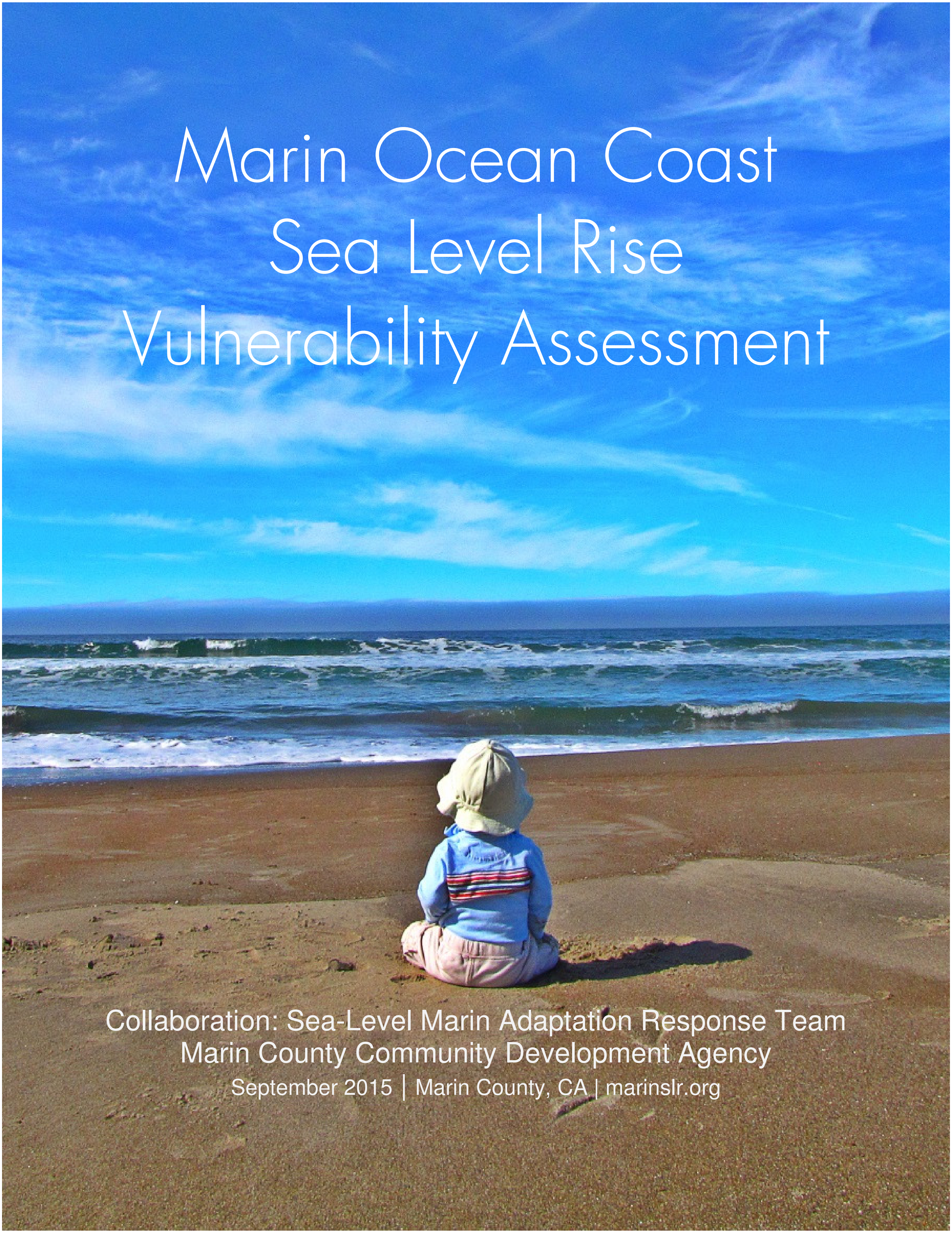

Marin Ocean Coast Sea Level Rise Vulnerability Assessment

Collaboration: Sea-Level Marin Adaptation Response Team
Marin County Community Development Agency

September 2015 | Marin County, CA | marinslr.org

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Cover Photo: Caden at the Beach September 2013. Credit: Rendel

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Acknowledgements

Marin County Board of Supervisors

District 1 - Damon Connolly
District 2 - Katie Rice
District 3 - Kathrin Sears
District 4 - Steve Kinsey
District 5 - Judy Arnold

Marin County Planning Commission

Katherine Crecelius
Don Dickenson
David Paoli
Margot Biehle
John Eller
Wade Holland
Peter Theran

Project Funders

California Coastal Commission
California Ocean Protection Council
Marin County

Authors

Bridgit Van Belleghem, Planner, Marin County CDA
Alex Westhoff, Planner, Marin County CDA
Lauren Armstrong, Planner, Marin County CDA
Nicole Le Baron, Planning Intern, Marin County CDA

Project Manager

Jack Liebster, Program Manager, Marin County CDA

Consultant

Environmental Science Associates

Stakeholder Advisory Committee

Community Representatives
Lawrence Crutcher, Stinson Beach
Alex Hinds, Inverness
Bob Johnston, Pt. Reyes Station
Michael Lawson, Dillon Beach/North County
Jeffrey Loomans, Stinson Beach (Seadrift)
Gerald Pearlman, Muir Beach
Jennie Pfeiffer, Bolinas
Arthur Walenta, East Shore/Marshall

Topical Area Representatives
Brian Aviles, National Park Service
Katie Beacock, Local Business Owner
Christopher Harrington, Local Business Owner
Michael Lawson, Agriculture
Gerald Pearlman, Recreation
Amy Trainer, Environmental Action Committee
Daphne Hatch, National Park Service (Alternate)
Ben Becker, National Park Service (Alternate)

Technical Advisory Committee

Sarah Allen, Ocean and Coastal Resources Program, National Park Service
Victor Bjelajac, Maintenance Chief, Marin District, California State Parks
Julia Biggar, Associate Transportation Planner, CA Department of Transportation
Chris DeGabriele, General Manager, North Marin Water District
Kelsey Ducklow, Local Coastal Program Grant Manager, California Coastal Commission
Lesley Ewing, Senior Coastal Engineer, California Coastal Commission
Shannon Fiala, Coastal Planner, CA Coastal Commission
Darren Fong, Aquatic Ecologist, Golden Gate National Recreation Area
Ursula Hanks, Emergency Services Coordinator, Marin County Office of Emergency Services
Chris Kelley, Wastewater Inspector, Stinson Beach Water District
Neysa King, Watershed Coordinator, Tomales Bay Watershed Council
Roger Leventhal, Senior Engineer, Marin County Department of Public Works
Scott McMorrow, General Manager/Board President, Inverness Public Utility District
Kelsey Ducklow, Local Coastal Program Grant Manager, California Coastal Commission
Craig Richardson, Open Space Planner, Marin County Parks and Open Space
Nancy Scolari, Executive Director, Marin County Resource Conservation District

ACKNOWLEDGEMENTS

Ed Schmidt, General Manager/Secretary to the Board, Stinson Beach County Water District
Justin Semion, Aquatic Ecologist, WRA Environmental Consultants
Jack Siedman, Board President, Bolinas Community Public Utility District
Anita Tyrrell-Brown, Fire Chief, Bolinas Fire Protection District
Kristen Ward, Wetland Ecologist, Golden Gate National Recreation Area

Project Partners

Greater Farallones National Marine Sanctuary
United States Geological Survey
Point Blue Conservation Science
Coravai
Center for Ocean Solutions

Additional Advisors

Federal Emergency Management Agency (FEMA)
National Oceanic and Atmospheric Administration (NOAA)
Local and neighboring county experts

Volunteer Facilitators

Leslie Alden
Dana Armanino
Yanna Badet
Patricia Basset
Amy Brown
Brian Crawford
Kellen Dammann
Jocelyn Drake
Kristin Drumm
Christine Gimmler
Shelley Ingram
Tom Lai
Vivian Lo
Vicki Nichols
Maureen Parton
Marina Psaros
Heidi Scoble
Tammy Taylor
Jeremy Tejirian
Sandy Wallenstein

Additional Peer Reviewers

Rochelle Eremen, Marin County Health and Human Services

Other Participants

Audubon Canyon Ranch
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EXECUTIVE SUMMARY

Executive Summary

Sea level in the San Francisco Bay Area has risen eight inches in the past century, and could rise up to 70 inches by the end of the century.[1,2] Marin's coastline is vulnerable to sea level rise and changing storm patterns that accompany climate change. With over one-quarter of Marin County properties and hundreds of natural and community assets threatened by sea level rise along the coast, Marin County is engaging in the critical task of assessing these threats and planning how to prepare for, or adapt, to these changing conditions.

Inaccessible beach access during King Tide. Credit CDA

Led by the Marin County Community Development Agency, Collaboration: Sea-level Marin Adaptation Response Team (C-SMART) began in July 2014 with financial support from the California Ocean Protection Council (OPC) and the California Coastal Commission (CCC). Project partners include the Greater Farallones National Marine Sanctuary (GFNMS), United States Geological Survey (USGS), Point Blue Conservation Science, Coravai, Center for Ocean Solutions, and Marin County Department of Public Works (DPW). The technical advisory committee includes staff from local, state, and federal agencies, and the stakeholder advisory committee includes representatives from Marin's coastal communities.

An important outcome of the C-SMART process will be an amendment to the Local Coastal Program (LCP), a planning tool used by the County of Marin, in partnership with the Coastal Commission, to guide development and protection of resources in the Coastal Zone. Policies implemented through the LCP will help ensure adaptation occurs in a way that protects coastal resources, public safety, and continued public access to recreational areas.

This Vulnerability Assessment for Marin County's ocean coast presents asset profiles describing the vulnerability of parcels and buildings, transportation networks, utilities, working lands, natural resources, recreational activities, emergency services, and historic and archaeological resources; and community profiles highlighting vulnerable assets in Muir Beach, Stinson Beach, Bolinas, Inverness, Pt. Reyes Station, East Shore, and Dillon Beach (includes north of Dillon Beach to the county line). Each profile details key issues, geographic locations, existing policies, and other economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be independently of the others to enable asset managers to focus on their professional area, and community members, elected officials, and others to read the results for a community as a whole.

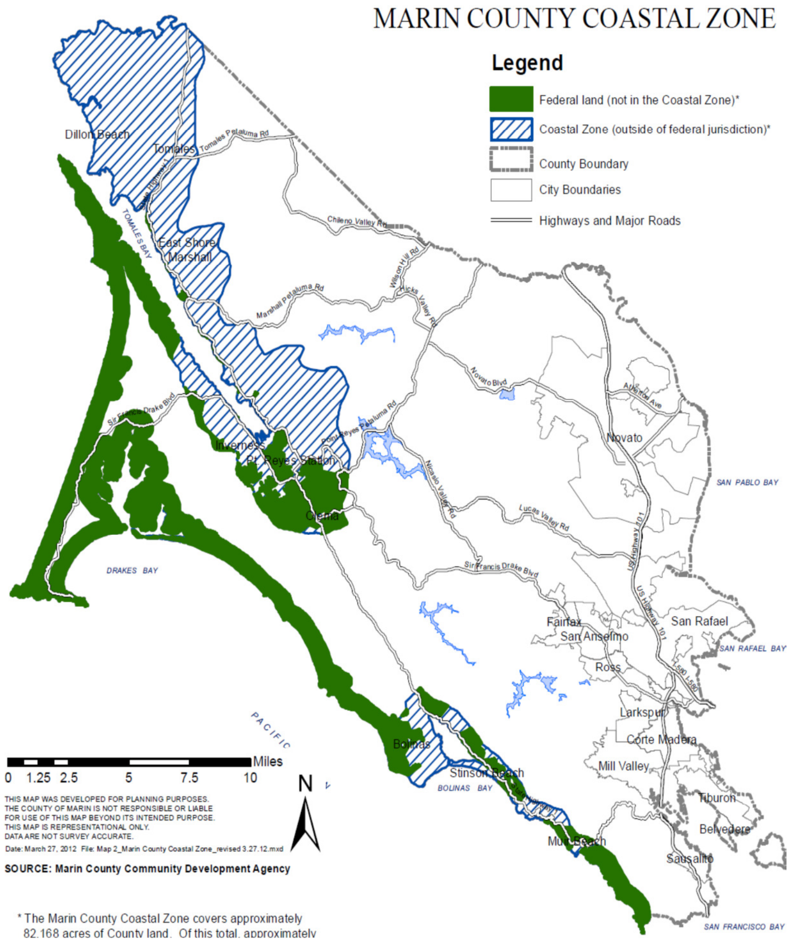
[1] Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present and Future. National Research Council (NRC), 2012.

[2] Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate. Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters.

EXECUTIVE SUMMARY

Map 1. Study Area

The Marin County Coastal Zone covers approximately 82,168 acres. Of this, approximately 33,913 acres are owned and managed by the National Park Service, leaving 48,255 acres of the Coastal Zone under County jurisdiction [Pursuant to the Federal Coastal Zone Management Act of 1972 (16 U.S.C. 1451, et seq.)]



IMPORTANT: *This Vulnerability Assessment is advisory and not a regulatory or legal standard of review for actions that the Marin County government or CA Coastal Commission may take under the Coastal Act. This assessment provides the best available science, and is part of an ongoing process to understand and prepare for sea level rise.*

Vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to rising waters and storm threats. If an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity, the asset is considered vulnerable. The project team interviewed asset managers using the "Asset Vulnerability Assessment Tool" to assess built and natural resource assets. The interview results were combined with geographic data and citizen input gathered during public workshops to develop the Vulnerability Assessment.

Table 1 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, Marin County used a scenario-based approach to assess a range of potential sea level rise impacts. The five scenarios selected for this

EXECUTIVE SUMMARY

Vulnerability Assessment are derived from the U.S. Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) that combines global climate and wave models with projected sea level rise to identify areas that could be flooded across 10 different sea levels (ranging from 0 to 200 inches) and 4 storm severities (none, annual, 20-, 100-year storms) to total 40 scenarios. All of these scenarios are available on the Our Coast Our Future (OCOF) website.

Table 1. Sea Level Rise Projections for San Francisco, CA Region

Time Period	Projected Range
by 2030	1.6 – 11.8 inches
by 2050	4.7 – 24 inches
by 2100	16.6 – 65.8 inches

Source: NRC 2012

Table 2. C-SMART Sea Level Rise & Storms Scenarios

Sea Level Rise Scenario		Term
1	10 inches+Annual Storm	Near
2	10 inches+20-year Storm	Near
3	20 inches+20-year Storm	Medium
4	40 inches+100-year Storm	Long- Low
5	80 inches+100-year Storm[3]	Long- High

The key findings of this assessment are based on five the sea level and storm combinations in Table 2 representing near-term, medium-term, and long-term futures. Scenarios 1 and 2 represent the near-term, and correspond to the 2030 NRC projected sea level range. Scenario 3 is considered medium-term and is within the 2050 NRC range. Scenarios 4 and 5 represent the long-term. Scenario 4 corresponds to the 2100 NRC range, and Scenario 5 represents levels based on additional research theorizing the worst case for sea level rise by 2100 is nearing 70 inches globally,[4] with the most reflective CoSMoS option of 200 centimeters, or 77 inches, and is referenced as 80 inches in this assessment.

[3] The upper limit for 2100, scenario 5, was selected based on: *Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate.* Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters. The article calculate 70 inches. In the scenario options, 80 inches (rounded up from 77 inches) is the closest option.

[4] Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate. Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters.

EXECUTIVE SUMMARY

King tides provide a preview of future water levels. Brighton Road, Bolinas King Tide 7.3 foot 8:52 a.m., Dec. 12, 2012. Credit : K. Moor

Key Findings

In the coastal zone, over 10 percent of buildings are vulnerable at the low end of the long-term scenario (scenario 4, 40 inches with a 100-year storm), and 20 percent are vulnerable at the high end of the long-term scenario (scenario 5, 80 inches with a 100-year storm). These buildings are concentrated in the Calles and Patios neighborhoods, Downtown Bolinas, and the Tomales Bay shorelines in Inverness and East Shore (Marshall). On the East Shore, 90 to 100 percent of commercial, and 78 to 84 percent of residential parcels are vulnerable in the medium-term and high-end of the long-term respectively- the majority of buildings on along the eastern shore of Tomales Bay. In Bolinas, 27 to 87 percent of commercial properties are vulnerable in the medium-term and high end of the long-term respectively, including both resident and visitor services. In Stinson Beach, nearly 70 percent of residential parcels are vulnerable in medium-term and onward.

Nearly twenty miles of public and private roadways could be compromised. Roadways exposed in short-term include Shoreline Highway between Bolinas and Stinson (20 percent compromised in Coastal Zone), Calle del Arroyo, all private Calles and Patios streets, Wharf Road., and several creek crossings and bridges. Other low-lying portions of Shoreline Highway, several local roads, and Sir Francis Drake Blvd. (17 percent compromised) are vulnerable in long-term. Coastal communities also rely on vulnerable septic systems, water supply systems, and shared septic or sewerage systems that could be vulnerable to sea level rise and storms. Roadways and utilities are lynch pin assets, such that their dysfunction or destruction will have negative consequences for nearly all other built assets.

Overall, in their current conditions, the most vulnerable coastal Marin assets, in order of onset and flood depth, are:

- Near-term (scenarios 1 & 2)
  - Beaches, underground on-site wastewater treatment systems (OWTS), buildings, and streets in Stinson Beach west of Shoreline Highway.
  - Shoreline Highway between Stinson Beach and Bolinas, at Green Bridge over Lagunitas Creek in Pt. Reyes Station, the Walker Creek crossing in Marshall, and bridges on Middle Road and Valley Ford Lincoln School Road.
  - Beaches and beach front and downtown buildings and streets in Bolinas.
  - Septic systems, beaches, marshes, and buildings along the eastern and western shores of Tomales Bay.
  - The water distribution pipe underneath Shoreline Highway and Sir Francis Drake Boulevard serving many Inverness residents.
  - Intertidal rocky lands in Muir Beach and (Duxbury Reef) in Bolinas.
  - Fire service facilities and tsunami evacuation routes in Stinson Beach.
  - Recreational facilities at Dillon Beach Resort and Lawson's Landing.
  - Blufftop buildings in Muir Beach, Bolinas, and Dillon Beach may be vulnerable to accelerated erosion.
- Medium-term (scenario 3)
  - Olema-Bolinas Road, which is the only road to Bolinas.
  - Additional buildings and streets in downtown Bolinas, including the historic district.
  - Bolinas Public Utilities District lift station at the end of Wharf Road.
  - Shoreline Highway in Pt. Reyes Station and East Shore, and Sir Francis Drake Blvd. in Inverness.
- Long-term (scenarios 4 & 5)
  - Shoreline Highway along the East Shore.
  - Buildings in Inverness west of Sir Francis Drake Blvd.
  - Downtown Bolinas up to Brighton Road, including the market, library, community center, gas station, museum, and other valued places.

Assets

Parcels & Buildings

Almost all buildings along Marin's ocean coast are vulnerable to storms; however, factors such as construction materials, low elevation near the coast, and location over or directly bordering waterways (Inverness, East Shore, and Bolinas) can impact an individual buildings vulnerability to sea level rise and storms. In the long-term, approximately 1,300 parcels (25 percent of total in coastal zone) and 1,100 buildings (18 percent of total) could be exposed to sea level rise and storms. Approximately 70 percent of the affected buildings are residential. Erosion associated with high sea levels could also impair nearly 450 bluff top buildings in the coastal communities of Muir Beach, Stinson Beach, Bolinas, and Dillon Beach.

The communities of Stinson Beach and East Shore contain the highest percentages of vulnerable properties on Marin's ocean coast. In every scenario, Stinson Beach has a relatively high number of buildings exposed to sea level rise and storms, ranging from 15 percent in scenario 1 to 60 percent in scenario 5, with the most vulnerable buildings in the low-lying Calles neighborhood. For the East Shore, in the near-term, 49 percent of homes and 90 percent of commercial buildings may be exposed to sea level rise and storms. In the long-term, 84 percent of homes and 100 percent of commercial buildings could be exposed. While Bolinas has a smaller overall portion of its building stock at risk, a majority of downtown properties are exposed to sea level and several more are vulnerable to bluff erosion.

In addition to structural threats, non-structural components, such as mechanical and utility systems, at or below grade also influence a building's vulnerability. Damage to and malfunction of these systems may render a building unusable before its structure is exposed. In addition, oceanfront and bluff properties are also subject to erosion. Finally, properties completely untouched by rising ocean water could still become isolated and cut off from essential services due to compromised access routes, utilities, civic facilities, and more. This is especially a concern in Bolinas and Inverness, where thousands of households could be isolated while high and dry.

Transportation: Roads & Waterways

Transportation network disruptions would negatively impact daily life, access to goods and services, recreation opportunities, safety, and economic viability of coastal communities. Low-lying roads in Marin's coastal communities are already susceptible to flooding at high tides, especially king tides and storms. At worst, some roadways will see relatively chronic flooding and could lose their functionallity as the ocean rises. Postal service could be interrupted, schools closed down, and tourism capacity significantly reduced. Evacuation routes may be crowded or impassable, and emergency services may be unable to reach those in need.

In the near-term, approximately 2.5 miles of roads concentrated in or near Stinson Beach, may be exposed to sea level rise and storm flooding. In the medium-term, 5.2 miles may be exposed, including additional roadways in Bolinas. In both long-term scenarios, approximately 20 miles of road segments, or 7 percent of total miles across all of the communities assessed could be exposed to sea level rise and storm threats. Roads of greatest concern are Shoreline Highway, Sir Francis Drake Boulevard, Calle del Arroyo, Wharf Road, and Olema-Bolinas Road. These major roads are exposed at several places along their route. This vulnerability is exacerbated by the low density of roads and lack of alternative routes. Additionally, roads along or crossing creeks, such as Easkoot, Keys, Walker, Lagunitas, and others, experience fluvial (land-based) flooding during storms.

Parking areas can tolerate temporary flooding; however, permanent loss could reduce visitor and residential parking capacity. Increased temporary flooding could increase maintenance needs. Public transit services could be interrupted; impacting residents, visitors, and businesses.

Water travel infrastructure is physically integrated with the ocean and will likely see changing conditions warranting adaptation measures. Key locations include Bolinas Lagoon, and boat launches along Tomales Bay. While water travel has high adaptive capacity to sea level rise, boats and boat lauches, marinas, and piers could see significant damage from storms.

Utilities: Water, Wastewater, Gas, Electricity, & Telecommunications

Electricity, propane procurement, water supply, and wastewater removal are essential for habitable buildings. In addition, other utilities, such as telecommunications and stormwater infrastructure, greatly contribute to the usefulness of a building or property.

Potable water distribution lines are vulnerable in Stinson Beach west of Shoreline Highway, downtown, Little Mesa, and Big Mesa in Bolinas, and Inverness. Dillon Beach has a pump station and water collection pond near the Estero and a community well near Tomales Bay at Dillon Creek that are vulnerable. Wells and private springs along the East Shore may be impacted in the near-term. A public NMWD well in Pt. Reyes Station along Lagunitas Creek may be vulnerable to saltwater intrusion in the long-term.

Gravity-fed OWTS in Stinson Beach, Inverness, and East Shore are vulnerable to inundation and erosion, and escaping effluent could pollute surrounding ocean and freshwater resources. In Dillon Beach, the Oceana Marin lift station could be susceptible to increased erosion rates. Downtown Bolinas depends on a gravity-fed lift station that is also vulnerable to long-term sea level rise.

Propane tanks are stored outside and are typically at or slightly above grade, making them highly vulnerable to sea level rise and storm impacts. In addition to propane, one automotive gas station is vulnerable in downtown Bolinas. No major electrical or telecommunication assets are vulnerable. However, several government facilities, such as the Bolinas lift station and

Inverness Fire Department, use back-up generators that may need to be further elevated. Communication cables under the roads may be impacted by erosion. Finally, sediment build-up and higher sea levels can block stormwater drainage through outfalls or culverts, for example around Bolinas Lagoon, causing localized stormwater flooding that can also weaken the road.

Working Lands: Agriculture and Aquaculture

Loss of vehicular access to working lands on a temporary and permanent basis threatens the viability of agricultural operations. This is especially the case north of Dillon Beach and along the East Shore where creek crossings are vulnerable on Middle and Franklin Valley School Roads, and along Shoreline Highway. In the long-term scenario, approximately 457 acres on 45 agricultural parcels are exposed to sea level rise and storm conditions. Exposed agricultural parcels are concentrated north of Point Reyes Station, with the exception of the Green Gulch Zen Center organic farm near Muir Beach and lagoon side fields in Bolinas. Land-based operations on the coast face saltwater intrusion and erosion, and will likely need to adjust highly regulated management plans. Parcels further inland and along streams can also be exposed during high tides that push brackish conditions upstream and further out on the land, reducing grazing acreage.

Aquaculture operations' buildings on the shoreline are vulnerable and as tides push landward, aquaculture operations may need to adjust their harvesting practices for higher tides. These operations, and others, could see declines in their on-site customers as road access is compromised. In the water, fishing vessels will face new challenges and may need to adjust practices.

Natural Resources: Habitats & Wildlife

The inter-agency report *Climate Change Vulnerability Assessment for the North-central California Coast and Ocean* and consultant work from ESA identify beaches, estuaries, marshes, wetlands, and intertidal areas on the Marin coast as vulnerable to sea level rise and storms. Nearly all beaches in the study area, except Dillon Beach and the federal portion of Stinson Beach, could be lost entirely in the long-term. Roughly 9,000 acres in the estuaries of Tomales Bay, Bolinas Lagoon, and Esteros Americano and San Antonio, 1,800 acres of wetlands and marshlands could be impacted to varying degrees across all of the scenarios in all of the communities. Sea level rise may push coastal habitats inland where possible, flooding tidal areas more frequently and new inland areas with saltwater. The *North-central California Coast and Ocean Vulnerability Assessment* identified the five most vulnerable species to sea level rise are the Western snowy plover, black oystercatcher, black rail, California mussel, and red abalone.

Recreation (Public Access)

Inundation and erosion of the beaches, estuaries, and marine wetlands and marshes mentioned above would alter recreational opportunities significantly. Flooding of Shoreline Highway, Sir Francis Drake Boulevard, and others could limit access to West Marin's natural resource attractions and have negative consequences on the regional economy and sense of place.

Historic & Archaeological Resources

Bolinas, Inverness, and Marshall (East Shore) contain historic districts that could be exposed to sea level rise and storms. In addition to physical impacts, exposure of historic sites can lead to irreplaceable loss of cultural heritage. Archaeological resources are prevalent in West Marin and, in some cases, are already showing impacts of erosion. Efforts are underway to inventory all of the archaeological sites in West Marin.

Communities

Muir Beach

Access to homes and recreational areas in this small community could be compromised by flooding on Pacific Way in the long-term scenario. The emergency route from the Muir Beach public area through the Green Gulch Zen Center could also be flooded in the long-term, especially combined with creek flooding. Despite little flooding impacts, over 50 homes on the blufftops could be impacted by increased erosion associated with sea level rise.

Stinson Beach

Stinson Beach's built assets most vulnerable to sea level rise and erosion include water distribution pipes, OWTSs, buildings west of Shoreline Highway, local roads including Shoreline Highway and Calle del Arroyo, the water district office, and Fire Station No. 2. Nearly $200 million of assessed value and $1.5 billion in market value in properties could be exposed in the long-term scenario. The beaches at Stinson are also highly vulnerable, as are the marshlands associated with Bolinas Lagoon. Erosion could force beach and dune habitats inland; however where development abuts the beach in the Calles, Patios, and Seadrift neighborhoods, the beach could disappear by the end of the century. Flooding from Bolinas Lagoon and Easkoot Creek already occur and will likely worsen.

Bolinas

The most vulnerable built assets in Bolinas are the Bolinas Wye, Bolinas-Olema Road, Gospel Flats homes, downtown buildings and roads, and over 200 homes above eroding cliffs along Terrace Avenue on the Big Mesa, Little Mesa, and Surfer's Overlook.

If Bolinas-Olema Road or its creek spanning bridges become dysfunctional for extended period of time, Bolinas residents will be cut off from the rest of the coast, and from propane, food, and gasoline suppliers. Over $18 million worth of assessed property value is vulnerable, including several historic locations downtown. The most vulnerable buildings are those directly above the lagoon on piers along Wharf Road.

With respect to wastewater removal, the most vulnerable asset is the lift station that serves Downtown and the Little Mesa. Small scale agriculture in Gospel Flats is threatened, as protective earthen berms could fail under sea level rise conditions. Brighton and Agate beaches could disappear by mid-century because they are backed by development or bluffs. Increased tidal inundation of Bolinas Lagoon will affect plant and animal species, though could improve sediment concentrations. However, the lagoon is bordered by roads and development, leaving little room for migration inland. If water levels raise high enough, the lagoon with convert to mud flats and could overtop the surrounding roadways and properties.

Inverness

Inverness's most vulnerable built assets include Sir Francis Drake Blvd., water distribution pipelines beneath Sir Francis Drake Blvd., and a number of shoreline developments of economic, civic, recreational, and/or historical value. Over $11 million of assessed value in buildings could be vulnerable. Inverness residents depend on private and individual propane service and could be cut off from supply if Sir Francis Drake Blvd. is compromised for an extended period. Tomales Bay, Tomales Bay State Park, Martinelli Park, and Shell Beach are also vulnerable. With rising waters these sites may shrink and could disappear altogether. Loss of these access points could make recreation much more difficult.

Pt. Reyes Station

Pt. Reyes Station's most vulnerable built assets include NMWD water distribution pipelines (primarily serves Inverness residents) beneath Sir Francis Drake Blvd. and Shoreline Highway, Shoreline Highway at and south of Green Bridge, and the surrounding the wetlands and marshes. Wetlands and marshes are popular visitor attractions in this area that could be degraded. Olema Marsh and Giacomini Wetlands are large marshes in Marin County that support habitat for a variety of bird species. Though high adaptive capacity is anticipated, degradation of these resources could have negative impacts on Pt. Reyes Station and surrounding ecological communities.

East Shore

The East Shore's most vulnerable assets include Shoreline Highway, development, private wells, OWTSs, aquaculture facilities and a number of recreation assets including the Marconi Boat Launch, Tony's Restaurant, and the Inn at Tomales Bay west of Shoreline Highway.

Shoreline Highway, parallel to Tomales Bay, is exposed to potential flooding at the baseline scenario near creek crossings. This would cut off southern access to Marshall, leading to potential economic, quality of life, sense of place, and emergency access impacts to locals and visitors alike. When overflowing its banks onto Shoreline Highway, Walker Creek can be a north-south ground transportation access barrier.

Moreover, septic systems near the shoreline and connections to wastewater leach fields east of Shoreline Highway are vulnerable and could lead to water resource contamination. Aquaculture operations land based facilities in Tomales Bay are vulnerable, as are Keys Creek Fishing Area, Miller Boat Launch, Marconi Boat Launch, and Millerton Point. Marshes and beaches along the shoreline are also vulnerable because they are already narrow and often backed by bluffs, the roadway, or buildings.

Dillon Beach

Dillon Beach's most vulnerable assets include its centralized Oceana Marin sewer system, Bay Drive, which connects Lawson's Landing to the rest of the community, recreational assets including Dillon Beach Resort and Lawson's Landing facilities, grazing lands, and the nearby Estero Americano and Stemple Creek Recreation Areas. Further north, a few bridges along Middle Road and Valley Ford Franklin School Road could flood and prevent continuous ground transportation. Moreover, over 100 homes on the bluff tops could be impacted by increased erosion associated with sea level rise.

Maps for these assets and areas are provided in the asset and community profiles. The maps are also available on Marin Sea Level Rise Website.

INTRODUCTION

Introduction

Climate change is affecting natural and built systems around the world, including the California coast. In the past century, average global temperature has increased about 1.4°F, and average global sea level has increased 7 to 8 inches.[5] Sea level at the San Francisco tide gauge has risen 8 inches over the past century, and the National Research Council (NRC) projects that by 2100, sea level in California south of Cape Mendocino may rise 66 inches.[6] Recent research shows that in the worst case scenario, sea level could rise 70 inches by 2100.[7] The two major causes of global sea level rise are thermal expansion of warming oceans and the melting of land-based glaciers and polar ice caps.[8]

While Marin's ocean coast regularly experiences erosion, flooding, and significant storm events, sea level rise will exacerbate these natural processes, leading to significant social, environmental, and economic impacts. The third National Climate Assessment cites strong evidence showing that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.[9] Therefore, it is critically important that Marin County plan and prepare for the impacts of sea level rise to ensure a resilient coast for present and future generations.

[5] Heberger, M., Cooley, H., Moore, E. and Herrera, P. 2012 The Pacific Institute.. *The Impacts of Sea Level Rise on the San Francisco Bay*. California Energy Commission. Publication number: CEC-500-2012-014.

[6] *Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present and Future.* National Research Council (NRC), 2012.

[7] *Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate.* Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters.

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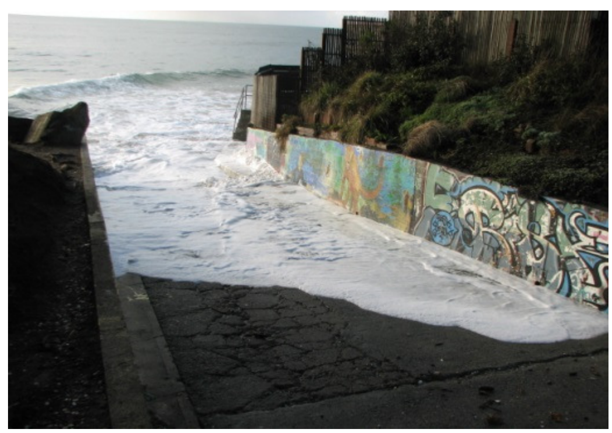
[9] Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014: Ch. 25: *Coastal Zone Development and Ecosystems. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, , 579-618. doi:10.7930/J0MS3QNW. http://nca2014.globalchange.gov/report/regions/coasts

This publication presents Collaboration: Sea-level Marin Adaptation Response Team's (C-SMART) Marin Coast Sea Level Rise Vulnerability Assessment for the built and natural assets according to available science and data resources. The goals of this coastal assessment are to provide localized information about sea level rise and its associated flood threats and to characterize in what ways the built and natural resources are vulnerable to sea level rise.

The Assessment was performed by the Marin County Community Development Agency (CDA), with funding support from the California Ocean Protection Council (OPC) and the California Coastal Commission (CCC). Project partners include the Greater Farallones National Marine Sanctuary (GFNMS), United States Geological Survey (USGS), Point Blue Conservation Science, Coravai, Center for Ocean Solutions, and Marin County Department of Public Works (DPW). The technical advisory committee includes staff from local, state, and federal agencies, and the stakeholder advisory committee includes representatives from Marin's coastal communities.



King tides give a preview of future water level. Brighton Road, Bolinas. King Tide 7.3 foot. 9 a.m., Dec. 12, 2012. Credit: K. N. Moor

INTRODUCTION

This Vulnerability Assessment is advisory and not a regulatory document or legal standard of review for actions Marin County government or California Coastal Commission may take under the Coastal Act. Such actions are subject to the applicable requirements of the Coastal Act, the federal Coastal Zone Management Act, certified Local Coastal Program (LCP), and other applicable laws and regulations as applied in the context of the evidence in the record for that action. This Assessment will inform the Marin County LCP Amendment, and is part of an ongoing scientific and public process to understand and prepare for the impacts of sea level rise.

Marin County has had a focus on sea level rise planning and climate action for several years. The County is updating its Local Coastal Program (LCP) to reflect the changing risks to its coastal areas and to develop appropriate policies and actions to avoid and minimize the risk of disaster and harm to its residents, infrastructure, and coastal resources. *Policy C-EH-22 Sea Level Rise and Marin's Coast* states "the best available and most recent scientific information with respect to the effects of long-range sea level rise shall be considered in the preparation of findings and recommendations for all geologic, geotechnical, hydrologic and engineering investigations, including the coastal hazards analysis identified in C-EH-5 (New Shoreline and Blufftop Development). Support scientific studies that increase and refine the body of knowledge regarding potential sea level rise in Marin, and possible responses to it." To fulfill these policies, this assessment summarizes and applies the best available sea level rise science to Marin's coast.

The California Coastal Commission recently adopted policy guidance on how to assess and address sea level rise risks in local communities.[10] While only advisory, the guidance includes steps for addressing sea level rise in Local Coastal Programs, including choosing a range of sea level rise projections, identifying potential impacts, assessing risks to coastal resources and development, identifying adaptation measures and LCP policy options, drafting updated or new LCP policies for certification with the Coastal Commission, implementing the updated LCP, and monitoring and revising the LCP as needed. The County's assessment is in accordance with the Commission's Guidance, is consistent with planning standards used in hazards mitigation planning, and is submitted in partial fulfillment of the required information for an LCP update.

The LCP regulates lands in the Coastal Zone (see Map 2. Study Area) as defined under California Law. This zone serves as the study area boundary for this assessment. The communities most likely to see sea level rise and storm impacts in this century within the Coastal Zone are low-lying areas in Muir Beach, Stinson Beach, Bolinas, Inverness, Point Reyes Station, East Shore, and Dillon Beach. Inland or higher up areas are also vulnerable to erosion or lack of vehicular access in Bolinas, Inverness, and Stinson Beach. Olema and Tomales are not likely to see direct sea level rise threats because of their inland geography.[11] Note that while on the Marin County coast, the Point Reyes National Seashore, and Golden Gate National Recreation Area, including the Marin Headlands, and portions of Muir Beach and Stinson Beach, are under Federal jurisdiction and, therefore, not the focus of this assessment. A separate assessment for the Federal Parks can be found at http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm.

[10] California Coastal Commission. August 12, 2015. *California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for addressing Sea Level Rise in Local Coastal Programs and Coastal Development.*. http://www.coastal.ca.gov/climate/slrguidance.html

[11] http://cal-adapt.org/sealevel/ Cal Adapt Sea Level Rise Threatened Areas Map

INTRODUCTION

Map 2. Study Area

The Marin County Coastal Zone covers approximately 82,168 acres. Of this, approximately 33,913 acres are owned and managed by the National Park Service, leaving 48,255 acres of the Coastal Zone under County jurisdiction [Pursuant to the Federal Coastal Zone Management Act of 1972 (16 U.S.C. 1451, et seq.)]

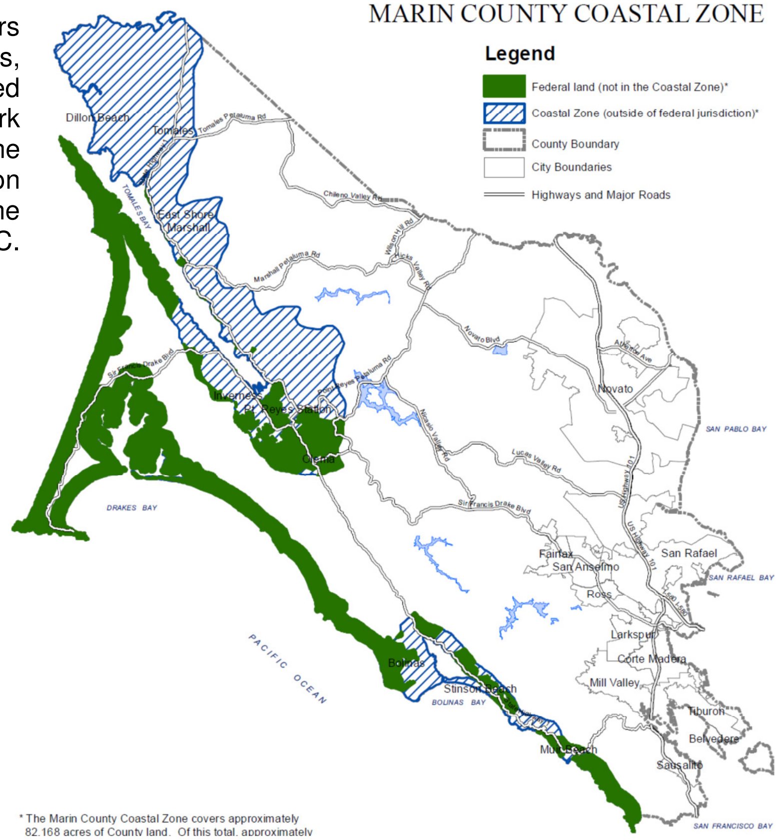
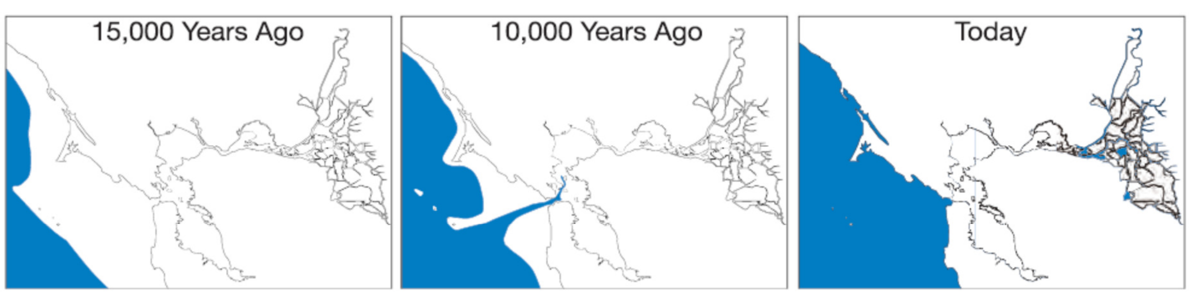


Figure 1. Historic Coastline Image Series



Cohen and Laws (2000)[12]

[12] Cohen, A. and J. Laws. 2000. *An introduction to the San Francisco Estuary*. San Francisco Estuary Project, Save the Bay, and San Francisco Estuary institute.

INTRODUCTION

This Assessment is organized into three major sections: (1) Marin County Context and Methodology, (2) Asset Profiles, and (3) Community Profiles. The first section details the background science and research methods used in the Marin County C-SMART process. Asset Profiles highlight the vulnerable assets coastal residents, employees, and visitors depend on, such as buildings, roads, drinking water access, septic, and others. The last major section details all asset vulnerabilities for the communities of Muir Beach, Stinson Beach, Bolinas, Inverness, Point Reyes Station, East Shore (Marshall), and Dillon Beach. profile details key issues, geographic locations, existing policies, and other economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be independently of the others to enable asset managers to focus on their professional area, and community members, elected officials, and others to read the results for a community as a whole. The appendices provide background on community workshops, vulnerability analysis, and other research.

The Vulnerability Assessment analyzed nearly 200 exposed assets identified at community workshops (see Appendix A for methods and workshop details) and several others contained in existing digital and paper data sources. Of these, assets deemed vulnerable will be carried over into the adaptation planning phase. Key findings across assets and communities include:

- Roads and utilities are lynch pin assets, such that if these are compromised, the functions of the buildings and people they serve, including those further inland and higher up, will be compromised also.
- Access along State Route 1 (Shoreline Hwy) in Stinson Beach, Bolinas, and several bridges in the near-term are of concern. Nearing the end of the century, flooding issues on Shoreline Highway along the East Shore, Sir Francis Drake between Pt. Reyes Station and Inverness, and the Olema-Bolinas Road could arise. Overall, 20 miles of public and private roadways in the Coastal Zone could be impacted. In addition, bayside access to and from the Marin Coast at the Manzanita Interchange of Highway 101 and State Route 1 could impact coastal residents.
- Several communities depend on on-site septic systems (Stinson Beach, East Shore), private wells (East Shore), public water (Stinson Beach, Inverness, Point Reyes Station, Dillon Beach), or public sewer (Dillon Beach) that are vulnerable to sea level rise and storms.
- Reductions in useable space for modern living, tourism, transportation, and natural resources could impact approximately 1,300 properties and over 1,100 buildings, 3,000 year-around residents, employees, and millions of visitors could have significant economic impacts locally and beyond.
- Wave, wind, and temporary flooding could account for $5 million to a quarter billion dollars in damages in every severe storm event.
- Physical and economic impacts will be felt differently across the various income and age groups, causing potential social and economic inequities.
- In California, tidelands (below the mean high water mark) and submerged lands are part of the public trust. As the sea level rises, additional private property could be subject to the Public Trust Doctrine and become Waters of the State.
- The most vulnerable habitats are beaches (including dunes), estuaries, and rocky intertidal.
- Marin is not self-contained and could feel impacts from changes in neighboring counties, such as Alameda County where the Port of Oakland receives imports and exports for the entire Bay Area and beyond, or flooding in low-lying areas in San Francisco and the East Bay that disrupt commuting and travel across the region and globe.
- Sea level rise is only one of several climate change impacts residents will likely face. Combined with typical hazards that already exist (liquefaction and ground shaking near fault lines, erodible soils, and storm flooding) the Marin Coast, and much of California, is more vulnerable than this assessment can fully describe. Interrelationships between these factors could impact real-world outcomes and should be monitored and studied moving forward.

This assessment is the first step in an iterative process that will need to be updated as additional science becomes available and adaptation efforts are implemented over the coming decades. The sea level rise preparation process will require consistent monitoring and evaluation to improve modeling assumptions and ensure preparation efforts are well targeted, efficient, and adequate.

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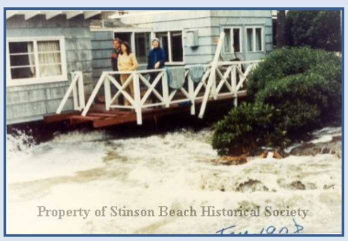
Coastal Flood History

West Marin is no stranger to storms, floods, erosion, and other disasters, and storms are anticipated to intensify with climate change. The Stinson Beach Historical Society's virtual exhibit with images and details of such disasters can be accessed at: http://stinsonbeachhistoricalsociety.org/collections/virtual_exhibits. Some of the most striking disasters are listed below.

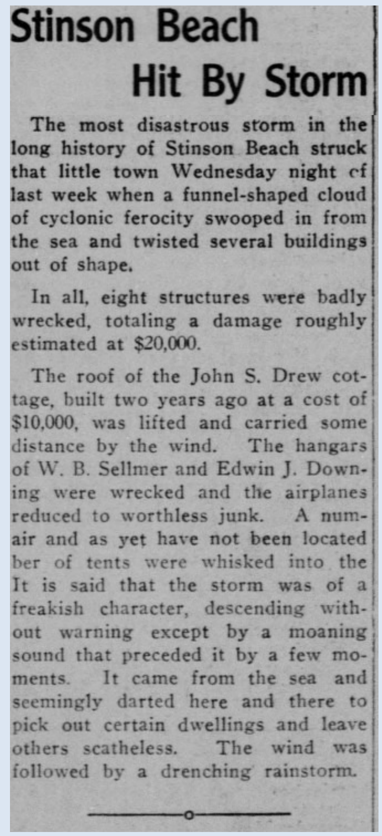
1956 Storm devastates the community, flooding Easkoot Creek, inundating the Hwy 1 bridge, and damaging the Calles neighborhood,. Resulting mudslides isolated Stinson Beach and neighboring Bolinas' streets were described as "rivers of mud."



1978 Storm with high tides and strong waves caused significant beach erosion and destroyed Stinson Beach homes . Some even washed property out to sea.

1982 Storm caused 12 inches of rain in 32 hours. Four residents died, more than 35 Marin homes were destroyed, and 2,900 damaged, totaling $80 million. Bolinas and Stinson Beach were isolated by mud, high water, rock slides, and washed out roads.

February 1922 (Marin Journal)



Stinson Beach Hit By Storm

The most disastrous storm in the long history of Stinson Beach struck that little town Wednesday night of last week when a funnel-shaped cloud of cyclonic ferocity swooped in from the sea and twisted several buildings out of shape.

In all, eight structures were badly wrecked, totaling a damage roughly estimated at $20,000.

The roof of the John S. Drew cottage, built two years ago at a cost of $10,000, was lifted and carried some distance by the wind. The hangars of W. B. Sellmer and Edwin J. Downing were wrecked and the airplanes reduced to worthless junk. A num- air and as yet have not been located ber of tents were whisked into the It is said that the storm was of a freakish character, descending without warning except by a moaning sound that preceded it by a few moments. It came from the sea and seemingly darted here and there to pick out certain dwellings and leave others scatheless. The wind was followed by a drenching rainstorm.

METHODS

Methodology

The C-SMART Vulnerability Assessment process (see Figure 2) is guided by CalAdapt[13] (see Figure 3) and provides background and analysis for individuals, communities, Marin County, and local and state agencies to use as a basis for deciding to accommodate or protect against rising waters, or retreat from hazard areas.

Figure 3. Vulnerability Assessment Phases (adapted from CalAdapt)

Phase 1| Exposure: Assess potential changes in water level from sea level rise, storm events, and geomorphic change, and the built and natural assets that could be impacted.

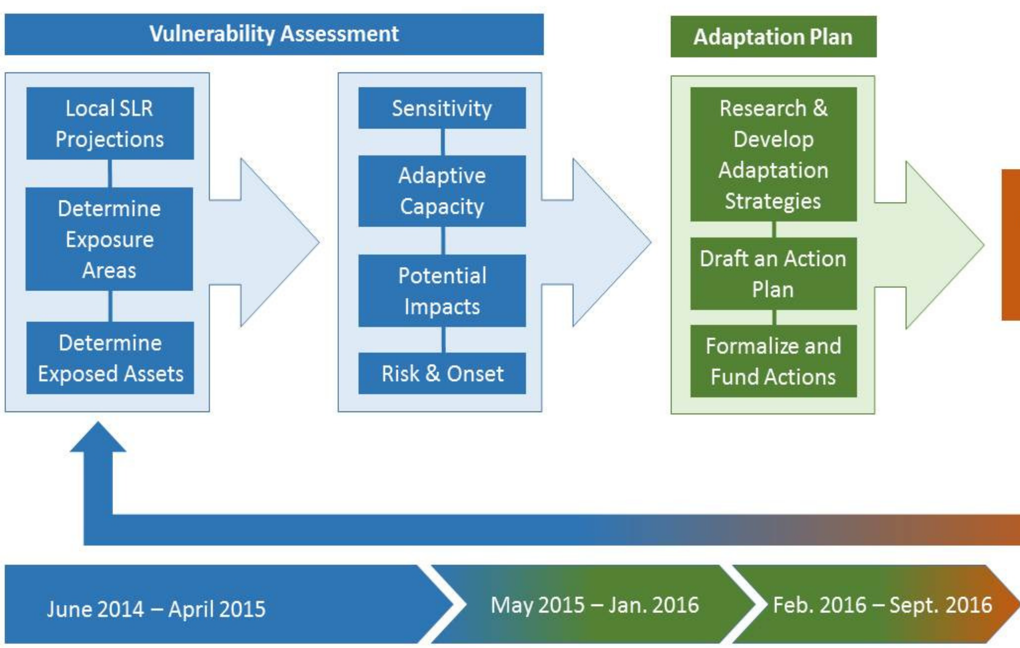
Phase 2| Sensitivity: Assess the degree of damage or disruption sea level rise and storms could cause on the exposed assets.

Phase 3| Adaptive Capacity: Assess each asset's adaptive capacity, or ability to respond successfully, to sea level rise and storms.

Phase 4| Potential Impacts: Evaluate the potential consequences to the assets and larger context, assuming no intervention actions.

Phase 5| Risk & Onset: Describe the certainty and timing of impacts.

Figure 2. C-SMART Process



[13] CA Emergency Management Agency, CA Natural Resource Agency. *California Climate Adaptation Planning Guide (APG).* July 2012. http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf

METHODS

Modeling Methods

Sea level rise estimates used in this analysis are from the Our Coast Our Future (OCOF) tool. OCOF was developed through a partnership of several notable institutions and agencies and represents the best available sea level rise and coastal storm science for the Bay Area Region and other parts of Coastal California. OCOF uses the USGS's Digital Elevation Model (DEM) constructed for the region (http://topotools.cr.usgs.gov/topobathy_viewer/) with 2-meter horizontal grid resolution and USGS's numerical modeling system called Coastal Storm Modeling System (CoSMoS) to produce a combination of 40 different sea level rise and storms scenarios. These scenarios include sea level rise, tides, storm surge, El Niño effects, wave set up, and wave run up. CoSMoS scales down global and regional climate and wave models to produce local hazard projections.[14] High quality elevation data incorporated in the DEM is used to create maps of mean higher high water (MHHW) tidal elevation plus sea level rise heights and provides the option to add storm impacts. Mean higher high water is the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.[15,16] Because the analysis uses high tide, properties exposed to MHHW, could be dry at lower tides.

Note that this tool only accounts for ocean levels and does not incorporate impacts from creek flooding or changes in the coast line (geomorphology) as erosion continues. The Stinson Beach profile is supplemented with analysis from a recent Department of Public Works study on Easkoot Creek and sea level rise; however, this analysis is not available for other creeks in the study area.

Table 3. Sea Level Rise Projections for San Francisco, CA Region

Time Period	Projected Range
by 2030	1.6 – 11.8 inches
by 2050	4.7 – 24 inches
by 2100	16.6 – 65.8 inches

Source: NRC 2012

Table 3 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, Marin County used a scenario-based approach to assess a range of potential sea level rise impacts. Assessing a range of scenarios provides a framework for analyzing the vulnerability of Marin's assets to sea level rise and storm scenarios. The five scenarios selected for this Vulnerability Assessment are derived from the U.S. Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS).

The C-SAMRT scenarios in Table 4 were selected based on geographic extent and variety of storm severity and when combined, cover the full range of impact to affected coastal communities by the end of the century. Scenarios 1 and 2 represent near-term, and correspond to the 2030 NRC projected sea level range. Scenario 3 is considered medium-term and is within the 2050 NRC range. Scenarios 4 and 5 represent the long-term. Scenario 4 corresponds to the 2100 NRC range, and Scenario 5 represents levels based on additional research theorizing the worst case for sea level rise by 2100 is nearing 70 inches globally,[17] with the most reflective OCOF option of 77 inches, rounded to 80 inches in this document.

Maps 3-9 show where the C-SMART scenarios overlap the coastal zone. Overall, the scenarios cover 4,690 acres in the Coastal Zone. Scenario 1 covers 1,681 acres, and scenarios 2-5, an

[14] Ballard, G., Barnard, P.L., Erikson, L., Fitzgibbon, M., Higgason, K., Psaros, M., Veloz, S., Wood, J. 2014. Our Coast Our Future (OCOF). [web application]. Petaluma, California. www.pointblue.org/ocof. (Accessed: Date August 2014]).

[15] National Tidal Datum Epoch is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal data.

[16] NOAA / National Ocean Service.. *Tidal Datums*. Access Oct. 19, 2015. Last updated: 10/15/2013 . Center for Operational Oceanographic Products and Services. https://tidesandcurrents.noaa.gov/datum_options.html.

[17] *Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate.* Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters.

additional 373, 381, 1,091, and 1,165 acres respectively.

Table 4. C-SMART Sea Level Rise & Storms Scenarios

Sea Level Rise Scenario		Term
1	10 inches + Annual Storm	Near
2	10 inches + 20-year Storm	Near
3	20 inches + 20-year Storm	Medium
4	40 inches + 100-year Storm	Long- Low
5	80 inches + 100-year Storm[18]	Long- High

The scenarios include storms because they have the potential to cause catastrophic damage and hazardous coastal conditions that could increase in geographic extent as sea levels rise. The storm frequencies presented in the scenarios in Table 3 are the annual, 20-year, and 100-year storms. An annual storm has a high likelihood of happening in most years. A 20-year storm has a five percent chance of happening annually. And a 100-year storm has one percent chance of happening in any given year. Within a 30-year mortgage, a 100-year storm has a nearly 30 percent chance of occurring. Note that there are also 200-year and 400-year floods (one-half percent probability of occurring each year, and one-quarter percent annual probability, and so on). The residual risk of flooding from these larger, less frequent floods is significant.[19]

Note also that different types of storms behave differently, leading to locations where a lower storm scenario out-floods a more intense storm scenario. This occurs because storms vary in wave patterns and angles. For example, the 100-year storm used in this model has higher wave heights offshore than the 20-year storm; however, the waves approach the coast from a more northerly direction. This difference in direction alters how the waves interact with the ocean bottom as they transit to shore and where wave energy is focused. Additionally, as waves change direction to approach the shore head on, energy and height is lost. This is especially common at southern-facing beaches of Muir Beach, Stinson Beach, and others at the Point Reyes National Seashore. This is called non progressive flooding. Another reason for non-progressive flooding is the complex nature of beach erosion simulated within CoSMoS. Each scenario used the same starting beach profile at specific locations along the coast and allowed to erode given wave height, length, and angle of approach at that location. This behavior is most notable during the stronger storm events (20-year and 100-year) when there is typically the greatest shoreline erosion.

In addition to flooding and storm impacts, communities may also be vulnerable to increased erosion. To assess this, accelerated rates incorporating higher sea levels were developed for each water level associated with the C-SMART scenarios. These estimates do not include the storm component, which would only exacerbate erosion rates. Bluff erosion areas were based on a baseline bluff edge and select sea level rise-accelerated cliff erosion rates from the OPC study (2009). Distances for erosion buffers for sea level rise-accelerated cliff erosion rates were calculated for near-, medium-, and long-term time horizons. To calculate the accelerated erosion rates, historic erosion rates were prorated a proportion of the relative increase in time the toe of a cliff is inundated by increasing wave run-up for higher sea levels (for more detail on methods see *California Coastal Erosion Response to Sea Level Rise Analysis and Mapping* report.[20] For beach erosion see "Additional Methods for the Natural Resource Profile." The computed accelerated bluff and shoreline erosion layers were overlaid with buildings, roads, and other vulnerable assets to determine if buildings, roads, and other vulnerable assets could be susceptible to erosion impacts.

[18] The upper limit for 2100, scenario 5, was selected based on: *Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate*. Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the journal Environmental Research Letters. The article calculate 70 inches. In the scenario options, 80 inches (rounded up from 77 inches) is the closest option.

[19] W. Eisenstein, M. Kondolf, and J. Cain. *ReEnvisioning the Delta: Alternative Futures for the Heart of California.* Department of Landscape Architecture and Environmental Planning. University of California, Berkeley. University of California Publishing Services. IURD report # WP-2007-01. http://landscape.ced.berkeley.edu/~delta

[20] Philip Williams & Associates, Ltd. March 11, 2009. *California Coastal Erosion Response to Sea Level Rise Analysis and Mapping.* Prepared for the Ocean Protection Council. PWA Ref. # 1939.00. San Francisco. Sacramento.

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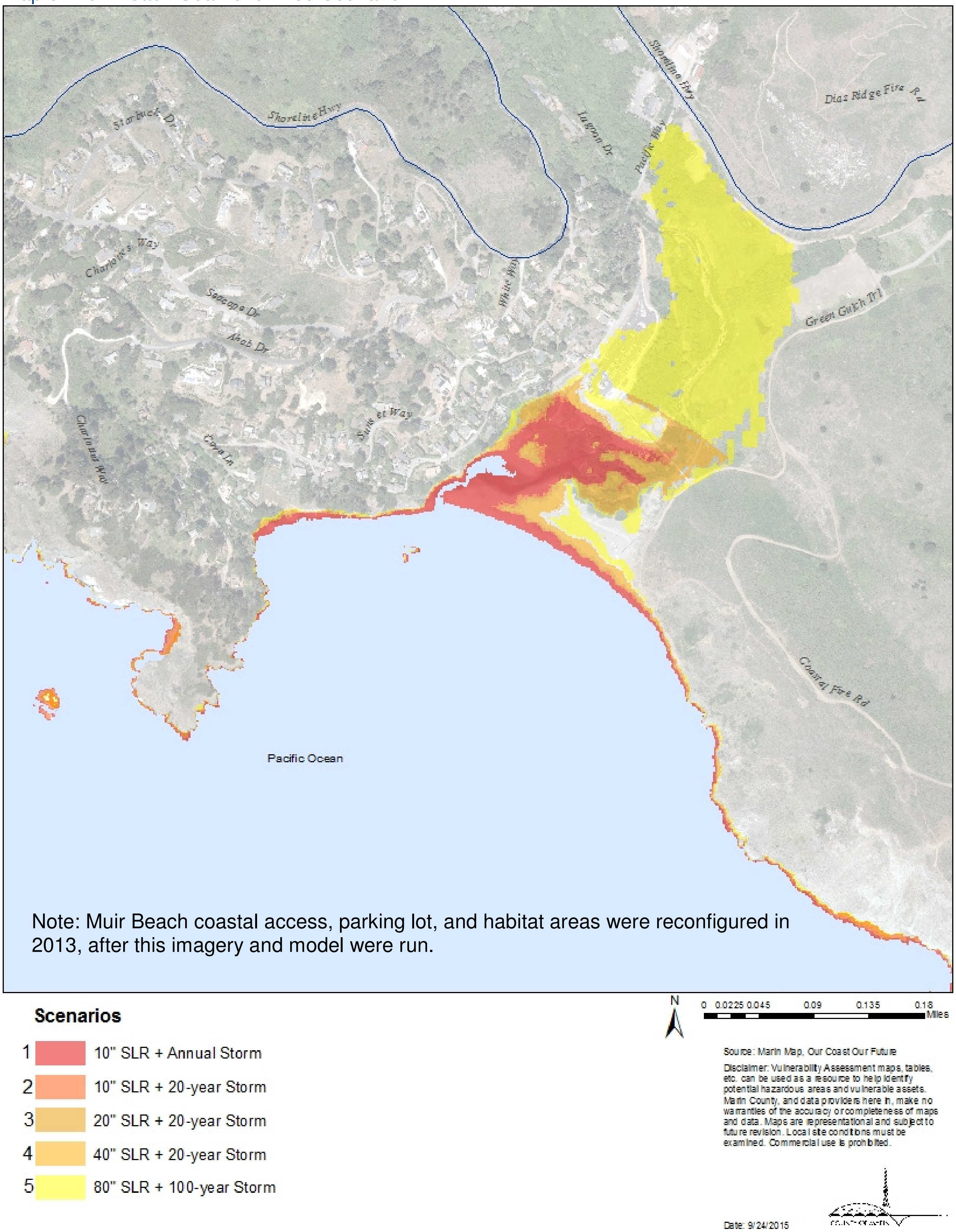
Map 3. Muir Beach Sea Level Rise Scenario



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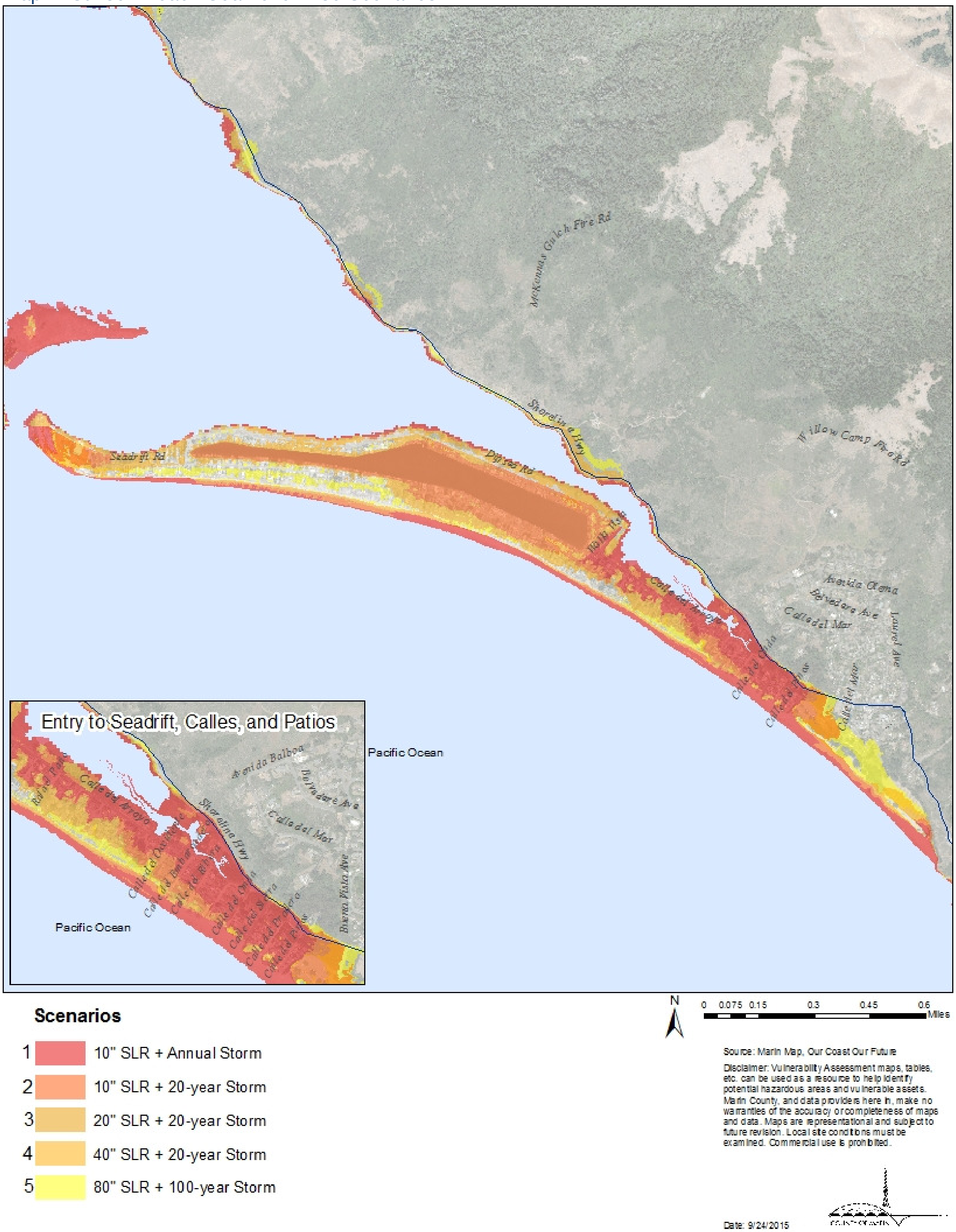
Map 4. Stinson Beach Sea Level Rise Scenarios



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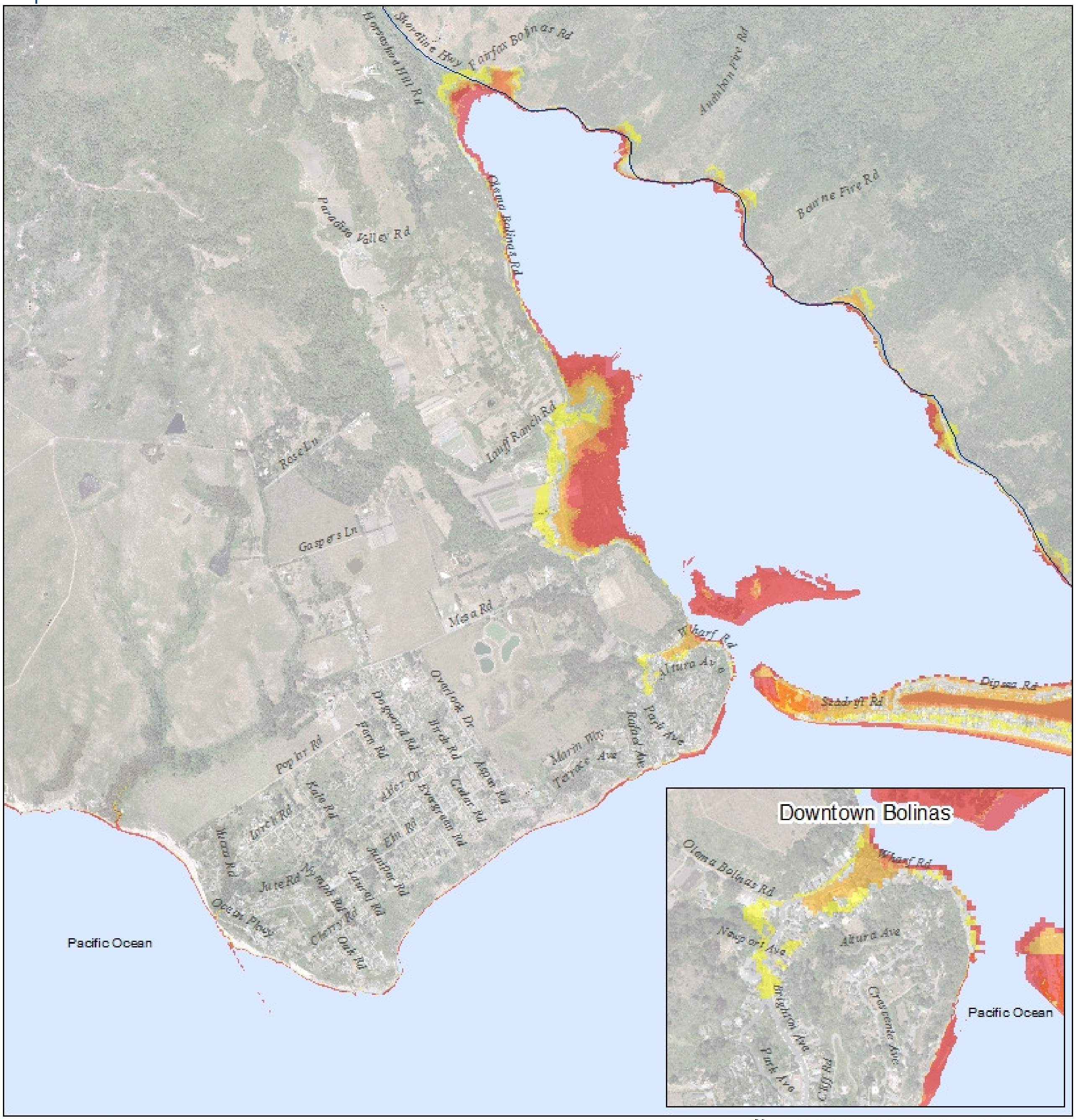
Map 5. Bolinas Sea Level Rise Scenarios



Scenarios

1 10" SLR + Annual Storm
2 10" SLR + 20-year Storm
3 20" SLR + 20-year Storm
4 40" SLR + 20-year Storm
5 80" SLR + 100-year Storm

N

0 0.075 0.15 0.3 0.45 0.6 Miles

Source: Marin Map, Our Coast Our Future

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers herein, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.

Date: 9/24/2015

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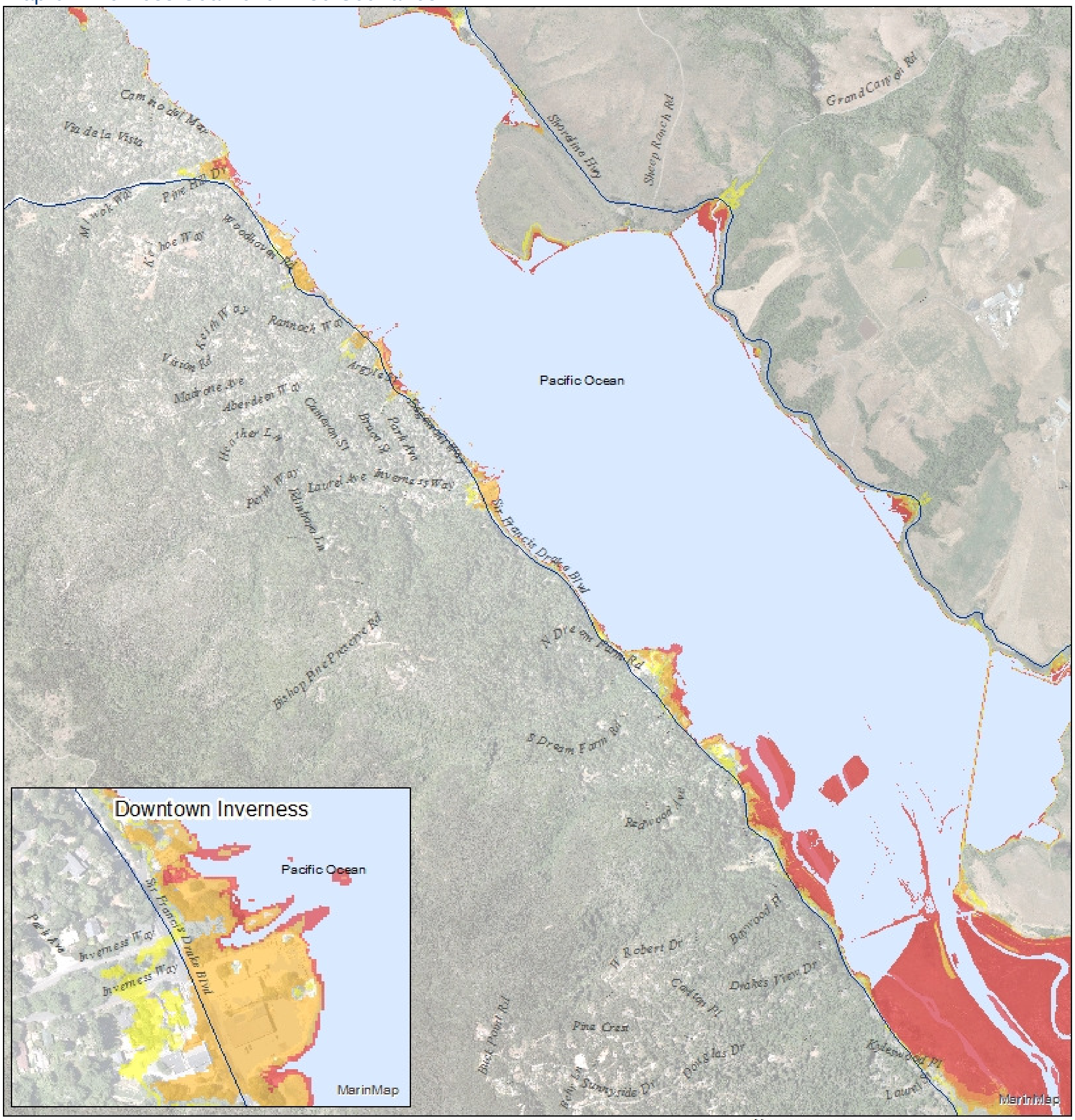
Map 6. Inverness Sea Level Rise Scenarios



Scenarios

1 10" SLR + Annual Storm
2 10" SLR + 20-year Storm
3 20" SLR + 20-year Storm
4 40" SLR + 20-year Storm
5 80" SLR + 100-year Storm

N

0 0.075 0.15 0.3 0.45 0.6 Miles

Source: Marin Map, Our Coast Our Future

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers herein, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.

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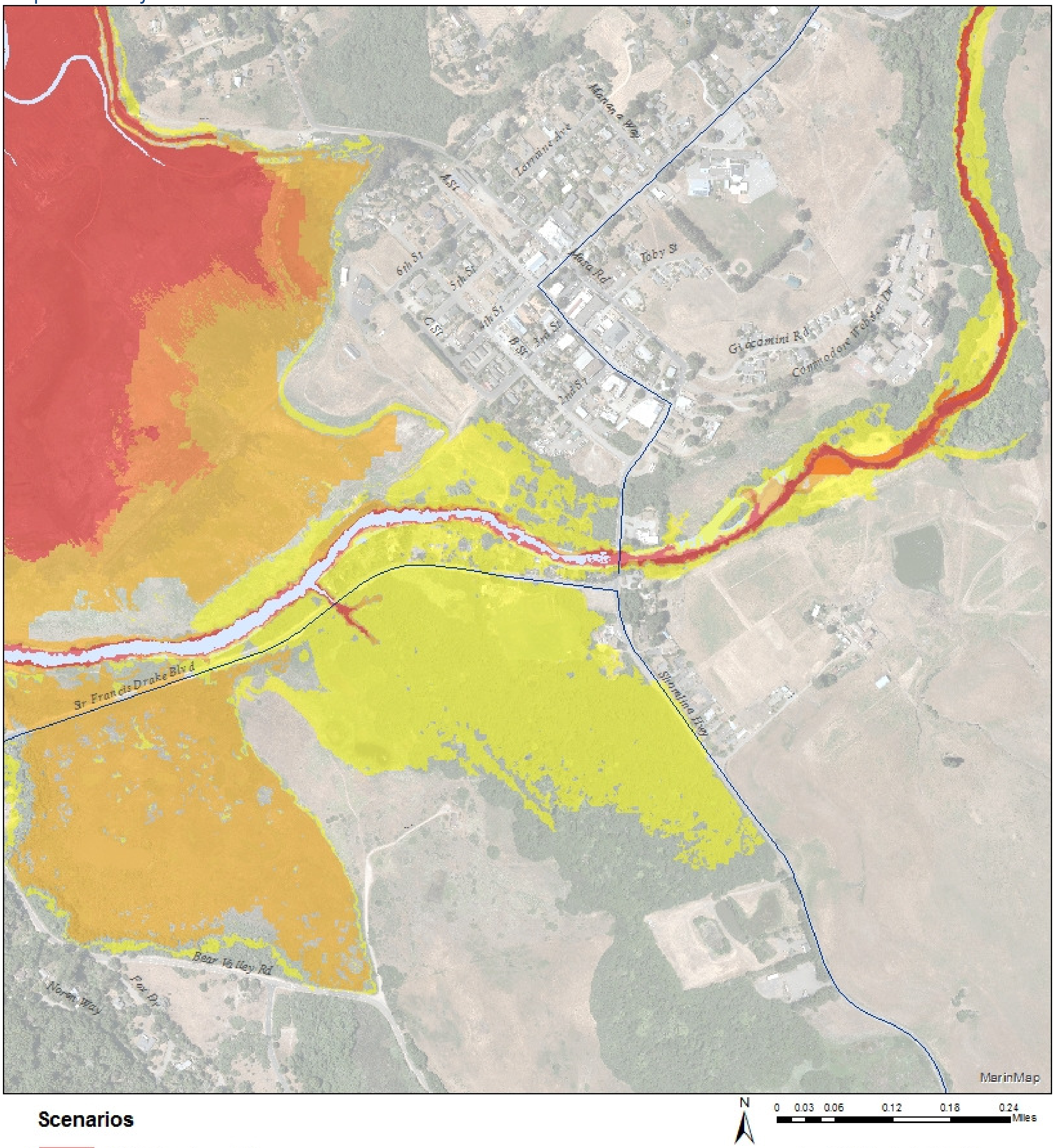
Map 7. Pt. Reyes Station Sea Level Rise Scenarios



Scenarios

1 10" SLR + Annual Storm

2 10" SLR + 20-year Storm

3 20" SLR + 20-year Storm

4 40" SLR + 20-year Storm

5 80" SLR + 100-year Storm

Source: Marin Map, Our Coast Our Future

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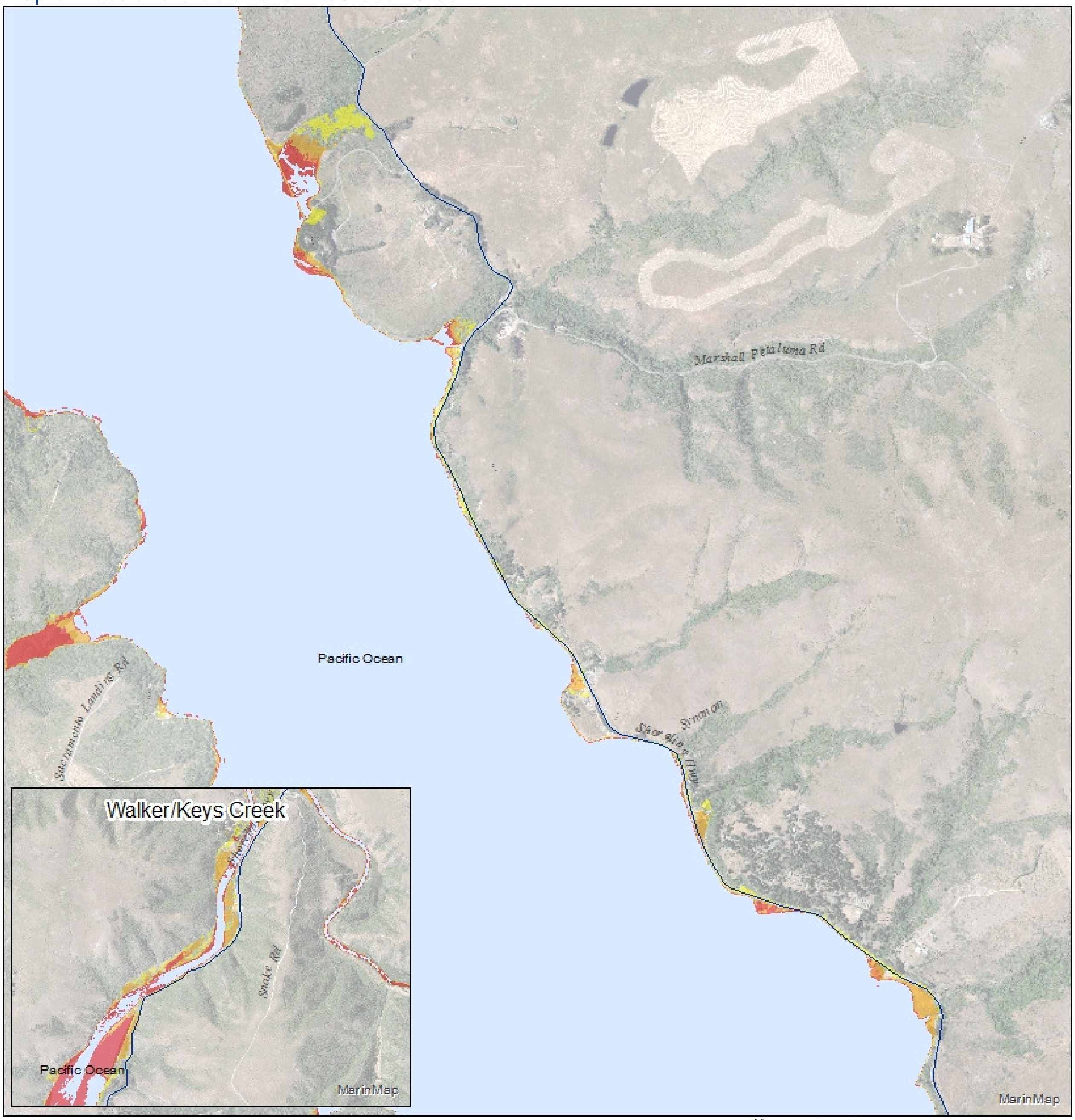
Map 8. East Shore Sea Level Rise Scenarios



Scenarios

1. 10" SLR + Annual Storm
2. 10" SLR + 20-year Storm
3. 20" SLR + 20-year Storm
4. 40" SLR + 20-year Storm
5. 80" SLR + 100-year Storm

N

0 0.075 0.15 0.3 0.45 0.6 Miles

Source: Marin Map, Our Coast Our Future

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers herein, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.

Date: 9/24/2015

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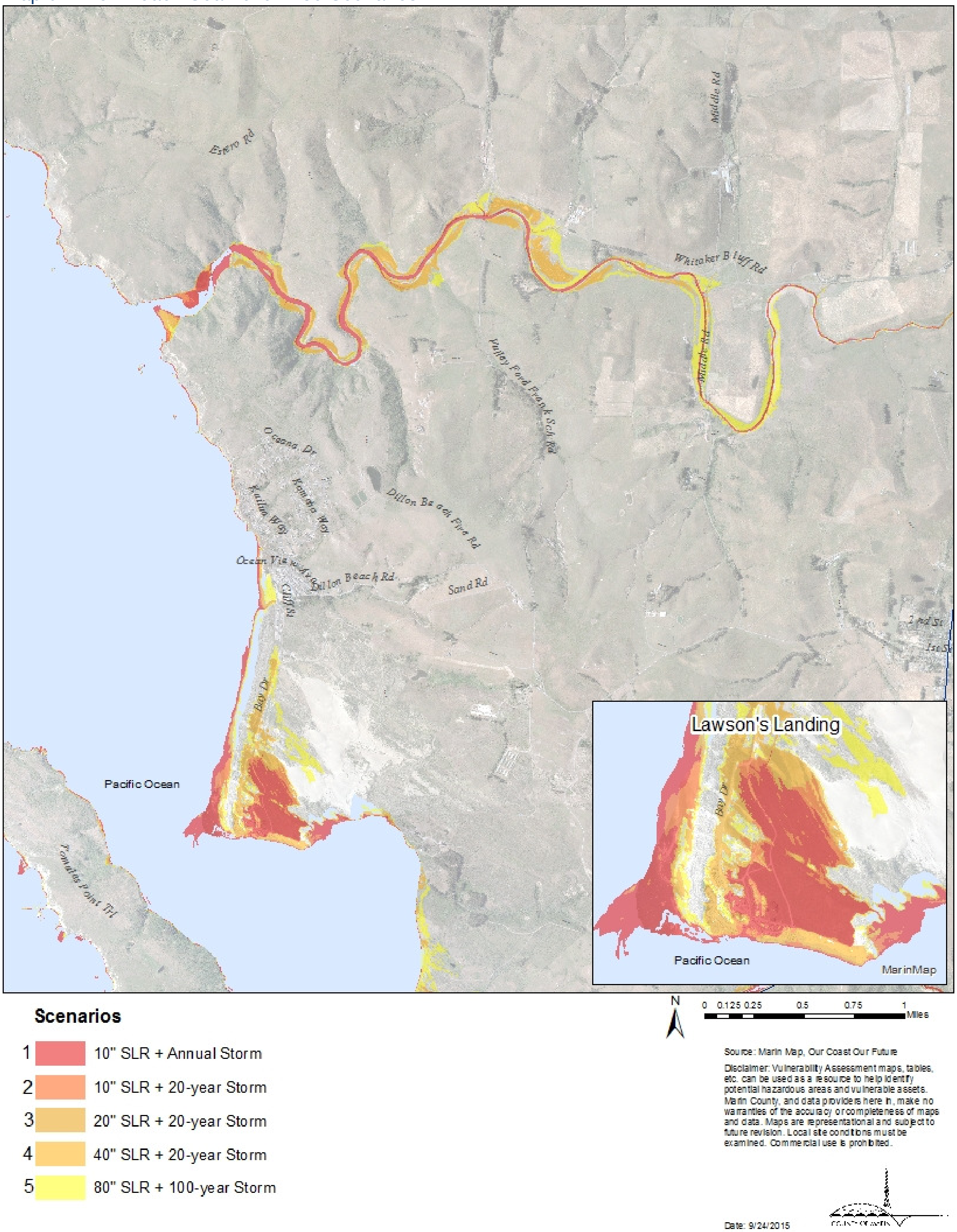
Map 9. Dillon Beach Sea Level Rise Scenarios



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Evidence shows that winter storms (i.e., extra-tropical cyclones) have increased in frequency and intensity since 1948 in the North Pacific,[21] increasing regional wave heights and water levels during events. However, global climate models suggest the storm track in the northeast Pacific Ocean will migrate to the north during the 21 century,[22] resulting in no significant changes to the wave heights for the Marin Coast compared the last several decades.[23,24]

The high degree of uncertainty and differing assumptions in carbon emissions in sea level rise modeling results in a wide range of onset conclusions, especially further out in time. This uncertainty is exacerbated by the non-linear growth rate of sea level rise[25,26] and the evolution of the wave climate. Because of this wide variation in onset projections, the C-SMART sea level rise scenarios do not focus on years, rather a framework of near, medium, and long-term scenarios as previously described. The OCOF tool enables the user to view the year a projection could be met according to the various published estimates on the OCOF website http://data.prbo.org/cadc/tools/sealevelrise/compare/.

Note, however, even if the world limits GHGs to stable levels in the atmosphere, sea level rise will continue. Moreover, even if the global population reduces GHGs to levels where atmospheric concentrations decline, the decline will be slow and sea levels will continue to rise for decades, and hundreds of years could pass before sea level stabilizes or drops.[27,28]

Another uncertainty is that OCOF's flooding projections are based on 2010 elevation data, and therefore do not incorporate more recent changes to the coastal landscape. For example, the LIDAR imagery used was taken before a major restoration project at Muir Beach, and it is possible the parking lot realignment and wetland habitat restoration could affect flooding outcomes differently than the scenarios estimate (see Figure 4).[29] However, if the CoSMoS model is updated, locations like these can serve as case studies for calibrating and validating the model and estimating the success of adaptation measures using the model. Local expertise and context is provided to highlight concerns the CoSMoS model may not predict. Known issues from OCOF are in Figure 5.

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[21] Graham, N. E., and H. F. Diaz (2001*), Evidence for intensification of North Pacific winter cyclones since 1948*, Bull. Am. Meteorol. Soc.,82, 1869–1893, doi:10.1175/1520-0477(2001)082<1869:EFIONP>2.3.CO;2.

[22] Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai, 2013: Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[23] Graham, N. E., D. R. Cayan, P. D. Bromirski, and R. E. Flick, 2013 *Multi-model projections of twenty-first century North Pacific winter wave climate under the IPCC A2 scenario. Clim Dynam*, **40,** 1335-1360.

[24] Erikson, L.H., Hegermiller, C.A., Barnard, P.L., Ruggiero, P. and van Ormondt, M., 2015 (in press). *Projected wave conditions in the Eastern North Pacific under the influence of two CMIP5 climate scenarios. Ocean Modeling*

[25] P. Barnard. C-SMART Kick-off Meeting July 2014. htttp://walrus.wr.usgs.gov/coastal_processes/cosmos/

[26] Annual mean Sea Level Rise, San Francisco Tidal Gage. Wwwlpsmsl.org/data/obtaining/stations/10.php

[27] IPCC Fourth Assessment Report: Climate Change 2007. Climate Change 2007: Working Group I: The Physical Science Basis. 10.7.2 Climate Change Commitment to Year 3000 and Beyond to Equilibrium. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-7-2.html

[28] IPCC Fourth Assessment Report: Climate Change 2007. Climate Change 2007: Working Group I: The Physical Science Basis. 10.7.4 Commitment to Sea Level Rise. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-7-4.html

[29] National Park Service, Golden Gate Recreation Area, March 25, 2010. "Post Project Redwood Creek Restoration at Muir Beach Golden Gate National Recreation Area" (map), (http://www.nps.gov/goga/naturescience/upload/MUBE_RWC_Pre_PostProject_03252011_smaller.pdf).

METHODS

Figure 4. Muir Beach Parking Lot Reorientation and Habitat Restoration

BEFORE (used in model)

Photo Credit: Marin Map

CURRENT (Completed in

Photo Credit: NPS

Figure 5. Known Issues from OCOF for Select Scenarios

Muir Beach: The imagery at Muir Beach does not reflect recent topographic changes. The floodplain, channel, and lagoon were regraded and realigned and the parking area was moved to a new location and elevation.

Stinson Beach: Scenario sea level rise 20 inches with a 20-year storm showed likely under-predicted flooding extents given beach profiles and adjacent flooding behavior. Sections with particularly disproportionate predictions in flooding extents have been corrected to reflect probable flooding extents based on beach topography and flooding performance of comparative scenarios. Non-progressive flooding (when more intense storms produce less flooding compared to less intense storms) behavior is also exhibited at small portions of these areas during stronger storm events (20-year and 100-year events). Small portions of the DEM within Seadrift Lagoon contain elevation inconsistencies, due to originating LIDAR picking up docks within the lagoon; flooding extents and depths are not accurately predicted at these locations.

Tomales Bay: Two embayments (near White Gulch and Sacramento landing) are not correctly depicted within the DEM. Consequential flooding extents are not properly projected, likely under-predicting the flooding extent. Scenario sea level rise 10 inches, most storm conditions shows irregular flooding behavior and exhibits non-progressive flooding (when more intense storms produce less flooding compared to less intense storms) along portions of Lagunitas Creek and Walker Creek.

Assessment Methods

Vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to rising waters and storm threats. For example, if an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity to them, the asset is vulnerable. The project team interviewed asset managers using the "Asset Vulnerability Assessment Tool" to assess built and natural resource assets. based on several previous pre- and post- disaster assessments conducted in the Bay Area, Southern California, New Orleans, New York City, and guidance from State of California and the U.S. EPA.[30,31,32,33,34,35,36]

In many cases, the assets are public and managed by a government or quasi government agency. In cases where private property owners are the managers, their association, or the owner was assigned. Two homeowners' associations were interviewed, however, individual home owners were not individually interviewed.

The interviews also determined if historic impacts had occurred and what the nature of potential impacts could be The interview results were combined with geographic data and citizen input gathered during public workshops to develop the Vulnerability Assessment. These phases are detailed in Figure 6).

[30] U.S. EPA. Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans. August 2014.
[31] CURRV-Tijuana River Valley - http://trnerr.org/currv/
[32] Bay Conservation & Development Commission: Adapting to Rising Tides. Hayward Resilience Study. 2014.
[33] City and County of San Francisco Sea Level Rise Committee. Guidance for incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation. September 2014.
[34] http://mitigationguide.org/task-5/steps-to-conduct-a-risk-assessment-2/3-analyze-risk/
[35] California Emergency Management Agency, California Emergency Natural Resource Agency. California Climate Adaptation Planning Guide (APG). July 2012. http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[36] Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Mike Culp, IFC International, *Literature Review: Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches.* http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment/index.cfm#Toc236233837

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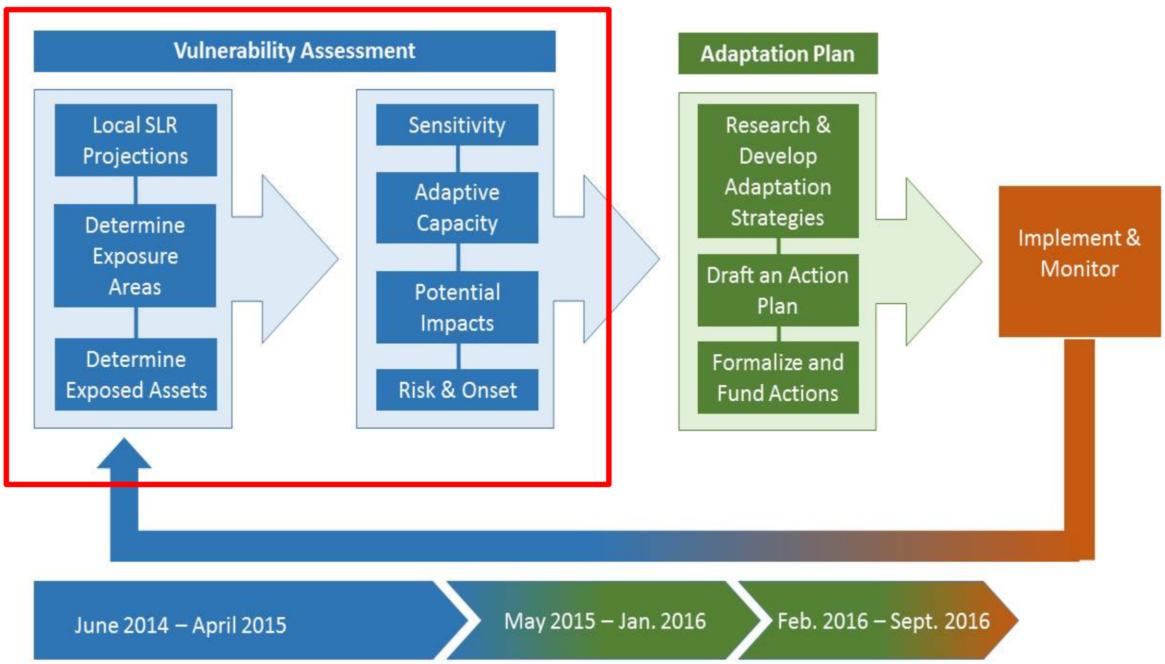
Figure 6. C-SMART Process: Vulnerability Assessment Phases



This assessment analyzes over 200 exposed assets. Assets were identified using existing Marin Map geographic data layers for roads, trails, parks, public facilities, utility districts, buildings, and parcels, and Department of Fish and Wildlife sources for wildlife species, habitats, fishing piers, marinas, access points, and ports were overlain to determine which assets could be exposed. Members of the community, and the technical and stakeholder advisory committees, supplemented these data sources with additional assets and accounts of historic weather events. These additions, along with emergency evacuation routes, utilties, and recreation assets were digitized for this assessment (based on road network colocations).

Phase 1: Exposure

To determine which areas of Marin could be exposed to MHHW or storm waters, the five C-SMART scenarios and identified assets were overlaid on aerial imagery of the Marin Coast. Assets intersecting sea level rise and storm scenario were identified as "exposed assets" and further assessed for sensitivity and adaptive capacity to determine if the asset was vulnerable to:

- Extreme event flooding (flooded during the annual highest high tides and/or in high tide and storm combinations). This is commonly referred to as nuisance flooding.
- Inundation at regular high tides. This is commonly referred to as chronic flooding.
- Erosion and geomorphic evolution from typical conditions and extreme storm events,
- Wave run up and high winds in extreme storm events,
- Saltwater intrusion,
- Rising water table,
- Combination of ocean and temporary creek flooding, and/or
- Habitat shifts (applicable to natural resources).

In addition to geographic extent, OCOF GIS layers illustrating potential flood depth were overlaid on the Marin Coast map imagery. The flood depth layers were spatially joined with each vulnerable asset yielding an average depth for each. Depths were distinguished as daily tidal inundation or storm flooding based on whether it was observed with the area exposed to sea level rise alone or in the expanded area when a storm is added to the rise in sea level. Measurements were taken from one point on a site located at the most landward intersection with the C-SMART scenarios. In the onset and depth tables in each profile, roads were assigned high and low values along the exposed segments for each scenario. Where buildings are presented as a neighborhood group, a maximum value was selected. This is supplemented with buildings flood level exposure tables in each community profile.

For buildings, additional exposure analysis was conducted to determine the potential damages and monetary losses that could be incurred. The first method applies FEMA damage levels to all buildings exposed in Scenario 5 in the respective communities based on the HAZUS model intervals for yellow, minor damage of $5,000-17,000,, orange, damage of $17,001+, and red, destroyed, post-disaster inspection tags.[37] Additionally, FEMA standards that establish existing v-zone areas, areas designated as at risk for hazardous, potentially destructive, conditions, for federally backed flood insurance programs were applied to the potential future conditions portrayed by the C-SMART scenarios. This method used the OCOF flood depth and wave velocity layers to establish a momentum index threshold based on wave run up to determine where hazardous conditions could develop. Hazardous areas are those where projected height multiplied by velocity squared is greater than or equal to 200 ft^3/sec^2.

Phases 2 & 3: Sensitivity and Adaptive Capacity

With the exception of the work performed by ESA and Greater Farallones Marine Sanctuary, the bulk of the assessment occurred in sensitivity and adaptive capacity phases, when asset managers were interviewed in person or by phone using the Vulnerability Assessment Tool describe earlier. In addition, individual property owners had several opportunities to attend community meetings to provide input on sensitivity and adaptive capacity (see Appendix B). Asset manager interviews asked two questions:

1. How ***sensitive*** is the asset to each exposure or threat?[38]
2. And if sensitive, what is the ***adaptive capacity***, or the asset's ability to maintain its function without further intervention (human action)?[39, 40,41, 42]

Any asset deemed moderately or highly sensitive to any of the exposures with low to no adaptive capacity is considered vulnerable. Other questions about previous disruptions and the nature of potential disruptions were also discussed to provide context to the qualitative measures.

Assets assessed as vulnerable will be carried over into the adaptation planning phase for further analysis and development. The findings of this process are summarized in the Asset and Community Profiles. To view the survey instrument and a spreadsheet of asset findings and managers, see Appendix C.

Additional Analysis for Natural Resources

The Natural Resources Profile has additional analysis from partners and consultants to supplement OCOF outcomes for erosion and saltwater impacts on natural resources and species assets.

Potential accelerated cliff and beach erosion rates were examined separately because CoSMoS makes projections of erosion based on historical retreat rates, and therefore, does not calculate potential increased rates of erosion triggered by sea level rise. To gain a better understanding, an erosion hazard analysis was conducted for Stinson Beach, Bolinas, and Marshall on the East Shore.

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[37] Federal Emergency management Agency (FEMA) Website. Hazus. Last updated July 8, 2015. http://www.fema.gov/hazus.

[38] Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco. September 22, 2014. Appendix 5. OneSF Checklist

[39] Center for Science in the Earth System (CSES), University of Washington, *Conduct a Climate Resiliency Study*, Chapter 8. Conduct a Climate Change Vulnerability Assessment. http://cses.washington.edu/db/pdf/snoveretalgb574ch8.pdf

[40] Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Mike Culp, IFC International, *Literature Review: Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches.* http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment/index.cfm#Toc236233837

[41] California Energy Commission Public Interest Environmental Research Program. Adapting to Sea Level Rise: A Guide for California's Coastal Communities. 2012.

[42] Bay Conservation & Development Commission: Adapting to Rising Tides. Hayward Resilience Study. 2014.

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Beach Evolution
Shoreline erosion was modeled using only the Bruun rule (Bruun 1962)[43] (1.0-1.5 meters of shoreline recession for every centimeter of sea level rise) in Stinson Beach. As sea level rises, the beach profile and shoreline is assumed to move inland based on the shape of the beach and the amount of sea level rise:

$$Sea\ Level\ Rise\ Transgression = \frac{increase\ in\ sea\ level}{shoreface\ slope}$$

To develop a scheme that relates beach width to vulnerability level, storm erosion distances various were analyzed including input data from a previous study covering the County[44] and chose the beach width thresholds presented in Table 5. If a beach width narrows to within these proposed distance levels, the beach is vulnerable to erosion or even complete loss during a coastal storm. Only the sea level rise component of each scenario was used for this analysis.

Table 5. Beach Width Vulnerability Threshold

Beach Width (meters)	Vulnerability Level
Width > 15	Low
15 > Width > 10	Medium
10 > Width	High

Source: ESA, 2015.

To tabulate beach widths, the existing beach areas were digitized in ArcGIS from the OCOF 2010 shoreline to the back of beach (toe of a cliff, dune, armor or other structure). These areas were clipped by the projected shoreline erosion hazard zones for each sea level rise scenario. The erosion model does not allow the backshore to retreat with the shoreline; consistent with the response of armored back beaches (Seadrift) and cliffs (Bolinas) to coastal storm erosion, and also reflects the County's desire not to consider inland transgression of the beach through dunes and into parking lots and other resources in the southern parts of Stinson Beach (assuming active management of these areas into the future). To read more about this analysis, see Appendix D.

Marshes
To determine the vulnerability of marsh habitat in the study area, rates of sedimentation, biomass production, and changing sea levels were considered along with the topographic constraints that exist or are imposed upon the marsh. As sea levels rise and marshes are flooded more often, there will likely be some positive feedback to maintain elevation, as lower elevations will lead to greater rates of mineral sediment inputs. However, this feedback depends on inland sediment sources. Similarly, there is strong feedback between the inundation regime and organic matter accumulation rates. At very low elevations within the marsh, primary biomass production is inhibited by increased stress from anaerobic conditions associated with high rates of inundation. At the upper end of the marsh, salt stress leads to a reduction in wetland primary productivity. Together, these two factors typically result in a peak of biomass productivity somewhere close to or just below marsh plain elevations.[45]

If inundation is frequent enough to reduce marsh vegetation production, the marsh may not be able to maintain sufficient biomass and could inundate more quickly. Eventually, the water will reach too high for marsh vegetation to grow in the space available. If tidal marshes cannot keep pace with sea level rise and begin to see regular standing water, tidal marsh habitat will be lost and converted to mudflats. In places where adjacent areas are relatively flat and at slightly higher

[43] The Bruun rule (1962) states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth. This simple model states that the beach profile is a parabolic function whose parameters are entirely determined by the mean water level and the sand grain size. The analysis by Bruun assumes that with a rise in sea level, the equilibrium profile of the beach and shallow offshore moves upward and landward. An increase in sea level, (S), cross shore distance (L) to the water depth (h) taken by Bruun as the depth to which near shore sediments exist (depth of closure), and B is the height of the dune. Based on this estimate of shoreline recession is 1.0-1.5 meters of shoreline recession for every centimeter of sea level rise.

[44] Heberger, M., Cooley, H., et. al. May 2009. *The Impacts of Sea-Level Rise on the California Coast*. California Climate Change Center. The Pacific Institute. CEC-500-2009-024-F.

[45] Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., Cahoon, D. R. 2002. Responses of Coastal Wetlands to Rising Sea Level. Ecology, 83(10), pp. 2869-2877.

elevations, marshes could migrate inland. However, if there are areas around the lagoon bordered by road berms or other areas with abrupt elevation changes, migration will be constrained. In areas where migration is physically possible, there may also be limitations depending on land ownership and future land management decisions.

To assess these critical points and the transitions in habitat, an elevation capital method was used, comparing the absolute elevation of a marsh with the local water levels and tide range[46] using a dimensionless indicator (z*) of elevation capital[47] based on mean sea level (MSL) and MHHW:

$$z^* = \frac{z - MSL}{MHHW - MSL}$$

This non dimensional parameter is calculated using existing marsh elevation data (e.g., from LiDAR and a nearby tidal datum), and makes it possible to compare marshes at different elevations and tide regimes. Vulnerability is correlated to elevation capital as shown in Table 6.

Table 6. Vulnerability Levels for Ranges of Elevation Capital (z*, dimensionless)

Elevation Capital	Vulnerability Level
2.5 > z* > 1	Low
1 > z* > 0.3	Medium
0.3 > z*	High

The long term evolution of Bolinas Lagoon and its overall sedimentation regime is set by its recovery from rapid and repeated subsidence during tectonic events.[48] The combination of littoral and fluvial sediment sources and the episodic increase of accommodation space from tectonic events have led to relatively high sedimentation rates averaging about 6.8 mm/year in the lagoon.[49] A 2009 study extrapolated the 6.8mm/year sedimentation rate to the whole of the lagoon to get an average sediment delivery rate of about 43,000 cubic yards per year.[50,51] Based on the geometry of the Pine Gulch Creek delta and the known rate of growth of the delta footprint, vertical accretion rate of the delta is estimated to be about 15 mm/year in 2050 and about 8 mm/year by 2150. The rate decreases as the footprint of the delta expands but the sediment supply was held constant.[52] To read more about this analysis, see Appendix D.

Additional habitat and species analysis from the interagency *Climate Change Vulnerability Assessment for the North-central California Coast and Ocean* is incorporated to supplement Marin County's assessment.[53] The interagency study examines several climate change factors, including sea level rise. The report authors isolated their findings for sea level rise, where feasible, for inclusion in the Natural Resources Profile. The inter-agency study uses a different methodology to examine sensitivity, adaptive capacity, and exposure through a scientific review process, provides confidence evaluations for all climate change factors, and overall vulnerability (an average of scores 1-5, 1 being low and 5 being high), and confidence scores (an average of scores 1-3, 1 being low and 3 being high) for each habitat and species. Scores for the exposure were weighted less than scores for the sensitivity and adaptive capacity components of vulnerability by a factor of 0.5 due to uncertainty about the magnitude and rate of future change. Sensitivity,

[46] Cahoon, D. R., Guntenspergen, G. R. 2010. Climate Change, Sea-Level Rise, and Coastal Wetlands. National Wetlands Newsletter, Vol. 32, No. 1. Washington, DC.

[47] Swanson, K. M., Drexler, J. Z., Schoellhamer, D. H., Thorne, M. T., Casazza, M. L., Overton, C. T., Callaway, J. C., Takekawa, J. Y. 2013. Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) and Its Application to Habitat Sustainability for Endangered Species in the San Francisco Estuary. Estuaries and Coasts Vol 37, No. 2, pp. 476-492.

[48] PWA, 2006. Projecting the future evolution of Bolinas Lagoon. Prepared for Marin County Open Space District.

[49] Byrne, R., Reidy, L., Schmidt, D., Sengupta, D., Arthur, A.2005. Recent (1850-2005) and late Holocene (400-1850) sedimentation rates at Bolinas Lagoon. Prepared for Marin County Open Space District.

[50] PWA, 2009. California Coastal Erosion Response to Sea Level Rise – Analysis and Mapping. Prepared for the Pacific Institute.

[51] These estimates come with the caveats that the cores reported in Byrne *et al* (2006) were limited to unvegetated mudflats and subtidal shallows due to permit restrictions.

[52] PWA, 2006. Projecting the future evolution of Bolinas Lagoon. Prepared for Marin County Open Space District.

[53] Hutto, S.V., K.D. Higgason, J.M. Kershner, W.A. Reynier, D.S. Gregg. 2015. Climate Change Vulnerability Assessment for the North-central California Coast and Ocean. Marine Sanctuaries Conservation Series ONMS-15-02. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD.

adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as follows:

Vulnerability = Climate Exposure 0.5)+Sensitivity)/ Adaptive Capacity

Over 60 representatives from federal and state agencies, non-governmental organizations and academic institutions contributed to the vulnerability assessments. For more details on how this was applied for climate change factors visit the GFNMS website.

Phase 4: Risk & Onset
Risk & onset assess when and how likely impacts will occur and attempts to assess the expected level of damage and timing, to prioritize actions and funding. Onset is determined by the scenario an asset is exposed under. However, instead of using specific years, we have noted, near-, medium, and long- term impacts with the NRC 2012 sea level ranges shown in Table 3**Error! Reference source not found.**. Due to the significant number of uncertainties in the onset, or timing, of the sea level rise amounts, a standard risk assessment involving probabilities was not performed for each scenario or asset. In fact, this is a task sea level rise scientists are working on.[54] As improvements in science and feedback from monitoring improve, specific studies can examine risk in greater detail. At this time; however, the analysis conducted for vulnerability can equate a general understanding of risk, such that vulnerable assets are at risk for the designated sea level rise exposures.

Other Considerations Methods

As adaptation planning moves forward, more detailed study and assessment across each of the Countywide Plan (2007) 3 E's—economy, environment, and equity—will be critical. Moreover the California Coastal Commission's Sea Level Rise Policy Guidance calls for assessing the economic, ecological, social, cultural, and legal consequences, cumulative and secondary consequences of both the vulnerabilities and the human responses to them.[55] This section in each asset profile begins to identify issues and opportunities for each "E," as well as management, and is informed through literature review, asset manager interviews, and policy analysis.

Economic: Highlights costs of damage or preparation and the cost burden to residents. Potential economic issues and opportunities were determined using several geographic and tabular data sources maintained by Marin County, US Census, and Zillow. Note that population and monetary figures are based on current or historic values. Generally, both populations and property values are projected to grow, thus, this assessment likely underestimates the number of people and value of property that could be impacted in the future.

Environmental: Highlights how disruption to buildings, roads, septic systems, and other assets could have secondary impacts on the environment. Environmental impacts were gathered from asset managers, literature review, and significant contributions from the Greater Farallones National Marine Sanctuary, U.S. Department of Fish and Wildlife, and Audubon Canyon Ranch.

Equity: Highlights the disparity in cost burden across populations of different social and economic means, and how the social fabric of communities may shift. Several storms from the south (i.e. Hurricane Katrina, Hurricane Audrey) have "shown that natural disasters can cause the greatest harm to low-income communities and communities of color."[56] At the community workshops, community members expressed a strong interest in ensuring recommendations and actions prioritize social equity and environmental justice needs. Populations that may be at higher risk than the average citizen include, low-income, no to poor English speaking, children, and those with limited mobility or sensory abilities.

[54] Barnard, P. Aug. 24, 2015. CoSMoS Presentation at the California Climate Change Symposium. Sacramento California.

[55] *California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for addressing Sea Level Rise in Local Coastal Programs and Coastal Development.* August 12, 2015. http://www.coastal.ca.gov/climate/slrguidance.html

56 The Impacts of Sea-Level Rise on the California Coast. California Climate Change Center. Heberger, M., Cooley, H., et. al. The Pacific Institute. CEC-500-2009-024-F. May 2009

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Management: Highlights jurisdictional concerns, plans, policies, regulations, ordinances, etc. Management concerns are based on review of existing plans and regulations, including the Local Coastal Program (includes land use regulations), Hazard Mitigation Plan, and several asset specific plans. This preliminary review highlights political and management issues that will need to be considered when planning for sea level rise to ensure the public health, safety, and welfare of Marin Coast residents.

To get a better idea of these secondary consequences, asset managers were asked several questions about the nature of the damage or disruption that could happen, levels of risk, persons impacted, and if environmental, economic, equity, or political issues could arise. Secondary impacts include:[57, 58]

- Contaminant releases from industrial sites or storage tanks (environmental),
- Loss of habitat from increased erosion (environmental),
- Loss of jobs and revenue streams (economic),
- Loss of community or sense of place (social), and
- Increased need for government services or intervention (management).

Collectively these methods determine what is vulnerable to sea level rise on the Marin Coast and at what levels of sea level rise impacts could be felt. This assessment can be a useful tool in developing adaptation strategies and policies that are suited for this unique and valuable coastal region.

[57] Delaware Coastal Programs, *Sea Level Rise Adaptation*. http://www.dnrec.delaware.gov/coastal/Pages/SeaLevelRiseAdaptation.aspx

[58] City and County of San Francisco Sea Level Rise Committee. *Guidance for incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation*. September 2014.