City of Capitola
Coastal Climate Change Vulnerability Report

Appendices

JUNE 2017

CENTRAL COAST WETLANDS GROUP

MOSS LANDING MARINE LABS | 8272 MOSS LANDING RD, MOSS LANDING, CA

Appendix A.

Coastal Adaptation Policy Assessment: Monterey Bay

(Center for Ocean Solutions, 2016)

Coastal Adaptation Policy Assessment: Monterey Bay

August 30, 2016

To support decisionmakers in their efforts to manage coastal resources in a changing climate, the Center for Ocean Solutions (Center) engaged with Monterey and Santa Cruz Counties and other partners to model, map and assess the role of natural habitats along the coast of Monterey Bay in providing the ecosystem service of coastal protection. In addition, the Center evaluated existing and potential land use policy strategies that prioritize nature-based climate adaptation strategies. Ecosystem service modeling and assessment was conducted using the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) decision support tool, a suite of tools to map and value the goods and services from nature. Specifically, the Center utilized the InVEST Coastal Vulnerability model for this assessment.

This ecosystem services and adaptation policy assessment focuses on the coastline of Monterey Bay and two specific geographic areas of interest: Capitola in Santa Cruz County and Moss Landing in Monterey County. For each location, we identify the distribution and ecosystem services provided by coastal habitats, map the role of those habitats in reducing exposure to storm impacts, evaluate land use policy adaptation strategies with the potential to maintain or improve nature's role in reducing exposure to these impacts, and highlight policy considerations relevant for each strategy. In addition, we include an introduction to our science-to-policy approach, a compilation of general considerations for pursuing land use policy approaches, as well as a summary of our analysis methodology.

This assessment addresses Task 4B of the Ocean Protection Council's grant entitled: "Collaborative Efforts to Assess SLR Impacts and Evaluate Policy Options for the Monterey Bay Coast." Results from this assessment will inform local planning in both Capitola and Moss Landing, as well as regional or county-wide planning in both Monterey and Santa Cruz Counties. This collaborative, regional project is underway in parallel with other coastal jurisdictions through a statewide investment in updating coastal land use plans in accordance with projections of rising sea levels and more damaging storms.

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Coastal Adaptation Policy Assessment: Monterey Bay

EXECUTIVE SUMMARY

As sea levels rise, the impacts of more frequent large storm events driven by the El Niño Southern Oscillation (ENSO) will be greater than those historic events of similar magnitude, exposing coastal areas to the combined effects of elevated tides, increased storm run up and enhanced wave impacts. This increase in the frequency and intensity of storms will likely lead to economic, social and environmental vulnerabilities for coastal communities. California has proactively prioritized coastal adaptation planning that addresses vulnerabilities associated with a changing climate. As a result, the Monterey Bay Region is one of many locations to receive significant funding support to conduct a regional assessment of coastal vulnerability. The results of this coastal adaptation policy assessment will provide information that municipalities can leverage as they engage in adaptation planning for coastal land use.

Successful local, regional and state climate adaptation planning should take into account the role of natural habitats in ensuring a resilient coastline. Coastal habitats can play a protective role in reducing exposure to wind and wave impacts while also providing many additional beneficial ecosystem services to people and nature. Through proactive climate adaptation planning, coastal communities should prioritize nature-based strategies (e.g., dune or wetland restoration, conservation easements, etc.) when and where they are most feasible. If nature-based strategies are not practical in a given location, then coastal planners should consider approaches that seek to maintain the integrity of natural habitats and allow for adaptive coastal planning in the future (e.g., planned retreat, redevelopment limits, etc.).

With combined funding from the State Coastal Conservancy's (SCC) Climate Ready and Ocean Protection Council's (OPC) Local Coastal Program Sea Level Rise grant programs, the Monterey Bay Region is a part of a statewide investment to update coastal land use plans in accordance with projections of rising sea levels and more damaging storms. In parallel with additional select counties, the SCC and OPC provided funding in 2013 for Monterey and Santa Cruz Counties to include impacts from rising sea levels in their ongoing Local Coastal Program updates. The full study area includes the Monterey Bay coastline from Año Nuevo in Santa Cruz County to Municipal Wharf Two in Monterey County. Through discussion with county and city planners as well as with grant organizers from Central Coast Wetlands Group, two community-level study areas were identified—Capitola and Moss Landing—for exposure of coastal assets analyses, the role of natural habitats in reducing coastal exposure and the implications for potential climate adaptation strategies. Detailed analysis and synthesis in these case study locations will be the catalyst for similar investigations throughout Monterey Bay and potentially other sections of the California coast.

Executive Summary: Key Messages

Monterey Bay Coastal Study Area

- The Monterey Bay coastline features diverse coastal habitats including: dense kelp forests; brackish wetland habitats along creeks, lagoons, and sloughs; and expansive beach and dune systems that cover the central and southern sections of the coastline.
- While each coastal habitat plays some protective role, the dune systems in southern Monterey Bay play the highest role in reducing exposure of coastal development to erosion and inundation during storms relative to the entire study area.
- Any climate adaptation strategies under consideration along the Monterey Bay coastline should conform with the strictures of the Coastal Act, consider the recommendations from the Coastal Commission's sea level rise guidance, and respect the cultural significance of the region.
- A primary consideration for proactive coastal adaptation is to incentivize proactive climate adaptation planning that utilizes a blend of approaches across multiple timescales; optimal strategies should not limit adaptation options for future generations.

Capitola

- The small beach and lagoon system at the mouth of Soquel Creek plays a relatively moderate role in reducing exposure to erosion and inundation in comparison with the entire study area.
- The proximity of Capitola's commercial development to the coast limits the city's options for nature-based adaptation strategies.
- Adaptation options for developed sections of Capitola include implementing overlay zones that account for anticipated rising seas. In addition, limiting redevelopment or implementing redevelopment guidelines in these zones can provide a plan for relocation in coming years.

Moss Landing

- Relative to the entire Monterey Bay study area, the large dunes north and south of Moss Landing provide the highest protective role from coastal storm impacts.
- Nature-based climate adaptation options in the Moss Landing case study area include restoration or preservation of dune and wetland habitats. In addition, nourishing beachfront locations with additional sediment can be an option if appropriate environmental concerns are addressed.
- Built structures—including some coastal dependent structures—limit adaptation options for parts of Moss Landing. Critical infrastructure such as the Moss Landing power plant, harbor infrastructure, and Highway 1 all present challenges to implementing many otherwise viable strategies.

<u>Our Climate and Ecosystem Services Science-to-Policy Approach</u>

Coastal decisionmakers are actively determining how coastal communities will adapt to rising sea levels and more damaging storms. Favorable adaptation approaches consider the role of natural habitats and prioritize resilient strategies that do not limit future planning options.[1] Since 2010, the Center for Ocean Solutions has worked with coastal planners and managers to incorporate the role of natural habitats in climate adaptation planning.[2] Below, we outline our scalable, transferable approach to bridging a spatial assessment of natural protective services with coastal land use policy decisions in an era of changing climate.[3]

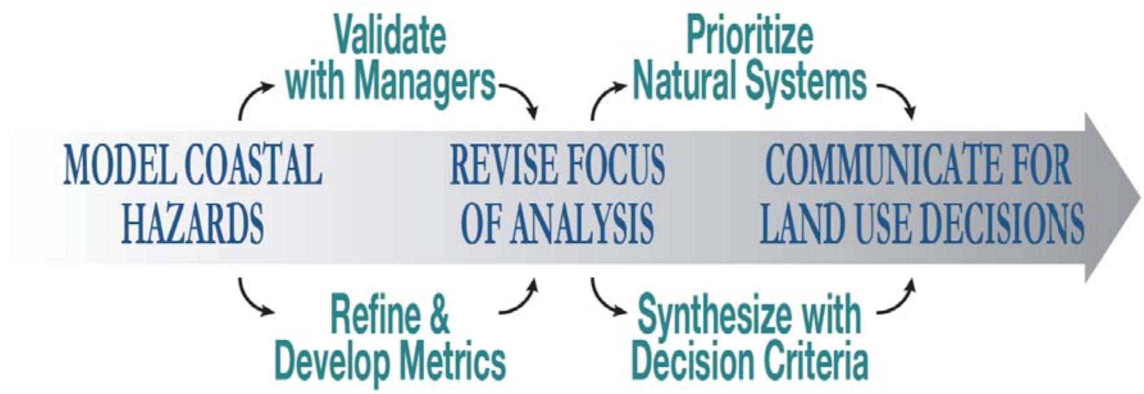

Fig. 1: Our transferable, scalable ecosystem services to coastal adaptation policy approach.

<u>Coastal Ecosystem Services</u>

Ecosystem services are the benefits that natural habitats provide to people (e.g., water purification, aesthetic attachment, carbon sequestration and coastal protection). Thriving, healthy ecosystems provide the greatest provision of services and are most resilient in the face of dynamic environmental conditions. In the coastal context, ecosystems play an important role in protecting shorelines against wave action by dissipating wave energy, or, in the case of sand dunes, physically impeding wave run-up. Climate change impacts, such as rising sea levels and increased storm intensity, are altering patterns of wave action along the coast and exposing new locations to physical forces. As waves travel from the open sea to coastal regions with shallower waters, they interact with the natural and geologic features of the seabed. Increased intensity and frequency of storms and rising seas, further emphasizes the important role of coastal habitats in reducing shoreline erosion and of increasing resilience in coastal areas.

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[1] Jon Barnett & Saffron O'Neill, *Maladaptation* 20 GLOBAL ENVTL. CHANGE 211 (2010).

[2] Suzanne Langridge et al., *Key lessons for incorporating natural infrastructure into regional climate adaptation planning* 95 OCEAN & COASTAL MANAGEMENT 189 (2014); Sarah Reiter et al., *Climate Adaptation Planning in the Monterey Bay Region: An Iterative Spatial Framework for Engagement at the Local Level* 6 NATURAL RESOURCES 375 (2015); Lisa Wedding et al., *Modeling and Mapping Coastal Ecosystem Services to Support Climate Adaptation Planning*, *in* OCEAN SOLUTIONS EARTH SOLUTIONS 389 (Dawn J. Wright ed., 2016).

[3] *See* Figure 1. For further information on this approach, see also the "Analysis, Methodology and Assumptions" section *infra*.

Diverse habitats along California's coastline (e.g., sea grasses, kelp forests, salt marshes, dunes) play a role in reducing exposure to storm impacts while also providing a variety of additional services. As coastal development and rising sea levels degrade or damage these habitats, coastlines, communities and infrastructure become increasingly vulnerable to storms. An important challenge for decisionmakers is determining the best climate adaptation strategies that protect people and property while also protecting the ability of coastal habitats to provide a protective service into the future. To address this challenge, coastal communities need to identify where natural habitats provide the greatest protective benefits so that they may prioritize adaptation planning efforts that protect or restore their critical natural habitats.

Spatial Modeling and Mapping of the Protective Services

Modeling and mapping the ecosystem service of coastal protection can support the spatial prioritization of science-based climate adaptation strategies. For this assessment, we used InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) in combination with ArcGIS to identify areas where natural coastal habitats provide greater relative protection from storms and shoreline erosion.[4] The spatial models account for service supply (e.g., natural habitats as buffers for storm waves), the location and activities of people who benefit from services and infrastructure potentially affected by coastal storms. The InVEST Coastal Vulnerability model produces a qualitative estimate of coastal impact exposure to erosion and inundation during storms. By coupling exposure results with population information, it can identify the areas along a given coastline where humans are most vulnerable to storm waves and surge. The model does not value any environmental service directly, but ranks sites as having a relatively low, moderate or high risk of erosion and inundation through an exposure index.

The Coastal Exposure index is calculated by combining the ranks of the seven biophysical variables at each shoreline segment: geomorphology, natural habitats (biotic and abiotic), net sea level change, wind and wave exposure, surge potential and relief (bathymetry and topography). Model inputs serve as proxies for various complex shoreline processes that influence exposure to erosion and inundation. The resulting coastal exposure ranks range from very low exposure (rank=1) to very high exposure (rank=5), based on a mixture of user- and model-defined criteria. The model output helps to highlight the relative role of natural habitats at reducing exposure—also through a 1–5 ranking. This relative role output can be used to evaluate, how certain management actions can increase or reduce exposure of human populations to the coastal hazards of erosion and inundation. For this assessment, the model outputs were mapped on the shoreline of the Monterey Bay study area in order to interpret the relative role of natural habitats in reducing nearshore wave energy levels and coastal erosion—thus highlighting the protective services offered by natural habitats to coastal populations.

[4] InVEST is a free and open-source suite of software models created by the Natural Capital Project at the Stanford Woods Institute for the Environment to map and value the goods and services from natural capital. *See* INTEGRATED VALUATION OF ECOSYSTEM SERVICES AND TRADEOFFS, http://www.naturalcapitalproject.org/models/coastal_vulnerability.html (last visited Aug. 30, 2016).

Coastal Vulnerability Model Considerations

While this vulnerability modeling approach includes average wave and storm conditions, the InVEST Coastal Vulnerability model does not account for coastal processes that are unique to a region, nor does it predict changes in fluvial flooding or shoreline position or configuration. The model incorporates a scenario-based approach to evaluate the role that coastal habitats play in reducing exposure to coastal impacts. We use the Coastal Vulnerability index here to better understand the relative contributions of different input variables to coastal exposure and highlight the protective services offered by natural habitats to coastal populations. Results provide a qualitative representation of erosion and inundation risks, rather than quantifying shoreline retreat or inundation limits. The compiled role of habitat map products depicts results from a "presence/absence" analysis that calculates the difference between erosion indices with and without habitats in place. In effect, this approach indicates the change in coastal exposure if natural habitats are lost or degraded.

Connecting Spatial Modeling to Planning

Understanding the role that nearshore habitats play in the protection of coastal communities is increasingly important in the face of a changing climate and rising seas. To develop this analysis, we integrated feedback from coastal planners to better understand their information needs on coastal vulnerability and potential adaptation options. The map products created from the InVEST Coastal Vulnerability model support the spatial evaluation of nature-based adaptation planning alternatives with rising sea levels, and highlight how protective services might change in the future. Connecting these model results with existing land use planning and zoning information and current policies provides a pathway for identifying locations in which nature-based strategies can be prioritized as more effective and feasible than competing traditional strategies.

Monterey Bay Coastal Study Area

Monterey Bay Coastal Management Context

The study area from Año Nuevo in Santa Cruz County to Wharf Two in Monterey County features a diverse range of land uses and densities. This range includes the City of Santa Cruz's highly developed coastline, the sparsely populated coastal properties of southern Santa Cruz County, and undeveloped beaches in Santa Cruz and Monterey Counties.[5] Farmlands dominate much of the inland areas, especially around Watsonville, Castroville, and Salinas. The main feature of the coastline is the Monterey Bay itself, which includes a submarine canyon leading seaward from Elkhorn Slough and the coast of Moss Landing. The Moss Landing power plant is the largest structure on the Bay, and the coastline features numerous important points of interest, roads, critical infrastructure, and research and educational facilities.

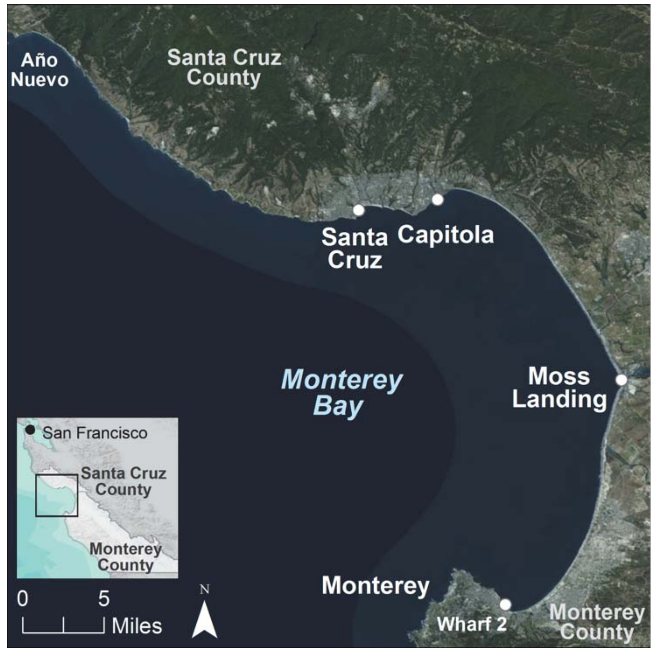

Fig. 2: Satellite image of Monterey Bay.

Several governmental agencies oversee the Monterey Bay coastline. For instance, the California Department of Parks and Recreation manages the state parks and reserves. The California Department of Transportation (CalTrans) oversees the coastal roadways, particularly the Pacific Coast Highway (Highway 1). The California Energy Commission regulates the Moss Landing power plant. The U.S. Fish and Wildlife Service governs the Salinas River National Wildlife Refuge. The National Oceanic and Atmospheric Administration (NOAA) administers the Elkhorn Slough National Estuarine Research Reserve (ESNERR) in partnership with the California Department of Fish and Wildlife. ESNERR and the non-profit Elkhorn Slough Foundation protect 5,500 acres of land, comprising property owned and managed by the reserve and property owned or managed by the foundation in the surrounding hillsides.[6] NOAA also administers the Monterey Bay National Marine Sanctuary and has jurisdiction over the marine mammals in the area. The most active land management agencies in the coastal zone include: the California Coastal Commission, which oversees land use and public access; the State Coastal Conservancy, which strives to protect or improve natural coastal ecosystems; and the State Lands Commission, which manages California's public trust lands.[7]

[5] The full project study area includes the Monterey Bay coast from Año Nuevo in Santa Cruz County to Municipal Wharf Two in the City of Monterey. Note that this study area does not include sections of Santa Cruz County north of Año Nuevo or sections of Monterey County west and south of Wharf 2. *See* Figure 2.

[6] ELKHORNSLOUGH.ORG, http://www.elkhornslough.org/conservation/what.htm (last visited Aug. 29, 2016).

[7] Public trust lands are held and managed by the state for the benefit of the public. In the coastal zone, public trust lands include all ungranted tide and submerged lands. The Coastal Commission also retains some oversight over the use of granted tide and submerged lands.

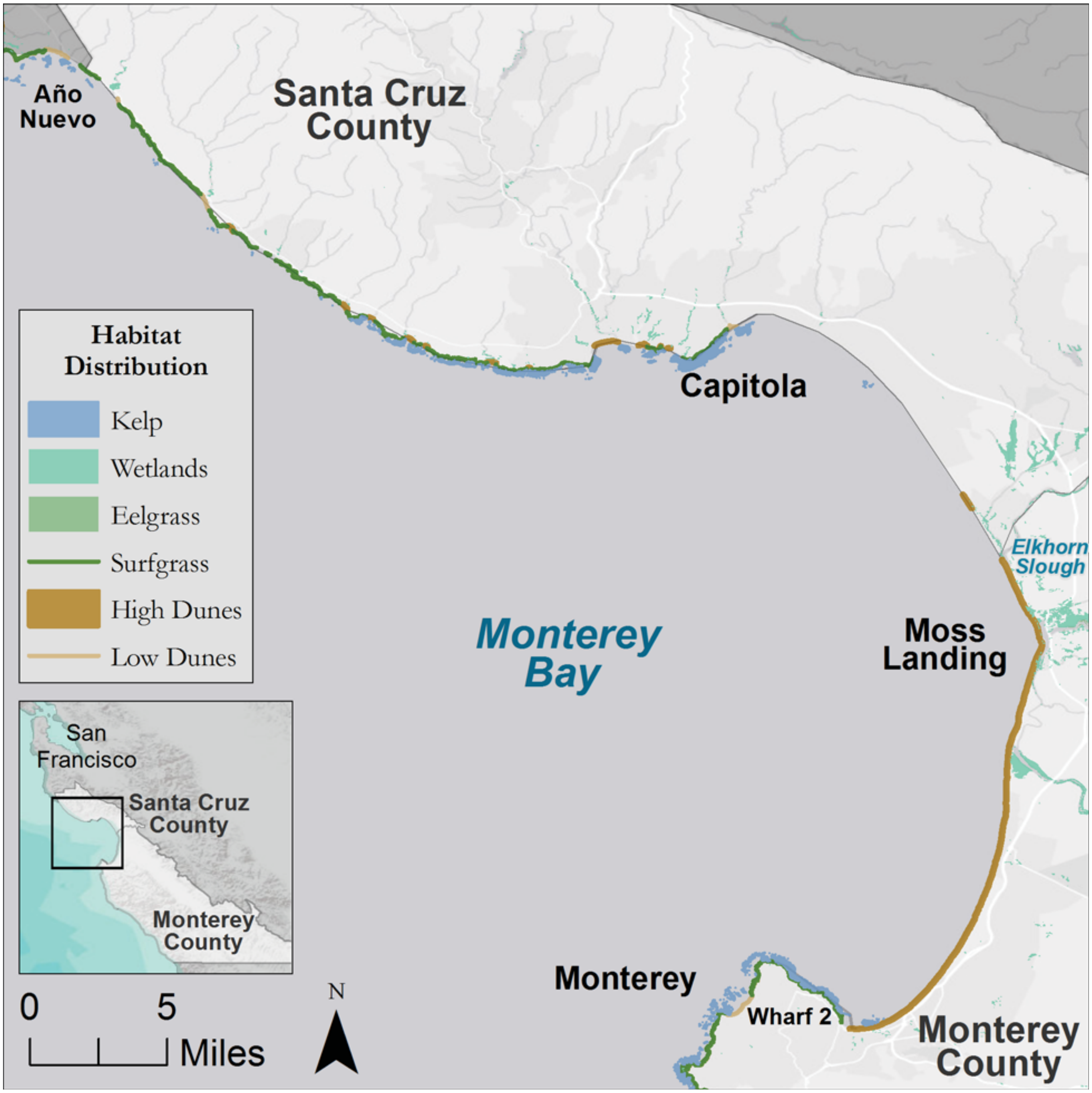

Fig. 3: Coastal habitats in Monterey Bay and surrounding area.

The Pacific coast of Santa Cruz and Monterey Counties has extensive natural habitats including some of the most imperiled habitats in the United States. Freshwater wetlands, coastal prairie and maritime chaparral, as well as kelp forests, estuarine wetlands, small and large beaches, and dunes are all present in the region.[8] The northern section of the study area (Año Nuevo to Capitola) includes a mostly rocky coastline fronted by seaweeds and surfgrass, backed by open agricultural lands. Occasional pocket beaches, typically fed by creeks, interrupt the bluffs and provide coastal access. Near the river mouths of the city of Santa Cruz, there is a greater concentration of small pocket beaches and wetland habitats than elsewhere in the area. The central section of the study

[8] *See* Figure 3.

area (Capitola to Moss Landing), is predominantly characterized by beaches and low dune systems backed by cliffs that decrease in size from north to south. The southern section of the study area (Moss Landing to Monterey) is dominated by large dune systems at the southern extent of the Santa Cruz littoral cell—the cycle of sediment sources and sinks from Pillar Point to the Monterey Canyon.[9] These habitats are all locally important and provides significant ecosystem services and benefits to certain communities.

Monterey Bay Protective Role of Habitats

Coastal habitats provide the ecosystem service of coastal protection for people, property and infrastructure by providing a natural buffer to mitigate erosion and inundation from ocean waves and storms. Our analysis focused on the direct effects of sea level rise on the risk of coastal communities to erosion and flooding. Our model results suggest that with rising sea levels the ability of dune systems to mitigate coastal exposure and keep this section of coastline in the low-moderate exposure range could be compromised.[10] Rising seas will likely impact the protective role of many beaches and dune habitat backed by coastal armoring that could result in the loss of existing beach area and the associated recreation and tourism income to coastal communities.[11] Overall, the loss of coastal dunes, wetlands, kelp forests and seagrass habitats would increase the exposure to erosion and flooding along the Monterey Bay study area. The extensive high dune systems throughout the southern section of Monterey Bay play a relatively high protective role compared to other natural habitats along the coastline. Storm surge is an important model factor from Marina to Monterey which alludes to the high role of coastal habitats in this area for protecting people and property along the coast. The coastal dune habitat in the Monterey Bay region suffers from high rates of erosion.[12] As a result, shoreline armoring has been used extensively along developed areas to address erosion and protect infrastructure and other areas of coastal development from waves, erosion and inundation. With increasing human pressure on these coastal ecosystems, there is a need to prioritize adaptation planning efforts in these important dune systems and other habitats that play significant roles in coastal protection.

Coastal wetlands along Monterey Bay stabilize shorelines and protect coastal communities by attenuating waves. Wetland habitat in the study area provides a relatively moderate role in mitigating erosion and inundation during storms. As sea levels rise, wetlands need to migrate to maintain their protective role. A recent study in Santa Cruz found that 17% of wetland habitat will be unable to migrate with sea level rise due to existing development.[13] The model does not predict migration or loss of habitat under the different sea level rise scenarios. Further research is needed to understand the extent to which habitats will be able to adapt to climate change effects.[14]

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[9] U.S. ARMY CORPS OF ENGINEERS, COASTAL REGIONAL SEDIMENT MANAGEMENT PLAN FOR THE SANTA CRUZ LITTORAL CELL, PILLAR POINT TO MOSS LANDING (2015).

[10] *See* Figure 4.

[11] Philip G. King et al., THE ECONOMIC COSTS OF SEA-LEVEL RISE TO CALIFORNIA BEACH COMMUNITIES (2011).

[12] Gary Griggs & Rogers Johnson, *Coastline erosion: Santa Cruz County, California* 32 CALIFORNIA GEOLOGY 67 (1979); Edward Thornton et al., *Sand mining impacts on long-term dune erosion in southern Monterey Bay* 229 MARINE GEOLOGY 45 (2006).

[13] MATTHEW HEBERGER ET AL., THE IMPACTS OF SEA-LEVEL RISE ON THE CALIFORNIA COAST (2009).

[14] Langridge, *supra* note 2.

The southern coastline of Monterey Bay is exposed to high wave energy, which was a substantial driver of the high coastal exposure in this area. Surfgrass provides some wave attenuation for the adjacent shoreline but compared to other habitats in the study area, it plays a relatively low role in reducing overall exposure. Although kelp forest habitats along the broader Monterey Bay coastline also play a relatively low role in reducing exposure to coastal hazards compared to the coastal dune habitats, these habitats offer important co-benefits to California's people and the economy such as fisheries habitat and recreation.

Monterey Bay Ecosystem Services of Coastal Habitats

The Monterey Bay is nationally regarded as a culturally important marine habitat. This section of the coast includes six state marine protected areas as well as a national marine sanctuary.[15] Monterey Bay also supports a diverse ocean and coastal-based economy including agriculture, tourism, industry, aquaculture, fishing as well as a number of marine research and education institutions. Many tourists flock to the area for offshore whale watching, coastal birding, kayaking, surfing, boating, fishing, and beach-going. The diverse habitats noted below play an important role in preserving the open natural system of this region.

Creeks, Rivers, and Lagoons

Along the Northern coast of Monterey Bay there are numerous creeks and rivers reaching coastal lagoons and beaches along the Pacific shoreline. Several waterways also weave through the urbanized residential areas in Santa Cruz or Capitola, along with more rural neighborhoods such as in Aptos. These coastal waterways provide habitat for commercially important fish species (e.g., salmon and steelhead) during juvenile stages of their lifecycle. Many non-commercial fish and birds are also endemic to these creeks, while amphibians and reptiles use the damp banks for shelter and a source for food.[16] These riparian corridors and their lagoons provide aesthetic value and streamside recreation opportunities in the form of parks and trails, particularly in more urbanized neighborhoods. They also perform water filtration services, and nutrient cycling. When this habitat remains intact, it can aid in flood control and water storage during the wet season and major storm events.[17]

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[15] The Marine Protected Areas include: Greyhound Rock and Elkhorn Slough State Marine Conservation Areas as well as Año Nuevo, Natural Bridges, Elkhorn Slough, and Moro Cojo State Marine Reserves.

[16] Mary E. Power et al., *Rivers*, *in* ECOSYSTEMS OF CALIFORNIA 713 (Harold Mooney & Erika Zavaleta eds., 2016).

[17] Walter G. Duffy et al., *Wetlands*, *in* ECOSYSTEMS OF CALIFORNIA 669 (Harold Mooney & Erika Zavaleta eds., 2016).

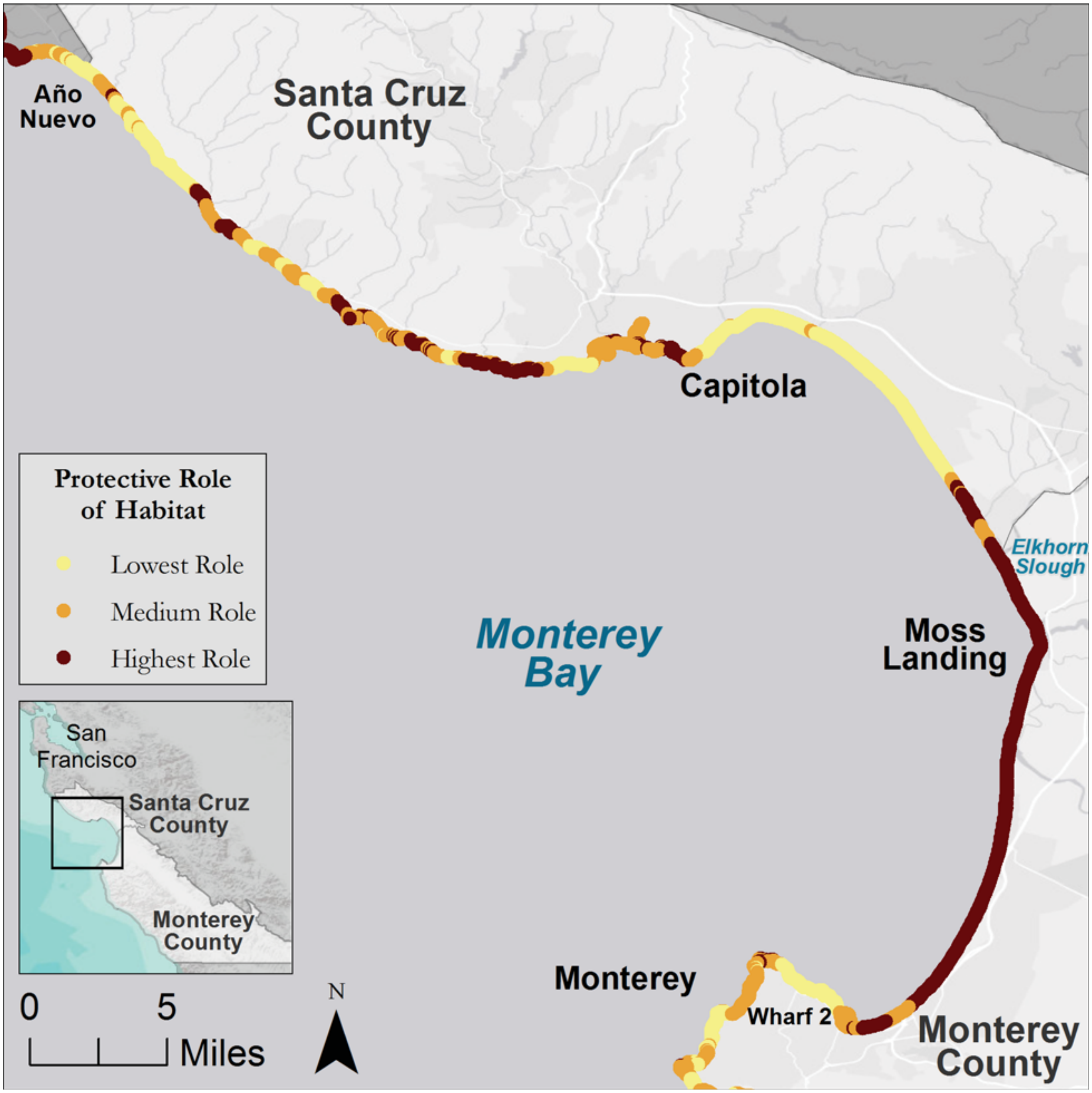

Fig. 4: Relative role of coastal habitats around Monterey Bay in reducing exposure to erosion and inundation.

Kelp Forests of Monterey Bay's Northern Coast

On the Northern end of the bay, near Año Nuevo, dense kelp forests grow from the sandstone and claystone reefs offshore. Kelp forests provide juvenile fish habitat and shelter them from predation. Kelp is also harvested at small scales to provide food for abalone aquaculture, particularly for abalone farms along the wharfs of Monterey.[18] Since no recreational or commercial fishing of any abalone species is allowed south of San Francisco, local aquaculture operations are the only source

[18] Mark H. Carr & Daniel C. Reed, *Shallow Rocky Reefs and Kelp Forests*, *in* ECOSYSTEMS OF CALIFORNIA 311 (Harold Mooney & Erika Zavaleta eds., 2016).

of Monterey Bay abalone for human consumption.[19] Forests of giant kelp (*Macrocystis pyrifera*) and bull kelp *(Nereocystis luetkeana*), nourished by cold, nutrient-rich waters, are highly productive and support a food web of hundreds of fish and invertebrate species along with a diverse assemblage of birds and marine mammals.[20] In addition, litter from broken kelp fronds washes up on local beaches as wrack and detritus, sustaining a separate food web of terrestrial insects and shorebirds.[21] Kelp require high light levels and cool water temperatures to grow. As such they are sensitive to excess sedimentation and nutrient overloads that stimulate growth of light-blocking organisms. Strong wave action from storms can rip out entire kelp patches and significantly damage the remaining fronds. Accordingly, shifts in ocean thermal regimes or winter storm patterns such as El Niño can pose threats to sustaining kelp habitats.[22]

Wetlands of Elkhorn Slough

At the heart of Monterey Bay is Elkhorn Slough, an estuarine system known for its biological significance. Its channels, mudflats, eelgrass beds, salt marshes, and hard substrates provide habitat for more than 100 fish, 265 bird, and 500 marine invertebrate species, and more than two dozen rare, threatened, or endangered species.[23] Elkhorn Slough also provides safe habitat for several species of marine mammals. Sheltered from larger marine predators, harbor seals and Southern sea otters use the Slough as a safe feeding and pupping ground. Because of its rich diversity of birds and mammals, Elkhorn Slough's sheltered waters are a popular location for kayaking, paddle boarding, and wildlife viewing. These wetlands contribute to flood control, water filtration, and nitrogen runoff control services.[24] Wetlands provide additional benefits as sinks for carbon through their vegetation growth and accumulation of slowly decomposing sediment.[25]

Coastal Dune and Beach Systems

Extensive coastal dune systems along the southern coast of Monterey Bay support important plant communities between mean high tide and the furthest reach of storm waves.[26] The Monterey Bay beaches and dunes are also a favorite for locals and tourists alike due to its pristine coastline and sandy shores along many coastal access sites. The beach and dune habitats in this region also

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[19] CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE, STATUS OF THE FISHERIES REPORT (2011).

[20] Yuri Springer et al., *Toward ecosystem-based management of marine macroalgae—the bull kelp, Nereocystis luetkeana* 48 OCEANOGR. MAR. BIOL. ANNUAL REVIEW 1 (2010); *see also* Carr & Reed, *supra* note 18.

[21] Jenny Dugan et al., *The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California* 58 ESTUARINE COASTAL AND SHELF SCIENCE 25 (2003).

[22] Yuri Springer et al., *Toward ecosystem-based management of marine macroalgae - the bull kelp, Nereocystis luetkeana* 48 OCEANOGRAPHY AND MARINE BIOLOGY: AN ANNUAL REVIEW 1 (2010); Paul Dayton & Mia Tegner, *Catastrophic Storms, El Niño, and Patch Stability in a Southern California Kelp Community* 224 SCIENCE 283 (1984).

[23] CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH 4 (Jane Caffrey et al. eds., 2002) (Elkhorn Slough's habitats include "the slough's channels, mudflats, eelgrass beds, salt marsh, and hard substrate; the adjacent harbor, coastal dunes, and open beaches; and the grasslands, oak, woodlands, chaparral, and other upland areas.").; Jessica Lyons, *Scientists and Activists Aim to Save Elkhorn Slough from Erosion and Development Before it is too Late*, MONTEREY CNTY. WEEKLY, Dec. 13, 2007, *available at* http://www.montereycountyweekly.com/news/cover/article_11c69d2e-dfd5-502d-92ca-bada34be8709.html.

[24] James E. Cloern et al., *Estuaries: Life on the Edge, in* ECOSYSTEMS OF CALIFORNIA 359 (Harold Mooney & Erika Zavaleta eds., 2016).

[25] John Callaway et al., *Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands* 35 ESTUARIES AND COASTS 1163 (2012).

[26] Iris Hendriks et al., *Photosynthetic activity buffers ocean acidification in seagrass meadows* 11 BIOGEOSCIENCES 333 (2014).

provide numerous benefits to people and nature, such as critical shoreline bird habitat, mammal haul out locations, as well as coastal recreation and shoreline fishing spots.

General Policy Considerations

There are several general policy considerations that apply to the entire study area, regardless of the adaptation strategy implemented.[27] Most importantly, any climate adaptation strategies should conform to the various strictures of the Coastal Act, and take into account the Coastal Commission's sea level rise recommendations. Additionally, adaptation solutions should be place-based, designed with each specific location's characteristics and limitations in mind. Adaptation strategies should also incentivize proactive planning and limit subsidizing building in hazardous locations. Finally, the cultural significance of the study area should be considered. These considerations are investigated below.

The Coastal Act sets out various legal requirements with which all coastal adaptation policies must be consistent.[28] Likewise, the Commission's Sea Level Rise Guidance (Guidance) contains several persuasive and compelling recommendations. The Guidance recommends pursuing a suite of actions designed to protect in the short term, accommodate in the midterm, and promote retreat in the long term, instead of focusing on any one strategy type or time scales.[29] This hybrid approach permits flexibility and allows communities to tailor adaptation strategies to their unique circumstances. For instance, it would allow the use of protection, accommodation, and retreat strategies simultaneously—as needed and as appropriate—and would also allow these strategies to change over time.[30] Under such an approach, protection of existing structures is allowed but may be limited by certain factors, such as the economic life of a structure.

While a variety of coastal adaptation strategies for adjusting coastal land uses in response to climate impacts are possible in any given area, the appropriate adaptation measures for specific locations will depend on factors such as those locations' topographies and existing infrastructure. Accordingly, each location's unique characteristics should inform the adaptation strategies employed there. For example, the strategies suitable for the study area's open and undeveloped coastlines are likely unsuitable for the city of Santa Cruz and other highly developed areas. Furthermore, specific strategies should take into account predicted rates of local sea level rise and an area's vulnerability to storm events. Finally, existing regulations for each targeted location—such as local coastal programs, rules specific to the Monterey Bay National Marine Sanctuary[31] and any other applicable federal, state or local laws[32]—should be noted and followed.

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[27] These considerations are in addition to the overarching policy consideration of this assessment: that nature-based solutions could be prioritized when possible to ensure maximum co-benefits and beneficial services associated with these strategies.

[28] *See, e.g.*, CAL. PUB. RES. CODE §30235.

[29] CALIFORNIA COASTAL COMMISSION, SEA LEVEL RISE ADOPTED POLICY GUIDANCE 125 (2015) *available at* http://www.coastal.ca.gov/climate/slrguidance.html.

[30] *Id.* at 122-23 ("In many cases, a hybrid approach that uses strategies from multiple categories will be necessary, and the suite of strategies chosen may need to change over time.").

[31] *See, e.g.*, 15 C.F.R. § 922.132 (listing prohibited or otherwise regulated activities in the MBNMS).

[32] For instance, the National Historic Preservation Act of 1966 would govern efforts to move or alter historic buildings on the National Register of Historic Places. 16 U.S.C. §§ 470 *et seq.*

Keeping these limitations in mind, communities should pursue strategies that internalize the risks associated with building and buying properties in hazardous locations and incentivize proactive planned retreat and relocation where appropriate. Proactive planning is especially important in areas with a large number of repetitive loss properties, such as Aptos.[33] Superstorm Sandy and other disasters have proven that making decisions early is less expensive, and potentially less devastating, than waiting until the effects of a disaster take hold.[34] One way governments could internalize the risks associated with building in hazardous locations would be to stop spending public funds to rebuild private structures on sites damaged by rising seas and storms. Another option to internalize these risks would be to amend existing flood insurance policies.[35]

The cultural significance of California's beaches and the Monterey area can also be considered. California's beaches are important to Californians and play a large part in the State's identity. Furthermore, Monterey, and its surrounding areas, are culturally important for many reasons. Coastal adaptation planning can take the area's rich heritage into account when considering which coastal adaptation strategies to pursue. Particularly, adaptation decisions should consider the potential social impacts of decisions affecting culturally and socially significant areas. Moreover, culturally important points of interest in the area should be preserved if possible. Accordingly, decisionmakers can consider the social impacts of any proposed adaptation actions when prioritizing coastal adaptation strategies.

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[33] Particularly State Park Drive and Beach Drive in Aptos, CA. COUNTY OF SANTA CRUZ LOCAL HAZARD MITIGATION PLAN 2015-2020 64 (2015) *available at* http://www.sccoplanning.com/Portals/2/County/Planning/policy/2015%20LHMP%20Public%20Review%20Draft.pdf.

[34] *See, e.g.*, Anne R. Siders, *Anatomy of a Buyout—New York Post-Superstorm Sandy*, Vermont Law School 16th Annual Conference on Litigating Takings Challenges to Land Use and Environmental Regulations (Nov. 22, 2013) (explaining lessons learned in acquisition and buyout programs post-Sandy in New York).

[35] Such a change would need to come at the federal level through amendment to the National Flood Insurance Program. 42 U.S.C. § 4001.

Community-Level Study Areas

Capitola: Coastal Setting

Fig. 5: Satellite image of Capitola.

Capitola was one of the earliest populated beaches on the west coast and hosts a highly developed coastline. Similar to the neighboring city of Santa Cruz, Capitola faces flooding, cliff erosion and episodic bluff failure during King Tides—highest annual tides—and ENSO storm events. Soquel Creek bisects Capitola, and its beach, and plays a large role in riverine inundation in the area. Riprap lines the beach and protects both the beach and development beyond it, such as a modest commercial area that is the economic center of the community.

Capitola's unique characteristics inform the adaptation policies and strategies that might be prioritized in the area.[36] The coastal city of Capitola is dominated by steep cliffs, pocket beaches and low dune systems. Surfgrass beds line the shore and kelp forests populate nearshore reefs from the mouth of Soquel Creek westward toward the city of Santa Cruz. There are a number of low coastal terraces and cliffs that allow coastal access to these scattered beaches. Downtown Capitola and Capitola Beach are saddled between two steep coastal cliffs forming an economically important beachfront tourist destination and coastal recreation site for the community. Soquel Creek runs through downtown Capitola, housing a string of wetlands before flowing to the ocean through an ephemeral lagoon system.

Capitola: Protective Role of Habitats

The low dune and beach habitat in Capitola plays a relatively moderate role in reducing the exposure of Capitola Village and the mouth of Soquel Creek to erosion and inundation during storms compared to the lower protection provided by rest of the adjacent coastline.[37] Beach sands in front of the creek mouth buffer wave run-up and the reach of salt water upstream during storm surge. The main drivers of coastal exposure in the Capitola area are the low elevation and erodible geomorphology surrounding Soquel Creek. The presence of wetlands reduces wave heights along the overall Monterey Bay coastline as coastal wetland and creek vegetation serve as a shoreline buffer. However, model results suggest that Soquel Creek does not serve a strong role in protecting the Capitola shoreline in all locations or scenarios due to the low-lying elevation and coastal flooding during storm events. This phenomenon is not unique to Soquel Creek as large scale regional erosion and river outflow can often overwhelm the ability of vegetation to attenuate waves.[38] The Capitola area is less exposed to wind and waves compared to the broader Monterey Bay study region, yet the relatively greater distance from the continental shelf drives an increase in storm surge potential. Kelp forest habitats along the broader Capitola coastline play a relatively low protective role, based on the model ranking methodology, in reducing exposure compared to the coastal dune and wetland habitats in this area.

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[36] *See* Figure 5.
[37] *See* Figure 6.
[38] Keryn Gedan et al., *The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm* 106 CLIMATIC CHANGE 7 (2011).

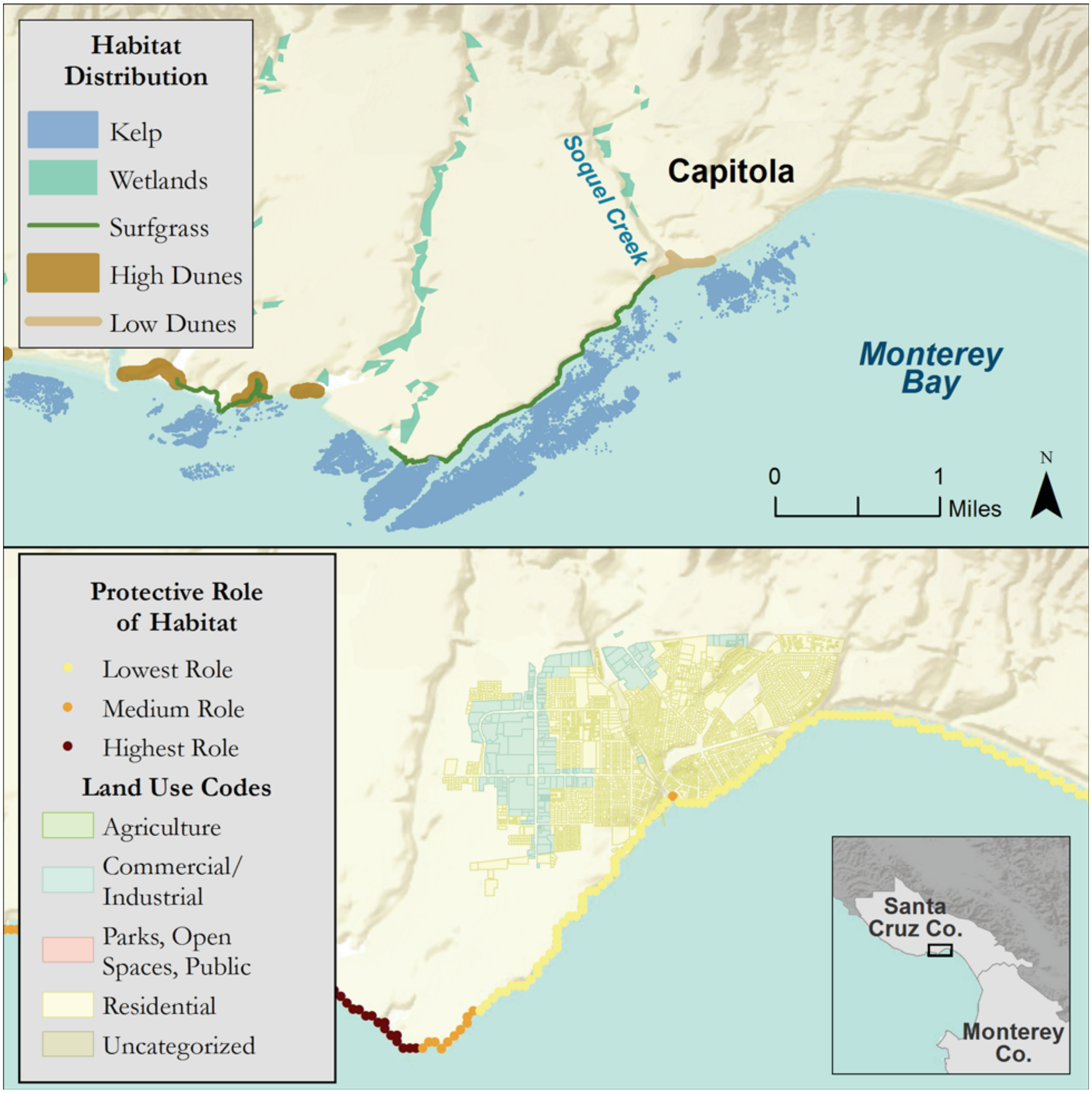

Fig. 6: Coastal habitats around Capitola, CA (Top). The relative role of coastal habitats along the shoreline of Capitola in reducing exposure to erosion and inundation with relevant land use zoning information (Bottom). Land use categories from the General Plan Land Use Codes were aggregated into four broad land use codes (see Bottom legend). Nearly all areas belonged distinctly to one category of land use. Only one land classification, Visitor Serving/L-M Density Residential, had uses from multiple categories, and it was categorized as Residential for this map.

<u>*Capitola: Ecosystem Services of Coastal Habitats*</u>

Wetlands in Riverine System

As Soquel Creek approaches the Pacific Ocean, the change in slope provides opportune locations for wetland habitats that slow the pace of the river and filter nutrients and pollutants, which leads to an improvement in water quality.[39] Closer to the coast, the river may transition into a lagoon

[39] Duffy et al., *supra* note 17.

system depending on the extent of the beach and low dune system at the mouth. Fish, small invertebrates and birds inhabit the lagoon as a feeding and breeding ground.[40] During strong rains, the lagoon typically breaches to create a direct opening to the ocean.[41] The distinction between this tidal versus lagoon interface plays a significant role in managing flood risks for the city of Capitola, particularly due to the many homes that line the creek and lagoon. While lagoon status influences the volume of tidal water that enters the creek system, intact wetlands can buffer surrounding areas against inundation. For instance, water is absorbed into soils instead of collecting on impermeable surfaces.[42]

Coastal Dune and Beach Systems

The beach and low dune habitat along the mouth of Soquel Creek provides the coastal community with recreation opportunities (e.g., surfing, fishing, kayaking, swimming, beach access). The Capitola Village and beach areas near the mouth of the creek draw over twenty percent of Santa Cruz County's tourism visitors annually.[43] The lagoon system at the mouth of Soquel Creek is actively managed by articifical breaching to release water as part of flood control and water quality maintainence. When open to the ocean, lagoons effectively function as small estuaries. Breaching alters the amount of tidal exchange, temperatures, salinity profiles and water flow for the lower portion of the creek. Depending on time of year and conditions surrounding the breaching event, the shift from closed to open system may influence patterns of species movement and habitat use.[44] Controlled breaching events are typically closely overseen by City Watershed Management monitoring teams, with crews on hand to keep threatened and endangered fish in their respective habitats with nets or transport upstream if needed.[45]

Kelp Forests and Surfgrass

Surfgrass and kelp forest habitats near the Capitola shoreline serve an important natural service by providing food and habitat for a suite of marine species that are also important to recreational fishing for residents and visitors. Kelp forests of the Monterey Bay support rockfish, urchins, crabs and many other commercially valuable species, while surfgrass acts as a nursery for juveniles of these adult kelp forest species.[46] Detritus from kelp forests washes out into open water and submarine canyons, providing subsidies of nutrients and food material to the Monterey Bay's deeper habitats.[47]

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[40] Cloern et al., *supra* note 24.
[41] *Id.*
[42] Walter Duffy and Sharon Kahara, *Wetland ecosystem services in California's Central Valley and implications for the Wetland Reserve Program* 21 ECOLOGICAL APPLICATIONS S18 (2011).
[43] LAUREN SCHLAU CONSULTING, SANTA CRUZ COUNTY VISITOR PROFILE (2010).
[44] Cloern et al., *supra* note 24.
[45] Jessica York, *Beach lagoon breached to alleviate flooding*, SANTA CRUZ SENTINEL, August 17, 2015, http://www.santacruzsentinel.com/article/NE/20150817/NEWS/150819676.
[46] Kevin Hovel, *Habitat fragmentation in marine landscapes: relative effects of habitat cover and configuration on juvenile crab survival in California and North Carolina seagrass beds* 110 BIOLOGICAL CONSERVATION 401 (2003); Carey J. Galst & Todd W. Anderson, *Fish-habitat associations and the role of disturbance in surfgrass beds* 365 MARINE ECOLOGY PROGRESS SERIES 177 (2008); *see also* Carr & Reed, *supra* note 18.
[47] Christopher Harrold et al., *Organic enrichment of submarine-canyon and continental-shelf macroalgal drift imported from nearshore kelp forests benthic communities by macroalgal drift imported from nearshore kelp forests* 43 LIMNOLOGY & OCEANOGRAPHY 669 (1998).

Both kelp forests and surfgrass beds also have potential to sequester some carbon dioxide from the atmosphere and surrounding water by incorporating carbon into their tissues. On a short-term scale, photosynthesis temporarily removes carbon dioxide from the water during the day, potentially reducing the impacts of ocean acidification.[48] Over time, marine sediments slowly bury and trap the plant matter—and therefore the carbon—for longer time scales.[49] As carbon sequestration markets develop, this ecosystem function could be of economic interest to the Capitola area from both a hazard and emission mitigation perspective.

Capitola: Adaptation Strategies & Considerations

Coastal Adaptation Options

Capitola's highly developed coastline limits the available coastal adaptation options. Due to high-density development and the prevalence of cliffs and bluffs, limited opportunities exist to apply nature-based strategies, with the exception of Capitola's beach—a possible candidate for beach nourishment. Beach nourishment could reinforce the beach and surrounding areas, slowing coastal erosion due to rising seas. This strategy would also buffer the upland structures—at least in the short term—from rising seas and storm events.

Other adaptation options would also be feasible in Capitola. A particularly useful and flexible option would be to develop sea level rise overlay zones for Capitola's vulnerable areas.[50] An overlay zone is a tool that groups certain properties together because of a feature they share, or because of some regulatory aim that a local government wishes to accomplish. An overlay zone would allow additional zoning regulations or building code restrictions to be established in the future for the properties in that zone, as deemed necessary. Establishing a sea level rise overlay zone would provide immediate notice to owners of homes and businesses that they are in an area that is vulnerable to rising sea levels.[51] This zone could be coterminous with, or go beyond, existing floodplain zones in the area.[52]

Overlay zones can also designate certain areas as protection, accommodation, or retreat zones and implement appropriate regulations for restricting future development and redevelopment in each zone. For instance, regulations might allow rebuilding of structures in an "accommodation zone," but only if they are raised or otherwise built to withstand rising seas. Likewise, a "retreat zone" might include setbacks and other redevelopment restrictions, such as requiring certain uses to end after a specific time period. Finally, a "protection zone" could allow protection strategies for properties that feature coastal dependent structures, such as harbors.

An overlay zone might also include additional strategies to promote responsible coastal adaptation. For instance, redevelopment in vulnerable areas could be limited through downzoning. This

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[48] Hendriks, *supra* note 26; Lester Kwiatkowski et al., *Nighttime Dissolution in a Temperate Coastal Ocean Ecosystem Increases under Acidification* 6 SCIENTIFIC REPORTS 1 (2016).

[49] Elizabeth McLeod et al., *A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering* CO_2 9 FRONTIERS IN ECOLOGY AND THE ENVIRONMENT 552.

[50] Capitola currently uses several overlay districts in its zoning classifications. *See, e.g.*, CAPITOLA CITY, CAL., MUNICIPAL CODE §17.20.010 (affordable housing overlay district).

[51] A building moratorium could be put in place while overlay zones are developed. The building moratorium could encompass all areas that might be included in these zones. *See* CAL. GOV. CODE § 65858 (outlining procedures for local governments adopting interim ordinances as urgency measures).

[52] CAPITOLA CITY, CAL., MUNICIPAL CODE §17.50.090.

strategy rezones land to less intensive uses. Currently, the properties at the greatest risk of flooding and rising seas in Capitola are those close to Soquel Creek. These properties are currently zoned for several different land uses and could be prioritized for efforts to downzone.[53] Downzoning would lead to nonconforming uses in the short term—i.e., uses not allowed under the new zoning ordinances, but nonetheless "grandfathered" in because they existed prior to the downzoning. Regulations can be framed to allow these nonconforming uses initially but require them to cease after some period of time.

To achieve these longer-term coastal adaptation strategies, Capitola could consider taking several proactive steps in the short term. For instance, retreat strategies require that uplands be identified and purchased to make space for relocated structures. Land banking properties now could satisfy this future need.[54] Since these lands might not be used for this purpose immediately, this strategy could proceed gradually through phased and voluntary purchases of suitable upland properties. If this strategy does not succeed, or if the timeline becomes more urgent due to rising seas, it could be accomplished through eminent domain.[55] Likewise, Capitola could use transfers of development rights (TDRs) (where landowners sell the rights to develop their property) of vulnerable properties to help facilitate retreat.[56] This strategy could monetarily incentivize coastal landowners to provide their properties for retreat, and it could keep undeveloped coastal land undeveloped.

Capitola's existing coastal protection structures might also be studied to determine their efficacy and need for replacement or removal. Capitola's large sandy beach currently relies on two rip-rap groins on its east end to accumulate sand. To facilitate managed retreat, some of the existing coastal protection structures might need to be phased out. Others might need to be replaced if they are deemed necessary to coastal protection and provided they fit within Capitola's overall coastal adaptation strategy now and in the projected future.

Barriers and Considerations

There are several considerations that should be taken into account when moving forward with any of these coastal adaptation strategies in Capitola. First, limited undeveloped land is available immediately upland of the vulnerable areas, limiting retreat options in the area. As a result, businesses and residences that relocate might have to be moved farther inland than would be necessary elsewhere on the coast. Furthermore, the vulnerability of properties on bluffs and cliffs are less predictable than those along the lower-lying coastline, making long-term planning in these areas more challenging.[57]

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[53] *See* Figure 6.

[54] Land banking is the buying of land for some future use. Michael Allan Wolf, *Strategies for Making Sea-Level Rise Adaptation Tools "Takings-Proof"* 28 J. LAND USE & ENVTL. L. 157, 182 (2013).

[55] Eminent domain is the power of the government to take land for a public purpose. This power is limited by the U.S. Constitution and the California Constitution. U.S. CONST. AMEND. V; CAL. CONST. ART. I § 19.

[56] JESSICA GRANNIS, ADAPTATION TOOL KIT: SEA-LEVEL RISE AND COASTAL LAND USE 57-60 (2011).

[57] Cliffs and bluffs are more vulnerable to episodic erosion than beaches, which alternatively face constant erosive pressures. *See, e.g.,* episodic erosion events at Pacifica Lands End Apartments.

Takings concerns routinely arise when local governments undertake proactive planning for rising seas.[58] To avoid takings concerns, restrictions could be tailored to avoid depriving property owners of all economic value of their parcels.[59] Furthermore, restrictions could account for the economic lives of properties to avoid takings concerns, or could be grounded in avoiding and abating nuisances. Furthermore, any building moratoria could be tailored to be temporary.[60]

Third, regarding zoning classifications, any changes to the current classifications would likely include a grandfather provision allowing existing nonconforming uses to continue.[61] If grandfathering provisions are included in new ordinances, downzoning would only immediately affect undeveloped properties or properties whose uses have been abandoned. But, "grandfathered" provisions could be written to require landowners to comply with new zoning restrictions after a landowner renovates or rebuilds on his property, or when s/he changes the use.[62] Furthermore, as explained above, nonconforming uses could only be allowed for a certain period of time, after which they must cease.

Finally, cost and ecological drawbacks of proposed coastal adaptation strategies are necessary considerations when planning coastal adaptation strategies in Capitola. Cost is an important consideration because Capitola is highly developed and much of its vulnerable areas are in private ownership. Some parcels will be more expensive to buyout or pay just compensation for than others. Likewise, buyouts of private property might be less feasible than comparable options involving state or city lands. Property buyouts to facilitate relocation and to promote retreat face similar concerns. Likewise, cost versus long-term benefits of competing coastal adaptation options should be considered. Similarly, the ecological drawbacks of strategies such as beach nourishment should be weighed against their cost and their relatively short-term effectiveness.

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[58] Governmental taking of private property for public good—as well as regulations that "go too far" and result in "regulatory takings"—are common themes and constant considerations that arise when considering coastal adaptation strategies that require retreat from increasingly dangerous coastlines due to rising seas. Penn Coal Co. v. Mahon, 260 U.S. 393 (1922).

[59] Lucas v. South Carolina Coastal Council, 505 U.S. 1003 (1992).

[60] Tahoe-Sierra Preservation Council, Inc. v. Tahoe Regional Planning Agency, 535 U.S. 302 (2002).

[61] *See, e.g.,* CAPITOLA MUNICIPAL CODE § 17.50.310 ("A structure which was lawful before enactment of this chapter, but which is not in conformity with the provisions of this chapter, may be continued as a nonconforming structure subject to the following condition: if any nonconforming structure is destroyed by flood, earthquake, tsunami or, for another cause to the extent of fifty percent or more of its fair market value immediately prior to the destruction, it shall not be reconstructed except in conformity with the provisions of this chapter.").

[62] Local governments may end nonconforming uses in a variety of ways. Declare nuisance, pay just compensation, or require use to stop after a date certain. CECILY TALBERT BARCLAY & MATTHEW S. GRAY, CALIFORNIA LAND USE & PLANNING LAW 60-61 (2016).

Moss Landing: Coastal Setting

Moss Landing's relatively undeveloped coastline, surrounded by large tracts of farmlands, provides more adaptation options than other more densely populated sections of the coast. The shores surrounding Moss Landing are lined with high dune and sandy beach habitats extending north to Rio Del Mar and south to the edges of the city of Monterey.[63] This area includes many state beaches as well as local beach access points. Sediment for these beaches originates from rivers draining into the Monterey Bay.[64] Just inland of Highway 1, Elkhorn Slough drains the seasonal creeks and rivers that supply water to the surrounding agricultural areas, creating a network of wetlands and estuaries of gradually changing salinity.[65] Within the estuary, eelgrass and salt marsh habitats are prevalent. Much of this area is part of the ESNERR or the California network of Marine Protected Areas. While agriculture often runs up to the boundaries of arable land, most public recreational access to the water is constrained to a few entry points in local parks or at the Moss Landing Harbor.

Fig. 7: Satellite image of Moss Landing.

Moss Landing is the center point of the Monterey Bay coastline and is adjacent to diverse natural systems, including extensive wetland habitats in nearby Elkhorn Slough, sand dunes along the open coast, and sandy beaches north and south of the harbor mouth. Along with this connection to multiple natural systems, Moss Landing is a primary commercial and party-boat fishing hub for the central California coast with landing locations for market squid, rockfish, crab, lingcod, groundfish and other fisheries. Moss Landing also functions as a key marine research center due to the confluence of ecosystems and direct access to the deep Monterey Submarine Canyon.[66]

Moss Landing: Protective Role of Habitats

The dune and beach systems starting just north of Moss Landing and continuing south to Monterey play a greater protective role relative to the full study area extent.[67] The orientation of the coastline in the Moss Landing study area, which directly faces predominant incoming waves, is a significant driver of exposure in this region. In addition, coastal geomorphology and low elevation contribute to high exposure index scores in this location, meaning that existing habitats are critical to countering this relatively high exposure to hazards. Model results indicate that the presence of wetlands can reduce wave heights and associated damages to property from storm events. Coastal wetlands are not as effective at reducing erosion in areas of high wave energy.[68] The Moss Landing coastline is a high wave energy environment and the wetlands in this area play a moderate role in reducing coastal exposure to erosion and inundation during storms compared to the large dune

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[63] *See* Figure 7.

[64] *See* U.S. ARMY CORPS OF ENGINEERS, *supra* note 9.

[65] A key concern in this area is the historic changes in groundwater levels in the Pajaro and Salinas Valleys. These changes are further exacerbated by the effect of saltwater intrusion on highly productive agricultural lands as well as domestic potable water quality.

[66] Monterey Bay Aquarium Research Institute (MBARI) and Moss Landing Marine Labs (MLML) are two primary centers for marine research in the region.

[67] *See* Figure 7.

[68] Gedan, *supra* note 38.

systems. Loss of wetland habitat with rising seas will affect agriculture lands near Moss Landing. These wetland areas are highly exposed to waves mainly due to their large extent and proximity to the coastal zone.

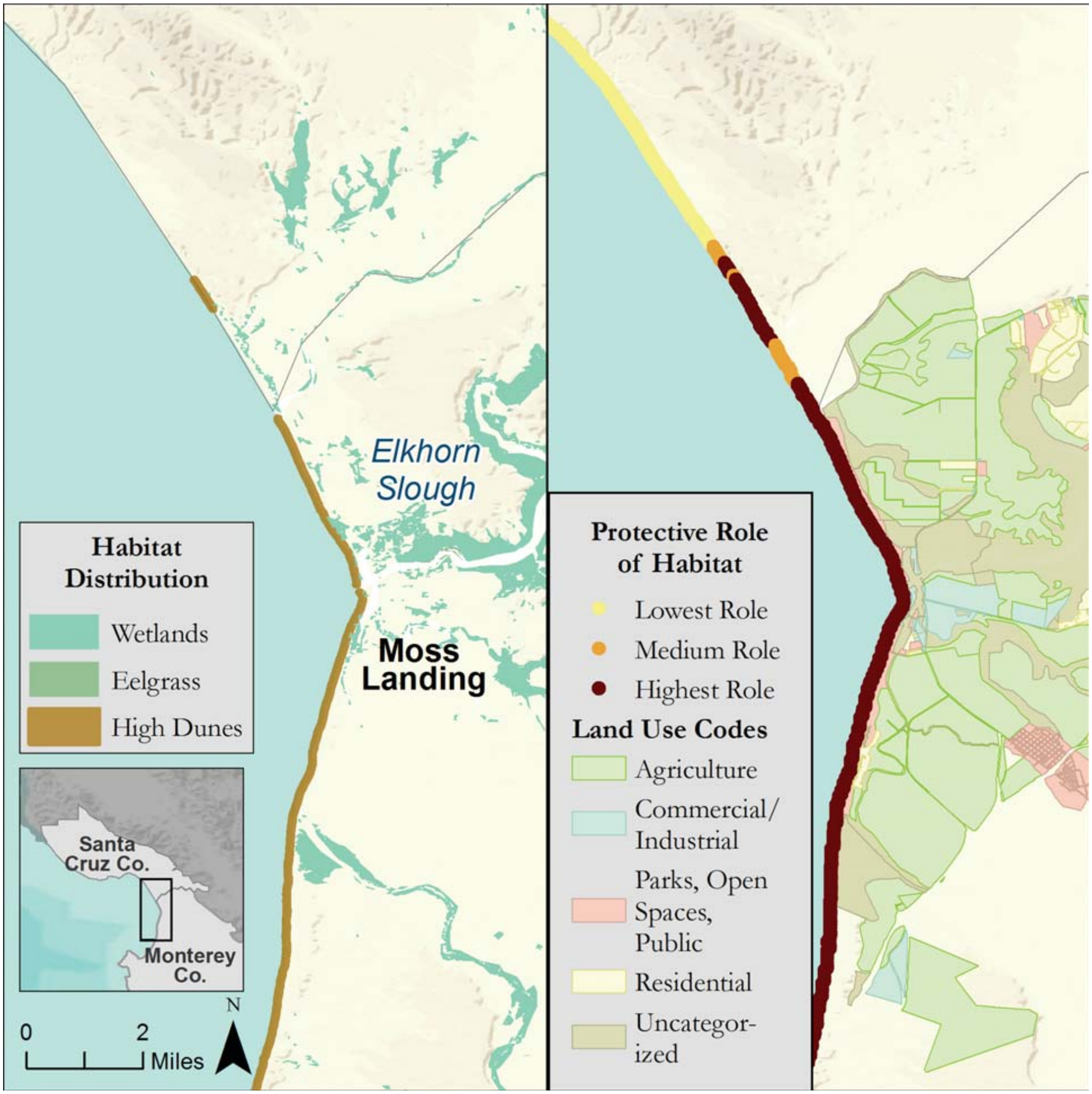

Fig. 7: Coastal habitats around Moss Landing, CA (Left). The relative role of coastal habitats near the mouth of Elkhorn Slough in reducing exposure to erosion and inundation with relevant land use zoning information (Right). Zoning information was distilled using the same methodology used for Capitola (Fig. 5).

Moss Landing: Ecosystem Services of Coastal Habitats

Coastal Dune and Beach Systems

The relatively dry areas on the high beach behind dunes are sheltered from wind and spray, serving as nesting grounds for endemic shorebirds and haul out spots for marine mammals. These beaches provide opportunities for coastal recreation, fishing, and wildlife viewing in the surrounding area in addition to their role protecting the coastline from high energy waves.

Elkhorn Slough

The estuarine system of Elkhorn Slough is the largest marsh habitat in California outside of San Francisco Bay and provides critical habitat for shorebirds and fishes. This area has also been home to a suite of competing human uses for more than 150 years (e.g., agriculture, cattle grazing, railroad and road construction, fishing, municipal energy production, marine research, tourism, recreation) that have led to the historical development of engineered structures (e.g., levees, embankments) and the construction of Moss Landing Harbor at the mouth of the estuary. These engineered structures have significantly influenced the structure and function of the estuarine system.[69] While the wetland systems in Elkhorn Slough are an ecologically and economically important feature of the area, they are also at risk due to a squeeze between rising sea levels and little room to migrate inland.[70]

Wetland habitats provide a number of key ecosystem services beyond coastal protection, including carbon sequestration, water quality improvement, flood abatement and biodiversity support.[71] The sheltered estuarine waters and seagrass meadows within the slough serve as a nursery for juveniles of commercially important fish species.[72] Elkhorn Slough is one of the few remaining freshwater and saltwater resting stops on the Pacific flyway. The slough is a critical habitat for migratory bird species and was designated a globally important bird area in 2000.[73] The banks of the Slough also serve as a major haul out area for marine mammals.

Additionally, wetland habitats store large amounts of carbon in their submerged soils when kept intact and have the potential to be used for carbon sequestration on the scale of decades or longer.[74] On a more immediate time scale, coastal vegetation helps buffer against ocean acidification by removing carbon dioxide from the water.[75] As larval fish and invertebrates experience more harmful effects from acidifying water conditions than adults, the wetlands and marshes of Elkhorn Slough may aid in protecting important species from harmful water chemistry in addition to protecting them from predators.[76]

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[69] Eric Van Dyke & Kerstin Wasson, *Historical Ecology of a Central California Estuary*: *150 Years of Habitat Change* 28 ESTUARIES 173, 179 (2005); *see also* CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH (Jane Caffrey et al. eds., 2002).

[70] Kerstin Wasson et al., *Ecotones as Indicators of Changing Environmental Conditions: Rapid Migration of Salt Marsh–Upland Boundaries* 36 ESTUARIES AND COASTS 654 (2013).

[71] WORLD RESOURCES INSTITUTE, ECOSYSTEMS AND HUMAN WELL-BEING: WETLANDS AND WATER SYNTHESIS (2005) (a report of the Millennium Ecosystem Assessment).

[72] Michael Beck et al., *The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates* 51 BIOSCIENCE 633 (2001).

[73] CHANGES IN A CALIFORNIA ESTUARY: A PROFILE OF ELKHORN SLOUGH, *supra* note 23.

[74] Cloern et al., *supra* note 24; McLeod, *supra* note 49.

[75] Hendriks, *supra* note 26.

[76] Haruko Kurihara, *Effects of CO2-driven ocean acidification on the early developmental stages of invertebrates* 373 MARINE ECOLOGY PROGRESS SERIES 275 (2008); Philip Munday et al., *Replenishment of fish populations is threatened*

Wetland habitats are threatened in the Elkhorn Slough area—and throughout the state—due to increased erosion from rising sea levels and land use development (agricultural, urban and/or rural). Fertilizer from agricultural runoff contributes to eutrophication and massive algal blooms that smother native flora, while urban pollutants may impair water quality.[77] Wetlands and coastal dunes that are exposed to coastal hazards could potentially migrate upslope given a path free of barriers from coastal development or shoreline hardening.

Moss Landing: Adaptation Strategies & Considerations

Coastal Adaptation Options

Moss Landing's coastline lends itself to several nature-based adaptation strategies. For instance, because the dunes in the area play a large role in protecting Moss Landing's coastline, adaptation strategies that protect, restore and enhance these areas could be targeted to maintain the integrity of the area. A dune restoration and enhancement project currently provides protection for MBARI. Additional suitable areas for dune restoration in Moss Landing could be identified and prioritized based on the protective role of specific dune habitats as well as factors specifically relevant to the local planning community. Beach nourishment might also be used to stem beach loss and to buffer these important dunes from erosion. Wetland restoration is another nature-based solution possible for Moss Landing. Wetland restoration in the area would carry various possible co-benefits including: sequestration of carbon dioxide, maintaining these areas as corridors for gradual coastline retreat and providing protection against storm surges.

Other nature-based options might be suitable here as well. Conservation easements could be implemented in some of these areas, particularly those most vulnerable to rising seas. This strategy involves either paying a landowner not to develop vulnerable land, or the landowner agreeing to do so without compensation, or in exchange for some other incentive, such as a tax break. This strategy would ensure that undeveloped lands stay undeveloped, and it could help transition currently developed but threatened lands to undeveloped lands. Rolling easements are another attractive but controversial option.[78] These can be used to allow the sea to migrate inland while slowly requiring the removal of structures within some distance of the approaching sea.[79]

In addition to the nature-based options outlined above, Moss Landing's coastline might also be suitable for other coastal adaptation strategies. For instance, accommodation and armoring might be appropriate for Moss Landing because it features a number of coastal dependent structures, such as the Monterey Bay Aquarium Research Institute, the Moss Landing Marine Laboratories, the Moss Landing power plant, and various boating and fishing facilities. Any of these structures might be protected or raised, depending on building design and construction, the anticipated

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by ocean acidification 107 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE OF THE UNITED STATES OF AMERICA 12930 (2010).

[77] Brent Hughes et al., *Recovery of a top predator mediates negative eutrophic effects on seagrass* 111 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 36444 (2014).

[78] *See generally* Meg Caldwell & Craig Holt Segall, *No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast*, 34 ECOLOGY L.Q. 533, 535 (2007) (explaining that a rolling easement is "a device, rooted in statutory or common law or in permit conditions, that allows the publicly owned tidelands to migrate inland as the sea rises, thereby preserving ecosystem structure and function.").

[79] JAMES G. TITUS, ROLLING EASEMENTS (2011) *available at* https://www.epa.gov/sites/production/files/documents/rollingeasementsprimer.pdf.

building life cycle, end of use, and planned deconstruction. Furthermore, because of the various coastal-dependent buildings in the area, moveable structures could be installed and moved as needed in order to keep these structures on the coast as needed.

Other options can be pursued for undeveloped parcels in the area and existing structures that are not coastal dependent. Highway 1 could be moved inland or raised.[80] As was discussed for Capitola, an overlay zone could provide notice to the owners of vulnerable properties and restrict building and redevelopment in the area, as deemed appropriate. Furthermore, a moratorium on development could be imposed for some certain time period, while proactive coastal planning is pursued.

Moss Landing has a large amount of surrounding undeveloped and agricultural land.[81] Accordingly, some of these open spaces may be appropriate, stable sites for managed retreat of buildings in the area. Buyouts might be necessary in certain areas where planning is not able to sufficiently address increasingly rising seas.[82] Transfers of development rights might also be appropriate in certain similar circumstances.[83]

Barriers and Considerations

This area of the coastline is dominated by water, protected areas and sensitive ecosystems. The abundance of seawater and wetland areas might pose challenges for coastal adaptation for several reasons. For instance, the abundance of inland waterways and wetlands means that there is not much land immediately upland to move vulnerable buildings via managed retreat. Additionally, while this area features many coastal dependent facilities that might be protected or raised, there are drawbacks to pursuing these strategies. For instance, raising structures might bring additional regulatory requirements, such as those imposed by the Americans with Disabilities Act.[84]

Developing coastal adaptation strategies for coastal dependent structures carries with it its own set of unique challenges. Coastal dependent structures are prioritized for coastal land use under the Coastal Act.[85] Coastal dependent structures are not a high priority to move upland because of their dependence on water, but they need to be protected from rising seas nonetheless. Leaving these coastal dependent assets where they are makes them more susceptible to massive storm events than slowly rising seas. However, protecting these structures by armoring with seawalls would exacerbate erosion around these protective structures. If these coastal dependent structures are armored in the short term, long-term plans should be made to remove the armoring and move the structures.

Moving or raising Highway 1 presents issues as well. While raising Highway 1 in place is a possible short-term solution, Highway 1 may eventually need to be moved inland due to rising seas and repeated storm events. Moving Highway 1 immediately landward of its current location also presents drawbacks. Inland relocation would put it right in the middle of protected areas such

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[80] The issues with this proposition are discussed *infra* in the Barriers and Considerations section.
[81] *See* Figure 7.
[82] *See, e.g.*, New York's Recreate NY Smart Home Buyout Program.
[83] *See, e.g.*, Penn Central Transportation Co. v. New York City, 438 U.S. 104 (1978).
[84] 42 U.S.C. §§12101-12213.
[85] CAL. PUB. RES. CODE §§ 30235 & 30255.

as Elkhorn Slough[86] and could restrict coastal access.[87] Moving Highway 1 would also require CalTrans to exercise its eminent domain authority, which can be controversial. Finally, moving Highway 1 to upland areas, such as those currently used for agriculture, will introduce additional complexities because of how these lands are currently prioritized in the current LCP.[88]

Managed retreat faces several challenges in this area. While Moss Landing is surrounded by open area, much of the region comprises wetlands or otherwise sensitive or protected areas. For instance, the area features Elkhorn Slough State Marine Conservation Area, Elkhorn Slough State Marine Reserve, Moro Cojo Slough State Marine Reserve, Moss Landing State Beach, and the Moss Landing Wildlife Area. The abundance of state lands and conservation lands creates challenges for managed retreat. On the other hand, public and open spaces might be well-suited for conservation easements such that they are set aside to become inundated and form new wetland and marsh areas. Section 30240 of the Coastal Act protects environmentally sensitive habitat areas (ESHAs), and further complicates using any of the areas surrounding these protected areas in Moss Landing for managed retreat.[89]

Another issue is possible challenges to zoning changes in the area. Property owners affected by new regulations sometimes claim that these regulations impermissibly "take" their property without just compensation. As was the case for Capitola, local governments should be weary of enacting regulations that possibly deprive property of all of its economic value and of instituting moratoria that do not specify end dates.

<u>Summary</u>

Communities in the Monterey Bay region, like many areas of California and the nation, are actively planning for a changing climate. Rising sea levels and increasingly damaging storm events are expected to cause increased erosion and inundation, which will further threaten people, property, infrastructure and coastal habitats. If these habitats are lost, degraded or unable to adapt by migrating inland, then local communities also lose the beneficial services they provide, including carbon sequestration, improving water quality, buffering ocean chemistry, providing nursery or nesting grounds, and protecting from erosion and inundation.

Proactive adaptation planning that takes into account the role of coastal habitats—coupled with advanced construction designs and technologies—and policy pathways for implementation, will allow local communities to proceed from planning to implementation more effectively. Ultimately, this approach—in concert with similar coastal adaptation decisions throughout California—can lead to coastal management processes that are consistent for statewide needs and flexible for local needs while ensuring a vibrant coastline for future generations.

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[86] *See* list of protected areas in region *supra* note 15.
[87] The Coastal Act seeks to protect and maximize public coastal access. CAL PUB. RES. CODE. § 30211.
[88] MONTEREY COUNTY, NORTH COUNTY LAND USE PLAN 45-49 (1982).
[89] CAL. PUB. RES. CODE § 30240.

Habitat Type	Relative Protective Role*	Protective Attributes	Additional Ecosystem Services	Management Options
Kelp Forests	Relatively Low Role	Kelp forests attenuate low-energy wave action and have a dimished protective role as wave power increases.	Habitat for commercially viable fish and invertebrate species	Maintain healthy water conditions for kelp growth and reproduction.
			Vegetation harvested for commercial abalone aquaculture	
			Nutrient and vegetation export to local beach ecosystems	
			Integral ecosystem for culturally important species	
Wetlands	Relatively Moderate Role	Wetland ecosystems absorb water to reduce inundation and also serve to dissipate wave energy.	Flood control from inland inundation	Consider conservation of key areas of vegetation and soils before allowing development.
			Nutrient and sediment retention for improved water quality	
			Habitat for diverse species including marine mammals	Provide space for habitat to migrate inland as sea level rises.
			Carbon sequestration	
Seagrass	Relatively Low Role	Eelgrass beds attenuate low-energy waves which help decrease erosion of loose soils.	Wave attenuation	Provide space for habitat to migrate inland as sea level rises.
			pH buffer	Conserve existing habitat and restore damaged submerged aquatic vegetation.
			Nursery and essential habitat for fish and invertebrate species	
			Carbon sequestration	Maintain healthy water conditions and limit habitat degradation.
High Dune Systems**	Relatively High Role	Large dune systems dissipate high-energy waves and resist runup from powerful storms.	Cultural and aesthetic attachment	Maintain dune structure and vegetation.
			Location for recreation	
			Habitat for important bird and plant species	Regulate and/or limit dune sediment extraction.
Low Dunes & Beaches**	Relatively Moderate to High Role	Low dune systems and beaches dissipate low and moderate energy waves.	Habitat for important bird and plant species	Limit the implementation of built structures that impede migration of beach systems.
			Location for recreation	
			Cultural and aesthetic attachment	Maintain beach structure and access to continued sediment supply.

Table 1: Compilation of Ecosystem Services

*Protective role is based on model outputs created for and relative to the full study area (Año Nuevo to Wharf 2).
**Dunes were classified as “high dune” if their crest was higher than five meters. High dunes are less likely to lead to overwash and inundation from coastal storms.

Adaptation Strategy	Definition*	Example**	Potential Applications	Role of Natural System
Protection: *Hold the Line*	Employ built measure to defend development in current location	Wetland Restoration	Elkhorn Slough; northern section of Moss Landing Harbor; potentially in creeks near Capitola	Enhances extent of ecologically important natural areas
		Dune Restoration	North and south of Moss Landing on outer coast; southern Monterey Bay	Enhances extent of ecologically important natural areas
		Beach Nourishment	Soquel Creek Lagoon; outer coast of Moss Landing	Adds to natural system; requires thorough environmental monitoring
		Hard Protection	Near coastal-dependant or critical infrastructure such as power plant or critical transportation routes	Often limits natural habitat migration and increases erosion at edges of armoring
Accommodation: *Adjust to the line*	Modify existing or new development to decrease hazard risks	Overlay Zones	Existing flood zones or areas expected to be impacted by rising sea levels	N/A
		Limit Redevelopment	Locations that encounter repetitive loss or in (newly delineated) sea level rise overlay zones	May facilitate migration of natural systems or allow them to reestablish themselves
		Mobile Structures	Structures that are location dependent yet also encounter large episodic flood events	N/A
		Conservation Easement	Open and undeveloped areas in existing flood plain and areas adjacent to flood plains	Keeps natural system intact
Retreat: *Get away from the line*	Relocate existing development out of hazard areas and/or limit construction of new development in vulnerable areas	Planned Retreat	Highly vulnerable areas or locations with suitable upland areas available nearby	Removes structures allowing corridor for habitats to naturally migrate inland
		Buyout Programs	Lands suitable for becoming open areas	Can help promote natural system to replace previously developed area
Hybrid: *Maintain a flexible line*	Using strategies from multiple categories that may need to change over time	Accommodate over short term; relocate over long term	Hybrid adaptation options could be designed with enough flexibility to be applied across many different areas as needed	Provides pathway for taking actions that allow habitat to migrate and may provide opportunities for nature-based solutions
		Update land use designations and zoning ordinances		
		Redevelopment restrictions		
		Permit conditions		

Table 2: Compilation of Adaptation Strategies

* Definitions of adaptation strategies are distilled explanations derived from chapter seven of the California Coastal Commission's Sea Level Rise Guidance (Guidance).

** Many examples are summarized descriptions from figure 17 of the Guidance.

Analysis, Methodology, and Assumptions

This assessment involved a combination of ecosystem service modeling and adaptation policy research in an effort to identify and map priority locations for nature-based strategies that reduce vulnerability of critical assets using feasible land use policy methods.

To map and value the goods and services from natural habitats, we used the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) free and open-source suite of software models created by the Natural Capital Project at Stanford University. The InVEST Coastal Vulnerability model incorporates a scenario-based approach to evaluate the role of natural habitats in reducing exposure to coastal impacts.[90] The InVEST Coastal Vulnerability model produces a qualitative estimate of coastal exposure. The Exposure Index differentiates areas with relatively high or low exposure to erosion and inundation during storms.

Data inputs included: 1) **Geomorphology**: Polyline representing coastal geomorphology based on the National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index; 2) **Coastal habitat**: Polygons representing the location of natural habitats (e.g., seagrass, kelp, wetlands, etc.) from the Department of Fish and Wildlife website created for Marine Life Protection Act process; 3) **Wind and wave exposure**: Point shapefile containing values of observed storm wind speed and wave power across an area of interest using Wave Watch III data provided by NOAA; 4) **Surge potential**: Depth contour that can be used as an indicator for surge level default contour is the edge of the continental shelf. In general, the longer the distance between the coastline and the edge of the continental shelf at a given area during a given storm, the higher the storm surge; 5) **Relief**: A digital elevation model (DEM) representing the topography and (optionally) the bathymetry of the coastal area—this analysis includes a five meter bathymetric and topographic merge from US Geologic Survey for the California coast; 6) **Sea-level rise**: Rates of (projected) net sea-level change derived from the National Research Council 2012 report (highest range for 2030: 12" of sea level change);[91] 7) **Hard Armoring**: Data set inventory of man-made structures and natural coastal barriers that have the potential to retain sandy beach area in California. This armoring dataset is a compilation of the UC Santa Cruz Sand Retention Structures, Monterey County Barriers, and US Army Corps of Engineers Coastal Structures.

One main limitation with this modeling approach is that the dynamic interactions of complex coastal processes occurring in a region are overly simplified into the geometric mean of seven variables and exposure categories. InVEST does not model storm surge or wave field in nearshore regions. More importantly, the model does not take into account the amount and quality of habitats, and it does not quantify the role of habitats for reducing coastal hazards. Also, the model does not consider any hydrodynamic or sediment transport processes: it has been assumed that regions that belong to the same broad geomorphic exposure class behave in a similar way. In addition, using this model we assume that natural habitats provide protection to regions that are protected against erosion independent of their geomorphology classification (e.g., rocky cliffs). This limitation artificially deflates the relative vulnerability of these regions, and inflates the relative vulnerability

[90] INTEGRATED VALUATION OF ECOSYSTEM SERVICES AND TRADEOFFS, http://www.naturalcapitalproject.org/models/coastal_vulnerability.html (last visited Aug. 30, 2016).

[91] NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON SEA LEVEL RISE IN CALIFORNIA, OREGON, AND WASHINGTON, SEA-LEVEL RISE FOR THE COASTS OF CALIFORNIA, OREGON, AND WASHINGTON: PAST, PRESENT, AND FUTURE (2012).

of regions that have a high geomorphic index. Based on these limitations and assumptions, the InVEST Coastal Vulnerability tool is an informative approach to investigate *relative exposure* for a coastline and identify locations where coastal habitats play a relatively significant role in reducing exposure. However, for local scale decisions regarding locally specific geomorphic conditions, further analysis is needed (e.g., the InVEST Nearshore Wave and Erosion model).

Results can help evaluate tradeoffs between climate adaptation strategy approaches. In this assessment, we compared the InVEST Exposure Index results both with and without the protective services provided by natural habitats. This approach (computing the difference between exposure indices) provides a priority index for locations in which coastal habitats play the largest relative role in reducing exposure to erosion and inundation. These locations can then be further investigated for nature-based strategies to reduce vulnerability.

We began our policy research by exploring academic and practitioner guidance on potentially appropriate coastal adaptation strategies for sea-level rise. We reviewed a number of guidance documents that outline land use planning and regulatory options that should be considered in coastal areas. Next, we identified how priority or high-risk locations align with various land-use or zoning designations in Monterey and Santa Cruz Counties using land use zoning layers provided by Monterey and Santa Cruz Counties as well as from planning staff from the City of Capitola. The zoning designations and population density in the various high-risk areas guided our determination of the strategies most feasible in each location. For example, high-density zoning designations—in most cases—reduce the feasibility of habitat restoration or retreat options. We also researched relevant state- and county-level laws and policies on acceptable strategies for near- and long-term adaptation to rising sea levels. We identified the limitations these policies place on adaptation options in the Monterey Bay Region and explored potential changes to the existing policies that may increase adaptive capacity. Ultimately, these prioritized policy considerations may be relevant to both Santa Cruz and Monterey Counties—as well as local jurisdictions—through the development of the Local Coastal Program update process.

In addition to this specific engagement in the Monterey Bay Region, the Center for Ocean Solutions is also involved in Local Coastal Program updates throughout the state. The Center is playing a key role in compiling, distilling, and distributing information on incremental adaptation actions with current county partners (i.e., Sonoma, Marin, Santa Cruz, and Monterey Counties) as well as with the State Coastal Conservancy and California Coastal Commission through the development of the California Coastal Adaptation Network. By developing a transferable methodology that incorporates the role of natural capital into county-level coastal adaptation planning, the Center for Ocean Solutions is scaling these best practices to a statewide prioritization of adaptation strategies that preserve the integrity of natural systems. The Center's work advances the state's efforts for flexible consistency in accordance with the California Coastal Commission's Sea Level Rise Policy Guidance.

Appendix B.

Climate Change Impacts to Combined Fluvial and Coastal Hazards (ESA, 2016)

MONTEREY BAY SEA LEVEL RISE

Climate Change Impacts to Combined Fluvial and Coastal Hazards

Prepared for
Moss Landing Marine Labs with Funding from the
California Ocean Protection Council

May 13, 2016

MONTEREY BAY SEA LEVEL RISE

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1 INTRODUCTION

As part of the Sea Level Rise study for the Monterey County Local Coastal Program (LCP) ESA simulated and mapped the potential inundation from extreme coastal and fluvial conditions for multiple scenarios of future climate conditions. Two fluvial systems were analyzed for this effort (1) the Reclamation Ditch watershed which includes Gabilan Creek and Tembladero Slough the and drains to the Moss Landing Harbor, and (2) Soquel Creek which runs through the City of Capitola in Santa Cruz County. The Reclamation Ditch watershed is mostly agricultural while the lower reaches on Soquel Creek are mostly urbanized. These two systems were selected to enable risk assessment for a range of natural and manmade resources.

Climate data analysis was conducted to evaluate future extreme rainfall-runoff events and extreme coastal tide and wave events. For the rainfall-runoff and fluvial climate change analysis ESA used public climate model data to develop medium and high estimates of 100-year discharge for 2030, 2060, and 2100 time periods. ESA also developed estimates of extreme tide conditions with sea level rise for medium and high climate change scenarios for the three future periods. The flood levels and extents were then estimated for these scenarios using hydraulic modeling driven by combined watershed and coastal water level conditions under climate stress.

The study developed geospatial datasets for the extent and depth of inundation under flooding for existing conditions and future climate scenarios. The key products and findings for this study include:

- **Key products developed**
    - GIS layers of flood inundation extent for the Moss Landing Harbor and surrounding areas, and Soquel Creek in Capitola, for six scenarios (1) existing conditions 100-year flood, (2) future conditions 100-year flood under high emissions for 2030, (3 and 4) medium and high emissions for 2060, and (5 and 6) medium and high emissions for 2100.
    - GIS depth rasters for both systems and the six scenarios listed above.
    - Amendments to previously developed coastal flooding layers based on newly surveyed structural information in flooded areas in Monterey Bay.
    - Technical metadata and reporting contained herein
- **Key analysis findings**
    - Analysis of existing hydrologic climate data indicates an increase in peak flow for the 100-year discharge of 337 cfs (25%) for high emissions by 2100 on the Reclamation

Ditch system and by 1660 cfs (95%) for Soquel Creek for the same emissions and time horizon scenario.

- Analysis of existing sea level rise trends and anticipated coastal flood levels indicate an increase in downstream water level of 5.2 ft for high emissions by 2100.
- As anticipated the increase in rainfall intensity and 100-year discharge combined with the increase in sea level under climate change increases flood extent on both systems. In comparing the 100-year event under existing conditions with the year 2100 high-emissions scenario, the increase in flood extent for the Reclamation Ditch system is approximately 1736 acres (95%) and the change in flood depth is approximately 2.6 feet (36%). The same comparison for Soquel Creek, which is more topographically constrained, shows a total increase in flood extent of 65 acres (65%) and an increase in flood depth of 3.01 feet (29%).

The following four report sections lay out the technical analysis methodologies, flood hazard mapping results, and applications for the resulting information in planning and adaptation assessments. Specifically Section 2 describes the climate analysis conducted to develop boundary conditions for the hydraulic model for several scenarios representing change in 100-year discharge due to increased precipitation intensity and depth with climate change and the change in extreme ocean level coincident with the 100-year flow. Section 3 describes the model development process for both the Reclamation Ditch and Soquel Creek systems. Section 4 summarizes the flood hazard mapping analysis conducted to develop the geospatial datasets of flood hazard for the climate scenarios analyzed. Section 5 summarizes the applicability of the datasets to planning and adaptation efforts for the communities that may be at risk of additional flooding under stress by climate change.

2 CLIMATE ANALYSIS

2.1 Emissions Scenarios

The goal of the climate change data analysis was to review existing climate model data to estimate changes in extreme rainfall, coastal water level, and the resulting extent of flood hazards. The changes in extreme rainfall conditions were used to drive the inflow boundary for the hydraulic models of the two systems. Climate model data were evaluated for the latest set of General Circulation Models (GCMs) developed for the IPCC's fifth Assessment Report (AR5). The GCM data produced for AR5 has been aggregated by the World Climate Research Programme under the Coupled Model Intercomparison Project Phase 5 (CMIP5). The emissions scenarios used to drive the GCMs for CMIP5 are referred to as Representative Concentration Pathways (RCPs). The highest scenario, RCP 8.5, reflects a track with little mitigative measures to reduce greenhouse gas emissions resulting in a net increase in radiative forcing of 8.5 W/m^2 by 2100 relative to pre-industrial conditions. A medium level emissions scenario, RCP 4.5, reflects a future wherein changes in technology and energy usage stabilize the increase in net radiative forcing to 4.5 W/m^2 by 2100. These emissions scenarios, RCP 4.5 and RCP 8.5, were used to reflect respectively medium and high emissions trajectories for this study. Existing conditions was also modeled which is representative of a low emissions scenario thus the scenarios selected effectively span low, medium, and high climate change conditions.

These emissions scenarios supersede the scenarios developed in the Special Report on Emissions Scenario (SRES) utilized for the IPCC's fourth Assessment Report (AR4) and used to drive GCMs for CMIP Phase 3 (CMIP3). In general, the RCP4.5 emissions scenario tracks closely with the prior SRES B1 scenario, while RCP8.5 tracks slightly above SRES A2. The following figure (Figure 1) compares the change in mean surface temperature for the SRES and RCP emissions scenarios.

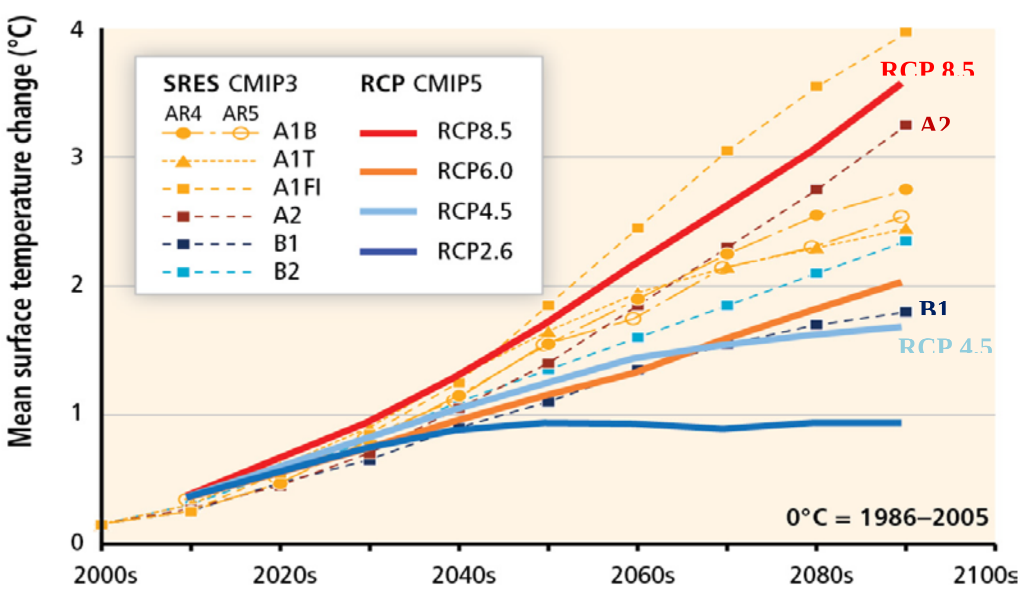

Figure 1. Comparison between SRES and RCP emissions scenarios. Reproduced from Figure 1-4 of IPCC AR5, WGII, Chapter 1

2.2 Extreme Fluvial Streamflow Analysis

Model output from GCMs driven by the RCP emissions scenarios was downscaled by CMIP5 institutions to regionalize the data from a global scale to higher resolution local scale. The downscaled data were then used to drive hydrologic models and estimate runoff for a daily timestep on a 12km x 12km grid from 1950-2100 in a study conducted by the USBR (2014). ESA used the resulting data from the USBR study to route baseflow and surface runoff and generate a time series of daily streamflow at the outlet of the two systems. The routing routine used is a component of the Variable Infiltration Capacity (VIC) model used in the USBR study to develop the runoff datasets.

The resulting daily streamflow time series from 1950-2100 was used to conduct flood frequency analysis to estimate 100-year discharge (Q_{100}) for medium and high emissions for 2030, 2060, and 2100. From the daily time series, peak annual flows were extracted for each year from 1950- 2100. A frequency curve was then fit to subsets of the peak annual flows using the Log Pearson III (LP-III) fitting method outlined in the USGSs Bulletin 17b (USGS, 1982). The USGS conducted a 2011 study updating many of the elements of Bulletin 17b based on updated gage records through water year 2006 for California gages (USGS, 2011). Two significant elements that were updated were the methods for estimating values for generalized skew (G_{gen}) and mean square error for generalized skew (MSE-G_{gen}) based on the average elevation of the basin. The average elevation of the basin is 479 feet for the Reclamation Ditch system and 1,141 feet for Soquel Creek. Based on the non-linear model for G_{gen} and the relationship between MSE-G_{gen} and average basin elevation summarized in USGS, 2011 Tables 7 and 8 respectively, the values estimated for G_{gen} and MSE-G_{gen} for the Reclamation Ditch watershed are -0.613 and 0.14, respectively, and -0.581 and 0.14 respectively for Soquel Creek.

Using these updated values in the LP-III method, we computed 100-year discharge for each GCM and each emissions scenario for an historical period, and three future time periods—2030, 2060 and 2100. A sample figure for the flood frequency curve for the historic time period for a single GCM for RCP4.5 is shown in Figure 2. Subsets of the data were selected for the time periods as summarized in Table 1.

TABLE 1
SUBSETS FOR TIME PERIODS USED IN FLOOD FREQUENCY ANALYSIS

Time period	Years for which peak annual flow was used in flood frequency analysis	Emissions scenario	GCM percentile	Resulting 100-year flow variable
2030	2015-2045	RCP 4.5 (medium)	50^{th}	Q_{100}-2030-medium
		RCP 8.5 (high)	90^{th}	Q_{100}-2030-high
2060	2045-2075	RCP 4.5 (medium)	50^{th}	Q_{100}-2060-medium
		RCP 8.5 (high)	90^{th}	Q_{100}-2060-high
2100	2070-2100	RCP 4.5 (medium)	50^{th}	Q_{100}-2100-medium
		RCP 8.5 (high)	90^{th}	Q_{100}-2100-high

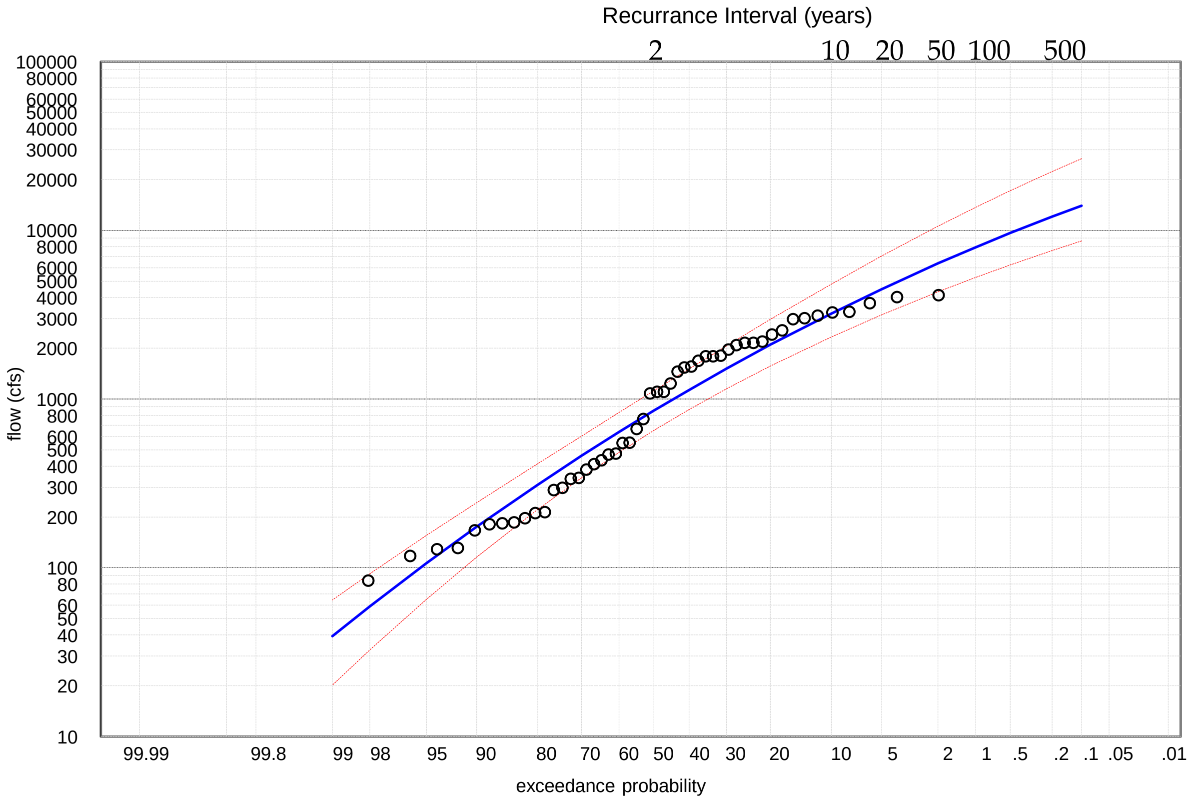

Figure 2. Log Pearson III flood frequency curve for historic time period (1950-2000) for GCM ACCESS[1] 1-0 for the RCP4.5 emissions scenario. The black dots show peak annual flow from routed GCM hydrology, the blue line shows the fitted LP-III curve, and the red lines show the 95- and 5-percent confidence intervals.

Because this analysis was conducted for each individual GCM, a distribution of GCMs can be created. The distribution highlights the discrepancy between individual models and the need to select a representative percentile for characterizing climate risk on any system. An example of the distribution of all models considered for a single emissions scenario and selected percentiles within the model distribution is shown for change in peak annual flow in Figure 3.

[1] Australian Community Climate and Earth-System Simulator (ACCESS)

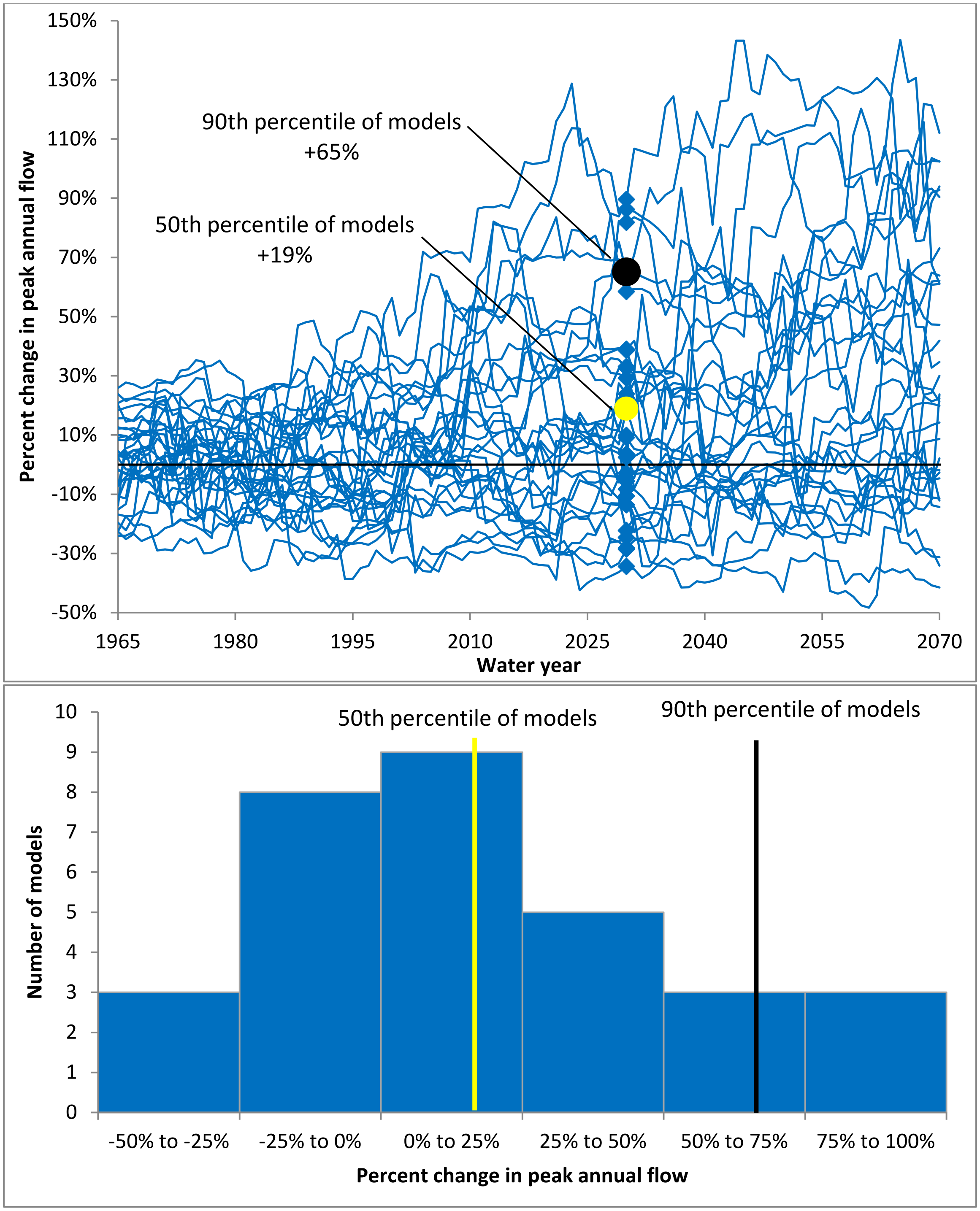

Figure 3. Percent change in peak annual flow relative to 1950-2000 average for all GCMs under RCP 4.5 emissions, blue lines show individual GCM trajectories and blue dots show result at year 2030 (top), and (bottom) histogram of total number of models for given ranges of percent change in peak annual flow

The 100-year discharge and the change in 100-year discharge for the three future time periods relative to the historic time period was calculated for each GCM based on the following equation:

$$\Delta Q_{100} = Q_{100-year-emissions} - Q_{100-hist}$$

Where ΔQ_{100} is the change in Q_{100} in cfs

$Q_{100\text{-year-emissions}}$ is the Q_{100} for a given GCM at a specific time horizon and emissions scenario

$Q_{100\text{-hist}}$ is the Q100 for the historical time period based on the GCM data

The distribution of GCMs for the change in Q_{100} on the Reclamation Ditch is shown for RCP 4.5 in Figure 4 and for RCP 8.5 in Figure 5. The distribution of GCMs for the change in Q100 on the Soquel Creek is shown for RCP 4.5 in Figure 6 and for RCP 8.5 in Figure 7.

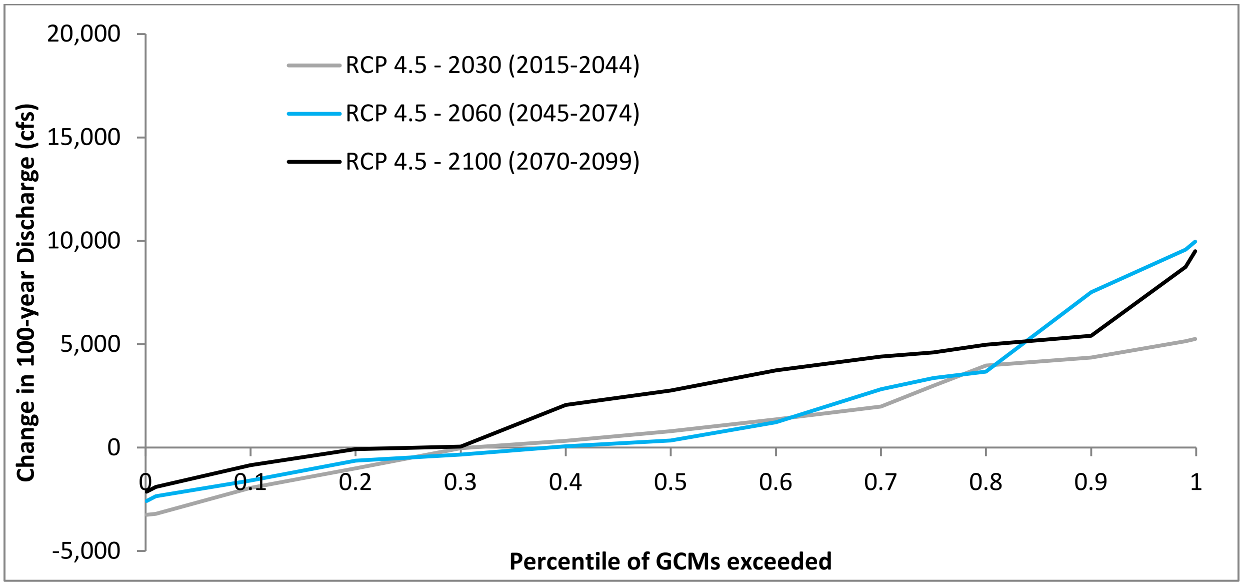

Figure 4. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 4.5 on the Reclamation Ditch System

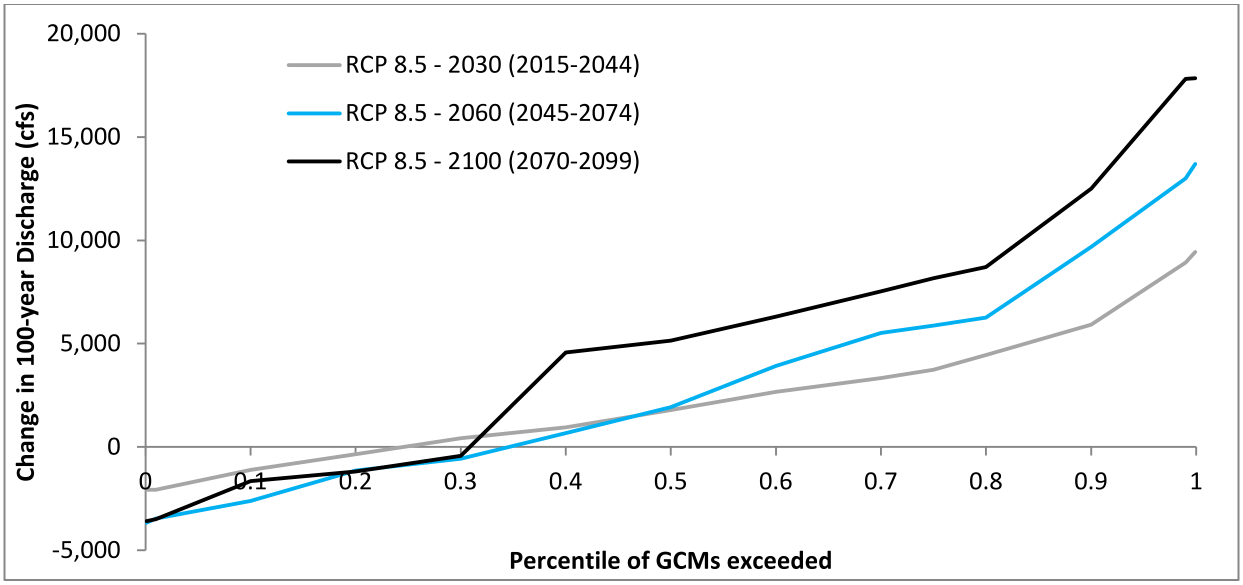

Figure 5. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 8.5 on the Reclamation Ditch

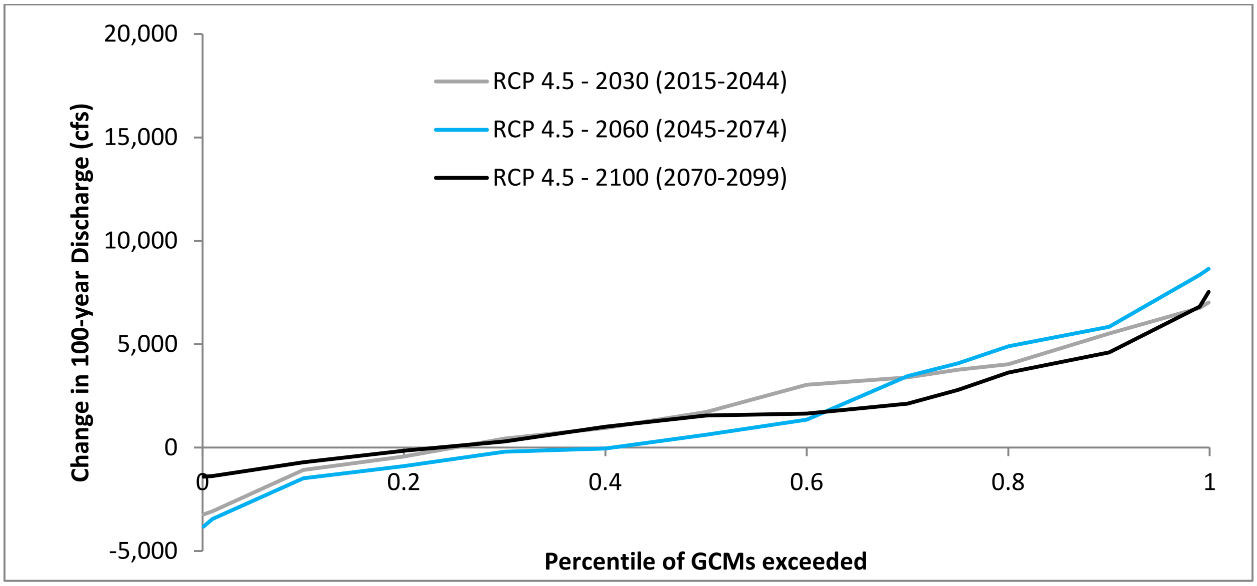

Figure 6. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 4.5 on Soquel Creek

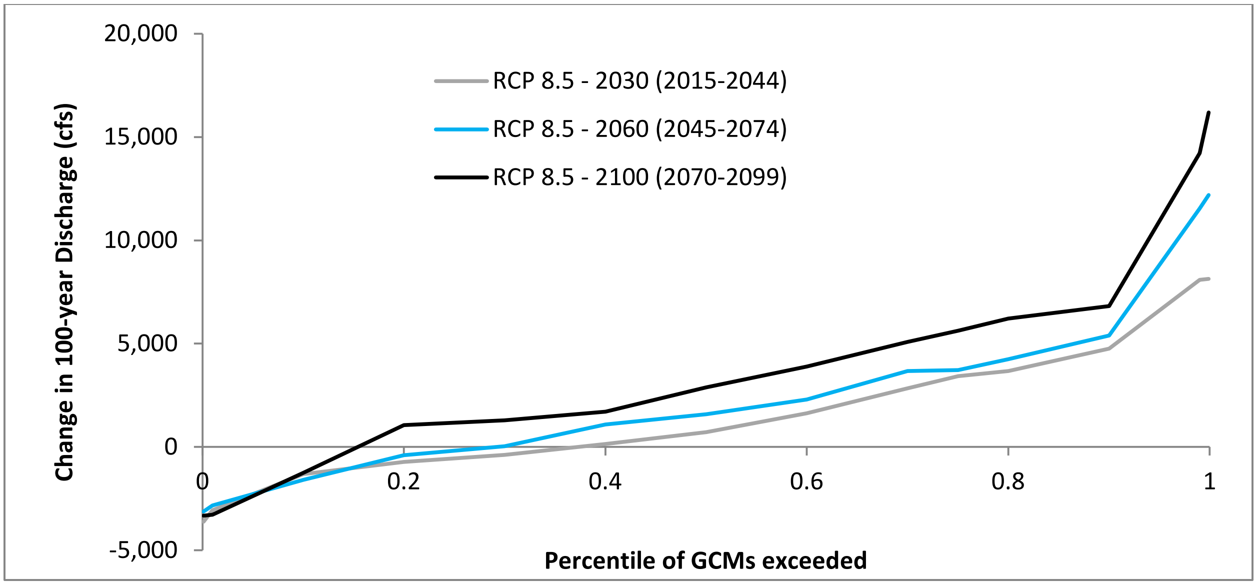

Figure 7. Distribution of change in Q_{100} for each GCM for 2030, 2060, and 2100 for RCP 8.5 on Soquel Creek

These figures indicate that for RCP 4.5, the emissions scenarios are grouped fairly closely for each future time period. The 'medium' emissions scenario was estimated from approximately the 50th percentile for the three time periods for RCP 4.5. It was determined that the 90th percentile of the models for RCP 8.5 for each individual year would be used to represent the 'high' emissions scenario. The changes estimated for 100-year discharge for both systems are summarized in Table 2.

TABLE 2
CHANGE IN 100-YEAR DISCHARGE FOR BOTH SYSTEMS RELATIVE TO HISTORIC PERIOD (1950-2000)

	Reclamation Ditch system			Soquel Creek		
Emissions scenario	**2030**	**2060**	**2100**	**2030**	**2060**	**2100**
Medium (RCP 4.5 50th percentile)	20%	40%	60%	13%	15%	20%
High (RCP 8.5 90th percentile)	140%	210%	275%	62%	68%	95%

The flows estimated in the extreme streamflow analysis were used to drive the hydraulic models which, in turn, were used to map inundation extents for existing conditions and the five future climate conditions (2030 high, 2060 and 2100 medium and high emissions). In addition to the extreme streamflow change, the downstream coastal water levels are influenced by sea level rise. The following section describes the analyses conducted to characterize the extreme coastal water level that would be coincident with the 100-year flood.

2.3 Extreme Coastal Water Level Analysis

2.3.1 Reclamation Ditch Extreme Tide Levels

The ocean boundary condition from the existing unsteady HEC-RAS hydraulic model consisted of a repeated tide cycle that peaked at about MHHW. To represent extreme tide conditions we used a 10-year tide as the ocean boundary for existing conditions. Given that the mouth of this system (the mouth to Moss Landing Harbor) is relatively deep we assumed that the mouth would not support wave setup, and therefore no additional water level increase was added for wave setup. The input ocean stage hydrograph was scaled up to peak at the 10-year water level (7.69 ft NAVD, from Monterey NOAA Buoy 9413450).

For future conditions the 10-year tide was increased at the rate of sea level rise based on the CA Coastal Commission guidance document (CCC, 2013). The total amount of SLR added for each scenario was estimated by fitting curves to the NRC 2012 SLR values, following this guidance. The peak tide elevation for each scenario is summarized in Table 3. These are the same water levels used by ESA for the Monterey Bay hazard mapping (ESA PWA, 2014).

TABLE 3
EXTREME TIDE CONDITIONS FOR RECLAMATION DITCH SYSTEM

	Sea level rise (ft)		10-year tide level + SLR (ft NAVD)	
Time period	Medium	High	Medium SLR	High SLR
2015	-	-	7.69	
2030	0.3	0.7	8.0	8.4
2060	1.1	2.4	8.8	11.0
2100	2.9	5.2	10.6	12.9

2.3.2 Soquel Creek Extreme Tide Levels

The Soquel Creek model is steady state thus there is no time dimension to the peak coastal water level. Recognizing this, it was deemed not representative to use the 10-year peak water level to represent extreme tide levels given that this elevation is only reached for a brief period during the 10-year event. We selected the 1-year recurrence interval as a tide level that would have a long enough time dimension to be considered credibly steady-state during an extreme tide event. Based on the Monterey Bay tide gauge (NOAA# 9413450), the 99% exceeded (1-year recurrence) tide elevation is 6.87 ft NAVD. Additionally, given the geomorphic configuration of this system, we added an additional increase in the steady state boundary to account for storm surge and wave setup. We selected 2-feet to account for these factors based historic data and previous studies of joint probability between coastal storm surge and high intensity rainfall as described below.

The steady downstream water surface boundary condition for Soquel Creek was chosen based on review of traditional practice and consideration of past analyses of joint probability of peak river discharges with elevated ocean water levels. A past study on San Lorenzo Creek by (USACE 2011) showed a correlation between peak discharges and storm surges, with average tidal residuals during river flood events ranging from 0.4 to 1.5 feet and wave setup ranging from 0.2 to 2 feet. We also examined historic data for Soquel Creek and nearby Aptos Creek for coastal storm events based on USGS stream gauge, CDIP buoy, and NOAA tide gauge records to estimate the wave setup during past events. We found similar patterns in the tide residuals, wave setup, and tide peak elevation during the storm. The wave setup and tide peak for a set of extreme tide and flow events is summarized in Table 4. The tidal peak water level that occurred around the time of the peak river discharge was found to be near the 1-year recurrence elevation with an average residual 0.5 feet and average estimated wave runup of 1.2 feet.

TABLE 4
COASTAL STORM SURGE AND WAVE SETUP FOR EVENTS ON SOQUEL AND APTOS CREEKS

Creek	Date	Approximate peak flow (cfs)	Ocean Residual ft (1-day average)	Offshore Wave Height, H (ft) approx	Wave Setup hsetup (ft)[1]	Total ocean water anomaly (wave setup + residual) ft	Tide Peak During Storm (ft NAVD)
Aptos	2/6/1983	210	0.74	16	1.6	2.38	6.1
Aptos	2/25/1983	210	0.43	11	1.1	1.58	6.9
Aptos	2/23/2009	280	-0.04	7	0.7	0.7	5.6
Aptos	1/20/2010	210	1.17	21	2.1	3.3	6
Aptos	12/21/2010	310	0.65	10	1	1.63	7
Aptos	12/29/2010	140	0.23	16	1.6	1.87	6.3
Aptos	2/25/2011	n/a	0.12	8	0.8	0.94	5.6
Soquel	10/13/2009	4000	0.85	7	0.7	1.51	6.1

[1]steady (average) setup ~= 0.1*H

The future conditions 100-year discharge combined with the future conditions extreme coastal tide level were used as boundary conditions for the hydraulic modeling analysis. The modeling analysis is described in the following section.

3 HYDRAULIC AND HYDRODYNAMIC MODELING ANALYSIS

3.1 Reclamation Ditch Unsteady Modeling

The basis for the unsteady HEC-RAS hydraulic model was a model provided by the Monterey County Water Resources Agency (MCWRA) to ESA in 2014. The model is an updated version of the HEC-RAS model originally developed by Schaaf & Wheeler (1999) for flood analysis. The model has been periodically updated for flood mapping studies. However, the original channel data dates back to the original study. The existing conditions 100-year hydrology was also developed by Schaaf & Wheeler in 1999 using a HEC-1 hydrologic model for the Gabilan Creek watershed. This formed the basis for the existing conditions 100-year unsteady hydrograph boundary conditions used in the model. Updates to the model geometry required including positioning the model in real geospatial coordinates and updating overbank areas with LiDAR topography are described in the following section.

3.1.1 Model Geometry Development

Hydraulic Roughness – The parameter representing the resistance to flow within a channel or floodplain due to vegetation, bedform, and bed material is known as the manning's roughness or 'n' value. The manning's n values were adopted from the existing model. The values are 0.025 for channel roughness and 0.065 for floodplain roughness.

Georeferencing – The original model provided by Monterey County required georeferencing to spatially orient the model input and output. The original mode was shifted to correctly orient the confluence of the Tembladero Slough and drainage canal from Merritt Lake (just upstream of Castroville). Tembladero Slough was digitized from Moss Landing up the Reclamation Ditch to the Hwy 101 crossing in Salinas using the HEC-GeoRAS toolbar in ArcGIS and then imported to the HEC-RAS model. Cross section spacing was then adjusted in HEC-RAS to align known bridge crossings with their spatial location. The model layout is shown in Figure 8.

Figure 8. Reclamation Ditch hydraulic model layout

Update with LiDAR – Because the overbank representation of the existing model was limited, it was necessary to update the overbank topography from new sources. This was accomplished by first extending the channel cross sections to include the full floodplain and then updating the cross section station-elevation data with topography from the 2009-2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM that was downloaded from http://coast.noaa.gov/dataviewer/. This was only done for cross sections downstream of the railroad crossing west of Hwy 183, as the focus was primarily on flood behavior downstream. We determined that the elevations of the existing model were vertically referenced to an old vertical datum NGVD29. We thus converted the elevations to NAVD88 using the conversion factors listed in the FIS (+2.7 ft for Tembladero Slough, +2.77 ft for Reclamation Ditch). The model was also expanded into the Moro Cojo Slough and historic slough area between the Tembladero and Moro Cojo to represent alternate flood pathways that became apparent during the December 2014 flood.

Incorporation of MLML data – Hydraulic structure data was provided by Ross Clark, Charlie Endris, that was used to develop preliminary geometry for hydraulic structures located in the expanded portions of the model including:

1. Cabrillo Hwy crossing over Moro Cojo Slough
2. Moss Landing Rd tide gates at Moro Cojo

Other minor structure crossings in the model area were not accounted for due to lack of data. One improvement to the model would be to survey these crossings and add them into the model geometry to improve the representation of flow routing in the system.

3.1.2 Model Hydrology Inputs

Future flows determined in the future Q_{100} climate analysis were simulated by scaling the existing unsteady 100-year hydrographs that came with the HEC-RAS model provided by Monterey County. Base flow was maintained for the input hydrographs by only scaling the peak of each input hydrograph (flows > ~75% of the existing peak discharge). Within each hydrograph peak, a polynomial scaling function was used to produce smooth transitions between the existing rising and falling limbs and the future hydrograph peaks.

Inflow hydrographs were developed for Moro Cojo Slough and the unnamed canals/historic slough watershed. Area was determined for each watershed using USGS streamstats online tools. Then hydrographs were scaled from nearby subwatersheds analyzed by Schaff and Wheeler that possessed similar attributes (drainage area, relief, and impervious percentage) using watershed area as the scaling factor. These were scaled for future conditions using the method described above.

The downstream boundary was driven by an unsteady tide as described in the extreme coastal tide level section for the Reclamation Ditch.

3.1.3 Model Validation

The results of the updated hydraulic model run with the existing conditions 100-year hydrology and MHHW tailwater were compared to flooding extent and hydraulic flowpaths from a flood event that occurred in December 2014. The MLML provided a map of estimated extents and observed flow directions during this event. One key observation for this event was that flow backing up at the Moss Landing tide gates overtopped adjacent farm fields contributing additional water into Moro Cojo Slough which routes water to the harbor through the culverts under Moss Landing Road. The model reproduced this observed pattern for the 100-year flow as shown in Figure 9.

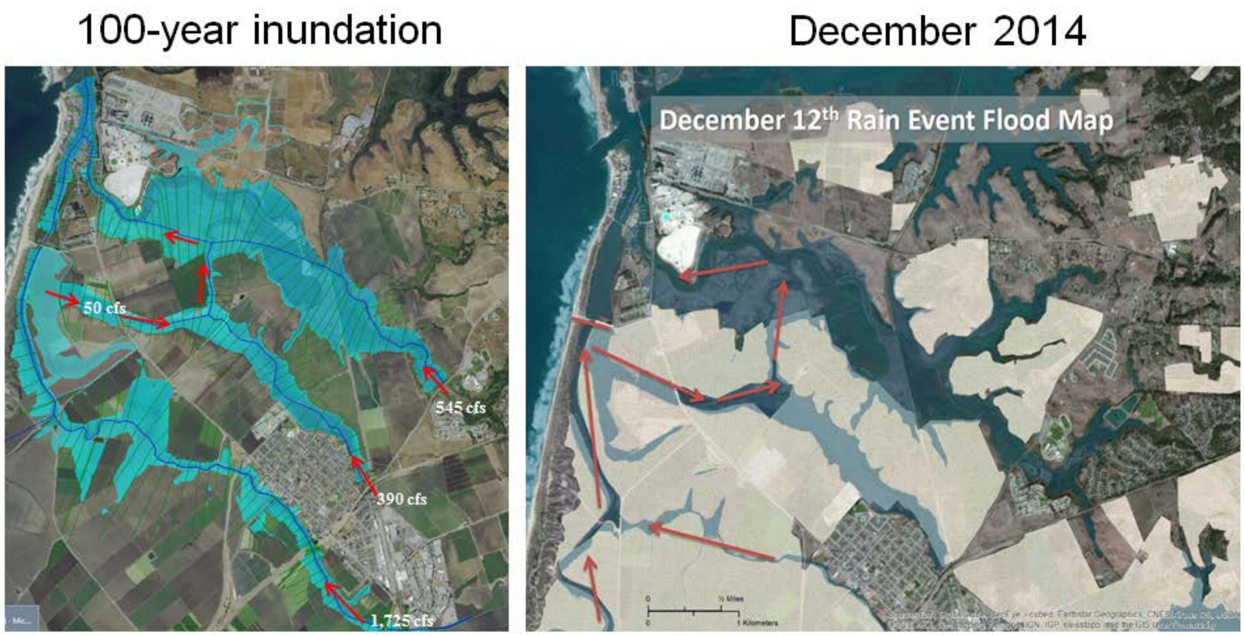

Figure 9. Comparison of Modeled 100-year flowpaths and observed flowpaths during December 2014 flood

3.1.4 Model Limitations

Flood mapping was truncated for Tembladero Slough at the Cabrillo Hwy, Moro Cojo up to the Railroad, and the historic slough in between. From the Tembladero up to the City of Salinas, the cross sections are limited to in channel portions, and floodplains were not mapped for any of the model coverage upstream. Given the uncertainty regarding the location of cross-sections an improvement to the model would be collecting new channel cross-sections and channel bathymetry in the model domain. Additionally, replacing the overbank areas with 2D flow elements would improve the routing of flow once it escapes the channel and goes out of bank. Lastly, the main Salinas River channel is not represented in the model. There are known interactions with the Salinas River and the Reclamation Ditch system including breakout flows from upstream entering the Reclamation Ditch and a water control structure connection between the mouth of the Salinas River and the old Salinas River alignment. The model could be improved significantly by combining the model with a model of the Salinas River and replacing the overbank areas with 2D flow elements.

3.2 Soquel Creek Steady State Modeling

3.2.1 Model Geometry Development

Hydraulic Roughness – The manning's n values were adopted from the existing FEMA model to maintain consistency. The channel and floodplain n values are 0.1 and 0.4 respectively.

Georeferencing – The existing conditions model for Soquel Creek came from the effective FEMA model for the system which was provided by FEMA as HEC-2 data-the precursor to HEC-RAS. The model was converted to HEC-RAS and georeferencing was performed to geospatially orient the model cross-sections and flood results. The georeferencing was accomplished by digitizing the length of Soquel Creek from the Pacific Ocean upstream to the limit of existing model coverage with HEC-GeoRAS tools in ArcGIS. Once the new stream centerline was imported to HEC-RAS, cross section spacing was adjusted to align bridge crossings with the known locations determined by the Terrain or aerial imagery. The model cross-section layout is shown in Figure 10.

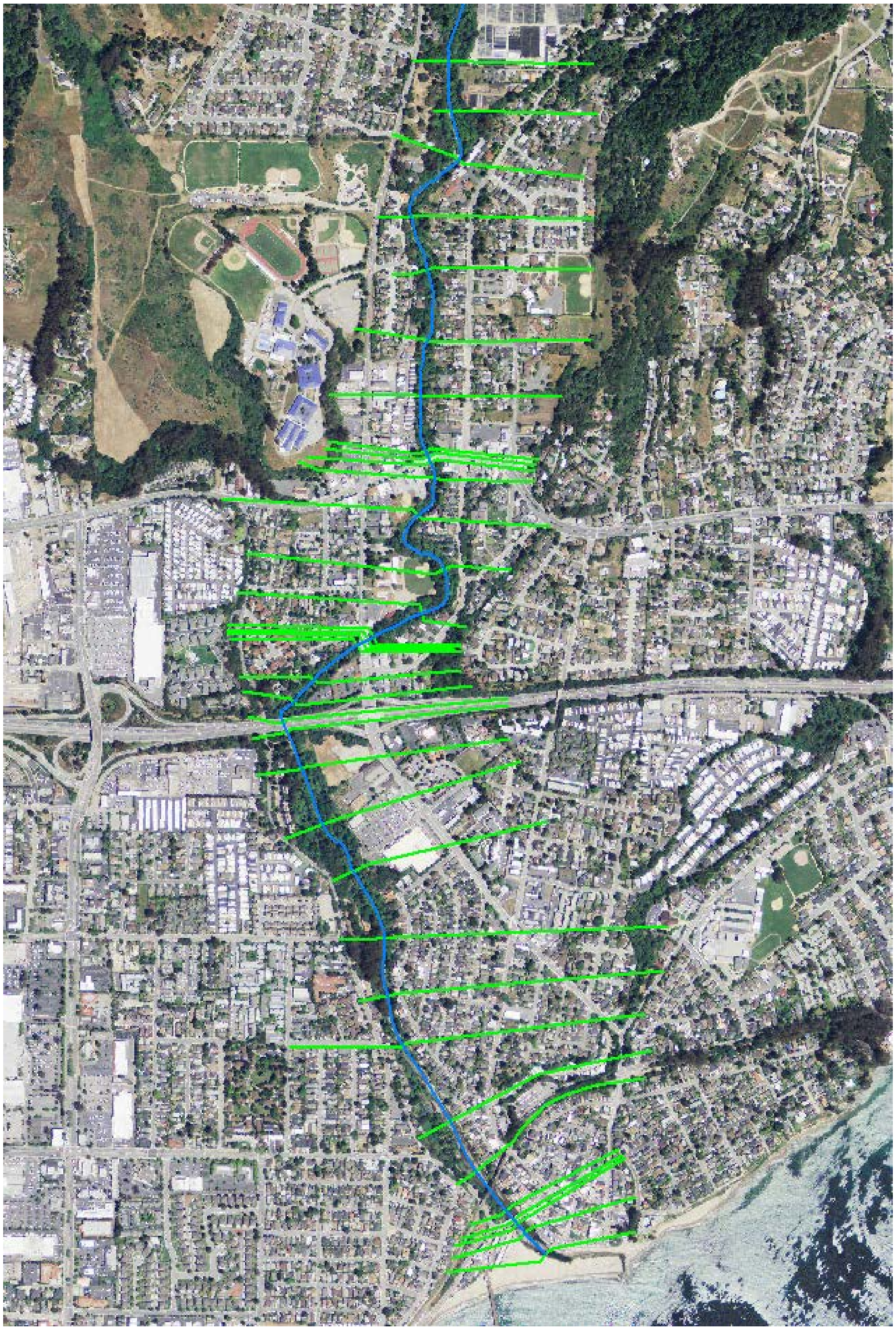

Figure 10. Soquel Creek hydraulic model layout

Update with LiDAR – Channel cross sections were extended to include the full floodplain and the cross section station-elevation data was updated with topography from the 2009 - 2011 CA Coastal Conservancy Coastal Lidar Project: Hydro-flattened Bare Earth DEM (downloaded here: http://coast.noaa.gov/dataviewer/). This was only done for cross sections downstream of Soquel Nursery Growers Plant Nursery. In-channel bathymetry and hydraulic structure data were maintained, and were shifted from NGVD29 to NAVD88 using the datum conversion factor from the FIS (+2.75 ft).

Incorporation of MLML data – Hydraulic structure data (stormdrains, manholes, etc.) were provided by Ross Clark, Charlie Endris, but were not used in the model. These data can (are going to) be used to update flood connectivity of previously mapped coastal flooding hazards (ESA 2014), and would serve to improve fluvial flood mapping from an unsteady model of Soquel Creek.

3.2.2 Model Hydrology Inputs

Future peak flows determined in the future Q_{100} climate analysis were modeled in steady state. Flows were increased by the percent change calculated for the medium and high emissions scenarios and the three future time horizons. The downstream boundary was driven by a steady tide as described in the extreme coastal tide level section for Soquel Creek.

3.2.3 Model Limitations

The geometry information in the model, including hydraulic structures and in-channel bathymetry, are out of date and may not be representative of current channel conditions. These should be updated to better represent the current conditions in Soquel Creek. Because the model is steady state, overbank flooding is potentially overestimated. Flooding extents could be improved by switching to an unsteady model.

4 MODEL RESULTS AND FLOOD HAZARD MAPPING

The hydraulic model results include water elevations in each cross-section which were translated into geospatial datasets of flood extent and depth for each of the scenarios modeled. This flood hazard mapping process was accomplished using the HEC-GeoRAS toolbar for ArcGIS which enables data transfer between GIS and HEC-RAS. Water surface profiles from the model results were exported to GIS and differenced against the underlying NOAA LiDAR topography to map flood extent. This topographic dataset does not include bathymetry below the water line thus flow depths in the channel are representative of depth above the water line at the time during which the LiDAR data were surveyed. Though some channel bathymetry for Tembladero Slough and the Reclamation Ditch was present in the original HEC-RAS model, no clear geospatial information was available for precisely locating these data. Thus the bathymetry from the cross-sections was not integrated into the topographic surface. The results of the inundation mapping are shown for the Reclamation Ditch system in Figure 11 and for Soquel Creek in Figure 12.

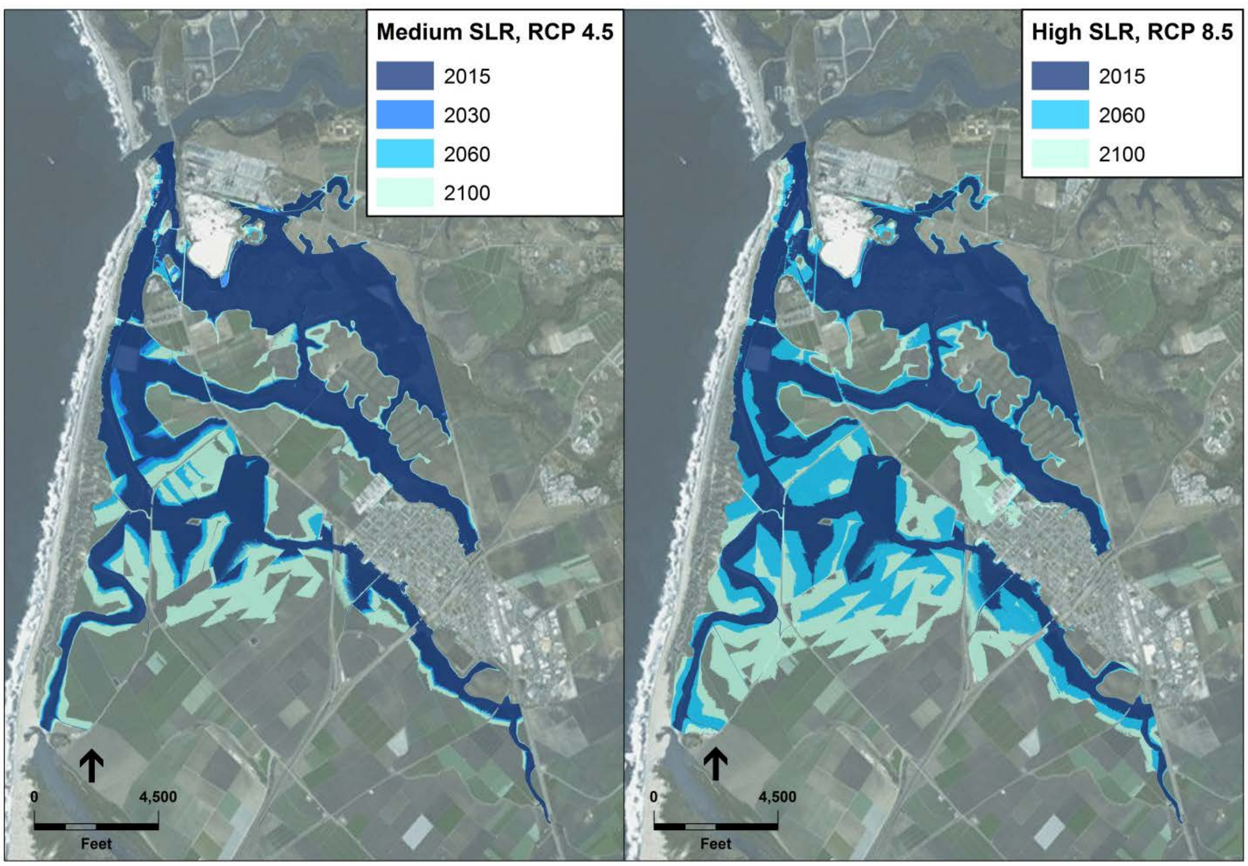

Figure 11. Flood inundation hazard maps for multiple climate scenarios on the Reclamation Ditch system

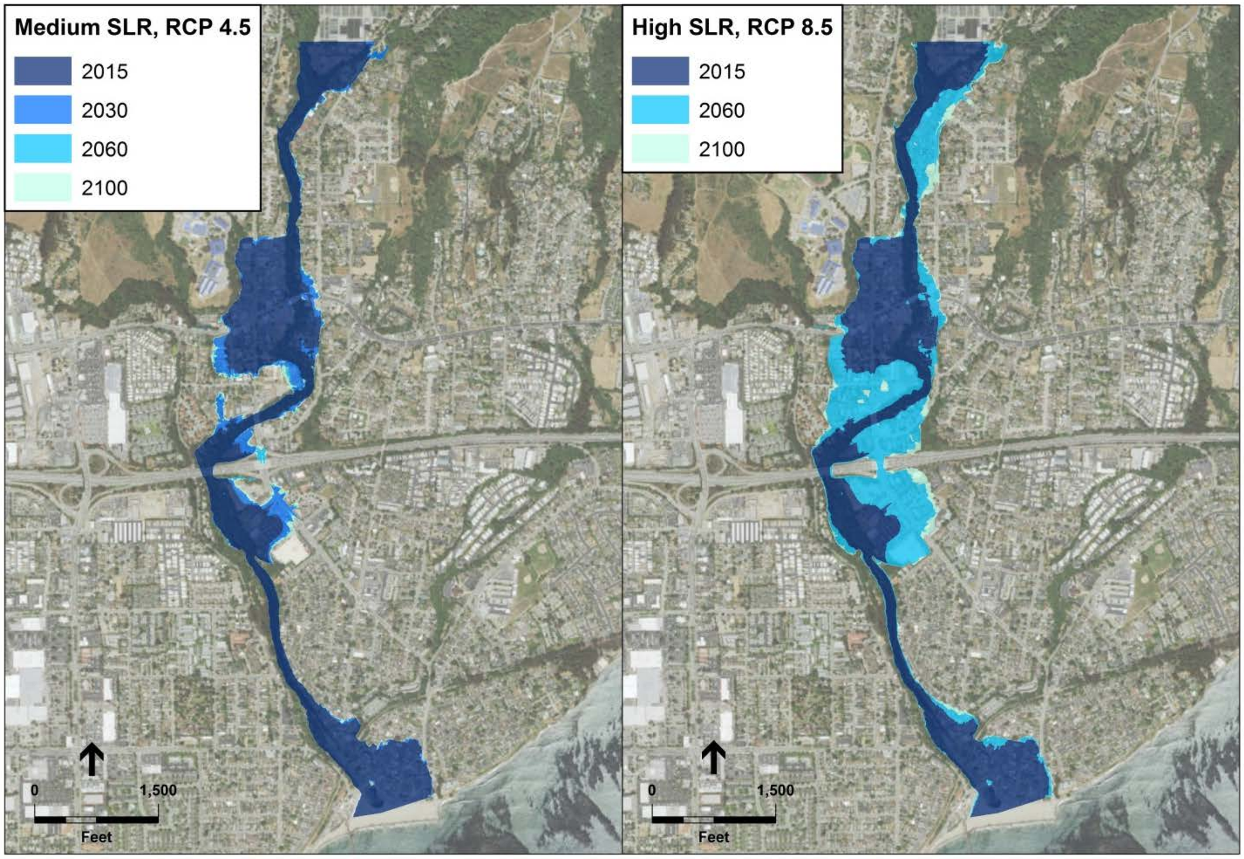

Figure 12. Flood inundation hazard maps for multiple climate scenarios on Soquel Creek

As Figure 11 shows, the flood extent increases significantly from existing conditions to 2100 on the Reclamation Ditch system. The majority of additional flooding is on the agricultural properties adjacent to Tembladero Slough and the Old Salinas River channel. The increase is exacerbated by the flatness of the terrain which results in a large increase in flooding for small increases in discharge. The additional flooded area is approximately 960 and 1740 acres for the Medium and High scenarios respectively, and the increase in flood depth is approximately 1.1 and 2.6 feet respectively. Depth measurements were sampled just upstream of the Hwy 156 crossings on Tembladero Slough.

For Soquel Creek, the change in 100-year discharge is less significant than on the Reclamation Ditch system. Additionally, the topography is more constrained in areas that are already flooded by the existing conditions 100-year flood. Thus the extent of flooding does not change as significantly on this system. The additional flooded area is approximately 18 and 65 acres for the Medium and High scenarios respectively, and the increase in flood depth is approximately 0.8 and 3.0 feet respectively.

In addition to the fluvial flood hazard mapping analysis, coastal storm flooding hazard zones were provided for the purposes of updating flooding connectivity in the Capitola and Salinas-Elkhorn areas. Coastal storm flooding hazards were previously mapped for the Monterey Bay Sea Level Rise Vulnerability Study (ESA PWA 2014) prepared for The Monterey Bay Sanctuary Foundation, and were provided in shapefile format for these two areas.

For the Capitola area (Soquel Creek), ESA provided MLML with intermediate coastal hazards shapefiles that contained separate polygons for the various hazards modeled. Equipped with the separated hazards and by using GIS data of storm drain networks and other flood management infrastructure, staff at MLML can make any warranted flood connectivity updates to the coastal flooding hazard layers provided in the MBSLR study (ESA PWA 2014). Described in the shapefile metadata, the separated versions of the coastal flooding hazards include layers for wave overtopping, wave runup, event tide flooding (100-yr tide), and erosion layers depicting eroded conditions of cliffs and dune areas (which would be considered as flooded in the future). Elevations associated with each flooding mechanism (except the erosion layers) are provided as attributes for each mechanism ("Method" in the attributes table).

As a part of a subsequent study "Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay" by ESA, The Nature Conservancy and others, flood connectivity was updated to reflect known water control structures in the area. The main structures considered are the tide gates on Tembladero Slough at Potrero Road, the Cabrillo Hwy road crest separating low lands from backwatering from the Moro Cojo Slough, and the water control structure between the Salinas Lagoon and Old Salinas channel to the north. In this update, flooding methods and associated flooding elevations for the Salinas River were altered to produce more accurate flood extents:

- Beach berm flooding – the elevation of flooding behind the beach berm at the Salinas River lagoon mouth was lowered from 4.88 m NAVD to 3.66 m NAVD (from 16ft to 12 ft) to represent the hydraulic control structure that diverts water north to the old Salinas River channel. These flooding layers also assume a 15 ft crest elevation for the levee on the north bank of the Salinas River, estimated from LiDAR.

- 100-yr tide flooding – flooding by the 100-year tide was updated to reflect the Potrero Rd tide gates and the road crest at Cabrillo Hwy, which affects primarily farmlands south of the Elkhorn Slough mouth.

The geospatial layers for the flood hazard extent and depths were compiled in an ESRI ArcGIS compatible geodatabase. The geodatabase was provided to MLML on 1/29/2016. Additionally the coastal flooding shapefiles adjusted to incorporate structural information on both systems was provided with this geodatabase. A table of the layers provided is included in Attachment A.

5 DISCUSSION

The climate analysis and hydraulic modeling show how future conditions flooding can change with increased precipitation intensity and higher coastal water levels with extreme coastal flood events. The flood hazard inundation extents can be used to inform planning efforts in the areas that are at risk of increased flooding as climate change puts added pressure on flood parameters. The range of scenarios provided allows for interpretation of potential flood risk given uncertainty in how climate will evolve. Planning efforts can be informed by considering a range of future scenarios and associated vulnerabilities, and the community's tolerance for risk, which should conceptually relate to the community's resilience.

The fluvial flood hazard maps add value to the previous coastal flooding analyses conducted by ESA by incorporating changes to watershed hydrology into the flood potential. This enables an assessment of the flood risk from combined changes in increasing coastal water levels and increased precipitation intensity. This is beneficial to communities at risk of flooding from both coastal and fluvial sources and provides a more complete set of scenarios for planning in those communities.

The resulting hazard maps can be used to assess risk as well as plan for future adaptation measures. By highlighting areas at risk currently and areas potentially at risk under different climate scenarios, communities can begin to develop and implement specific localized measures for adapting to these future risks. Future study should be considered to develop adaptation plans now that the tools for assessing risk have been developed and are available for further use.

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Monterey Bay Sea Level Rise

Climate Change Impacts on Combined Fluvial and Coastal Hazards

ATTACHMENT A

GIS Data Layers Provided With Report

Attachment A - Files transmitted via 20150126_fluvialHZ_w_Metadata.zip

Folder	Subfolder	File	Geographic Location	Type	SLR	Emissions
RecDitch_Tembladero_UTMz10						
	area					
		river100yr_floodplain_ec2010.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	none	none
		river100yr_floodplain_hi2060.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_hi2100.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_med2030.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2060.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2100.shp	Tembladero Slough	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
	depth					
		MaxDepth_100yr_ec2010.tif	Tembladero Slough	Fluvial flooding max depth raster	none	none
		MaxDepth_100yr_hi2060.tif	Tembladero Slough	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_hi2100.tif	Tembladero Slough	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_med2030.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2060.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2100.tif	Tembladero Slough	Fluvial flooding max depth raster	Medium	RCP 4.5
SoquelCreek_UTMz10						
	area					
		river100yr_floodplain_ec2010.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	none	none
		river100yr_floodplain_hi2060.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_hi2100.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	High	RCP 8.5
		river100yr_floodplain_med2030.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2060.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
		river100yr_floodplain_med2100.shp	Soquel Creek	Fluvial flooding extents polygon shapefile	Medium	RCP 4.5
	depth					
		MaxDepth_100yr_ec2010.tif	Soquel Creek	Fluvial flooding max depth raster	none	none
		MaxDepth_100yr_hi2060.tif	Soquel Creek	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_hi2100.tif	Soquel Creek	Fluvial flooding max depth raster	High	RCP 8.5
		MaxDepth_100yr_med2030.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2060.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5
		MaxDepth_100yr_med2100.tif	Soquel Creek	Fluvial flooding max depth raster	Medium	RCP 4.5

Key

SLR	High	high sea level rise (NRC 2012) of 159 cm by 2100, relative to 2010
	Med	medium sea level rise (NRC 2012) of 72 cm by 2100, relative to 2010
Emissions	RCP 8.5	future emissions scenario (IPCC, AR 5)
	RCP 4.5	future emissions scenario (IPCC, AR 5)

100-year fluvial flooding rasters and polygons are projected to UTM Zone 10N coordinates. Raster depths are in Feet.

Attachment A - Files transmitted via 20150129_Draft_UpdatedCoastalFloodHZ

Folder	File	Geographic Location	Type	SLR
coastal_storm_flood_MBSLR_Capitola				
subfolder "combined"	coastal_floodhz_ec2010_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	none
	coastal_floodhz_s12030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s12060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s12100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Low
	coastal_floodhz_s22030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s22060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s22100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	Medium
	coastal_floodhz_s32030_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
	coastal_floodhz_s32060_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
	coastal_floodhz_s32100_dissolved.shp	Capitola / Soquel Creek	Coastal Storm flooding extents	High
subfolder "separated"	coastal_floodhz_ec2010.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	none
	coastal_floodhz_s12030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s12060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s12100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Low
	coastal_floodhz_s22030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s22060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s22100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	coastal_floodhz_s32030.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	coastal_floodhz_s32060.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	coastal_floodhz_s32100.shp	Capitola / Soquel Creek	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
event_flood_SMB_SalinasElkhorn				
subfolder "combined"	event_flood_AER_ec2010.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	none
	event_flood_AER_s22030.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	Medium
	event_flood_AER_s22060.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	Medium
	event_flood_AER_s22100.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	Medium
	event_flood_AER_s32030.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	High
	event_flood_AER_s32060.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	High
	event_flood_AER_s32100.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents	High
subfolder "separated"	event_flood_AER_ec2010_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	none
	event_flood_AER_s22030_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s22060_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s22100_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	Medium
	event_flood_AER_s32030_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	event_flood_AER_s32060_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	High
	event_flood_AER_s32100_EL.shp	Salinas River / Elkhorn Sloug	Coastal Storm flooding extents, with separate EL and HZ type attributes	High

Key

SLR	low sea level rise (NRC 2012) of 22 cm by 2100, relative to 2010
	medium sea level rise (NRC 2012) of 72 cm by 2100, relative to 2010
	high sea level rise (NRC 2012) of 159 cm by 2100, relative to 2010

coastal storm flooding rasters and polygons are projected to UTM Zone 10N coordinates