Dana Point Harbor
AB 691 Sea Level Rise Assessment

Draft

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June 2019

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Document Verification

Client	County of Orange, OC Parks
Project Name	Dana Point Harbor, Sea Level Rise Assessment of Granted Public Trust Lands pursuant to Assembly Bill 691
Document Title	Dana Point Harbor, AB 691 Sea Level Rise Assessment
Document Sub-title	–
Status	Draft Report
Date	May 3, 2019
Project Number	10186-02
File Reference	Q:\LB\10186-02\8 Deliverables

Revision	Description	Issued by	Date	Checked
00	Draft Report for Internal Review	JT/AH	4/26/2019	KG
01	Draft Report for Client Review	JT	5/3/2019	AH
02	Draft Report for submittal to State	AH	6/28/2019	TQ

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1. Introduction

1.1 Study Approach

As part of California Assembly Bill 691 (AB-691), the County of Orange is required to perform a Sea Level Rise (SLR) Vulnerability Assessment for its granted public trust tidelands within Dana Point Harbor. The California State Lands Commission (CSLC) has jurisdiction over public lands, which include tidelands. Tidelands are a type of sovereign land held by the state of California where land is covered and uncovered by the ebb and flow of tides. Tidelands can be granted to local trustees for purposes of commerce, navigation, and fisheries as well as other public trust purposes.

The landward limit of tidelands is typically defined as the intersection of the mean high tide line with the shore. However, in the case of Dana Point Harbor, portions of the upland development were built on reclaimed land that was once historic tidelands. Therefore, the granted tidelands boundary at Dana Point Harbor extends landward of today's mean high tide line to the historic mean high tide line which followed the base of the bluff, prior to harbor development. The tidelands granted to the County of Orange for Dana Point Harbor are illustrated in Figure 1-1.

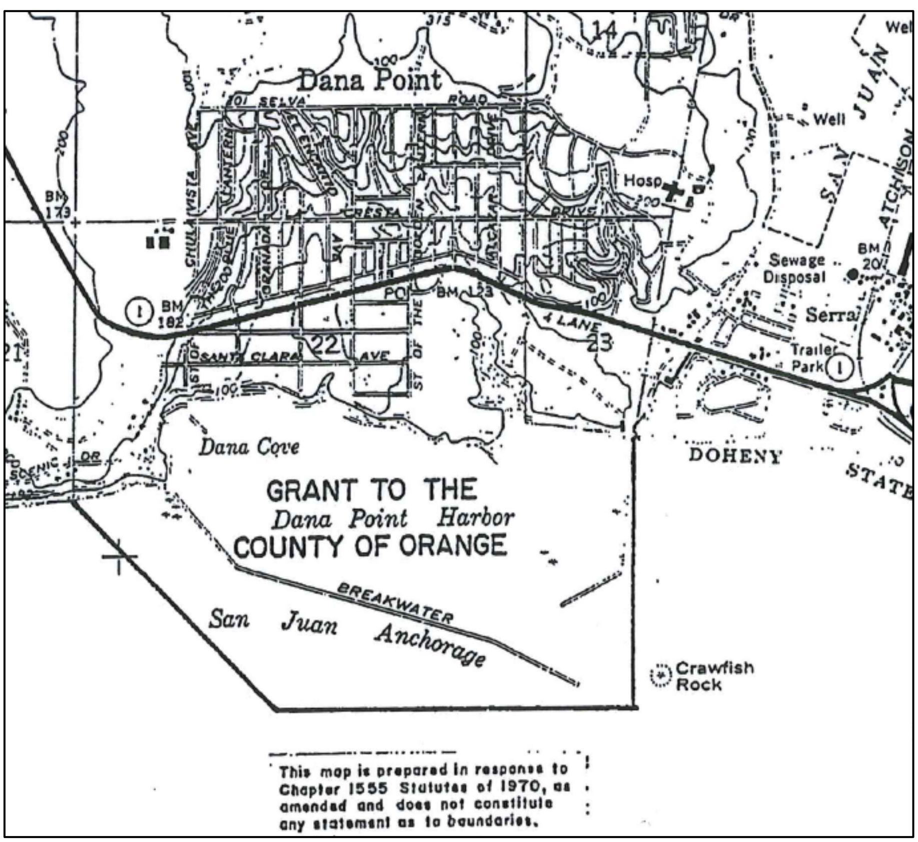

Figure 1-1: Tidelands granted for Dana Point Harbor

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

- **Assessment of SLR impacts:** Inventory of potentially vulnerable resources and facilities, assessment of storms and extreme events (100-Year/1% annual chance event), evaluation of changing shorelines, trends in local sea level, and potential impacts to public access, commerce, recreation, coastal habitats, and navigability.
- **Maps of 2030, 2050, and 2100 SLR impacts:** Plan view mapping is used to illustrate hazard zones and potential impacts for a range of SLR scenarios representative of the 2030, 2050 and 2100 time horizons.
- **Estimate of financial costs of SLR:** Replacement and repair costs of resources and facilities, including non-market values of resources and costs of adaptation and mitigation measures.
- **Description of how trustee proposes to protect and preserve resources and structures that would be impacted by SLR:** Mitigation, adaptation, and resiliency measures including hazard monitoring and mitigation implementation triggers.

The purpose of this AB-691 Vulnerability Assessment is to understand how rising seas could impact coastal resources under Orange County jurisdiction within Dana Point Harbor. Within this study, the term “coastal resource” is used to describe natural or manmade features that provide a benefit to the Harbor. The Vulnerability Assessment was performed by first establishing an inventory of coastal resources and then identifying how coastal hazards will evolve with various increments of SLR. By comparing the hazard zones with coastal resources in the Harbor, the magnitudes of SLR that present thresholds at which significant impacts occur were determined.

Figure 1-2: Aerial view of Dana Point Harbor (Photograph by D Ramey Logan)

The vulnerability of a coastal resource to SLR hazards was evaluated based on three factors: its exposure to hazards, its sensitivity to said hazards, and its adaptive capacity. Each of these factors is defined below.

- **Exposure** refers to the type, duration, and frequency of coastal hazard a resource is subject to under a given SLR scenario. A resource that experiences daily wave and water level fluctuations would be considered more exposed than a resource that only experience some minor flooding during an extreme event.
- **Sensitivity** is the degree to which a resource is impaired by exposure to a coastal hazard. For example, a structure with a shallow foundation (i.e., slab on grade) would be more sensitive to undermining from erosion than a pile-supported structure.
- **Adaptive capacity** is the ability of a resource to adapt to evolving coastal hazards. Beaches can be thought to have a natural ability to adapt because sand will migrate upward and landward in response to rising sea levels if sufficient sand exists in the system and landward space is available for this migration. Infrastructure typically has a low adaptive capacity because increased coastal hazards that exceed the design capacity often require significant improvements to maintain the same level of protection.

The vulnerability assessment addresses the assessment criteria for AB 691 by determining potential consequences and key SLR thresholds for resources on granted public tidelands managed by the County of Orange, including estimates of the financial cost of sea level rise.

2. Coastal Setting

Dana Point Harbor is located in southern Orange County within the City of Dana Point (Figure 2-1). The harbor is located immediately downcoast of the Dana Point Headland, a notable landform and natural boundary between the narrow pocket beaches to the north and sandy beaches to the south. Dana Point Harbor, built in the late 1960s and dedicated in 1971, spans 260 acres in Dana Cove and is protected by two breakwaters (east and west breakwaters). The west breakwater is approximately 5,500 linear feet (lf) with a design crest elevation of +18 ft MLLW and the east breakwater is 2,250 lf with a crest elevation of +14 ft MLLW.

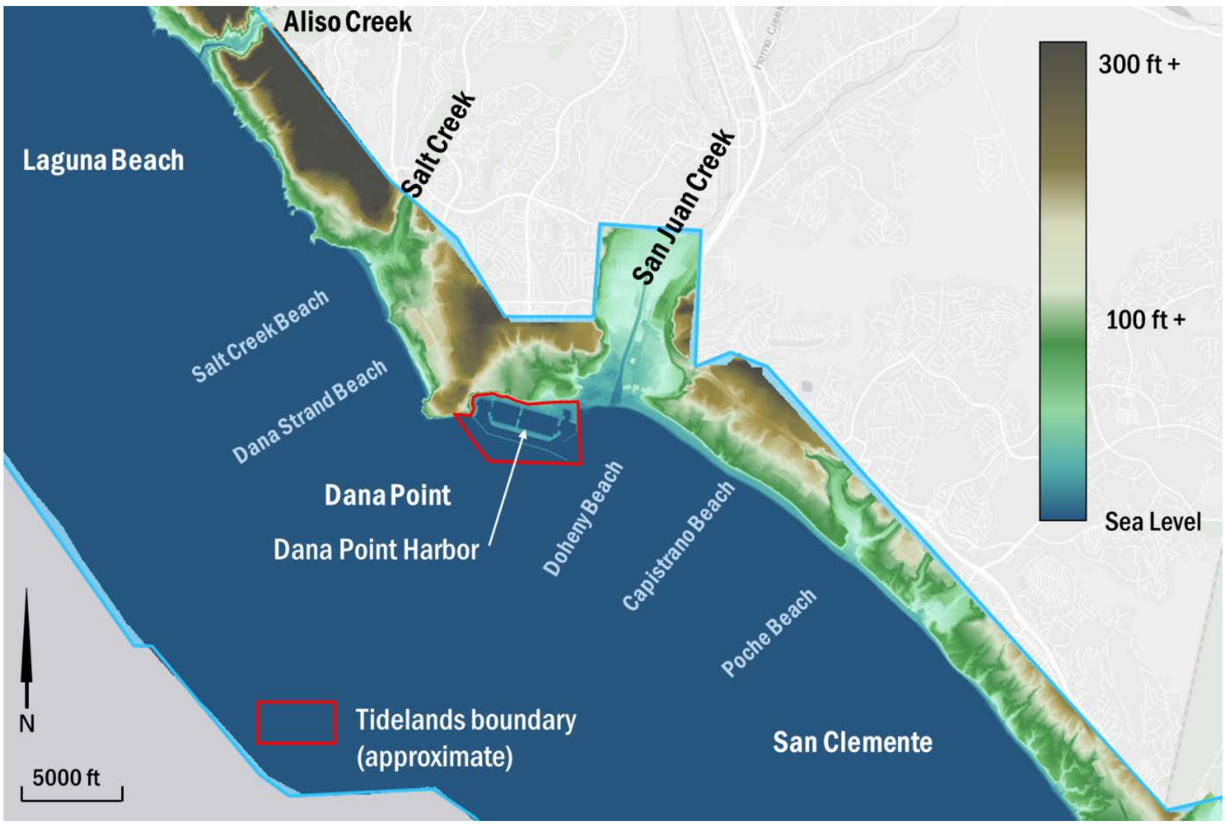

Figure 2-1: Geographic vicinity of the Dana Point Harbor

The harbor is owned and managed by the County of Orange, OC Parks department and is built partially on tidelands granted to the county by the State of California. For purposes of this study it was assumed that all development associated with the harbor, including upland development located above mean higher high water, are located on granted tidelands within the approximate boundary shown in Figure 2-1. The harbor consists of a variety of land uses including the Ocean Institute, Dana Point Pier, Baby Beach, parks and open space, a marina made up of two basins (approximately 2,500 slips), a boat launch ramp, dry docks and storage facilities, youth and group events center, yacht clubs, and mixed-use commercial development (Figure 2-2). The Dana Point Harbor is currently in the planning phase of a proposed $300 million redevelopment project.

The harbor area is a valued resource for the region. In addition to recreational boat slips, it contains a calm water beach in Baby Beach, historic ships such as the Pilgrim and Spirit of Dana Point, art galleries, the Ocean Institute, the county-owned Dana Point Youth & Group Facility, whale watching and sports fishing hubs, commercial areas, hotels, and yacht clubs. Development in and around the harbor is managed by the County of Orange as part of the County granted public trust lands, which produced $27 million in gross revenue in 2017.

Figure 2-2: Dana Point Harbor Areas by Use and Function, Imagery: Google Earth.

Structures and development in Dana Point Harbor, including parking lots in the marina and wharf, sit on engineered fill at approximately 9 to 15 ft NAVD88 and are stabilized by concrete bulkheads (Figure 2-3) and rock slope. The top of bulkhead around most of the harbor is at an approximate elevation of 10 ft NAVD88. The harbor's main hydraulic connection to the ocean is the entrance channel on its east side; however, the breakwaters were designed to be semi-permeable to allow for better water circulation within the harbor.

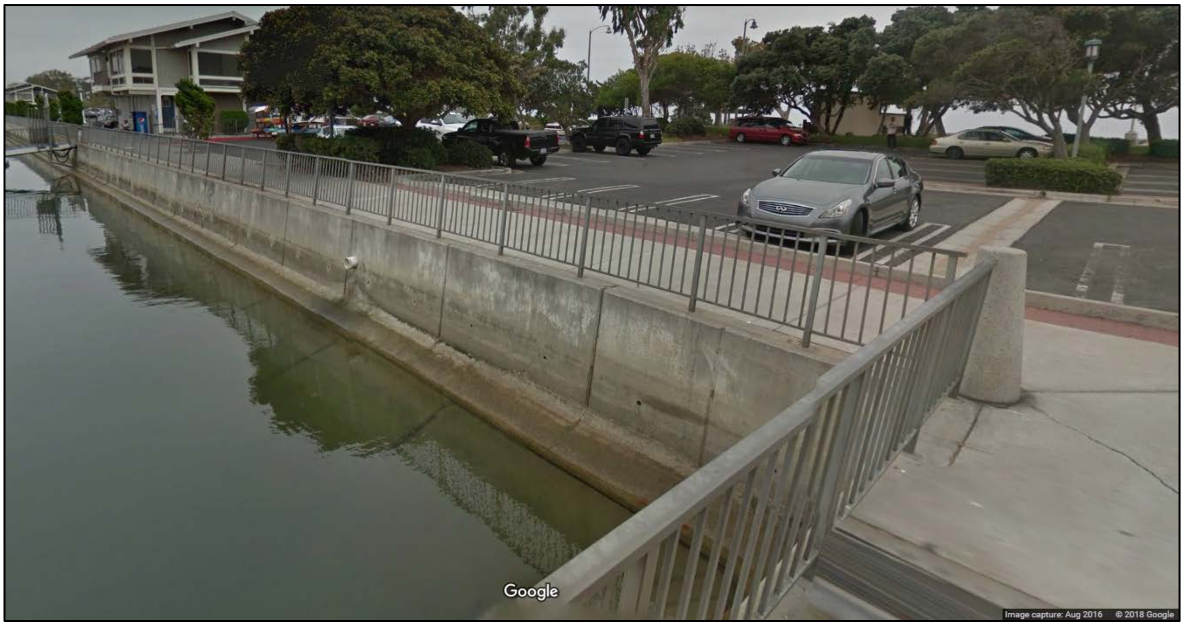

Figure 2-3: Typical Edge Condition for Dana Point Harbor Comprising a Concrete Bulkhead with Rail Fencing (Google Streetview, 2016)

3. Coastal Resources

An inventory of coastal resources was created to identify resources, assets, land uses, and infrastructure potentially at risk within Dana Point Harbor. These resources were identified through a variety of methods including publicly available government databases, technical reports, and aerial imagery. The inventory of resources is summarized in Table 3-1 and focuses on all resources located on granted public trust tidelands within Dana Point Harbor. Identified resources were mapped using GIS and can be found on the hazard overlay maps in Figure 3-1.

Table 3-1: Summary of Coastal Resources Inventory

Resource	
Transportation Infrastructure	Local roadways that serve coastal areas within Dana Point Harbor as well as the Catalina Express Terminal
Utilities	Stormwater, potable water, electrical and irrigation water infrastructure
Upland Development	Commercial development areas located inland from Harbor shorelines

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Figure 3-1: Coastal Resources within Dana Point Harbor

4. Coastal Processes

4.1 Littoral Processes

A littoral cell is a coastal compartment or physiographic unit that contains sediment sources, transport paths, and sediment sinks (Patsch and Griggs, 2007). The City of Dana Point spans two littoral cells on either side of the Dana Point Harbor. The Laguna Beach littoral cell extends 13 miles from the Newport Bay entrance to the Dana Point Harbor and includes 23 mini sub-cells consisting of pocket beaches backed by seacliffs and separated by headlands with rocky reef extensions (Everest, 2013). The primary sources of sediment to the pocket beach north of Dana Point Headland are fluvial discharges from Aliso Creek and Salt Creek (Everts Coastal, 1997). South of Dana Point Harbor is the Oceanside littoral cell, which extends 51 miles from Dana Point to La Jolla. The primary sources of littoral sediment for beaches south of the Harbor are San Juan Creek and erosion of coastal bluff and dunes. In the past, beach nourishment has accounted for up to 34% of sand within the Oceanside littoral cell. The net direction of sediment transport is toward the south. While Dana Point Harbor is more isolated from sand transport than surrounding bluff and beaches, some upcoast sediment does bypass the Dana Point headland and reaches the interior of the Harbor. This material is removed through periodic dredging in order to maintain safe navigation within the Harbor.

4.2 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 La Jolla tide gage (Station 9410230), operated by the National Oceanic and Atmospheric Administration (NOAA), provides a long-term sea level record near Dana Point Harbor. The gage is located on the Scripps Pier and has been collecting data since 1924. These data are applicable to the Dana Point coastline and can be used to characterize the variability in existing water levels, illustrated in Figure 4-1.

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 5.3 ft. During spring tides, which occur twice per lunar month, the tide range increases to almost 7 ft due to the additive gravitational forces during 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.

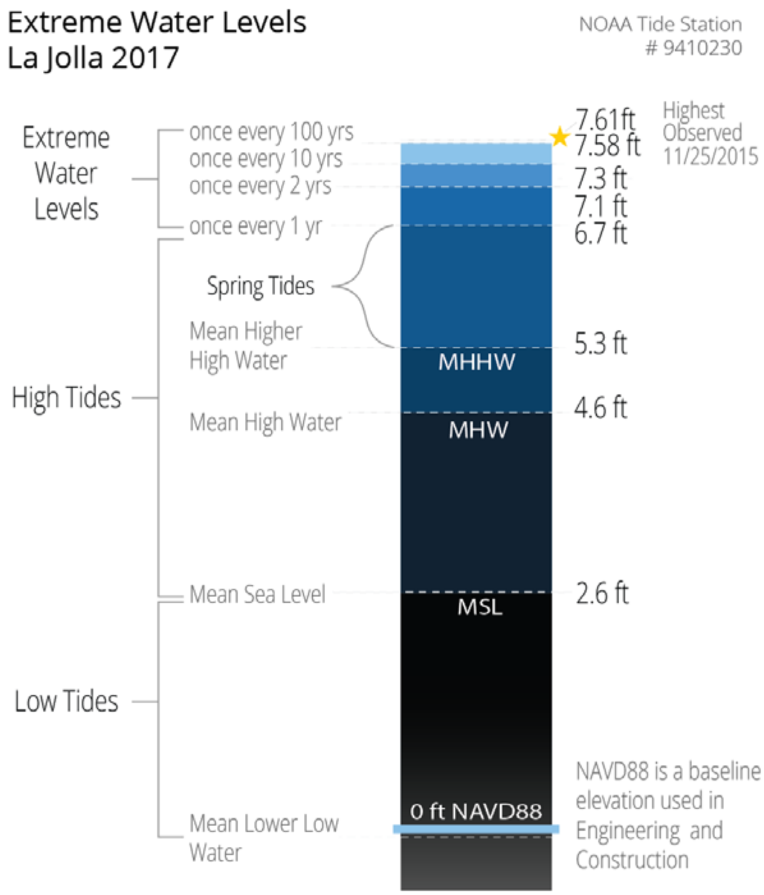


Figure 4-1: Daily and Extreme Water Levels Based on Observations from the NOAA La Jolla Tide Station

In addition to astronomical tides, factors such as sea level anomalies (El Niño events) and storm surge also contribute to water level elevations along Dana Point. 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 26, 2015 when a king tide of about 6.7 ft above MLLW was predicted, but an actual water level of 7.8 ft was measured at NOAA station 9410230 in La Jolla. The tide series from this event is shown in Figure 4-2. The predicted astronomical tide was elevated by more than 1 ft due to a sea level anomaly related to the strong El Niño weather pattern and high ocean temperatures during the 2015-2016 winter season (Doherty, 2015). The water levels of late November 2015 exceeded the 100-year water level of 7.6 ft on two consecutive days at this tide station due to the combination of these factors.

Ocean water levels are dynamic and typically vary within predictable ranges; however, it is not uncommon to experience sea level anomalies that significantly increase the predicted water level above the normally-occurring astronomical tide. When considering the effects of SLR on coastal hazards, it is important to keep in mind that SLR increases existing water levels across the entire tidal range, causing what are currently anomalous tidal elevations to become more commonplace.

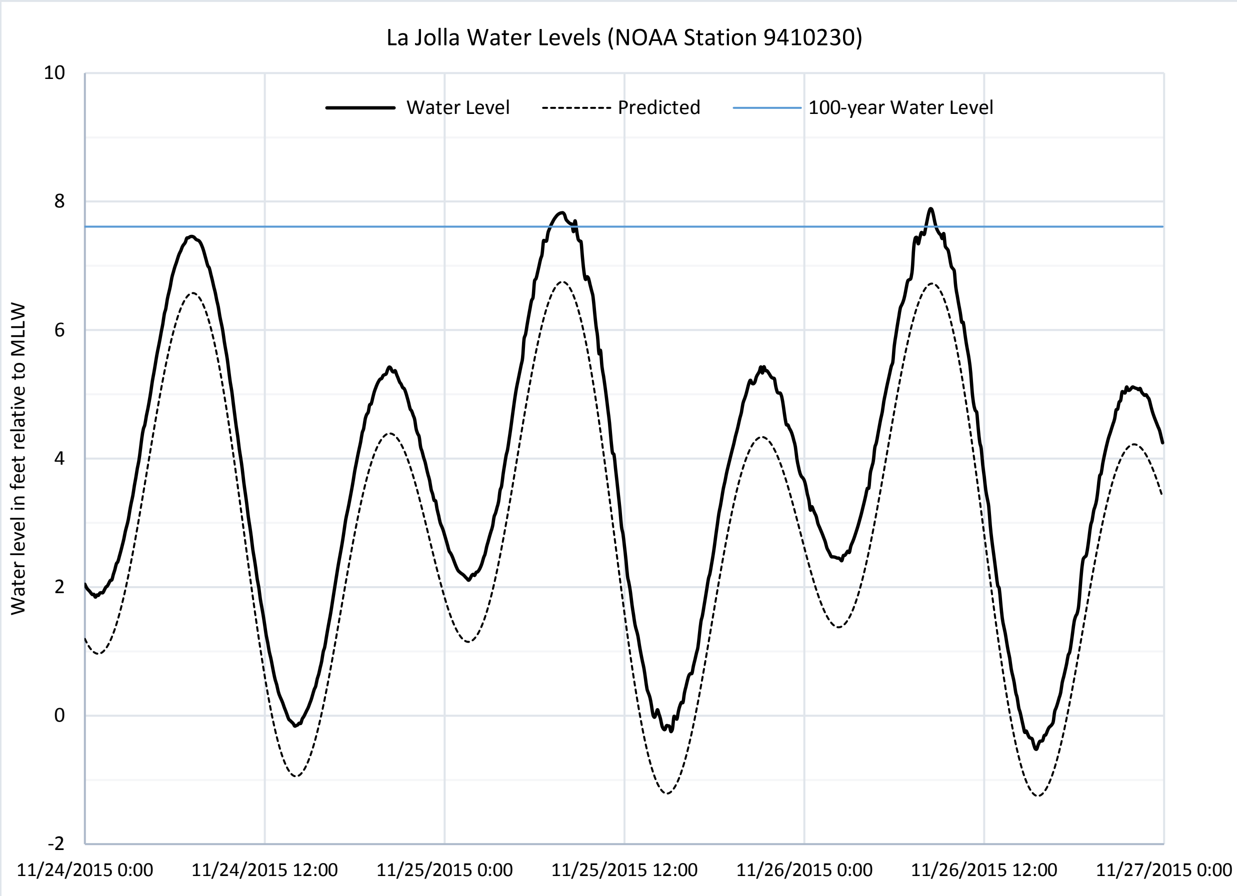


Figure 4-2: November 2015 tide series from NOAA tide station 9410230

4.3 Wave Climate

Waves can also cause short-duration flooding events by creating dynamic increases in water levels. Thus, the wave climate, or long-term exposure of a coastline to incoming waves, and extreme wave events are important in understanding future SLR vulnerabilities within Dana Point Harbor.

The general wave exposure of Dana Point is characterized by south swells in summer, which typically consist of smaller wave heights with long wave periods of approximately 18-22 seconds, and west-northwest swells in winter months, which have much larger wave heights and wave periods in the 16-20 second range. The nearshore wave exposure along the coastline varies with shoreline orientation. Salt Creek and Dana Strand, which face southwest, are more exposed to west swells than Doheny Beach, which faces south and is sheltered by the harbor breakwater. Due to its location just south of the Dana Point Headland, the Dana Point Harbor complex is exposed to both west and south swell events.

The United States Army Corps of Engineers (USACE) characterized extreme wave events in the Oceanside Littoral Cell as part of the CCSTWS-SD by analyzing historic data from the largest tropical and extratropical storms on record (USACE, 1991). Based on this analysis, the 10-year deepwater significant wave height (H_s) was estimated to be approximately 20 ft and the 100-year H_s was estimated at approximately 28 ft.

For much of Southern California, especially coastlines exposed to south swell such as Dana Point Harbor, the largest wave event on record was the September 1939 tropical storm. A maximum wind of 50 knots was recorded at the Los Angeles-Long Beach Outer Harbor during the storm, with wave heights of 30 to 40 ft estimated by people ashore (M&N, 1985). Ships in the Catalina Channel reported 45 ft high waves that resulted in significant damage to the Los Angeles-Long Beach Harbor breakwater. A wave event of this magnitude today would result in considerable damage to coastal resources and assets within Dana Point Harbor.

While the outer harbor breakwaters provide a significant amount of protection from wave energy, some wave energy (and sediment) is transmitted into the inner basins of Dana Point Harbor, especially during large wave events, as illustrated in . Significant wave heights in the interior of the eastern portion of the Harbor have been estimated at 2.1 - 2.3 feet for a 100-year return period storm (Everest, 2008). Wave modeling studies have also estimated the 100-year return period significant wave height at the end of the eastern breakwater at 2.9 feet, reflecting the greater wave exposure at the Harbor entrance (USACE, 2011). Though these wave heights are much smaller in magnitude than offshore wave conditions, wave energy transmitted within the Harbor remains sufficient to result in overtopping of boat ramp and seawall structures under a combination of 100-year storm and high-tide conditions (Everest, 2014), as well as posing a hazard to boaters transiting the main channel.

Figure 4-3: Overtopping of West Breakwater in April 2007

5. Sea Level Rise

Rising sea levels are a product of multiple global, regional, and local factors including thermal expansion of oceans with warming temperatures, increased runoff from melting ice sheets, and land subsidence. Sea level rise projections are generated through modeling efforts based on the current best understanding of these global and local oceanographic and atmospheric processes and how these processes will change over time. Given the continual evolution of the science surrounding sea level rise, models and projections are periodically updated to reflect these advances.

5.1 Sea Level Rise Projections

The 5th International Panel on Climate Change (IPCC) assessment, released in 2014, provides the most recent global-scale sea level rise projections, which rose by 50% compared to previous projections due to updated effects of melting ice sheet dynamics and their contribution to sea level rise. A number of sea level rise modeling efforts have been conducted at national, regional, and local scales. Within California, the California Coastal Commission's (CCC) current recommendation on the best-available sea-level rise science is the Ocean Protection Council's (OPC) 2018 State of California Sea Level Rise Guidance.

The 2018 OPC report provides probabilistic SLR projections under high and low-emissions scenarios based on the IPCC 5th assessment, expanding upon the IPCC projections by considering a wider range of SLR probabilities and tailoring results to specific regions of California. The use of probabilistic SLR projections represents an update from the state's 2013 SLR guidance, which relied on scenario-based projections that lacked associated probabilities. SLR probabilities within the 2018 OPC report represent an assessment of the strength of the observational, numerical, and theoretical evidence that supports a specific future SLR outcome and are intended as a guidance tool rather than a precise prediction of future conditions, as climate models and associated probabilities are likely to change as climate science continues to evolve.

Specific probabilistic scenarios in the 2018 OPC report (Figure 5-1) include a likely range accounting for 66% of projected conditions, a median (50%) value, a 1-in-20 chance (5%), and a 1-in-200 chance (0.5%). It is important to note that the probabilities associated with each projection represent the probability that SLR meets or exceeds the specified value. The report also includes a "H++" scenario which represents the maximum amount of SLR that is physically plausible given new information on ice sheet dynamics (Sweet et al., 2017). The H++ scenario, which does not have an associated probability, is intended for use in cases where extreme levels of risk aversion are necessary.

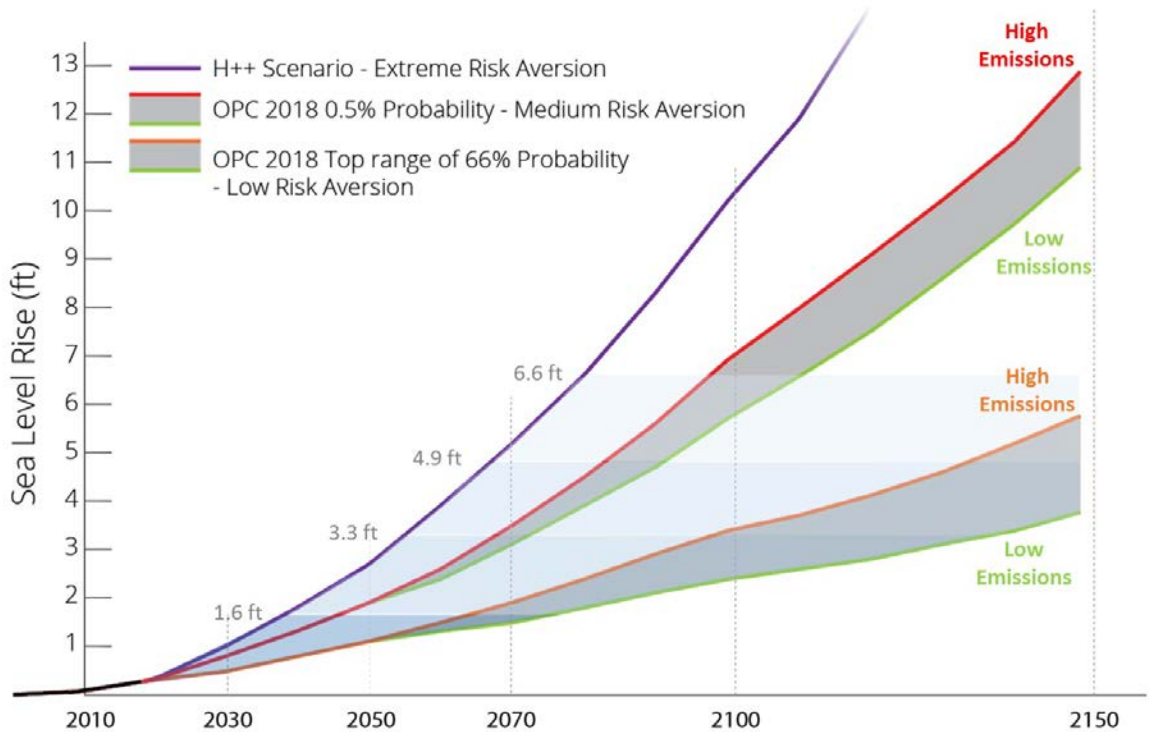


Figure 5-1: Sea level rise projections per 2018 OPC guidance

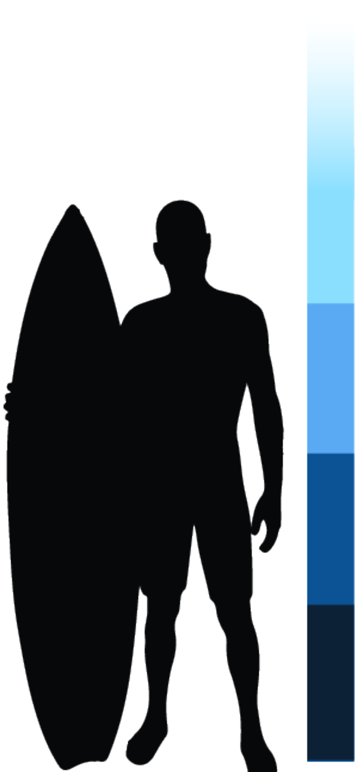
5.2 Selected Sea Level Rise Scenarios

Due to the high degree of uncertainty associated with predicting when and at what rate SLR will occur, this study looks at a range of SLR increments (scenarios) starting with present day conditions and including upper limits of probabilistic SLR projections. Four scenarios have been selected for this study that consider increments of SLR between 1.6 and 4.9 ft, as shown in Figure 5-2. This range of scenarios is based on available hazard data for the region and accounts for the full range of SLR projections recommended in CCC SLR guidance documents for the time horizons provided in the AB 691 assessment criteria. The range in SLR projections at time horizons of 2030, 2050 and 2100 are described below.

- 2030 – The median SLR projection for 2030 is 0.5 feet which means there is a 50% chance SLR will exceed this amount. There is a 95% chance SLR will not exceed 0.7 feet by 2030. Under a worst-case scenario (H++), SLR could be as much as 1.1 feet by 2030. The present day extreme event hazards and the non-storm hazards for a 1.6 foot SLR scenario are the best representation of the impacts at this time horizon.
- 2050 – The median SLR projection for 2050 is 0.9 feet, but could be as high as 2.8 feet under a worst-case (H++) scenario. There is a 95% chance SLR will not exceed 1.4 feet by 2050. The hazards depicted under a 1.6 foot SLR scenario are

the best representations for hazards in this time frame. Hazards depicted for the 3.3 foot SLR scenario could be interpreted as a worst-case depiction of coastal hazards if SLR follows an H++ trajectory.

- 2100 – OPC projections vary widely for the end of the century. The median projection is 2.6 feet but the worst-case (H++) projection is over 10 feet. SLR scenarios of 3.3, 4.9 and 6.6 feet all depict hazards in the 2100 time horizon with varying degrees of probability. There is a 33% chance SLR will exceed 3 feet in 2100 and only a 3% chance it would exceed 5 feet.



Sea level Rise above '91-'09 baseline	When might it occur?*
6.6 feet (200 cm)	2080 to 2150+
4.9 feet (150 cm)	2070 to 2130
3.3 feet (100 cm)	2060 to 2100
1.6 feet (50 cm)	2040 to 2070

* ranges are estimated from OPC (2018) at La Jolla for low to extreme risk aversion projections

Figure 5-2: Sea level rise scenarios and projected range of occurrence

6. Sea Level Rise Hazard Analysis

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

The modeling system incorporates state-of-the-art physical process models to enable prediction of currents, wave height, wave runup, and total water levels (Barnard et al. 2009). A total of 10 SLR scenarios are available, increasing in 0.8 ft (0.25 m) increments from 0 to 6.6 ft (0 to 2 m) and also including an extreme SLR scenario of 16.4 ft (5 m). The results provide predictions of shoreline erosion (storm and non-storm), coastal flooding under both average conditions and extreme events, and cliff erosion.

The Dana Point Harbor hazard analysis focuses primarily on coastal flood modeling results given the lack of erodible shoreline within the Harbor. The hazards depicted in this report are presented solely based on the assumptions and limitations accompanying the CoSMoS data available at the time of this study. No additional numerical modeling or independent verification of the CoSMoS data was performed.

6.1 Wave Modeling

CoSMoS Version 3.0 model provides nearshore wave heights for a range of storm events including the annual, 20-year, and 100-year recurrence intervals. The nearshore wave heights for an annual and 100-year wave event, provided in Figure 6-2, were generated by using the Our Coast Our Future (OCOF) web-based application (Ballard et al., 2016) that can be accessed to view all of the CoSMoS hazard data. The nearshore wave heights for an annual event range from 8-10 ft with largest waves focused at the Dana Point Headland and Salt Creek. Nearshore wave heights for a 100-year event range from 12-15 ft upcoast of the Dana Point Headland with lower wave heights (8-10 ft) downcoast of the Harbor. These wave heights were used to drive the regional CoSMoS shoreline erosion and coastal flooding models.

Model results at the Harbor entrance location included in previous studies show a significant wave height of approximately 2.5 feet for a 100-year storm. CoSMoS wave modeling results in the interior portion of the eastern harbor show greater wave heights than previous modeling efforts, with significant wave heights in the 3 foot range. The CoSMoS results also indicate wave heights inside the harbor would increase with SLR. However, it’s uncertain how well the breakwater structures were resolved in the CoSMoS model and if the interior waves were incorporated into the flood modeling. A plot of the total water levels from the CoSMoS data illustrate a linear increase based on the SLR amount which is an indication wave setup and runup were not accounted for in developing flood projections for the inner harbor areas. This limitation would lead to an underestimate of potential flooding, especially for the higher SLR scenarios (3.3 - 4.9 feet).

The eastern and western breakwaters of Dana Point Harbor provide critical wave protection to inner harbor infrastructure and navigability within the harbor. These structures will be exposed to greater wave heights and water levels as sea levels rise. If wave heights exceed initial design values, or if breakwater infrastructure is not adequately maintained under increased wave exposure, the functionality of breakwater structures may decline significantly under projected SLR scenarios (Figure 6-1). Wave transmission and shoaling of the main channel occur from penetration through a rubble-mound structure and overtopping of the breakwater, both of which will increase with SLR. It is important to note that CoSMoS modeling efforts do not take into account the specific characteristics of individual shoreline protection structures or how any such structures are projected to perform over their estimated design life when considering future projections of coastal flooding. Previous studies specific to Dana Point Harbor shoreline protection infrastructure have estimated that overtopping volumes will increase substantially along inner harbor seawalls with approximately 2.5 feet of SLR (Everest, 2014).

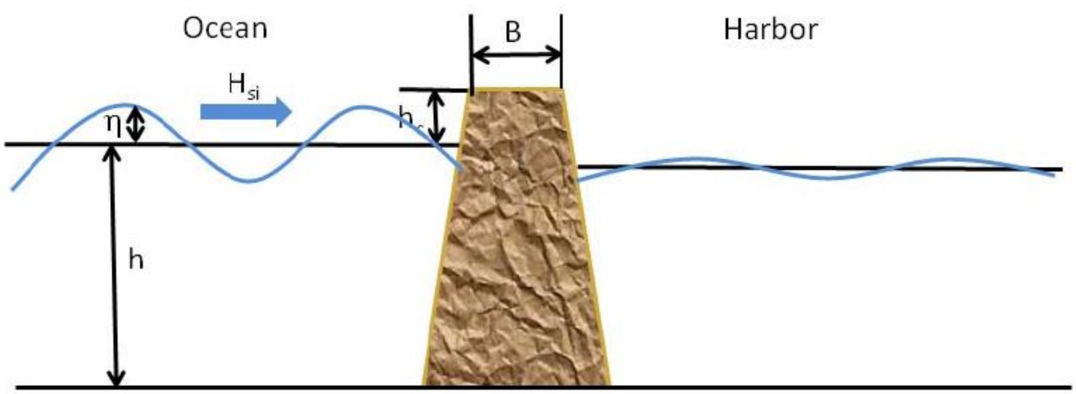


Figure 6-1: Sketch of wave transmission and flow penetration through a porous structure (USACE, 2011)

As sea levels rise, Dana Point Harbor breakwaters will be subject to increased wave transmission and sedimentation through and over the rubble mound structures. Theoretical increases in wave transmission through breakwaters under different SLR scenarios were evaluated during preliminary assessments of Dana Point Harbor infrastructure. Results indicate that the effectiveness of harbor breakwaters could be significantly reduced under severe SLR scenarios as initial wave heights rise and breakwater freeboard is decreased, resulting in a potential 3-ft increase in wave height within the harbor (Table 6-1). This increase in wave energy would not only impact navigation within the harbor but would also increase flood risk due to wave runup and overtopping of interior harbor development.

Table 6-1: Theoretical Increases in Breakwater Wave Transmission under Various SLR Scenarios

SLR Scenario	Initial wave height, in ft (m)	Breakwater freeboard, in ft (m)	Transmitted wave height, in ft (m)
No SLR	10.2 (3.1)	10.5 (3.2)	0.7 (0.2)
1.6 ft (50 cm)	10.5 (3.2)	9.2 (2.8)	1.3 (0.4)
3.3 ft (100 cm)	10.8 (3.3)	7.5 (2.3)	2.3 (0.7)
4.9 ft (150 cm)	11.2 (3.4)	5.9 (1.8)	3.0 (0.9)
6.6 ft (200 cm)	11.5 (3.5)	3.9 (1.2)	3.9 (1.2)

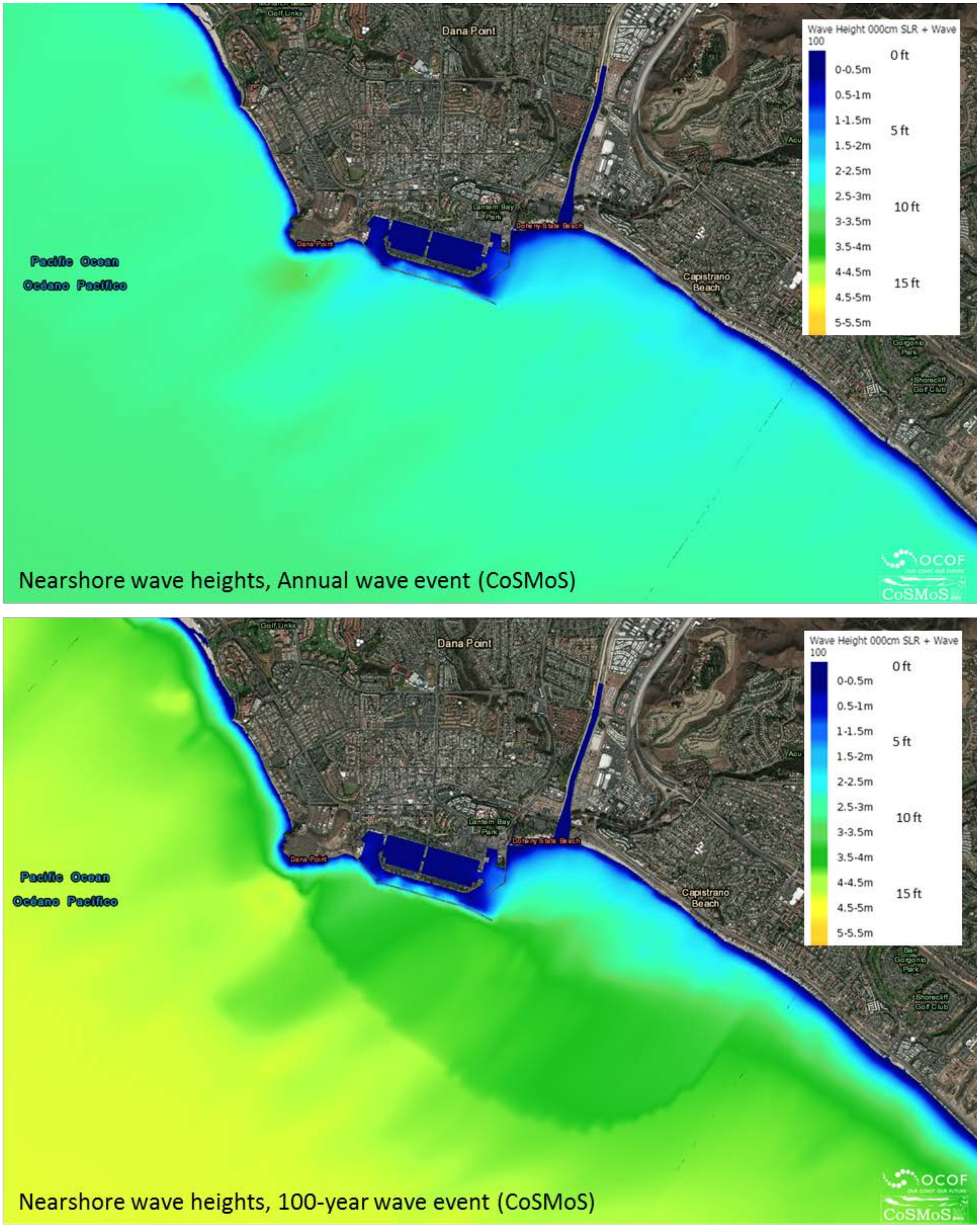


Figure 6-2: CoSMoS nearshore and harbor wave heights adapted from Ballard et al., 2016

6.2 Coastal Flood Projections

CoSMoS coastal flooding projections were used to map the potential hazards in the harbor under baseline (non-storm) conditions and in an extreme (100-year return period) event. The still water level applied in the CoSMoS baseline condition is representative of a typical spring high tide. The 100-year event simulated flooding from a total water level of ~7.4 feet NAVD88 in the inner harbor areas. Although this is a relatively high water level, it does not seem to capture the effect of wave action within the harbor that would be expected under such an extreme event. Therefore, the potential flood extents for a 100-year event may be underestimated and representative of a lower return period event.

Under current conditions, CoSMoS flood modeling shows limited hazard exposure within Dana Point Harbor for a 100-year storm event (Figure 6-3). Flooding does not extend beyond seawall structures within any portion of the Harbor. While structural impacts are limited, flood projections extend landward at Baby Beach, covering approximately 50% of available beach area. This would likely result in short-term inundation and potentially some erosion while elevated water levels and storm conditions are present.

SLR up to 1.6 ft could impact several resources within the harbor (Figure 6-4). Baby Beach could lose more than 50 ft of available flat, sandy beach area under non-storm conditions, which would impact the recreational opportunities at this beach. Baby Beach area also shows additional storm-related flooding covering almost the entirety of the existing sandy beach area. High tide conditions will also encroach on the lower portions of the boat launch under a 1.6 ft SLR scenario. A 100-year storm event combined with 1.6 ft of SLR results in additional hazard exposure within Baby Beach and eastern portions of the Harbor. Low-lying parks, parking lots, walkways, and trails along the bulkheads and rock slopes could experience temporary flooding. Temporary flooding is also likely in the region of the dry boat storage lot and boat launch, with shallow flooding extending into nearby parking lots. The CoSMoS projects water levels during a major storm event could reach elevations of 10 ft NAVD88 in areas surrounding the Embarcadero Marina. Flooding would remain shallow (<1 ft depth) and temporary, occurring during the peak of the tide cycle during the storm event. CoSMoS modeling results in other areas of the Harbor show approximately 9ft water elevations during storm events. Water levels of this magnitude could also put stress on some marina infrastructure such as gangways and docks.

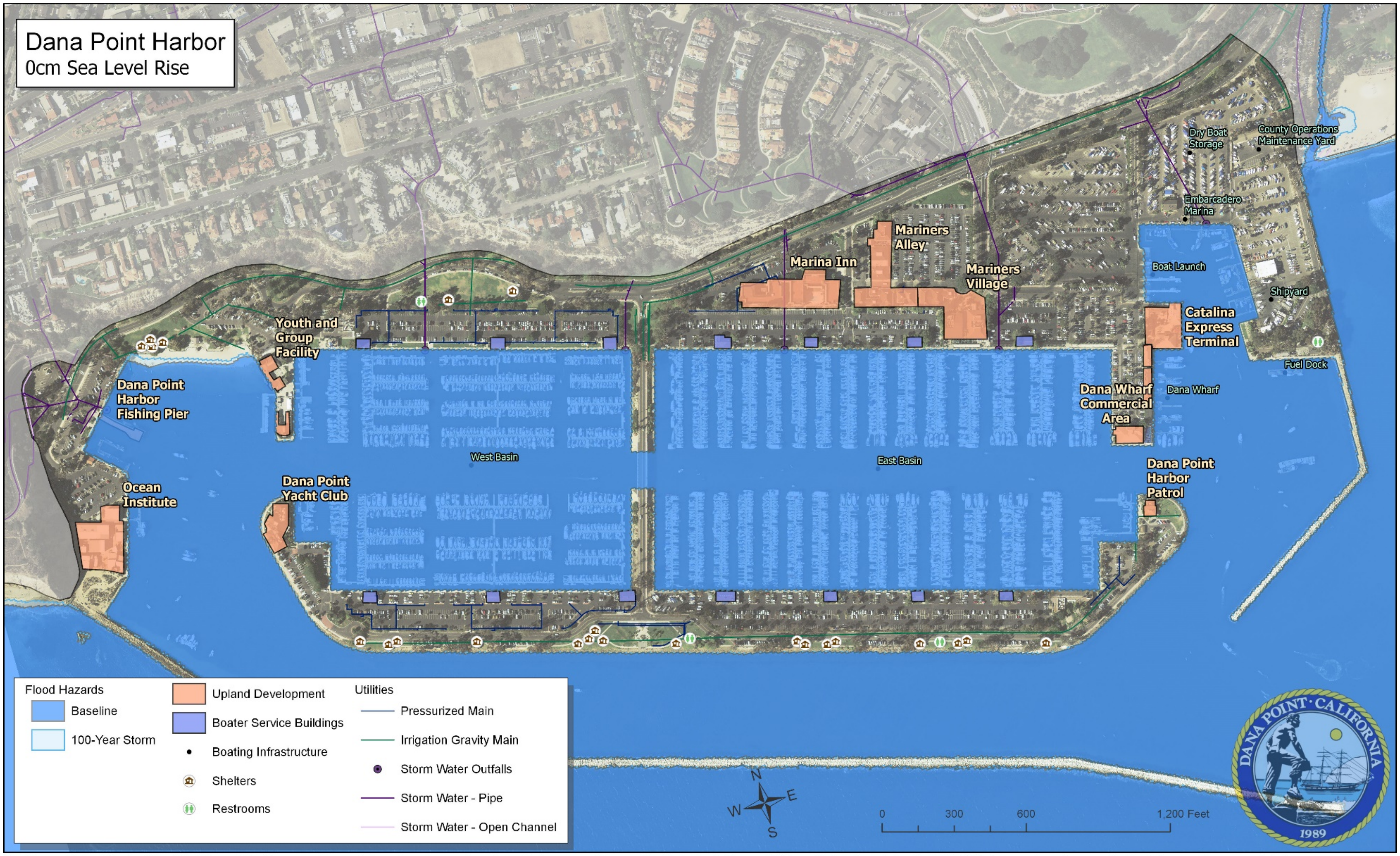


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Figure 6-3: Dana Point Harbor hazard vulnerability under current conditions

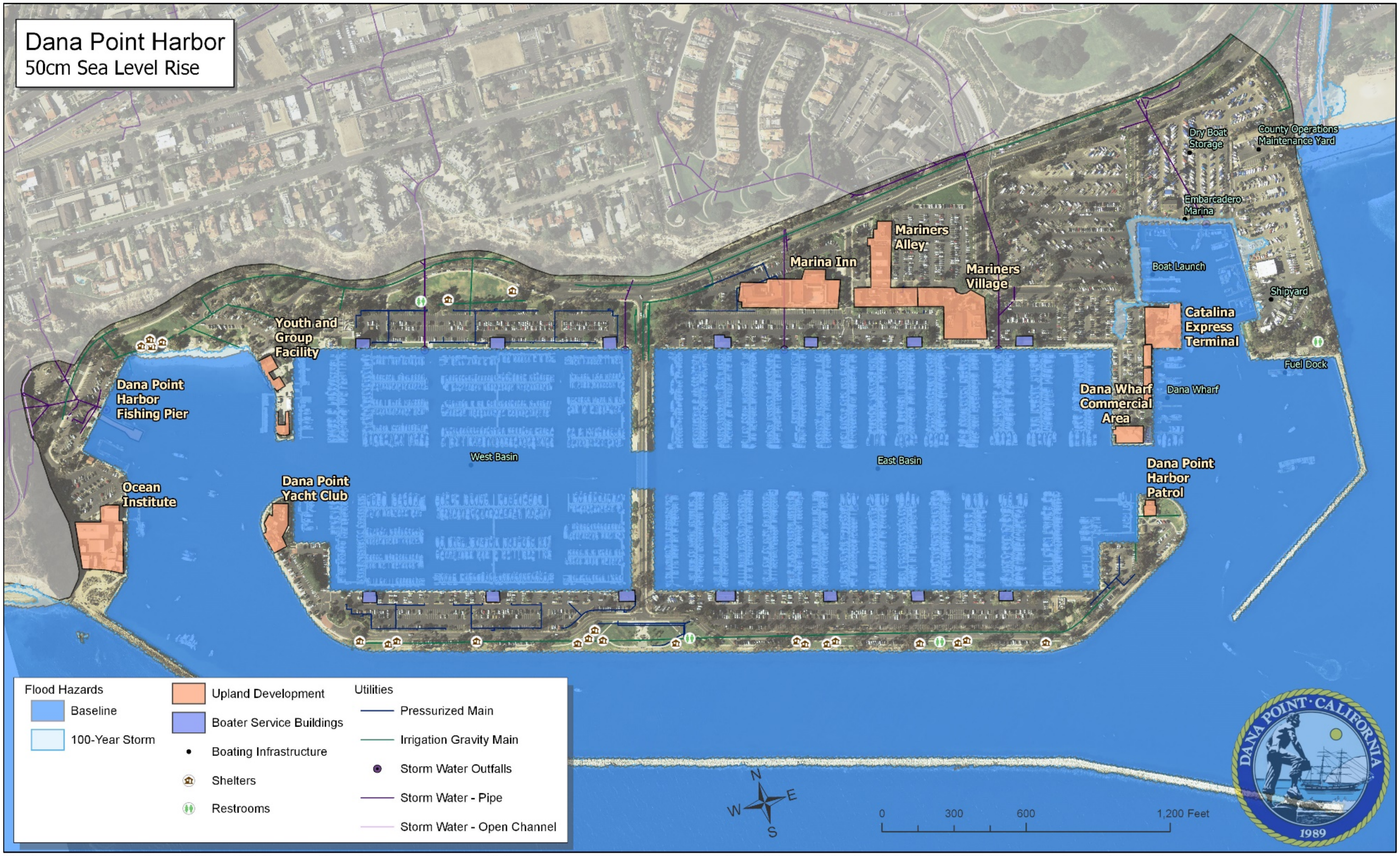

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Figure 6-4: Dana Point Harbor hazard vulnerability under a 50cm (1.6ft) SLR scenario

SLR of 3.3 ft appears to be a critical threshold for the harbor area in terms of exposure to flooding and inundation (Figure 6-5). Areas around the entire harbor would be inundated regularly during high tides with 3.3 ft of SLR. Specific areas subject to tidal flooding include the parks along the central island within the Harbor, walkways and adjacent parking lots of the two marina basins, low-lying parking lots in the region of the Catalina Express Terminal and boat launch, areas to the north and south of the eastern shipyard, parking lots to the north of the Ocean Institute, and park space within and adjacent to Baby Beach. Water depths would vary based on the severity of the high tides and could be inundated for minutes to hours at a time depending on tidal cycles. The harbor perimeter walkways and wharf parking lots have the greatest exposure to recurring tidal flood events due to their low-lying elevations, particularly those in the interior of the east basin. This type of inundation can also damage utility infrastructure that supports the harbor and surrounding development. Affected storm drains with shallow slopes subject to tidal influence could experience bio-fouling, a reduction in capacity, or both.

A 100-year storm event in combination with 3.3 feet of SLR increases flood extents across the entirety of the harbor, extending approximately 5 – 20 feet further inland into parking lots and low-lying areas surrounding harbor basins. A 3.3 ft rise in sea level could also impact the wave climate within the harbor. This magnitude of SLR combined with extreme storm waves would increase the wave energy transmitted through and over the west breakwater and could result in damage to the breakwater itself. Even if the breakwater remained intact, the increased wave energy could result in damage to interior revetments, navigation challenges during storm events, and possibly damage to moored vessels and docks.

High-tide flooding becomes more severe with 4.9 ft of SLR (Figure 6-6). Under this scenario CoSMoS projections show flooding across the entirety of parking lots surrounding the eastern and western basins of Dana Point Harbor. Tidal flood projections also fully cover the shipyard, boat launch, and significant portions of the dry boat storage area in the eastern basin. Within Dana Point Harbor Park tidal flooding approaches roadways and is projected to impact structures within parking lots as well as the police station located at the eastern end of the park. In the western basin high-tide flood areas have the potential to impact Ocean Institute structures along with the majority of parking lots surrounding the institute and nearby fishing pier. The park area behind Baby Beach will also undergo more severe tidal flooding, with flood projections now covering the majority of the area. A 100-year storm event in combination with this level of SLR again results in marginal increases in flood projections, notably within the Baby Beach parking area, dry boat storage areas, and areas surrounding the Dana Point Harbor Fishing Pier, where flood projections extend into Dana Point Harbor Drive.

In comparing the 4.9 and 3.3 ft SLR scenarios within Dana Point Harbor it is important to consider the increased frequency and duration of flooding as well as the greater geographic extent. Under 4.9 ft of SLR the flood hazard threshold seen in the 3.3 ft SLR scenario would no longer be limited to high tide events, instead occurring regularly and for longer durations. This type of frequent flood event has the potential to severely disrupt services throughout the Harbor that depend on maintaining access such as the Catalina Express Terminal, boat launch, and Baby Beach.

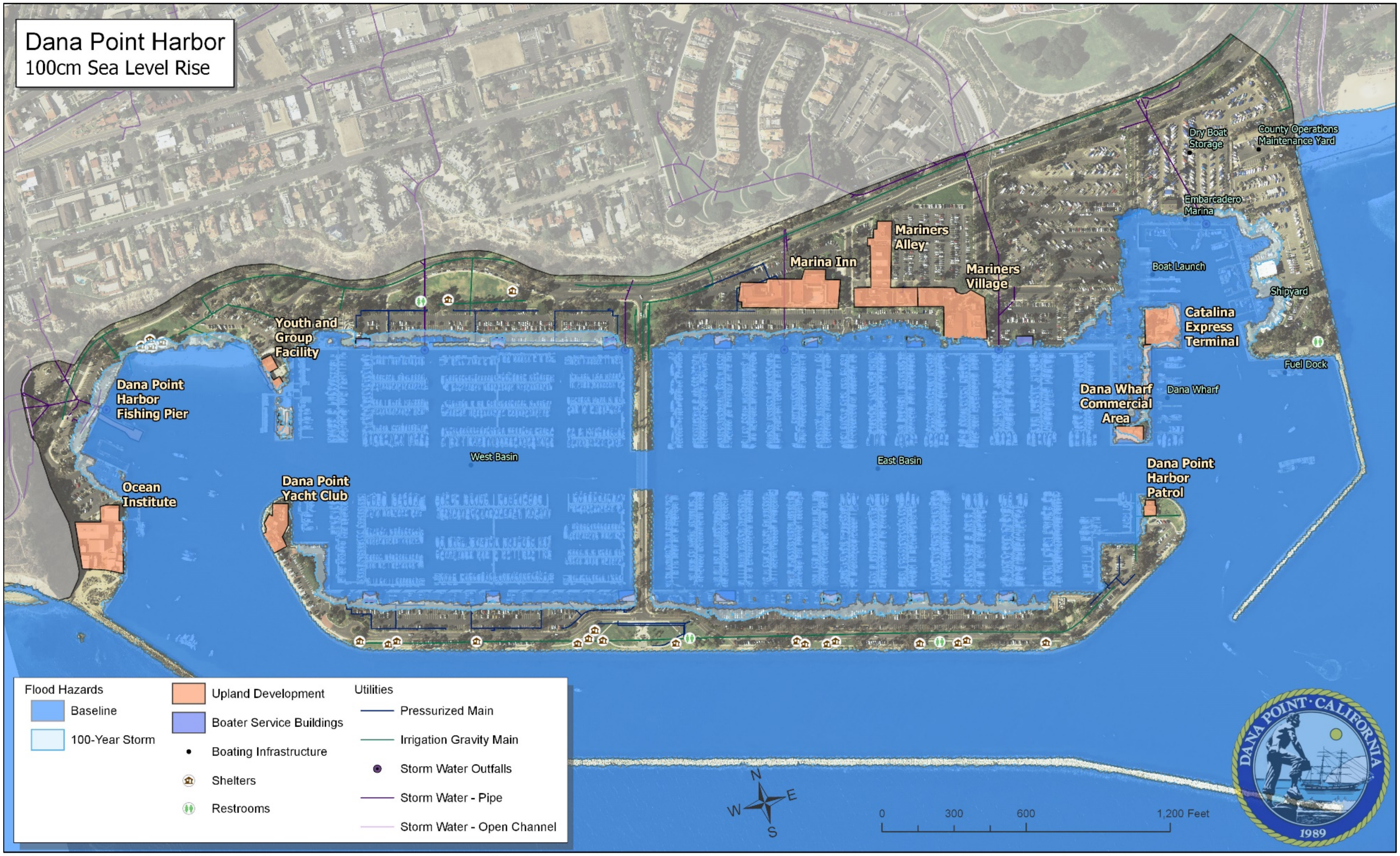

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Figure 6-5: Dana Point Harbor hazard vulnerability under a 100cm (3.3ft) SLR scenario

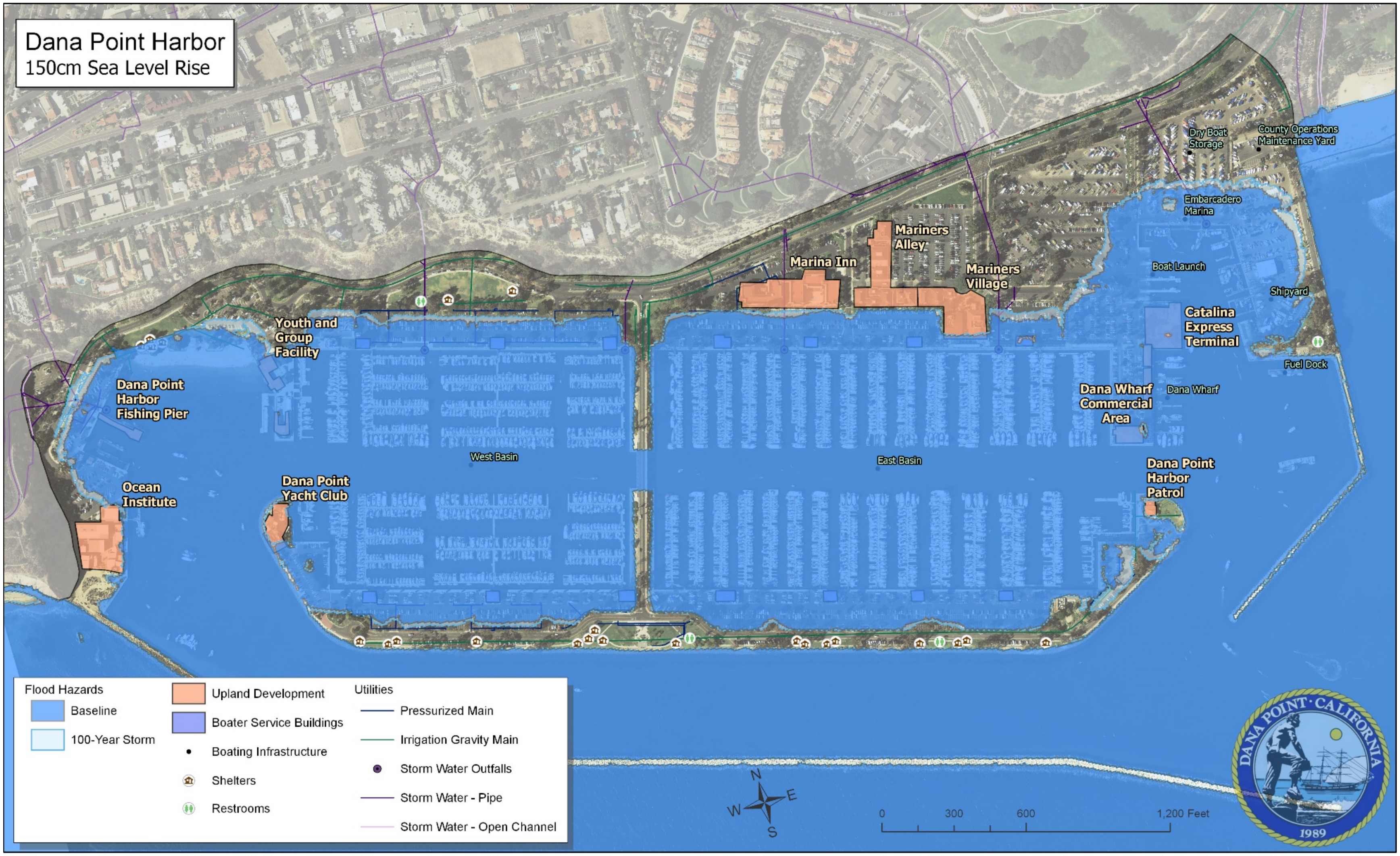

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Figure 6-6: Dana Point Harbor hazard vulnerability under a 150cm (4.9ft) SLR scenario

7. Vulnerability Assessment

The purpose of this assessment is to identify potential significant physical impacts and their various externalities to better understand future local hazard conditions under a range of SLR scenarios. A resource's vulnerability to SLR is a product of its exposure to hazards, its sensitivity to said hazards, and its adaptive capacity. Within the assessment exposure refers to the hazard type, duration, and frequency a coastal resource is subject to. Sensitivity describes the degree to which a resource is impaired by exposure to SLR hazards, and adaptive capacity addresses the ability of a coastal resource to adapt to evolving hazards over time.

7.1 Coastal Protection Infrastructure

7.1.1 Short-term Vulnerability (2030-2050)

Coastal protection infrastructure within Dana Point Harbor, including federally owned breakwaters, interior concrete bulkhead walls, and interior rock revetments has some degree of vulnerability under all SLR scenarios examined due to incremental reductions in the distance between structure height and water elevations, also known as freeboard. Under short-term SLR scenarios reduced freeboard of outer Harbor breakwaters is projected to result in increased wave transmission of approximately 0.6ft (Table 6-1), leading to increased wave action along interior revetments. Bulkheads within the Harbor interior will also see reduced freeboard, but overtopping is not projected except in select areas surrounding the Harbor boat launch.

Water levels under a 1.6ft SLR scenario are projected to remain below the majority of shoreline protection infrastructure within the Harbor, but structures may still be sensitive to any water elevations and wave heights that extend outside the original design. This may result in increased maintenance requirements even in the absence of structural failure. Loss of protective functions may also increase potential for navigational hazards due to shoaling of the main Harbor channel.

7.1.2 Long-term Vulnerability (2100)

Water levels are projected to extend beyond the majority of current shoreline protection infrastructure within Dana Point Harbor under a 3.3ft SLR scenario. Under a 4.9ft SLR scenario projections extend past all interior shoreline bulkheads and significant portions of rock revetments. Water levels projected under this scenario also approach the upper limits of the western Harbor breakwater.

Shoreline protection infrastructure in its current state will be highly sensitive to such hazards. Interior bulkheads are projected to be overtopped even under non-storm conditions, resulting in frequent loss of all flood protection benefits and reduced utility of landward resources. Wave overtopping of interior rock revetments is also likely to become more common due to substantial increases in wave transmission through outer breakwaters. In addition to increased flood hazards, increased wave action within the Harbor under long-term SLR conditions will reduce the safety of navigational channels through increased wave height and shoaling.

Impacts to shoreline protection infrastructure can be significantly mitigated through adaptation efforts, potentially reducing long-term vulnerability of the structures themselves and any landward resources. While short-term adaptation is likely to center on maintenance or enhancements to existing structures, long-term adaptation efforts may require significant redesign or realignment of shoreline protection infrastructure to maintain current function.

7.2 Ocean Institute

7.2.1 Short-term Vulnerability (2030-2050)

Short-term SLR hazard vulnerability is limited for the Ocean Institute primarily due to minimal hazard exposure. CoSMoS coastal flood projections for current conditions and a 1.6ft SLR scenario do not extend past current shoreline boundaries even when considering 100-year storm conditions. Access to the Ocean Institute is also projected to remain unaffected under these scenarios.

7.2.2 Long-term Vulnerability (2100)

The Ocean Institute becomes more vulnerable under long-term SLR projections due to increased SLR hazard exposure. The 3.3ft SLR scenario represents a potential exposure threshold for the structure as coastal flood projections extend past the shoreline in the vicinity of the adjacent boat dock and parking areas. This is the case for both baseline and 100-year storm conditions, indicating potential for tidal flooding within the northern parking lot and along the eastern shoreline of the facility. SLR hazard exposure increases incrementally under the 4.9ft SLR scenario. Under this scenario baseline and 100-year storm flood projections extend further inland along the surrounding shoreline and northern parking lots.

Flood projections under the 3.3ft and 4.9ft SLR scenarios reach only the outermost portions of the Ocean Institute, reducing the long-term vulnerability of the structure. Though large coastal structures such as the Ocean Institute can experience extensive damage if exposed to coastal flood hazards, the limited extent of SLR hazard projections surrounding structures makes significant structural damage unlikely. The tidal flooding projected under the 3.3ft and 4.9ft SLR scenarios will more likely disrupt access to the Ocean Institute due to flooding of nearby parking areas, causing repeated disruptions to services if unaddressed. Flooding beyond the current shoreline is also likely to impact the normal use and operation of the attached gangway and floating dock, limiting public access to community resources such as the historic tallship Pilgrim.

The relatively high elevation of Ocean Institute structures bolsters its long-term adaptive capacity. Large engineered structures often have a low adaptive capacity due to the high costs associated with adaptation measures, but low-cost solutions such as temporary flood barriers or minor retrofits will likely be able to address projected flood hazards for Ocean Institute structures under all SLR scenarios evaluated within this study. More exposed areas of the Institute such as attached docks and gangways may require more substantial adaptation measures such as structural elevation in order to maintain access under long-term SLR scenarios. Any major remodeling efforts between now and the end of the century provide an opportunity to incorporate additional SLR resilience measures as hazard projections are refined.

7.3 Boating and Marina Infrastructure

7.3.1 Short-term Vulnerability (2030-2050)

Boating and marina infrastructure within Dana Point Harbor have a low vulnerability to SLR hazards in the short-term. Hazard exposure is limited, as both baseline (non-storm) and storm flood projections under current conditions do not extend past the shoreline of the eastern or western marina basins. Increased flood hazard exposure is seen in limited areas under the 1.6ft SLR scenario, primarily along the Embarcadero Marina and nearby boat launch. Storm flood projections under this scenario indicate the potential for temporary disruptions from shallow flooding and increased wave action and surge at the boat ramp during major storm events.

Boating and marina infrastructure also have a low sensitivity to short-term SLR hazards. These structures are designed to accommodate frequent changes in water levels including current tidal extremes, and adaptive capacity is built into floating infrastructure that can rise with additional SLR. While SLR will increase the range of tidal extremes in the short-term, it is unlikely that a 1.6ft SLR scenario will result in appreciable damages. A possible exception is the boat launch located north of the Catalina Express Terminal, where increased wave action and surge during storm events with 1.6ft SLR could damage dock structures and disrupt access.

7.3.2 Long-term Vulnerability (2100)

The vulnerability of boating and marina infrastructure increases substantially when considering potential long-term SLR hazards. Hazard exposure becomes widespread with 3.3ft SLR. Under this scenario both storm flood projections and baseline flood projections extend beyond the shoreline throughout the eastern and western Harbor basins as well as in the area surrounding Embarcadero Marina. Baseline flood projections extend further inland under the 4.9ft SLR scenario, well beyond the current shoreline and location of existing boating and marina infrastructure.

Flood projections that extend beyond the current Harbor shoreline significantly alter the hazard sensitivity of boating and marina infrastructure such as floating docks or piers. Though these structures can easily accommodate water levels up to the current shoreline, structures are likely to experience extensive damage if water levels exceed the elevation of the shoreline connection point or initial design limits, creating a tipping point for SLR hazard damage. Boater service buildings are also likely to be significantly damaged by frequent tidal inundation. Frequent loss of access to boating and marina infrastructure caused by tidal flooding also contributes to long-term SLR vulnerability. Even if structural elements remain undamaged, the recurrent disruption of access and use severely reduces the utility of boating and marina infrastructure.

The adaptive capacity of boating and marina infrastructure remains relatively high when considering long-term SLR hazard projections. Elevation or relocation of floating infrastructure could be incorporated when the existing dock systems reach the end of their service life. An exception to this would be piling-supported pier structures such as the Dana Point Harbor Fishing Pier which have a fixed deck elevation and therefore require a significant overhaul to accommodate higher water levels associated with long-term SLR hazards. Higher relief areas landward of existing boating and marina infrastructure are primarily occupied by parking lots. Parking lots and boater service buildings facilities could be elevated, protected with higher bulkhead walls, or re-configured to improve long-term adaptive capacity.

7.4 Coastal Access and Recreation

7.4.1 Short-term Vulnerability (2030-2050)

The primary coastal recreation resource that is vulnerable to SLR hazards in the short-term is Baby Beach. Other major recreational structures such as the nearby Youth and Group Facility and Dana Point Yacht Club have minimal hazard exposure up to the 1.6ft SLR scenario. Coastal access points within Dana Point Harbor are also not projected to be impacted under this short-term scenario.

As a popular destination for locals and visitors with an estimated annual attendance over 1.2 million (Everest, 2013), Baby Beach remains sensitive to the loss of sandy beach area projected under a 1.6ft SLR scenario. The gentle slope of the sandy beach area contributes to its hazard sensitivity. Flood projections indicate that the beach may retreat 20 to 30 feet landward under a 1.6ft SLR scenario, reducing the overall carrying capacity of the beach and impacting access opportunities. Existing spring tide and 100-year storm conditions will also be exacerbated under a 1.6ft SLR scenario. Flood projections under this scenario show potential tidal inundation of more than half of the current beach area and near total loss of sandy beach area during major storm events. Substantial impacts to coastal access and recreation opportunities are likely if these conditions occur during peak beach visitation times.

The short-term SLR hazard vulnerability of Baby Beach is mitigated by the adaptive capacity of the area. Traditional forms of beach nourishment remain as options for adaptation, but alternative strategies may also be feasible in the area. Open space is available immediately landward of the sandy beach area, potentially allowing for gradual retreat of the beach area over time to maintain beach width as water elevation increases.

7.4.2 Long-term Vulnerability (2100)

Coastal access and recreation resources within Dana Point Harbor are highly vulnerable to projected long-term SLR hazards. Hazard exposure for Baby Beach, the Harbor Youth and Group Facility, and grassy park amenities with the island increases substantially under a 3.3ft SLR scenario. Under this scenario tidal flooding is projected to fully inundate sandy areas of Baby Beach, and storm flooding is projected to extend inland into the park area located landward of the beach. Tidal flooding with 3.3ft SLR is also projected to extend inland along the shoreline surrounding the Youth and Group Facility. A number of parking lots throughout the Harbor are also projected to be inundated during spring tide and storm events under this scenario, reducing coastal access opportunities. SLR hazard exposure is further exacerbated under a 4.9ft SLR scenario. Tidal flood projections under this scenario show potential inundation of the park area landward of Baby Beach including several park shelters, the full extent of the Youth and Group Facility, the majority of Harbor basin parking lots, and the Dana Point Yacht Club.

Many of the coastal access and recreation resources exposed to potential long-term SLR hazards are highly sensitive to these impacts. Large structures such as the Youth and Group Facility or Dana Point Yacht Club are likely to experience substantial damage during flood events, especially if structures are exposed regularly during tidal extremes. While significant structural damage is unlikely within Baby Beach or Harbor basing parking lots, the extensive and repeated tidal inundation seen under 3.3ft SLR and 4.9ft SLR is likely to severely reduce the utility of these resources.

Long-term hazard vulnerability for coastal access and recreation resources is again mitigated to a degree by the lack of major landward development. In many cases landward areas are occupied by open park space or parking lots, providing flexibility for potential alternative SLR hazard mitigation strategies if traditional means such as shoreline protection or structural elevation become infeasible. These areas become more limited under the 4.9ft SLR scenario, particularly in the areas surrounding Mariners Alley.

7.5 Upland Development

7.5.1 Short-term Vulnerability (2030-2050)

Upland development within Dana Point Harbor, including the Marina Inn, Mariners Alley, Mariners Village, and the retail area at the southern portion of Dana Wharf, has minimal short-term SLR hazard vulnerability due to the low hazard exposure. Tidal and storm flood projections under a 1.6ft SLR scenario do not extend beyond the shoreline in the eastern Harbor basin, preventing any structural flood impacts.

7.5.2 Long-term Vulnerability (2100)

When considering potential long-term SLR hazards, upland development is most vulnerable at the southern portion of Mariners Village and within Dana Wharf. Tidal flood projections under a 3.3ft SLR scenario extend beyond the shoreline into the patio area and structures of Mariners Village. Large portions of Dana Wharf are also projected to be inundated under this scenario. Tidal flood projections extend further inland under a 4.9ft SLR scenario, encompassing additional areas of Mariners Village and the majority of parking lots south of the Marina Inn and Mariners Alley. Dana Wharf is projected to be completely inundated by tidal flooding with 4.9ft SLR. Storm flood projections under a 4.9ft SLR scenario show additional potential for temporary flooding of the southern portion of the Marina Inn.

Though long-term hazard exposure remains relatively low for the Marina Inn and Mariners Alley, the long-term vulnerability of major structures within Mariners Village and Dana Wharf remains a concern due to high hazard sensitivity. Frequent tidal flooding along the southern portions of Mariners Village and Dana Wharf as projected under 3.3ft SLR is likely to cause structural damages and lead to significant disruptions of use. Additional tidal flooding of structures and parking areas as projected under 4.9ft SLR will result in more frequent and severe damages and impacts to normal use and operations, especially within Dana Wharf where flood projections fully cover existing structures.

Adaptive capacity is also limited for exposed upland development within Dana Point Harbor. Significant financial barriers are often an issue when implementing SLR adaptation measures for large structures such as those found in Dana Wharf, Mariners Alley, Mariners Village, and the Marina Inn. Structural elevation or relocation, for instance, may prove to be cost-prohibitive for major development even with available areas at higher relief immediately landward. Floodproofing and retrofitting to address long-term SLR hazards remain as options to address increasing risk and vulnerability over time.

7.6 Transportation Infrastructure

7.6.1 Short-term Vulnerability (2030-2050)

Transportation infrastructure such as the Catalina Express Terminal and local roads within Dana Point Harbor have low vulnerability to short-term SLR hazards. The only area of potential hazard exposure is the boat launch just north of the Catalina Express Terminal, where storm flood projections under a 1.6ft SLR scenario extend slightly inland and approach Terminal structures. Though this small amount of hazard exposure during extreme storm conditions is present, these conditions are unlikely to result in any damages or disruptions to Catalina Express Terminal operations or use of local roads.

7.6.2 Long-term Vulnerability (2100)

The 3.3ft SLR scenario represents a critical hazard exposure threshold for transportation infrastructure within Dana Point Harbor. Tidal flood projections under this scenario become extensive in the areas surrounding the Catalina Express Terminal, covering large portions of Dana Wharf and the area between the boat launch and the eastern Harbor basin. Tidal flood projections also extend into the outer limits of Catalina Express Terminal structures and select areas of coastal roadways. Under a 4.9ft SLR scenario tidal flood projections cover the entirety of Catalina Express Terminal structures and the surrounding area. Tidal flood projections also extend across local roads in the areas of the Embarcadero Marina, boat launch, and Dana Wharf. Projections also show potential for temporary storm flooding along roadways landward of the Dana Point Harbor Fishing Pier.

The Catalina Express Terminal is highly sensitive to long-term SLR hazard projections. Repeated tidal flooding in surrounding areas is likely to limit access to Terminal structures and cause frequent disruptions in Terminal operations. Tidal flooding is also likely to cause recurring damages to Terminal structures if not addressed, especially under 4.9ft SLR flood hazard projections. Local roadways within the harbor area are also likely to experience disruptions in use if subject to tidal flooding through, major structural damages may not occur.

The adaptive capacity of the Catalina Express Terminal is limited due to its coastal-dependent use, which necessitates that structures be located close to the shoreline to facilitate ferry passenger loading and unloading. No major structures exist landward of the terminal, but relocation would likely be complicated by reconfiguration of Harbor infrastructure to maintain necessary proximity to the shoreline.

Local roads that provide access throughout the harbor will likely need to be reconfigured or elevated to avoid projected hazard areas while maintaining shoreline access. However, the primary vehicular access route to the harbor, Dana Point Harbor Drive, is not exposed to flooding until SLR exceeds 6.6 feet. While significant adaptation efforts would be required for roads and parking within the harbor footprint there is higher adaptive capacity in the regional transportation network providing vehicular access to the harbor.

7.7 Utilities Infrastructure

7.7.1 Short-term Vulnerability (2030-2050)

Stormwater infrastructure has low vulnerability to short-term SLR hazards. 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 1.6ft SLR scenario 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.

7.7.2 Long-term Vulnerability (2100)

Long-term SLR hazard projections have a greater potential to disrupt the normal function of stormwater and electrical infrastructure. Tidal flood projections under a 3.3ft SLR scenario extend beyond the shoreline at all stormwater outfall locations within Dana Point Harbor, increasing the frequency and duration of stormwater outfall inundation. Electrical transformers, switchgear and other infrastructure that provide power to the marinas could also be vulnerable to this flooding. Tidal flood projections with 4.9ft SLR will further exacerbate this effect and increase potential for upstream flooding. Under each SLR scenario the potential for backwater flooding is greatest if extended tidal inundation coincides with an extreme rainfall event.

Note, the assessment of utility infrastructure was not comprehensive and was limited to the data gathered as part of the resource inventory effort which primarily consisted of stormwater lines, irrigation lines and some water supply infrastructure. Therefore, additional utility infrastructure vulnerabilities (electrical, telecommunications, wastewater, etc.) may exist in the SLR hazard zones identified within the harbor. Coordination with utility owners regarding location and sensitivity of their infrastructure along with some field assessments would be required to provide a more comprehensive assessment of these vulnerabilities.

8. Financial Costs of SLR

Dana Point Harbor and associated tidelands include several sources of revenue generation. Total tideland revenues were greater than $27 million in 2017. These revenues are generated almost entirely through rents and concessions, which account for over $25 million of revenue. The next most significant source of revenue is park and recreation fees that account for over $700,000. Other revenue streams include other charges for services, interest accrues, and other miscellaneous sources. The total value of tideland assets is approximately $102 million.

Given the majority of tidelands revenue is generated from rents and concessions, the estimate of financial impacts will evaluate the potential for structural damage to these facilities under each SLR scenario. This will provide an indication of where and when the potential for structural damage and therefore impacts to this revenue stream may occur. However, this is not intended to be a comprehensive economic analysis of all direct and in-direct impacts resulting from SLR and coastal hazards.

Potential damage to Tideland structures within Dana Point Harbor resulting from SLR and coastal hazards are based on depth-damage relationships established through the USACE North Atlantic Coast Comprehensive Study (NACCS), which are designed to better capture damage due to coastal storms as opposed to riverine flooding (USACE, 2015). The USACE functions provide estimates of minimum, most likely, and maximum damages to structures as a percentage of total structure value. Flood damage estimates due to inundation are based on USACE prototype structure types found within the harbor. Individual damage assessments are provided for major structures within the harbor, and more generalized damage assessments are made for structures located in the inner and outer portions of harbor basins.

One challenge in applying the depth damage functions to structures in Dana Point Harbor is to identify the most representative prototype structure evaluated in the NACCS study. The prototypes evaluated in the NACCS report that are most representative of structures in Dana Point Harbor are shown in Figure 8-1. Prototype 2 (Commercial Engineered) is most representative of the upland development around Dana Point Harbor. The depth damage function for Prototype 2 indicates structural damage increases significantly from 1 to 3 feet of flood depth, with 50% damage occurring at a flood depth of 6-7 feet. Prototype 7A (Building on Open Pile Foundation) is most representative of the fishing pier. This function indicates a steep increase in damage when the flood depth reaches the finish floor elevation (FFE) of a pile supported structure.

For each prototype considered in the NACCS report a minimum, maximum, and most likely depth damage function is provided. The range of expected damage is a function of individual building characteristics including structure type, age, utility location, and condition. Many of these variables are unknown so the full range of damage potential is provided in the following tables.

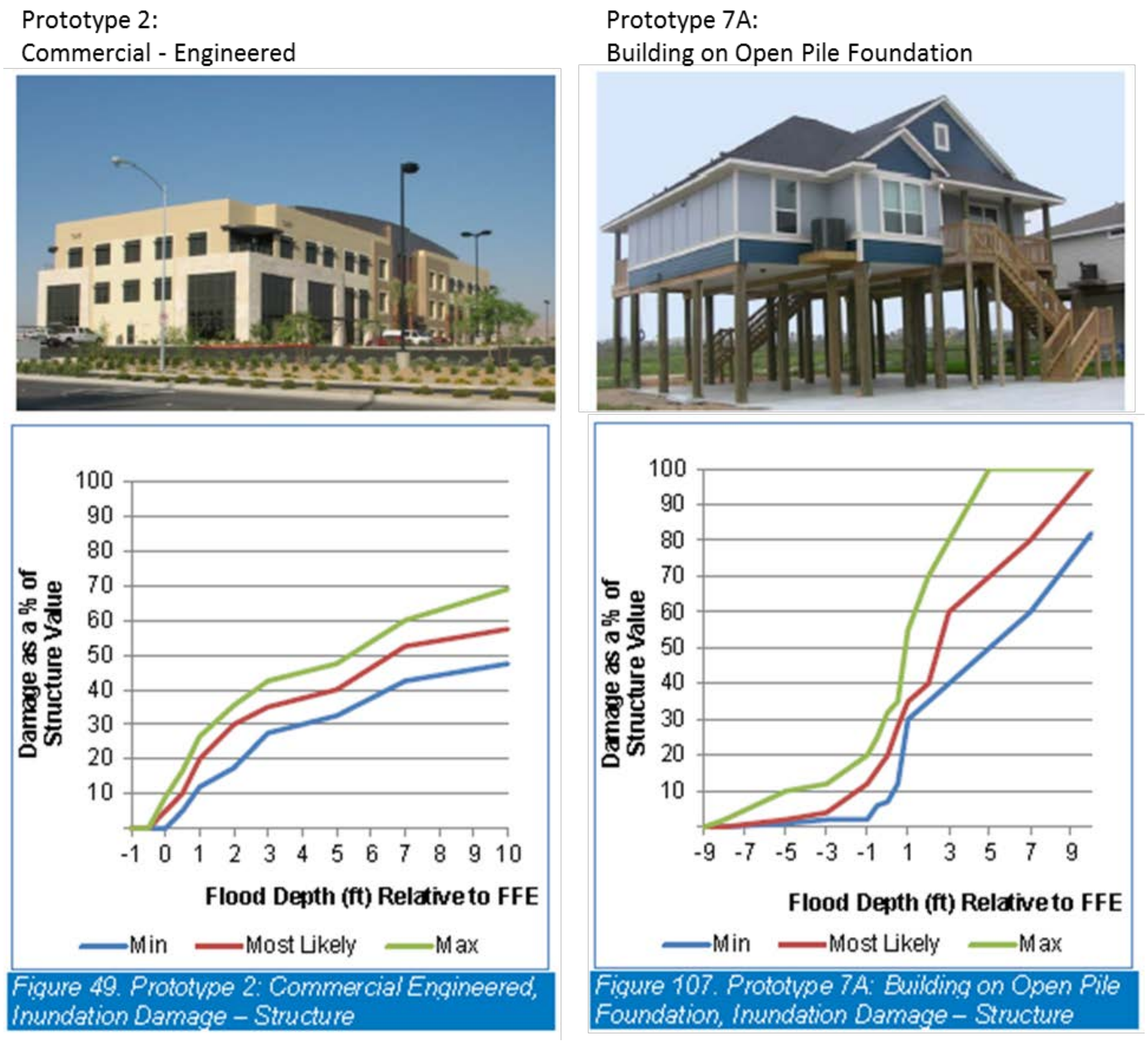

Figure 8-1: NACCS prototype 2 and 7A depth damage functions

8.1 Structural Damages

8.1.1 Upland Development

Generalized inundation damage estimates for upland development within Dana Point Harbor are based on NACCS Prototype 2: Commercial Engineered depth-damage relationships. Analysis is generalized due to the relative uniformity of flood depths surrounding inner harbor basins and the proximity to the shoreline of many structures. Structures that do not share these general characteristics are analyzed individually.

No structural damages are projected under current conditions for such structures, and flood depth projections with 1.6ft SLR show minimal potential for structural damages. Damage projections increase substantially under the 3.3ft SLR scenario as significant impacts become likely. Marginal increases in flood inundation damage projections are observed under the 4.9ft SLR scenario, with the largest increase seen in minimum damage projections (Table 8-1).

Table 8-1: Upland development structural damages

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	0	0	0
1.6	0	5	9
3.3	12	20	27
4.9	18	30	36

8.1.2 Ocean Institute

Inundation damage estimates for the Ocean Institute are based on NACCS Prototype 2: Commercial Engineered depth-damage relationships. Flood levels in the 0ft, 1.6ft, and 3.3ft SLR scenarios are not projected to cause any structural damages, and flooding in the 4.9ft scenario is projected to result in only minimal structural damages (Table 8-2).

Table 8-2: Ocean Institute structural damages

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	0	0	0
1.6	0	0	0
3.3	0	0	0
4.9	0	5	9

8.1.3 Dana Point Harbor Fishing Pier

Inundation damage estimates for the Dana Point Harbor Fishing Pier are based on NACCS Prototype 7A: Building on Open Pile Foundation depth-damage relationships. Damage estimates are based on flood depth projections seen at the base of the pier structure. Minimal structural damages are projected under current conditions, and damage projections under a 1.6ft SLR scenario show only a small increase. The 3.3ft SLR scenario shows a significant increase in structural damages, likely exceeding a third of the overall structural value. Minimum and likely inundation damage estimates increase slightly with 4.9ft of SLR, with maximum damage estimates showing a larger increase (Table 8-3).

Table 8-3: Dana Point Harbor Fishing Pier structural damages

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	2	4	12
1.6	6	16	25
3.3	30	35	55
4.9	35	40	70

8.1.4 Dana Point Harbor Patrol Station

Inundation damage estimates for the Dana Point Harbor Patrol Station are based on NACCS Prototype 2: Commercial Engineered depth-damage relationships. Flood depth projections show little potential for structural damage under current conditions and the 1.6ft SLR scenario. Minimum and likely damage estimates increase under the 3.3ft SLR scenario but remain relatively small, though maximum damage estimates show potential for more severe impacts. Significant structural impacts become likely under the 4.9ft SLR scenario (Table 8-4).

Table 8-4: Dana Point Harbor Patrol Station structural damages

SLR (ft)	Minimum Damage	Most Likely	Maximum Damage
0	0	0	0
1.6	0	0	0
3.3	5	10	17
4.9	18	30	36

8.2 Non-Market Value Loss

Non-market value refers to those goods and services that cannot be directly measured through a market price when bought or sold. The non-market value of coastal resources is defined in terms of recreation value and ecosystem services such as water quality improvements in wetlands or the provision of ecological diversity within coral reefs. Though the majority of Dana Point Harbor is engineered in nature, non-market values loss within Dana Point Harbor is likely due to projected significant loss of sandy beach area at Baby Beach as SLR increases.

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

Determination and quantification of non-market values associated with beaches remains challenging due to the inherent variability between locations. 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. The U.S. EPA estimates of the economic value of coastal ecosystems are used in this analysis to define Baby Beach value loss in a spatially explicit manner. Value estimates are 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 and 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 8-5).

Table 8-5: Non-market values of California beach ecosystems in 2008 U.S. dollars (Raheem et al., 2009)

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

Baby Beach contains approximately 1.1 acres of sandy beach area, resulting in a total annual value of approximately $62,000 based on EPA non-market service valuations and adjustments to 2018 dollars using Consumer Price Index values. Sea level rise is projected to significantly reduce this sandy beach area. While CoSMoS shoreline change projections do not extend to areas within Dana Point Harbor, estimates of beach loss can be made from changes in flood extents, presented in Table 8-6.

Table 8-6: SLR impacts on spatially explicit non-market values for Baby Beach

SLR Scenario	Percent Loss of Beach Area	Service Flow Per Year
0 feet	0	$ 62,000
1.6 feet	20	$ 49,600
3.3 feet	50	$ 31,000
4.9 feet	90	$ 6,200

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 Baby Beach 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 and 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 (Kidlow and Pendelton, 2006) and recent CCC studies of beach value in southern California (CCC, 2017).

Past studies have estimated an annual beach attendance of 1,200,000 at Baby Beach (Everest, 2013). 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 Baby Beach, limiting any excess recreational carrying capacity. The results of this analysis are presented in 2018 U.S. dollars in Table 8-7.

Table 8-7: SLR impacts on recreational values using consumer surplus estimates for Baby Beach

SLR Scenario	Percent Loss of Beach Area	Annual Recreational Value
0 feet	0	$ 48,000,000
1.6 feet	20	$ 38,400,000
3.3 feet	50	$ 24,000,000
4.9 feet	90	$ 4,800,000

9. SLR Adaptation Strategies

Sea level rise is unique among other hazard because it's a slow moving disaster that will develop over the span of decades. The vulnerabilities identified for sea level rise projections at the end of the century are overwhelming, but the slow moving nature of climate change and sea level rise allows for time to plan, fund and mitigate these impacts.

This section presents strategies for protecting and preserving resources impacted by sea level rise. The strategies are organized by asset and relevant time horizon for each strategy. Short-term strategies focus on addressing vulnerabilities identified for ~1-2 feet of SLR, which capture all but the most extreme sea level rise projections through mid-century (2050). Long-term strategies focus on addressing the vulnerabilities identified for the ~3-5 foot SLR scenarios. There is a 33% probability that SLR will exceed 3 feet by 2100 and a 3% probability of exceeding 5 feet by 2100 (OPC, 2018).

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 a SLR adaptation context, protection refers to those strategies that employ hard or soft engineered measures to defend existing development from future SLR hazards without changes to the development itself. Accommodation refers to strategies that involve modifying existing development or designing new development in a way that reduces the potential future impacts of SLR. Adaptation strategies centered on retreat focus on measures to relocate or remove existing development from identified high-hazard areas while limiting the construction of any new development in such areas. In practice, SLR adaptation often relies on hybrid approaches that combine elements from multiple categories over different spatial and temporal scales.

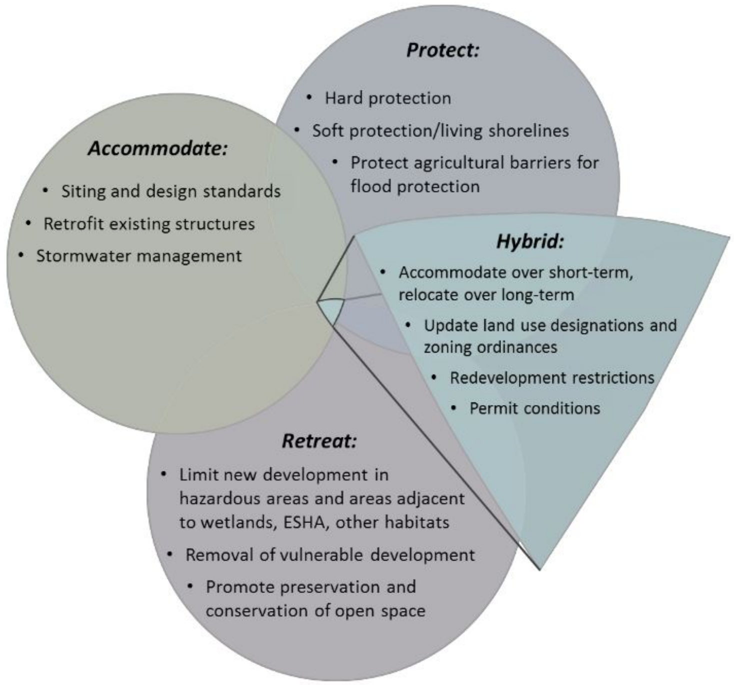

Figure 9-1: General SLR adaptation strategies and mechanisms (California Coastal Commission, 2015)

9.1 Baby Beach

Higher water levels from SLR will result in the loss of dry beach area at Baby Beach impacting recreational beach users, swimmers, kayakers, and paddle boarders. Flood projections indicate that the dry beach may retreat 20 to 30 feet landward under a 1.6ft SLR scenario, a 20% reduction in beach area.

An opportunistic beach nourishment program could be an effective measure in the short-term to widen the beach and offset impacts from rising sea levels. Nourishment of Baby Beach occurs during DPH maintenance dredging cycles, but additional more frequent nourishment may be required. These types of programs have been implemented in numerous California beach cities and typically involve designated receiver beaches and requirements for sediment compatibility that have been subject to the environmental review process. Given the relatively small pocket beach and sheltered wave climate even a small amount of beach quality sediment (i.e. 1,000 to 5,000 cubic yards) could offer significant and lasting benefits at Baby Beach. Potential sources of sediment could be harbor maintenance dredging, sediment removed from flood control facilities and upland construction projects that involve excavation of beach compatible material.

Opportunistic nourishment alone may not be sufficient to maintain a sandy beach area under high to extreme rates of sea level rise. A re-configuration of the park amenities could improve the long-term sustainability of recreation opportunities at Baby Beach. These amenities include a low wall, sidewalk and picnic tables, presently located along the back beach. The re-configuration could involve elements of managed retreat and dune restoration combined with relocated park amenities between Dana Point Harbor Drive and the sandy beach area.

9.2 Upland Development

Existing upland development within Dana Point Harbor (e.g. Marina Inn, Mariners Alley, Mariners Village, Dana Wharf and the Ocean Institute) has minimal short-term SLR vulnerability since the existing bulkhead wall has enough adaptive capacity to accommodate 1.6 feet of SLR. Over the long-term, however, SLR of 3 ft or more would result in significant coastal flooding of this development, especially at Dana Wharf and Mariners Village.

A hybrid adaptation strategy consisting of improved protection, accommodation and relocation could reduce the long-term hazard exposure to upland development in the harbor. Below is a description of how each strategy could be applied around the harbor:

Protection

There are nearly 4 miles of shoreline around the harbor, most of which consist of a bulkhead wall and/or a rock revetment that protects and stabilizes the upland development. In order to adapt to SLR over the long-term, this perimeter protection system will need to be modified. These modifications could include retrofits or replacement of the existing perimeter protection system to elevate the crest to keep pace with SLR. Another option could be to install features such as berms and walls throughout the landscape to provide a secondary line of flood protection. A key challenge of these protective strategies will be preserving access to the marinas through, or over the elevated flood protection barriers.

Accommodation

Coastal resources and structures can accommodate SLR hazards through both modification of existing development and design of new development. Accommodation strategies based on structural modification include actions such as structural elevation, retrofitting for flood resilience, and the use of flood resistant materials during construction (Figure 9-2). 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. Temporary or permanent floodproofing retrofits can be employed to reduce the impacts and recovery time following flood events. Improvements to stormwater infrastructure is another example of an accommodation strategy discussed in Section 0.

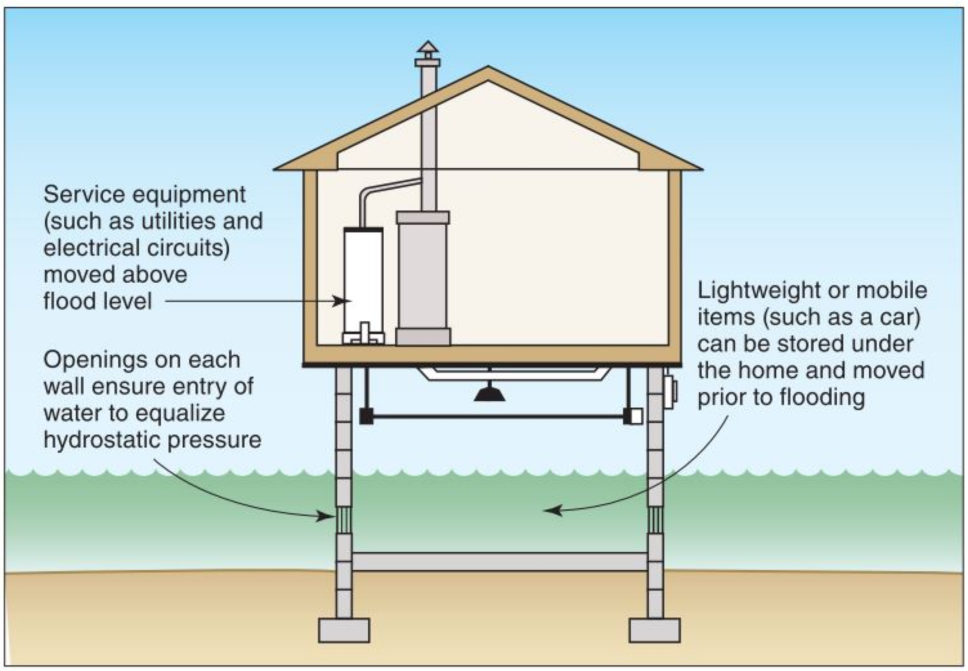

Figure 9-2: Example cross section of an elevated home using continuous foundation walls (FEMA, 2014)

Retreat

Directly removing or relocating vulnerable structures away from hazard areas represents an effective long-term form of SLR adaptation under high to extreme SLR scenarios. Retreat strategies can be employed for cases in which any feasible protection or accommodation strategies become insufficient to address coastal hazards. There is some topographic variation in the harbor which provides some opportunity for relocation of high value and long-term development to higher ground. The Marina Inn is an example of existing development that is setback from the waterfront and elevated such that it could accommodate up to ~5 feet of sea level rise.

9.3 Stormwater Infrastructure

The widespread flooding predicted for SLR of 3 ft or more would place a major burden on the stormwater infrastructure of the harbor to collect and convey flooding away from sensitive development. SLR will reduce the capacity of gravity storm drain lines as higher ocean water levels cause backwater effects that reduce conveyance capacity. Coincident rainfall and high tide events could result in localized flooding for SLR scenarios less than 3 feet.

There are several ways in which stormwater infrastructure can become more resilient to SLR hazards. Green infrastructure strategies (e.g. permeable pavement and rainwater harvesting) can provide multiple benefits of reducing runoff volume and improving water quality. Bio-swales, detention basins and other strategies can provide additional storage to reduce the extent and duration of flooding. Conveyance systems can be adapted to accommodate higher water levels by installing tide gates, increasing capacity of conveyance structures, or installing pump stations.

An example of stormwater infrastructure improvements to accommodate increased coastal and inland flooding is illustrated in Figure 9-3. This graphic illustrates multiple features such as impermeable surfaces, deployable flood walls and pump stations in order to mitigate the potential for increased flooding in the future.

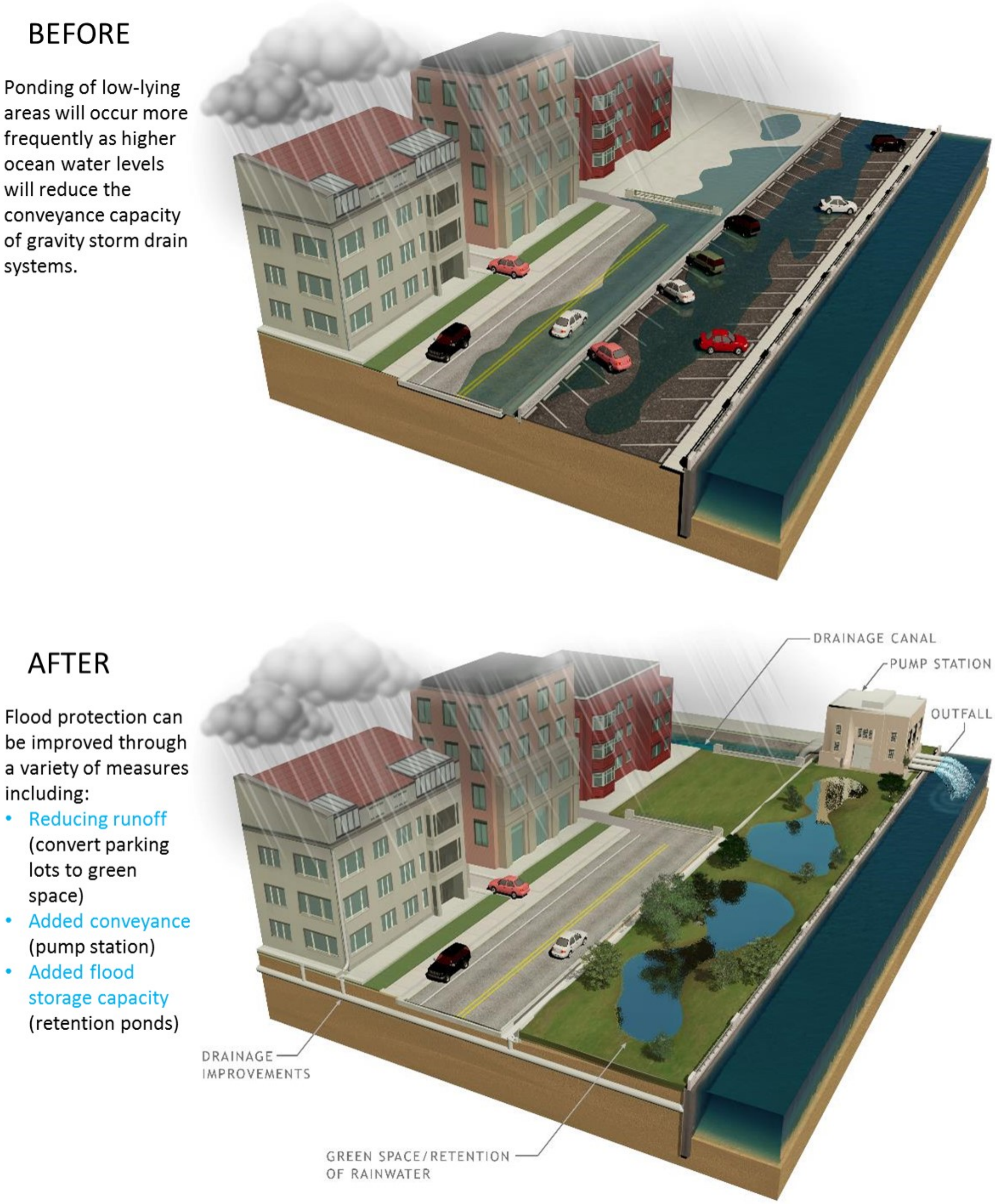

Figure 9-3: Example of landside drainage improvements to reduce flooding (USACE, 2015)

9.4 Boating and Marina Infrastructure

The infrastructure which supports commercial and recreational boating activities in Dana Point Harbor include protective structures (east and west breakwaters), floating docks and piles, utilities, launch ramp, boater service buildings and parking. Some adaptation strategies for these facilities are described in this section.

9.4.1 Wave Protection

The eastern and western breakwaters of Dana Point Harbor provide critical wave protection to inner harbor infrastructure and navigability within the harbor. These structures will be exposed to greater wave heights and water levels as sea levels rise. If wave heights exceed initial design values, or if breakwater infrastructure is not adequately maintained under increased wave exposure, the functionality of breakwater structures may decline significantly under projected SLR scenarios. Additionally, increased shoaling within the main channel is likely to occur, resulting in the need for increased frequency of maintenance dredging.

Overtopping and wave transmission can be reduced through several structural means including elevation of crest height, slope adjustments, and additional armoring to reduce permeability. If redesign or reinforcement is not feasible, additional maintenance can also be employed to ensure maximum functionality of structures in their current state. Maintenance could also be supplemented by secondary wave protection within the harbor, providing a level of redundancy in the event of breakwater failure. Breakwater adaptation measures can also incorporate “green” design elements aimed at enhancing the ecological value of the structure. Figure 9-4 is an illustration of a “Living Breakwater” concept currently in the design phase along the southwestern shoreline of Staten Island, New York. This concept was developed through the Resilient by Design competition to respond to damage from Superstorm Sandy and was awarded $60 million of Community Development Block Grant Disaster Recovery (CDBG-DR) funds. The living breakwater concept applies several ECOncrete® products designed to increase local biodiversity and biological productivity.

Further coordination with the U.S. Army Corps of Engineers would be required for any breakwater modifications as the breakwaters are Federal structures.

9.4.2 Access and Parking

Vehicular access and parking is an essential element of the boating infrastructure in Dana Point Harbor. Although Dana Point Harbor Drive has a low exposure to SLR and coastal flooding, many of the parking lots and boater service buildings are exposed to flooding with 1.6 to 3.3 feet of SLR. Some adaptation strategies could include improved flood storage or conveyance infrastructure (Section 9.3), barriers to prevent flooding of the parking areas (Section 9.2), or simply elevating the parking areas.

9.4.3 Floating Docks, Piles and Utilities

The floating docks, guide piles and utility infrastructure of the marinas are perhaps the most adaptive infrastructure in the Harbor since they are designed to function with the ~8 foot tide range. The floating docks are held in place by a system of anchors or guide piles which vary around the harbor. The adaptive capacity of the existing dock systems are a function of their freeboard/tolerance for high water levels of the future.

The typical service life of floating docks is 20-30 years with some newer products designed to last up to 50 years. In most cases, the service life of the existing docks will expire before SLR becomes a major concern since the likely range of SLR over the next few decades is in the 0.5-1 foot range. Therefore, SLR adaptation strategies for marina infrastructure can be incorporated into planning and design of future marina upgrades. A key question will be whether the existing piles could remain, or if new (higher) guide piles will be needed to accommodate SLR over the facilities service life. Other marina elements to consider in future project planning include landside utility infrastructure and access gangways which may need to be modified to accommodate higher water levels.

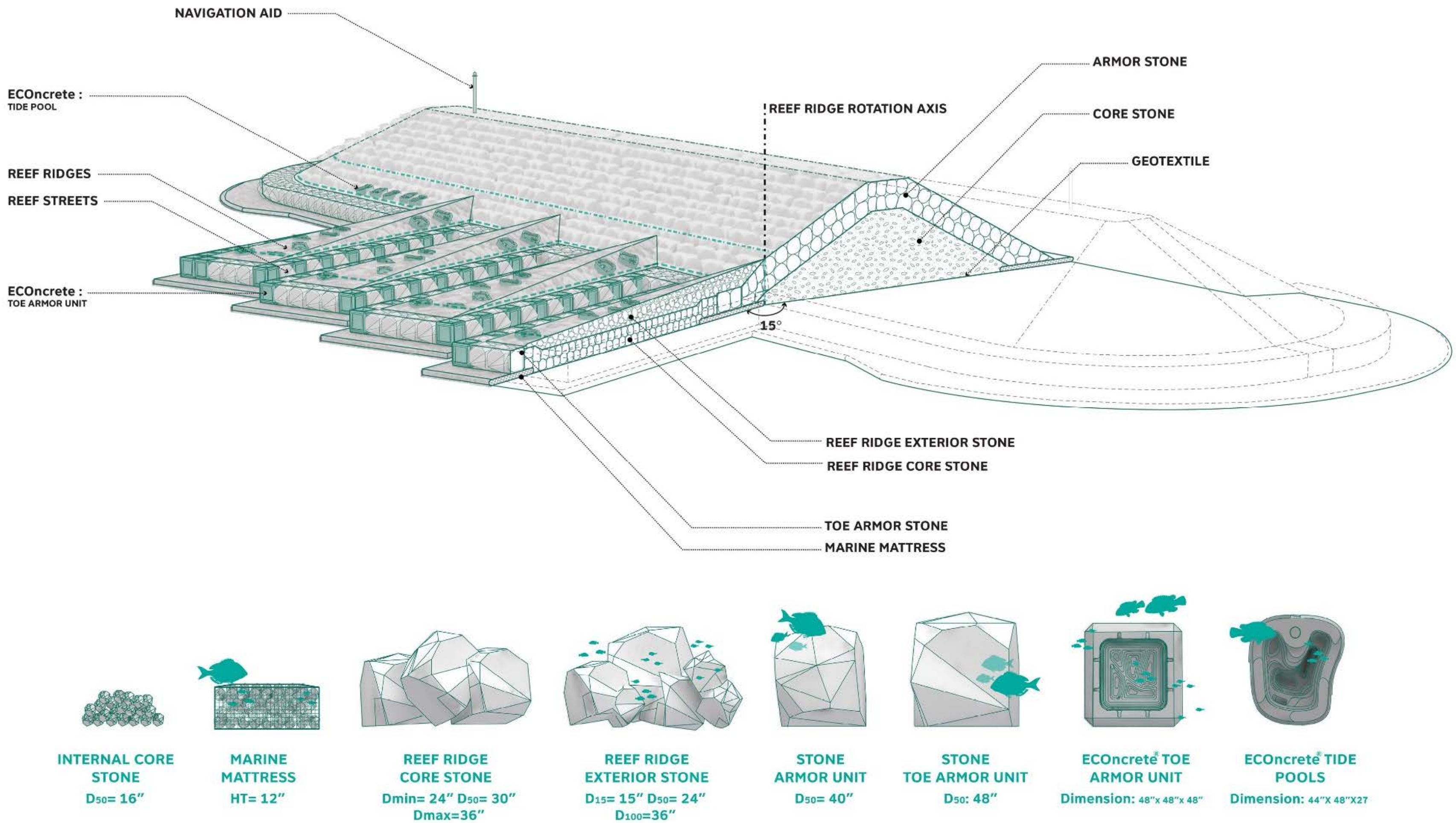

Figure 9-4: Living breakwater concept for use in Staten Island, New York

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