated to maintain accessibility under higher water level conditions.

6.8 Pebbly Beach Road Industrial Area

Exposure

Flood projections for the low-lying industrial area at the southeastern portion of Pebbly Beach Road show minimal hazard exposure under non-storm conditions for the 0ft SLR scenario (Figure 6-7). Flood projections under the 2-ft SLR scenario show potential for a small amount of tidal flooding along the northwestern shoreline of the area. Non-storm flood projections extend further inland under the 4-ft SLR scenario, approaching several structures along the northwestern shoreline of the area which include the Avalon Freight Services facility. Flood projections under the 6-ft SLR scenario are projected to overtop low-lying stretches of shoreline within the industrial area, resulting in tidal flooding of a number of structures further inland including the boatyard.

100-year storm flood projections for the Pebbly Beach Road utilities area show some degree of hazard exposure for all SLR scenarios examined (Figure 6-8). Flooding due to wave overtopping is projected along the shoreline of the western portion of the area under 0-ft SLR, consistent with past observations of storm impacts. Storm flood projections extend further inland under the 2-ft SLR scenario, reaching several structures in low-lying portions of the boatyard and freight delivery area. Flood projections become extensive in the 4-ft SLR scenario, covering a significant portion of the northwestern half of the utilities area. Storm flood projections again increase significantly under the 6-ft SLR scenario. Under these conditions the entirety of the northwestern half of the utilities area is projected to become inundated during major storm events.

Sensitivity

The Pebbly Beach Road industrial area has a high overall sensitivity to SLR hazards. SLR hazard sensitivity within the Pebbly Beach Road industrial area is two-fold. Extensive structural damage is likely for any areas inundated under storm flood conditions for each SLR scenario. In addition to any structural damage caused by tidal or storm related flooding, SLR hazards are also likely to disrupt the delivery of critical services until flood conditions subside or necessary repairs can be made. This is especially true for those structures along the immediate shoreline that are projected to become subject to frequent tidal flooding and damage during extreme events, such as the Avalon Freight Services facility. Given this dual nature of hazard sensitivity and past impact history, the area is highly sensitive to flood events as predicted under 2 ft, 4 ft, and 6 ft SLR scenarios. Under the H++ SLR scenario, recommended by state guidance for use when dealing with critical infrastructure, 2 ft, 4 ft, and 6 ft of SLR could occur by 2050, 2070, and 2080 respectively, discussed further in Section 4.3.

Adaptive Capacity

The adaptive capacity of the Pebbly Beach Road industrial area is limited due to the lack of accessible land at higher elevation in the surrounding areas. Many services in the area also rely on proximity to a low-lying coastline to allow for freight delivery by water. Almost the entire shoreline of the industrial area is protected by some form of engineered or non-engineered rock revetment. The adaptive capacity of these resources is dependent on the ability of these structures to retain the land behind them and dissipate wave energy during extreme events. Potential adaptation strategies within the area will likely require some form of shoreline protection, flood proofing or structural accommodation measures to prevent damage and loss of services under projected flood conditions associated with SLR scenarios above 2 ft. There may also be some potential for on-site relocation to move sensitive facilities or operations further away from future wave hazard zones.

Figure 6-7: Flood hazards with SLR under non-storm conditions for the Pebbly Beach Road Industrial Area.

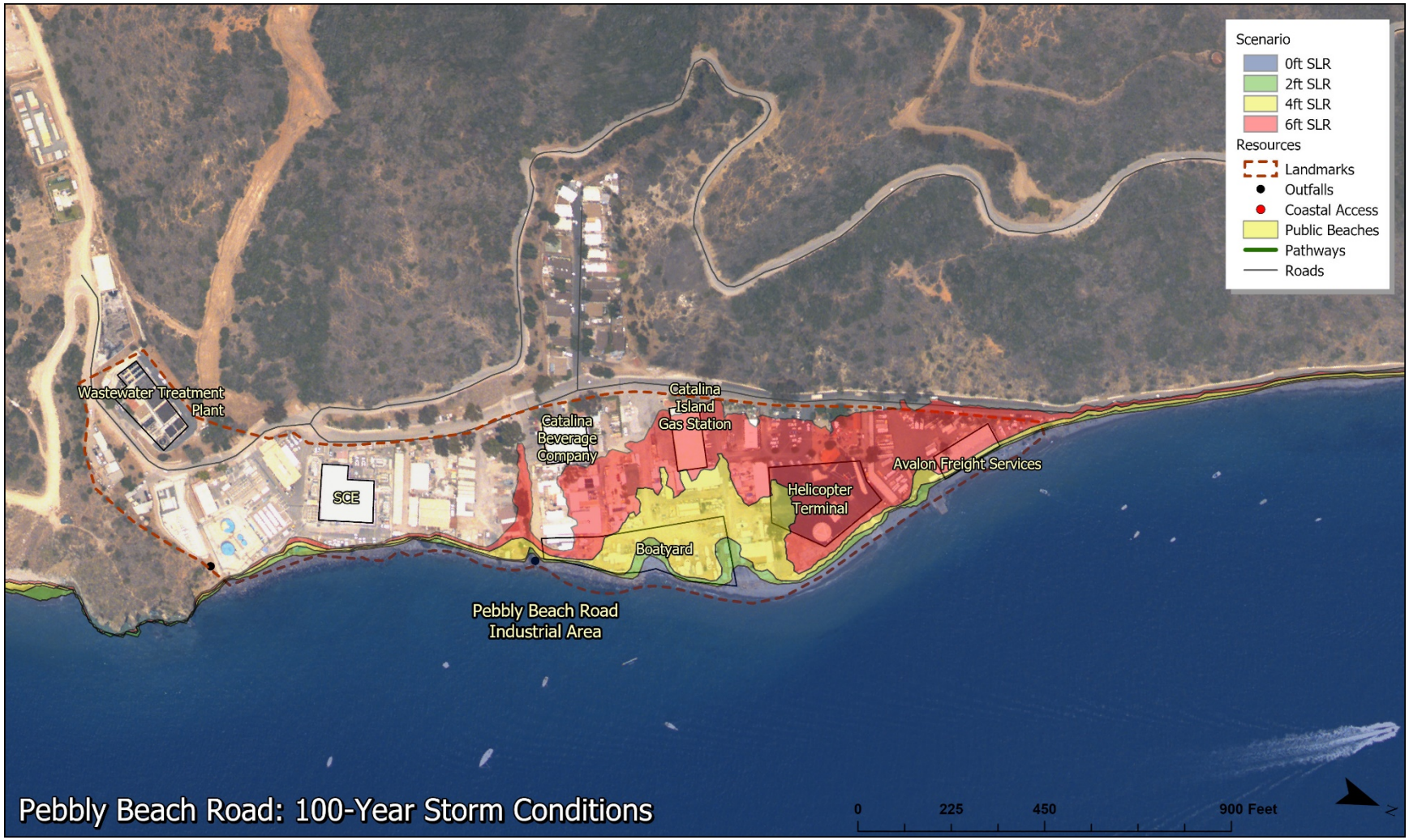

Figure 6-8: Flood hazards with SLR under 100-year storm conditions for the Pebbly Beach Road Industrial Area.

6.9 Transportation and Utilities

Exposure

Non-storm condition flood projections show minimal hazard exposure for transportation infrastructure under the 0-ft and 2-ft SLR scenarios. Flood projections under the 4-ft SLR scenario show potential tidal flooding along low-lying pathways in the southeastern portion of Avalon Bay, also resulting in tidal inundation of outfalls in the area (Figure 6-4). As is the case with other coastal resources, the 6-ft SLR scenario represents a critical SLR hazard exposure threshold under non-storm conditions for transportation infrastructure. Tidal flood projections under this scenario show extensive flooding along roads and paths of southeastern Avalon Bay, covering a large portion of the visitor arrival area between the Cabrillo Mole and Summer Avenue. High-tide elevations with 6-ft SLR will also increase the frequency and duration of outfall inundation along the shoreline.

Flood projections show greater hazard exposure for transportation infrastructure under 100-year storm conditions. Flooding due to wave overtopping is projected along Pebbly Beach Road in the 0ft SLR scenario (Figure 6-8). Erosion along Pebbly Beach Road is also a concern during a strong storm event, due to the history of rock slope protection failures along this stretch of road (Figure 6-9). Flood projections along Pebbly Beach Road increase under the 2-ft SLR scenario. Storm flood projections with 2-ft SLR also show flooding along low-lying coastal paths and roads in Avalon Bay, particularly in the vicinity of the Green Pleasure Pier and along Clarissa Avenue.

Figure 6-9: Erosion damage to Pebbly Beach Road, February 1988.

Flood projections from an extreme storm become extensive under the 4-ft SLR scenario, inundating Pebbly Beach Road, roadways from the Cabrillo Mole to Marilla Avenue, and

the majority of coastal pedestrian pathways within the city. Flood projections under the 6-ft SLR scenario show significant flooding along Pebbly Beach Road through Casino Way, with flood extents pushing further inland between Metropole Avenue and Clarissa Avenue. The 6-ft SLR scenario flood projections also show flooding across all coastal pedestrian pathways, save for those in the immediate vicinity of the Cabrillo Mole and the Catalina Island Casino. Exposure for individual transportation assets under each SLR scenario is summarized in Table 6-1, where "Minor", "Moderate", and "Severe" represent qualitative evaluations of the length of each asset subject to flooding.

Table 6-1: Projected flood hazard exposure for transportation assets under each SLR scenario.

Asset	SLR Scenario							
	Non-storm				Storm			
	0 ft	2 ft	4 ft	6 ft	0 ft	2 ft	4 ft	6 ft
Pebbly Beach Road	NA	NA	NA	Moderate	Minor	Moderate	Severe	Severe
Casino Way	NA	NA	NA	NA	NA	NA	Minor	Moderate
Clarissa Avenue	NA	NA	NA	Moderate	NA	Moderate	Severe	Severe
Metropole Avenue	NA	NA	NA	Moderate	NA	NA	Severe	Severe
Coastal Pathways	NA	NA	Minor	Severe	Minor	Moderate	Severe	Severe

Sensitivity

Transportation infrastructure has a low sensitivity to shallow and short duration flooding, as minor flooding is unlikely to result in significant damage. However, as flooding becomes more severe, as predicted for each SLR scenario, transportation infrastructure becomes more sensitive to these hazards with longer interruptions and more extensive damage expected to roads and pathways. This infrastructure is also sensitive to erosion and undermining, which can result in prolonged closures, safety concerns, and costly repairs.

The service provided by transportation infrastructure is more sensitive to SLR hazards. Minor flooding along coastal roads or pathways has the potential to severely disrupt transportation patterns within the City, given the reliance on pedestrian pathways and alternative modes of transportation such as golf carts. Widespread flooding, traffic

congestion from road closures or damage to key roads may also impact emergency response times. Due to these factors, coastal transportation is especially sensitive to tidal flooding, which is likely to result in frequent disruptions in use even if roads or pathways themselves experience minimal damage.

The normal operation of stormwater infrastructure can be affected if water levels rise to the point where backwater effects occur. A backwater effect occurs when a channel restriction or obstruction at the downstream end raises the surface of the water upstream from it, potentially leading to flooding. Tidal elevation projections under a 4-ft and 6-ft SLR scenarios may have some effect on stormwater operations if outfall locations become inundated for extended periods of time, but the potential for backwater effects is limited to events where a significant rainfall coincides with a high tide.

Adaptive Capacity

Coastal transportation infrastructure within Avalon has a moderate adaptive capacity. Strategies such as elevation are generally more feasible for roads and pedestrian pathways as compared to residential or commercial structures, but the location of most coastal roads and pathways is largely inflexible due to steep relief landward and the need to connect multiple water-dependent services within the City. The adaptive capacity of these coastal transportation corridors is also dependent on the ability of the existing shore protection structures to retain the land behind them and dissipate wave energy during extreme events. Given these factors, adaptation strategies will likely require measures to maintain the existing shoreline protection, accommodate extreme storm flood impacts and limit potential for more frequent tidal inundation events as SLR increases. Adaptation of stormwater infrastructure is complicated by the need to maintain function of the network as a whole, likely requiring additional hydraulic studies if significant changes are made. Opportunities exist to coordinate elevation of outfalls with any future improvements to or elevation of shoreline infrastructure if necessary.

6.10 Public Access

Exposure

Tidal flood projections under the 2-ft 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 4-ft SLR, disrupting coastal access in these regions (Figure 6-4). Non-storm flood projections also show impacts to coastal access points within Lover’s Cove and the Cabrillo Mole boat ramp under a 4-ft SLR scenario. All public beaches and coastal access points within Avalon Bay are projected to become submerged with 6-ft 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 0-ft SLR, along with coastal access points within Avalon Bay (Figure 6-5). Minimal beach area is projected to remain within Avalon Bay under a 2-ft 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 4-ft SLR scenario, with more severe inundation projected under a 6-ft SLR scenario.

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.

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 4 ft to 6 ft. 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 4 ft to 6 ft SLR scenario.

6.11 Ecological

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 shifts in water temperature, salinity, dissolved oxygen, and pH 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.

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.

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. 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.

Pollution burden within each census tract is characterized by CalEnviroscreen 3.0 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, with percentile ranks again ranging from 0 to 1. Specific variables included in pollution burden scoring and each SOVI theme are detailed below. As the City is defined by a single census tract, discussions of social and environmental burdens are presented on a City-wide basis due to data availability. Percentile rankings for each social and environmental theme are presented in Figure 7-1.

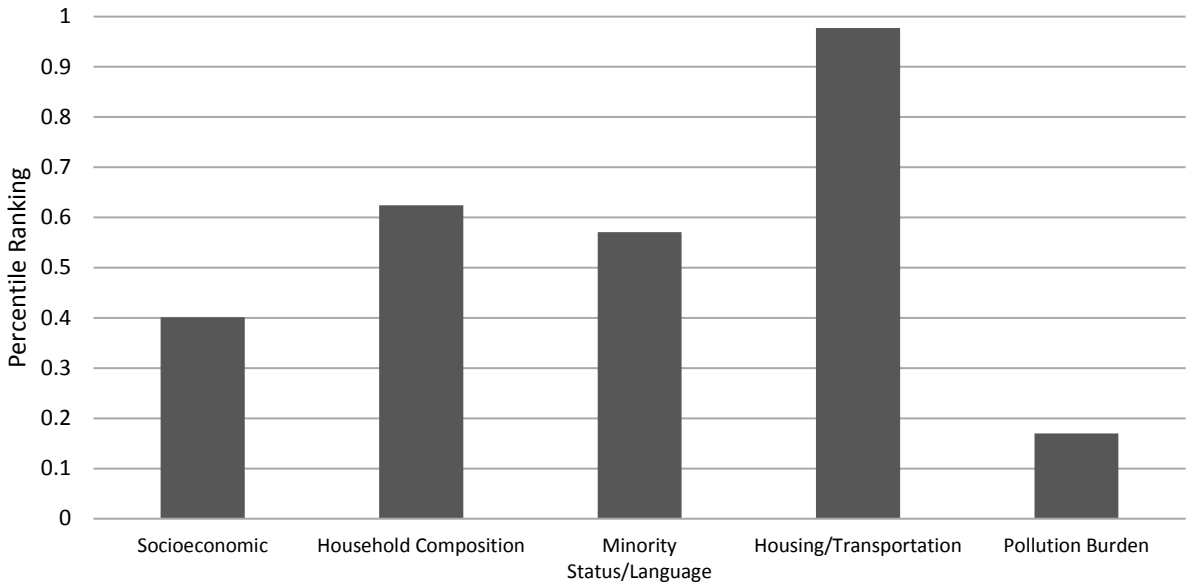

Figure 7-1: Social and environmental vulnerability metrics for Avalon.

7.1 Social Vulnerability

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. The City has a low to moderate vulnerability based on these factors, the most significant being the high school diploma indicator where a percentile rank of 0.64 is shown in SOVI analyses.

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. SOVI analyses show a moderate to high vulnerability within the City based on these factors, with indicators relating to single parent households and persons under the age of 17 ranked within the top 15% of census tracts within the state.

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”. The City shows moderate to high vulnerability based on these factors, balanced across each indicator.

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. The City ranks among the highest census tracts in the state based on these factors, primarily due to the unique transportation situation where cars are uncommon as well as indicators related to crowding. As discussed in Section 6.9, the reliance on pedestrian pathways and use of alternative vehicles for both residents and tourists has the potential to exacerbate any SLR-related impacts to transportation infrastructure, resulting in a loss of access to a number of coastal resources within the City.

7.2 Environmental Pollution Burden

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. EnviroScreen data shows a low pollution burden for the City under current conditions, ranked among the lowest 20% of census tracts evaluated, indicating that existing pollution burdens are unlikely to compound any impacts from SLR.

8. 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. Given that the City's tourism-dependent economy is focused on activities on or near the water, it is expected that adverse impacts to the visitor experience, or a reduction in visitor capacity due to SLR impacts could translate to significant direct and in-direct financial impacts.

SLR is expected to increase the potential for damage to natural and built 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 a 100-year coastal storm event in combination with each SLR scenario. The potential non-market impacts of SLR on beach recreation value and ecosystem services was also evaluated. However, a comprehensive economic analysis of all indirect impacts on the local economy due to SLR and associated impacts was beyond the scope of this study.

8.1 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 and Fuel Dock 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 8-1) indicate that the potential for damage increases significantly as the wave crest elevation approaches the finished floor elevation (FFE) of a given structure.

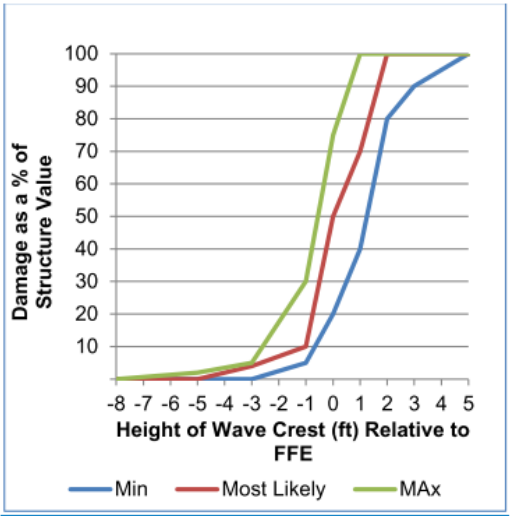

Figure 111. Prototype 7A: Building on Open Pile Foundation, Wave Damage - Structure

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 8-1: NACCS prototype 7A depth damage relationships.

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 8-1. 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 8-1: Damage potential based on building characteristics, adapted from NACCS results (USACE, 2015).

Building Characteristic	Damage Potential		
	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

Catalina Island Yacht Club

The Catalina Island Yacht Club is a pile-supported structure in the northwestern 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 2-ft 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 8-2). Potential damages increase further under the 4-ft SLR scenario, likely resulting in a complete loss of the structure due to wave damage during an extreme event.

Table 8-2: 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

Tuna Club

The Tuna Club is another timber pile-supported structure in the northwestern 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 8-3. 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 2-ft 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 4 ft to 6 ft of SLR.

Table 8-3: 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
6	95	100	100

Green Pleasure Pier

The Green Pleasure Pier is a pile-supported structure located in the southeastern 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. Due to these two factors, the pier is projected to experience less structural damage than other tideland structures under the 2-ft SLR scenario. 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 8-4. A 100-year storm under the 4-ft SLR scenario is a critical threshold with estimated damage approaching 50% of the value of the structure. 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 8-4: 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

8.2 Land Parcel Impacts

Economic impacts to inland structures are also estimated using NACCS depth-damage relationships. For the purposes of this analysis, damage estimates throughout the City are based on USACE Prototype 5A: Single Story Residence, No Basement. Damage estimates are based on inundation damage relationships using flood depths from both non-storm condition and 100-year storm SLR analysis for each parcel affected (Figure 8-2). These estimates are not intended to be exact measurements of structural damage to structures within the city but are instead meant to provide information on the relative scale of potential SLR damage in inland areas to inform adaptation planning initiatives.

Parcel data was obtained from the Los Angeles County GIS Data Portal. Parcel boundaries, land value, and improvement value are based on data from the Office of the Assessor Tax Roll, which maintains assessment records of real and personal property in the County of Los Angeles. These parcels are intended for tax assessment purposes only and are not guaranteed to be survey grade. The assessed value of property may also differ from current market value due to factors such as California Proposition 13, which limits any increase in value to two percent a year. Despite these potential limitations,

assessment records are reliable for the scope and purpose of this analysis. Results of this analysis are presented in Table 8-5 and Table 8-6.

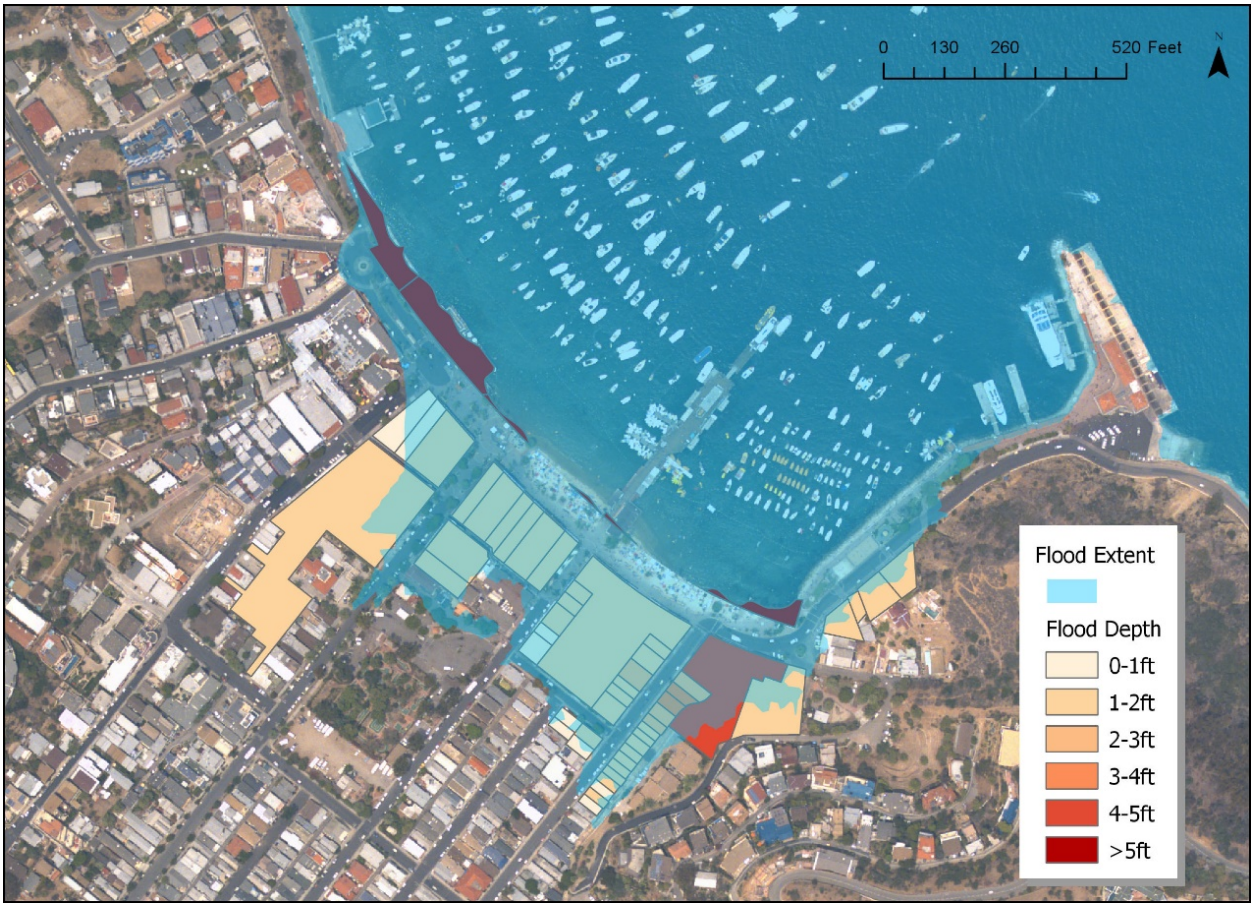

Figure 8-2: Example of 4-ft SLR storm flood depths within parcels used in damage analyses.

Inland 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 0-ft and 2-ft SLR scenarios. While the 4-ft scenario shows potential damages due to tidal inundation, these impacts remain limited in scope and could likely be reduced or avoided through strategic flood hazard mitigation initiatives. It is the 6-ft SLR scenario where tidal flooding becomes widespread, affecting over 50 parcels and potentially resulting in over $10 million in damages when considering both land and structural value.

Damage thresholds are also apparent for 100-year storm conditions. Structural damage is projected under both the 0-ft and 2-ft SLR scenarios, with likely damages potentially exceeding $1 million under the 2-ft scenario. The 4-ft SLR scenario represents a significant damage threshold for 100-year storm conditions as the number of parcels impacted rises from 11 to 58. Under such a scenario, the minimum projected damage to

structures alone is in excess of $3 million, and the total value of damages is likely to exceed $10 million. Projected damages again increase substantially under the 6-ft SLR scenario with 100-plus parcels impacted. Minimum projected structural damages in this scenario approach twice that of the 4-ft scenario at $5.9 million, and total damages are likely to exceed $20 million.

Table 8-5: Financial impacts of SLR hazards in inland areas under non-storm conditions. Total value refers to combined land and improvement value.

SLR (ft)	Conditions	Parcels Impacted			Damages to Improvements			Damages to Total Value		
		Number	Improvement Value	Total Value	Minimum	Likely	Maximum	Minimum	Likely	Maximum
0	MHHW	0	-	-	-	-	-	-	-	-
2	MHHW	0	-	-	-	-	-	-	-	-
4	MHHW	6	1,529,400	1,747,300	382,400	565,900	795,300	436,800	646,500	908,600
6	MHHW	52	18,791,000	40,113,400	2,874,100	4,469,400	7,400,600	4,786,800	7,859,835	13,262,000

Table 8-6: Financial impacts of SLR hazards in inland areas under storm conditions. Total value refers to combined land and improvement value.

SLR (ft)	Conditions	Parcels Impacted			Damages to Improvements			Damages to Total Value		
		Number	Improvement Value	Total Value	Minimum	Likely	Maximum	Minimum	Likely	Maximum
0	100-year	5	1,529,400	1,747,300	305,900	504,700	688,200	349,500	576,600	786,300
2	100-year	11	3,558,400	6,991,300	503,000	735,000	1,202,000	663,000	1,003,100	1,727,500
4	100-year	58	20,503,100	45,399,200	3,012,400	5,020,600	7,896,600	6,034,700	10,299,400	16,165,300
6	100-year	112	36,353,500	75,097,600	5,940,800	9,267,000	13,977,400	13,690,100	21,341,600	31,372,800

8.3 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. Any loss of open space along the coastline is also a concern due to the relatively low amount of existing open space within City limits, which currently stands at approximately 1.6 acres per 1,000 residents.

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 8-7).

Table 8-7: 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 Vulnerability Assessment, estimates of beach loss can be made from changes in MHHW elevations, presented in Table 8-8.

Table 8-8: 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. This figure is used within this analysis as a rough estimate of annual visitation for the City. 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 8-8 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 8-9.

Table 8-9: 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

9. SLR Adaptation Strategies

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

9.1 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 9-1). In an SLR adaptation context protection refers to those strategies that employ an engineered structure or other measure 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 developments 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.

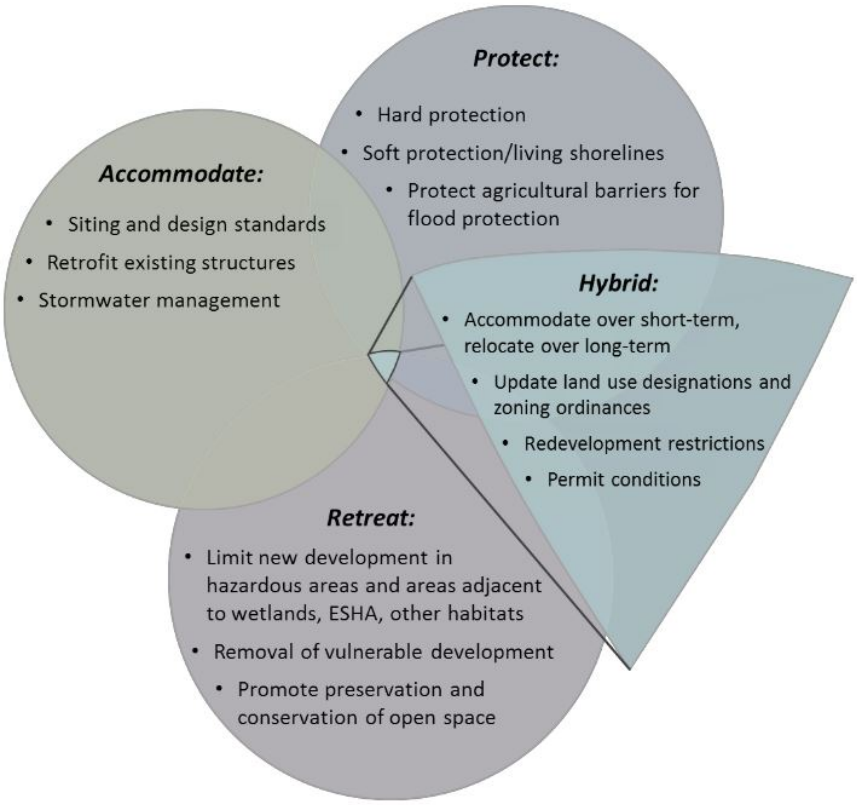

Figure 9-1: General SLR adaptation strategies and mechanisms (California Coastal Commission, 2018a).

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 Avalon. 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 effectiveness changes.

9.1.1 Protection

Shoreline protection has been a key coastal hazard adaptation strategy for the City of Avalon throughout its history. As detailed in Section 1.2, the majority of Avalon's shoreline currently has some form of engineered or non-engineered protective device in place, such as rock revetments within the Pebbly Beach Road industrial area or seawalls along Avalon Bay. Cross-channel travel is also largely dependent on the protective functions provided by the Cabrillo Mole during vessel loading and unloading. Due to the widespread presence and long history of shoreline protection structures within the City of Avalon, the continued maintenance and improvement of shoreline infrastructure will be an important component of near-term SLR adaptation efforts.

Protection strategies provide a means to minimize projected damage and disruption from coastal erosion, higher water levels, and wave events associated with low to moderate SLR scenarios. Protection strategies are most effective at mitigating periodic hazards due to wave overtopping associated with storm events. Frequent tidal flooding associated with high to extreme SLR scenarios (6 ft of SLR or higher) is likely to overwhelm any feasible protective measure along low-lying portions of the Avalon shoreline, especially in cases where future non-storm water levels are projected to exceed current shoreline elevations. Given these limitations, protective structures alone are unlikely to form an effective long-term adaptation strategy for highly vulnerable areas if SLR reaches the upper bounds of current projections, but protection strategies can 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 Avalon is the ability to utilize and enhance existing infrastructure as opposed to constructing new shoreline protection structures. Both hard and soft shoreline protection measures can be employed to enhance and maintain existing shoreline infrastructure within the City of Avalon. Hard measures include traditional engineered structures such as seawalls, revetments, and bulkheads, while soft armoring involves the use of nature-based infrastructure such as beaches, reefs, or dune systems to reduce SLR hazards in coastal areas. Additional hard protection measures within Avalon can be used in high-risk areas where existing structures experience storm damage or significant overtopping under current conditions, such as the Pebbly Beach Road area and the low-lying portions of southeast Avalon Bay. Protection measures that provide benefits to ecosystems can also be employed. One such method would be to integrate materials such as ECOncrete® into existing or enhanced revetment structures that are designed to increase local biodiversity and biological productivity. Similar materials could also be used to create artificial reefs to provide wave protection and additional hard-bottom habitat along the coastline and within harbors (Figure 9-2).

A key drawback of shoreline protection strategies is the potential disruption of natural littoral processes. The fixed barrier created by hard shoreline structures prevents the inland migration of natural beaches and habitats over time as SLR increases. This phenomenon can already be seen along the seawall within Avalon Bay, where sandy beach areas have been diminished over time due to higher water levels and increased erosion caused by the reflection of wave energy. If these coastal resources are unable to move inland, public beach recreational areas will likely be limited to sandy areas perched atop seawalls similar to those currently present in Avalon Bay and Descanso Bay, provided that existing perched beaches could be maintained or expanded as necessary to meet recreational demand. Extreme protection measures extending significantly above the current shoreline could become impediments to access and result in negative visual impacts along the waterfront.

Figure 9-2: Examples of hard-bottom, nearshore habitat created with ECOncrete® (econcretetech.com).

9.1.2 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 help mitigate vulnerabilities across low, moderate, and severe SLR scenarios.

Coastal resources and structures can accommodate SLR 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 9-3). 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.

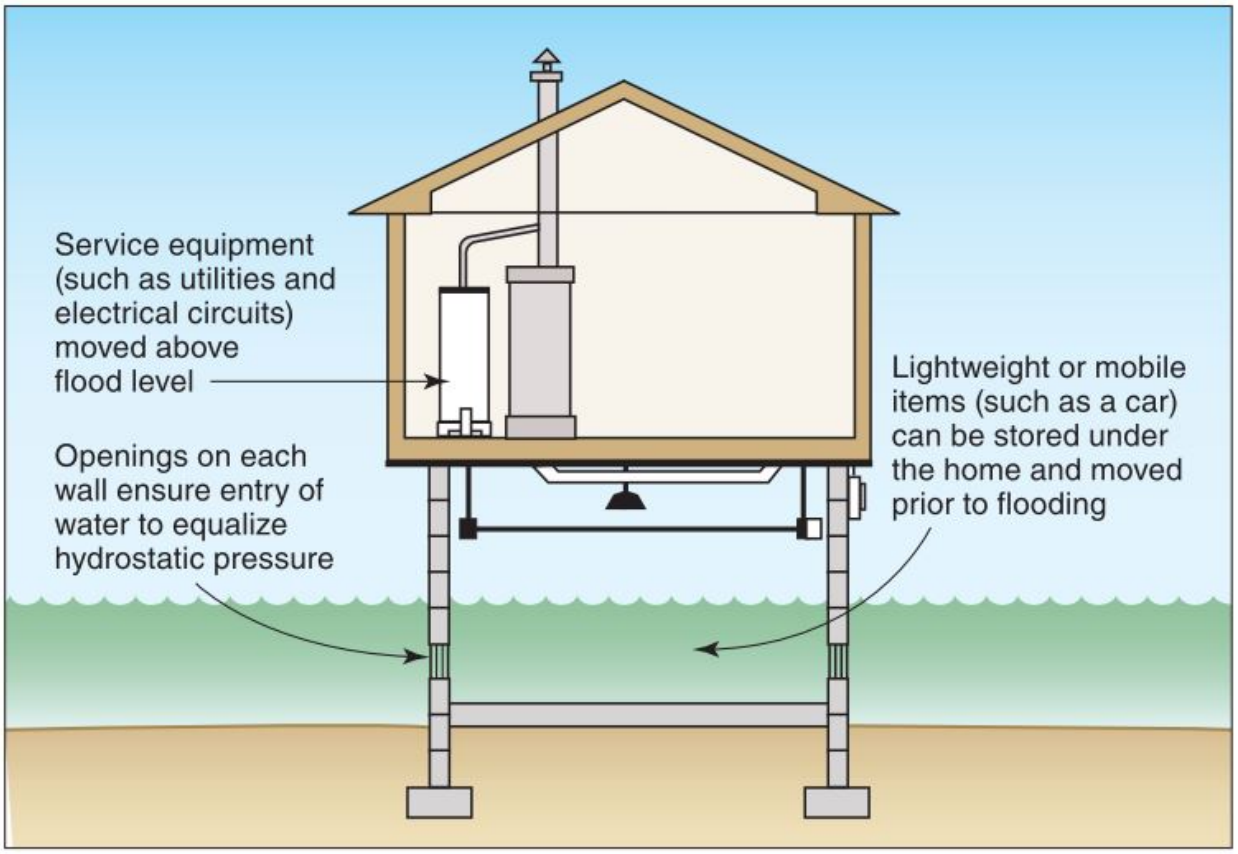

Figure 9-3: Example cross-section of an elevated home using continuous foundation walls (FEMA, 2014a).

Accommodation strategies can be implemented in a number of areas throughout the City of Avalon. Temporary or permanent floodproofing retrofits can be employed within current and projected future flood prone areas to reduce the impacts and recovery time following 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 Pebbly Beach Road to collect and convey flooding from wave runup and overtopping. Additional adaptation strategies are necessary within projected tidal flood zones along the immediate shoreline to accommodate future coastal hazards. Pile-supported structures such as those within Avalon Bay 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 is also dependent on elevation of other features such as roads, paths, ramps or stairs to maintain reliable access to these structures during non-storm conditions.

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.

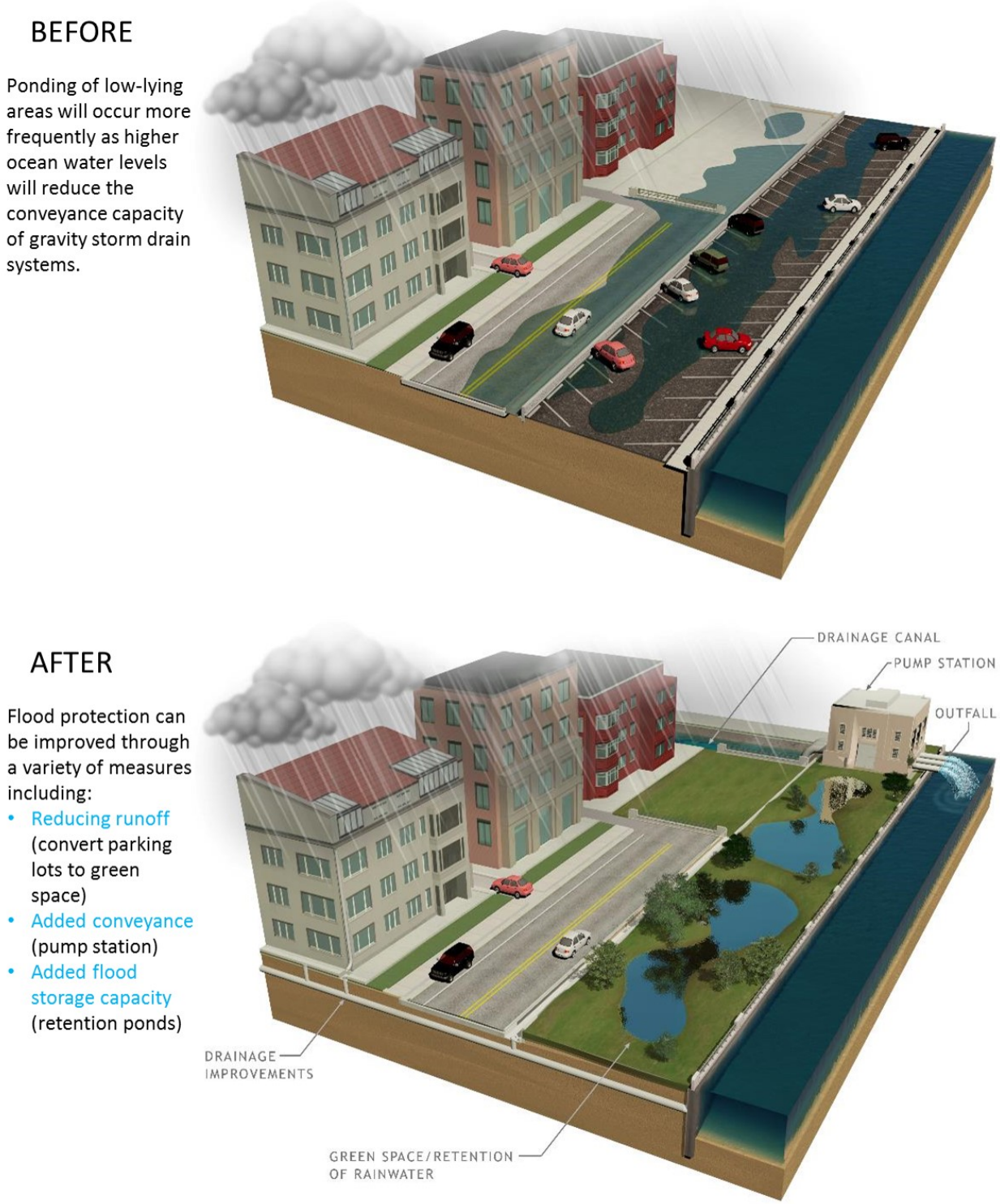

Figure 9-4: Example of drainage improvements to reduce flooding (U.S. Army Corps of Engineers, 2015a).

9.1.3 Retreat

Directly removing or relocating vulnerable structures away from hazard areas inherently represents the most 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 Avalon due to the natural topography of Catalina Island and existing development patterns. High-relief coastal bluffs are located immediately landward of many coastal resources such as the Pebbly Beach Road industrial area and the Catalina Island Casino, limiting potential retreat options. Dense residential and commercial development along the Avalon Bay waterfront present difficult challenges for a retreat strategy. Retreat strategies are more feasible in areas such as Descanso Bay, where coastal relief is more gradual and available open space already exists landward of vulnerable shoreline areas. Within such areas retreat may result in greater resilience to SLR hazards at a lower cost than protecting structures in place, 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 part of a phased adaptation plan to address SLR hazards under a worst-case scenario.

Figure 9-5: Example of a retreat project in which a parking lot was moved landward away from potential SLR hazard zones. Photo courtesy of Surfrider Foundation (California Coastal Commission, 2018a).

9.2 SLR Adaptation Goals

9.2.1 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 forecasted 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, documenting wind patterns that affect travel conditions, or maintaining an inventory of the status of shoreline protection structures. Tracking existing impacts such as beach width, freeboard of pile-supported structures, overtopping of existing shoreline protection, and frequency of flood events can also inform ongoing SLR adaptation efforts.

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 associated with new development can also provide an important mechanism for educating property owners about projected SLR hazards and their options for addressing them.

9.2.2 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 preventing 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.

9.2.3 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 structures can provide multiple benefits to SLR adaptation efforts. Policies that establish standards for the evaluation, repair, and maintenance of existing shoreline armoring enable the ongoing functionality of protective structures as coastal hazards change with rising water levels,

reducing potential for structural failure under future conditions. Policies related to new or additional shoreline armoring 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.

9.2.4 Use a Coordinated Approach to SLR Adaptation

Coastal processes that affect SLR hazards often extend beyond the parcel scale. Participating in coordinated SLR hazard mitigation planning 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 Avalon.

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 require elements of the Local Hazard Management Plan to align with the Local Coastal Program help to promote coordinated proactive adaptation efforts 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 leverage available federal and state funding opportunities.

9.2.5 Maximize Protection of Coastal Resources

Coastal resources, including public access points, recreation facilities, marine habitats, and scenic resources play critical cultural, social, and economic roles within the City of Avalon. Policies in pursuit of this goal will help ensure that these critical functions are maintained and enhanced as a part of future SLR adaptation efforts.

Replacing any projected loss of coastal access points, recreation areas, or visitor serving facilities is a necessary component of SLR adaptation efforts. Policies that establish appropriate standards for replacement of any access or recreational resources within hazard areas reduce the potential for permanent or temporary loss of these functions within coastal areas as SLR increases. Requirements related to consideration of SLR in planning for any new or redeveloped public access or recreation facilities can also mitigate potential hazards, future disruptions in service, and the need for additional SLR adaptation measures.

Protection and ongoing management of marine habitats in response to SLR provides an additional mechanism to preserve the value of coastal resources. Including SLR considerations in policies designed to identify and avoid any impacts to existing marine habitat, such as open space requirements or buffer zones, can aid future adaptation efforts by facilitating natural habitat migration over time. SLR can also be incorporated into policies related to the ongoing management of marine habitats to prevent loss of function. Formal support of research efforts on potential SLR impacts to marine habitats within the City can help inform these efforts and improve management decisions.

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