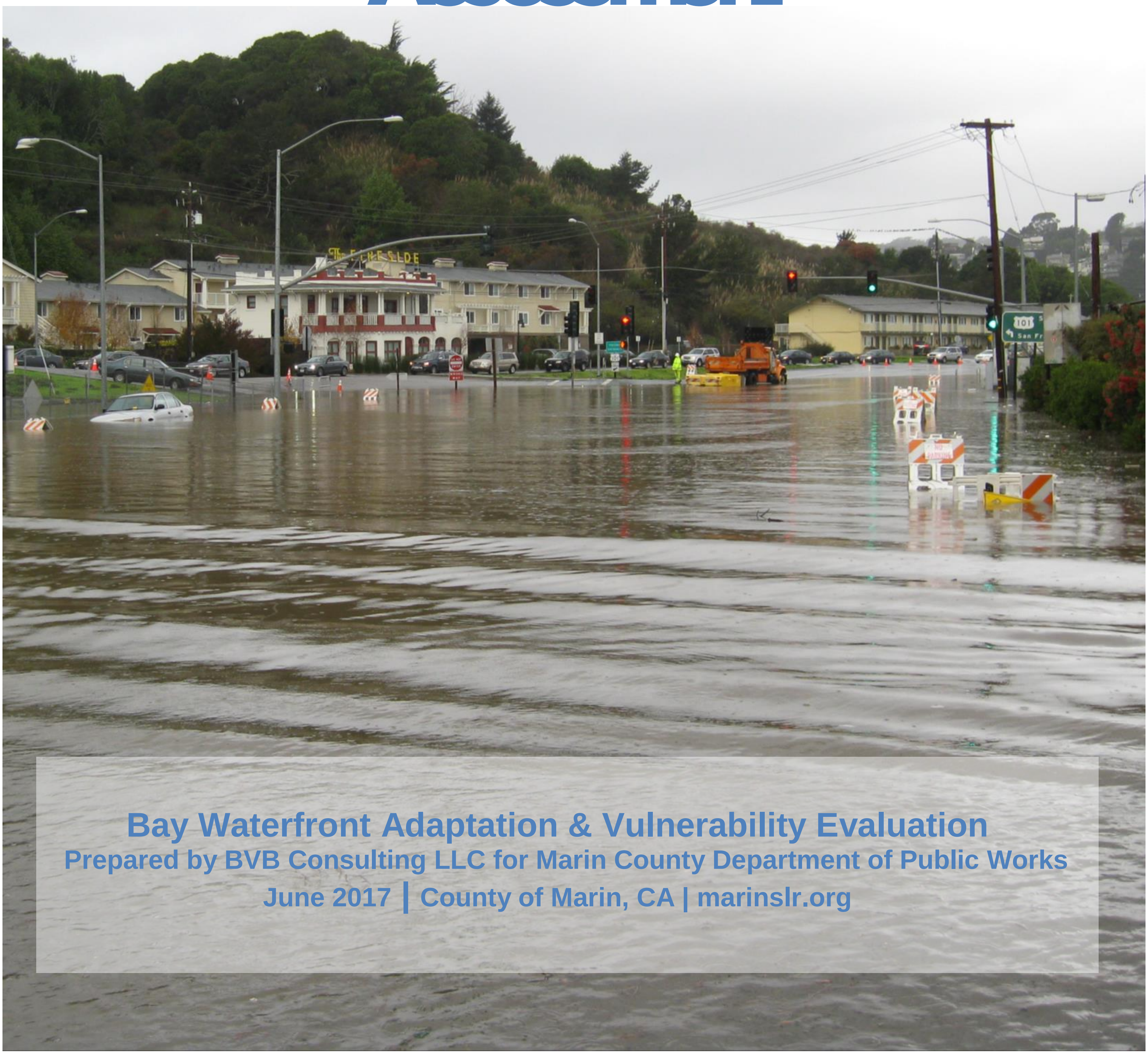
Marin Shoreline Sea Level Rise Vulnerability Assessment



Bay Waterfront Adaptation & Vulnerability Evaluation

Prepared by BVB Consulting LLC for Marin County Department of Public Works

June 2017 | County of Marin, CA | marinslr.org

Marin Shoreline
Sea Level Rise
Vulnerability Assessment

Bay Waterfront Adaptation & Vulnerability Evaluation
(BayWAVE)

With special thanks to the California State Coastal Conservancy's Climate Ready Grant Program
Prepared by BVB Consulting for Marin County Department of Public Works
June 2017| County of Marin, CA | marinslr.org

Cover Photo: Manzanita Parks & Ride, December 2, 2014. Almonte. Marin County Department of Public Works

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ACKNOWLEDGEMENTS

County of Marin Board of Supervisors

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

Project Funders

County of Marin
California Coastal Conservancy

Primary Author

Bridgit Van Belleghem, AICP, BVB Consulting LLC

Additional Author

Alex Westhoff, Planner, AICP, County of Marin CDA

Project Manager

Chris Choo, Program Manager, County of Marin Department of Public Works

Executive Steering Committee

Damon Connolly, County of Marin Board of Supervisors (from September 2016)
Matthew Hymel, County Administrator, County of Marin Administrative Office
Steve Kinsey, County of Marin Board of Supervisors (through August 2016)
Eric Lucan, Council Person, Novato
Claire McAuliffe, Council Person, Belvedere
Jim McCann, City Manager, Mill Valley
Stephanie Moulton-Peters, Co-Chair, Council Person, Mill Valley
Kate Sears, Co-Chair, County of Marin Board of Supervisors

Policy Committee

Kay Coleman, Council Person, San Anselmo
Kate Colin, Council Person, San Rafael
Diane Furst, Council Person, Corte Madera
Alice Fredericks, Council Person, Tiburon
Kevin Haroff, Council Person, Larkspur
Katie Hoertkorn, Council Person, Ross
Steve Kinsey, County of Marin Board of Supervisors
Peter Lacques, Council Person, Fairfax
Eric Lucan, Council Person, Novato
Claire McAuliffe, Council Person, Belvedere
Stephanie Moulton-Peters, Council Person, Mill Valley
Kate Sears, Co-Chair, County of Marin Board of Supervisors
Ray Withy, Council Person, Sausalito

Technical Advisory Committee

Scott Anderson, Tiburon Director of Community Development
Kelly Crowe, Corte Madera Associate Engineer
Julie Eichner, Novato Public Works Director
Jonathon Goldman, Sausalito Public Works Director
Paul Jensen, San Rafael Community Development Director
Rob Marccario, San Anselmo Public Works Director
Jim McCann, Mill Valley City Manager
John Moe, PE, PLS, Ross, Moe Engineering, Inc.
Mary Neilan, Belvedere City Manager
Barbara Salzman, Marin Audubon Society
Elise Semonian, San Anselmo Planning Director
Neal Toft, Larkspur Planning and Building Director
Garret Toy, Fairfax City Manager

Additional Advisors

Federal Emergency Management Agency (FEMA)
State Coastal Conservancy

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List of Acronyms

BayWAVE	Bay Waterfront Adaptation and Vulnerability Evaluation
MHHW	Mean Higher High Water
GGBHTD	Golden Gate Bridge, Highway and Transportation District
GGT	Golden Gate Transit
GGF	Golden Gate Ferry
C-SMART	Collaboration: Sea-Level Marin Adaptation Response Team
OWTS	On-site Wastewater Treatment System
CDA	Community Development Agency
DPW	Department of Public Works
NMWD	North Marin Water District
MMWD	Marin Municipal Water District
PG&E	Pacific Gas and Electric
SASM	Sewerage Agency of Southern Marin
NSD	Novato Sanitary District
USFWS	United States Fish and Wildlife Service
CADFW	California Department of Fish and Wildlife
LGVSD	Las Gallinas Valley Sanitary District
CMSA	Central Marin Sanitation Agency
LHMP	Local Hazard Mitigation Plan

EXECUTIVE SUMMARY

Executive Summary

Sea level in the San Francisco Bay Area has risen eight inches in the past century, and could rise up to 70 inches by the end of the century.[1, 2] Marin's bay shoreline is vulnerable to sea level rise and intensifying storm patterns. The third National Climate Assessment cites strong evidence that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.[3] Therefore, it is critical the County of Marin, incorporated jurisdictions, and special districts plan and prepare for the impacts of sea level rise to ensure a resilient county for present and future generations.

The County of Marin Department of Public Works and Community Development Agency are the project leads for the Bay Waterfront Adaptation & Vulnerability Evaluation (BayWAVE) program. The program began in September 2015 with funding from County of Marin and additional financial support from the California Coastal Conservancy.

Several committees support the BayWAVE process. The Executive Steering Committee consists of County of Marin and local jurisdiction representatives. The Technical Advisory Committee includes staff from local, state, and federal agencies. Lastly, the Policy Committee includes elected officials from the participating jurisdictions. These committees serve as the beginning of the program's goals to establish an efficient shared learning process and community messaging, and create a collaborative environment for preparing for sea level rise for all shoreline communities, and others inland, that could face the impacts of sea level rise in the coming decades. This effort may also support these communities in collaborating with and benefiting from the larger Bay Area region efforts underway.

The Vulnerability Assessment is an initial effort to identify the risks and exposure from sea level rise. Future tasks could include development of an adaptation report and may occur at different jurisdictions: local municipalities, service districts, and County of Marin could update general plans, master plans, capital improvement plans, hazard mitigation plans, and other relevant plans and procedures in the near future. While this effort focuses on sea level rise, Marin County experiences flooding from creeks, tides, and stormwater. Planning for solutions should evaluate the combined impacts of flooding to best prepare for a range of conditions.

This effort is part of an ongoing scientific and public process to understand and prepare for sea level rise along the shoreline This Vulnerability Assessment seeks to provide context and estimates of the physical and fiscal impacts across the County of Marin's bayside shoreline over the coming decades. These data highlight the complexity of the potential impacts and the need for concerted and individual actions in the face of rising tides. The data can be used to prioritize efforts, seek funding, and shape policy and development discussions that will guide the plans mentioned above.

This document presents asset profiles describing the potential consequences of a no-action, or business as usual political environment, especially for existing development. Asset profiles present potential consequences for parcels and buildings, transportation networks, utilities, working lands, natural resources, recreational assets, emergency services, and cultural resources. Vulnerable assets are also presented by jurisdiction in community profiles to enable local professionals, officials, and residents to engage is local discussions and relate to their neighbors. The following exposed and vulnerable communities have community profiles and make up the 85,840 acre study area shown in Map 1.

- Municipalities
    - Belvedere
    - Corte Madera

[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.

[3] 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

    - Larkspur
    - Mill Valley
    - Novato
    - San Rafael
    - Sausalito
    - Tiburon
- Unincorporated Jurisdictions
    - Almonte
    - Bayside Acres
    - Bel Marin Keys
    - Black Point
    - California Park
    - Country Club
    - Greenbrae
    - Kentfield
    - Marin City
    - North Novato
    - Paradise Cay
    - Point San Pedro
    - San Quentin
    - Santa Venetia
    - St. Vincent's
    - Strawberry
    - Tamalpais Valley
    - Unincorporated Tiburon
    - Waldo Point Harbor

Map 1. BayWAVE Study Area

Each profile details key issues and geographic locations. Asset profiles include economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be read independently of the others, enabling asset managers to focus on their professional area, and community members, elected officials, and others to read the analysis for a community as a whole.

Methods

Table 1 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, this Assessment uses a scenario based approach to assess a range of potential sea level rise impacts. The scenarios selected for this Vulnerability Assessment are derived from the U.S. Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) that combines global climate and wave models with projected sea level rise to identify areas that could be flooded across 10 different sea levels (ranging from 0 to 200 inches) and 4 storm severities (none, annual, 20-, 100-year storm surges) to total 40 possible combinations. All of these scenarios are viewable on the Our Coast Our Future (OCOF) Flood Map website.

One limitation of the model and every sea level rise model available at this time is the failure to combine sea level rise, stormwater drainage, and creeks. The model displays the impacts of flooding from the bay overtopping the shoreline edge and flooding low-lying areas. However, in Marin areas experience the impacts of high tides that coincide with storms, which result in water coming from the hills and the bay. Additionally, underground or low-lying drainage pipes and channels allow water to flood areas where the shoreline edge is sufficiently elevated to prevent direct overtopping. These vulnerabilities are described in the text, but tables and maps show sea level rise as presented in the CoSMoS model.

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

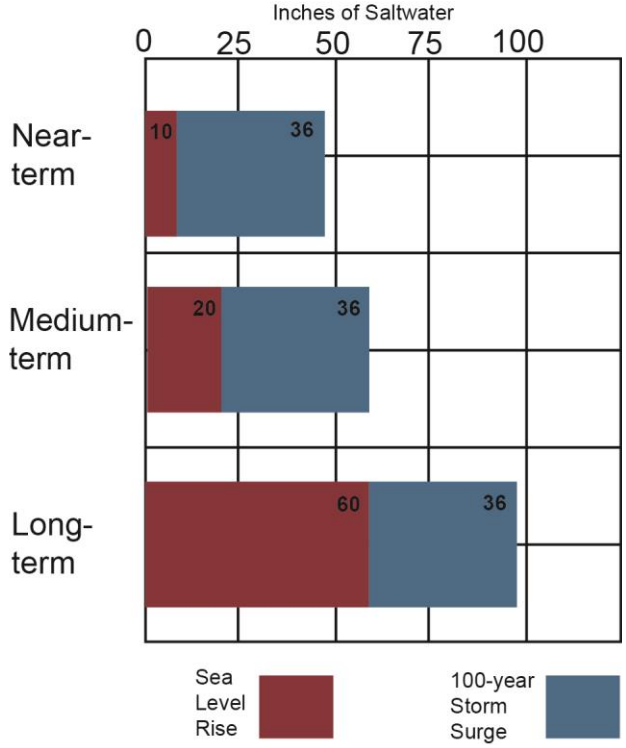
Time Period	Projected Range
by 2030	1.6 – 11.8 inches
by 2050	4.7 – 24 inches
by 2100	16.6 – 65.8 inches

Source: NRC 2012

Table 2. BayWAVE Sea Level Rise Scenarios

Scenario 1	10 inches
Scenario 2	10 inches+100-year storm surge
Scenario 3	20 inches
Scenario 4	20 inches+100-year storm surge
Scenario 5	60 inches
Scenario 6	60 inches+100-year storm surge

Figure 3. BayWAVE Scenarios Associated Water Levels



The findings of this assessment are based on three sea levels and each sea level combined with a 100-year storm surge as shown in Table 2. Scenarios 1 and 2 represent the near-term, and correspond to the 2030 NRC projected sea level range. Scenarios 3 and 4 represent the medium-term and are within the 2050 NRC range. Scenarios 5 and 6 represent the long-term and correspond to the 2100 NRC range. Figure 2 presents another view of the BayWAVE scenario where the red lengths represent tidal flooding in sea level rise scenarios 1, 3, and 5, and the blue lengths represent the addition storm surge water level associated with scenarios 2, 4, and 6. Together these bands show the cumulative potential flooding in the near-, medium-, and long-terms.

Vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to rising bay waters and storm surge threats. If an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity, the asset is considered vulnerable. Vulnerable assets may be vulnerable to flooding and/or increased rates of subsidence over the coming decades. Extensive geographic mapping was conducted overlapping layers of assets from MarinMap and sea level rise extent and flood depth layers to determine exposure. To ascertain sensitivity and adaptive capacity, the project team interviewed 115 asset managers, for example, the heads of public works departments, using the *BayWAVE Asset Vulnerability Assessment Tool* to assess more than 350 built and natural resource assets. The interview results were combined with the geographic data to develop the Vulnerability Assessment.

15-year Expectations

Sea level rise flooding could reduce useable living space and adversely affect tourism, transportation, and natural attractions and resources within 15 years. The first threats are to buildings, roads, and original utility systems along the shoreline. Disruptive flooding to the road and utility networks could have regional ripple effects for extended periods of time. In the near-term, San Rafael and Southern Marin shoreline communities are most at risk to tidal and storm surge flooding.

In this near-term timeframe, tidal flooding at 10 inches of sea level rise (MHHW) could reach 5,000 acres, 1,300 parcels, and 700 buildings, potentially impacting tens of thousands of residents, employees, and visitors. Regular tidal flooding could adversely impact San Rafael east of US Highway 101, bayfront Belvedere and Tiburon, Greenbrae, Waldo Point, and Paradise Cay.

With an additional 100-year storm surge, the previously impacted acres, parcels, and buildings could face tidal and storm surge flooding. An additional 3,000 acres, 2,500 parcels, and 3,800 buildings could anticipate storm surge flooding. These figures amount to six percent of parcels and buildings in the study area. Storm surge flooding, could impact North Novato at Gnoss Field, Black Point on the Petaluma River, lower Santa Venetia, Belvedere around the lagoon, bayfront Corte Madera, bayfront Mill Valley, Marinship in Sausalito, Tamalpais, and Almonte, in addition to the communities vulnerable to tidal flooding.

Eight miles of road could expect tidal flooding. Many of these flooded areas already experience seasonal and king tide flooding. These are:

- Manzanita, Almonte
- Miller Avenue in Mill Valley,
- the Marinship area in Sausalito,
- US Highway 101 in Marin City, Corte Madera, Larkspur, and
- State Route 37 in Novato.

This is expected to worsen in severity and become increasingly frequent. Tidal flooding would reach the Canal area of San Rafael, spreading to I-580. Several roads in Santa Venetia, Tamalpais, Belvedere, Mill Valley, Marin Lagoon of San Rafael, and bayfront Corte Madera and Larkspur would begin to experience seasonal, king tide, and storm surge flooding more frequently.

Water travel infrastructure could be compromised at ferry facilities in Larkspur, Tiburon, and Sausalito preventing commuters from traveling to work. Even if the facilities are able to handle near-term higher tides, providing safe parking and access to ferry users could prove challenging. Samller public and private and marinas and boat launches along the bay in Sausalito, Mill Valley, Strawberry, Tiburon, Belvedere, Bel Marin Keys, and Black Point could be flooded out and unusable. Storm surges can be powerful enough to damage and sink boats. This is especially a corncen for residential boats.

Southern Marin Fire Protection and Sausalito Police Deparmtent boats are included in the boats harbored in marinas vulnerable to sea level rise. The Castro Fire Station in San Rafael is vulnerable to tidal flooding in the near-term and the California Highway Partrol offices in Corte Madera could expect storm surge flooding in this time period. Most concerning, however; is the potential inability of emergency professionals and vehicles to access people in or through flooded areas.

In addition, the marshlands that buffer the shoreline communites from high tides and storm surges could begin to experience transitions in habitat, especially those in Southern Marin where they are typically bordered by urban development. Consequently, the waters here would get deeper and flood out the existing habitat, shifting high marsh to low marsh, low marsh to mud flat, and mud flats to open water. Without adequate light of shallow water, eelgrass beds would shrink. Collectively, these habitat shifts could have significant impacts on vulnerable specieis such as the salt marsh harvest mouse, Ridgway's Rail, or the long-fin smelt.

EXECUTIVE SUMMARY

Greenbrae Boardwalk. April, 2016. Credit: BVB Consulting LLC

IMPACTS AT-A-GLANCE: SCENARIO 2

5,000 acres flooded @ MHHW	200,000+ residents plus commuting employees
8,000 acres flooded @ MHHW +100-year storm surge	2,000 agricultural acres (mostly ranch)
4,500 homes, businesses, & institutions	Property Owners County of Marin Municipalities Caltrans Sanitary Districts Water Districts Fire Districts Sausalito Police Department CHP SMART GGBHTD MTA PG&E AT&T CADFW
30 miles of wet road, 3 ferry landings, 5 marinas, 4 boat launches	
Beaches Tidal Marshes Eelgrass beds Wetlands	

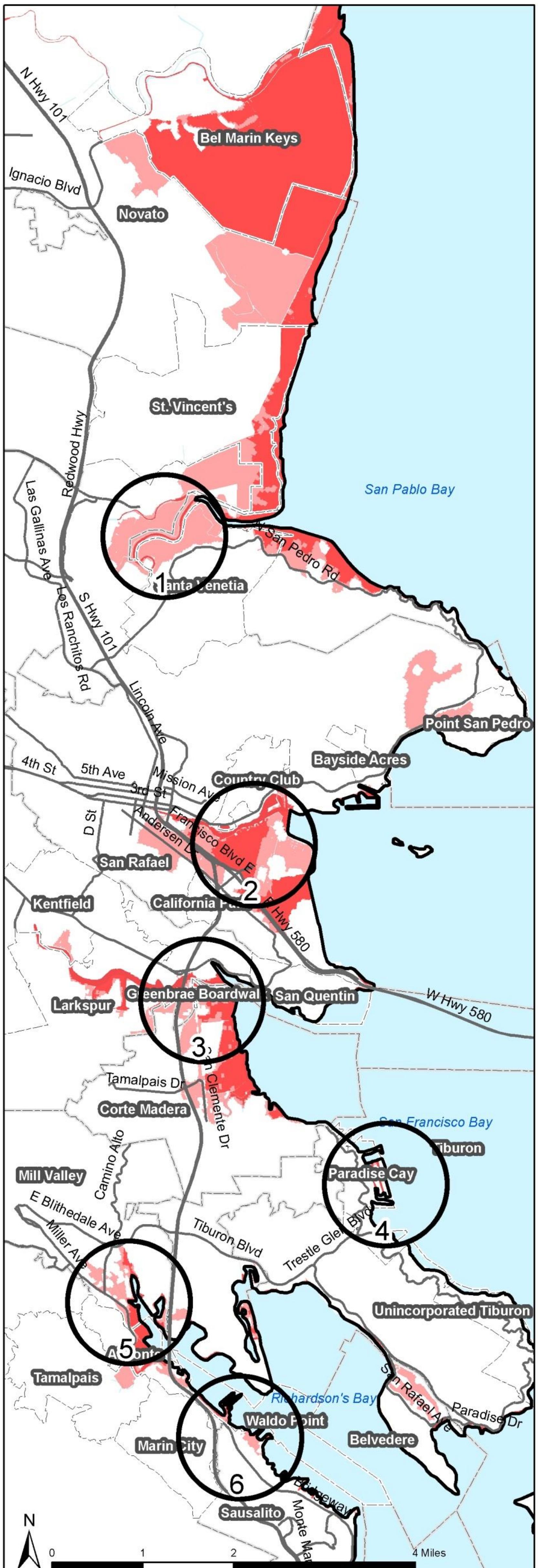
Map 131. Fifteen-year Expectation: Near-term Vulnerable Assets

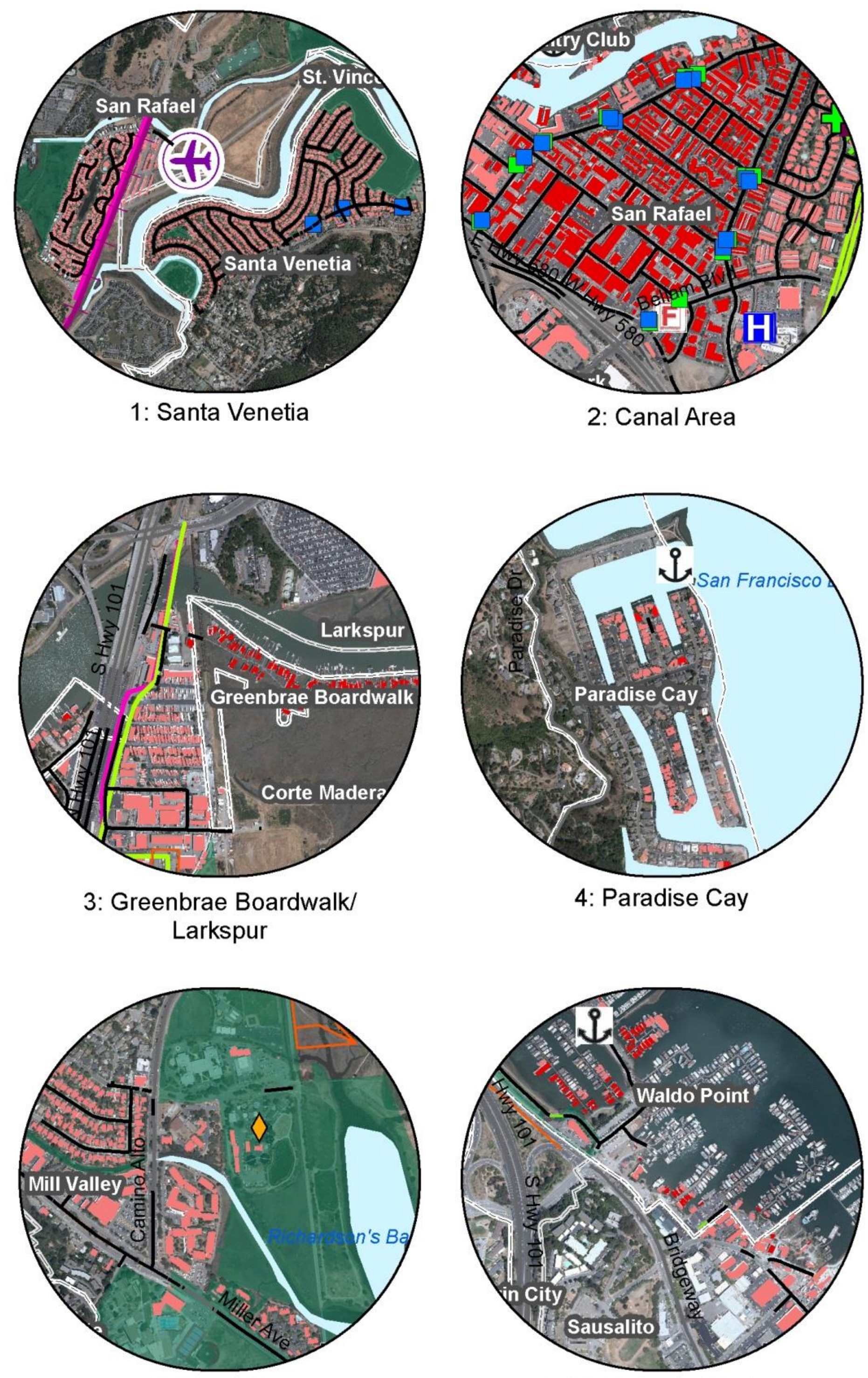
NEAR TERM

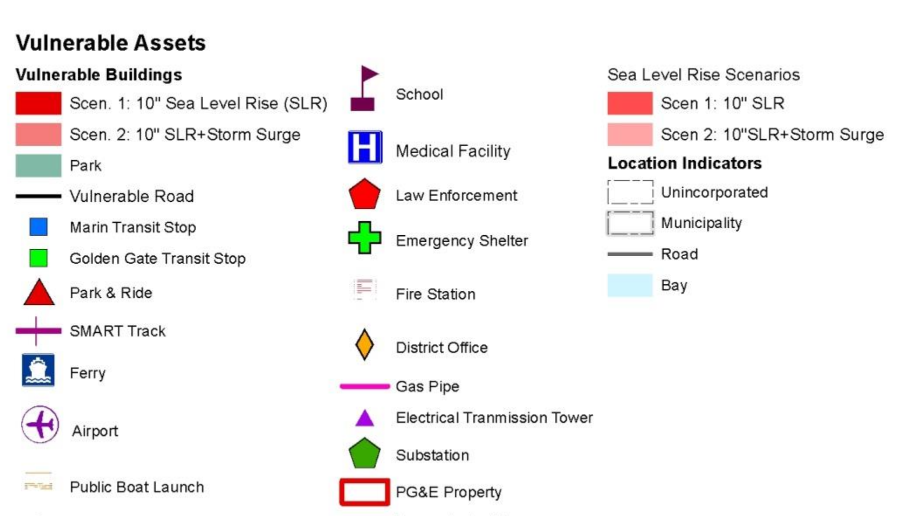
Scenario 1:
10 in. Sea Level Rise

Scenario 2:
10 in. Sea Level Rise
+ 100-year storm surge

In 15 years, high tides could threaten Marin's shoreline buildings, roads, and original utility systems. Damage and breakdowns in road and utility networks would impact the entire County, especially Southern Marin. Tidal flooding (red) could reach 5,000 acres, 1,300 parcels, 700 buildings, and 8 miles of road in San Rafael east of State Route 101, bayfront Belvedere and Tiburon, Greenbrae Boardwalk, Waldo Point, and Paradise Cay. A 100-year storm surge (pink) would flood these areas with storm surge flooding, and flood an additional 3,000 acres, 2,500 parcels, 3,800 buildings, and 20 miles of road in North Novato, Black Point on the Petaluma River, lower Santa Venetia, Belvedere Lagoon, bayfront Corte Madera and Mill Valley, Marinship in Sausalito, Marin Lagoon in San Rafael, Tamalpais, and Almonte. Flooded ferry facilities would prevent commuters and visitors from traveling across the Bay. Boating facilities in Sausalito, Mill Valley, Strawberry, Tiburon, Belvedere, San Rafael, Bel Marin Keys, and Black Point may be inaccessible. This is especially a concern for marinas with residential boats and Southern Marin Fire and Sausalito Police boats. The Castro St. Fire Station in San Rafael is vulnerable to tidal flooding, though all emergency professionals would be denied vehicular access to people in vulnerable areas Southern Marin marshlands would shift high marsh to low marsh to mud flat, and eelgrass beds could shrink under deeper darker waters. These habitat shifts would have significant repercussions for plant, insect, fish, and animal species.







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: 2/18/2017

EXECUTIVE SUMMARY

IMPACTS AT-A-GLANCE: SCENARIO 4

6,700 acres flooded @ MHHW	**200,000+ residents plus commuting employees**
13,500 acres flooded @ MHHW +100-year storm surge	**2,000 agricultural acres** (mostly ranch)
5,600 homes, businesses, & institutions	**Property Owners County of Marin Municipalities Caltrans Sanitary Districts Water Districts Fire Districts Sausalito Police Department CHP SMART GGBHTD MTA PG&E AT&T CA DFW**
62 miles of wet road, 3 ferry landings, 5 marinas, 4 boat launches	
Beaches Tidal Marshes Creeks Eelgrass beds Ponds Wetlands	

King tides preview future water levels. Mill Valley. 10:41 a.m., Nov. 25, 2015. Credit: Light Hawk Aerial

Mid Century Expectations

In this medium-term timeframe, tidal flooding at 20 inches of sea level rise (MHHW) could reach nearly 7,000 acres, 3,000 parcels, and 2,000 buildings, potentially impacting even more residents, employees, and visitors than in the near-term. Regular high tide tidal flooding could adversely impact the same locations tidally flooded in the near-term, though more severely.

With an additional 100-year storm surge, the previously impacted acres, parcels, and buildings could face tidal and storm surge flooding, and an additional 7,000 acres, 2,200 parcels, and 3,600 buildings could anticipate storm surge flooding. These figures amount to eight percent of parcels and seven percent of buildings in the study area. Most levees south of Novato are not designed to withstand this level of flooding and could be overtopped. Storm surge flooding would impact the same locations as in near-term scenario 2, 10 inches with a 100-year storm surge, and extends further inland beyond the marshy areas of Mill Valley, Strawberry, San Rafael, St. Vincent's, and North Novato.

Eighteen miles of roadway, ten more miles than in the near-term, could expect tidal flooding. Many of the impacted roads are the same as those impacted in the near-term, though much greater lengths could anticipate tidal flooding and flooding depths would increase. Storm surge flooding could reach a total of 44 additional miles of roadway. Water travel could experience similar outcomes as in the near-term, though the highest high tides and storms surges would cause even more damage than weathered twenty years earlier.

With respect to utilities, pipelines under vulnerable roads, and lateral pipes to vulnerable properties, would become squeezed between rising groundwater and the confining roadway. This could cause pipes to bend and break, and could even damage roadways. In the medium-term, impacts to the North Marin Water District service area would impact water service in Bel Marin Keys and unincorporated Novato. In fact, Bel Marin Keys already experiences seasonal saltwater contamination. Vulnerable substations, electrical transmission towers and lines, and underground natural gas pipelines along the shoreline would be compromised by flooding and subsidence. Disruptions or failures in this network could also have far reaching impacts in transportation, sanitary service, stormwater management facilities, food storage, communications, and general public safety.

This twenty inch increase in sea level would continue to shrink Southern Marin, Tiburon Peninsula, and Pt. San Pedro marsh and tidal habitats. Complimentary recreational trails, parks, althetic facilities would experience reductions in capacity with increases in maintainance costs.

Mill Valley-Sausalito Path. Credit: J. Poskazner

Historic Flood on US Highway 101 and fronting marshes. Larkspur. Credit: Marin DPW

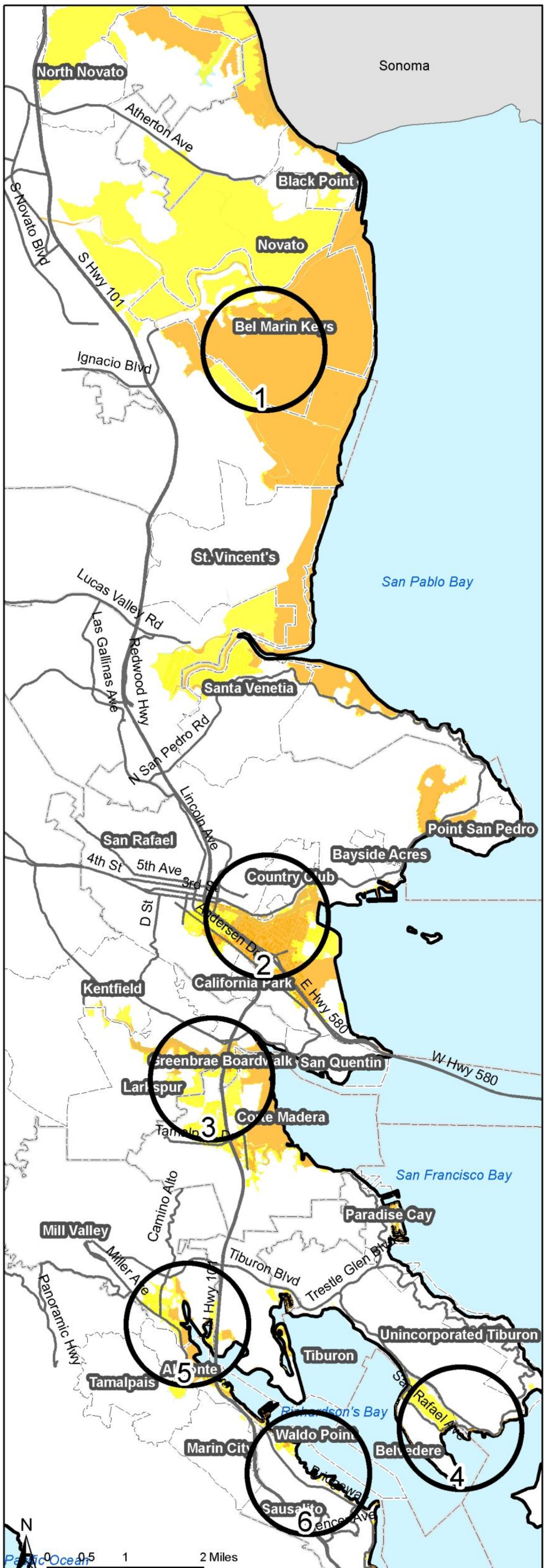
Map 132. Mid-century Expectation: Medium-term Vulnerable Assets

MEDIUM TERM

Scenario 3:
20 in. Sea Level Rise

Scenario 4:
20 in. Sea Level Rise
+ 100-year storm surge

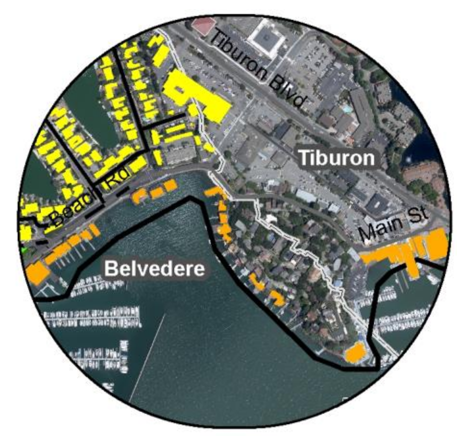
Tidal flooding could reach 7,000 acres, 3,000 parcels, 2,000 buildings, and 18 miles of roadway in the same locations impacted in the near-term, though more severely. With a 100-year storm surge, the area vulnerable to tidal flooding would also experience storm surge flooding. An additional 7,000 acres, 2,200 parcels (8%), 3,600 buildings (7%), and 40 miles of roadway could anticipate storm surge flooding. Most levees south of Novato are not designed to withstand this level of flooding and would be overtopped. Storm surge flooding would extend further inland beyond the marshy areas of Mill Valley, Strawberry, San Rafael, St. Vincent's, and North Novato. Water travel could experience similar outcomes as in the near-term, though the highest high tides and storms surges would cause even more damage than weathered twenty years earlier. Pipelines beneath flooded roads could become squeezed between rising groundwater and the roadway, cause pipes to bend and break, and even damage roadways, this is true for sanitary, stormwater, and potable water pipes. PG&E substations, electrical transmission towers and lines, and natural gas pipelines could be bent or broken by flooding, subsidence, and erosion, with far reaching impacts on utilities, buildings, and transportation. This ten inch increase in sea level would continue to shrink trapped beach and marsh habitats in Southern Marin. Shoreline parks and pathways would flood often.



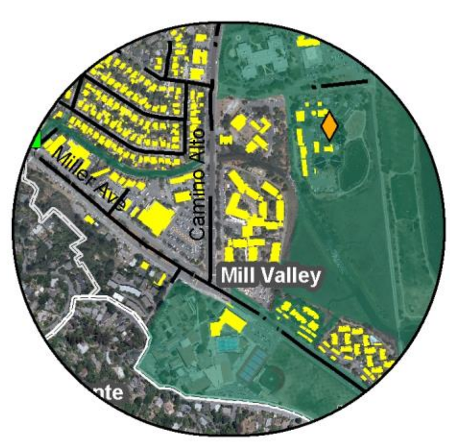
1: Southern Bel Marin Keys

2: U.S. Hwy. 101 @ Interstate 580

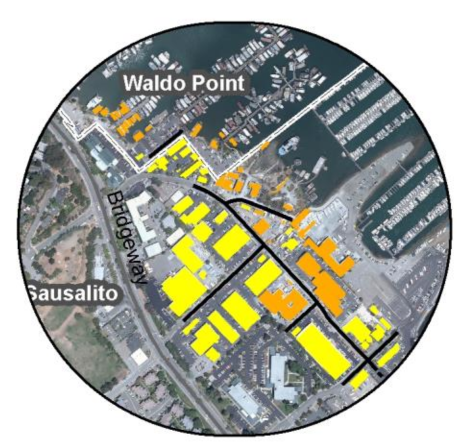
3: Riviera Circle



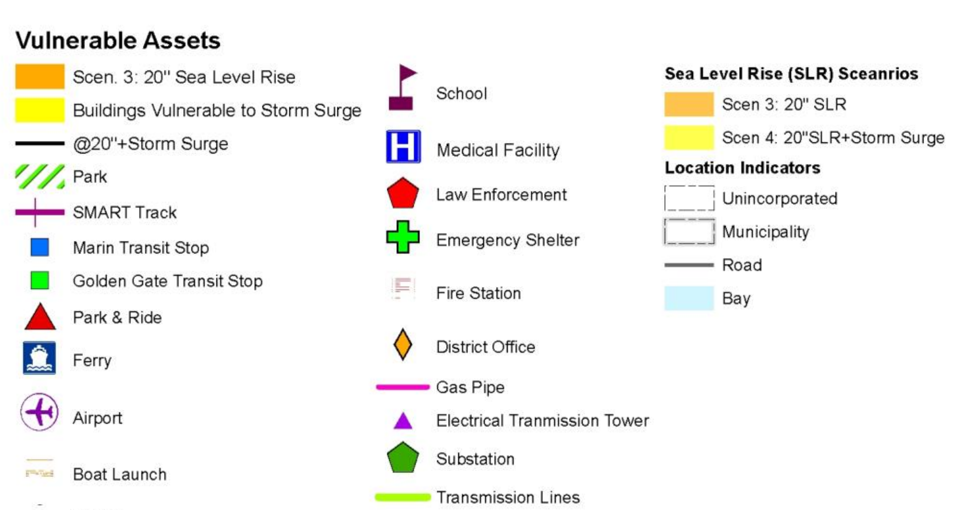
4: Tiburon/Belvedere



5: Mill Valley



6: Marinship



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Date: 4/1/2017

IMPACTS AT-A-GLANCE: SCENARIO 6

16,300 acres flooded @ MHHW	200,000+ residents plus commuting employees
18,000 acres flooded @ MHHW +100-year storm surge	4,150 agricultural acres (mostly ranch)
12,100 homes, businesses, & institutions	Property Owners County of Marin Municipalities Caltrans Sanitary Districts Water Districts Fire Districts Sausalito & Central Marin Police Departments CHP SMART GGBHTD MTA PG&E AT&T CADFW
$15.6 billion in assessed property value[4]	
200 miles of wet road, 3 ferry landings, 5 marinas, 4 boat launches	
Beaches Tidal Marshes Creeks Eelgrass beds Ponds Wetlands	

Kappas Marina. April 2016. Credit: Richardson's Bay Floating Homes Association.

End of Century Expectations

In this long-term timeframe, tidal flooding at 60 inches of sea level rise (MHHW) could reach nearly 7,000 acres, 8,000 parcels, and 9,000 buildings, potentially impacting hundreds of thousands of residents, employees, and visitors. These figures amount to 13 percent of parcels and 12 percent of buildings in the study area. Regular tidal flooding could adversely impact the same locations impacted in the near- and medium-terms and significant portions of what would have previously only flooded from the 100-year storm surge. The additional areas that would tidally flood at 60 inches of sea level rise are:

- Tamalpais Valley,
- Mill Valley from the Richardson's Bay shoreline up to and beyond Camino Alto between Miller and East Blithedale Avenues,
- Mill Valley and Strawberry fronting US Highway 101 between Seminary Drive and Tiburon Boulevard,
- Santa Venetia north of N. San Pedro Boulevard,
- Cove Neighborhood, Tiburon,
- Belvedere Lagoon neighborhood,
- Paradise Cay
- Mariner Cove, Marina Village, Madera Gardens, and major retail centers lining US Highway 101,
- Riviera Circle, Creekside, and Heatherwood neighborhoods, Larkspur,
- Interstate 580 and westward towards Andersen Drive in San Rafael and the community of California Park,
- Marin Lagoon and Peacock Gap neighborhoods, San Rafael,
- Bel Marin Keys northern and southern lagoon areas,
- Hamilton, Vintage Oaks, and pockets of development east of US Highway 101 at Rowland Boulevard and State Route 37 in Novato, and,
- North Novato at US Highway 101 and Binford Road.

In long-term scenario 6, storm surge flooding could occur on nearly 13,500 acres hosting 12,600 parcels with 12,000 buildings, potentially impacting 200,000 residents, thousands of employees, and several million visitors. These figures amount to nearly one-fifth of parcels and more than 15 percent of the buildings in the study area. Area that could anticipate storm surge flooding are:

[4] 2016 dollars

- Sausalito west of Bridgeway,
- Marin City neighborhood,
- Mill Valley east of East Blithedale Ave at Alto Shopping Center,
- Las Gallinas and N. San Pedro Blvd, east of US Highway 101, San Rafael,
- Bayside Acres,
- Country Club, and
- Kentfield.

Tidal and storm surge flooding could cause significant economic losses. Minor storm impacts alone could account for $61 million[5] in property damages. The market value of vulnerable single-family homes could exceed $20 billion in 2016 dollars. The assessed value, typically less than market value, for all the vulnerable parcels in the study area is $15.5 billion.[6] By the end of the century, these figures could be even higher.

One-hundred miles of public and private roadways, or five percent of all road miles in the study area, could be vulnerable to tidal exposure. Roads could degrade more quickly, or if flood waters are deep enough, become impassable. Lane miles could be more than double this figure. An additional 30 miles of roadway could be vulnerable at 60 inches of sea level rise and a 100-year storm surge. Moreover, several park and rides, several hundred bus stops, and bus transit and SMART rail routes could flood. The San Rafael Transit Center, where the SMART train and nearly all local and regional buses stop, could expect tidal flooding at MHHW and storm surge flooding in the long-term. Breakdowns in the transportation network would have major impacts on the economy and daily life functions. In addition, significant safety hazards could cause injury or loss of life.

Flooding at the SASM and Novato Sanitary Wastewater Treatment Plants is a significant vulnerability that could arise, potentially disrupting hundreds of thousands of people. By this time, much of the low-lying shoreline sanitary sewer and stormwater infrastructure could be flooded out.

By the end of the century, sea level rise could have direct impacts to Tiburon Fire Station No. 1, Corte Madera Station No. 13, and Novato Atherton Avenue Fire Station. A few emergency shelters in Southern Marin communities could be vulnerable to tidal flooding, and several more could expect storm surge flooding and may not be available when needed most. By this time, the Central Marin Police Department could have to wade through saltwater surrounding the site to reach Larkspur and Corte Madera residents in need.

Southern Marin marshes may no longer exist by the end of the century, destroying the habitat of several shoreline birds and mammals. Northern Marin marshes would become increasingly tidally influenced, with tide water reaching US Highway 101 in Bel Marin Keys and North Novato up the Petaluma River. Typically freshwater marshes west of US Highway 101, for example, Sutton Marsh, could also expect damaging salinity impacts. Tidal marsh lands may increase in Northern Marin if they not prevented from migrating inland.

In the long-term scenario, approximately 1,358 acres on 30 agricultural parcels could be vulnerable to sea level rise and storm conditions. Another 3,000 acres are public agency lands near Bel Marin Keys, Hamilton Field, and the Novato Sanitary District that are leased for agricultural use. Higher high tides could push brackish conditions inland, reducing grazing, manure spreading, and cultivation area. Moreover, reduced vehicular access on State Routes 37, 101, and other major roads could disrupt product distribution.

Finally, all of these assets contain or contribute to the well-being of the region's cultural, archeological, and historic resources that constitute each community's sense of place. This is especially a concern for Sausalito, Tiburon, and Novato.

China Camp Historic pier. December 2016 King Tide. Credit: Ron Rothbart

[5] 2016 dollars
[6] 2016 dollars

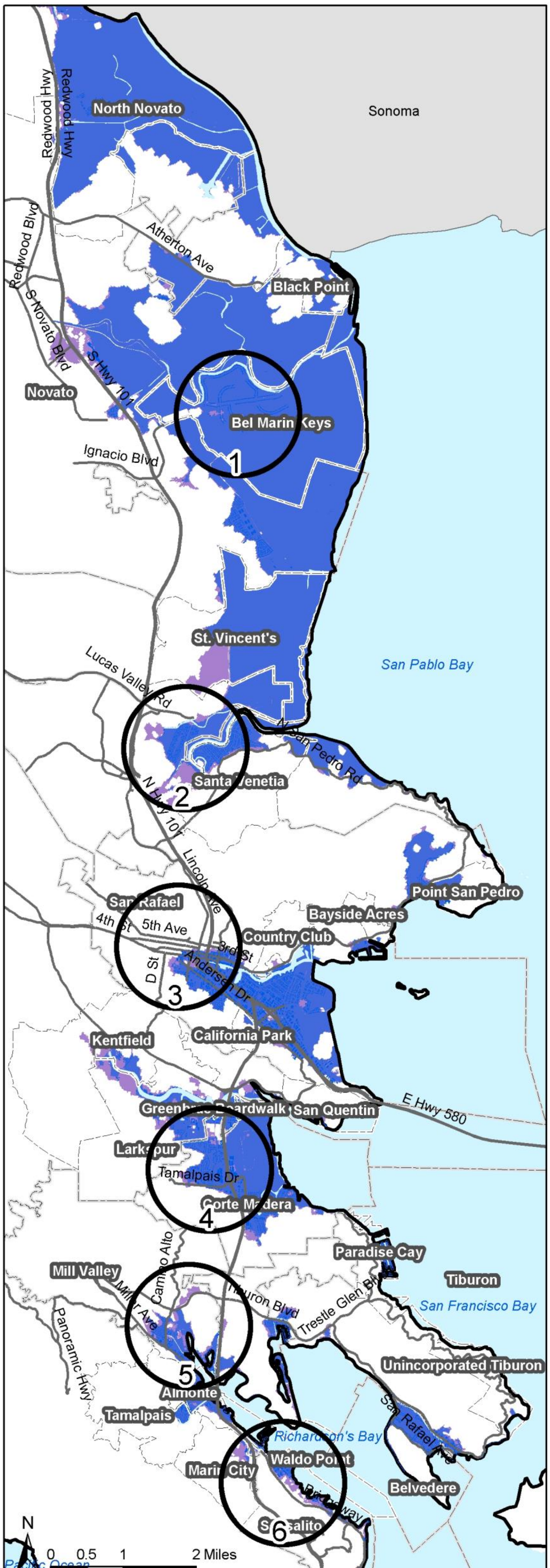
Map 133. End of Century Expectations: Long-term Vulnerable Assets

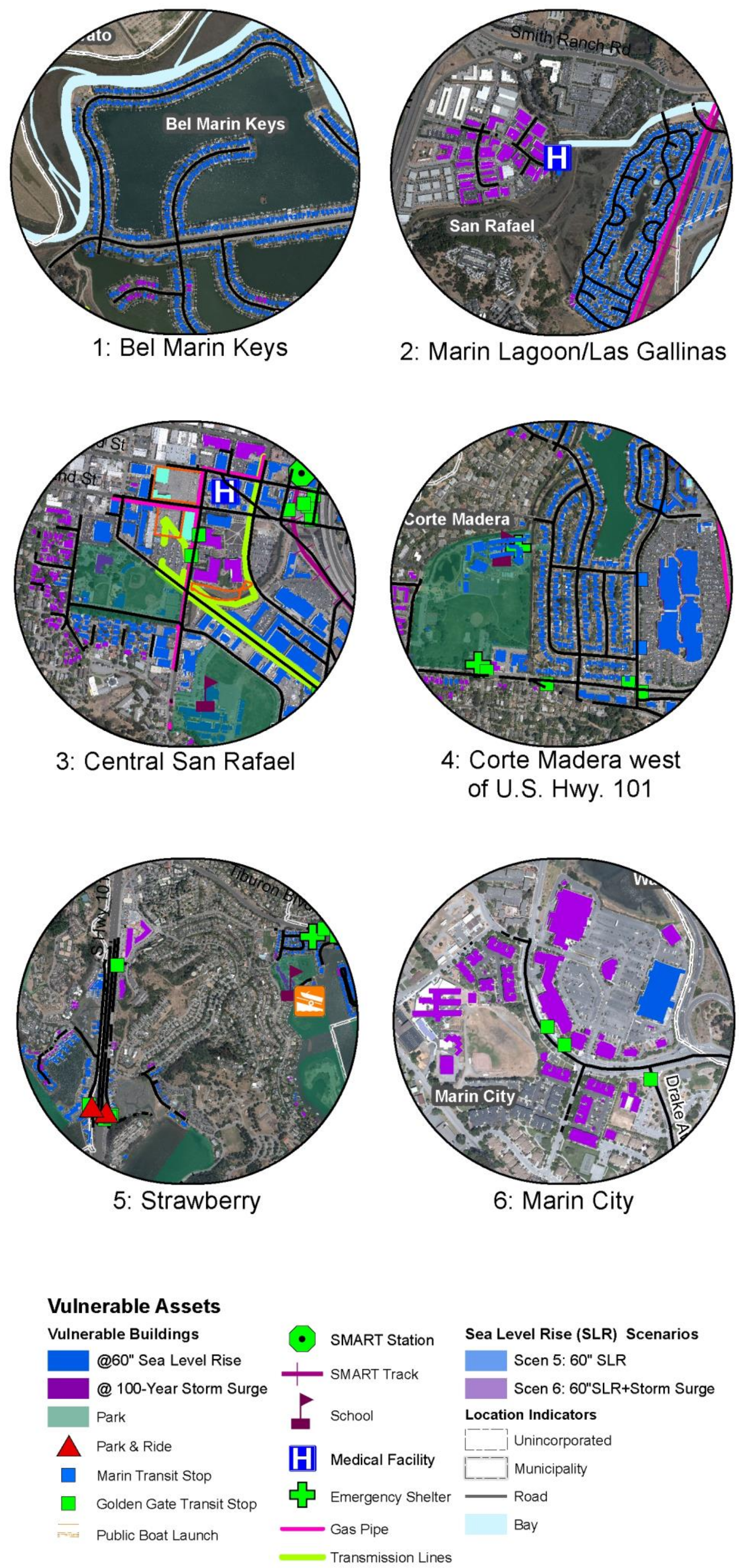
LONG TERM

Scenario 5:
60 in. Sea Level Rise

Scenario 6:
60 in. Sea Level Rise
+ 100-year storm surge

By 2100, tidal flooding could reach nearly 7,000 acres, 8,000 parcels (13%), 9,000 buildings (12%), and 100 miles of road. Higher high tides could adversely impact the locations flooded in medium-terms, and significant portions of the areas that previously suffered storm surge flooding. Tidal flooding would reach beyond the State Routes 101and 580 in low-lying areas, into Southern Marin's narrow valleys and creek sides, and over every levee in Marin County. A 100-year storm surge could flood these areas, and an additional 6,500 acres, 4,600 parcels (20% total), 3,000 buildings (15% total), and 30 miles of road, extending to Sausalito west of Bridgeway, Marin City housing, Mill Valley's Alto Shopping Center, Las Gallinas and N. San Pedro Blvd. in San Rafael, Bayside Acres, Country Club, and Kentfield. Minor building damage could amount to $61 million (2016 dollars). Vulnerable single family homes exceed $20 billion in market value (2016 dollars). Several park and rides, hundreds of bus stops, and bus routes, and SMART rail track, including the San Rafael Transit Center, could experience flooding. Disruptive flooding at the SASM and NSD wastewater treatment plants and pump stations would affect tens of thousands of people. Storm surges could flood Tiburon Fire Station No. 1, Corte Madera Fire Station No. 13, and Novato Atherton Ave. Fire Station. A few emergency shelters in Southern Marin flood at high tide, and many more could be closed during a storm. The Central Marin Police Department may have to navigate deep water to reach Larkspur and Corte Madera shoreline residents. In Southern Marin, mud flats and water would dominate existing marshes. In the north, tidal marshes could expand.





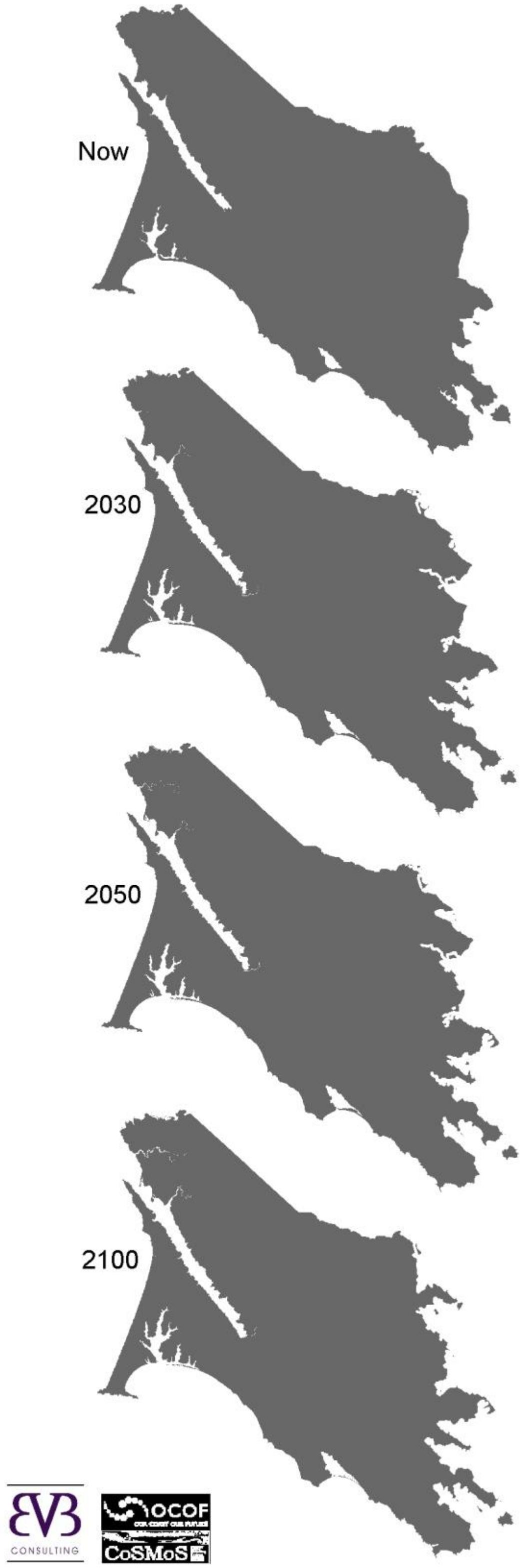
Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future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

EVB CONSULTING

Date: 4/1/2017

OCOF CoSMoS

Figure 6. Estimated Decreases in Marin County Land Area due to Sea Level Rise



A significant degree of uncertainty exists as to how soon these increases in sea level could occur because future carbon emissions are an unknown. However, even if global citizens stabilize carbon emissions, sea level rise would likely continue. Moreover, even if the growing global population reduces carbon emissions to levels where atmospheric concentrations decline, the decline will be slow and sea levels would still likely continue to rise for decades, and hundreds of years could pass before the sea level stabilizes or drops.[7,8] If emissions continue to increase, the rate of sea level rise is also likely to increase and these assets could be vulnerable sooner than this assessment presents. Because of this uncertainty, 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. The sea level rise preparation process will require consistent monitoring and evaluation to improve modeling assumptions and ensure preparation efforts are effective and efficient.

Hamilton Wetlands and Aramburu Wildlife Preserve were recently enhanced, and wetland restoration is in planning for Bothin Marsh, McInnis Park, and Novato's baylands. Nonprofits are also working to include: Marin Audubon Society project in Corte Madera, and the Coastal Conservancy's Bel Marin Keys restoration project once funds are secured.

Combined with potential losses in West Marin due to potential sea level rise, the impacts to Marin County will be significant across all asset categories. The image to the left combines estimates for land area that would be lost at MHHW across the near-term, 2030, the medium-term, 2050, and the long-term, 2100 scenarios applied to Western and Eastern Marin.

[7] 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

[8] 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

EXECUTIVE SUMMARY

With this vulnerability assessment, Marin County professionals, officials, residents, employees, and other Bay Area communities can gain an understanding of the potential fallout from higher high tides in a no action scenario. With this comprehensive view of the potential issues, Marin County communities can approach preparing for this shared concern with greater efficiency and collaboration.

Tiburon's Main Street buildings are from the early 1900s, and are adjacent to the ferry terminal. Credit: Marin CDA

Low lying properties in Black Point. Credit: Marin 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.[9] Sea level at the San Francisco tide gauge has risen 8 inches over the past century, and the National Research Council (NRC) projects that by 2100, sea level in California south of Cape Mendocino may rise 66 inches.[10] 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.[11]

View of Almonte from Shoreline Highway. Dec. 2014. Credit: Marin DPW

While Marin's shoreline already experiences regular 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 that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.[12] Therefore, it is critical the County of Marin, municipalities, and special districts plan and prepare for the impacts of sea level rise to ensure a resilient county for present and future generations.

This publication presents the Bay Waterfront Adaptation and Vulnerability Evaluation (BayWAVE) for Marin's San Francisco, Richardson's, and San Pablo Bay communities' built and natural assets. This effort is part of an ongoing scientific, collaborative, and public process to understand and prepare for sea level rise along the Marin shoreline. This Vulnerability Assessment seeks to provide context and estimates of the physical and fiscal impacts to shoreline over the coming decades. This analysis highlights the complexity of the potential impacts and the need for both concerted and individual actions in the face of rising tides. The data presented can be used to prioritize efforts, seek funding, and shape policy and development discussions.

The County of Marin Department of Public Works is the project lead for the Bay Waterfront Adaptation & Vulnerability Evaluation (BayWAVE) program. The program began in September 2015 with funding from County of Marin and additional financial support from the California State Coastal Conservancy. Several multi-jurisdictional committees guide the BayWAVE process. The Executive Steering Committee consists of County of Marin and local jurisdiction representatives to guide staff and provide direction at critical milestones. The Policy Committee is made up of elected officials from each city and the County of Marin. The Technical Advisory

[9] 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.

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

[11] 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.

[12] 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

Committee includes staff from local, state, and federal agencies. These committees are essential in achieving the BayWAVE goals to establish an efficient shared learning process and messaging platform, and create a collaborative environment to prepare for sea level rise. See the Acknowledgements for a complete list of committee participants.

This Vulnerability Assessment is advisory and not a regulatory document or legal standard of review for action the County of Marin, municipalities or other involved special governments may take. Such actions are subject to the applicable requirements in each jurisdiction's governing documents and applicable state and local regulations.

The County of Marin, municipalities, and special jurisdictions participating in this assessment have engaged in sea level rise planning and climate action for several years. For example, Marin's Countywide Plan (2007) addresses sea level rise in two policies: EH-3.k Anticipate Climate Change Impacts, Including Sea Level Rise and C-EH-22 Sea Level Rise and Marin's Coast. Other local efforts include sea level rise white papers for San Rafael and Novato, the Here.Now.Us project started by Marin County Supervisor Kate Sears for Southern Marin, the Department of Public Works *Richardson's Bay Shoreline Study*, Novato, Southern Marin, and Gallinas Watershed Program's demonstration projects, and the Collaboration: Sea-level Marin Adaptation Response Team (C-SMART) Program for the West Marin coastline.

This assessment follows extensive efforts throughout the nation, state, and region to understand the science of sea level rise and the impacts it could have. The San Francisco Bay Conservation and Development Commission (BCDC) established the Adapting to Rising Tides program, which includes adaptation planning guidance, and local to regional case studies, and previously published *Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on the Shoreline* and *Innovative Wetland Adaptation Techniques.* Most recently, BCDC released a Levee Overtopping Study that determines the water levels required to spill over the tops of levees into the areas the aim to protect. Pacific Gas & Electric (PG&E) also released a climate change vulnerability assessment for the Bay Area. In addition, the California Energy Commission (CEC) released *Impacts of Predicted Sea-Level Rise and Extreme Storm Events on the Transportation Infrastructure in the San Francisco Bay Region*. Finally, released two years ago with special attention to climate change impacts is the Baylands Ecosystem Habitat Goals Science Update 2015.

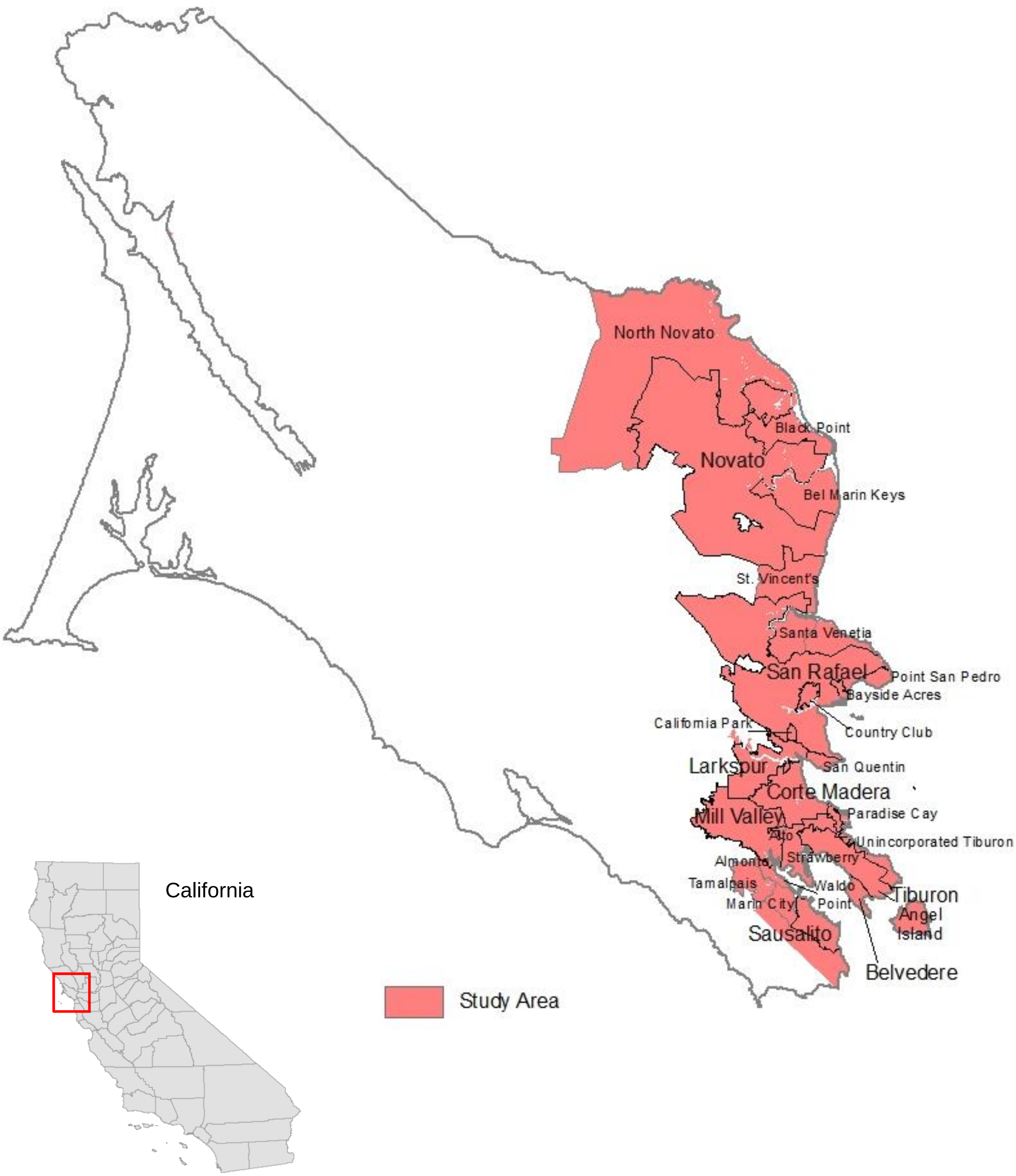
In an effort to dovetail with these studies, goals, and regulations, this assessment applies and presents the best available sea level rise and storm surge science to Marin's shoreline to generate an understanding of Marin's potential future.

This Assessment examines lands on the Marin County bay shoreline from the Golden Gate Bridge to the Petaluma River (see Map 1). The study area is approximately 85,840 acres and comprises of the entire jurisdiction for each municipality and unincorporated community vulnerable to sea level rise under the BayWAVE scenarios. Communities exposed to sea level rise are:

- Municipalities
  - Belvedere
  - Corte Madera
  - Larkspur
  - Mill Valley
  - Novato
  - San Rafael
  - Sausalito
  - Tiburon
- Unincorporated Jurisdictions
  - Almonte
  - Bayside Acres
  - Bel Marin Keys
  - Black Point
  - California Park
  - Country Club
  - Greenbrae
  - Kentfield
  - Marin City
  - North Novato
  - Paradise Cay
  - Point San Pedro
  - San Quentin
  - Santa Venetia
  - St. Vincent's
  - Strawberry
  - Tamalpais Valley
  - Unincorporated Tiburon
  - Waldo Point Harbor.

INTRODUCTION

Map 1. BayWAVE Study Area



INTRODUCTION

Tiburon revetment looking to Corinthian Marina and Tiburon Ferry Terminal, 2016. Credit: BVB Consulting LLC

The locations in the study area most likely to experience sea level rise and storm surge impacts in this century are low lying areas in Marin's shoreline communities, especially east of US Highway 101. However, the dry unexposed portions of every community in the study, Tamalpais Valley, Strawberry, Da Silva Island, Mill Valley, Belvedere Island, Tiburon uplands, Sausalito, and San Rafael, could be indirectly impacted. Similarly, East Marin communities outside of the study area, such as Fairfax, San Anselmo, Ross, Alto, Lucas Valley, and others could be vulnerable to transportation network and utility impacts.[13] Note that while in Marin County, the Marin Headlands and Fort Baker are Federal property and not the focus of this assessment. The Federal Parks assessment is at http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm.

This assessment is organized into five major sections: (1) methods, (2) asset profiles, and (3) municipality profile, and (4) the Conclusion. The methods section details the background science and research methods used in the BayWAVE process. Asset profiles highlight the vulnerable features bayside residents, employees, and visitors depend on, such as buildings, roads, drinking water, septic, and others. The municipality profiles detail all asset vulnerabilities for each exposed municipality. The Unincorporated Marin profile also provides the same analysis for areas within County of Marin jurisdiction. Each profile details key issues and geographic locations. Asset Profiles highlight initial economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be read independently, enabling asset managers to focus on a professional area, and community members, elected officials, and others to read about their community as a whole. The conclusion summarizes the impacts by time-period or onset of near-, medium-, and long-term impacts across all asset types and communities.

Key findings include:

- Southern Marin would likely suffer the worst flooding impacts, and could experience these impacts in the near-term.
- Increasingly compromised access to and from the Manzanita Interchange of US Highway 101 and 1 could affect hundreds of thousands of residents, employees, and visitors.
- Reductions in useable space for living, tourism, transportation, and natural resources could impact approximately 12,750 properties, more than 12,000 buildings, and 100 miles in roads.
- Based FEMA HAZUS damage estimates, waves, wind, and temporary flooding during storms could account for $60 million to $6 billion (2016 dollars) in building damages.
- Impacts to wastewater treatment in the Sausalito, Tamalpais, Almonte, Alto, Mill Valley, Novato, and Bel Marin Keys could affect tens of thousands of residents.
- Physical and economic impacts will be felt differently across the various income and age groups, causing social and economic inequities.
- In California, tidelands (land below the mean high water mark) and submerged lands are under public trust. As the sea level rises, thousands of private properties, if still in use, could be subject to the Public Trust Doctrine, become Waters of the State, and be required to pay a leasing fee.
- The most vulnerable habitats are shoreline beaches and marshes south of St. Vincent's.
- Areas that are not exposed to rising bay waters under the BayWAVE scenarios can still be vulnerable to sea level rise when the wastewater treatment plant, ports, and major roadways become compromised under flooding conditions.
- Marin is not self-contained and could feel impacts from across the Bay region, such as the Port of Oakland, which receives imports and exports for the entire Bay Area, or transportation network in San Francisco and the East Bay that,

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

when flooded, would disrupt commuting, and regional and global travel.

- Sea level rise is one of several climate change impacts residents will likely face. Combined with typical hazards that already exist (e.g. liquefaction and ground shaking near fault lines, erodible soils, and heavy rainfall), Marin is more vulnerable than this assessment can describe.

This assessment is the first step in an ongoing iterative process. The sea level rise preparation process will require consistent monitoring and evaluation to improve modeling assumptions and ensure preparation efforts are effective and efficient. With this vulnerability assessment, Marin County professionals, officials, residents, employees, and other Bay area communities can gain an understanding of the potential fallout from higher high tides in a no action scenario. With this comprehensive view of the potential issues, Marin County communities can approach preparing for this shared concern with greater efficiency and collaboration.

Marin Flood History

Understanding past floods can inform future vulnerabilities. Marin is no stranger to damaging floods. Major floods occurred in 1952, 1955-1958, 1967, 1969 and 1970. In later years, portions of Corte Madera, Larkspur, Greenbrae, Mill Valley, Ross, San Anselmo, San Rafael and Novato flooded in the winters of 1982/1983, 1986, 1997/1998, and 2005/2006, during El Niño events. Recent media attention has focused on the king tides that flood Southern Marin.


Ross Business District during the 1925 flood. Credit: Marin History Museum

February 10th 1925 More than seven inches of rain fell in the Ross Valley, overflowing creeks, and flooding streets. Extensive damage occurred to homes and infrastructure in San Anselmo, Ross and Kentfield.[14]

Credit: Independent Journal

1956-58 Corte Madera Creek experienced major flooding that prompted a large Army Corps of Engineers flood control project. Due to continuous flooding, the Kentfield Fire Department tied a rowboat to the Laurel/Sir Francis Drake sign for use.[15]


Credit: San Anselmo Historical Museum

January 1982 The 'Great Storm of 1982,' dumped sixteen inches of rain that killed four residents, destroyed 35 Marin homes, and damaged 2,900 more, totaling $80 million in damages.[16, 17]

December 1969
Independent-Journal


I.J. 12/31/69 P. WEATHER

Marin County Is Declared Disaster Area

ALIFORNIA ROOM

I-J Special Report

SAN FRANCISCO — Marin County today was declared a disaster area by the Small Business Administration, Rep. William S. Mailliard, R-Sixth District, reported.

The declaration, one day after an official of the SBA toured the county to inspect homes and businesses damaged by the recent floods, means that property owners will be eligible for low-interest SBA loans to repair damages, and that the county will be eligible for flood relief grants.

The SBA based its declaration on an estimate by the county that damage by flood water and landslide damage totaled $400,000. Four homes suffered major damage, the SBA said, and minor damage was reported at 190 homes, five apartment buildings and 18 businesses.

The county estimated damages at $250,000 to private property and $150,000 to public property.

[14] San Anselmo Historical Museum. 2015. *San Anselmo's Long History of Flooding.* http://sananselmohistory.org/articles/flooding/. Accessed 1/29/16
[15] Source Unknown
[16] Blodgett J.C., and Edwin H. Chin. 1989. *Flood of January 1982 in the San Francisco Bay Area, California.*
[17] Marin Independent Journal. 2011. *Highlights of Marin's History, from 1850-2010*

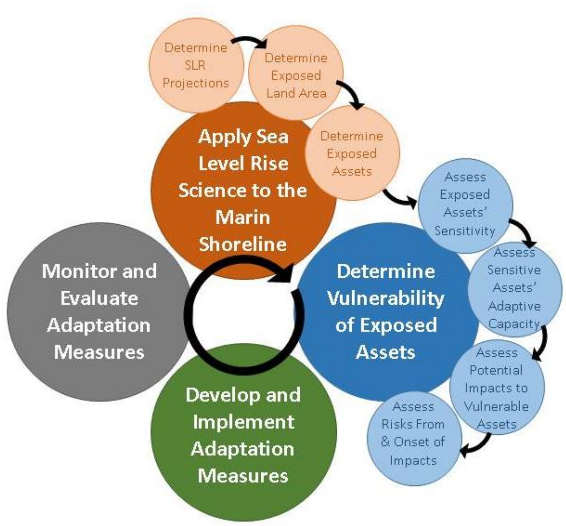
METHODS

Methodology

The BayWAVE Vulnerability Assessment process (see Figure 1) is guided by CalAdapt[18] through the following phases of analysis:

- Phase 1: Exposure: Assess potential changes in water level from sea level rise, storm events, and geomorphic change to determine the built and natural assets that could be exposed to saltwater.
- Phase 2: Sensitivity: Assess the degree of damage or disruption tidal and storm surge flooding could cause on the exposed assets.
- Phase 3: Adaptive Capacity: Assess each asset's adaptive capacity, or ability to respond successfully, to flooding, without human intervention
- Phase 4: Potential Impacts: Evaluate the potential consequences to the assets and larger context, assuming no intervention actions.
- Phase 5: Risk & Onset: Describe the certainty and timing of impacts.

Figure 1. BayWAVE Process



[18] 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

Modeling Methods

Sea level rise estimates used in this analysis are from the USGS Coastal Storm Modeling Systems (CoSMoS) and are viewable online through the Our Coast Our Future (OCOF) Flood Map tool. OCOF was developed through a partnership of several notable institutions and agencies, and represents the best available sea level rise and storm science.

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 based on North American Vertical Datum of 1988 (NAVD88) elevations, 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. CoSMoS scales down global and regional climate and wave models to produce local hazard projections.[19]

High quality elevation data incorporated in the DEM was used to create maps of mean higher high water (MHHW) tidal elevation, and provides the option to add storm surges of different magnitudes. Mean higher high water is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch.[20,21] Each day has two high tides, one typically higher than the other. The higher values are used for this analysis. Some days the higher high tide will be lower or higher than other days, however, several days of flooding a month, several months a year, or even once every year would be problematic depending on the resource being examined.

Note, also because the analysis uses high tide, properties near the inland extent of properties exposed to MHHW may not flood at low tides. On

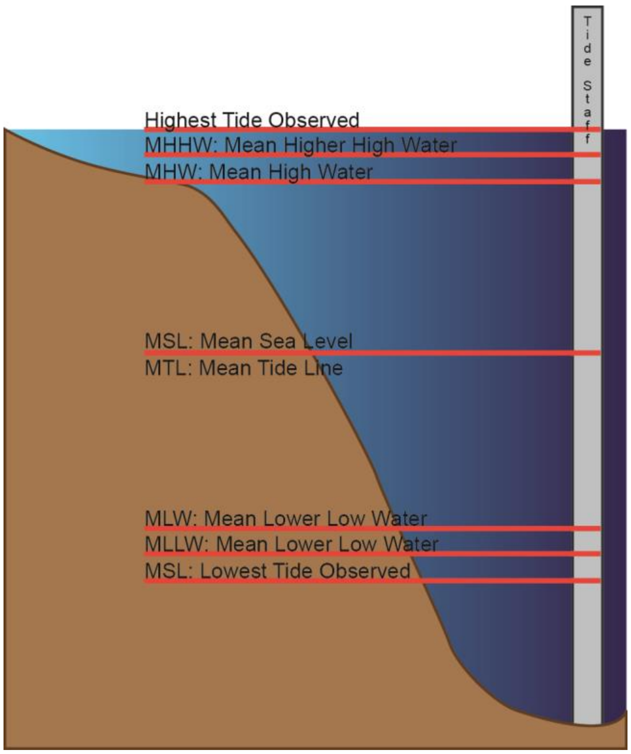
[19] Ballard, G., Barnard, P.L., Erikson, L., Fitzgibbon, M., Higgason, K., Psaros, M., Veloz, S., Wood, J. 2014. Our Coast Our Future (OCOF). [web application]. Petaluma, California. www.pointblue.org/ocof. (Accessed: Date August 2014]).

[20] 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.

[21] 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.

the other hand, these properties, and properties just beyond the inland extent of scenario 6, the most-severe scenario examined in this report, could experience flooding from the highest high tides, especially in combination with storms and/or king tides.

Figure 2. Tidal Datum Comparing MHHW to Mean Sea Level and Low Water Levels



Source: National Oceanic and Atmospheric Administration. Credit: BVB Consulting LLC

King tides preview future water levels. Mill Valley. 10:41 a.m., Nov. 25, 2015. Credit: LightHawk

CoSMoS accounts for wave run-up and set-up, storm surge of the ocean, seasonal effects, tides, levees, river discharge, and wind from the San Francisco Bay. Note that this tool only accounts for bay water levels and does not assess fresh stormwater flooding upstream or changes in the shoreline (geomorphology) as erosion continues. Thus, storms used in this analysis include bay storm surge only, not additional freshwater creek flooding upstream. In addition, this analysis does not account for the ability of pump stations to drain flooded areas.

Table 1 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, this analysis uses a scenario based approach to assess a range of potential sea level rise and storm surge exposure. The six USGS CoSMoS scenarios selected for the BayWAVE Vulnerability Assessment in Table 2 align with the NRC 2012 estimates as follows:

- Scenarios 1 and 2 represent the near-term projection anticipated by 2030.
- Scenarios 3 and 4 represent the medium-term projection anticipated by 2050.
- Scenarios 5 and 6 represent the long-term projection anticipated by 2100.

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. BayWAVE Sea Level Rise & Storms Scenarios

Sea Level Rise Scenario		Term
1	10 inches	Near
2	10 inches+100-year storm	
3	20 inches	Medium
4	20 inches+100-year storm	
5	60 inches	Long
6	60 inches+100-year storm	

Figure 3. BayWAVE Scenarios Associated Water Levels

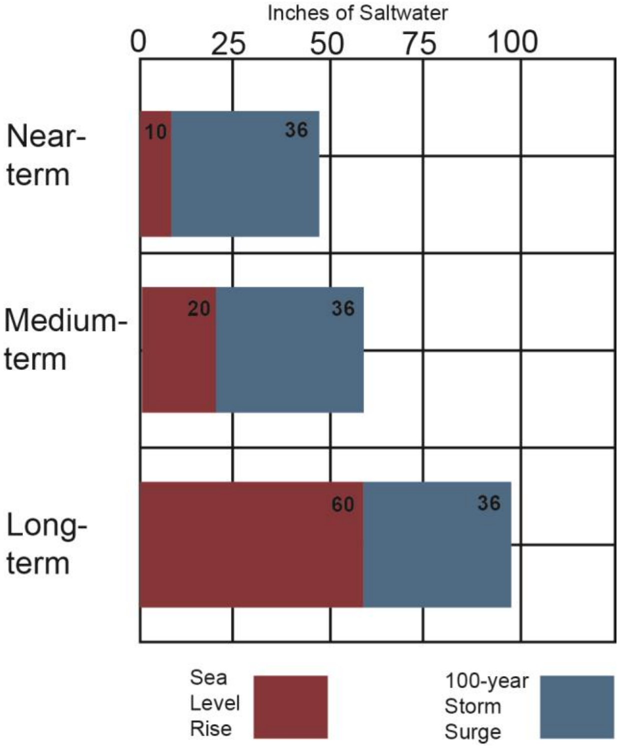


Figure 3 presents another view of the BayWAVE scenarios where the red lengths represent tidal flooding in sea level rise scenarios 1, 3, and 5, and the blue lengths represent the additional storm surge water level associated with scenarios 2, 4, and 6. Together these bands show the potential flooding in the near-, medium-, and long-terms.

The odd numbered scenarios illustrate sea level rise only. Even numbered scenarios illustrate sea levels and incorporate the storm flooding from a future based 100-year storm surge. The scenarios include storm surges because storm surges have the potential to cause catastrophic damage. The CoSMoS model uses research and predictions for future storm patterns to create the future storm typology used in the BayWAVE scenarios. Future storms are anticipated to come from a southerly direction, as opposed to historic storms, which tend to come from the north. For more information on how storms were modeled see references on the OCOF website.

A 100-year storm surge has one percent chance of happening in any storm in a given year. Within a 30-year mortgage, a 100-year storm has a nearly 30 percent chance of occurring. Note that, as climate change continues, the 100-year storm surge level of flooding may occur more frequently, increasing the annual risk of this level storm occurring from a 100-year storm surge to a 50-year storm surge, for example. In addition, there are more frequent storm surges, and less frequent storm surges such as the, 200-year, 400-year, annual, or 5-year storm surges. Less frequent larger storms would result in more severe flooding than presented in this report,[22] whereas, smaller storm surges would produce less severe flooding.

Maps 2 and 3, on the following pages, show the furthest inland extent of scenario 6. Maps 4 and 5 show scenarios 1, 3, and 5, and Maps 6 and 7 show scenarios 2, 4, and 6. The shoreline is typically mapped in two maps: (1) the northern study area, north of Pt. San Pedro, and (2) the southern study area, south of Pt. San Pedro, halves of the study area. The call out circle maps show zoomed in images of locations that may be difficult to se. The circles do not indicate these do not indicate that there areas are more vulnerable than areas not depicted in the circular maps.

[22] 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. Northern Study Area Inland Extend of Scenario 6

Inland Extent: Sea Level @ 60"+100-year Storm

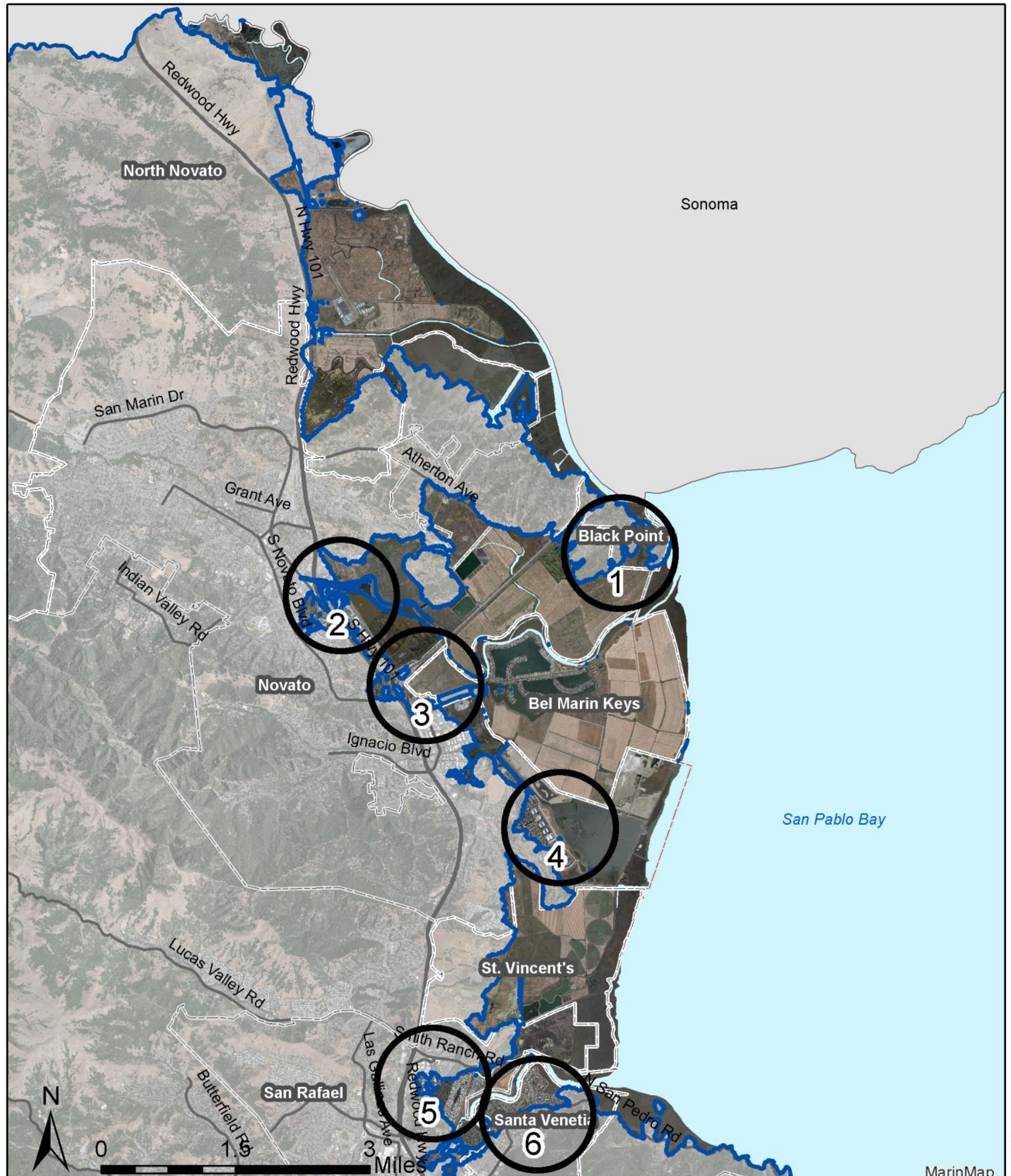
Location Indicators

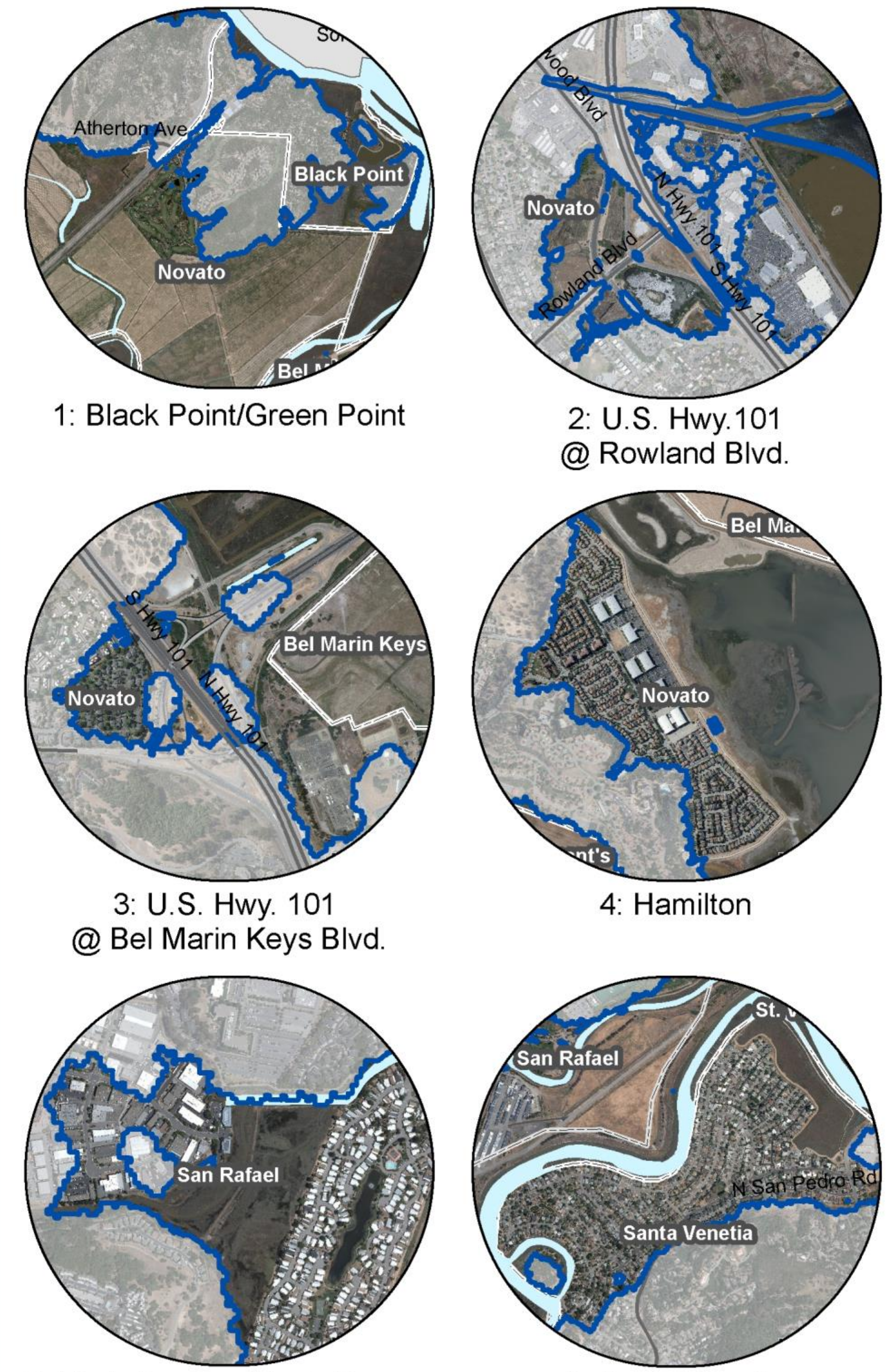
Unincorporated

Municipality

Road

Bay





1: Black Point/Green Point

2: U.S. Hwy.101 @ Rowland Blvd.

3: U.S. Hwy. 101 @ Bel Marin Keys Blvd.

4: Hamilton

5: Marin Lagoon/Marin Commons

6: Santa Venetia

Marin County

Date: 4/1/2017

CONSULTING

CoSMoS

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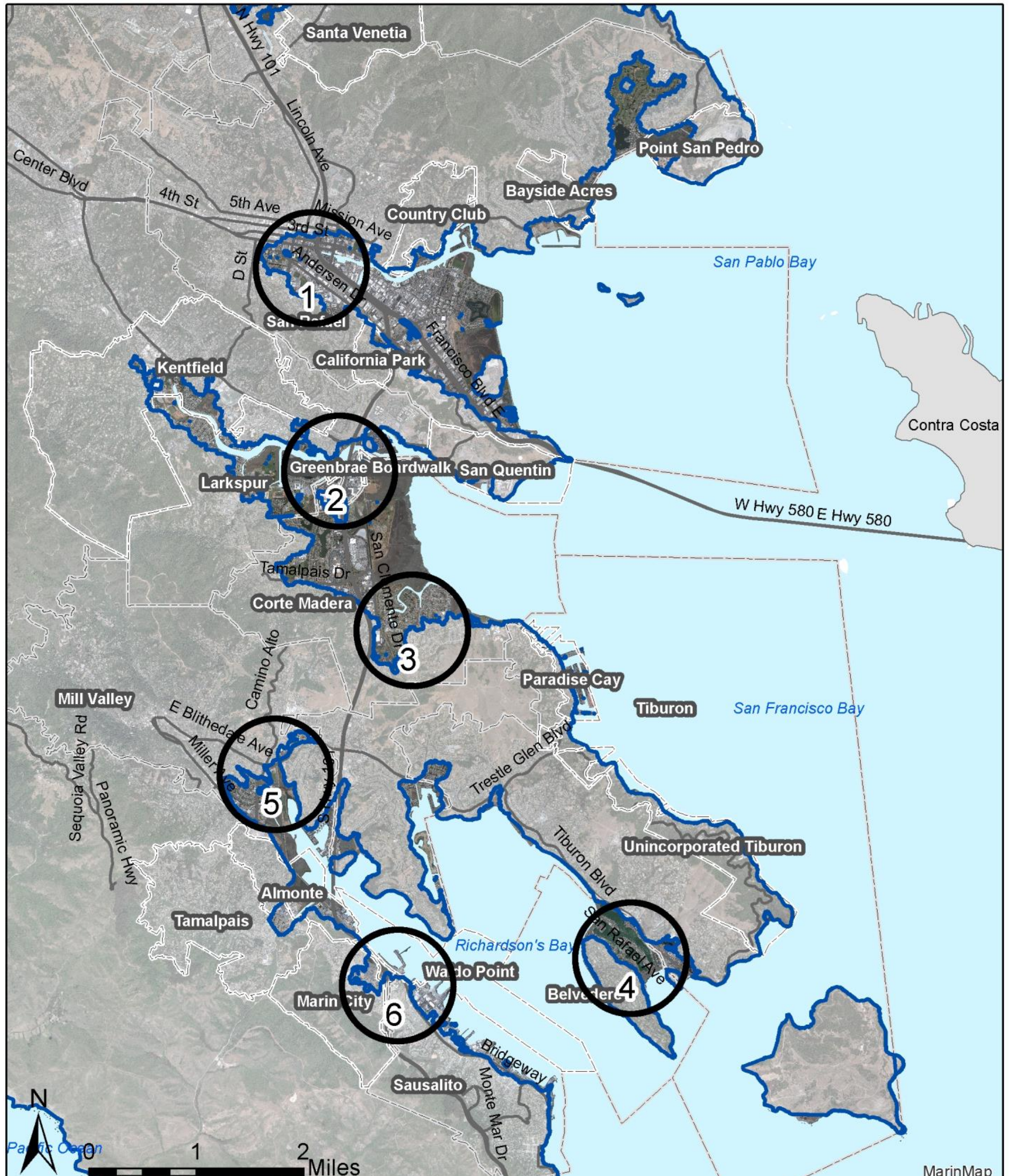
Map 3. Southern Study Area Inland Extent of Scenario 6

Inland Extent: Sea Level @ 60"+100-year Storm

Location Indicators

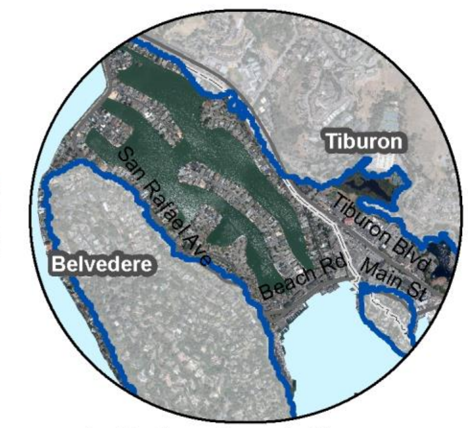
- Unincorporated
- Municipality
- Road
- Bay



1:Downtown San Rafael

2: Greenbrae/Larkspur

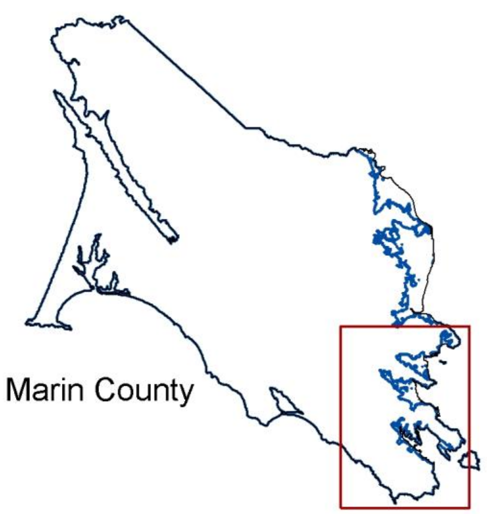
3: Corte Madera



4: Belvedere/Tiburon

5: Mill Valley

6: Waldo Pt. Harbor



Marin County

Date: 1/7/2017

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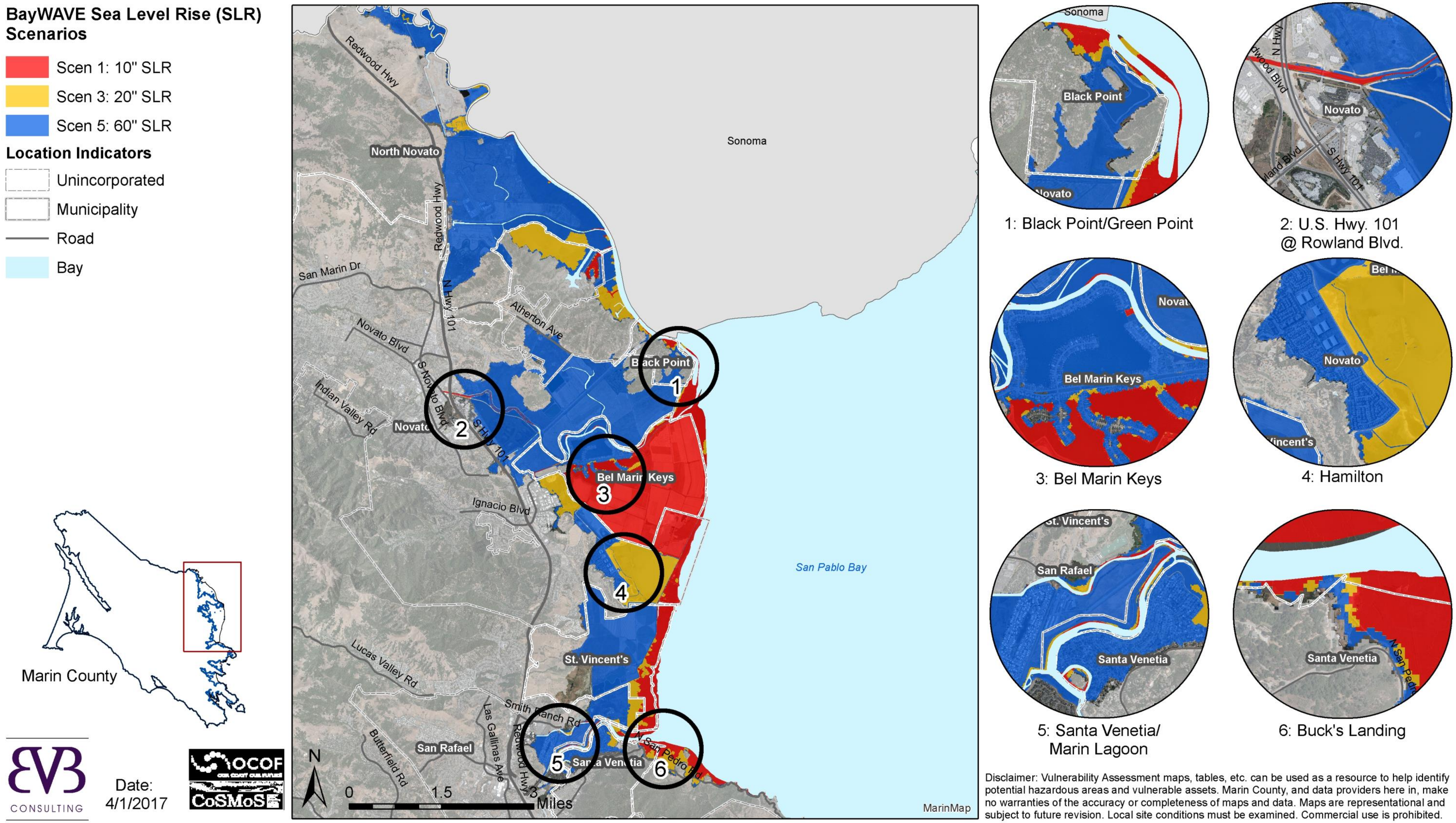
Map 4. Northern Study Area Sea Level Rise Scenarios



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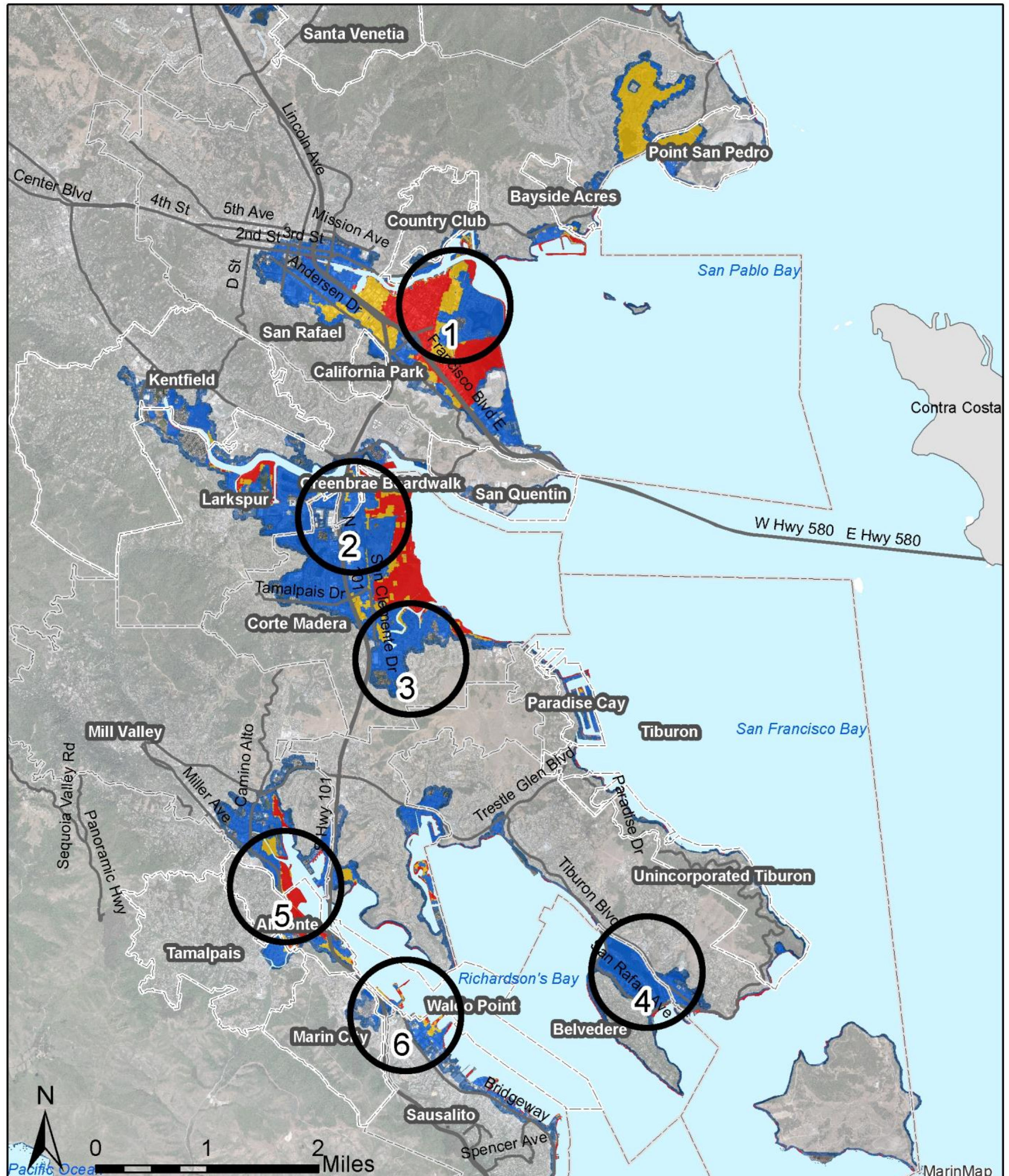
Map 5. Southern Study Area Sea Level Rise Scenarios

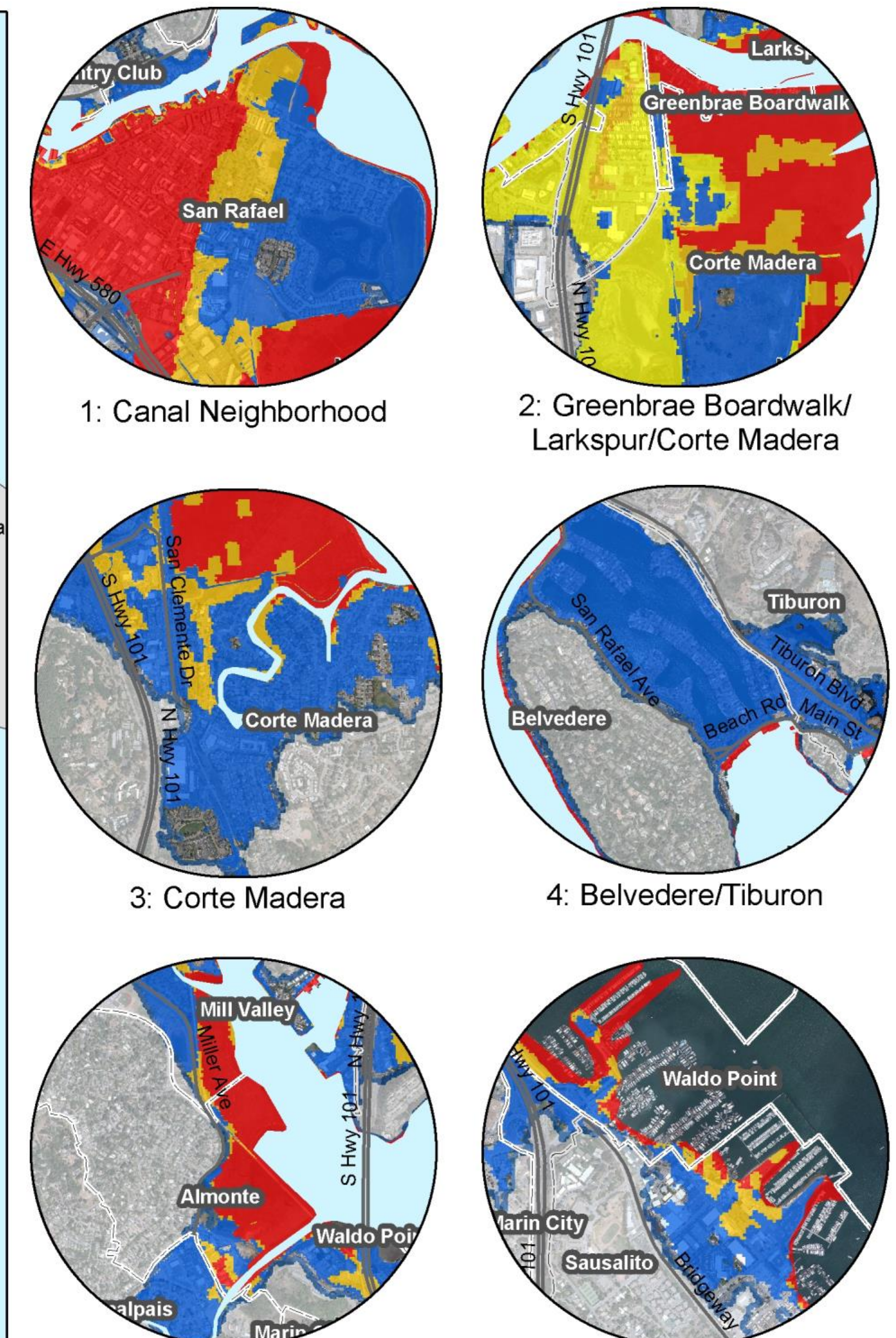
BayWAVE Sea Level Rise (SLR) Scenarios

- Scen 1: 10" SLR
- Scen 3: 20" SLR
- Scen 5: 60" SLR

Location Indicators

- Unincorporated
- Municipality
- Road
- Bay





1: Canal Neighborhood

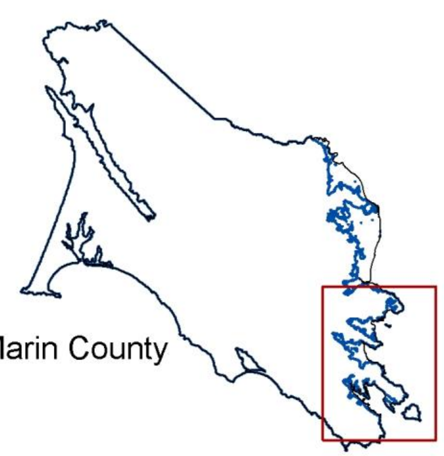
2: Greenbrae Boardwalk/ Larkspur/Corte Madera

3: Corte Madera

4: Belvedere/Tiburon

5: Almonte/Mill Valley

6: Marinship



Marin County

EVB CONSULTING

Date: 1/7/2017

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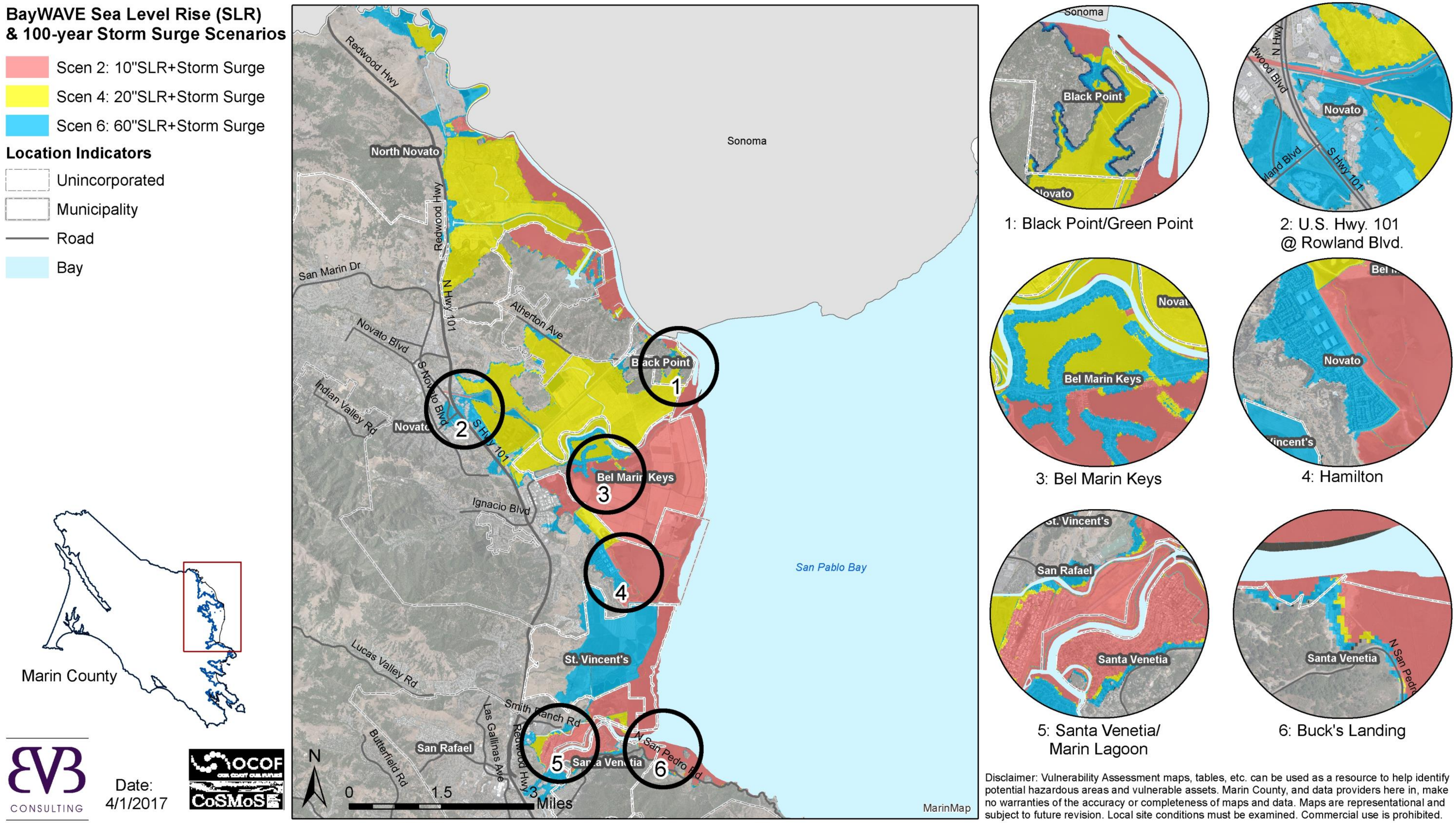
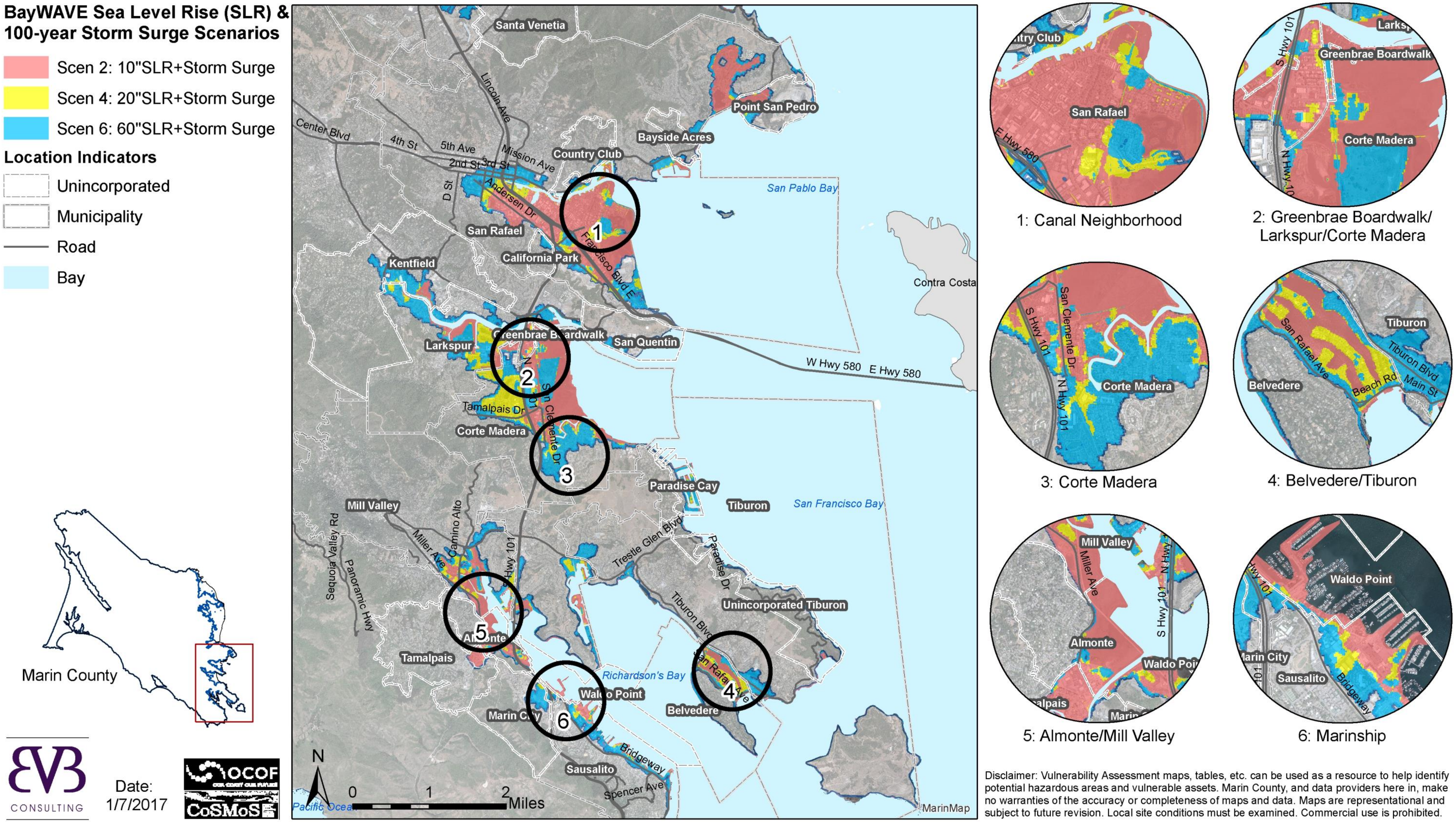
Map 6. Northern Study Area Sea Level Rise and 100-year Storm Surge Scenarios



METHODS

Map 7. Southern Study Area Sea Level Rise and 100-year Storm Surge Scenarios



According to the San Francisco Bay Conservation and Development Commission's *A Sea Level Rise Strategy for the San Francisco Bay Region* noted that it is particularly difficult to develop a strategy for dealing with sea level rise when the temperature increase scenarios yield a tenfold difference between the lowest and highest potential increases in the San Francisco Bay water level over the next 100 years.[23]

This high degree of uncertainty, due differing assumptions in carbon emissions, in sea level rise modeling results in a range of onset predictions. Variances between the predictions increase further out in time. This uncertainty is heightened by the non-linear growth rate of sea level rise.[24,25] Because of this variation, the BayWAVE scenarios do not focus on years, rather a framework of near-, medium-, and long-term scenarios. The OCOF tool enables the user to view the year a sea level projection could be met across the various published sea level estimates on the OCOF website.

Regardless, even if the world stabilizes carbon emissions, sea level rise will continue. Even if the global population reduces carbon emissions to levels where atmospheric concentrations decline, the decline will be slow, sea levels could continue to rise for decades, and hundreds of years could pass before sea level stabilizes or drops.[26,27]

Known Issues

The USGS acknowledges local modeling issues at the Petaluma River where dense vegetation leads to a false elevation reading and thus, under-predicts the potential flooding extent. Maximum flood potential indicates more probable flooding extents in these locations. In addition, the 100-year storm scenario flooding extents in the vicinity of Petaluma River and Novato may be under-predicted. The modeling team manually adjusted parameters to show more probable flooding behavior. Local professionals also suspect that water absorbed by the marshes at China Camp State Park may yield less flooding than the model estimates.

In addition, several sites underwent, or are currently undergoing, elevation increases after the baseline imagery was taken in 2010. Thus, the model and maps may overestimate flooding. These projects are shown on Maps 8 and 9 and include:

- Waldo Point Harbor: Filled and elevated parking and entrance area.
- Rose Garden Neighborhood, Larkspur: This recently completed development was elevated to meet FEMA and County flood prevention requirements.
- Aramburu Island, Strawberry: This man-made barrier island off Harbor Point in Strawberry was improved in 2012 and offers enhanced protection from wave impacts during storms.
- Hospice and base of Cal Park Hill: Recent construction may have elevated the site above 2010 elevations. This could result is less than flooding than estimated in this assessment.
- The Strand and Loch Lomond Marina, San Rafael: This project is near completion. The sites were filled with sediment and elevated to meet FEMA standards.
- Redwood Landfill: Roughly two feet in height was added to the external and internal levees after 2010.

Another issue arises with the Belvedere and Bel Marin Keys Lagoons. These lagoons are managed with tide gates that can close during high tides. The model treats these gates as open. So long as the tide gates and levees are not over topped, closing these protective devices could reduce flooding to properties on the lagoons in the near- and medium-terms.

Finally, note that the model does not take planned projects into consideration and assumes no action taken to prepare of adapt for sea level rise. Several projects along the shoreline are planned that could also help to reduce sea level rise flooding threats. These projects will be presented in the BayWAVE sea level rise early action report, the counterpart to this Assessment.

[23] San Francisco Bay Conservation and Development Commission. Revised September 2008. *A Sea Level Rise Strategy for the San Francisco Bay Region*

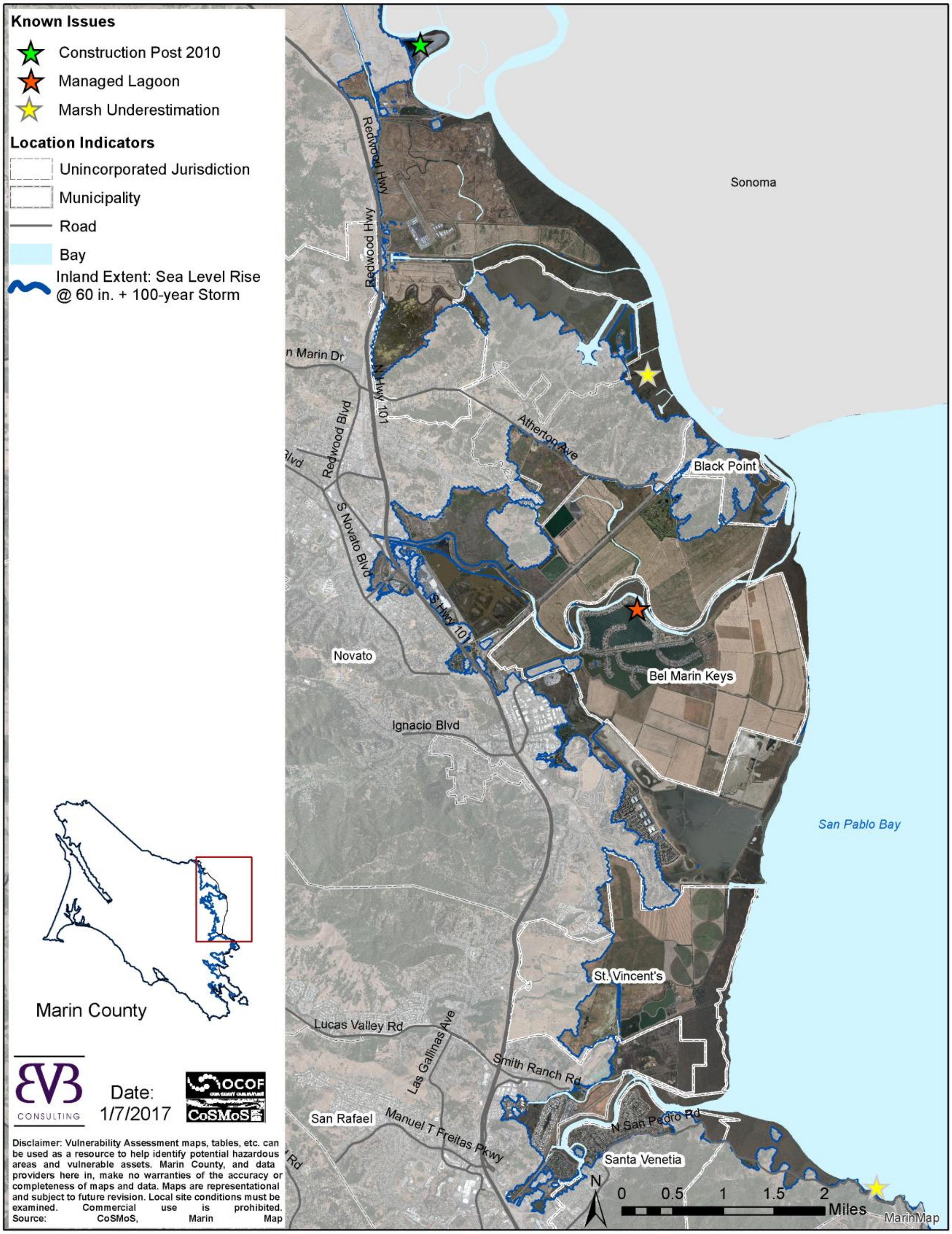
[24] P. Barnard. C-SMART Kick-off Meeting July 2014. htttp://walrus.wr.usgs.gov/coastal_processes/cosmos/

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

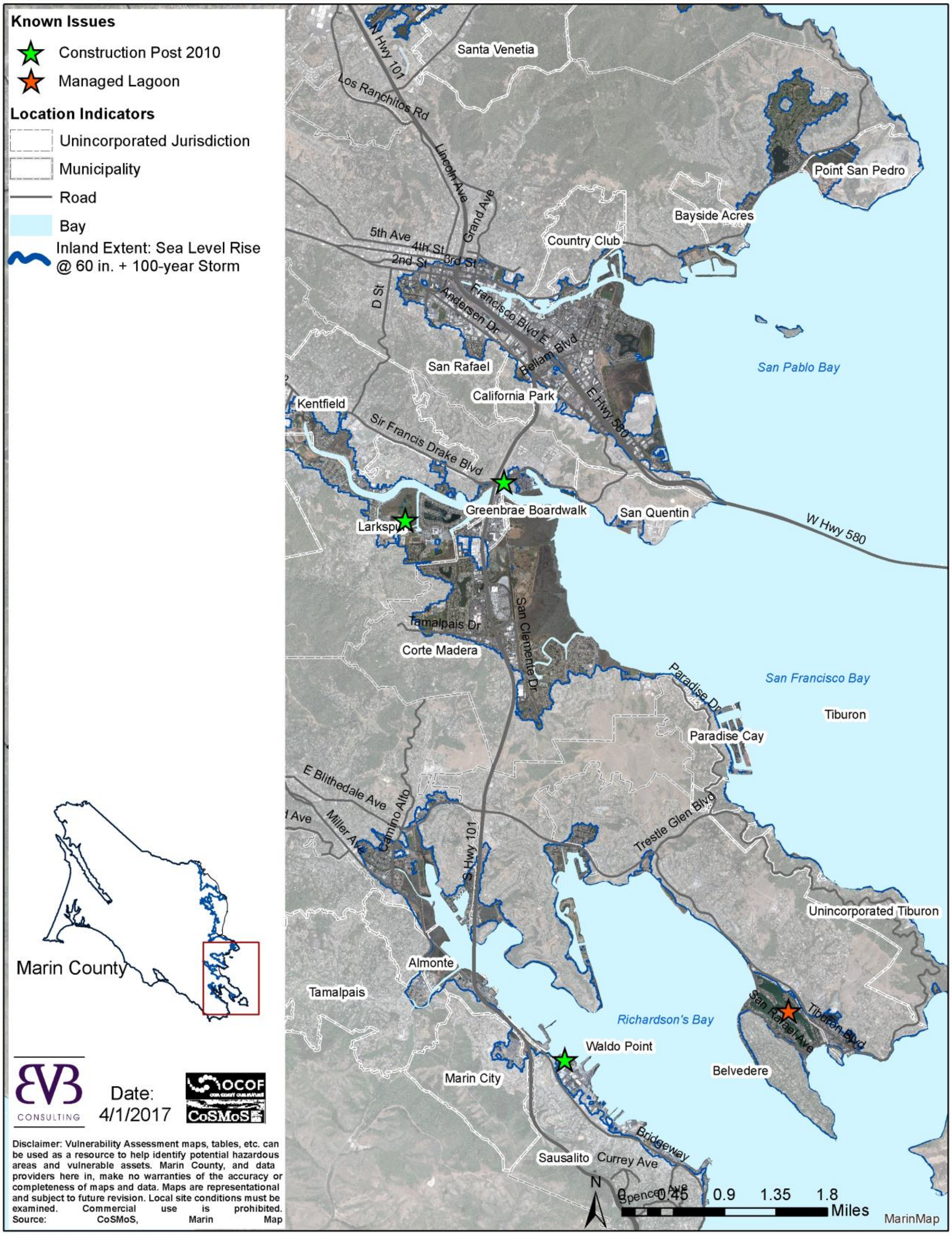
[26] IPCC Fourth Assessment Report: Climate Change 2007. Climate Change 2007: Working Group I: The Physical Science Basis. 10.7.2 Climate Change Commitment to Year 3000 and Beyond to Equilibrium. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-7-2.html

[27] 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

Map 8. Northern Study Area Known Issues with CoSMoS Model



Map 9. Southern Study Area Known Issues with CoSMoS Model



METHODS

Sea Level Rise Maps & FEMA

Several shoreline communities already grapple with stormwater and storm surge flooding on a near yearly basis and qualify for federal flooding insurance under the Federal Emergency Management Agency (FEMA). FEMA maps flood prone area in maps called Flood Insurance Rate Maps (FIRMs). These maps, while related to flooding, do not consider future potential sea level rise flooding. As the sea level rises, FIRMS would need to be updated to represent the new existing conditions. Other major differences between FIRMs and the sea level rise maps in this assessment are:

- FIRMs are based on *historic and current* trends and assumptions. CoSMoS sea level rise maps are based on modeling of potential *future* conditions.
- FIRMS address bay surge and stormwater creek flooding. CoSMoS does not address stormwater creek flooding, and
- FIRMS can incorporate policy decisions to exclude the role of non-FEMA certified protective shoreline armoring. CoSMoS is based solely on elevation, such that any shoreline armoring that contributes to elevation is accounted for.

Assessment Methods

As described in CalAdapt, vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to rising tides and bay surge threats. Such that, if an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity, the asset is vulnerable.

Assets were identified using existing MarinMap geographic data layers for roads, trails, parks, public facilities, utility districts, buildings, and parcels, and Department of Fish and Wildlife sources for wildlife species, habitats, fishing piers, marinas, access points, and ports. The Technical Advisory Committee supplemented these data sources with additional assets. Note that not all vulnerable assets are mapped due to data conflicts or unavailable geographic data. This does not imply that an asset is not vulnerable. This is especially true for utiltiy assets. The data layers generated span several years, and changes to the built environment may have occurred since the data was last updated. Where idetified, these areas were manually adjusted to reflect known current conditions. For example, based on aerial imagery, Niel Cumings Elementray school appears to be one large building, however, upon site visit, it becomes clear the site has four buildings connected by awnings. Improving the data comprehensively was not within the scope of this analysis, thus buildings numbers may be slightly off in some locations.

Phase 1: Exposure

To determine what could be exposed to sea level rise at MHHW and/or a100-year storm surge, the six BayWAVE scenarios, identified asset locations, and aerial imagery were overlaid in ArcGIS, a geographic statistical computer program. Assets intersecting sea level rise and storm scenarios were identified as exposed, and further assessed for sensitivity and adaptive capacity to determine if the asset is vulnerable to:

- Extreme event flooding during the annual highest high tides and/or storm surges that cause nuisance flooding,
- Inundation at,-at least, one high tide a day, several days a month, that results in chronic flooding,
- Erosion and geomorphic evolution from higher high tides and extreme storm events,
- Wave run up and high winds in extreme storm events,
- Saltwater intrusion,
- Rising water table, and/or
- Habitat shifts (applicable to natural resources).

In addition to geographic extent, CoSMoS GIS layers illustrating potential flood depth at MHHW were spatially joined with each vulnerable asset yielding average depths for scenarios 1, 3, and 5. Flood depth was calculated by converting GIS vector data to raster data to break the flood depth layer into thousands of cells, each with an assigned flood value. For roads, a high and low value was calculated on the line segment. Bridges are not quantitatively accounted for in this assessment. For buildings, cells underlying the building footprint were averaged to one flood depth at MHHW for scenarios 1, 3, and 5 for each building. Note that flood depth data is not available for all vulnerable areas and assets, especially those that exist in the bay beyond mean sea level and already subject to tidal influences. The data presented in this Assessment is for what is available and may not directly compare with data presented under exposure.

Flood depth figures are displayed in the onset and depth tables in each profile. In these tables, roads were assigned high and low values along the exposed segments for each scenario. Exposed road mileage provided is road miles, not lane miles. Lane mileage would more than double the mileage figures presented in this assessment. Where buildings are presented as a neighborhood group, a maximum average flood depth is provided. Where data is available, additional analysis summarizes how many buildings in each community could flood by one-foot flood depth intervals for scenarios 1, 3, and 5.

Phases 2 & 3: Sensitivity & Adaptive Capacity

The project team interviewed more than 100 asset managers, such as fire chiefs, city planners, transportation agency staff, using the Asset Vulnerability Assessment Tool, available in Appendix A, to assess built and natural resource assets. The tool is designed based on 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.[28,29,30,31,32,33,34]

Several public agency professionals were interviewed due to a high number of public assets in the exposed areas. Homeowners' association representatives were invited to be interviewed; however, home owners or non-public property owners were not individually interviewed. A list of interviews can be found in Appendix A

Asset managers were interviewed in person or by phone to answer two primary questions:

1. How ***sensitive*** is the asset to each exposure or threat?[35]
2. And if sensitive, what is the ***adaptive capacity***, or the asset's ability to maintain its function without further intervention (human action)?[36, 37,38, 39]

Any asset deemed moderately or highly sensitive to flooding or storm damage, with low to no adaptive capacity is considered vulnerable. Other questions about previous disruptions and the nature of potential disruptions were discussed to provide context to the qualitative statements. The interview results were combined with geographic data to develop this Vulnerability Assessment.

Additional analysis was conducted to determine the potential monetary losses from storm damages to buildings in scenario 6. Scenario 6 is chosen because it is the worst case scenario selected for assessment. This method applies damage levels to all vulnerable buildings in scenario 6 based on the FEMA HAZUS model intervals for yellow, minor damage of $5,000-17,000; orange, damage of $17,001+; and red, destroyed, post-disaster inspection tags.[40,41] Information on the real estate website Zillow was used to estimate median market value of single-family homes in February 2016.

The vulnerabilities found in the assessment process are summarized in Asset, Municipal, and Unincorporated Marin Profiles.

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[28] U.S. EPA. Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans. August 2014.
[29] CURRV-Tijuana River Valley - http://trnerr.org/currv/
[30] Bay Conservation & Development Commission: Adapting to Rising Tides. Hayward Resilience Study. 2014.
[31] 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.
[32] http://mitigationguide.org/task-5/steps-to-conduct-a-risk-assessment-2/3-analyze-risk/
[33] 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
[34] 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
[35] Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco. September 22, 2014. Appendix 5. OneSF Checklist
[36] 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
[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
[38] California Energy Commission Public Interest Environmental Research Program. Adapting to Sea Level Rise: A Guide for California's Coastal Communities. 2012.
[39] Bay Conservation & Development Commission: Adapting to Rising Tides. Hayward Resilience Study. 2014.
[40] Federal Emergency management Agency (FEMA) Website. Hazus. Last updated July 8, 2015. http://www.fema.gov/hazus.
[41] 2016 dollars

Phase 4: Risk & Onset
Risk & onset assess when and how likely impacts will occur to prioritize actions, though this alone may not be adequate criteria for decision-making. Onset is determined by the scenario an asset is exposed under. The scenario indicates a "no later than" timeline, as opposed to a "not until after" timeline, thus onset could occur before the snap shot in time represented by each scenario. Because of this, this assessment uses near-, medium-, and long-term labeling corresponding with the NRC ranges for before 2030, 2050, and 2100 respectively in Table 1.

All vulnerable assets are at risk of flooding and/or increasing rates of subsidence. Two types of flooding could occur, tidal flooding at MHHW or seasonal storm flooding. All assets that experience tidal flooding will also experience storm surge flooding. Tidal flooding at the average higher high tide could flood an asset once a day, several days a month. Each day has two high tides, thus it is possible that some properties could flood twice a day. Land that is flooded at this frequency is not useable for land based development. Storms surge flooding analyzed in this assessment is a 100-year storm surge, such that this storm surge has a 1 percent chance of occurring each year.

Other Considerations Methods

As adaptation planning moves forward, more detailed study and assessment across each of the 3 E's: economy, environment, and equity, will be critical. Moreover, the California Coastal Commission's Sea Level Rise Policy Guidance calls for assessing these, legal consequences, and the cumulative and secondary consequences of the vulnerabilities.[42] The "Other Considerations" section in each asset profile begins to identify issues and opportunities for each "E," and management. These sections are informed through literature review, asset manager interviews, and policy discussions with professional staff.

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 the County of Marin, 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 underestimates the number of people and value of property that would be vulnerable in the future.

Environmental: Highlights how disruption to buildings, roads, septic systems, and other assets could have secondary impacts on the environment and wildlife. Environmental impacts were gathered from asset managers and literature review.

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 impacting 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."[43] Populations that may be at higher risk include, low-income, limited English speaking, children, and those with limited mobility or sensory abilities.

Management: 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 East Marin residents.

To gain 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. Potential secondary impacts include:[44, 45]

- Contaminant releases from industrial sites or storage tanks,
- Loss of habitat from increased erosion,
- Loss of jobs and revenue streams,
- Loss of community or sense of place,

[42] *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

[43] 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

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

[45] 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.

- Increased need for government services or intervention, and
- Potential injury and loss of life.

Though the methods for this countywide assessment are robust, some areas may be represented as more vulnerable or less vulnerable than available information suggests. Some locations can only be represented accurately with onsite inspections of ground-level conditions. For example, the homes on Greenbrae Boardwalk, in unincorporated Marin and on Boardwalk One, in the City of Larkspur are raised on piers above tidal marshes. Utilities run to homes above the marsh plain along raised, wooden boardwalks. These communities already live with water and are accustomed to rising tides surrounding their homes. In theory, they can more easily and less expensively raise their homes and associated utilities to adapt to rising sea level (although they would still be impacted by the flooding in surrounding neighborhoods and streets). Understanding the vulnerability of these communities requires, at a minimum, onsite inspections of utilities and base floor elevations for each home; analysis that is beyond the scope of this report. The report uses the best available GIS data to analyze vulnerability. The data does not account for raised floor elevations, although future vulnerability assessments may include more specific data and the County is committed to regularly updating its assessments in response to new sea level rise projections and the availability of new and better data.

Collectively these methods determine what is vulnerable to sea level rise on the Marin shoreline and at what levels of sea level rise impacts could be felt by. This analysis can be a useful in assessing asset and community sea level rise vulnerabilities, and developing adaptation strategies and policies well suited for this unique and valuable bay region.