AB 691 Sea-Level Rise Assessment

Moss Landing Harbor
Sea Level Rise Vulnerability and Adaptation Strategy Report

June 2019

Prepared for the Moss Landing Harbor District

Prepared by the Central Coast Wetlands Group

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1. Introduction

Report Goals

This project will achieve four objectives (as defined by the State Lands Commission) intended to further regional planning for the inevitable impacts associated with predicted Sea Level Rise (SLR) on the Moss Landing Harbor, Elkhorn Slough and adjacent beach areas within the properties in and adjacent to the state lands granted to the Moss Landing Harbor District. Goals include:

- Identify what critical coastal infrastructure would be compromised due to predicted SLR for time horizons 2030, 2060[1], and 2100 and for extreme SLR scenarios (H++).
- Identify what critical coastal subtidal habitats would be compromised due to predicted SLR for time horizons 2030, 2060, and 2100 and for extreme SLR scenarios (H++).
- Identify appropriate response strategies for these risks and discuss the programmatic and policy options that can be adopted to address these risks.
- Quantify the potential financial losses of infrastructure within the predicted hazard zones and the costs of adaptation alternatives.

Products of this report include:

1. An assessment of the impact of SLR on granted public trust lands, as described in the Resolution of the California Ocean Protection Council on Sea-level Rise and the latest version of the State of California Sea-Level Rise Guidance Document.
2. Maps showing the areas that may be affected by SLR in the years 2030, 2060, and 2100. These maps shall include the potential impacts of 100-year storm events. A local trustee may rely on appropriate maps generated by other entities.
3. An estimate of the financial cost of the impact of SLR on granted public trust lands. The estimate considers, but is not limited to, the potential cost of repair of damage to, and the value of, lost use of improvements and land, and the anticipated cost to prevent or mitigate potential damage.
4. A description of how the local trustee proposes to protect and preserve natural and manmade resources and facilities located, or proposed to be located, on trust lands and operated in connection with the use of the trust lands. The description shall include, but is not limited to, how wetlands restoration and habitat preservation might mitigate impacts of SLR.

[1] In 2014 local SLR models were developed for the Monterey Bay and 2060 hazard predictions were selected instead of 2050 values. This decision has been determined by the State to meet state planning guidelines.

Background Vulnerability Assessments

In 2013 the State of California adopted policy requiring all entities with granted public trust lands to draft sea level rise vulnerability plans for resources within the jurisdictional boundaries of their State lands.

In 2017, the Central Coast Wetlands Group at Moss Landing Marine Labs (CCWG) completed a community-wide sea level rise vulnerability analysis for the Moss Landing Community.[2] The resulting report was funded by The Ocean Protection Council through the Local Coastal Program Sea Level Rise Adaptation Grant Program. This grant program is focused on providing resources to local governments to support the update to Local Coastal Programs (LCPs), and other plans authorized under the Coastal Act[3] such as Port Master Plans, Long Range Development Plans and Public Works Plans (other Coastal Act authorized plans) to address sea-level rise and climate change impacts, recognizing them as fundamental planning documents for the California coast.

The County of Monterey developed and adopted a Local Hazard Mitigation Plan in 2014. This plan works to "identify and profile natural hazards [storm surge, coastal erosion, earthquake, expansive soils, flood, and tsunami] and to lesser extent manmade hazards; assess vulnerability; set local hazard mitigation goals and strategies; and plan for future maintenance of the Local Hazard Mitigation Plan."[4] Sea level rise is not explicitly addressed by the plan, though increased intensity of coastal erosion and storm flooding due to sea level rise are discussed. The plan explores integrated mitigation strategies, which include actions to reduce vulnerability from erosion, flooding, and other natural and human hazards.

The Moss Landing Community Plan[5] discusses sea level rise and the importance of armoring the coastline in order to protect the harbor and its related coastal uses. This vulnerability report is intended to aid future planning to increase resiliency and provide greater detail on the risks to the Moss Landing area from coastal climate change during three future time horizons (2030, 2060 and 2100). Risks to properties were identified using the ESA PWA Monterey Bay Sea Level Rise Vulnerability Study[6] layers developed in 2014 using funding from the California Coastal Conservancy.

[2] Moss Landing Coastal Climate Change Vulnerability Report (2016)

[3] State of California. *California Coastal Act of 1976*. http://www.coastal.ca.gov/coastact.pdf

[4] Monterey Multi-Jurisdictional Hazard Mitigation Plan, 2014, ch 2, pg 3

[5] Moss Landing Community Plan, Revised Draft 2014

[6] ESA PWA. 2014. *Monterey Bay Sea Level Rise Vulnerability Study: Technical Methods Report Monterey Bay Sea Level Rise Vulnerability Study*. Prepared for The Monterey Bay Sanctuary Foundation, ESA PWA project number D211906.00, June 16, 2014

2. Sea-level Rise Vulnerability Assessment

Inventory of Vulnerable Natural and Built Resources and Facilities

State Grant Tide and Submerged Lands Description

In 1947 the State of California granted the Moss Landing Harbor District the Submerged and Tide lands of the Old Salinas River channel below the Potrero and Moss Landing tide gates and includes the main channel of Elkhorn and Bennet sloughs and the coastal tide lands to the north and south of the Moss Landing Harbor entrance (Figure 1). Within this area are significant natural habitat features, historical infrastructure (in various stages of disrepair) and currently operating infrastructure managed by the Harbor District, the Moss Landing power plant, the County, and by adjacent private land owners. Portions of the submerged lands of Elkhorn Slough are designated as Marine Protected Areas and managed by the Department of Fish and Wildlife and the Elkhorn Slough National Estuary Research Reserve.

The Moss Landing Harbor is the number one commercial fishing harbor in the Monterey Bay with 600+ slips for recreational boaters and commercial vessels. Partnering with marine research and education institutions, the Moss Landing Harbor District (MLHD) provides full public access to the marine environment. Designated as a year-round port of safe refuge, Moss Landing Harbor provides safe, reliable marine refuge and services to members of the boating public. Moss Landing Harbor supports the research and educational endeavors of the Monterey Bay Aquarium Research Institute and Moss Landing Marine Laboratories.

More than 100 active fishing vessels can be berthed in Moss Landing at any time along with 7 research and government vessels. Two eco-tour pontoon boats are docked here as well as charter fishing boats, whale watching vessels, and numerous kayak rentals and ecotourism businesses. The harbor supports commercial fishing and recreational boating as well as restaurants. The Jetty Road sand spit is located along the northeast side of the harbor. The Moss Landing Harbor provides parking and other harbor and beach access facilities which are located within both the north and south harbor areas (north and south of the main harbor entrance).

Moss Landing Harbor properties are surrounded by water—the ocean, Elkhorn Slough, Moro Cojo Slough, and the nearby Salinas River. The proximity to the Monterey Bay National Marine Sanctuary and the open ocean makes Moss Landing Harbor a valuable maritime resource that is also vulnerable to periodic impacts from ocean storms that will be exacerbated by sea level rise. Storm events have impacted the community in the past; including the 1995 flood and the 1982 and 1998 El Nino events. Each of these climatic events has damage infrastructure and properties.

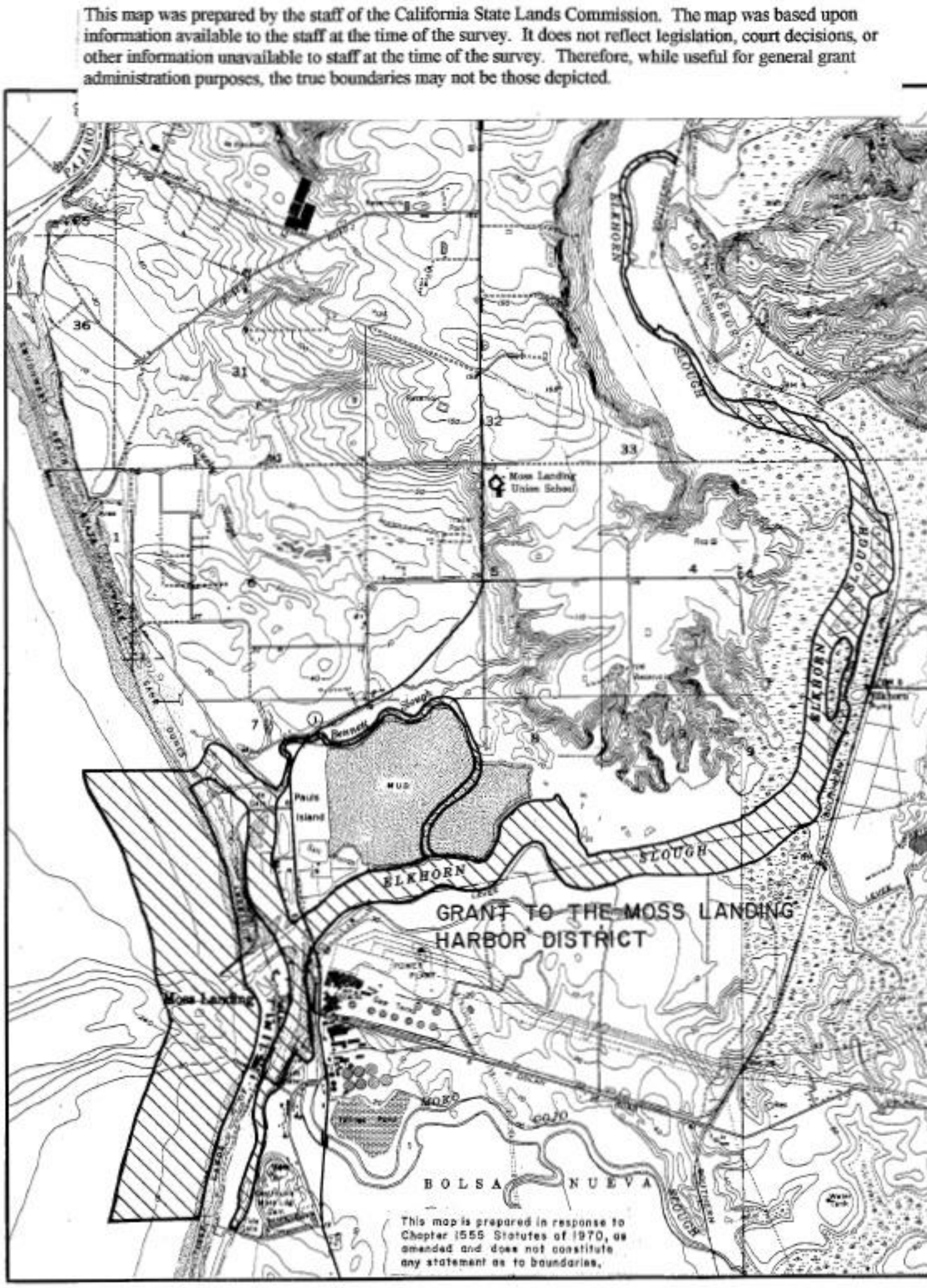

Figure 1. Submerged lands granted to Moss Landing Harbor District

Harbor Shoreline Structures

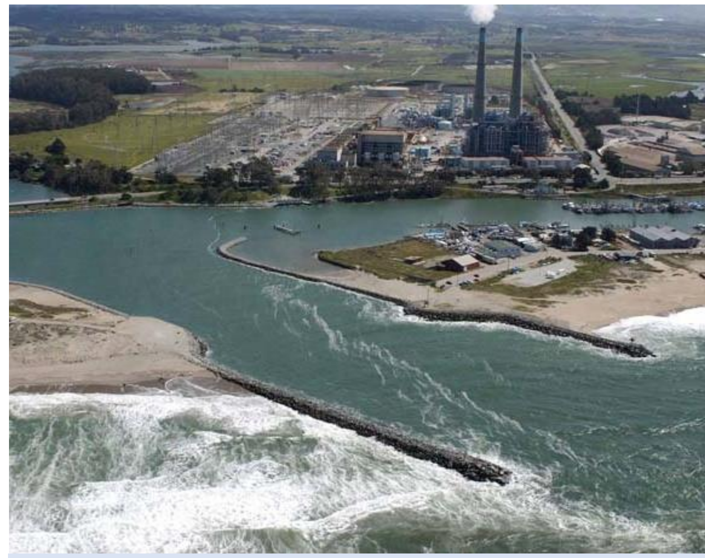

Figure 2. Moss Landing Harbor levees

(Image: Copyright 2002-2017 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org)

Much of the Moss Landing Harbor is developed for commercial and recreational boating with shoreline edges comprised of a mix of rip-rap and concrete sea walls. A large amount of harbor related infrastructure was built within the footprint of the historical Old Salinas River. The Harbor entrance is maintained by two large rock jetties that reach more than 1,500 feet out from the main harbor channel into the open Monterey Bay (Figure 2). The harbor mouth and main harbor channel are dredged periodically to maintain operational depth. While the jetties remain in good condition, the sand behind the inland end of structures has eroded by tidal eddies that scour sand and deposit those sediments elsewhere (in the north harbor area). Most of the 2.5 km of the south harbor waterfront is man-made and or hardened with rip-rap or concrete. Only one quarter (0.5km) of the north harbor waterfront is protected or hardened.

Tidal Management Structures

A number of tide gates, culverts and other water control structures have been installed, replaced, and upgraded since the late 1800s. Many of the structures were installed when the harbor was created to reduce erosion, lessen inland saltwater migration, and control tidal action. Many of these structures are in disrepair and maintenance responsibilities are not well defined and distributed among a number of state and county agencies. The Harbor District staff notes that the loss of wetlands in portions of Elkhorn Slough and the Bennett Slough have been intensified by the breaching (in the 1980s) of the original protective levees (which were installed when the harbor mouth was opened) in the eastern areas of the Elkhorn Slough, and the opening of the Bennett Slough to tidal scour when Jetty Road was rebuilt after the 1989 earthquake.

Moss Landing Village

The community of Moss Landing is a small fishing village with restaurants, antique stores, and galleries, best known for its working harbor and proximity to Elkhorn Slough and the productive fisheries of the Monterey Bay.

Elkhorn Yacht Club

Elkhorn Yacht Club was founded in 1946. The Elkhorn Yacht Club Mission Statement is: “A safe, family friendly, thriving entity providing our members with a social environment focused on ocean sports, environmental footprints and lifelong friendships.” The club supports expansive facilities overlooking the channel leading to the Elkhorn Slough. It hosts a bar, waterfront patio with fire rings, a garden courtyard, hearth room, dining hall, and kitchen.

Recreation and Public Access

Beaches, Parks, and Reserves: Moss Landing State Beach, Salinas River State Beach (part of which is designated as the Salinas River Dunes Natural Preserve), and Zmudowski State Beach Park, located to the north and south of the harbor entrance, offer great places for surfing, horseback riding, surf fishing, windsurfing, hiking, and wildlife-watching.

The Elkhorn Slough National Estuarine Research Reserve, the Elkhorn Slough State Marine Reserve, and the Moss Landing State Wildlife Area (limited recreation access), encapsulate Elkhorn Slough and its many surrounding wetlands, while also providing more than five miles of hiking and boardwalk trails, and a visitor center with restrooms and a paved overlook road. The slough is also accessible by kayak or small boat from the harbor, allowing up-close viewing of the incredible biodiversity.

The Monterey Bay Marine Sanctuary Scenic Trail runs through Moss Landing, helping link the Santa Cruz and Monterey County coastal access infrastructure.

Coastal Access and Public Parking: Boats within the harbor offer tours of Elkhorn Slough and the Monterey Bay National Marine Sanctuary to observe local wildlife. There are public parking lots and street parking on Jetty Road, just off of Highway 1, to provide easy access to the beach. There is a parking lot at Elkhorn Yacht Club, and there are parking lots around the harbor providing access to the Slough and the ocean. Access and parking to Salinas River State Beach is provided at the ends of Sandholdt, Potrero and Molera roads.

Transportation

Highway 1: Highway 1 runs through Moss Landing with a bridge crossing Elkhorn Slough. There are three locations along the highway where motorists can exit the highway and access the Harbor.

Rail: The rail line transects the Moss Landing area passing through Elkhorn and Moro Cojo sloughs. The rail line is operated by Southern Pacific for both commercial and passenger service.

Bridges: There are a number of bridges and roads that overpass the complex network of creek and wetland features within Moss Landing.

Moss Landing and Sandholdt Roads: Moss Landing and Sandholdt roads provide access to much of the Harbor Districts infrastructure and maritime access.

Natural Resources

Wetlands: Elkhorn Slough's tidal salt marsh provides critical habitats for many species, including more than 135 species of aquatic birds, 550 species of marine invertebrates, and 102 fish species, as well as sea otters, sea lions, and harbor seals. Surrounding wetlands including the Moro Cojo Slough and Old Salinas River provide important habitats for threatened species and flood attenuation during winter storms.

Dunes*:* The beach dunes along Moss Landing State Beach and Salinas River State Beach provide important habitat for many native plants and animals, including the western snowy plover, the white-tailed kite, western fence lizard, beach wild rye, beach bur, yellow sand verbena, and many more species.

Protected Habitats: Monterey Bay National Marine Sanctuary, Elkhorn Slough State Marine Conservation Area, Elkhorn Slough State Marine Reserve, Elkhorn Slough National Estuarine Research Reserve, Moss Landing State Wildlife Area, Moro Cojo State Marine Reserve, Salinas River Dunes Natural Preserve, and California State Beaches support special status species and their habitats.

Assets Used in Study

To meet AB 691 guidelines, this vulnerability assessment evaluates: 1) harbor infrastructure within the harbor public trust lands that are vulnerable to SLR and Climate Change impacts, 2) natural resources within areas vulnerable to SLR directly associated with harbor operations, 3) protective infrastructure (and associated development on those properties) that provide a buffer/boundary from ocean impacts, 4) Public access points and county roads needed to provide access to harbor infrastructure and properties, and 5) infrastructure and properties that are outside the public trust boundaries that are vulnerable to projected hazards and are vital to the continued operations of the harbor (Table 1).

Table 1. List of Assets Used in Analysis

ASSET CATEGORY	ASSET
Harbor Infrastructure	Harbor buildings
	Docks and entranceways to docks
	Electric meters
	Storm drains
	Trash enclosures
	Lift stations
	Parks
	Bathrooms
Access	Roads and parking
	Coastal access points
Natural Resources	Wetlands (NWI)
	Eelgrass beds
	Marine mammal haul-out areas
	Beaches and dunes
Protective Infrastructure	Coastal armoring
	Harbor jetties
	Culverts and tide gates
Infrastructure Outside of State Granted Lands	Buildings and parking lots

Current State Sea Level Rise Policy Guidance

Coastal Hazard Models

State guidance suggests that "a Bayesian probabilistic framework can support improved decision making and easily integrate new lines of scientific evidence but may under- or overestimate sea-level rise contributions beyond 2050 and could lead to confusion if decision makers are unclear about the difference between Bayesian and frequentist probabilities. Nonetheless, probabilistic projections represent consensus on the best available science for sea-level rise projections through 2150. With continued advances in sea-level rise science, it is expected that probabilistic projections will change in the future. However, the evolving nature of sea level rise projections does not merit taking a 'wait and see' approach. Acting now is critical to safeguard the people and resources of California."

However, within the Monterey Bay, probabilistic models are not yet available. Therefore, this study uses scenario-based models developed in 2014 which follow previous State guidance and crosswalks them with the most recent guidance. Previous guidance from The California Coastal Commission guidance document[7] recommends communities evaluate the impacts from sea level rise on various land use categories using a method called "scenario-based analysis" (described in Chapter 3 of the Guidance). Since sea level rise projections are not exact, but rather presented in ranges, scenario-based planning includes examining the consequences of multiple rates of sea level rise, plus extreme water levels from storms and El Niño events. As recommended in the guidance, this report uses sea level rise projections outlined in the 2012 NRC Report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*[8] (Figure 3).

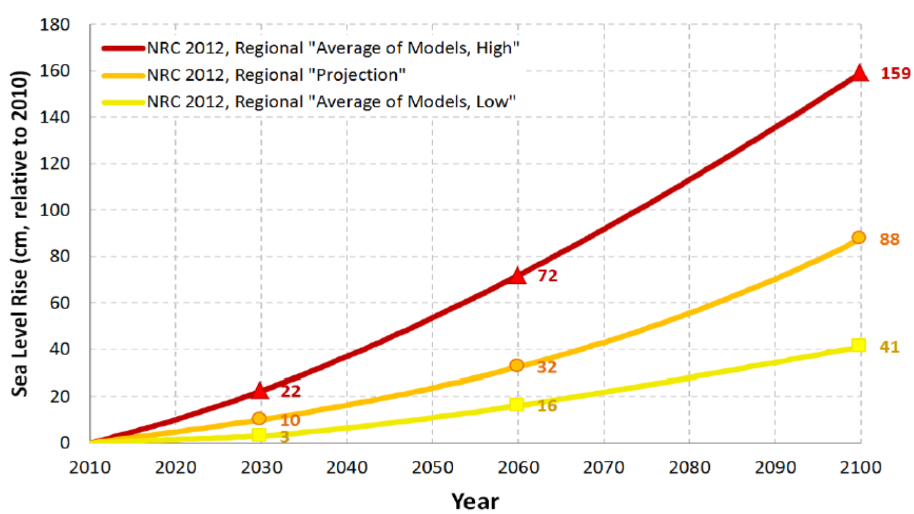

Figure 3. Sea level rise scenarios for each time horizon (Source: ESA 2014)

[7] California Coastal Commission. 2015. *California Coastal Commission Sea Level Rise Policy Guidance: Interpretative Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits.* Adopted August 12, 2015.

[8] National Research Council (NRC). 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Report by the Committee on Sea Level Rise in California, Oregon, and Washington. National Academies Press, Washington, DC. 250 pp.

The goal of scenario-based analysis for sea level rise is to understand where and at what point sea level rise and the combination of sea level rise and storms, pose risks to coastal resources or threaten the health and safety of developed and natural areas. This approach allows planners to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea level rise.

The guidance recommended evaluating the impacts of the highest water level conditions that are projected to occur in the planning area. In addition to evaluating the worst-case scenario, planners need to understand the minimum amount of sea level rise that may cause impacts for their community, and how these impacts may change over time, with different amounts of sea level rise.

The climate vulnerability maps used for this study identify hazard zones for each climate scenario for each of the three planning horizons. For clarity, this report focuses the hazard analysis on a subset of those scenarios, that can be cross-walked with the probabilistic based-scenario (Table 2).

Table 2. Comparison of OPC 2013 Guidance Document and 2018 Update's Probabilistic SLR projections

SCENARIO BASED PROJECTION: TIME HORIZON	SCENARIO BASED PROJECTION: EMISSIONS SCENARIO	SCENARIO BASED PROJECTION: SLR[9]	PROBABILISTIC PROJECTION: EMISSIONS SCENARIO	PROBABILISTIC PROJECTION: LIKELY RANGE*: 66% PROBABILITY SLR IS BETWEEN…	PROBABILISTIC PROJECTION: 1-IN-200 CHANCE**: 0.5% PROBABILITY SLR MEETS OR EXCEEDS…	H++ SCENARIO***
2030	Med	4 in	High	**3.6 – 6 in**	9.6 in	12 in
2060	High	28 in	Low	6 – 14.4 in	**27.6 in**	45.6
			High	8.4 – 16.8 in	31.2 in	
2100	High	63 in	Low	10.8 – 27.6 in	**66 in**	121.2
			High	18 – 39.6 in	82.8 in	

*Notes: * low risk aversion projection, **Medium-high risk aversion projection, ***Extreme risk aversion projection*

For management of ongoing harbor operations, considerations regarding predicted time horizons should be taken when decisions as to if and how to adapt are made. Specifically, new infrastructure built within hazard zones should be designed to withstand the predicted hazards while accommodating the appropriate level of uncertainty regarding the scale of the hazard (i.e. water elevation) and the predicted time horizon when these hazards will occur (i.e. 2030 through 2060). Red text highlights corresponding probabilistic sea level rise predictions with those used for modeling of Moss Landing Harbor hazards (scenario-based model). Because such probabilistic projections have not yet been integrated with predictions for storm intensity and wave height and for changes in rainfall, and future

[9] Erosion projections: 2030: Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm), 2060 and 2100: Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm). Future erosion scenario: Increased storminess (doubling of El Niño storm impacts in a decade).

emissions scenarios are extremely uncertain, it is likely inaccurate to assume the predicted impacts have less than a 1% chance of occurrence by 2060.

Impacts of Storms and Extreme Events

This sea level rise vulnerability analysis uses hazard layers developed by ESA in 2014 and modified by CCWG in 2016 to account for currently existing coastal armoring and other protective structures. The ESA coastal hazard modeling and mapping effort[10] led to a set of maps that integrate the multiple coastal hazards projected for the assessment area (i.e. hazards of coastal climate change). There is however a benefit to evaluating each hazard (or coastal process) separately. The hazard layers are available for further investigation through the online mapping viewer at www.coastalresilience.org.

Two important limitations of the original hazard maps were addressed within this focus effort for Moss Landing. ESA was contracted for this project to model the impacts of flooding from the combined effects of rising seas and changes in rainfall leading to an increase in winter stream flows. CCWG staff post-processed the 2030 hazard layers to account for reductions in potential hazards provided by current coastal protection infrastructure (tide gates, etc.). This refinement of coastal hazard mapping helped to better understand the future risks Moss Landing may face for each coastal hazard process.

It is understood that each modeled coastal process will impact various coastal resources and structures differently. This report evaluates the risks to infrastructure from each coastal hazard for each time horizon. This analysis helps to link risks with appropriate adaptation alternatives. The following is a description of the hazard zones that were used for this analysis. For more information on the coastal processes and the methodology used to create the hazard zones please see the Monterey Bay SLR Vulnerability Assessment Technical Methods Report.[10]

Combined Hazards

CCWG merged the coastal hazard layers (for the specific scenarios[11] as modified to account for structures) to create a new combined hazard layer for each planning horizon (2030, 2060 and 2100). These merged layers represent the combined vulnerability zone for "Coastal Climate Change" for each time horizon. Projections of the combined hazards of Coastal Climate Change are intended to help estimate the cumulative effects on the community and help identify areas where revised building guidelines or other adaptation strategies may be appropriate. Combined hazards however, do not provide municipal staff with the necessary information to select specific structural adaptation responses. Therefore, this study also evaluates the risks associated with each individual coastal hazard.

Rising Tides

These hazard zones show the area and depth of inundation caused simply by rising tide and ground water levels (not considering storms, erosion, or river discharge). The water level mapped in these inundation areas is the Extreme Monthly High Water (EMHW) level, which is the high water level reached approximately once a month. There are two types of inundation areas: (1) areas that are clearly connected over the existing digital elevation through low topography, (2) and other low-lying areas that

[10] ESA PWA. 2014. *Monterey Bay Sea Level Rise Vulnerability Assessment Technical Methods Report*

[11] See the 2017 Santa Cruz County Coastal Climate Change Vulnerability Report for the discussion on scenario selection

don't have an apparent connection, as indicated by the digital elevation model, but are low-lying and flood prone from groundwater levels and any connections (culverts, storm drains and underpasses) that are not captured by the digital elevation model. This difference is captured in the "Connection" attribute (either "connected to ocean over topography" or "connectivity uncertain") in each Rising Tides dataset. These zones do not, however, consider coastal erosion or wave overtopping, which may change the extent and depth of regular tidal flooding in the future. Projected risks from rising tides lead to reoccurring flooding hazards during monthly high tide events.

Coastal Storm Flooding

These hazard zones depict the predicted flooding caused by future coastal storms. The processes that drive these hazards include (1) storm surge (a rise in the ocean water level caused by waves and atmospheric pressure changes during a storm), (2) wave overtopping (waves running up over the beach and flowing into low-lying areas, calculated using the maximum predicted wave conditions), and (3) additional flooding caused when rising sea levels exacerbate storm surge and wave overtopping. These hazard zones also take into account areas that are projected to erode, sometimes leading to additional flooding through new hydraulic connections between the ocean and low-lying areas. Storm flood risks represent periodic wave impact and flooding. These hazard zones DO NOT consider upland fluvial (river) flooding and local rain/run-off drainage, which likely play a large part in coastal flooding, especially around coastal confluences where creeks meet the ocean (analyzed separately for the Moss Landing area).

Changing Shorelines: Beach and Dune Erosion

These layers represent future dune (sandy beach) erosion hazard zones, incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise and (in the case of the storm erosion hazard zones) the potential erosion impact of a large storm wave event. The inland extent of the hazard zones represents projections of the future crest of the dunes for a given sea level rise scenario and planning horizon. Erosion can lead to a complete loss of habitat, infrastructure and/or use of properties.

River Flooding

A river flooding vulnerability analysis was completed specifically for this study area to evaluate the cumulative impacts of rising seas and future changes in fluvial discharge within the Gabilan Watershed. The fluvial model estimates localized flooding along the Reclamation Ditch/Gabilan Creek when discharge is restricted behind the Potrero tide gates during high tides. The model results are presented here and the methodology is described within the separate Fluvial Report by ESA.[12]

The future hazards of river flooding due to the predicted increase in fluvial discharge, higher ocean elevations during storms and higher sea level elevations were evaluated for Moss Landing and the Lower Salinas Valley.[13] The predicted increase in fluvial discharge within the Gabilan/Rec Ditch due to more intense rainfall during storms used for this analysis is outlined in Table 3 .

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[12] ESA. 2016. *Climate Change Impacts to Combined Fluvial and Coastal Hazards*. May 13, 2016.

[13] ESA. 2016. *Climate Change Impacts to Combined Fluvial and Coastal Hazards*. May 13, 2016.

Table 3. Increases in 100-year Discharge for the Reclamation Ditch System Relative to Historic Period (1950-2000)

EMMISIONS SCENARIO	2030	2060	2100
Medium (RCP 4.5 5th percentile)	20% Increase	40% Increase	60% Increase
High (RCP 8.5 90th percentile)	140% Increase	210% Increase	275% Increase

CoSMoS and H++

The Coastal Storm Modeling System (CoSMoS) is a dynamic modeling approach that has been developed by the United States Geological Survey in order to allow more detailed predictions of coastal flooding due to both future sea level rise and storms integrated with long-term coastal evolution (i.e., beach changes and cliff/bluff retreat) over large geographic areas (100s of kilometers). CoSMoS models all the relevant physics of a coastal storm (e.g. tides, waves, and storm surge), which are then scaled down to local flood projections for use in community-level coastal planning and decision-making. Rather than relying on historic storm records, CoSMoS uses wind and pressure from global climate models to project coastal storms under changing climatic conditions during the 21st century.

Projections of multiple storm scenarios (daily conditions, annual storm, 20-year- and 100-year-return intervals) are provided under a suite of sea-level rise scenarios ranging from 0 to 2 meters (0 to 6.6 feet), along with an extreme 5-meter (16-foot) scenario. This allows users to manage and meet their own planning horizons and specify degrees of risk tolerance. Currently CoSMoS is not available for the study area.

To note, the ESA 2014 models used similar approaches and successfully integrated wave run up, local ocean level changes and sea level rise into their projections and further integrated fluvial discharge from the adjacent watershed. CoSMoS is not yet available for the study area but we assume that the CoSMoS hazard layers will suggest similar vulnerabilities to those documented here under the same climatic assumptions and time horizons.

An extreme scenario called the H++ has also been recommended for evaluation by the Ocean Protection Council. The probability of this scenario is currently unknown, but its consideration is important, particularly for high stakes, long-term decisions. Under the extreme H++ scenario, rapid ice sheet loss on Antarctica could drive rates of sea level rise in California above 50 mm/year (2 inches/year) by the end of the century, leading to potential sea level rise exceeding 10 feet. This rate of sea level rise would be about 30-40 times faster than the sea level rise experienced over the last century.

Since Moss Landing Harbor will likely no longer function under predicted 2100 sea levels of 6.9 feet (due to the loss of the barrier beach), estimating impacts from higher rates of sea level rise (10 feet - i.e. H++ SLR scenario) are not necessary or useful for planning purposes (Figure 4). Also, most adaptation measures identified within this document support the incremental resiliency of in-place harbor infrastructure rather than the development of new coastal amenities and therefore may not be classified as high stakes or long term.

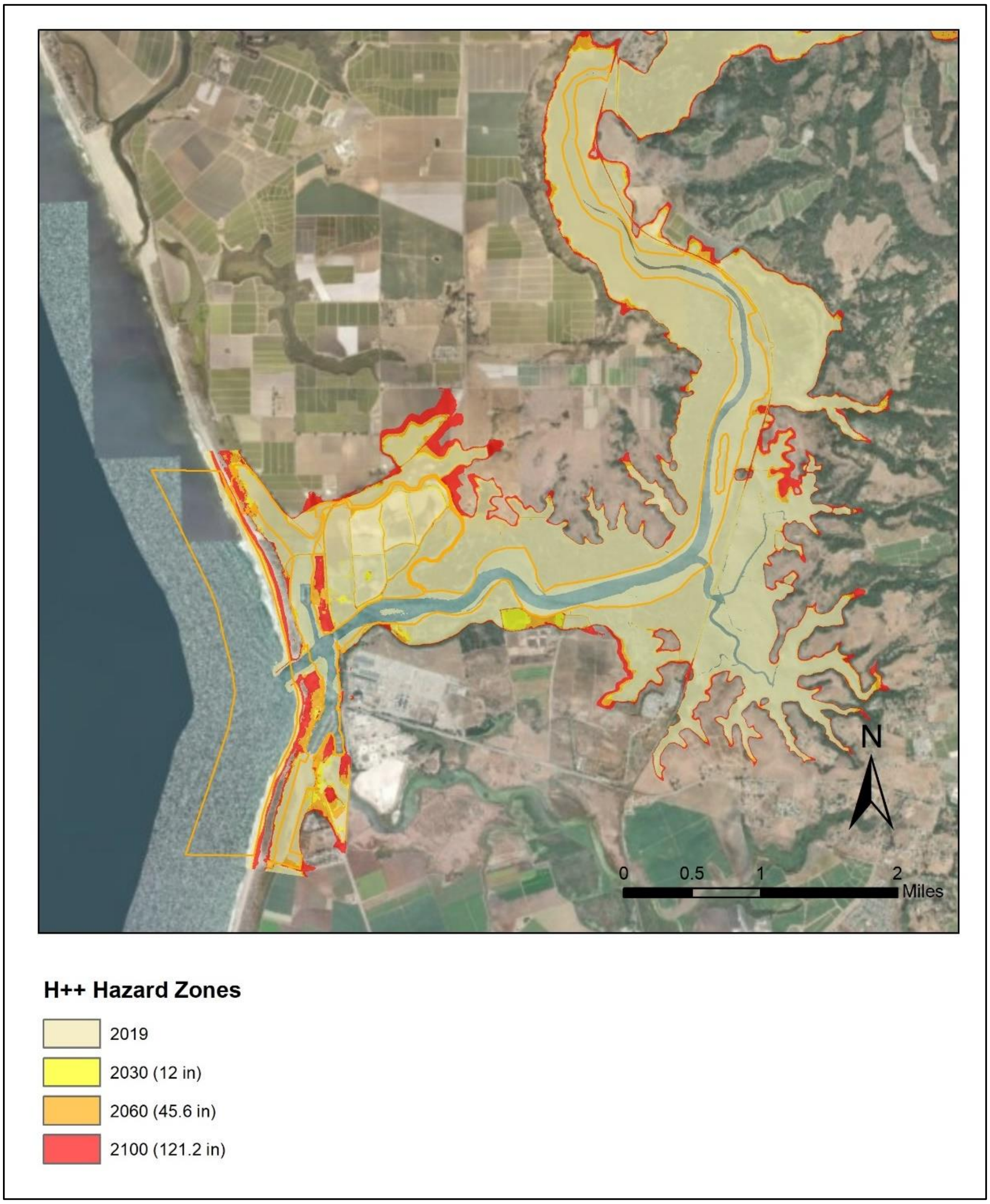

Figure 4. Flooding predicted using extreme rates of sea level rise (H++) for future time horizons.

Moss Landing Harbor Predicted Hazards for 2030

Tidal flooding

Flooding will occur in areas close to current high water (+4 inches) leading to a reduction in service and possible impacts from salt water flooding. Greatest tidal flooding impacts will occur during high tides (king tides) during storms that increase wave energy, local ocean levels, and increased river discharge (Figure 5).

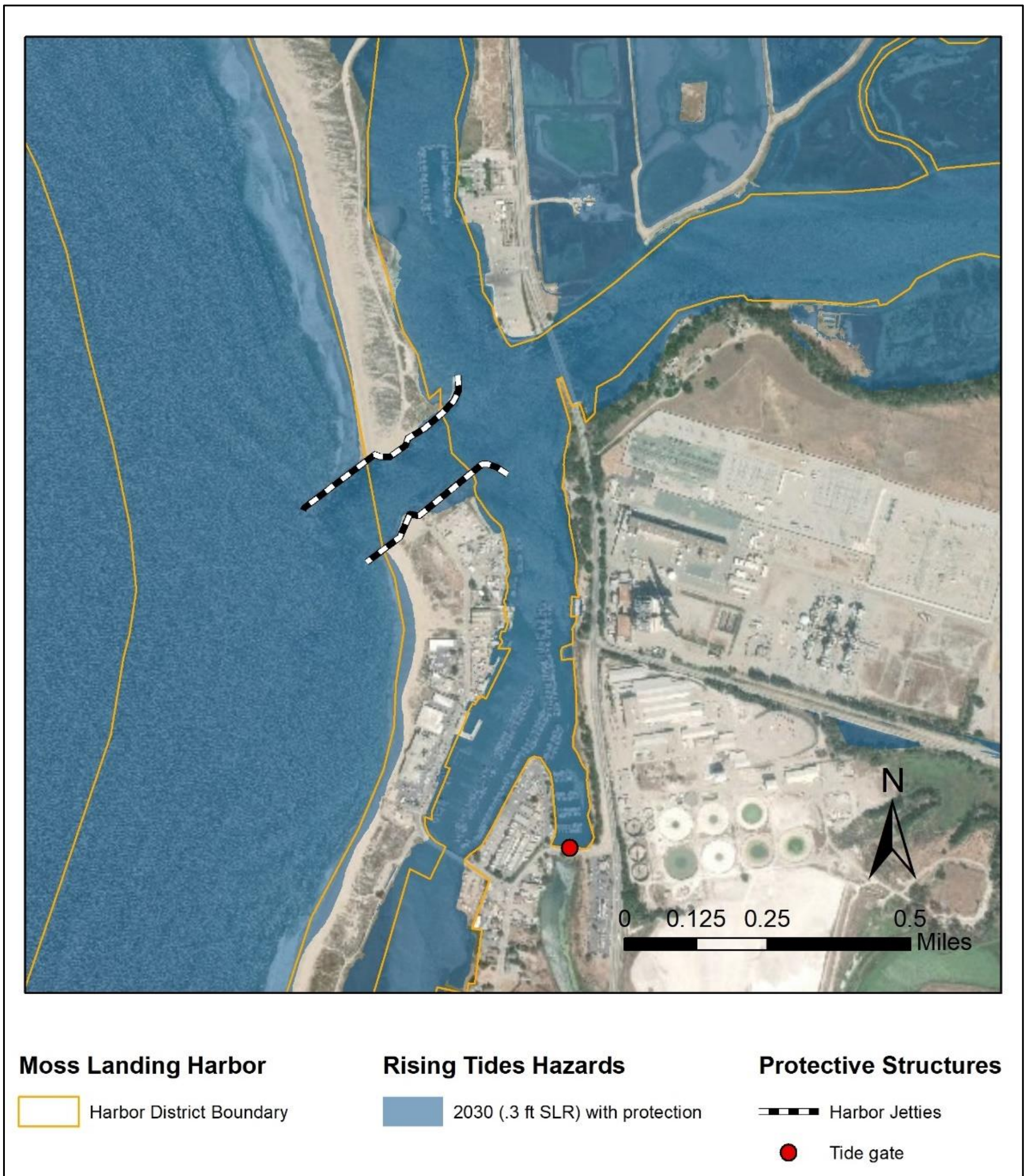

Figure 5. Flooding associated with 2030 increases in sea level (0.3ft)

Storm Flooding

Flooding risks during winter storm events is predicted to increase significantly and lead to the greatest 2030 vulnerabilities. Flooding of the parking areas of South and North Harbor is predicted. Access to the island during storms will be reduced.

Coastal Erosion

Coastal erosion of the sandspit that protects Moss Landing Harbor from ocean waves is predicted to be significant unless protective/adaptive actions are taken. Wave impacts along the beach are predicted to compromise dunes and coastal structures and reduce the long term protection to the harbor.

River/Fluvial Flooding

River discharge during winter storms is predicted to increase. These increases in river flows are predicted to cause localized flooding as stormwater from the watershed meets higher winter ocean elevations in the harbor. Greater velocity discharge from the Old Salinas River into the harbor is likely and may impact infrastructure in its path. Greater sedimentation of the harbor due to greater erosion in the watershed is likely.

Moss Landing Harbor Predicted Hazards for 2060

2060 Rising Tides

Flooding will occur monthly or daily in low-lying areas throughout the harbor leading to a reduction in service and possible impacts from salt water flooding (Figure 6). High tides are predicted to flood various harbor infrastructure and restrict access to docks if adaptive actions are not taken. Flooding of portions of Moss Landing and Sandholdt roads are predicted and will limit access to the harbor and harbor infrastructure on the “island” often. Tidal flooding across harbor granted lands is predicted to lead to inland flooding of the Moss Landing “downtown” area.

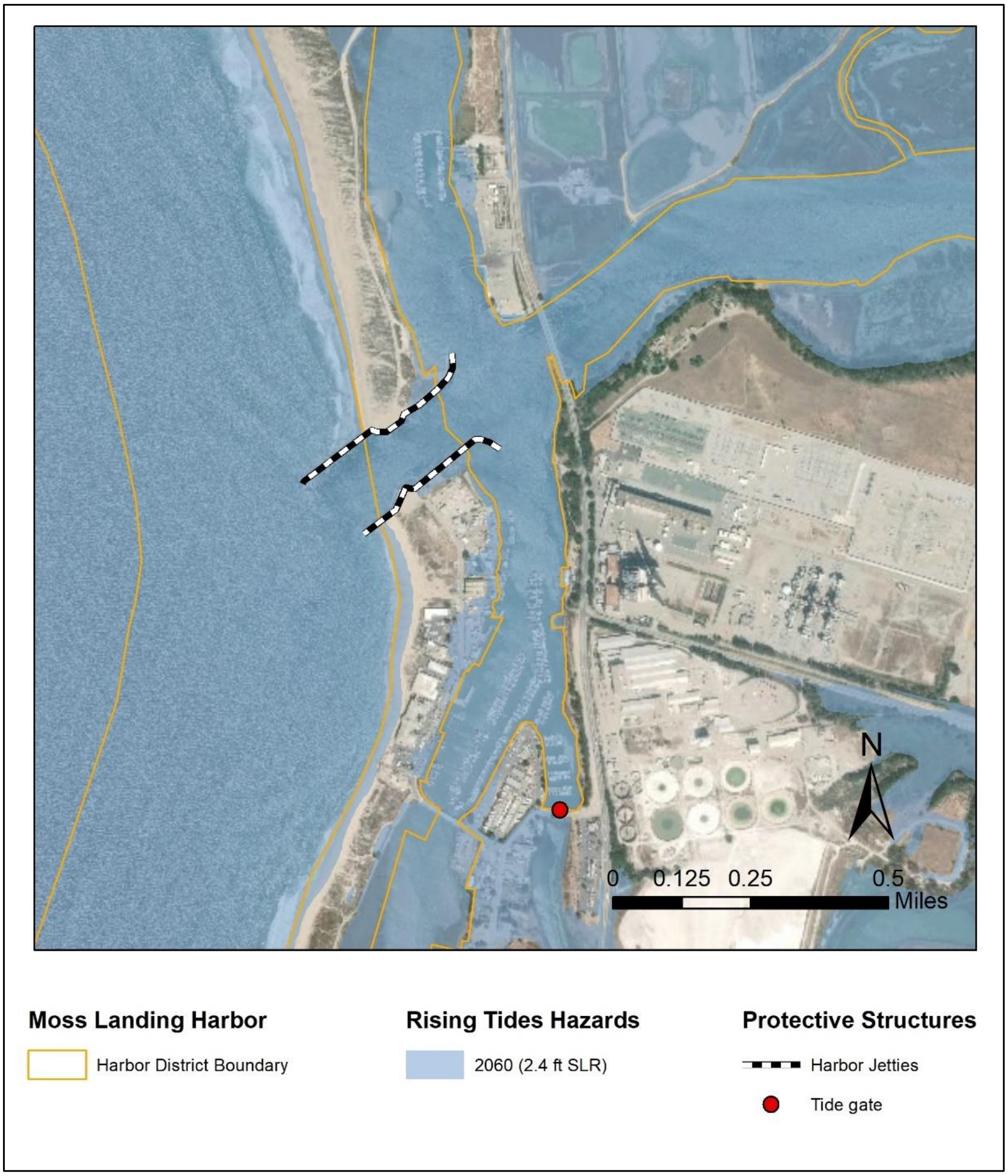

Figure 6. Flooding associated with 2060 increases in sea level (2.4 ft) including access roads to harbor infrastructure and Moss Landing community.

2060 Storm Flooding

Flooding risks during winter storm events is predicted to be significant (Figure 7). Flooding of more than half of the North Harbor land areas is predicted. Wave overtopping of the Island beach/dunes is predicted to be possible, leading to ocean waves (and sand) draining into Moss Landing Harbor. Access to the island during storms will be extremely limited and dangerous.

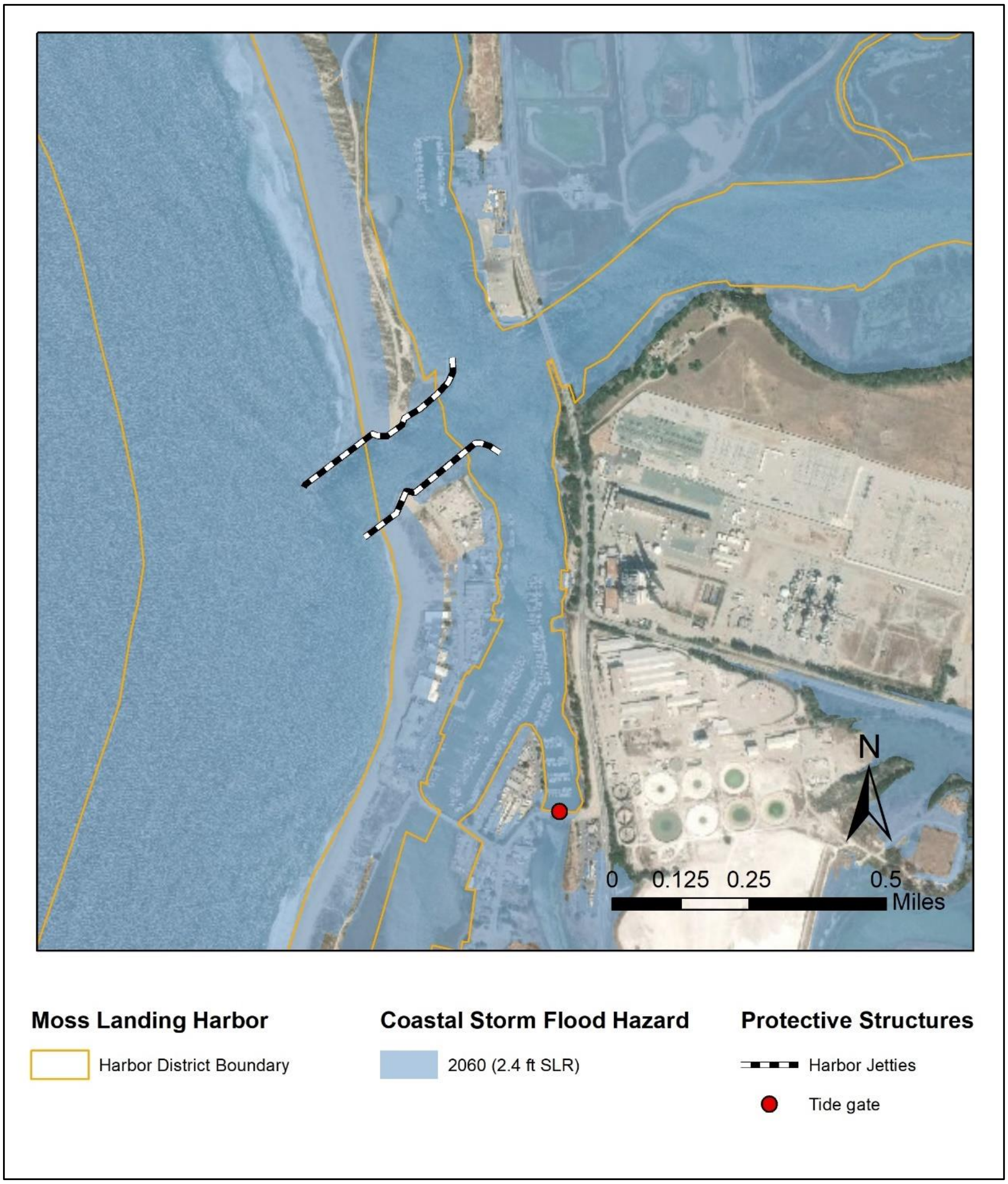

Figure 7. Flooding associated with 2060 storm surge.

2060 Coastal Erosion

By 2060, coastal erosion of the sandspit that protects Moss Landing Harbor from ocean waves is predicted to be significant and possibly jeopardize the harbor unless protective/adaptive actions are taken (Figure 8). Erosion of the dune barrier will likely lead to wave overtopping of the remaining dunes, allowing waves to enter the harbor, leading to vessel and dock damage and significant sedimentation. Failure of dunes are predicted along the entire stretch that parallels the harbor. Dunes adjacent to north harbor and dunes south of Sandholdt road have no structures or coastal armoring to reduce erosion, but also retain some natural dune building and migration capacity lost to development along Sandholdt Road. If dunes are allowed to migrate inland, these areas may retain their protective service.

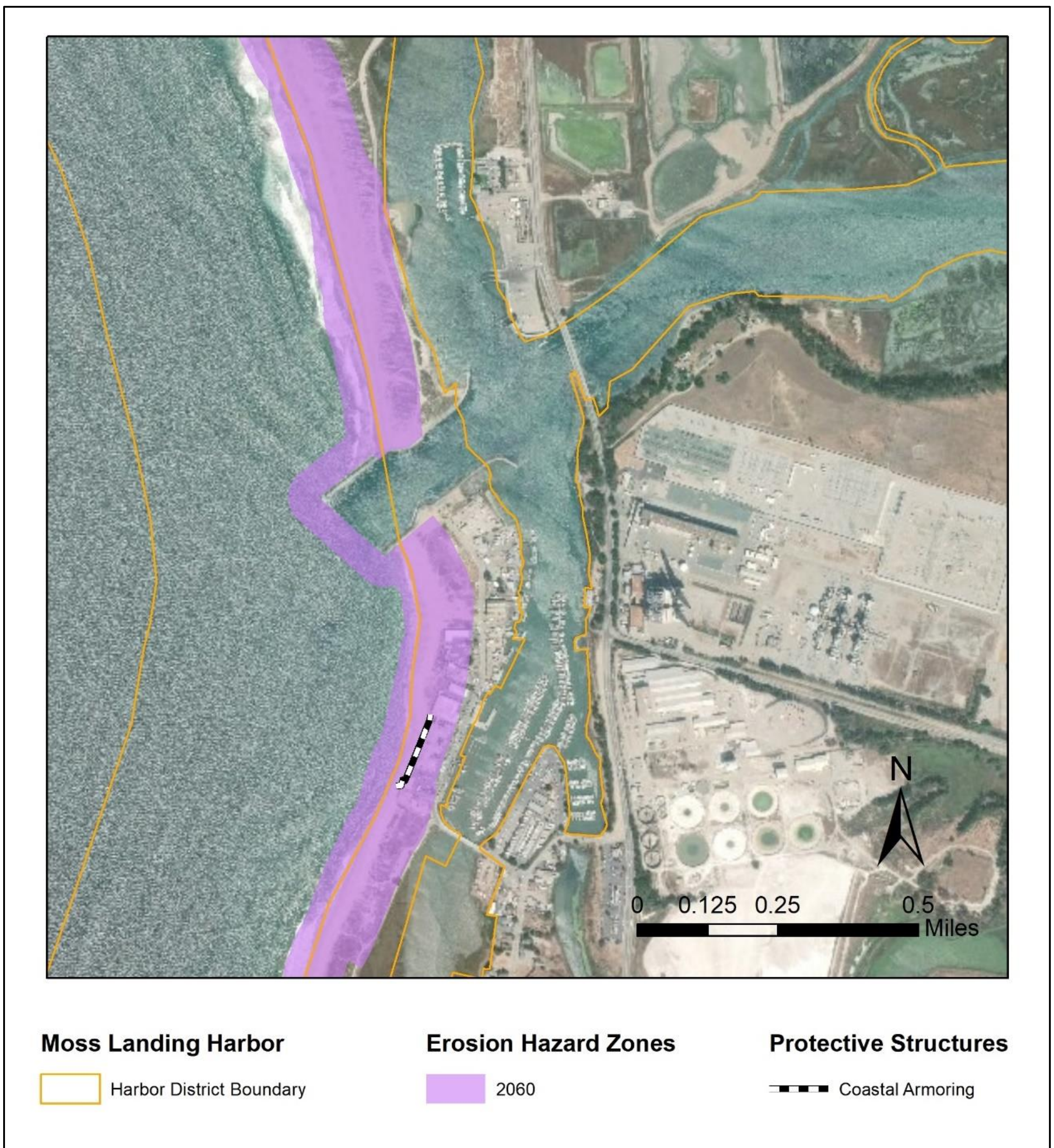

Figure 8. Inland erosion of coastline and loss of beach and dune habitat along the natural and developed sections of the sand spit, jeopardizing future harbor operations.

2060 River/Fluvial Flooding

River discharge during winter storms is predicted to increase. These increases in river flows are predicted to cause localized flooding as stormwater from the watershed meets higher winter ocean elevations in the harbor. Sedimentation of the harbor is also likely to increase due to increased erosion within the watershed during high flow events. Increased discharge velocity under Sandholdt Bridge may impact vessels and harbor infrastructure in south harbor.

Assets at Risk by 2030 and 2060

Public Access

2030: Moss Landing Harbor District provides the public with many unique opportunities to access and enjoy Elkhorn Slough and the Monterey Bay National Marine Sanctuary. Public trust lands granted to the Harbor District include much of Moss Landing tidal beach lands which provides lateral access along the coast between the harbor mouth and Salinas River State Beach. Visitors enjoy spectacular views, fishing opportunities, dog walking, surfing and small boat launching opportunities. The harbor district provides the public with access to 1) recreational fishing and whale watching boats from several public docks, 2) small boat launching for power boats and numerous self-propelled boats, 3) safe harbor berthing for traveling vessels, and 4) marine life viewing from restaurants and public viewing areas. The Harbor also provides private slips for resident vessels of all types.

Of the 11 designated public access areas within the Moss Landing Harbor and Elkhorn Slough, 2 of those access areas are located within the State granted lands. All 11 access areas however do provide public access to the granted lands.

The flooding extent from the combined effects of 2030 sea level rise and coastal storm flooding are predicted to restrict public access to numerous portions of the Moss Landing Harbor District Infrastructure (Figure 9). Specifically, portions of the main parking lot are predicted to be flooded during storms and restrict access to Docks A and B as well as adjacent parking. The small boat launch ramp and parking area of North Harbor are also predicted to be flooded. While access needs of the public will be limited during storm events, access to boat owners with slips in the harbor may be compromised.

Access to some of the harbor infrastructure via the low lying Moss Landing Road (figure 2) will be periodically restricted if the Moss Landing tide gates fail to mute tides to the Moro Cojo Slough. Launch Ramps and dock access areas in the North Harbor are estimated to be resilient to 2030 SLR (Figure 3).

2060: Monthly tidal flooding is predicted to be significant by 2060. Access to much of State granted lands managed by the Harbor District will be restricted during high tides (Figure 9). Flooding is predicted to be extensive within parking areas, dock access ways, launch ramps, and access roads, reducing the use of the harbor significantly and likely posing serious public safety challenges by restricting emergency service vehicles and staff.

Lands along the Moss Landing “island” will be lost as the ocean migrates inland (caused by sea level rise and associated storm waves and coastal erosion) and come into contact with current development, limiting lateral access along the beach. This “coastal squeeze” will likely limit lateral access along the beach between the harbor mouth and Salinas River State Beach.

Access to State granted lands will be restricted during monthly or daily high tides along much of the Island and within the public areas of the South Harbor parking areas. Tidal flooding of the small boat launch ramp and areas around the Elkhorn Yacht club are predicted. Access to north harbor docks is predicted to be restricted.

Public access to the beach and waterways will be compromised due to direct impacts to access locations and from flooding of roads to those locations. Dunes and Moss Landing Beach are predicted to be reduced in width unless they are enabled to migrate inland.

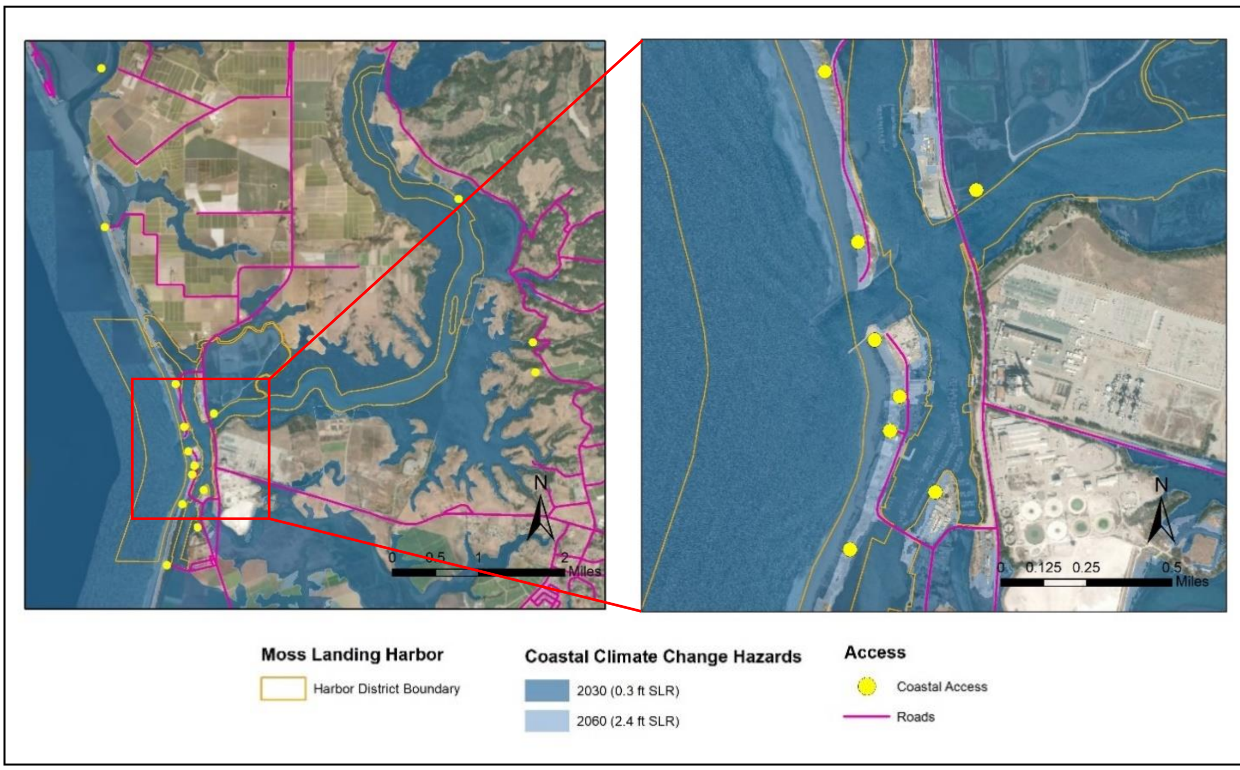

Figure 9. Coastal Access locations restricted by predicted future flooding.

Infrastructure

2030: Three storm drains and two electric meter junction boxes are within the cumulative flood risk areas for 2030. Trash enclosure 32 is located within the flood areas (Table 4, Figure 10 & Figure 11).

2060: 2060 storm and tidal flooding are predicted to compromise large portions of Moss Landing Harbor infrastructure including; two buildings (Cannery Building and Monterey Kayak), half of the storm drains, access to all docks and the used oil containment facility. The Moss Landing Road tide gates on the Moro Cojo Slough are predicted to be overtopped leading to inland flooding. Numerous dock pilings on Dock A are too short to retain floating docks during high tides and winter storms (Table 4, Figure 10 & Figure 11).

Table 4. Harbor infrastructure identified (noted with a number 1) as vulnerable to various SLR hazards during future time horizons

(ER= Erosion, CSF= Coastal Storm Flooding, RT= Rising Tides, TG=Tide Gate)

STRUCTURE	TYPE	ER 2030 (armor)	ER 2060	ER 2100	CSF 2030 (TG)	CSF 2060	CSF 2100	RT 2030 (TG)	RT 2060	RT 2100	FL 2030	FL 2060	FL 2100
Harbor Office	Building						1			1			1
Public Restrooms	Building						1			1			1
Boaters restrooms/laundry	Building						1			1			1
Maintenance Shop	Building						1			1			1
Cannery Building	Building					1	1			1		1	1
ML Storage	Building						1			1			1
ML Storage	Building						1			1			1
Sea Harvest	Building					1	1			1			
North Harbor Building site	Building						1			1			
Old Pot Stop Building	Building						1			1			
MB Kayak	Building					1	1			1			
Restroom Building	Building						1			1			
used oil containment facility	Building/Structure					1	1			1		1	1
Trash Enclosure	Structure					1	1			1			1
Trash Enclosure	Structure				1	1	1		1	1	1	1	1
Launch Ramps	Launch Ramp				1	1	1	1	1	1			
Old Launch Ramps	Launch Ramp				1	1	1	1	1	1			
Electric/ Sewer Lift Station	Lift Station						1						
Sewer Lift Station	Lift Station						1			1			1
Dry Storage	Lot					1	1		1	1		1	1
Maintenance Yard	Lot						1			1			1
Unimproved parking lot	Lot				1	1	1		1	1		1	1
Unimproved lot	Lot						1			1			
Moss Landing Community Park	Park						1			1			1
pier	Pier				1	1	1	1	1	1			
Storm Drain (total)	Storm Drain	0	0	0	7	12	16	2	7	15	2	8	8
Docks (total)	Dock	0	0	1	12	13	13	12	13	13	10	10	11
Electric Meter (total)	Electric Meter	0	0	2	3	6	7	1	5	7	2	5	6

Figure 10. South Harbor infrastructure vulnerable to 2030 and 2060 climate hazards.

Figure 11. North Harbor infrastructure vulnerable to 2030 and 2060 climate hazards.

Commercial Area Adjacent to Harbor

2030: Commercial areas of North Harbor are outside of predicted 2030 hazard areas. Commercial areas of “downtown” Moss Landing and the Moss Landing “island” are predicted to be cut off from highway access during storm events coinciding with high or king tides.

2060: Commercial operations that serve visitors to the Harbor are predicted to be impacted by winter storm flooding. The Elkhorn Yacht Club is estimated to be within tidal and storm flooding elevations. Much of downtown Moss Landing will be flooded if the Moss Landing Tide gates are compromised and across the dry storage area next to the Old Salinas River during winter storms with high river discharge. Commercial, research and industrial infrastructure on Moss Landing Island are vulnerable to frequent flooding and coastal erosion.

Natural Resources/Coastal Habitats

2030: Primary habitats within the State granted lands are subtidal mudflat, deep channel habitat, eel grass beds, tidal beaches and marine mammal haul out areas. These areas are likely resilient to 2030 predicted sea level rise. Adjacent tidal marsh habitat, however, will be submerged by 3-6 inches of additional tidal water, likely leading to the die off of lower portions of the estuarine marsh plain (Figure 12).

Coastal dunes and beaches within and adjacent to Moss Landing Harbor granted lands are predicted to be impacted by greater intensity winter storms that coincide with higher ocean levels. Portions of the beach in front of the Moss Landing sandspit are predicted to have limited lateral access except at low tides (Figure 8). Dune habitat south of Sandholdt Road are similarly likely to see erosion and a reduction in width if the dunes do not migrate inland.

2060: By 2060, lands that are currently intertidal marsh and beach habitat will be flooded and current environmental benefits will be lost as those habitats transition to subtidal landscapes. Much of Elkhorn Slough will become mudflats as marshlands die due to flooding. Sand dunes and beach areas will be lost to erosion and flooding.

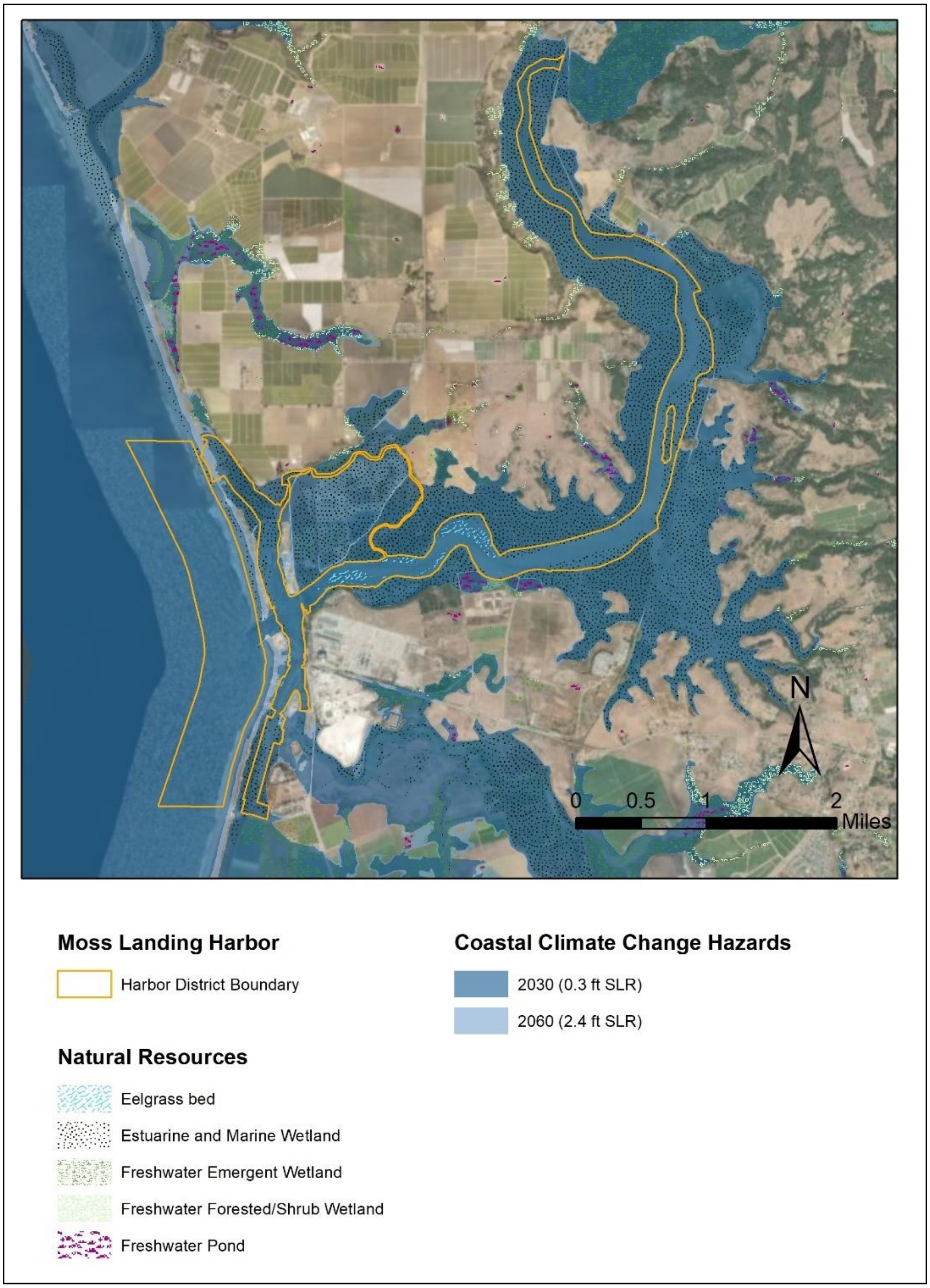

Figure 12. Natural habitats located within the granted lands that may be impacted by changes in water elevation and salinity.

Navigability

2030: Impacts of predicted 2030 risks are anticipated to be associated with restrictions of vessels to land during flooding of harbor parking lots. Some potential limitations to small boat launching are likely during storms. Increased sedimentation of the main channel is likely as tidal marsh transitions to subtidal habitat.

2060: Navigability will be compromised due to loss of access between tidal lands and adjacent public access lands. The harbor mouth jetty is predicted to be overtopped by winter waves. Increased sedimentation from the loss of tidal marshes of Elkhorn Slough and increased flooding in the Salinas Valley will likely lead to increased rates of sedimentation within the harbor. Dock infrastructure will be compromised by higher tides (overtopping older pilings), greater river discharge, and possible dune migration within the north harbor.

Critical Coastal Infrastructure at Risk by 2030, 2060, and 2100

2030 Risks of Coastal Climate Change

1. The flooding extent from the combined effects of 2030 SLR and coastal storm flooding are predicted to restrict access to portions of the main parking lot and restrict access to Docks A and B.
2. The small boat launch ramp and parking area of North Harbor are also predicted to be flooded.
3. Some periodic flooding is predicted for some low lying areas adjacent to the State tidal lands.
4. Access to some of the harbor infrastructure via the low lying Moss Landing Road will be compromised if the Moss Landing tide gates fail to restrict high tides to the Moro Cojo Slough.
5. Launch Ramps and dock access areas in the North Harbor are estimated to be resilient to SLR.
6. Impacts of SLR may lead to significant erosion to Kirby Park launch ramp and parking area.
7. Three storm drains and two electric meters are within the cumulative flood risk areas for 2030. Trash enclosure 32 is located within the flood areas.
8. Commercial areas of North Harbor are outside of predicted 2030 hazard areas. Commercial areas of “downtown” Moss Landing and the Moss Landing “island” are predicted to be cut off from highway access during storm events.
9. Primary habitats within the State granted lands are subtidal mudflat, deep channel habitat, eel grass beds and marine mammal haul out areas.
10. 2030 risks are anticipated to cause restrictions of vessels to land during flooding of harbor parking lots.
11. Limitations to small boat launching are likely during storms.

2060 Risks of Coastal Climate Change

1. Access to much of State granted lands managed by the Harbor District will be restricted during high tides.
2. Flooding is predicted to be extensive within parking areas, dock access ways, launch ramps, and access roads, reducing the use of the harbor significantly and likely posing serious public safety challenges by restricting emergency service vehicles and staff.

3. Lands along the Moss Landing “island” will be lost as the ocean migrates inland (caused by sea level rise and associated coastal erosion) and meet current development, limiting lateral access along the beach.
4. Access to granted lands will be restricted during monthly or daily high tides along much of the Island and within the public areas of the South Harbor parking areas.
5. Access to north harbor docks is predicted to be restricted.
6. Flooding risks during winter storm events is predicted to be significant.
7. Flooding of more than half of the North Harbor land areas is predicted.
8. Wave overtopping of the Island beach/dunes is predicted to be possible leading to ocean waves (and sand) draining into Moss Landing Harbor.
9. Access to the island during storms will be extremely limited.
10. 2060 storm and tidal flooding are predicted to compromise large portions of Moss Landing Harbor infrastructure including; two buildings, half of the storm drains, most electrical meters, access to all docks and the used oil containment facility.
11. The Moss Landing Road tide gates on the Moro Cojo Slough are predicted to be overtopped leading to inland flooding.
12. By 2060, lands that are currently intertidal marsh habitat will be flooded and current environmental benefits will be lost as those habitats transition to subtidal landscapes. Much of Elkhorn Slough will become mudflats as marshlands die due to flooding.
13. Navigability will be compromised due to loss of access between tidal lands and adjacent public lands.
14. The harbor mouth jetty is predicted to be overtopped by winter waves.
15. Increases of sedimentation from the loss of tidal marshes of Elkhorn Slough will likely lead to increased rates of sedimentation within the harbor.

2100 Risks of Coastal Climate Change

1. By 2100, access to all Harbor District infrastructure will be restricted/flooded during daily high tides.
2. Winter storm waves and coastal erosion will likely bisect the sand spit above and below the Sandholdt Bridge, leading to limited use of the granted lands as a safe harbor marina.
3. The community of Moss Landing and Highway 1 will most likely need to be moved out of harm’s way.

The cumulative impacts of sea level rise to harbor infrastructure are shown below in Table 5.

Table 5. Quantification of assets and infrastructure at risk for three time horizons.

STRUCTURE	2030 CUMULATIVE IMPACTS	2060 CUMULATIVE IMPACTS	2100 CUMULATIVE IMPACTS
Harbor Office	0	0	1
Maintenance Shop	0	1	1
Cannery Building	0	1	1
ML Storage	0	0	1
ML Storage	0	0	1
Sea Harvest	0	0	1
North Harbor Building site	0	0	1
Old Pot Stop Building	0	0	1
MB Kayak	0	0	1
Restroom Building	0	0	1
Electric Meters	2	6	7
Storm Drains	3	8	15
Dock Landings	11	12	12
Hazardous Waste	1	2	4
Public Services	0	0	1
Paved Areas	4	6	8

Prioritizing Assets for Adaptation

Considerations for determining adaptive capacity include: 1) continued functionality of infrastructure when not flooded, 2) duration of projected impact (infrequent/short period, monthly, frequent/ongoing), 3) feasibility to increase resiliency of current infrastructure, and 4) functionality of infrastructure given potential loss of access. Adaptations were prioritized based on costs to implement action and continued level of service once adaptation is complete. Adaptive capacity was therefore defined as 1) high if adaptation was cost effective and retained needed level of service, 2) medium if costs were higher but resulting infrastructure was resilient to predicted hazards through 2060, and 3) low if costs were significant and resulting level of service was reduced or impacted by other external hazards (Table 6).

Table 6. Adaptive capacity of various climate risks for 2030, 2060, and 2100.

IMPACTS OF HAZARDS BY TIME HORIZON	FREQUENCY OF HAZARD	DURATION OF IMPACT	FEASIBILITY TO INCREASE RESILIENCY	ADAPTIVE CAPACITY
2030 Risks of Coastal Climate Change				
1. The flooding extent from the combined effects of 2030 SLR and coastal storm flooding are predicted to restrict access to portions of the main parking lot and restrict access to Docks A and B.	Infrequent	Temporary	High	High
2. The small boat launch ramp and parking area of North Harbor are also predicted to be flooded.	Infrequent	Temporary	NA	High
3. Some periodic flooding is predicted for some low lying areas (parking) adjacent to the State tidal lands.	Infrequent	Temporary	Moderate	Moderate
4. Access to some of the harbor infrastructure via the low lying Moss Landing Road (figure 2) will be compromised if the Moss Landing tide gates fail to restrict high tides to the Moro Cojo Slough.	Monthly	Perpetual	Moderate	Moderate
5. Launch Ramps and dock access areas in the North Harbor are estimated to be resilient to SLR (figure 3).	NA			
6. Impacts of SLR have already led to significant erosion to Kirby Park launch ramp and parking area.	Frequent	Perpetual	Moderate	Moderate
7. Three storm drains (7, 11,30) and two electric meters (36 & 37) are within the cumulative flood risk areas for 2030. Trash enclosures 32 is located within the flood areas.	Monthly	Temporary	Low	High
8. Commercial areas of North Harbor are outside of predicted 2030 hazard areas. Commercial areas of "downtown" Moss Landing and the Moss Landing "island" are predicted to be cut off from highway access during storm events.	Infrequent	Temporary	Moderate	Moderate or Low

IMPACTS OF HAZARDS BY TIME HORIZON	FREQUENCY OF HAZARD	DURATION OF IMPACT	FEASIBILITY TO INCREASE RESILIENCY	ADAPTIVE CAPACITY
9. Primary habitats within the State granted lands are subtidal mudflat, deep channel habitat, eel grass beds and marine mammal haul out areas.	NA			
10. 2030 risks are anticipated to cause restrictions of vessels to land during flooding of harbor parking lots.	Infrequent	Temporary	High	High
11. Limitations to small boat launching are likely during storms.	Infrequent	Temporary	High	High
2060 Risks of Coastal Climate Change				
1. Access to much of State granted lands managed by the Harbor District will be restricted during high tides.	Frequent	Temporary	Moderate	Moderate
2. Flooding is predicted to be extensive within parking areas, dock access ways, launch ramps, and access roads, reducing the use of the harbor significantly and likely posing serious public safety challenges by restricting emergency service vehicles and staff.	Frequent	Temporary	Moderate	Moderate
3. Lands along the Moss Landing "island" will be lost as the ocean migrates inland (caused by sea level rise and associated coastal erosion) and meet current development, limiting lateral access along the beach.	Frequent	Perpetual	Low	Low
4. Access to granted lands will be restricted during monthly or daily high tides along much of the Island and within the public areas of the South Harbor parking areas.	Frequent	Temporary	Moderate	Moderate
5. Access to north harbor docks is predicted to be restricted.	Frequent	Temporary	Moderate	Moderate
6. Flooding risks during winter storm events is predicted to be significant.	Frequent	Temporary	Moderate	Moderate
7. Flooding of more than half of the North Harbor land areas is predicted.	Frequent	Temporary	Moderate	Moderate

IMPACTS OF HAZARDS BY TIME HORIZON	FREQUENCY OF HAZARD	DURATION OF IMPACT	FEASIBILITY TO INCREASE RESILIENCY	ADAPTIVE CAPACITY
8. Wave overtopping of the Island beach/dunes is predicted to be possible leading to ocean waves (and sand) draining into Moss Landing Harbor.	Infrequent	Perpetual	Moderate	Low
9. Access to the island during storms will be extremely limited.	NA			
10. 2060 storm and tidal flooding are predicted to compromise large portions of Moss Landing Harbor infrastructure including; two buildings, half of the storm drains, most electrical meters, access to all docks and the used oil containment facility.	Frequent	Perpetual	Moderate	Moderate
11. The Moss Landing Road tide gates on the Moro Cojo Slough are predicted to be overtopped leading to inland flooding.	Frequent	Perpetual	Moderate	Low
12. By 2060, lands that are currently intertidal marsh habitat will be flooded and current environmental benefits will be lost as those habitats transition to subtidal landscapes. Much of Elkhorn Slough will become mudflats as marshlands die due to flooding.	Frequent	Perpetual	Low	Low
13. Navigability will be compromised due to loss of access between tidal lands and adjacent public lands.	Frequent	Temporary	High	Moderate
14. The harbor mouth jetty is predicted to be overtopped by winter waves.	Infrequent	Temporary	Moderate	Low
15. Increases of sedimentation from the loss of tidal marshes of Elkhorn Slough will likely lead to increased rates of sedimentation within the harbor.	Frequent	Perpetual	Moderate	Moderate
2100 Risks of Coastal Climate Change				
1. By 2100, access to all Harbor District infrastructure will be restricted/flooded during daily high tides.	Frequent	Perpetual	Low	Low

IMPACTS OF HAZARDS BY TIME HORIZON	FREQUENCY OF HAZARD	DURATION OF IMPACT	FEASIBILITY TO INCREASE RESILIENCY	ADAPTIVE CAPACITY
2. Winter storm waves and coastal erosion will likely bisect the sand spit above and below the Sandholdt Bridge, leading to limited use of the granted lands as a safe harbor marina.	Frequent	Perpetual	Low	Low
3. The community of Moss Landing and Highway 1 will most likely need to be moved out of harm's way.	Frequent	Perpetual	Low	Low

3. Financial Loss Associated with Sea-level Rise Impacts

Direct Loss of Economic Benefits with Loss of Harbor Services

Several economic studies of the Elkhorn Slough and Moss Landing Harbor have been done that help to characterize the economic benefits provided by the harbor infrastructure and the associated access to coastal and marine environments (Table 7). Pomeroy and Dalton estimated the direct economic value of commercial fishing in Moss Landing to be between $18 million and $25 million per year (based on data from 1999-2001).[14] Six vessels were noted as retaining home port in Moss Landing as commercial passenger fishing vessels in 2007, reported to service just over 100 vessel trips annually with approximately 1000 anglers (2007 data) with adjusted value of approximately $100 per angler trip, or around $1 million.[15]

Table 7. Annual market and non-market valuation of various visitor related access uses of Moss Landing Harbor

ECONOMIC ACTIVITY (2007 DATA)	ECONOMIC VALUE	NON-MARKET VALUE
Commercial Fishing (Landed Value)	$ 24,000,000	N/A
Commercial Passenger Fishing Vessels (Charter Boats)	$ 1,000,000	$ 100,000
Nature-based Recreation (Kayaking & Whale Watching)	$ 7,000,000	$ 5,000,000
Beach going	$ 7,000,000	N/A
Recreational Boating	$ 7,000,000	$ 4,000,000
Boating and vessel related fees	$ 2,000,000	N/A
Research and Conservation (operating budgets)	$ 70,000,000	$ 10,000,000
Total	**$ 118,000,000**	**$ 19,100,000**

While commercial and charter boat fishing have been the long term centers of the local economy, recent studies suggest that research and conservation focused activities likely generate more to the economy currently in terms of gross revenues.[16] The harbor currently supports two highly respected research institutions: Moss Landing Marine Laboratories and the Monterey Bay Aquarium Research

[14] Pomeroy, C. and M. Dalton. 2003. Socio-Economic of the Moss Landing Commercial Fishing Industry. Report to the Monterey County Office of Economic Development.

[15] Miller, N. and J. Kildow. 2007. The Economic Contribution of Marine Science and Education Institutions in the Monterey Bay Crescent. National Ocean Economics Program.

[16] Kildow, J. and L. Pendleton, 2010, Elkhorn Slough Restoration: Policy & Economic Report. National Ocean Economics Program (NOEP). www.oceaneconomics.org

Institute, which combined support more than 420 jobs with annual budgets of more than $67 million. In total, our summary of economic benefits associated with the services and public access provided by the Harbor District through State granted lands is over $118 million annually (Table 7).

Indirect Loss (Non-market Values) of Recreation and Ecosystem Services

In a 2007 study, researchers found that Moss Landing State Beach hosted 200,000 visits annually and attendance at the Salinas River State Beach was approximately 250,000 annually (in 2007).[17] The authors find that beach goers tend to enjoy an average non-market value of roughly $15 per beach visit (year 2006 dollars) which would suggest that the non-market value of beach going at Moss Landing and Salinas River State Beaches could generate on the order of $7 million annually in economic value to beach goers. In another study, estimates that whale watching alone in the state generates more than $40 million in non-market value which can equate to more than $4 million in personal experience value for whale watching from Moss Landing alone.[18]

Table 8. Visitation records for various locations within and around State Granted Lands. (Source: Kildow and Pendleton 2010)

SITE	TOTAL NUMBER OF VISITS	PERCENT VISITATION
Bennet Slough	7	2.3%
Moss Landing North	133	42.9%
Moss Landing South	142	45.8%
Moro Cojo Slough	5	1.6%
SDFP Wildlife Area	63	20.3%
Seal Bend/Rubis Creek	58	18.7%
Moon Glow Dairy	20	6.5%
ESNERR North	35	11.3%
South March	35	11.3%
Visitors Center	67	21.6%
ESNERR North	47	15.2%
North Marsh	5	1.6%
Kirby Park	65	21.0%
Hudson's Landing	5	1.6%

[17] Kildow, J. and L. Pendleton, 2010, Elkhorn Slough Restoration: Policy & Economic Report. National Ocean Economics Program (NOEP). www.oceaneconomics.org

[18] Pendleton, L. 2005. Understanding the Potential Economic Value of Marine Wildlife Viewing and Whale Watching in California. California Marine Life Protection Act Initiative.

Impacts to Recreation

Impacts to coastal access and harbor related recreation were estimated for the two planning horizons of 2030 and 2060 (Table 9). Predicted flooding for the 2030 time horizon will lead to periodic and seasonal restrictions to public access to harbor infrastructure and estuarine and marine areas. Because most flooding impacts will occur during winter storm events and during some non-storm king tide events, restrictions to public access will be limited in numbers and duration (we estimate 15% maximum reduction in public use of beaches). We also anticipate a small reduction in demand for slips due to reductions in level of service during flood events (maximum of 10%). We do anticipate that the loss of estuarine habitat within Elkhorn Slough may lead to a reduction in ecotourism visitation (20%) to the kayak renters located in North Harbor area. Off shore kayak trips should not be impacted. Fishing within the harbor (no non-market valuation data available) was assumed to be unaffected.

By 2060, reduction in the level of service capacity of existing infrastructure is predicted to be significant and may lead to weekly or daily reductions in access to coastal and harbor resources. Unless upgrades are completed, we anticipate a 50% reduction in access and use of the harbor by commercial and privately owned vessels and a 40% reduction in ecotourism related use (because of the variability in access restricted by tidal flooding). Some of these reductions in access can be mitigated through upgrades to existing infrastructure (discussed below).

Impacts to Ecosystem Services

The predicted loss of estuarine marsh habitat due to submergence is expected to have a significant impact on some threatened and endangered species and the loss of important ecological habitat types within Elkhorn Slough. Loss of dune habitat (and resulting adaptive capacity of harbor resources) is also predicted but may be mitigated if coastal dunes are allowed or encouraged to migrate inland. Previous studies suggest that recreation is concentrated in coastal areas near Highway 1 (Moss Landing Harbor and the beaches, Table 8) which are less vulnerable to 2030 hazards.

By 2060 much of Elkhorn Slough will likely transition to a subtidal embayment which may lead to a reduction in ecotourism visitation to the Slough. Similarly, daily flooding of beaches and other natural coastline amenities will reduce visitation to the harbor and adjacent coastline.

Financial Loss of Recreation and Ecosystem Services

Based on our market and non-market resource valuations of the Moss Landing Harbor ($137 million (2007 dollars)) we anticipate a small but real ($3.6 million) impact to the recreation and ecotourism economy by 2030 due to predicted hazards if no adaptation measures are implemented. By 2060 approximately half of the estimated economic valuation will be lost due to the predicted impacts to ecosystem services and daily restrictions in access. Ecosystem and infrastructure vulnerabilities can be mitigated or made more resilient and regional and state partners should work with the Harbor District to prioritize long term management objectives for the harbor (See Table 11 in Section 4). Long term risks (2100) to infrastructure and coastal beaches and dunes will likely make protection of the harbor through the end of the century infeasible and adaptive strategies and retreat plans should be developed to relocate harbor infrastructure inland as needed to provide the necessary level of safe harbor infrastructure in Moss Landing for future boaters.

Table 9. Market and non-market cost implications of reduced level of service and access from predicted climate hazards.

VALUATION	ECONOMIC VALUATION (MARKET AND NON-MARKET)	2030 % SERVICE LOSS	2030 ECONOMIC LOSS	2060 % SERVICE LOSS	2060 ECONOMIC LOSS
Commercial Fishing (Landed Value)	$ 24,000,000	0%	$ -	50%	$ 12,000,000
Commercial Passenger Fishing Vessels (Charter Boats)	$ 1,100,000	0%	$ -	50%	$550,000
Nature-based Recreation (Kayaking & Whale Watching)	$ 12,000,000	20%	$ 2,400,000	40%	$ 4,800,000
Beach going	$ 7,000,000	15%	$ 1,050,000	50%	$ 3,500,000
Recreational Boating	$ 11,000,000	0%	$ -	50%	$ 5,500,000
Boating and vessel related fees	$ 2,000,000	10%	$ 200,000	50%	$ 1,000,000
Research and Conservation (operating budgets)	$ 80,000,000	0%	$ -	50%	$ 40,000,000
Total	**$ 137,100,000**		**$ 3,650,000**		**$67,350,000**

4. Adaptation Opportunities

Proposed Moss Landing Harbor Adaptation Strategies

Below is a description of proposed mitigation/adaptation measures which are intended to address vulnerabilities to existing harbor infrastructure from specific climate risks described in Section 2.

1. Do not build new infrastructure within projected hazard zones that will not be resilient (for the expected life of the infrastructure) to the predicted impacts of that hazard.
2. Upgrade Harbor infrastructure within and adjacent to tidelands to be resilient to 2060 predicted tidal range (>2.6-3.8ft).
    a. Harbor pilings in some areas that have not been upgraded will need to be replaced with taller posts to ensure that tides do not lead to docks overtopping pilings.
    b. Raise or relocate pedestrian walkways, dock access ramps (areas 1, 2 &3) and adjacent infrastructure (oil collection system, garbage enclosure).
3. Raise public parking and access areas of Harbor District property to above the predicted 2060 tidal range.
    a. Raise parking lot areas to above the predicted 2060 tidal range (>2.6-3.8ft). (See Figure 13)
    b. Access/launch ramps and other infrastructure should be upgraded in coordination with adjacent efforts to raise parking and access areas above 2060 tides.
4. Design and build low relief berms (with drainage infrastructure) along harbor waterfront and restore coastal beach and dunes to help reduce winter storm flooding to Harbor district property and adjacent roads and infrastructure.
    a. Design and construct (in partnership with the Monterey County, CalTrans and Moss Landing Community) low relief berms along waterfront areas where storm flooding is predicted to overtop and flood inland low-lying roads and properties. (See Figure 13)
    b. Upgrade storm drains to enhance drainage during rainstorms with high tides (king tides).
    c. Work with US Army Corps of Engineers and Monterey Bay National Marine Sanctuary (and other regulatory agencies) to investigate beach and dune nourishment opportunities for harbor dredge materials to increase SLR resiliency.
    d. Continue to support dune restoration and resiliency efforts on Salinas River State Beach sand dunes (Figure 13).
    e. Define inland zones to support dune migration (while maintaining harbor channel functions) needed to maintain a minimum dune barrier width (Figure 14a).

5. Work with Monterey County and Moss Landing Community to ensure road access to harbor infrastructure and docks.
    a. Continue to participate in the Moss Landing Community Plan development process and ensure that County services including roads and bridges and utilities are maintained, upgraded or relocated in ways that ensure continued access to and use of harbor infrastructure through 2060.
    b. Upgrade Moss Landing Road tide gates to enhance drainage during rainstorms with high tides (king tides).
6. Draft long range plan in partnership with Monterey County to relocate the harbor infrastructure (in tandem with the Moss Landing community, local roads and highway alignment) inland to serve 2100 community needs. Negotiate modified tidal lands lease agreement with State Lands Commission.
    a. Establish a long range planning effort within the Moss Landing Community Plan process to identify needed coastal retreat strategies and rezone areas for future development inland of mapped hazard areas (Figure 14b). Investigate new opportunities to relocate Moss Landing Harbor inland along the Elkhorn or Moro Cojo sloughs as coastal dunes fail or migrate inland.
    b. Ensure that County actions (road and bridge replacements) and state agency programs and policies support harbor district needs to re-locate new berthing inland within Elkhorn Slough (East of the current location of Highway 1), in order to continue safe harbor services to the citizens of California.

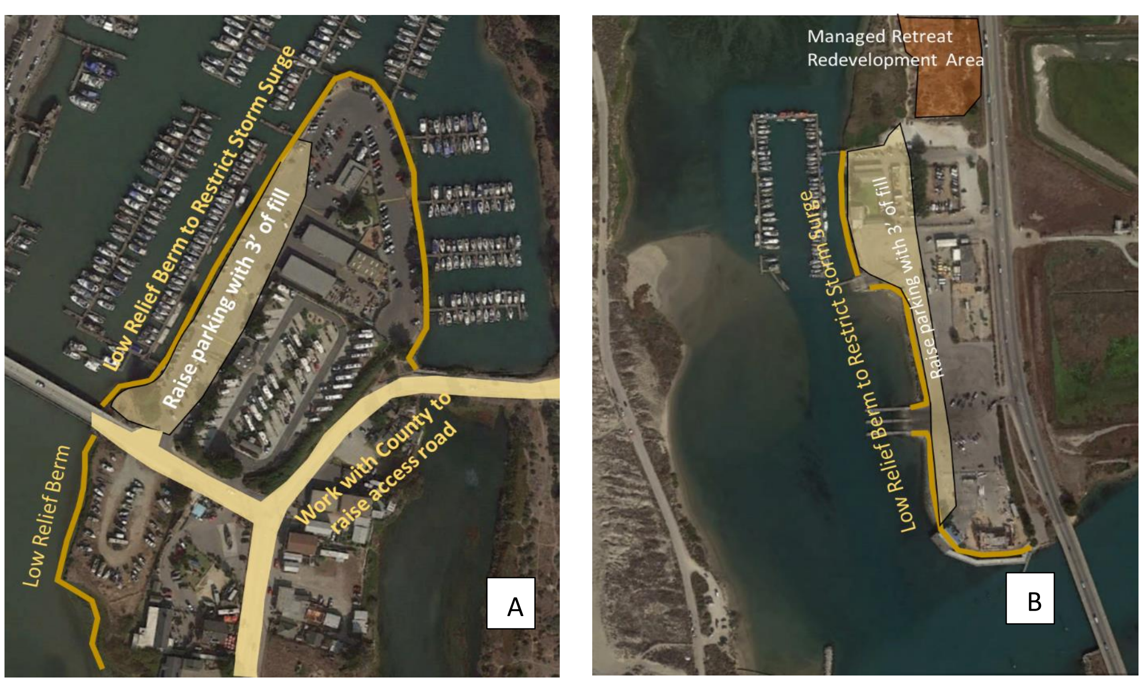

Figure 13. Maps of adaptation, resiliency and retreat planning areas including harbor berm to reduce storm related flooding and raising of parking/ public areas to reduce tidal flooding A) South Harbor, B) North Harbor.

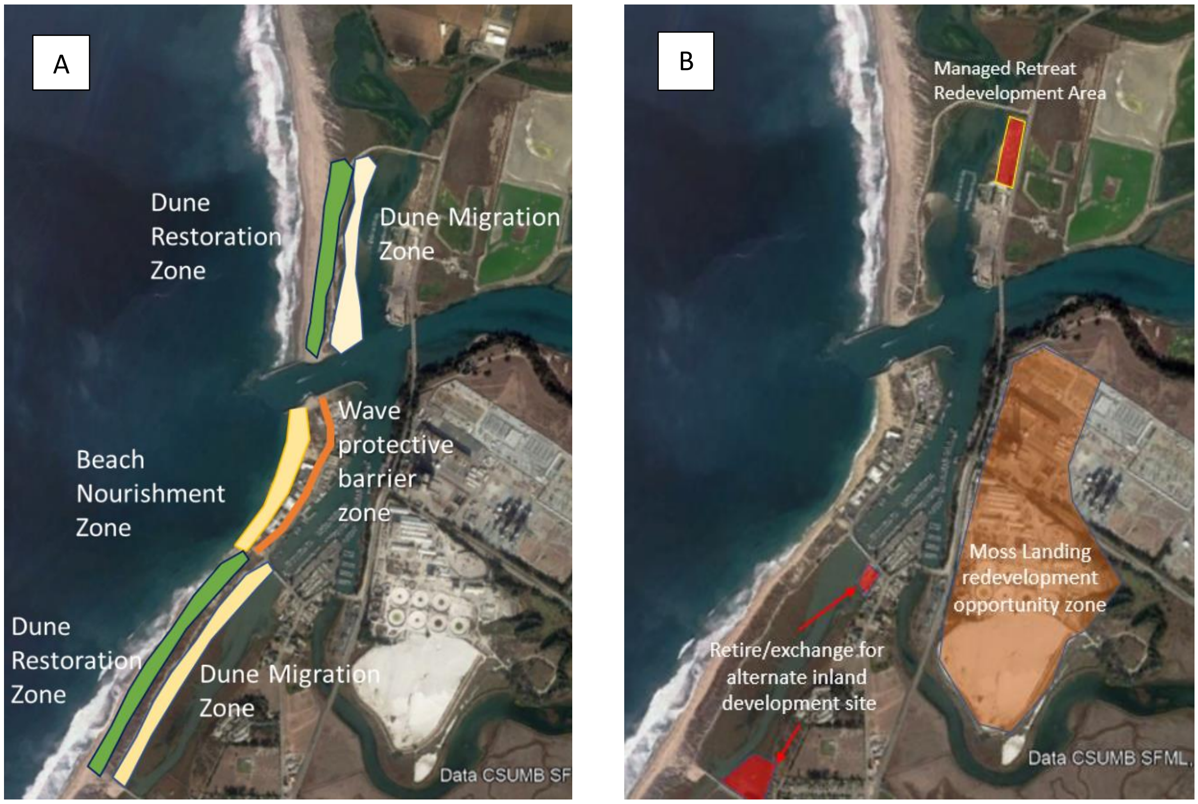

Figure 14. Maps of (A) areas for recommended coastal dune and beach management zones to increase resiliency of natural dune barrier and work with ML island property owners to develop a storm surge barrier into new and existing development and (B) possible areas in harbor ownership where development opportunities could be retired and exchanged for development in areas resilient to 2060 hazards (Moss Landing community redevelopment opportunity zone also noted although outside of harbor district control).

Timeframe of Implementation of Measures

Table 11 lists recommended timeframes for initiation and completion of various adaptation, protection and planning efforts needed to be completed by the Harbor District, Monterey County and private land owners to address predicted coastal climate hazards. Infrastructure upgrades identified within this hazard evaluation focus on increasing the elevation of parking and dock access ways (Figure 13) and the enhancement and management of coastal boundaries including dunes and beaches and harbor waterfront that provide resiliency to predicted flooding (Figure 14).

Monitoring of Sea-level Rise Impacts and Adaptation Strategies

Climate Impact Monitoring Strategy

It is recommended that the Harbor District adopt a simple tracking system to document impacts to infrastructure and reductions in levels of service associated with coastal flooding, erosion and other related coastal climate change hazards. Tracking should document 1) impacts that require replacement, repair or upgrades to harbor infrastructure and 2) flooding and other storm related events which restrict access to harbor infrastructure and public access to the harbor, Elkhorn Slough, beaches and Monterey Bay National Marine Sanctuary.

Regional Planning in Place to Address Sea-level Rise and Climate Change

Moss Landing Community Plan

The Moss Landing Community Plan and Coastal Implementation Plan, both of which are a part of the Monterey County Local Coastal Program, are currently being updated to provide a comprehensive planning framework to improve and enhance the Moss Landing community. This plan is being prepared by the Monterey County Resource Management Agency – Planning with the input and assistance from the community, stakeholders, planning & environmental consultants and associated agencies.

Integrated Regional Water Management Program

Integrated regional water management (IRWM) is an approach to water resource management in California that is being strongly promoted by the State as a way to increase regional self-sufficiency. IRWM offers an approach for managing the uncertainties that lie ahead, particularly in light of climate change. The IRWM planning process brings together water and natural resource managers, along with other community stakeholders, to collaboratively plan for and ensure the region's continued water supply reliability, improved water quality, flood management, and healthy functioning ecosystems—allowing for creative new solutions and greater efficiencies. The Greater Monterey IRWM Plan has been developed to fulfill the goals of IRWM planning in this region and to provide eligibility for State IRWM grant funds.

Elkhorn Slough Tidal Wetland Recovery Plan

With fifty percent, or 1,000 acres, of Elkhorn Slough's salt marshes being lost over the past 150 years and the ongoing marsh loss and habitat erosion, the Elkhorn Slough Tidal Wetland Program was formed. This unique program is a collaborative effort to develop and implement strategies to conserve and restore estuarine habitats in the Elkhorn Slough watershed. For the past several years, stakeholders and scientists participating in the Elkhorn Slough Tidal Wetland Project (TWP) have evaluated the pros and cons of different restoration alternatives for the estuary. The main channel and tidal creeks in Elkhorn Slough have undergone extensive erosion due to tidal scour following the opening of an artificial mouth to the estuary in 1946 to accommodate Moss Landing Harbor. The larger estuarine mouth also has contributed to dieback of salt marsh habitat in the slough. Tidal Wetland Project investigations explored whether a single large fix at the mouth of the estuary, effectively shrinking the mouth size, would benefit overall ecosystem health. The decision was that no large scale action should currently be undertaken at the mouth of the estuary, because of potential risks to water quality, negative impacts to recreational boating, and uncertainty about benefits to salt marsh habitat. However, smaller scale actions have been taken including the Parson's Slough sill, and raising the elevation of the Minhoto Marsh elevation with sediment from the Pajaro River.

Estimate of Financial Costs of Sea-level Rise Adaptation

Storm Cleanup, Replacement or Repair Costs

Costs associated with future cleanup after storm events is difficult to anticipate and budget. Previous cleanup and repair efforts have been completed by the Harbor District and often include repairs to docks due to fluvial discharge and storm surge, dredging due to erosion from the watershed, and road and parking lot cleanup due to storm surge and flooding. Such costs are anticipated to increase as storm events increase in frequency and intensity.

Anticipated Costs of Adaptation/Mitigation Measures, and Potential Benefits of Such Strategies and Structures

Costs to implement the 2030 and 2060 adaptation efforts was estimated with input from Harbor District Staff (Table 10 and Table 11). Costs include design, planning, permitting and construction activities. No adaptation strategies required the purchase of new properties but many adaptation actions needed to retain operations of the harbor are the responsibility of state and county agencies. Specifically, CalTrans is responsible for continued operations of Highway 1 (and currently studying long term management of the corridor in reference to predicted SLR hazards) and Monterey County which is responsible for local roads, bridges and tide gates.

Table 10. Adaptation Costs for 2030 and 2060 time horizons.

TIME HORIZON	ADAPTATION APPROACH	ADAPTATION COSTS
2019-2030	Adapt	$2,100,000
	Plan	$250,000
	Protect	$1,700,000
	2030 Total	***$4,050,000***
2030-2060	Adapt	$13,000,000
	2060 Total	***$13,000,000***
	Total	**$17,050,000**

Anticipated costs to relocate infrastructure and work with county agencies to upgrade roads is anticipated to cost approximately $4 million (Table 10). These activities are expected to reduce loss of service of Harbor infrastructure and help maintain access to boats during flooding, and estimated market and non-market cost of approximately $3.6 million annually or approximately ten times return on the investment to the boating community. Costs to raise parking and access ways, and construct storm surge protection around the harbor is anticipated to cost $17 million but will reduce market and non-market losses of approximately $67 million annually by 2060 (Table 9).

Costs to construct extensive sea walls or rip-rap needed to protect the harbor from wave overtopping of the coastal beach strand were not estimated but were assumed to be only partially effective and would likely be cost prohibitive when compared with relocating marina boat slips inland, away from wave hazards.

Cost Savings

Much of the costs to implement the actions was attributed to permitting and planning as well as state requirements to pay prevailing wages. Significant reductions in described costs could be made if permitting costs were reduced significantly and prevailing wage requirements were suspended for SLR mitigation and adaptation activities. Integration of these identified adaptation actions could be integrated into the Moss Landing Community plan and thus integrated with the North Monterey County Local Coastal Plan. Integration into the LCP may help to reduce permitting costs if the State adopts policies that support streamline permitting of SLR adaptation strategies outlined in adopted LCPs.

Table 11. Adaptation Strategy Implementation Timeline and Cost

TIME HORIZON	ADAPTATION APPROACH	ACTION	RELATIVE COST	SIZE OF EFFORT	ESTIMATED COST
2019-2030	Adapt	Upgrade older dock pilings with taller pilings that can withstand predicted 2060 tidal range.	Mid	50 Pilings	$700,000
		Move trash and oil recycling enclosures out of storm flood hazard area.	Low	2 enclosures	$1,000,000
		Investigate alternative routes to north harbor docks that will provide better access during winter storm flooding.	Low	1 access location	$400,000
	Plan	Work with Monterey County and Coastal Commission to transfer development rights to inland or more resilient areas.	Low	3 parcels	$250,000
		Work with Monterey County and Moss Landing Marine Labs to ensure proper functionality of Moss Landing Road/Moro Cojo Slough Tide Gates to minimize flooding to "downtown".	Mid	Three culverts and tide gates with upgrades to road	County
		Work with Elkhorn Slough NERR to identify marsh plain resiliency options (possibly using appropriate dredge spoils) to retain marsh habitat areas and reduce slough erosion and harbor siltation.	Low	1,000 Acres	N/A
	Protect	Design and construct (in partnership with Monterey County, CalTrans and Moss Landing Community) low relief berms along waterfront areas where storm flooding is predicted to overtop and flood inland low-lying roads and properties. Upgrade storm drains to enhance drainage during rainstorms with high tides (king tides).	Mid	650 Linear Feet (North Harbor) 1600 Linear Feet (South Harbor) 500 Linear Feet (OSR Storage)	$1,200,000
		Continue to support dune restoration and resiliency efforts on Salinas River State Beach sand dunes.	Low	25 acres	State Parks
		Work with Monterey County, State Lands Commission, US Army Corps of Engineers, and Monterey Bay National Marine Sanctuary to encourage beach nourishment on developed sections of the Moss Landing sandspit using appropriate harbor dredge spoils.	Low	6 acres of beach area	$500,000

TIME HORIZON	ADAPTATION APPROACH	ACTION	RELATIVE COST	SIZE OF EFFORT	ESTIMATED COST
2030-2060	Adapt	Upgrade access ramps and other infrastructure in coordination with adjacent efforts to raise parking and access areas above the predicted 2060 tidal range (>2.6-3.8ft)	Low	12 access landings	$1,000,000
		Raise parking lot areas, pedestrian walkways, dock access ramps (areas 1, 2 &3) and adjacent infrastructure (oil collection system, garbage enclosure) to above the predicted 2060 tidal range (>2.6-3.8ft). (See Figure 13)	High	1 Acre (North Harbor) 1.5 Acres (South Harbor) 1.25 Acres (Old Salinas Storage)	$10,000,000
		Move vulnerable infrastructure (trash enclosures, restrooms) away from hazard areas.	Mid	10 pieces of infrastructure	$2,000,000
		Work with Monterey County to raise Moss Landing and Sandholdt Roads to maintain access during high tides and winter storms.	High	2000 Linear Feet	County
	Plan	Ensure that County services, including roads and bridges, are maintained, upgraded or relocated in ways that ensure continued access to harbor infrastructure through 2060.	High	2000 Linear Feet	County
		Work with CalTrans to ensure highway service to Moss Landing either in current or new alignment. Investigate Dolan Road as community access road if Highway 1 is moved inland.	Very High	4 miles of highway	State
2060-2100	Adapt	Establish a long range planning effort within the Moss Landing Community Plan process to identify needed coastal retreat strategies and rezone areas for future development inland of mapped hazard areas. Investigate new opportunities to relocate Moss Landing Harbor inland along the Elkhorn or Moro Cojo Sloughs as coastal dunes fail or migrate inland.	Mid	Complete Redevelopment	N/A

5. Conclusion

To ensure continued harbor operations through 2060 CCWG, with input from the Harbor District, has identified a number of necessary adaptation actions (raising of parking and dock access) that will help increase the resiliency of infrastructure and continue to provide an expected level of service and access. The costs to build/construct these activities are expected to be spent as the reduction in service is documented (i.e. environmental triggers). By 2060 access to harbor infrastructure (and therefore State Granted Lands) will be greatly reduced due to monthly or daily tidal flooding. Adaptation and resiliency measures taken by the Harbor District will only be effective if Monterey County, CalTrans and regional utilities, California State Parks, and private land owners along the Island sandspit take concurrent actions to adapt current infrastructure and maintain resiliency. Road, bridge and tide gate infrastructure must be maintained and upgraded if the Harbor is to remain viable through 2060. Coastal resilience planning is needed to increase resilience to 2060 wave overtopping of the Island and will need to be coordinated and a plan agreed to by the County, State (specifically the Coastal Commission), and private land owners on the island.

The hazards predicted to occur sometime between 2060 and 2100 are significant and likely unsurmountable for the harbor to withstand and remain operational within its current layout. Retreat of harbor infrastructure inland within the Elkhorn and Moro Cojo sloughs is likely needed if the Moss Landing Harbor is to remain a viable California safe harbor.

State and County funding needed to retain access to Harbor infrastructure and utilities will need to be identified before the Harbor District can invest in necessary upgrades. Such retreat and relocation decisions will need to be made in consult with State Lands and California Boating and Waterways staff who will need to prioritize future expenditures needed to retain safe boating along the California Coast.