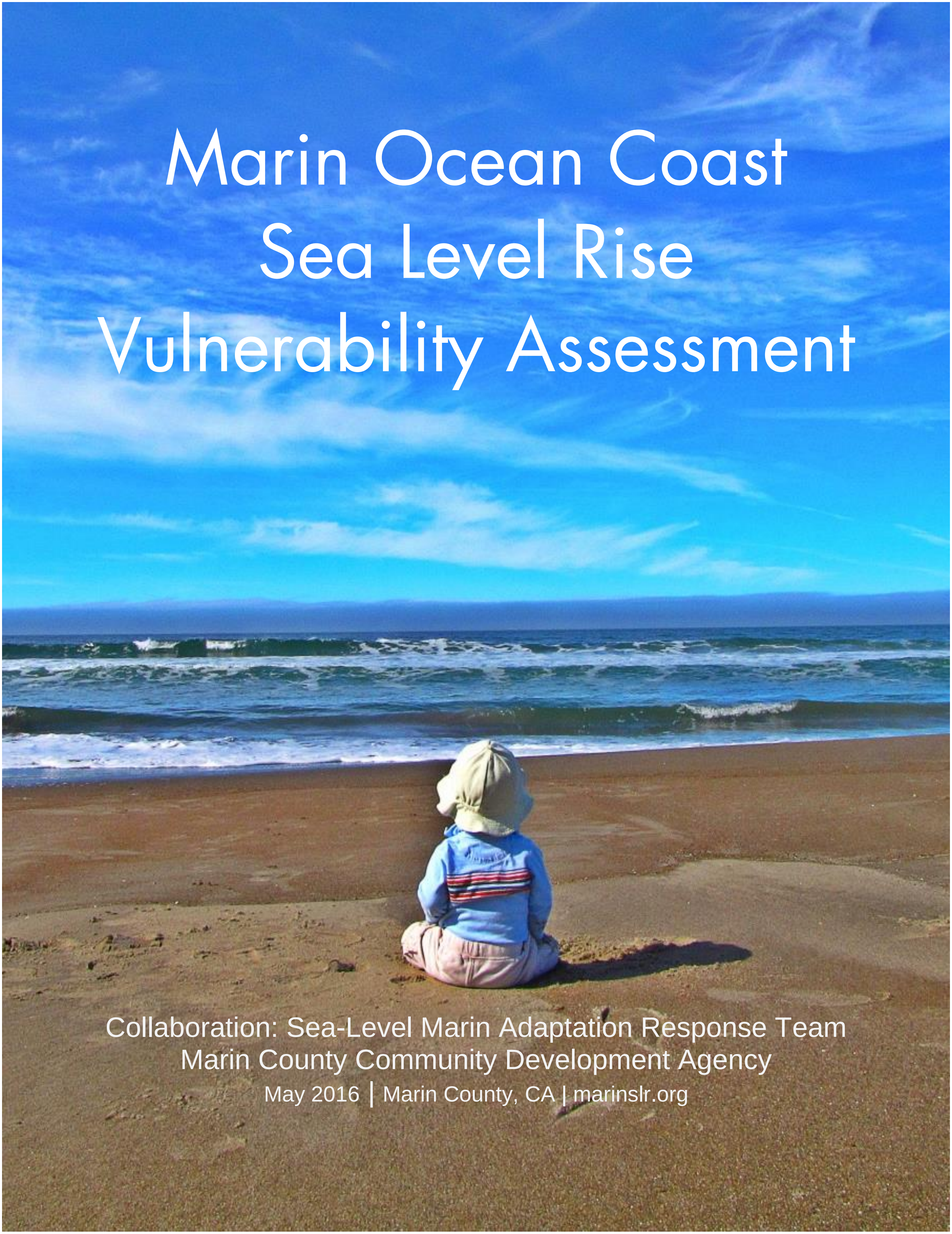

Marin Ocean Coast Sea Level Rise Vulnerability Assessment

Collaboration: Sea-Level Marin Adaptation Response Team
Marin County Community Development Agency
May 2016 | Marin County, CA | marinslr.org

Marin Ocean Coast Sea Level Rise Vulnerability Assessment

Collaboration: Sea-Level Marin Adaptation Response Team
Marin County Community Development Agency
February 2016 | Marin County, CA | marinslr.org

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

TABLE OF CONTENTS

Table of Contents

List of Maps

TABLE OF CONTENTS

TABLE OF CONTENTS

List of Figures

List of Tables

TABLE OF CONTENTS

TABLE OF CONTENTS

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Sonoma State Anthropological Studies Center

AND over 100 community members!

EXECUTIVE SUMMARY

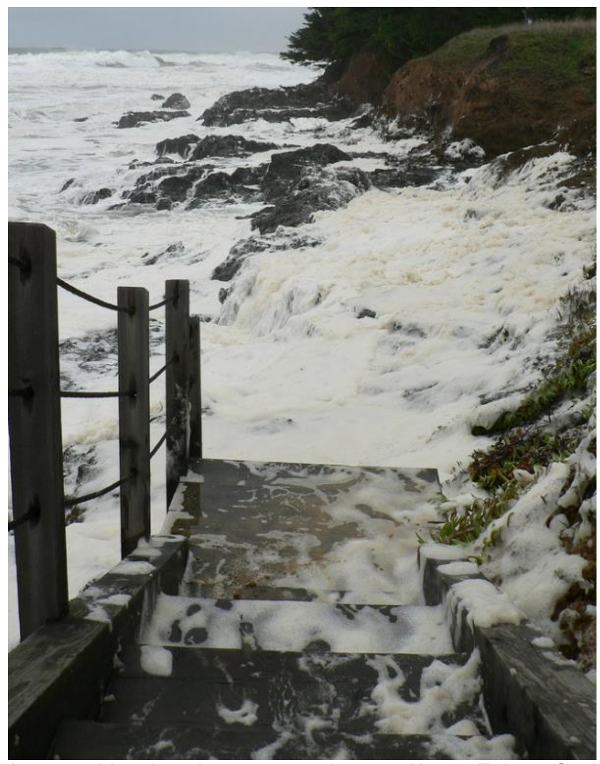
Executive Summary

Sea level in the San Francisco Bay Area has risen eight inches in the past century, and could rise up to seventy inches by 2100.[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.

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.*

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, the 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 is 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. LCP policies help ensure adaptation occurs in a way that protects coastal resources, public safety, and continued public access to recreational areas.



Inaccessible beach access during King Tide. Credit Rapapport

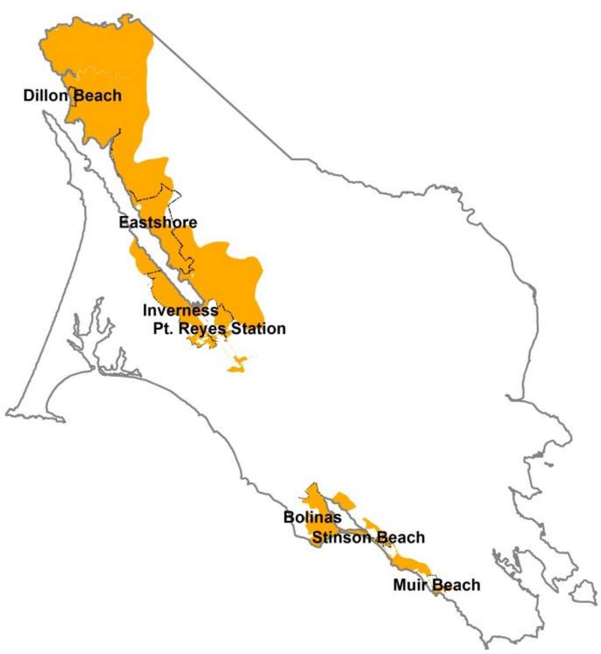
[1] Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present and Future. National Research Council (NRC), 2012.

[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

This Vulnerability Assessment for Marin County's ocean coast is organized into two major parts. The first part are 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, including the area 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 viewed independently of the others, enabling asset managers to focus on a professional area, and community members, elected officials, and others to read the results for a community as a whole.

Map 1. Study Area



The non-federal portion of the Marin County Coastal Zone covers approximately 48,255 acres [Federal Coastal Zone Management Act of 1972 (16 U.S.C. 1451, et seq.)].

Vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to rising waters. 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." The interview results were combined with geographic data and citizen input to develop the Vulnerability Assessment.

Table1 shows the range of sea level rise projections adopted by the National Research Council (NRC). Given the uncertainty in the magnitude and timing of sea level rise, Marin County used a scenario-based approach to assess potential sea level rise impacts. The five scenarios 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 flood across 10 different sea levels and 4 storm severities. All of these scenarios are viewable on the Our Coast Our Future (OCOF) website. Note that while the C-SMART scenarios all include storms, policies developed and adopted to address sea level rise will need to factor the sea level rise components and storm components individually.

Table1. 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 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

[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.

EXECUTIVE SUMMARY

Well after these scenarios were adopted for this assessment, the Ocean Science Trust released "Rising Seas in California." The report concludes that loss from Greenland and Antarctic ice sheets is occurring at a quicker rate than previously predicted causing sea level rise in California to exceed the global average rates predicted by the NRC.[4] The high range of uncertainly underscores the importance of staying abreast of evolving sea level rise science and being prepared planning.

The key findings of this assessment are based on five 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. Scenario 5 represents sea levels based on additional research theorizing the worst case for sea level rise by 2100 is 70 inches globally. The corresponding CoSMoS option for this timeframe is 200 centimeters, or 77 inches sea level rise, and is referenced as 80 inches in this assessment.

Key Findings

In their current conditions and without intervention, the most vulnerable coastal Marin assets are beaches and buildings on or near the water. Map - 87 and the following sections highlight major vulnerabilities by onset, or timing.

2030 Expectations (Scenarios 1 & 2)

- Beaches, underground on-site wastewater treatment systems (OWTS), buildings, and streets in Stinson Beach Calles and Patios neighborhoods.

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

IMPACTS AT-A-GLANCE: SCENARIO 2

<table>
<tr><td>1,681 acres flooded @ MHHW + annual storm surge</td><td colspan="2">3,000+ residents plus tourists</td></tr>
<tr><td>2,054 acres flooded @ MHHW +20-year storm surge</td><td>110 agricultural acres
(mostly ranch)</td><td>569 acres of aquaculture</td></tr>
<tr><td>588 homes & businesses could flood, 60 could suffer from erosion</td><td colspan="2" rowspan="4">Property Owners
County of Marin
Caltrans
Bolinas Public Utility
Stinson Beach Water
Fire Districts
National Parks Service
California State Parks
AT&T</td></tr>
<tr><td>$561 million in assessed property value</td></tr>
<tr><td>2.3 miles of wet road,
2 ports,
1 marina,
1 boat launch</td></tr>
<tr><td>Beaches
Tidal Marshes
Eelgrass beds
Estuaries</td></tr>
</table>

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http://www.sciencedaily.com/releases/2014/10/141014085902.htm.

[4] Griggs, G., Árvai, J., Cayan, D., DeConto, R., Fox, J., Fricker, H.A., Kopp, R.E., Tebaldi, C., Whiteman, E.A. (California Ocean Protection Council Science Advisory Team Working Group). Rising Seas in California: An Update on Sea-Level Rise Science, Ocean Science Trust, April 2017.

- Shoreline Highway between Stinson Beach and Bolinas, 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 Inverness residents.
- Intertidal rocky lands off 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.

These small pockets of flooding along the coast could result, at best, in daily road and recreation facilities closures. Consistent erosion exacerbated by higher tides and storm surges could take out portions of the roads for longer periods of time and may require repair. This level of damage would significantly impact all residents and tourists traveling this portion of the coast during high tides, as few alternative routes are available. Buildings, or land surrounding buildings, that flood near daily, or even only during annual storms, are not likely to sustain the expense and damage from reoccurring floods. This is especially a concern for the Calles and Patios neighborhoods in Stinson Beach and Tomales Bay homes that are not elevated to accommodate higher waters and waves.

EXECUTIVE SUMMARY

Map 83 Southern Marin Coast 2030 Sea Level Rise and Storm Surge Expectations

NEAR-TERM

Scenario 1: 10 in. Sea Level Rise +Annual Storm Surge
Scenario 2: 10 in. Sea Level Rise +20-year Storm Surge

By 2030, higher high tides could adversely impact shoreline natural resources, all overwater development, and shoreline development in the Calles and Patios neighborhoods of Stinson Beach and downtown Bolinas. A 20-year storm is enough to impact nearly all housing west of State Route 1 in Stinson Beach, and will reach further inland in Bolinas. Ten inches of sea level rise combined with an annual storm surge could reach 450 parcels, 235 buildings, 2 miles of road. Bluff erosion could compromise another 42 buildings in Bolinas and Muir Beach at ten inches of sea level rise. A more severe storm surge, such as a 20-year storm surge could reach 665 parcels, 455 buildings, and more than 2.5 miles of road. Shoreline Highway, between Stinson Beach and Bolinas, could face some tidal and storm closures. Similarly, flooding on Olema-Bolinas Road would prevent travel to lower Wharf Road and the Mesa. Recreational facilities and access points to the Pacific Ocean, including Muir, Stinson and Upton Beaches and Duxbury Reef, could become severely eroded and unavailable more often.

Sea Level Rise & Storm Scenarios 1 & 2
- 10"+annual storm surge
- 10"+20-year storm surge

Vulnerable Buildings
- @ 10"+annual storm surge (flooding)
- @ 10" + 20-year storm surge (flooding)
- @ 10" sea level rise only (erosion)

Vulnerable Roads
- @ 10" + Annual storm
- @ 10" + 20-year storm

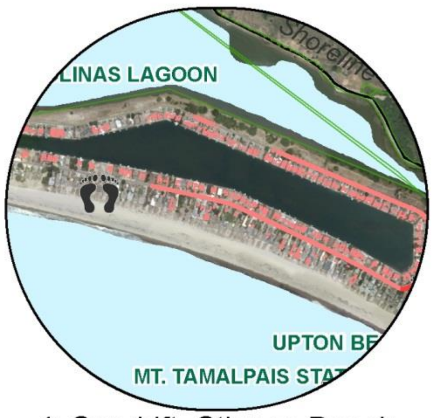
Other Vulnerable Assets
- Park
- Access Point
- Port
- Agriculture
- Emergency
- Historic
- Recreation

Location Indicators
- Communities
- Water

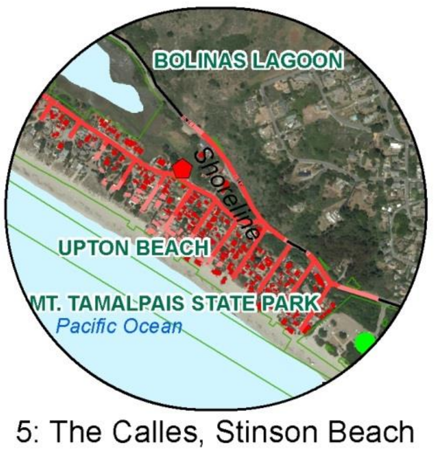
1: Bolinas Bluffs

2: Downtown Bolinas

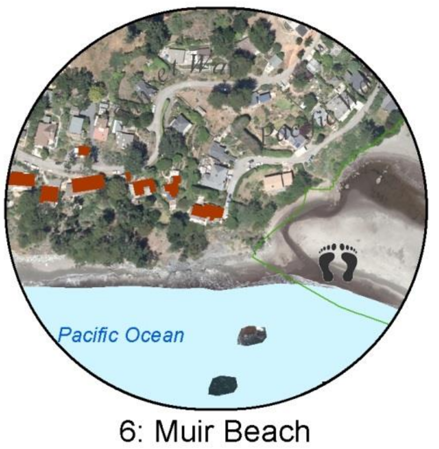
3: Bolinas Wye



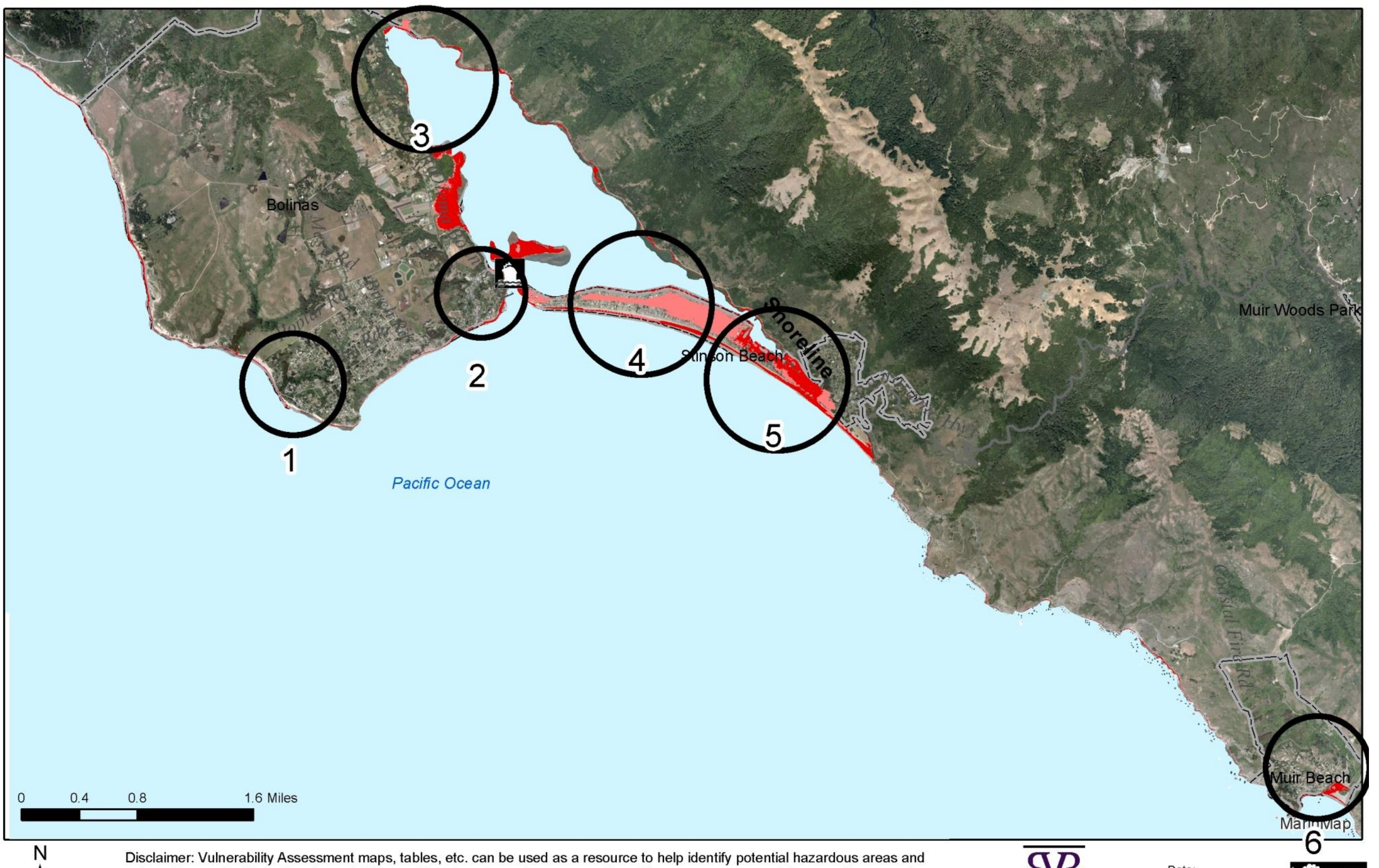
4: Seadrift, Stinson Beach



5: The Calles, Stinson Beach



6: Muir Beach



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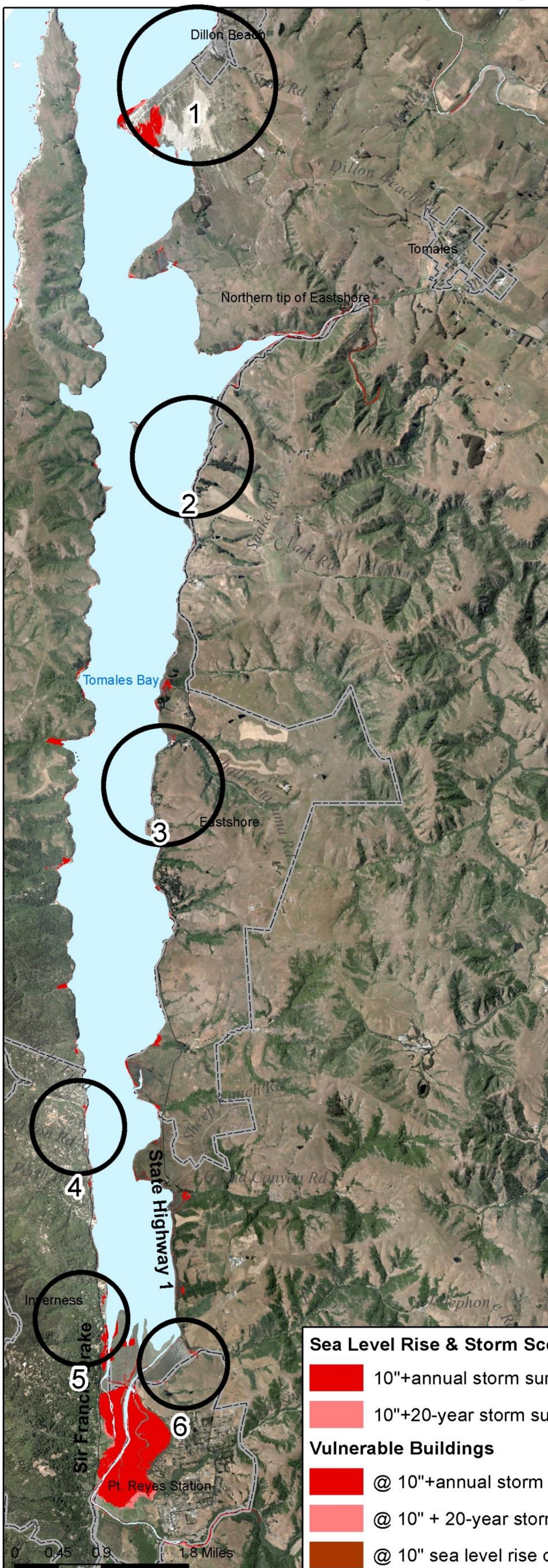
Date: 2/6/2018

EXECUTIVE SUMMARY

Map 84. Northern Marin Coast 2030 Sea Level Rise and Storm Surge Expectations

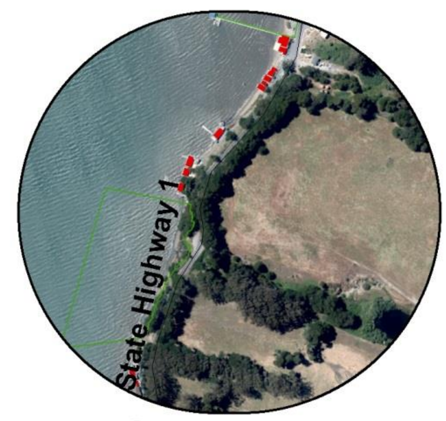
NEAR-TERM|

Scenario 1: 10 in. Sea Level Rise + Annual Storm Surge
Scenario 2: 10 in. Sea Level Rise +20-year Storm Surge

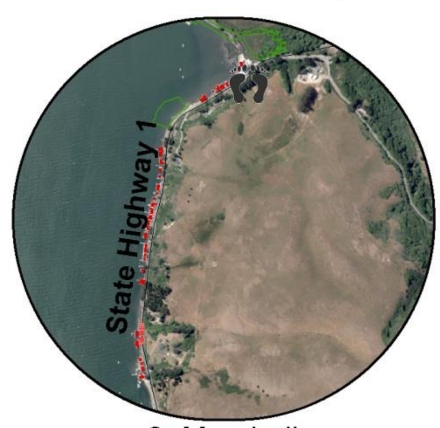


By 2030, high tides could adversely impact low-lying areas west of Shoreline Highway and east of Sir Francis Drake Boulevard. Ten inches of sea level rise combined with an annual storm surge could reach 290 parcels, 125 buildings, 0.14 miles of road. Bluff erosion could compromise another 42 buildings in Bolinas and Muir Beach at ten inches of sea level rise. A 20-year storm would marginally increase these numbers, though may have more severe consequences than the annual storm. Overwater and nearshore development in Inverness, Point Reyes Station, and East Shore would be at risk of tidal and storm surge flooding. Eight buildings in Dillon Beach would be vulnerable to bluff erosion. Sir Francis Drake Boulevard, Shoreline Highway and roads to Lawson's Landing would be subject to regular flooding at high tides and hazardous flooding during storms, especially near creeks. Recreational facilities and access points to the bay would close during high tide. Storm damage could require repairs.

1: Dillon Beach/ Lawsons's Landing

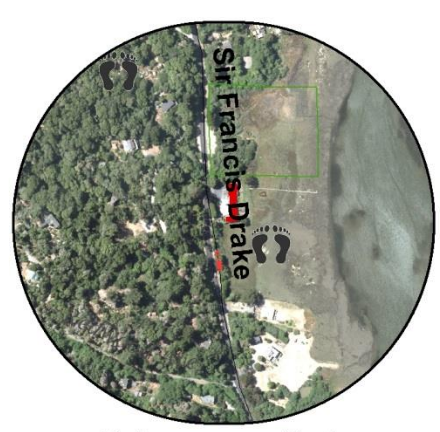


2: Shoreline Highway



3: Marshall

4: Inverness



5: Inverness Park

6: Shoreline Highway, Pt. Reyes Station

Sea Level Rise & Storm Scenarios 1 & 2
- 10"+annual storm surge
- 10"+20-year storm surge

Vulnerable Buildings
- @ 10"+annual storm surge (flooding)
- @ 10" + 20-year storm surge (flooding)
- @ 10" sea level rise only (erosion)

Vulnerable Roads
- @ 10" + annual storm
- @ 10" + 20-year storm

Other Vulnerable Assets
- Park
- Access Point
- Marina

- Historic

Location Indicators
- Communities
- Water

Date: 2/6/2018

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 here in, 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.

EXECUTIVE SUMMARY

Mid Century Expectations (Scenario 3)

The following places could face chronic and storm surge flooding and erosion at twenty inches of sea level and a 20-year storm surge by 2050.

- Locations presented in near-term scenarios 1 and 2.
- Seadrift neighborhood in Stinson Beach.
- Bluff top homes in Muir Beach, Bolinas, and Dillon Beach.
- Olema-Bolinas Road, the primary 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.
- The Bolinas Wye and local roads in Stinson Beach west of State Route 1, including Calle del Arroyo, the access road to nearly all lower Stinson Beach homes.
- Shoreline Highway in Stinson Beach, Pt. Reyes Station and East Shore at creek crossings, and low lying segments of Sir Francis Drake Boulevard in Inverness.
- Public access sites along these roads.

By mid-century, near-term impacts will continue to worsen and reach to new areas in Bolinas, Stinson Beach, and around Tomales Bay. Overwater housing may not be feasible without significant alterations. Road closures could last longer and repeated flooding could cause even greater damage. By this time period, significant alterations to the roadways maybe necessary to maintain through access and avoid frequent and costly repairs. Underground utilities in Stinson Beach and around Tomales Bay may become overburdened by higher waters and lose functionality, requiring conversion to other systems to ensure remaining homes are livable. Beaches would be severely eroded and bluff collapse an even greater risk than in the near-term. These closures would significantly impact existing and new residents and tourists that would have major ripple effects on the West Marin economy.

Seadrift neighborhood, Stinson Beach. Credit: CDA

IMPACTS AT-A-GLANCE: SCENARIO 3

2,062 acres flooded @ MHHW + 20-year storm surge

3,000+ residents plus tourists

680 homes, businesses, & institutions could flood, 148 could suffer from erosion

172 agricultural acres (mostly ranch)

569 acres of aquaculture

$793 million in assessed property value

5 miles of wet road,
1 port,
1 marina,
1 boat launch

Beaches
Tidal Marshes
Creeks
Eelgrass beds
Estuaries

Property Owners
County of Marin
Caltrans
Bolinas Public Utility
Stinson Beach Water
Fire Districts
National Parks Service
California State Parks
AT&T

EXECUTIVE SUMMARY

Map 85. Southern Marin Coast 2050 Sea Level Rise and Storm Surge Expectations

MEDIUM-TERM

Scenario 3:
20 in. Sea Level Rise
+20-year Storm Surge

By 2050, higher high tides could significantly alter the coastline with dramatic effect on all overwater and shoreline development. The Calles, Patios, and Seadrift neighborhoods of Stinson Beach, and downtown and flats areas of Bolinas, are at greater risk for more damage than before. Many assets that flooded only during storm conditions in the near-term could now flood at high tides. Twenty inches of sea level rise with a 20-year storm surge could flood 680 parcels, 40 buildings, and nearly 3 miles of road in West Marin's southern communities. Bluff erosion could compromise 100 buildings in Bolinas and Muir Beach. Shoreline Highway between Stinson Beach and Bolinas could face prolonged closures along this entire segment, as could local streets in lower Stinson Beach. High water levels in Bolinas could prevent access to the town center. Water and wastewater utilities could begin to fail or fall into disrepair more often with salt water exposure. Consistent water damage to buildings, roads, and utilities in these areas would make daily life difficult. Most access points to the Pacific Ocean could become severely eroded and only offer limited availability.

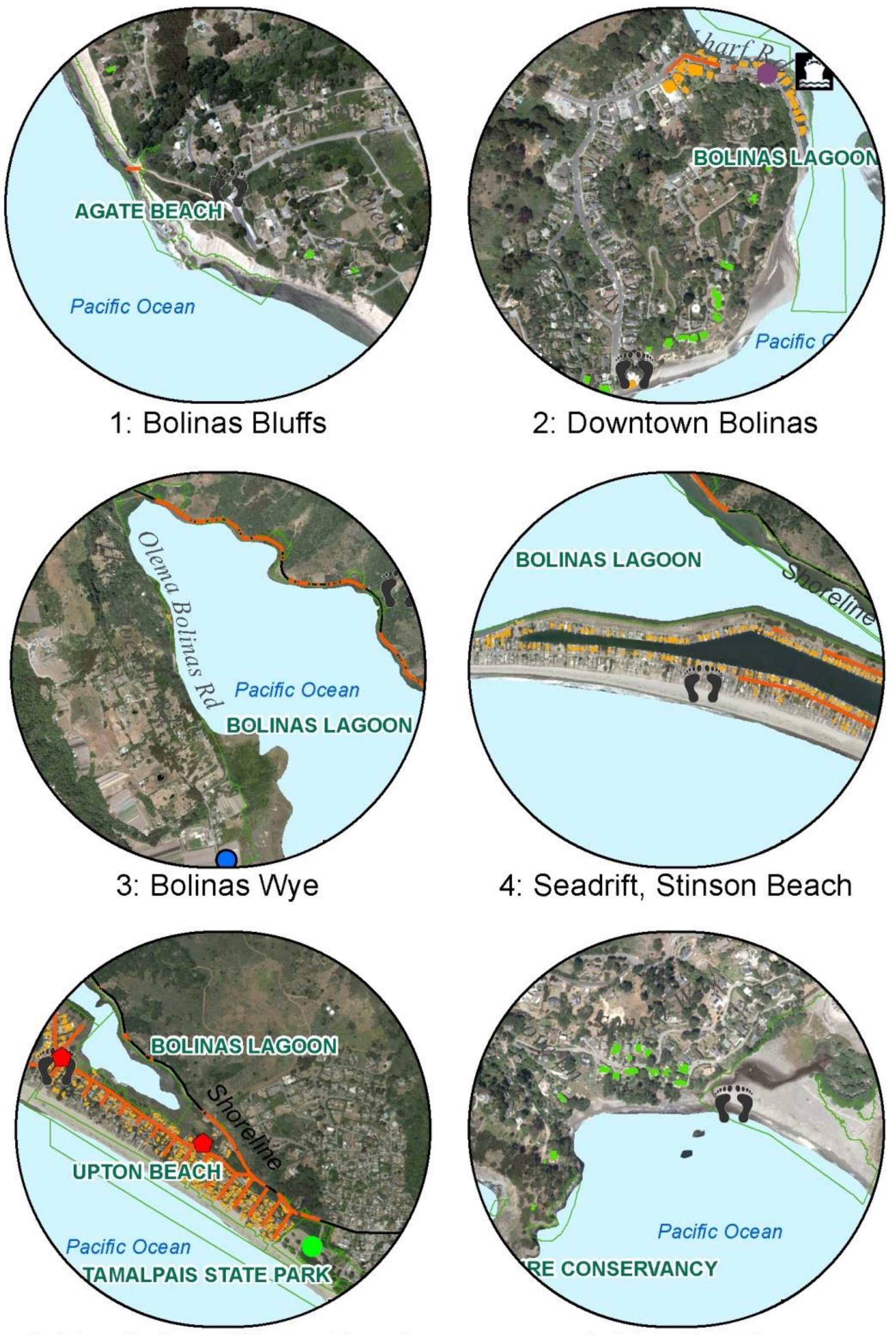
Sea Level Rise & Storm Scenario 3
- 20"+20-year storm surge

Vulnerable Buildings
- @ 20"+20-year storm surge (flooding)
- @ 20" sea level rise only (erosion)

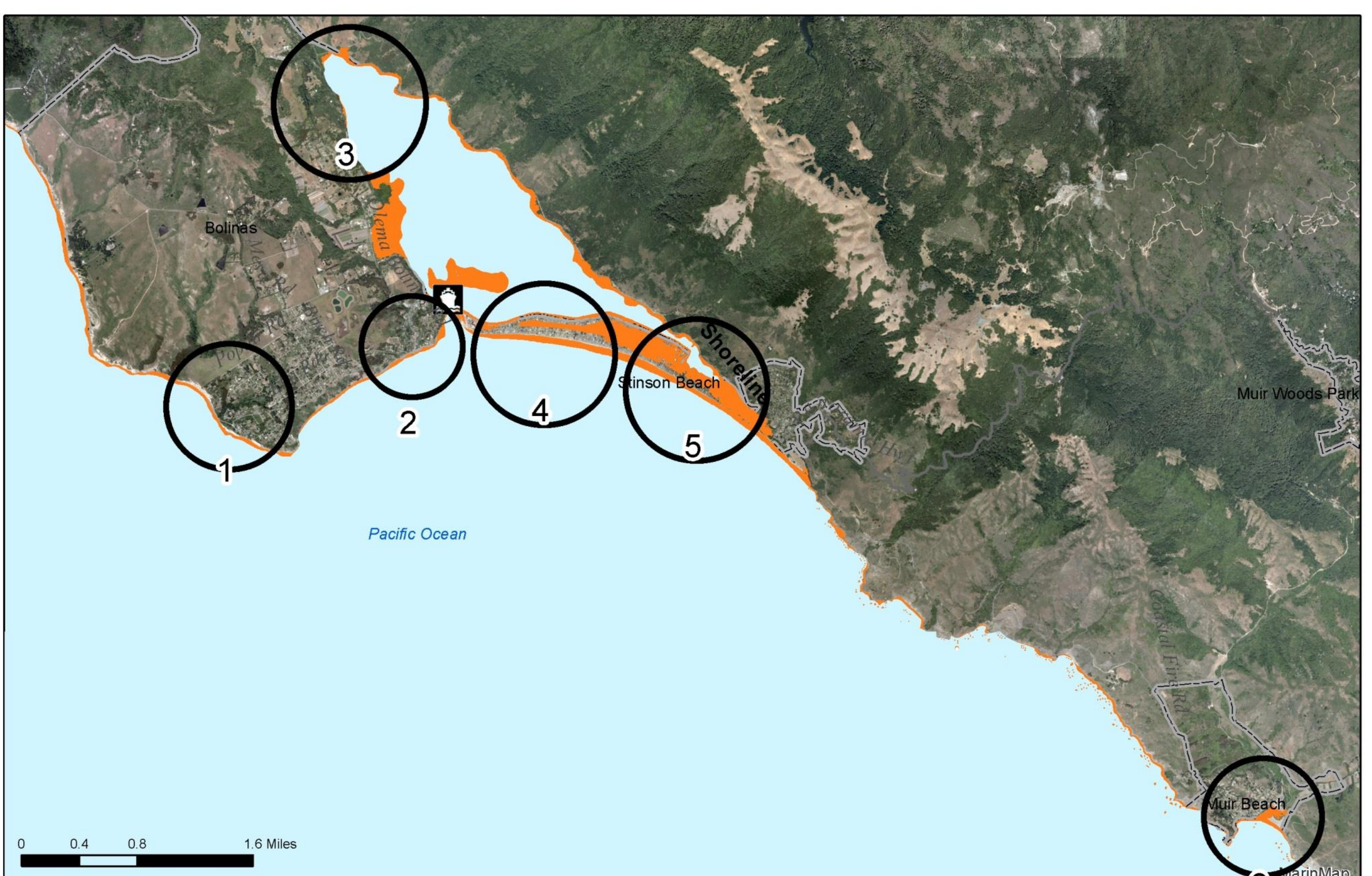
Vulnerable Roads
- @ 20"+20-year storm surge

Other Vulnerable Assets
- Park
- Access Point
- Port
- Agriculture
- Emergency
- Historic
- Recreation

Location Indicators
- Communities
- Water



1: Bolinas Bluffs
2: Downtown Bolinas
3: Bolinas Wye
4: Seadrift, Stinson Beach
5: The Calles, Stinson Beach
6: Muir Beach



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Date:
2/6/2018

EXECUTIVE SUMMARY

Map 86. Northern Marin Coast 2050 Sea Level Rise and Storm Surge Expectations

MEDIUM-TERM | Scenario 3:
20 in. Sea Level Rise
+ 20-year Storm Surge

By 2050, high tides could adversely impact overwater and low-lying shoreline locations in Inverness and East Shore west of Shoreline Highway and east of Sir Francis Drake Boulevard on a regular basis. Twenty inches of sea level rise combined with a 20-year storm surge could reach 270 parcels, 156 buildings, and 4 miles of road. Bluff erosion could compromise another 22 buildings in Dillon Beach at twenty inches of sea level rise. Sir Francis Drake Boulevard, Shoreline Highway, and roads to Lawson's Landing would be subject to increased tidal flooding due to high tides and potentially hazardous flooding during storms, especially near creeks. Several recreational facilities and access points to the bay in all of West Marin's northern communities would face prolonged closures, and require repairs or relocation. Aquaculture operations would face significantly higher tides that could reduce the amount of usable habitat and require operational changes.

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EXECUTIVE SUMMARY

End of Century Expectations (Scenarios 4 & 5)

By 2100, higher high tides at 80 inches of sea level rise could adversely impact the locations flooded in the near- and medium-terms, and significant portions of the areas that previously only suffered storm surge flooding. Tidal flooding would reach beyond State Route 1 and Sir Francis Drake Boulevard in low-lying areas. Daily tidal flooding at 40 inches, or about 3.5 feet with a 100-year storm surge could flood 1,150 parcels, 450 buildings, and 7.4 miles of road.

At 80 inches of sea level rise with a 100-year storm surge these areas and further inland could flood. Flooding could impact an additional 1,300 parcels, and a total of 1,075 buildings and 18 miles of road, including all low-lying areas in Muir Beach, Stinson Beach, Bolinas, Inverness, and East Shore. The damage would be exacerbated by storm water flowing down the hills into the ocean or bay. Destroyed building stock could compromise over $300 million (2015 dollars) in assessed value. Vulnerable single family homes amount to $855 million in market value (2015 dollars). In addition, bluff erosion could destroy several hundred buildings in Muir Beach, Bolinas, and Dillion Beach. Below is a list of additional areas that could be flooded.

- Locations presented in near- and medium-term scenarios 1, 2, and 3 would only see more frequent and severe flooding if they still exist.
- Shoreline Highway along East Shore.
- Buildings in Inverness west of Sir Francis Drake Boulevard.
- Downtown Bolinas up to Brighton Road, including the market, library, community center, gas station, museum, historic buildings and other valued places.

At this level and frequency of flooding, many of the vulnerable properties and roadways could not exist in their current state, thus, completely changing West Marin's look, feel, livability, economic activity, and accessibility; warranting a forward thinking examination of and funding for adaptation measures well before these risks arise.

IMPACTS AT-A-GLANCE: SCENARIO 5

2,772 acres flooded @ MHHW	**3,000+ residents plus tourists**	
2,846 acres flooded @ MHHW +100-year storm surge	**457 agricultural acres** (mostly ranch)	**569 acres of aquaculture**
1,075 buildings could flood, 719 could suffer from erosion	**Property Owners County of Marin Caltrans Bolinas Public Utility Stinson Beach Water Fire Districts National Parks Service California State Parks AT&T**	
$855.4 million in assessed property value[5]		
18 miles of wet road, 1 port, 1 marina, 1 boat launch		
Beaches Tidal Marshes Creeks Eelgrass beds Estuaries		

Inverness Yacht Club septic system covers. Credit: S. Callow

[5] 2016 dollars

EXECUTIVE SUMMARY

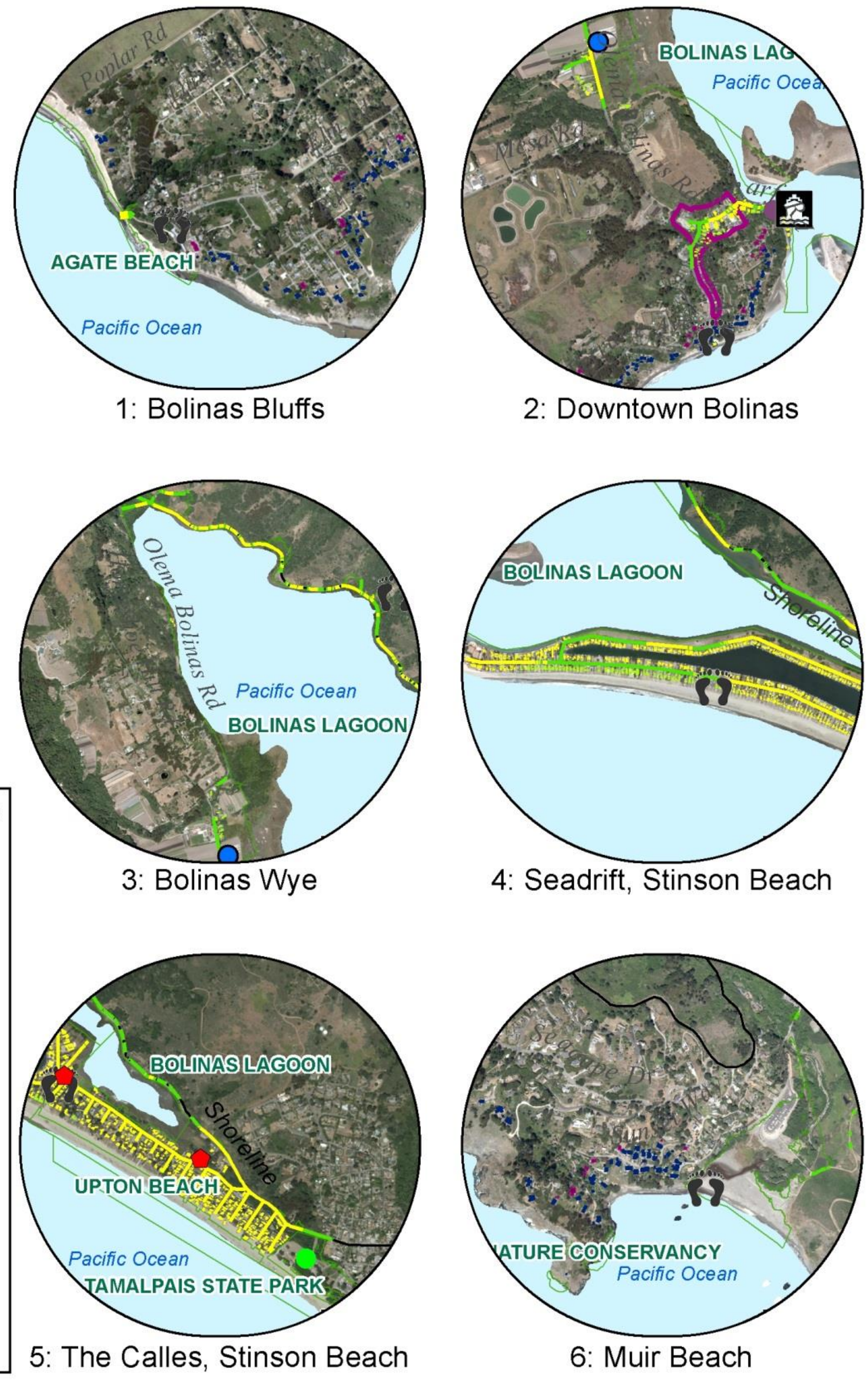
Map 87. Southern Marin Coast Long-term Sea Level Rise and Storm Surge Expectations

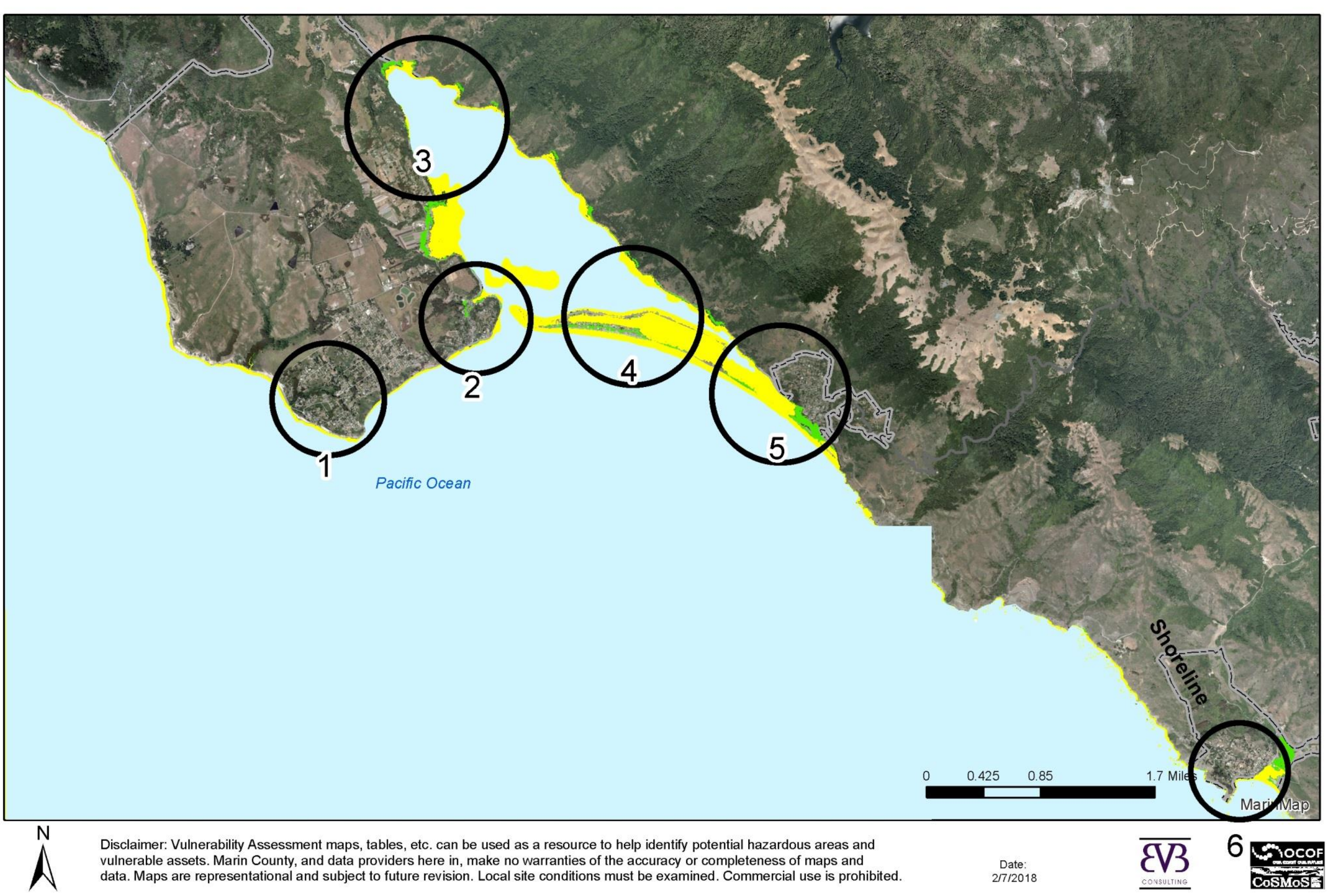
LONG-TERM

Scenario 4: 40 in. Sea Level Rise +100-year Storm Surge
Scenario 5: 80 in. Sea Level Rise +100-year Storm Surge

By 2100, the remaining properties in lower Stinson Beach could face tidal and/or storm surge flooding. Those that do not, may experience difficulties traveling to their home or business. Shoreline Highway, on the way to Bolinas, may not sustain continued flooding and erosion as is, preventing through traffic. In Bolinas, properties beyond Wharf Road up to Olema-Bolinas Road, Brighton Avenue, and north of Olema-Bolinas Road in the Gospel Flats area would face tidal and/or storm surge flooding, impeding access to the main activity centers. At the low end estimate for 2100, 40 inches of sea level rise plus a 100-year storm surge, could reach 700 parcels, 619 buildings, and almost 6 miles of road in West Marin's southern communities. Beach erosion in Stinson Beach could compromise 275 buildings. Bluff erosion in Bolinas and Muir Beach could compromise 330 buildings in. At the high end estimate for 2100, 80 inches of sea level rise plus a 100-year storm surge, flooding could reach 741 parcels, 758 buildings, and 10.5 miles of road in. Beach erosion in Stinson Beach could compromise 51 more buildings than at 40 inches of sea level rise. Bluff erosion in Bolinas and Muir Beach could threaten 276 more buildings than 40 inches of sea level rise. All roads vulnerable in previous scenarios, if accessible, would be regularly impassable. Existing recreation sites along the Pacific Ocean, including Stinson and Bolinas beaches, would not be usable. Muir beach would be compromised.

Sea Level Rise & Storm Scenarios 4 & 5	Other Vulnerable Assets
40"+100-year storm surge	Park
80"+100-year storm surge	Historic District
Vulnerable Buildings	Access Point
@ 40"+100-year storm surge (flooding)	Port
@ 80"+100-year storm surge (flooding)	Agriculture
@ 40"sea level rise only (erosion)	Emergency
@ 80"sea level rise only (erosion)	Historic
Vulnerable Roads	Recreation
@ 40"+100-year storm surge	**Location Indicators**
@ 80"+100-year storm surge	Communities
	Water





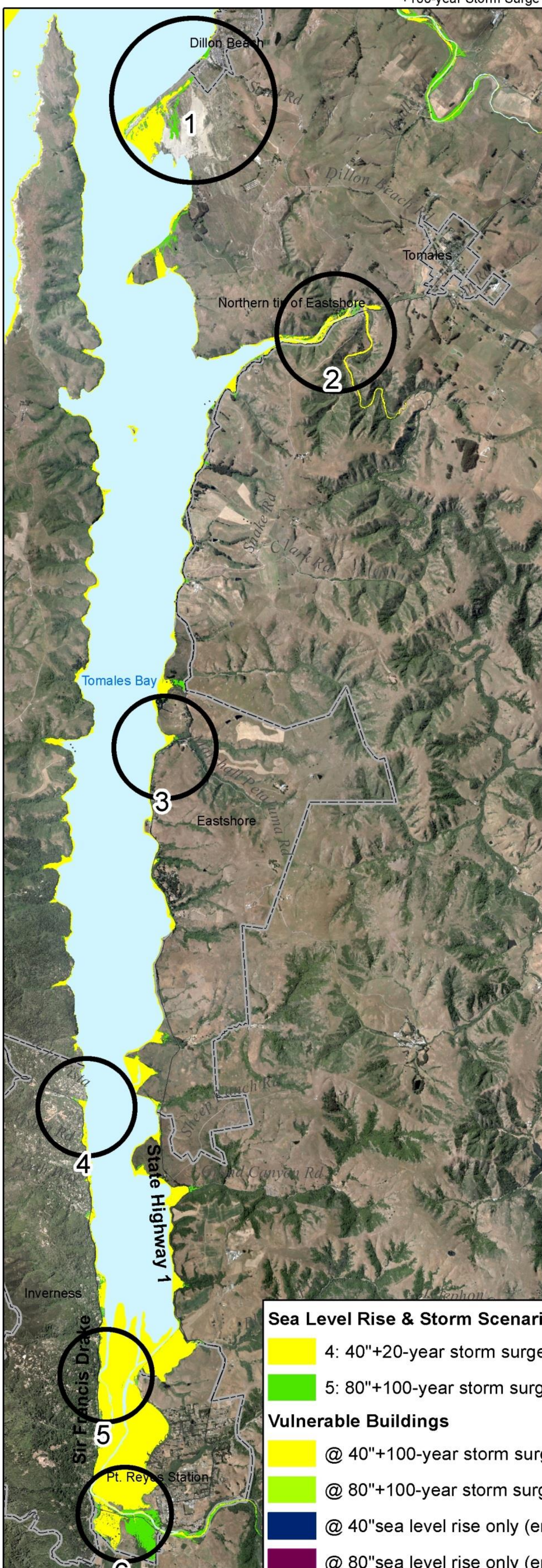
Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future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

Date:
2/7/2018

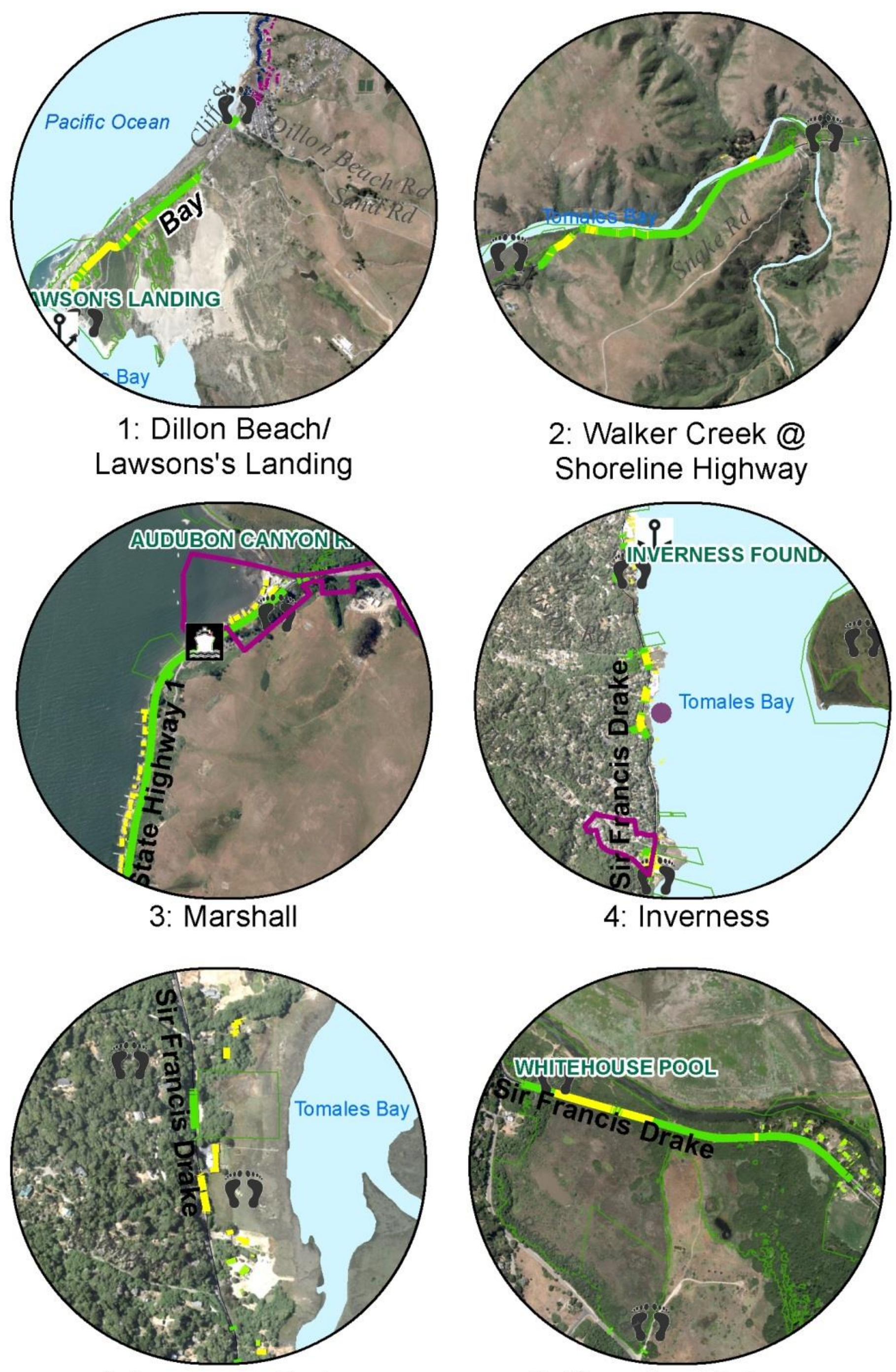
EXECUTIVE SUMMARY

Map 88. Northern Marin Coast Long-term Sea Level Rise and Storm Surge Expectations

LONG-TERM | Scenario 4: 40 in. Sea Level Rise +100-year Storm Surge Scenario 5: 80 in. Sea Level Rise +100-year Storm Surge



By 2100, south and north of Inverness Park and in Inverness, high tides could reach Sir Francis Drake Boulevard. At their current elevations, shoreline development would need to be elevated or relocated. Buildings along Sir Francis Drake Boulevard on the way to Point Reyes Station from Inverness may have already relocated, as would those currently over or along Tomales Bay in East Shore. Flooding would reach beyond State Route 1 in Marshall. In the northern portion of the study area, 40 inches of sea level rise plus a 100-year storm surge could reach 324 parcels, 197 buildings, and 1.3 miles of road, mostly Sir Francis Drake Boulevard. In Dillon Beach, bluff erosion could compromise 43 buildings. At the high end estimate for 2100, 80 inches of sea level rise and a 100-year storm surge, flooding could reach 364 parcels, 465 buildings, and 6 miles of road. Flooding would reach properties and roads west of Sir Francis Drake in Inverness and east of Shoreline Highway in East Shore about 3 miles outside of Point Reyes Station and north of Marshall. All overwater and nearshore development in its current state would be severely compromised, if not submerged at the floor level, during high tides and/or storm surges. In Dillon Beach, 100 buildings would be vulnerable to bluff erosion. Access to Lawson's Landing would also be subject to regular flooding and erosion. Existing bay access points and recreation sites would be flooded out. Aquaculture and ranch lands abutting creeks would face dramatically different conditions.



1: Dillon Beach/ Lawsons's Landing

2: Walker Creek @ Shoreline Highway

3: Marshall

4: Inverness

5: Inverness Park

6: Shoreline Highway, Pt. Reyes Station

Sea Level Rise & Storm Scenarios 4 & 5
- 4: 40"+20-year storm surge
- 5: 80"+100-year storm surge

Vulnerable Buildings
- @ 40"+100-year storm surge (flooding)
- @ 80"+100-year storm surge (flooding)
- @ 40"sea level rise only (erosion)
- @ 80"sea level rise only (erosion)

Vulnerable Roads
- @ 40"+100-year storm surge
- @ 80"+100-year storm surge

Other Vulnerable Assets
- Park
- Historic District

- Historic
- Access Point
- Marina

Location Indicators
- Communities
- Water

N 0 0.45 0.9 1.8 Miles

EVB CONSULTING Date: 2/7/2018 OCOF CoSMoS

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 here in, 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.

EXECUTIVE SUMMARY

Asset Vulnerabilities

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 locations over or bordering waterways (Inverness, East Shore, and Bolinas) can impact an individual building's vulnerability to sea level rise and storms.

In the near-term, the most vulnerable built areas are the Calles and Patios neighborhoods, with nearly 300 residential properties subject to flooding. In addition, 30 properties along the shoreline of Bolinas Lagoon, 38 properties in Inverness, and 66 properties impacted in East Shore could be vulnerable to tidal flooding.

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 by the end of the century.

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.

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 could see chronic flooding and 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, mostly private, concentrated in or near Stinson Beach, may be exposed to sea level rise and storm surge flooding. Roadways exposed in near-term include Shoreline Highway between Bolinas and Stinson (20 percent compromised in Coastal Zone), Calle del Arroyo, all private Calles and Patios streets in Stinson Beach, Wharf Road in Bolinas, and several creek crossings and bridges

In the medium-term, 5.2 miles may be exposed, including additional roadways in Stinson Beach, including Seadrift, and Bolinas. In long-term scenario 5, 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 number of roads and lack of alternative routes. Additionally, roads along or crossing creeks, such as Easkoot, Keys/Walker, Lagunitas, and others, experience land-based flooding during storms, exacerbating water levels.

Parking areas can tolerate temporary flooding; however, permanent loss could reduce visitor and residential parking capacity, and increase maintenance needs. Public transit services could be interrupted; impacting residents, visitors, and businesses, with direct impacts in Inverness and Point Reyes Station.

Marin facilities would likely be directly impacted by rising water levels. Key locations include Bolinas Lagoon, and boat launches along Tomales Bay in Inverness and the Eastshore. While water travel has high adaptive capacity to sea level rise, boats, boat lauches, marinas, and piers could see significant damage from storms.

EXECUTIVE SUMMARY

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

In the near-term, 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 East Shore's shoreline 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 on-site wastewater treatment systems (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 in the long-term. Downtown Bolinas depends on a gravity-fed lift station that is also vulnerable to medium-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 in the long-term. 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 East Shore where creek crossings are vulnerable on Middle and Franklin Valley School Roads, and along Shoreline Highway. In the long-term, 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 small areas at the Green Gulch Zen Center in 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.

Stinson Beach Seadrift neighborhood. March. 25, 2015. Credit: CDA

Aquaculture operations' buildings on the shoreline are vulnerable, and as tides push landward, these 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.

Natural Resources: Habitats & Wildlife

The inter-agency report *Climate Change Vulnerability Assessment for the North-central California Coast and Ocean* released by the Greater Farallones National Marine Sanctuary and findings from the ESA Consulting firm 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 Stinson Federal Beach, could be completely lost in the long-term. Roughly 9,000 acres in the estuaries of Tomales Bay, Bolinas Lagoon, and Esteros Americano and San Antonio, and 1,800 acres of wetlands and marshlands could be impacted to varying degrees across all of the scenarios. Sea level rise may push coastal habitats inland where possible; flooding tidal areas more frequently and inland areas with saltwater. The *North-central California Coast and Ocean Vulnerability Assessment* identified the five most vulnerable species to sea level rise as 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 East Shore contain historic districts that could be exposed to sea level rise and storms across all scenarios. In addition to physical impacts, exposure of historic sites can lead to the loss of cultural heritage. Archaeological resources are prevalent in West Marin and, in some cases, are already showing erosion impacts.

Communities

Muir Beach

Muir Beach may not see severe impacts to its built assets in the near and medium-terms. However, intertidal and beach areas could be affected. In the long-term, access to homes and recreational areas in this small community could be compromised by flooding on Pacific. In addition, the emergency route from the Muir Beach public area through the Green Gulch Zen Center could also be flooded, especially combined with creek flooding. Despite little flooding impacts, bluff top erosion could impact over 50 homes.

Stinson Beach

Stinson Beach's built assets most vulnerable to sea level rise and erosion in the near-term include water distribution pipes, OWTS, buildings west of Shoreline Highway, local roads including Shoreline Highway and Calle del Arroyo, the water district office, and Fire Station No. 2.

In the medium-term, 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 2100.

Beachgoers flock to Stinson Beach. Credit: CDA

In the long-term, nearly $200 million of assessed value and $1.5 billion in market value could be exposed to sea level rise and storms. By this time, nearly all roads west of Shoreline Highway could be vulnerable. Flooding from Bolinas Lagoon and Easkoot Creek already occur and could worsen.

Bolinas

The most vulnerable built assets here are the Bolinas Wye, Olema- Bolinas Road, Gospel Flats homes, downtown buildings and roads, and over 200 homes on eroding cliffs along Terrace Avenue on the Big Mesa, Little Mesa, and Surfer's Overlook. All of these areas could see tidal encroachment as early as the near-term, and could worsen in later scenarios. The most vulnerable buildings are those directly above the lagoon on piers along Wharf Road.

EXECUTIVE SUMMARY

If Olema-Bolinas Road, or its creek spanning bridges, becomes dysfunctional for an 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 County of Marin is examining alternatives for redesigning the junction of Olema-Bolinas Road and State Route 1 as part of a lagoon restoration project.

In the medium to long-term, the wastewater lift station that serves Downtown and the Little Mesa is vulnerable. All pipes under flooded and eroding roads are also vulnerable. Also in this timeframe, small scale agriculture in Gospel Flats is threatened, as protective earthen berms could fail under sea level rise conditions.

Olema-Bolinas Road, December 2014. Credit BPUD

Brighton and Agate beaches could disappear by mid-century because they are backed by armored 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 inland migration. If water levels rise high enough, the lagoon will convert to mud flat, then open water, and could overtop the surrounding roadways and properties at high tides.

Inverness

In the near-term, Inverness's most vulnerable built assets include low-lying segments of 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 east of the boulevard.

In the near and medium terms, shoreline areas of Tomales Bay State Park, Martinelli Park, Shell Beach, and others are also vulnerable. With rising waters these sites may shrink and, in some locations, could disappear altogether. Loss of these access points could make recreation much more difficult and negatively impact the tourism economy.

Overall, $11 million of assessed value in buildings could be vulnerable. Inverness residents depend on private and individual propane service and could be cut off if Sir Francis Drake Blvd. and Bear Valley Roads are compromised for an extended period by the end of the century.

Pt. Reyes Station

Pt. Reyes Station's most vulnerable built assets are vulnerable in the long-term. These include NMWD Gallagher well, water distribution pipelines (primarily serving Inverness residents) beneath Sir Francis Drake Blvd. and Shoreline Highway, Shoreline Highway at and south of Green Bridge, and the surrounding wetlands and marshes. Wetlands and marshes are popular visitor attractions and, though high adaptive capacity is anticipated, degradation of these resources could negatively impact Pt. Reyes Station and surrounding ecological communities.

East Shore

All development, private wells, OWTSs, aquaculture facilities, and a number of recreation assets, including the Marconi Boat Launch, Tony's Restaurant, and Nick's Cove, west of Shoreline Highway are vulnerable in the near-term. In addition, Shoreline Highway could see continued and worsening flooding at Walker Creek. 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. Aquaculture operations on land 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 vulnerable because they are already narrow and often backed by bluffs, roadways, or buildings.

In the long-term, greater areas of Shoreline Highway and waste and drinking water issues could also emerge.

Dillon Beach. Credit: Wanderbat

Dillon Beach

In the near-term, Dillon Beach's most vulnerable assets include Bay Drive, which connects Lawson's Landing to the rest of the community, the Coast Springs well, Dillon Beach Resort, Lawson's Landing facilities, grazing lands, and a few bluff top homes. Further north, bridges along Middle Road and Valley Ford Franklin School Road could flood and prevent continuous ground transportation.

In the long-term, the Oceana Marin sewer system and over 100 homes on the bluff tops could be impacted by increased erosion associated with sea level rise.

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

East Shore. May 30, 2008. Credit: CDA

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.[6] Sea level at the San Francisco tide gauge has risen 8 inches over the past century. 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.[7]

In 2012, the National Research Council (NRC) projected that by 2100 sea level in California south of Cape Mendocino may rise 66 inches.[8] This research is the basis for this assessment. A more recent assessment released by the Ocean Science Trust, "Rising Seas in California," concludes that more rapid ice loss from Greenland and the Antarctic is occurring than previously predicted, thus increasing the sea level rise risk for California above the predicted global average.[9]

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.[10] 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.

[6] 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.

[7] Ibid.

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

[9] Griggs, G., Árvai, J., Cayan, D., DeConto, R., Fox, J., Fricker, H.A., Kopp, R.E., Tebaldi, C., Whiteman, E.A. (California Ocean Protection Council Science Advisory Team Working Group). Rising Seas in California: An Update on Sea-Level Rise Science, Ocean Science Trust, April 2017.

[10] 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

King tides preview future water levels. Brighton Road, Bolinas. 7.3 ft. tide. 9 a.m., Dec. 12, 2012. Credit: K. Moor

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 goal of this assessment is to provide localized information about sea level rise, in combination with storms, and its associated flood threats.

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.

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,

INTRODUCTION

technical, and public process to understand and prepare for the impacts of sea level rise.

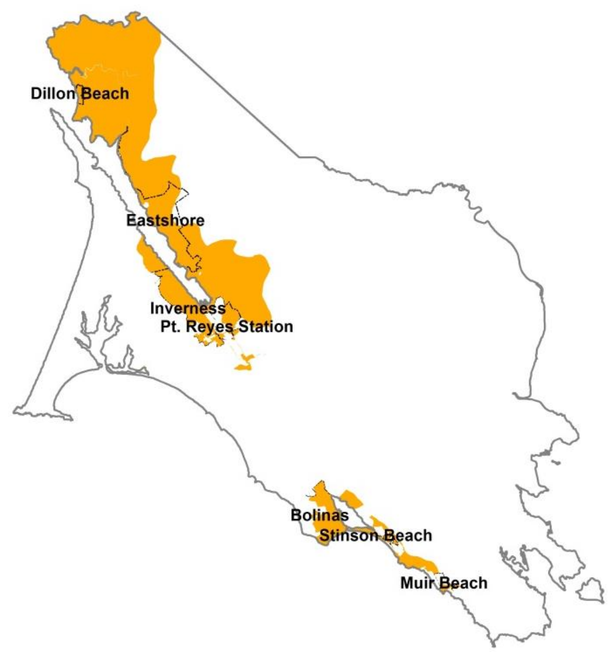
Marin County has had a focus on sea level rise planning and climate action for several years. The County is updating its Local Coastal Program (LCP) to reflect the changing risks to its coastal areas and to develop appropriate policies and actions to avoid and minimize the risk of disaster and harm to its residents, infrastructure, and coastal resources. Proposed *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.[11] 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 provides information for an LCP update.

The LCP regulates lands in the Coastal Zone (see Map 1) 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,[12] although regional impacts to Shoreline Highway could affect those communities as well. 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 is at http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm.

The non-federal portion of the Marin County Coastal Zone covers approximately 48,255 acres [Pursuant to the Federal Coastal Zone Management Act of 1972 (16 U.S.C. 1451, et seq.)].

Map 1. Study Area (in orange)



[11] 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

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

INTRODUCTION

This Assessment is organized into three major sections: (1) 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. 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 read 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 completed so far.

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:

- 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 East Shore, Sir Francis Drake Boulevard. 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, which could have significant economic impacts.
- Storm surges 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 and 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, wildfires, and stormwater 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. Adapting governance practices will be essential.

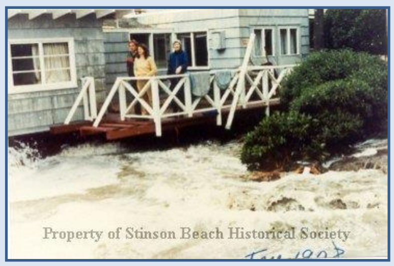
INTRODUCTION

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.

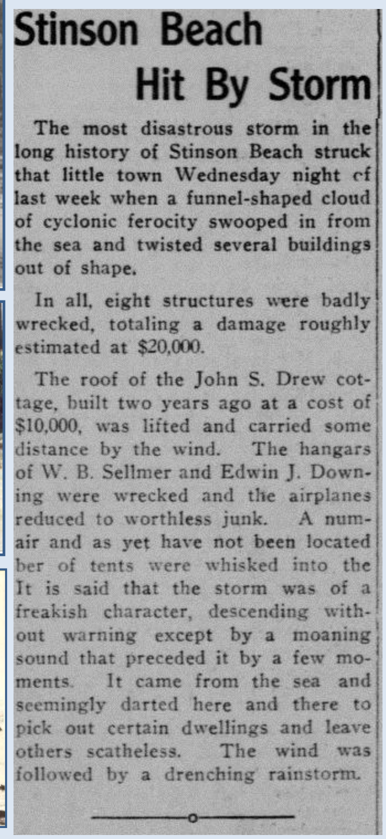
1956 Storm devastates the community, flooding Easkoot Creek, inundating the Hwy 1 bridge, and damaging the Calles neighborhood. Resulting mudslides isolated Stinson Beach and neighboring Bolinas' streets were described as "rivers of mud."

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 number of tents were whisked into the air and as yet have not been located. 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 CalAdapt[13] framework (see Figure 1) provides background and a guide to climate change analysis and is used in the C-SMART Vulnerability Assessment process as a tool to use in deciding to accommodate or protect against rising waters, or retreat from hazardous areas.

Figure 1. Vulnerability Assessment Phases (adapted from CalAdapt)

Phase 1| Exposure: Apply potential geographic changes in sea level, storm events, geomorphology, and the built and natural assets within that geography.

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 the assets' ability to respond successfully to, or recover from, sea level rise and storm impacts.

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.

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 nearest the limit of the exposure area 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 during storms 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. Geomorphology was also supplemented in a separate analysis of accelerated erosion in Bolinas and Stinson Beach.

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 sea level rise, Marin County used a scenario-based approach. Assessing a range of scenarios provides a framework for analyzing the vulnerability of Marin's assets to sea level rise and storm scenarios.

[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

[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.

METHODS

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 from CoSMoS (OCOF)

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[17]	Long- High

The five scenarios in Table 2 were selected for the C-SMART Vulnerability Assessment and are derived from the U.S. Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS). The scenarios 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. Note that while all the selected scenarios include storms, sea level rise and storms will have different impacts and may warrant alternative approaches. Similarly, policies seeking to reduce vulnerability will need to address sea level rise independently from storms. Standards for storm damage prevention already exist and are implemented on the coast. These policy mechanisms and methods can serve as examples in adapting to sea level rise.

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 a level based on additional research theorizing the worst case for sea level rise by 2100 could be 70 inches globally,[18] corresponding to the 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 additional 373, 381, 1,091, and 1,165 acres respectively.

The scenarios include storms because ocean levels increase during a storm and often cause damage. Creek flooding would only increase flood levels and could impact locations not vulnerable to sea level rise. The storm frequencies presented in the scenarios in Table 2 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. Over the course of 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 storms that could have greater impact.[19]

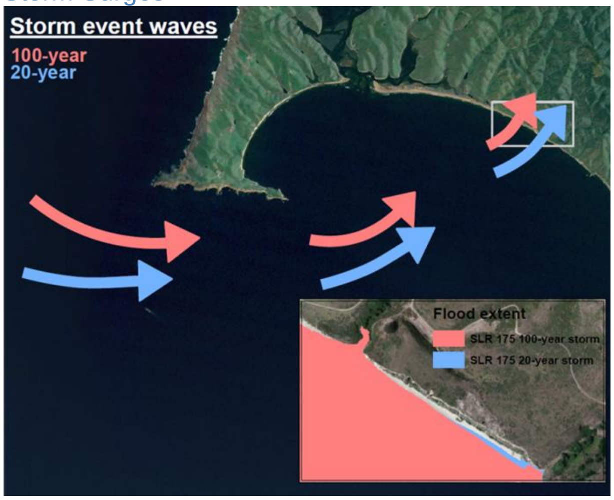
[17] The upper limit for 2100, scenario 5, was selected based on: *Rising sea levels of 1.8 meter in worst-case scenario, researchers calculate.* Science Daily Online News. University of Copenhagen. Oct. 14, 2014. http://www.sciencedaily.com/releases/2014/10/141014085902.htm Original published in the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

[18] *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.

[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

METHODS

Map 2. Water direction during 20 and 100-year Storm Surges



Different storms frequencies have different intensities and storm patterns. Source: USGS

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 roll to shore and where wave energy is focused. Additionally, as waves change direction to approach the shore head on, energy and height are lost. This is especially common at southern-facing beaches of Muir Beach and Stinson Beach. This is called non progressive flooding. Another reason for non-progressive flooding is the complex nature of beach erosion simulated by CoSMoS. Each scenario used the same starting beach profile and allowed the profile to erode based wave height, length, and angle of approach, and the stronger the storm the greater the impact.[20]

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 Ocean Protection Council study (2009). Distances 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 (for more detail on methods see *California Coastal Erosion Response to Sea Level Rise Analysis and Mapping* report).[21] The resulting bluff and shoreline erosion GIS mapping layers were overlaid with buildings, roads, and other GIS based asset layers that could be susceptible to erosion.

Evidence shows that winter storms (i.e., extra-tropical cyclones) have increased in frequency and intensity since 1948 in the North Pacific,[22] 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 21st century[23] resulting in no significant changes to the wave heights for the Marin Coast compared to the last several decades.[24,25]

20 Email Communication with USGS A. O'Neil. B. Van Belleghem. July 16, 2015.

21 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.

22 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.

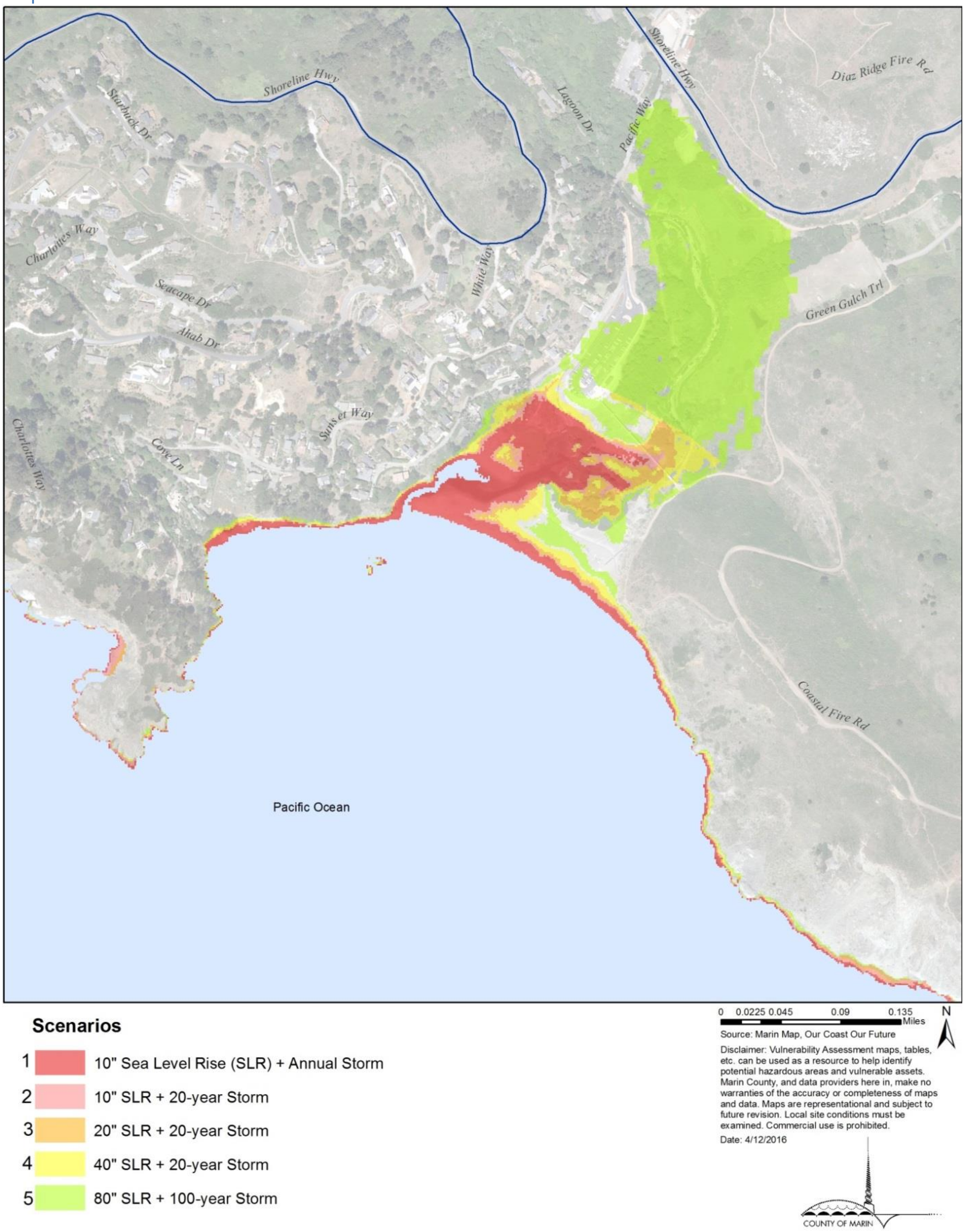
23 Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai, 2013: Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis.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

24 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.

25 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*

METHODS

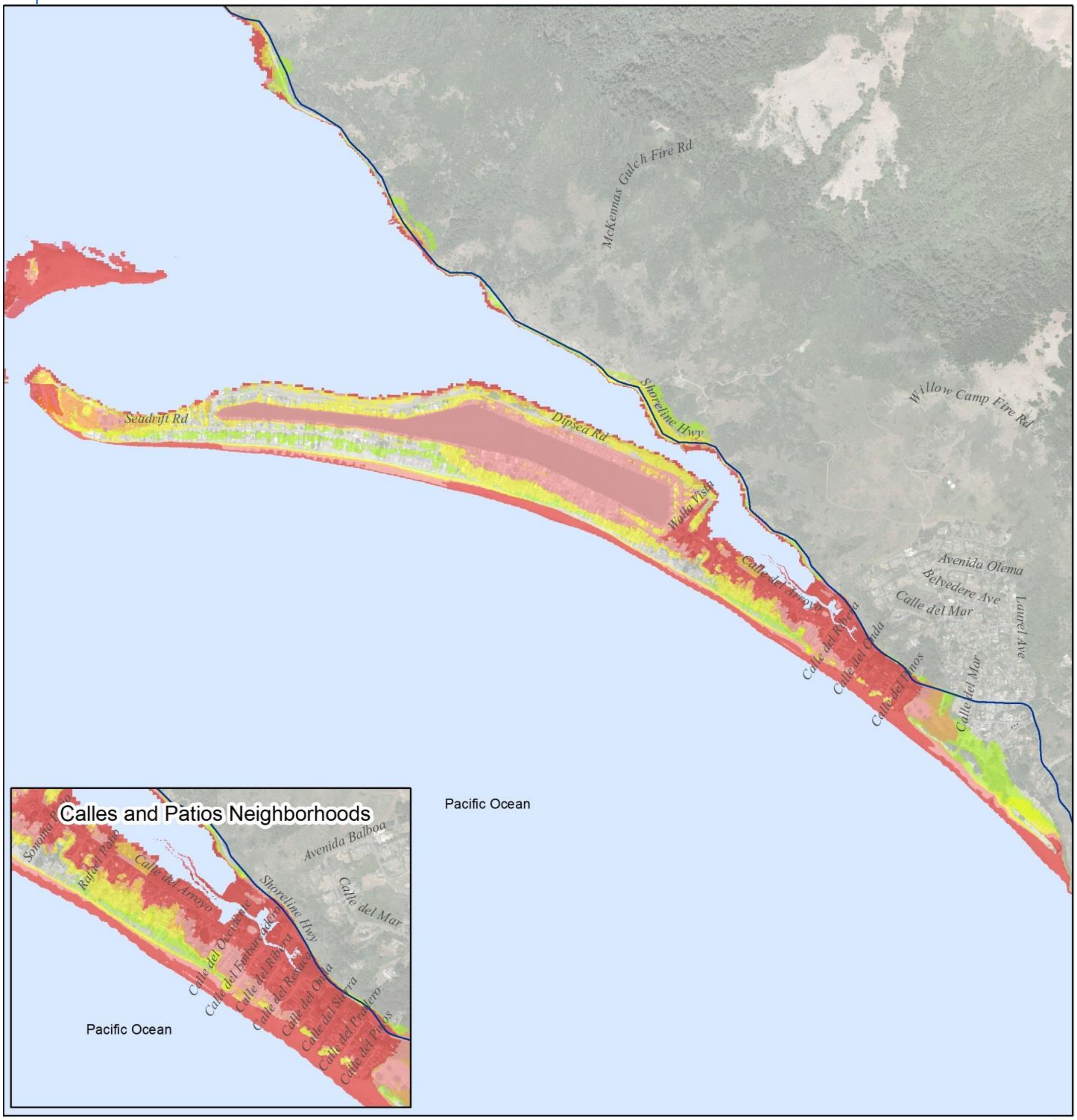
Map 3. Muir Beach Sea Level Rise Scenarios



Note: Muir Beach coastal access, parking lot, and habitat areas were reconfigured in 2013, after model imagery was taken and analyzed.

METHODS

Map 4. Stinson Beach Sea Level Rise Scenarios



Scenarios

1 10" Sea Level Rise (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

0 0.075 0.15 0.3 0.45 Miles

N

Source: Marin Map, Our Coast Our Future

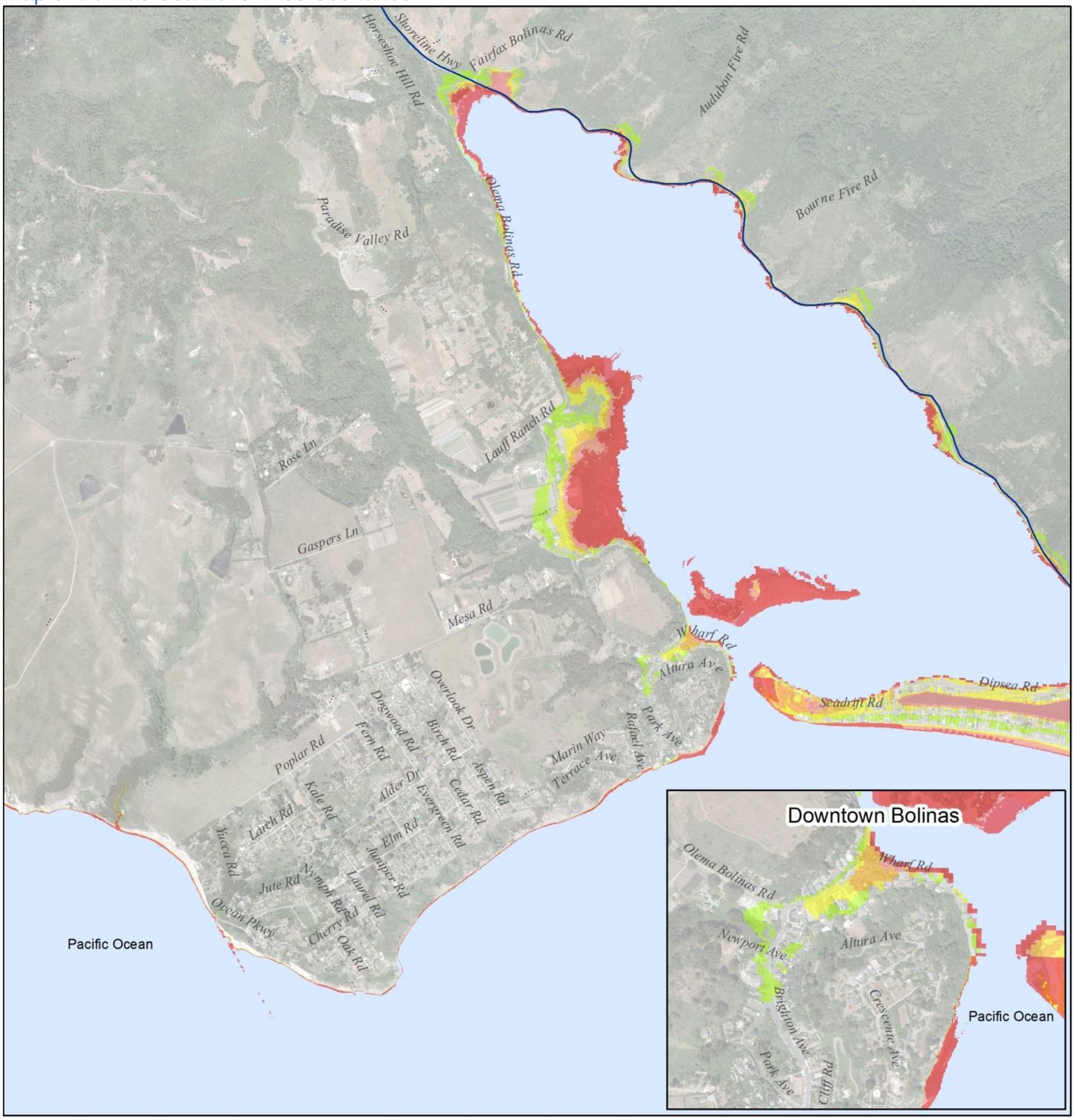
Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future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

Date: 4/12/2016

COUNTY OF MARIN

METHODS

Map 5. Bolinas Sea Level Rise Scenarios



Scenarios

1 10" Sea Level Rise (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

0 0.1 0.2 0.4 0.6 Miles

N

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 here in, 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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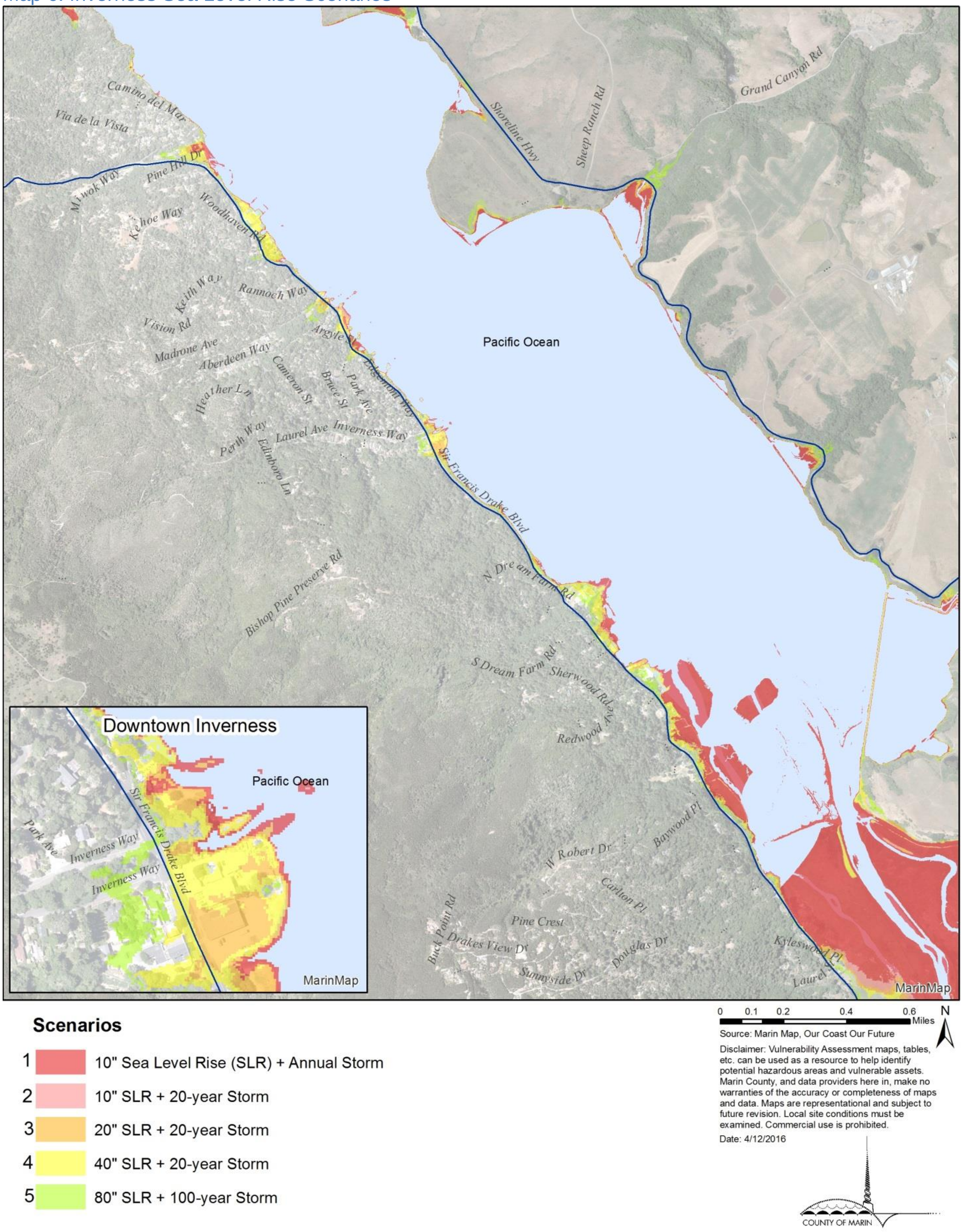
COUNTY OF MARIN

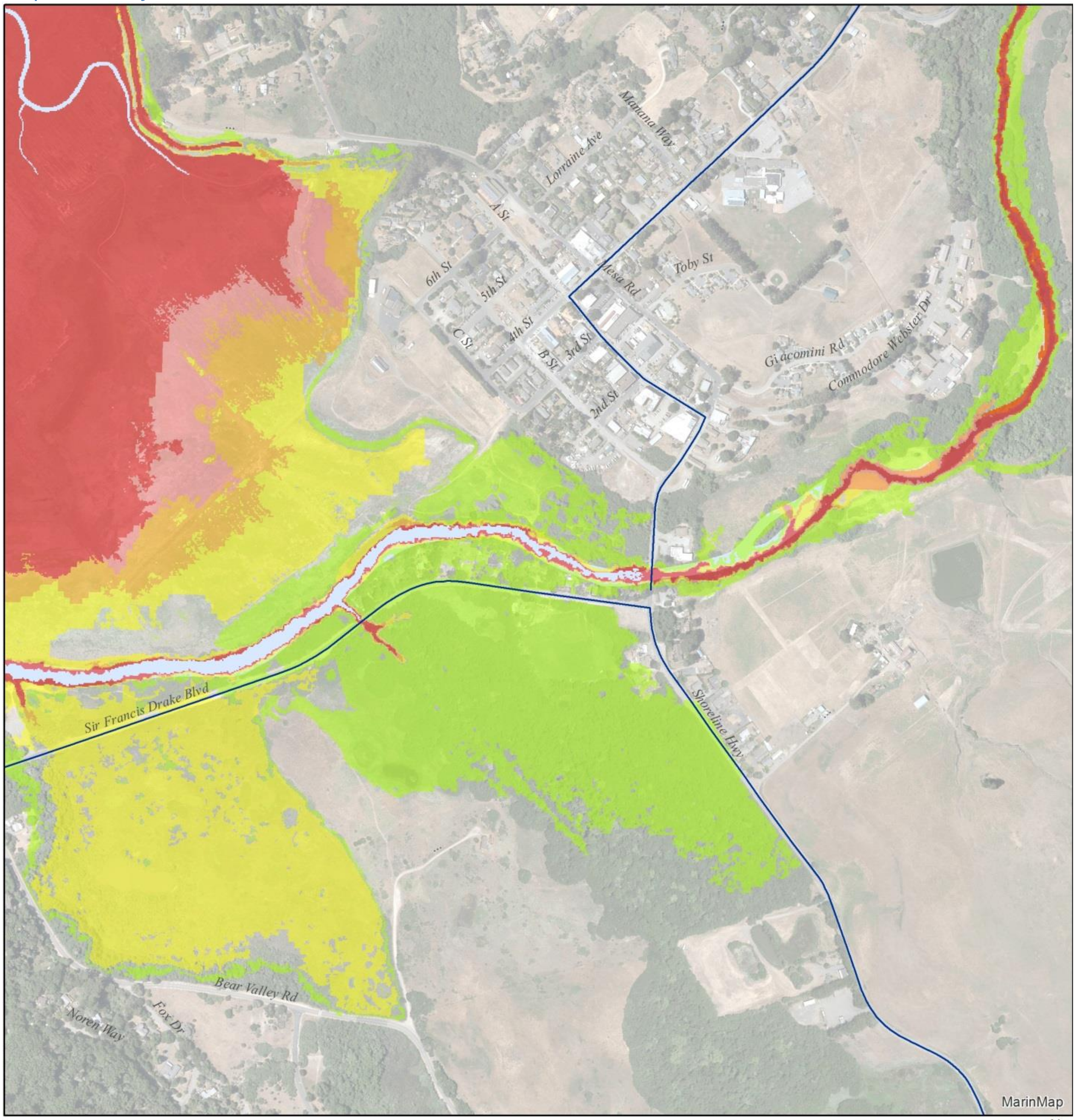
METHODS

Map 6. Inverness Sea Level Rise Scenarios



METHODS

Map 7. Pt. Reyes Station Sea Level Rise Scenarios



Scenarios

1. 10" Sea Level Rise (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

0 0.035 0.07 0.14 0.21 Miles

N

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 here in, 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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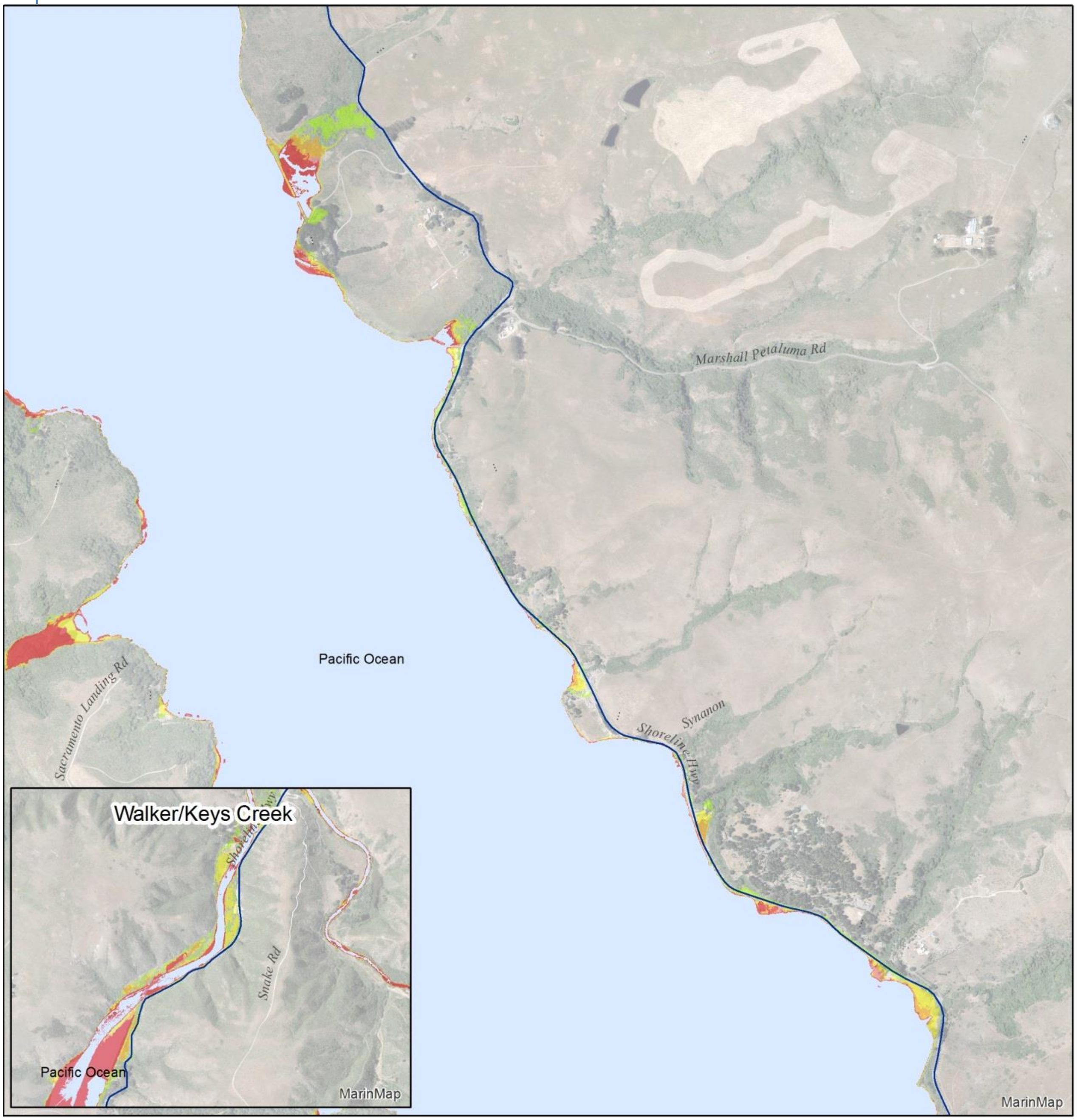
COUNTY OF MARIN

METHODS

Map 8. East Shore Sea Level Rise Scenarios



Scenarios

1 10" Sea Level Rise (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

0 0.075 0.15 0.3 0.45 Miles

N

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 here in, 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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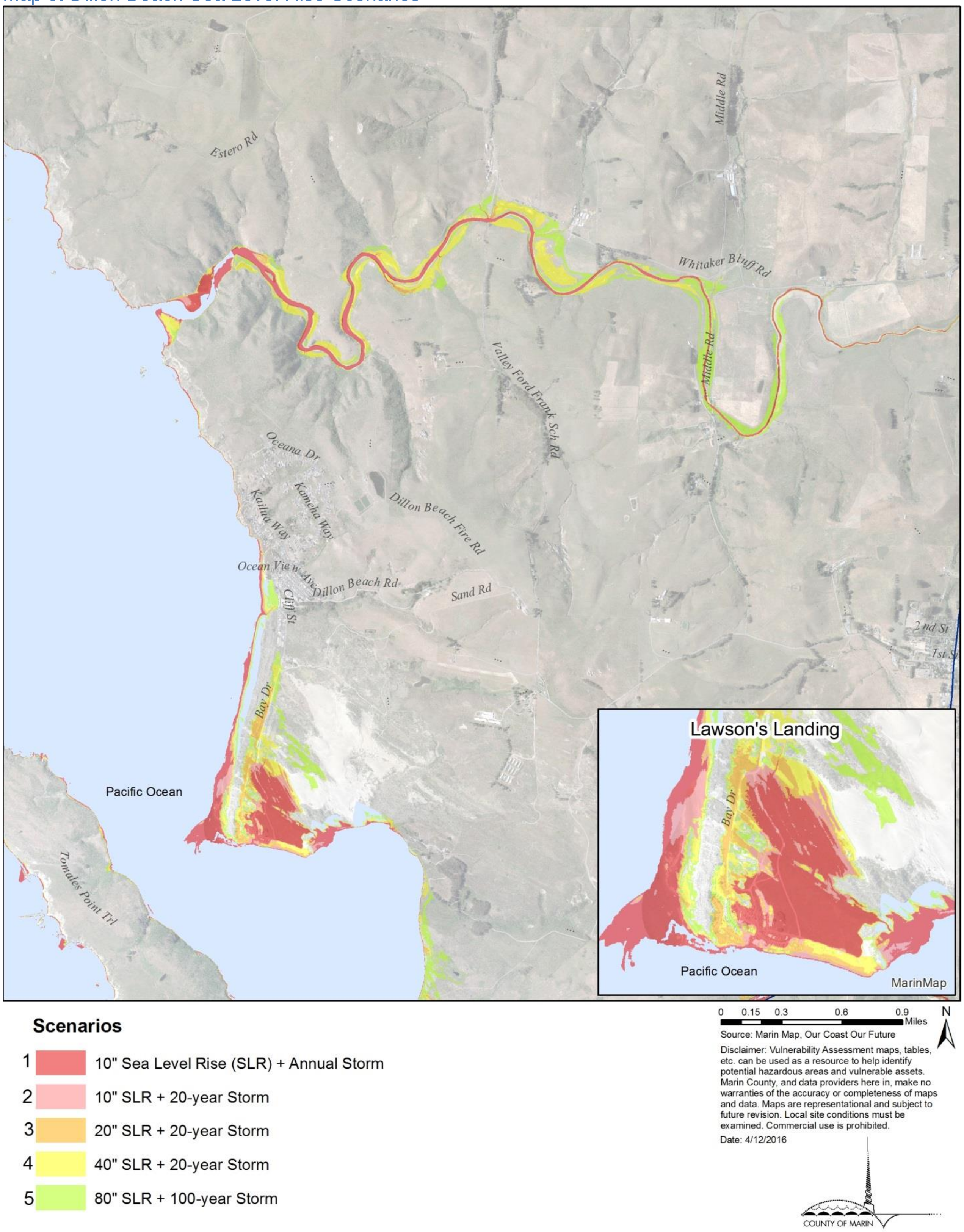
COUNTY OF MARIN

METHODS

Map 9. Dillon Beach Sea Level Rise Scenarios



METHODS

The high degree of uncertainty and differing assumptions in carbon emissions used in sea level rise modeling results in a wide range of onset, or timing, conclusions, especially further out in time. This uncertainty is exacerbated by the non-linear growth rate of sea level rise[26,27] and wave evolution. 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 users to view the timeframe a sea level could occur based on the various published estimates on the OCOF website http://data.prbo.org/cadc/tools/sealevelrise/compare/

Even if the world limits GHGs to stable levels in the atmosphere, sea level rise could continue. Moreover, even if the global population reduces GHGs to levels where atmospheric concentrations decline, the decline could be slow, sea levels could continue to rise for decades, and hundreds of years could pass before sea level stabilizes or drops.[28,29]

Another limitation is that OCOF's estimates are based on 2010 elevation data, and does not incorporate recent changes to the landscape. For example, a project at Muir Beach occurred in 2013, and it is possible the parking lot realignment and wetland restoration could affect flooding outcomes differently than the scenarios estimate (see Figure 2).[30] Local expertise and context is provided to highlight concerns the CoSMoS model may not predict.

Figure 2. Muir Beach Parking Lot Reorientation and Habitat Restoration

BEFORE (used in model)

Source: Marin Map

CURRENT (Completed in 2013)

Source: NPS

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

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

[28] 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

[29] 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

[30] 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

Other known issues are:

- Stinson Beach: Sea level rise 20 inches with a 20-year storm likely shows under-predicted flooding extents given beach profiles and adjacent flooding behavior. Sections with particularly disproportionate predictions in flooding extents were corrected to reflect probable flooding extents based on beach topography and flooding performance of comparative scenarios. Non-progressive flooding is 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 and inaccuracies near docks. Thus, 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 show 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.[31,32,33,34,35,36,37]

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.

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, along with Department of Fish and Wildlife sources for wildlife species, habitats, fishing piers, marinas, access points, and ports. All of these were overlain onto the sea level inundation scenarios to determine which assets would 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 evacutation 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

[31] U.S. EPA. Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans. August 2014.

[32] CURRV-Tijuana River Valley - http://trnerr.org/currv/

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

[34] 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.

[35] http://mitigationguide.org/task-5/steps-to-conduct-a-risk-assessment-2/3-analyze-risk/

[36] 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

[37] 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

scenarios 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.
- 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 storm impact area. Depth 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, a maximum value was selected.

For buildings, additional exposure analysis was conducted to determine the potential damages and monetary losses that could be incurred during storm events. The first method applies FEMA damage levels to all buildings exposed in scenario 5 based on post-disaster inspection tag designations from the HAZUS model as follows: yellow is minor damage of $5,000-17,000, orange, damage is $17,001+, and red is destroyed,.[38] 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 the ESA Consulting firm and Greater Farallones Marine Sanctuary, the bulk of the assessment occurred in sensitivity and adaptive capacity phases. Asset managers were interviewed in person or by phone using the Vulnerability Assessment Tool described earlier. In addition, individual property owners had several opportunities to attend community meetings to provide input on sensitivity and adaptive capacity (see Appendix A). Asset manager interviews asked two questions:

1. How ***sensitive*** is the asset to each exposure or threat?[39]
2. And if sensitive, what is the ***adaptive capacity***, or the asset's ability to maintain its function without further intervention (human action)?[40, 41,42, 43]

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

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

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

[40] 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

[41] 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

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

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

METHODS

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 analysis was conducted for Stinson Beach, Bolinas, and Marshall in East Shore.

Beach Evolution

Shoreline erosion was modeled using only the Bruun rule[44] of 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:

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

[44] 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.

To develop a model that relates beach width to vulnerability level, storm erosion distances were analyzed along with input data from a previous study covering the County,[45] resulting in the beach width thresholds presented in Table 3. 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 3. 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 the 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,

[45] 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.

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.[46]

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 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[47] using a dimensionless indicator (z*) of elevation capital[48] 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 4.

Table 4. 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.[49] 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.[50] 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.[51,52] 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.[53] To read more about this analysis, see Appendix D.

Additional habitat and species analysis from the interagency *Climate Change Vulnerability*

[46] 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.
[47] Cahoon, D. R., Guntenspergen, G. R. 2010. Climate Change, Sea-Level Rise, and Coastal Wetlands. National Wetlands Newsletter, Vol. 32, No. 1. Washington, DC.
[48] 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.
[49] PWA, 2006. Projecting the future evolution of Bolinas Lagoon. Prepared for Marin County Open Space District.
[50] 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.
[51] PWA, 2009. California Coastal Erosion Response to Sea Level Rise – Analysis and Mapping. Prepared for the Pacific Institute.
[52] 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.
[53] PWA, 2006. Projecting the future evolution of Bolinas Lagoon. Prepared for Marin County Open Space District.

METHODS

Assessment for the North-central California Coast and Ocean is incorporated to supplement Marin County's assessment.[54] 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, 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 **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.[55] 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 3 E's, economy, environment, and equity, will be critical. Moreover the California Coastal Commission's Sea Level Rise Policy Guidance suggests assessing the economic, ecological, social, cultural, and legal consequences, cumulative and secondary consequences of both the vulnerabilities and the human responses to them.[56] 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

[54] 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.

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

[56] *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

METHODS

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."[57] 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.

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:[58, 59]

- 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 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

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

59 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.