Appendix E

Sea-Level Rise Adaptation Technical Guidance Study, Geotechnical Investigation, and Conceptual Design Report

ESA

San Rafael Sea-Level Rise Adaptation Technical Guidance Study

SAN RAFAEL SEA-LEVEL RISE ADAPTATION TECHNICAL GUIDANCE STUDY

Prepared for
City of San Rafael

June 19, 2020

SAN RAFAEL SEA-LEVEL RISE ADAPTATION TECHNICAL GUIDANCE STUDY

Prepared for
City of San Rafael

June 19, 2020

550 Kearny Street
Suite 800
San Francisco, CA 94108
415.896.5900
www.esassoc.com

Prepared by: ESA

Bend
Camarillo
Delray Beach
Destin
Irvine
Los Angeles
Miami
Oakland
Orlando
Pasadena
Petaluma
Portland
Sacramento
San Diego
San Francisco
Santa Monica
Sarasota
Seattle
Sunrise
Tampa

D180140

San Rafael Sea-Level Rise Adaptation Technical Guidance Study

TABLE OF CONTENTS

Appendices

List of Figures

List of Tables

1 STUDY PURPOSE

The City of San Rafael's vibrancy emanates, in part, from the City's ten miles of shoreline along San Francisco Bay. However, when Bay water levels surge above their typical elevations, this shoreline is currently susceptible to overtopping, threatening substantial portions of the City with flooding. In addition, much of the City's stormwater drains through low-lying areas near the shoreline and out to the Bay. This drainage can be impeded by elevated Bay water levels and cause flooding.

These flood hazards will be exacerbated by future sea-level rise. Sea-level rise is a consequence of climate change caused by global increases in greenhouse gas emissions. These gases have and will continue to increase Earth's temperatures. The increased temperatures then cause sea-level rise through thermal expansion of the oceans and melting of ice sheets. Sea-level rise of about eight inches has already occurred in the last century and several feet or more of sea-level rise is projected by the end of this century. By elevating Bay water levels, sea-level rise will increase the frequency and severity of flooding along the City's shoreline.

To plan for these existing and future hazards, the City's Department of Public Works initiated this study, and has collaborated with the City's Department of Community Development and Marin County. The study's goal is to develop a sea-level rise adaptation plan that can be implemented for the benefit of the City and its residents. To meet this goal, this study's objectives are:

- Assess existing flood risk and flood risk that includes future sea-level rise projections
- Develop reasonable and feasible sea-level rise adaptations appropriate to the City's shoreline
- Evaluate adaptation measures to characterize the measures' costs and benefits
- Integrate recommended measures into phased adaptation plan to guide implementation

To achieve these objectives, this study conducted flood hazard mapping and vulnerability assessments for the City shoreline. Based on this assessment, the study recommends adaptation measures for each shoreline region. Adaptation measures that address sea-level rise for the City shoreline will need to be integrated with a larger, regional strategy of flood management and adaptation. Planning for this regional strategy is beyond the scope of this study, but being addressed by other City, County, and Bay area planning efforts.

This study builds on prior countywide and City efforts that identified areas vulnerable to sea-level rise. In particular, the City developed a white paper in 2014 (City of San Rafael, 2014) that identified the need to incorporate sea-level rise into long-term planning efforts and listed opportunity areas for addressing vulnerabilities. The County's BayWAVE study (BVB, 2017) combined flood mapping with public asset data to identify flood hazards throughout the County. This present study advances the BayWAVE mapping by providing vulnerability information at a more granular City scale and City-specific adaptation measures to address these hazards.

2 FLOOD SOURCES, HAZARDS, AND VULNERABILITIES

The foundations for managing for and adapting to flooding are descriptions of how and where flooding occurs and what assets flooding is likely to affect. This section summarizes these factors for the City's shoreline, starting with the flood sources which threaten the City shoreline. San Francisco Bay is the primary flood source of concern, with additional concern from watersheds that drain through the shoreline. These sources can generate flood hazards, which need to be characterized in terms of the area which they can inundate and the depth of inundation. Vulnerability takes another step by considering what assets fall within flood hazard areas and how these assets may be damaged.

2.1 Flooding from San Francisco Bay

2.1.1 Astronomic Tides

Pacific Ocean water levels propagate through the Golden Gate and largely determine water levels in San Francisco Bay. Under typical conditions, ocean water level fluctuations are caused by astronomic tides. As indicated by their name, astronomic tides are generated in the ocean by forces between the earth, the sun, and the moon. These tidal fluctuations are well-understood and can be predicted with high accuracy. The highest astronomic tides of each year are commonly referred to as 'king tides'.

Tidal water level fluctuations are commonly extracted at distinctive phases of the tide and then averaged, to provide representative elevations known as tidal datums. Three common tidal datums are mean higher-high water (MHHW), mean sea level (MSL), and mean lower-low water (MLLW). Tidal datums, measured relative to North American Vertical Datum of 1988[1] (NAVD88), are available from a number of NOAA stations near the San Rafael shoreline, as shown in Table 1. ESA (2018) collected tidal data at Tiscornia Marsh (immediately south of the mouth of San Rafael Creek) in September and October of 2017 and calculated tidal datums based on comparison with the NOAA Richmond gauge and the NOAA (2003) methodology.

This comparison of City tidal datums with NOAA tidal datums confirms that the longer NOAA records and tidal datums can be applied along the City's shoreline.

[1] This study uses the North American Vertical Datum of 1988 (NAVD88) as a reference point for measuring and comparing elevations of water levels, flood management measures, and development subject to flooding.

TABLE 1
TIDAL DATUMS IN VICINITY OF PROJECT SITE

	Nearby NOAA Tidal Datum Elevations (1983-2001 Tidal Epoch) ft NAVD88			Estimated Tiscornia Tidal Datums[4] ft NAVD88
	Richmond[1]	Point San Pedro[2]	Point San Quentin[3]	
Mean Higher High Water (MHHW)	6.06	6.04	5.95	6.06
Mean Sea Level (MSL)	3.26	3.24	3.24	3.24
Mean Lower Low Water (MLLW)	0.00	0.17	0.17	0.17

[1] NOAA Station 9414863
[2] NOAA Station 9415009
[3] NOAA Station 9414873
[4] Based on data collected in September and October 2017 by ESA (2018), and methodology of NOAA (2003)

2.1.2 Coastal Flood Events

Flood conditions above the typical astronomic tides are caused by atmospheric and oceanic processes. The processes that raise ocean water levels are mostly associated with winter storm events, so the resulting water level increase is often termed 'storm surge'. Storm-related processes that cause surge are lower atmospheric pressure and wind. In addition, changes in large-scale oceanic circulation, particularly during winters with El Niño conditions, can cause higher-than-normal water levels for several months at a time. Depending on the intensity of each of these processes, as well as their coincident occurrence relative to astronomic tides, storm surge can result in water levels up to three feet higher than just astronomic tides. Winter storm winds can also generate waves that may pose an additional flood hazard, particularly when the waves ride on storm-surge-elevated water surface.

Historical flood events in San Francisco Bay from the last several decades are listed in Table 2, along with the estimated 99%, 10%, and 1% annual chance[2] still water levels. These extreme statistical water levels are based on the hydraulic analysis used by FEMA (2017) for its revised coastal flood mapping and are tabulated in AECOM (2016). As still water levels, they do not include the additional effects of wave runup.

Flood events in February 2017 resulted from high rainfall combined with elevated Bay water levels, leading to peak water levels at the NOAA Richmond (Chevron Pier) gauge reaching 7.9 feet NAVD88 on February 7th and 14th. These events fell between the 99% and 10% annual chance flood level at the site. While water level observations aren't available along the San Rafael shoreline for most time periods, ESA (2018) found that water levels at the NOAA Richmond gauge are similar and are useful as a proxy for water levels along the San Rafael shoreline.

[2] 'Annual chance' refers to the probability of a flood event being equaled or exceeded each year. An alternate naming convention is based on the return interval concept, where the return interval is the inverse of the annual chance. For example, the 99% annual chance may also be called the 1-year event and the 1% annual chance may also be called the 100-year event.

Flood water levels exceeding the 2017 events were recorded in 1998, 2001, 2003, 2005, 2011, and 2014 (Figure 2). The events in 2005 and 1998 fell between the 10% and 1% annual chance water level. Although the Richmond gauge does not have data before 1995, the largest recorded water level at the Presidio gauge in San Francisco occurred during the winter 1982-83 El Niño event, when water levels around the Bay were estimated (USACE, 1984) and thought to yield levels similar to the 1% annual chance water levels throughout the Bay.

TABLE 2
FLOOD WATER LEVELS SINCE 1998 IN SAN FRANCISCO BAY

Annual Chance (Return interval) OR Event	Richmond[4]	San Francisco[5]
Daily (MHHW) [1]	6.1	6.1
99% annual chance (1-year, approx. king tide)[1]	7.3	7.2
February 7, 2017[2]	7.9	7.4
February 14, 2019[3]	7.9	7.5
December 3, 2014	8.0	7.8
January 10, 2001	8.1	8.1
March 20, 2011	8.1	7.7
December 24, 2003	8.3	8.2
10% annual chance (10-year)[1]	8.3	8.3
January 8, 2005	8.5	8.2
February 6, 1998	8.7	8.4
1% annual chance (100-year)[1]	9.5	9.5

[1] Based on AECOM (2016)
[2] Coincident with ~1" precipitation
[3] Coincident with ~ 5" precipitation
[4] NOAA Station 9414863
[5] NOAA Station 9414290

2.2 Flooding from Watersheds

While this study mainly focuses on vulnerability of San Rafael to coastal flooding from the Bay, large rainfall events can occur simultaneously with high tides and storm surge. Elevated Bay water levels may then impede the drainage of creeks and stormwater systems to the Bay, resulting in watershed-sourced flooding more severe than flooding due to watershed or storm surge events on their own.

Runoff reaches the Bay primarily from Las Gallinas Creek and San Rafael Creek (whose lower end is also referred to as the San Rafael Canal). Tributaries Irwin Creek and Mahon Creek drain into San Rafael Creek in downtown, near the Irwin Street crossing. The City's stormwater system also conveys runoff across and from the low-lying land just behind the shoreline, to discharge to the Bay. Because of the low elevations behind the shoreline, pump stations are located throughout the City to lift stormwater into the San Rafael Canal and the Bay.

2.2.1 San Rafael Creek

San Rafael Creek drains a 6.4-square-mile watershed in central and northern San Rafael that is largely urban. The creek drains to the Bay near the Al Boro Community Center and the Marin Yacht Club.

Peak flows are reported by FEMA (2017) and shown in Table 3. The portion of the creek located east of Main Street is oversized for the freshwater runoff conveyed through the creek (Appendix B in ESA, 2018). East of the Highway 101 crossing, the creek is periodically dredged to maintain depths for an active boating community. Flood water levels in the dredged reach nearly match Bay water levels and are relatively unaffected by riverine flood events, indicating that Bay storm surge is the principal flooding source in this reach.

TABLE 3
PEAK RIVERINE DISCHARGE IN LAS GALLINAS AND SAN RAFAEL CREEKS, CUBIC FEET PER SECOND (CFS)

Annual Chance	Las Gallinas Creek North Fork[1]	Las Gallinas Creek South Fork[1]	San Rafael Creek at Grand St[2]	San Rafael Creek at B St[2,3]
1% (100-year event)	1,563	1,596	1,995	1,090
2% (50-year event)	1,377	1,401	1,865	905
10% (10-year event)	923	920	1,430	750
50% (2-year event)	353	340	--	--

[1] USACE (2011), ESA (2019)
[2] FEMA (2017)
[3] Note that this tributary portion of San Rafael Creek is also referred to as Mahon Creek

2.2.2 Lower San Rafael Creek Tributaries

Downtown San Rafael includes two tributary channels that feed into the lower portion of San Rafael Creek. Due to their confluence to San Rafael Creek, both tributaries experience some extent of tidal influence and have segments within the FEMA 100-year flood zone.

Irwin Creek is a small flood control channel contained within earthen embankments and riprap, running north-south underneath of Highway 101. The creek has steep banks and is laterally constrained (approximate width of 30 feet). The creek experiences tidal action from its confluence with San Rafael Creek to approximately as far north as Mission Avenue. The creek's connection with San Rafael Creek is south of 3rd Street, and this portion could be widened in the future, as well as the portion north of the 2nd Street crossing.

Mahon Creek is a tributary to San Rafael Creek with a confluence near the Highway 101 crossing in downtown San Rafael. West of Highway 101, the creek turns south at the City's Old Corporation Yard pump station, and passes under Lincoln Avenue before turning west near the Lindaro pump station. This portion of the creek is tidally-influenced, relatively wide (approximately 100 feet), and has a vegetated slope on both sides, flanked by earthen embankments and a bike path. Upstream from the Lindaro pump station and Anderson Drive crossing, the creek becomes more constrained by development (approximate width of 25 feet) and continues to have tidal influence at least as far as the B Street crossing. The creek is not differentiated from San Rafael Creek by FEMA (2017), which lists flood flows and flood stages from the tidally influenced areas up to the upper watershed (Table 3). Potential widening of a portion of the creek is being considered.

2.2.3 Las Gallinas Creek

Las Gallinas Creek drains a 7.5-square-mile watershed bounded by Lucas Valley Ridge and Sleep Hollow Ridge to the west, the Gallinas Hills to the north, and San Rafael Hill and San Pedro Ridge to the south. The creek has north and south forks which join near the east end of the San Rafael Airport and continue for about 7,000 feet before draining into the Bay. The creek's flood hydrology was studied by USACE (2011) and more recently in conjunction with marsh restoration planning for McInnis Park (ESA 2019). Table 3 lists the peak flow rates for the north and south forks of the creek.

ESA (2019) modeled creek water levels under a range of scenarios including high flows (10- and 100- year fluvial flood events) coincident with Bay storm surge (10- and 100-year coastal water level). This modeling indicates that Bay water levels propagating up the channels are the principal determinant of peak flood water levels along the lower reaches of the creek.

2.3 Sea-Level Rise Projections

The accumulation of human-produced greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and climate change. Along the Bay shoreline, climate change will cause sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets. Over the last century, the tide gauge in San Francisco has recorded sea-level rise of eight inches over the last century (Figure 32). In addition to these observed sea-level rise trends, the best available science, as reviewed specifically for California (Griggs et al., 2017; OPC, 2018), predicts that sea-level rise will continue and accelerate throughout this century and into the next century. Because specifics about future greenhouse gas emissions and climate response are not fully known, the exact sea-level rise scenario that will occur is not precisely known at this time. However, considering a range of all but the most extreme scenario, sea-level rise by 2100 is projected to be between two and nearly seven feet in San Francisco Bay by 2100 (OPC, 2018).

Table 4 lists sea-level rise projections for 2030, 2050, 2070, and 2100 relative to sea level in 2000. The 'likely range' for low risk aversion is estimated to have a 66% chance of occurrence, whereas the medium-high risk aversion range is estimated to have a 0.5% chance of exceedance.

TABLE 4
SEA-LEVEL RISE PROJECTIONS FOR SAN FRANCISCO, IN FEET

Scenario	2030	2050	2070	2100
66% Likely Occurrence: Low Risk Aversion	0.5	1.1	1.5 - 1.9	2.4 – 3.4
0.5% Chance of Exceedance: Medium-High Risk Aversion	0.8	1.9	3.1 – 3.5	5.7 – 6.9

Source: OPC (2018)

Table 5 shows how extreme water levels near San Rafael would change with different amounts of sea-level rise. The table's cells are shaded to indicate correspondence between existing conditions with zero sea-level rise and future conditions. For example, the existing 10-year water level of 8.3 ft NAVD88 will occur with a 1-year return interval with one foot of sea-level rise and with a daily return interval with two feet of sea-level rise. These intervals were chosen to best illustrate the concept with conventional intervals. The County BayWave study (BVB 2017) were based on a intervals based on the metric system (e.g. 50 cm, 100 cm).

TABLE 5
FUTURE WATER LEVELS WITH SEA-LEVEL RISE AT SAN RAFAEL, IN FEET NAVD88

Annual Chance (Return Interval)	0 ft SLR	1 ft SLR	2 ft SLR	3 ft SLR	5 ft SLR
(Daily MHHW)	6.1	7.1	8.1	9.1	11.1
99% annual chance (1-year)	7.3	8.3	9.3	10.3	12.3
10% annual chance (10-year)	8.3	9.3	10.3	11.3	13.3
1% annual chance (100-year)	9.5	10.5	11.5	12.5	14.5

Source: NOAA Station 9414863 and OPC (2018)

In addition to climate change causing sea-level rise, future conditions are also projected to increase precipitation intensity (Swain et al. 2018). This change would likely increase flood hazards from stormwater and creek discharge. However, this aspect of climate change was not characterized for this study.

2.4 Flood Mapping

Flood mapping characterizes the extent and depth of flood hazards from coastal and watershed sources. FEMA conducts mapping nationwide to inform flood management and its flood insurance program. Coastal flood maps for the City were recently updated by FEMA. However, FEMA only considers existing conditions and does not account for sea-level rise in its mapping. To provide an assessment of future conditions, the County's BayWAVE study evaluated flood mapping that includes sea-level rise. This effort also considered vulnerability by tabulating what assets are within areas mapped flood hazard areas.

2.4.1 FEMA

FEMA performed detailed coastal engineering analyses (DHI, 2011) of water levels and waves in San Francisco Bay for the nine San Francisco Bay Area counties. These analyses were then used to revise the Marin County Flood Insurance Study (FIS) and Flood Insurance Rate Map (FIRM) panels along the San Francisco Bay shoreline. For San Rafael, the revised FIRM became effective on March 16, 2016.

Special Flood Hazard Areas (SFHA) mapped on the revised FIRM are shown on Figure 4. None of the City's shoreline levees are accredited as meeting FEMA crest elevation and geotechnical standards. Therefore, FEMA assumes the levees do not protect inland areas from inundation, but do block inland wave propagation. The Base Flood Elevation (BFE), for the 1% annual chance flood event varies along the San Rafael shoreline from elevations 10 to 13 feet NAVD88. The BFEs are derived from the 1-percent-annual-chance Total Water Level (TWL), which includes still water elevation level (SWL) and wave runup. The 1-percent-annual-chance SWL along the San Rafael shoreline is a constant 9.7 feet NAVD88. Therefore, the variability in BFEs is due to varying wave exposure and shoreline geometry. Table 6 lists BFEs along the regions of the San Rafael shoreline considered in this study.

TABLE 6
FEMA COASTAL FLOOD ZONE INFORMATION

Region	FEMA Coastal Transect	BFE (ft NAVD88)
Bayfront South	B69 – B76	10 - 12
Canal South	N/A	10
Canal North	B65 – B67	10 - 13
Loch Lomond	B64	12
Point San Pedro Road	B58 – B61	10 - 12
Las Gallinas	B17 – B20	10 - 12

Source: FEMA (2016)

2.4.2 BayWAVE

2.4.2.1 Flood Hazards

The Marin BayWAVE study provided vulnerability assessments for cities throughout Marin County, including San Rafael (BVB, 2017). This study's vulnerability assessment was based on modeling results from the Coastal Storm Modeling System (CoSMoS), developed by USGS. CoSMoS provides predictions of coastal flood hazards with future sea level rise, whereas FEMA only considers existing conditions. CoSMoS predictions are accessible via the website for the Our Coast, Our Future program.

As described in more detail in Appendix B, the BayWAVE study used the coastal flood hazard mapping predicted by the USGS to map which assets are vulnerable to flooding under a range of future scenarios. The modeled inundation extents and depths are from a two-dimensional numerical model (Ballard et al. 2016). The numerical model's Bay water level predictions have not been fully validated, nor has the model's representation of the City's shoreline elevations been confirmed. These factors probably explain why the BayWAVE mapping for lower water levels (e.g. Scenarios 1 and 3) predict extensive inundated areas that do not correspond to little or no inundation observed during recent events with similar water levels. However, in spite of these sources of uncertainty, the study provides useful screening level assessment, particularly for more extreme conditions anticipated to occur with sea-level rise.

2.4.2.2 Flood Vulnerability

Table 7 lists built assets that were identified as vulnerable by the BayWAVE study for a scenario of peak water level three feet above current MHHW. This is roughly equivalent to the 1% annual chance coastal flood event occurring now or the daily water levels that would occur with three feet of sea-level rise. As part of this project, the vulnerability of these areas to flooding was also compared with other sources, including FEMA's mapping, a site visit with City staff, and a targeted topographic survey of parts of the shoreline. Sections 3.2.1 through 3.2.6 describe vulnerabilities targeted for each of the City's shoreline regions.

TABLE 7
ASSETS VULNERABLE TO FLOODING FOR WATER LEVEL THREE FEET ABOVE CURRENT MHHW

Region	Roads		Example Built Assets Impacted
Bayfront South	Bahia Pl. [L] Bahia Wy. [L]	Bahia Cir. [L] Kerner Blvd. [L]	Businesses adjacent to Francisco and Kerner Blvds
Canal South	Alto St. [L] Amalfi Pl. [L] Bellam Blvd [L] Belvedere St. [L] Canal St. [L] Capri Ct. [L] Castro Ave. [L] Charlotte Dr. [L] Elaine Wy. [L] Fairfax St. [L] Francisco Blvd E [L] Front St. [L] Grand Ave [L] Hwy 101 [C] Hwy 580 [C] Irene St. [L,P]	Larkspur St. [L] Lido Ln. [L] Lisbon St. [L] Louise St. [L] Market St. [L] Medway Rd. [L] Mill St. [L] Novato St. [L] Portofino Rd. [L] Shoreline Path Sonoma St. [L] Sorrento Wy. [L] Tiburon St. [L] Verdi St. [L] Vivian St. [L]	Beach Park Canal Neighborhood Pickleweed Park facilities
Canal North (East of Hwy 101)	Grand Ave [L] Irwin St. [L]	Mooring Rd [L] Sea Wy [L] Summit Ave [L]	Marin Community Clinic Montecito Plaza San Rafael High School San Rafael Yacht Club
Canal North (West of Hwy 101)	Hetherton St. [M] 2nd St. [M] 3rd St. [M] 4th St. [L]	Tamalpais Ave. [L] Francisco Blvd W. [L] Lincoln Ave. [L]	San Rafael Transit Center SMART Rail Station San Rafael Corporate Center Businesses along Francisco Blvd W and South Irwin St.
Loch Lomond	Point San Pedro Rd [L,C]		Loch Lomond Marina
Point San Pedro Rd	Point San Pedro Rd [L,C]		Peacock Gap Park
Las Gallinas	Smith Ranch Airport Rd. [L]		Smith Ranch Airport SMART Rail Marin Lagoon

M = Marin County; C = State; L = Local; P = Private.

Source: MarinMap, CoSMoS

3 FLOOD HAZARD AND VULNERABILITY

As identified by the City of San Rafael (2014), FEMA (2016), and the BayWAVE study (BVB, 2017), parts of San Rafael are already vulnerable to flooding, particularly due to combined high water levels and wave runup in the Bay threatening the shoreline, and watershed runoff that occurs during elevated Bay water levels. Information on existing flood vulnerability was gathered from several sources for this study:

- **FEMA:** The FIRM (effective March 2016) maps flood hazard zones for the 1% and 0.2% annual chance coastal flood events and the FIS (effective August 2017) provides additional details about base flood elevations.

- **BayWAVE Study:** maps of predicted flooding from the USGS CoSMoS model overlaid with publicly available asset data from MarinMap and other sources. This study looked at a range of future sea-level rise scenarios.

- **Coordination with City of San Rafael staff:** ESA met with City staff from the Public Works and Community Planning departments. Public Works staff provided locations of known flood vulnerabilities and met ESA staff on May 2nd, 2019 to tour the sites. Community Planning staff provided information on shoreline developments, sea-level rise planning, and the City's General Plan.

- **Site topographic survey:** ESA performed a targeted RTK GPS topographic survey on May 2nd, 2019. Site photos and elevation data were collected in areas where flooding is known to already occur, and along outboard levees adjacent to the Bay (Appendix A).

- **San Francisco Bay Tidal Datums and Extreme Tides Study:** This study by AECOM (2016) aggregates hydraulic modeling that was conducted for FEMA (DHI, 2011). The modeling hindcasted multiple decades of Bay water levels and was analyzed to estimate tidal datums and extreme water levels along the Bay shoreline.

- **Concurrent planning and restoration efforts:** Ongoing studies provided valuable information on local hydrology and flooding, including the McInnis Marsh Restoration Project Hydraulic Modeling Report (ESA, 2019) and the Tiscornia Marsh Conceptual Design Report (ESA, 2018).

3.1 Shoreline Delineation

The City consists of low-lying areas vulnerable to coastal flooding within the City of San Rafael. Much of the vulnerable areas were built on former tidal marshes (USCS, 1853), which were raised with earthen fill and/or protected by levees to make more suitable for development. However, none of the City's shoreline levees are accredited as meeting FEMA crest elevation and geotechnical standards.

Based on San Rafael's topographic layout, existing shoreline flood protection, flood hazard exposure, and land use, this study defines the six shoreline regions shown in Figure 1. The characteristics used to designate each of these regions are described in the sections below. From south to north, these regions are:

- Bayfront South
- Canal South
- Canal North
- Loch Lomond
- Point San Pedro Road
- Las Gallinas

Other portions of the City border the Bay besides these six areas. However, in these other areas, the land rises steeply from the shoreline and structures are typically several feet or more above the current and future flood hazard elevations. As such, these areas are not considered in this study. However, the vulnerability of these shoreline segments and structures to flooding and erosion should be assessed on a case-by-case basis.

While these six areas do not include all land within the City, many public resources are within these areas that serve portions of the City and region outside of these six areas. For instance, many roads that serve as key transportation corridors, pump stations that convey stormwater from uplands, businesses, and City services are located within the six vulnerable areas.

3.2 Hazard Assessments

3.2.1 Bayfront South

This region comprises the southern shoreline of San Rafael from the mouth of San Rafael Creek to the high ground near Point San Quentin (Figure 5). Except for Tiscornia Marsh on the north end and the interior of the Canalways property, most of this region was built on Bay fill to elevations above high tide elevations, but below the 1% annual chance Bay water level. Its levees were constructed sometime between 1950 and 1968 (Siegel Environmental, 2016). This region's shoreline faces the Bay and is exposed to waves as well as high Bay water levels. The City owns much of this region's shoreline. Low-lying areas on the west side of this region are hydraulically connected to low-lying areas in the next region, Canal South.

The Bayfront South region is protected by levees along the edge of the Spinnaker and Baypoint neighborhoods, Canalways, and other properties to the City's southern boundary (Figure 6). The northern half of this region is shown in more detail in Figure 7, and the southern half in Figure 8.

Based on hazards and vulnerabilities in this area, focus areas for adaptation in this region are:

- **Focus Area BF-1:** The approximately 2,200-foot levee and walkway fronting the Al Boro Community Center, City-owned diked pickleweed marsh, and Schoen Park varies in elevation from about 9 to 13 feet NAVD88. The levee has not qualified for FEMA accreditation criteria for crest elevation and geotechnical specifications. The outboard

FEMA BFE is 10 feet NAVD88. The adjacent marsh provides some protection from wind wave runup and erosion, but the marsh's outboard edge has been eroding at a rate of 1-5 feet per year and will continue to erode without restoration (ESA, 2018).

- **Focus Area BF-2:** The northern shoreline of Spinnaker Point is protected by an unaccredited levee that varies in elevation from about 11 to 12 feet NAVD88 (Figure 6). The local FEMA BFE is 12 feet NAVD88, higher than just Bay water levels alone, indicating that waves contribute to the flood hazard.

- **Focus Area BF-3:** The eastern shoreline of the Spinnaker Point neighborhood is protected by an unaccredited levee with an average elevation of about 12 feet NAVD88, similar to the local BFE, and therefore not providing enough freeboard for accreditation and flood hazards with future sea-level rise. The levee's performance relative to geotechnical accreditation criteria is unknown.

- **Focus Area BF-4:** The unaccredited levee fronting the undeveloped Canalways property has a relatively low crest elevation (between 9 and 10 feet NAVD88) and is vulnerable to overtopping from high Bay water levels and waves. The site also receives runoff from surrounding areas. Canalways is privately-owned property, with much of the site below tidal water levels. Development and a possible extension of Kerner Boulevard has been proposed near the southwest portion of the site.

- **Focus Area BF-5:** East of Kerner Way, between Shoreline Parkway and Grange Avenue, City-owned land along the shoreline includes unaccredited levees and managed wetlands. The levees vary in height, with lower portions vulnerable to wave overtopping for present conditions. The wetlands are connected to the Bay via culverts with hydraulic structures to only allow muted tides within the tidal marshes. The southern wetland is drained by the Piombo pump station. Developed areas behind the levee ranges in height from lower than current high tide to higher than the 100-year still water level even with several feet of sea-level rise.

3.2.2 Canal South

This region includes the area bordered by the southern shoreline of San Rafael Canal and Kerner Boulevard. Due to subsidence, much of this region lies at elevations from 4-7 ft NAVD. These elevations are below high tide elevations and would be inundated daily were it not for the high ground along the canal's south shoreline. Its primary flood hazard stems from coastal Bay flood events, which may be supplemented by high creek and stormwater discharge. Because this area is below typical tidal water levels in the canal, this region depends on pump stations to remove storm water. Most of this shoreline consists of residential private property. Low-lying areas within this region are hydraulically connected to low-lying areas in the prior region, Bayfront South.

The Canal South region (Figure 9) has the greatest number of vulnerable roadways and building assets within the FEMA 1% SFHA (Figure 4). As noted elsewhere (City of San Rafael, 2014;

ESA, 2018), this region also has a high density of low-income and low English-proficiency households.

All along the southern shoreline of San Rafael Creek, this region is vulnerable to flooding from the current 1% annual chance Bay water levels. The eastern portion of the creek shoreline is particularly vulnerable as the area starting from right behind the shoreline, at Canal Street, is lower than the daily high tide and susceptible to substantial inundation depths. Most parcels along the shoreline are privately-owned. Many have building encroaching on the shoreline edge, which obscures the elevation of the shoreline and would complicate flood barrier improvements.

In addition to this overall vulnerability, a focus area for adaption in Canal South is:

- **Focus Area CS-1:** A low-lying portion of the shoreline adjacent to 15 Harbor Street (Figures 10 and 11) has experienced overtopping in recent years (pers. comm. DPW), causing flooding on streets and within adjacent buildings. The shoreline elevations are as low as 7.8 feet NAVD88, lower than multiple observed water levels in the last decade.

3.2.3 Canal North

This region is located along the northern shoreline of San Rafael Creek, from Downtown San Rafael on the west to the Marin Yacht Club and the neighborhoods on Summit Drive and Sea Way to the east (Figure 12). Most of the developed land in this region is above high tide elevations, although some portions at either end are still lower than the 1% annual chance water levels (Figure 13). Its primary flood hazard stems from coastal Bay flood events, which may be supplemented by high creek and stormwater discharge. Like Canal South shoreline, much of this shoreline is at or below the 1% annual chance Bay water level and will face substantially increased flood hazard with future sea-level rise. Vulnerable portions of this region are a mix of publicly and privately owned land and are clustered into two locations: near the Highway 101 crossing over San Rafael Creek (Figure 14) and near the Marin Yacht Club (Figure 15). Based on hazards and vulnerabilities in this area, focus areas for adaptation in this region are:

- **Focus Area CN-1:** The Mahon Creek channel includes a focus area from its connection with San Rafael Creek at Highway 101 to as far upstream as 2nd Street. This segment of the creek is within the FEMA 1% annual chance SFHA. Tidal influence is experienced at least as far upstream as the B Street crossing. Pending coordination with private land owners, this focus area could include private parcels bounded by Mahon Creek to the west, Francisco Blvd W to the east, and the shopping center to the south.

- **Focus Area CN-2:** The Irwin Creek channel includes a focus area spanning from its connection to San Rafael Creek near 3rd street, to as far north as Mission Avenue. This segment was identified by the City as a region experiencing tidal inundation, and could become a pathway for flooding in the future with sea-level rise. Currently, the segment from 2nd Street to San Rafael Creek is mapped within the FEMA 1% annual chance SFHA.

- **Focus Area CN-3:** Mooring Road is a focus area as both a portion of the road and all of the private residences on its southern end are mapped within the FEMA 1% annual chance SFHA. The road forms a narrow peninsula which is bordered on the south by San Rafael Creek and on the north by a yacht harbor. The source of potential flooding is from encroachment by elevated water levels in the creek. Given its location, private residences are at risk from both direct flooding and from flooding of their evacuation route to Point San Pedro Road.

- **Focus Area CN-4:** Near where Highway 101 crosses the canal (Figure 14), flooding is already reported at the intersection of 2nd and Irwin Streets. Based on information from City DPW staff, elevations of the stormwater system, and the known high tide levels, flooding at the intersection can occur due to high Bay water levels that propagate through the storm drain system and are exacerbated with high Bay water levels occur at the same time as precipitation.

- **Focus Area CN-5:** Point San Pedro Road along the Marin Yacht Club harbor (Figure 15) is known to flood every few years due to elevated Bay water levels, with the last documented event in January 2017. The vulnerable area includes a low-lying portion of the road and a drainage system which drains the homes immediately north of the roadway via a culvert under the road.

- **Focus Area CN-6:** Summit Drive experiences flooding near the intersection with Somers Peterson Lane, where a small drainage ditch along the eastern edge of Summit Drive discharges to a dredged arm of San Francisco Bay. The low shoreline elevations here suggest flooding is a result of high tides overtopping the roadway and limiting the conveyance capacity of the drainage ditch (Figure 13).

- **Focus Area CN-7:** The bayward portions of Summit Drive and Sea Way are grouped together into Focus Area CN-7. Flooding likely occurs on Summit Drive from the western shoreline (freeboard deficient) and from high tides backing up a culvert outlet that drains the stormwater network on the roadway. Both Summit Drive and Sea Way contain a number private properties with varying amounts of privately funded flood protection walls (City of San Rafael 2014). A small drainage ditch running along the east side of Sea Way is connected to the Bay via a small tide gate, and the roadway adjacent to the ditch is low (6-7 feet NAVD88), meaning that the homes here would be vulnerable to flooding during high tides if the tide gate were to fail.

3.2.4 Loch Lomond

This region comprises a marina and an adjacent neighborhood between two small headlands (Figure 16). The region's lower portions are above high tides but vulnerable to the 1% annual chance Bay water level and impeded stormwater drainage (Figure 17). Nearby stretches of shoreline are mapped within the FEMA 'VE' zone, signifying additional flood hazard due to wind waves. However, because of the marina's breakwater, the Village at Loch Lomond Marina is designated an 'AE' zone, indicating FEMA considers this area to face limited additional hazard due to wind waves. A portion of the City's storm drain network is vulnerable, and the rest of the vulnerable areas are privately owned.

Based on hazards and vulnerabilities in this area, focus areas for adaptation in this region are:

- **Focus Area LL-1:** The intersection of Point San Pedro Road and Lochinvar Road (Figure 16) experiences occasional flooding, beginning with water first ponding at the intersection's southeast stormwater grate. This flooding could be exacerbated by stormwater drainage being impeded by high Bay water levels. The stormwater drainage network within the Village includes subgrade storage to manage drainage for the 1% annual chance precipitation, even when Bay water levels are elevated too (San Rafael, 2007).

- **Focus Area LL-2:** Much of the Village area is mapped within the FEMA 1% annual chance SFHA, but this mapping appears to be based on older ground surface elevation data, prior to construction of the Village. As part of the development of the Village, the existing grade was raised with fill and the breakwater around the marina was improved. These improvements enabled the new Village structures to apply for and receive a Letter of Map Change indicating their lowest floor elevations are above the BFE. However, these structures will become exposed to 1% annual chance flooding with sea-level rise. In addition, while the new Village structures benefit from being above the current BFE, this section of shoreline does not have a contiguous flood barrier to block coastal flooding from inundating Point San Pedro Road and other adjacent areas which have not been raised.

- **Focus Area LL-3:** This managed wetland is separated from the Bay with low embankments that could be overtopped by king tides. The embankment would be vulnerable to more frequent overtopping and erosion with future sea-level rise. Continued separation of the wetland from the Bay reduces the wetland's capacity to naturally adapt to sea-level rise.

3.2.5 Point San Pedro Road

All of this region is fronted by Point San Pedro Road where it runs through the Glenwood and Peacock Gap neighborhoods (Figure 18.). The roadway is protected by an armored levee that is occasionally overtopped by waves during high Bay water level events, and thereby designated a FEMA 'VE' zone with a BFE of 12 ft NAVD88 (Figure 19). Wave overtopping was documented in 2017 (Appendix A). The road is jointly maintained by the City and County.

Based on hazards and vulnerabilities in this area, focus areas for adaptation in this region are:

- **Focus Area SP-1:** The existing levee along Point San Pedro Road is vulnerable to flooding from combined high tides and wave runup. Wave overtopping has been observed during recent kind tide events, and this will become more common with sea-level rise, threatening to cut off access to the Peacock Gap neighborhood and Point San

Pedro. Between Main Drive and Riviera Drive, the elevation of the unaccredited levee varies from about 9 to 11 feet NAVD88.

- **Focus Area SP-2:** A box culvert under Point San Pedro Road serves as an outlet to the Bay for a drainage channel from the Glenwood neighborhood. Although there is mounting hardware suggesting that a tide gate used to cover the outboard end of this culvert, the culvert currently allows Bay water levels to propagate into the drainage channel unimpeded. This culvert serves as a pathway for coastal flooding to reach the Glenwood neighborhood.

3.2.6 Las Gallinas

This region includes low-lying areas adjacent to the south and north forks of Las Gallinas Creek (Figure 20). Properties in this region are protected by levees that are typically just above the 1% annual chance water level (Figure 21). Flooding along the creek was recently studied by USACE (2013) and ESA (2019). These studies indicate that the highest flood water levels occur during coastal storm surge from the Bay propagating upstream. High riverine discharge events can also raise flood levels, but not to the levels of coastal storm surge. Residences behind the levees are at a range of elevations both below and above the 1% annual chance water level. This area also includes a stretch of the SMART railroad tracks and a small private airport. The levees are on privately-owned land.

Based on hazards and vulnerabilities in this area, focus areas for adaptation in this region are:

- **Focus Area LG-1:** The Contempo Marin mobile home community is mapped within the FEMA 1% SFHA since its surrounding levee is unaccredited. LiDAR data indicates that this levee's crest elevations are typically between 10 to 11 feet NAVD88 and may include some lower portions. These elevations are just above the 1% annual chance water level and would become vulnerable to more frequent events with sea-level rise.

- **Focus Area LG-2:** The SMART rail segment crossing Las Gallinas Creek dips below the 1% annual chance water level for most of its length and its lowest portion may even be below the 99% annual chance king tide event. This vulnerability is mitigated on the west by the levee fronting Contempo Marin and on the east by the levee surrounding the San Rafael Airport. Without these levees on adjacent properties, the lowest portion of the tracks could be inundated annually.

- **Focus Area LG-3:** The Marin Lagoon development is protected by an unaccredited levee along three sides of its perimeter and high ground to the south. While most of the levee's crest appears to be a foot or more above the 1% annual chance water level, the LiDAR data suggest that a short section may dip below this water level. The levee is not high enough to meet FEMA freeboard requirements and its geotechnical properties may also not be sufficient.

4 ADAPTATION MEASURES

This section presents a series of potential adaptation approaches for reducing flood vulnerability along San Rafael's shoreline. In keeping with the format of Section 4, approaches are targeted by region, to account for variability in causes of flooding and regional constraints. Adaptation strategies presented here fall within several categories:

- Raising low-lying portions of the shoreline,
- Installing backflow-prevention devices on culverts that discharge stormwater to the Bay
- Increasing pump station capacity
- Conducting additional targeted local flood studies of combined stormwater runoff and high tides
- Considering marsh restoration combined with construction of setback of levees where opportunities exist
- Incorporate nature-based approaches to complement flood protection measures

The following subsections list the main considerations, outline the proposed strategies, and discuss potential funding sources.

4.1 Considerations

The following considerations were used to develop and initially screen adaptation measures for their suitability along the City shoreline.

4.1.1 Area Affected

The broad and interconnected extent of flooding predicted both by FEMA (2017) for existing conditions and by the BayWAVE Study (BVB 2017) for sea-level rise makes it difficult to precisely rank sites by the area affected. This is because many of the focus sites are affected by the same local cause of flooding (e.g. overtopping of a particular shoreline levee) and have overlapping impact zones. However, in some cases, local topography limits the area of impact, and in other cases, potential blockage of emergency access routes by flooding has the potential for wider impacts. To account for these differences, sites are classified as small-, medium-, or large-impact area based on the area exposed to flood hazard for the 1% annual chance event:

- **Small:** Areas where flooding is limited to fewer than 25 properties
- **Medium:** Areas where flooding could impact 25-100 properties

- **Large:** Areas with larger than 100 properties affected, or where access to an emergency evacuation route would be impacted

4.1.2 Time Frame

While most of the areas discussed in this report are within the 100-year FEMA floodplain, the level of vulnerability varies markedly from region to region. As described in Section 4, some areas are already exposed to flooding from the 99% annual chance event, whereas others face flood hazards from 10% to 1% annual chance events. As discussed in Section 2.3, each foot of sea-level rise will increase the frequency, such that a location exposed to the 1% annual chance today will be exposed to the 10% annual chance with one foot of sea-level rise. For the purpose of this study, we note whether the focus areas are vulnerable in the 'short-term', 'medium-term', or 'long-term':

- **Short-term:** Areas with documented flooding in recent years' high water events, or where the shoreline levels indicate flooding could occur for less than a 10% annual chance flood event.

- **Medium-term:** Areas vulnerable to the 10% to 1% annual chance flood event, or for 99% annual chance events with one foot of sea-level rise.

- **Long-term:** Areas where flooding would be expected to occur for the 1% annual chance flood event with one or more feet of sea-level rise.

None of the focus areas of this study are in the 'long-term' category, since a large number of sites require attention in the near future. However, since this study is likely to be extended in the future, we have included it here at this time. Appendix B discusses potential extents and impacts of flooding for the 1% annual chance flood event for escalating amounts of sea-level rise.

4.1.3 Land Ownership

Much of the low-lying and shorefront areas of the City are privately-owned. While these areas will require coordination with the City and County to address flooding, one of the goals of this initial study is to identify areas that the City can address first to mitigate flood risks under current conditions. Publically-owned parcels allow the City to implement projects in a shorter time frame. In the long-term, a comprehensive strategy for the City's shoreline will require outreach and partnerships with private landowners. Property owners can assist in long-term planning through actions such as development clustering and transfer of development rights. These actions are not explored in this study.

4.1.4 Cost Estimate

While flood management measures can provide definite public benefits, the cost to achieve these benefits is an important consideration. For this study, rough order of magnitude implementation costs ("cost estimate") were developed for the measures which would likely be led by the City. These estimates are based on their conceptual-level descriptions, as described below.

In addition to construction itself, the cost estimates also include related soft costs for engineering, design, and permitting. To account for uncertainties surrounding these costs, the estimates assumes a 30% contingency. The estimates include design and environmental compliance allotments, but do not include environmental mitigation or right-of-way costs. The cost estimates made for this study are rough order of magnitude estimates in 2019 dollars and have an anticipated accuracy range of +50%/-30%. Further design efforts are needed to reduce uncertainties and improve the accuracy of the cost estimate. Appendix C provides additional information about the cost estimates.

4.1.5 Flood Hazard Reduction

The fundamental criteria for flood management is the capacity of a measure or plan to reduce flood hazard to assets in the project area. Many of the areas in San Rafael that are predicted to flood during extreme events are interconnected, making it difficult to say with certainty whether or how much a flood protection measure in one area would be effective, when flooding from adjacent areas could overlap. The City will need to collectively decide what level of protection to build to, and this study does not provide a recommendation for that level of protection. However, to help understand the potential benefit of certain measures, what level of flood protection might be achieved is identified while also noting where the need for more widespread protection is necessary.

4.2 Potential Adaptation Measures

Adaptation measures are summarized in Table 8 and described in more detail in the subsections below.

TABLE 8
ADAPTATION STRATEGIES BY REGION AND FOCUS AREA

Focus Area #	Location	Likely/Potential Cause of Flooding	Potential Adaptation Strategy	Area affected[1]	Time-frame[2]	Land Owner-ship	Affects Primary or Secondary Evac. Route?	Cost[3]	Flood Hazard Reduction[4]
City-Wide Measures									
CW-1	Canal Feasibility Study	Much of Canal shoreline currently exposed to 1% annual chance Bay water levels	• Flood barriers (levees, floodwalls) OR • Hydraulic structure & pump station	Large	Short	Private	Yes	$200,000	Protect from 1% annual chance event[4]
CW-2	Sea-level rise zoning overlay	Varies from 99% to 1% annual chance Bay water levels	Guidance on structure elevations, shoreline setback, and/or disclosure	Large	Short	City + Private	Yes	--	Depends on guidance assigned to layer
CW-3	Shoreline pump stations assessment	tbd	Develop and apply protocol for assessing pump station inflows, discharge capacity, and resilience with climate change	Large	Short	City	Yes	$25,000-$150,000	Maintain existing stormwater design criteria
Bayfront South									
BF-1	Al Boro Community Center	Mapped 1% annual chance floodplain. Future flooding potential from wave runup during high tides	Currently being addressed with Measure AA-funded planned restoration of Tiscornia Marsh	Large	Short	City	No	--	Protect from 1% annual chance event[4]
BF-2	Northern shoreline along Spinnaker Point	Mapped 1% annual chance floodplain. Future flooding potential from wave runup during high tides	Raise levee to FEMA-accredited level, to map Spinnaker neighborhood out of floodplain and provide longer-term protection from sea-level rise	Medium/ Large	Medium	City + Private (HOA common areas)	No	$2,200,000-$4,800,000	Protect from 1% annual chance event[4]

Focus Area #	Location	Likely/Potential Cause of Flooding	Potential Adaptation Strategy	Area affected[1]	Time-frame[2]	Land Owner-ship	Affects Primary or Secondary Evac. Route?	Cost[3]	Flood Hazard Reduction[4]
BF-3	Eastern shoreline along Spinnaker Point, in front of Spinnaker Lagoon	Mapped 1% annual chance floodplain. Future flooding potential from wave runup during high tides	• Raise levee to FEMA-accredited level, to map Spinnaker neighborhood out of floodplain and provide longer-term protection from sea-level rise • Restore diked marsh and build setback levee in front of Spinnaker Lagoon	Medium/ Large	Medium	City + Private (diked marsh)	No	$2,200,000-$4,800,000 + marsh restoration	Protect from 1% annual chance event[4]
BF-4	Canalways property	Levee crest below 1% annual chance wave runup elevation and mapped 1% annual chance floodplain. Future flooding potential from wave runup during high tides	Consider long-term restoration plan for Canalways and consider raising levee protecting properties along its western edge as part of Kerner Blvd connection and development (as per General Plan)	Large	Medium	Private (levee and diked marsh) + City (drainage pond)	No	--	Design-dependent
BF-5	East of south Kerner Way	Mapped 1% annual chance floodplain. Future flooding potential from wave runup during high tides	Raise shoreline levee, either along existing alignment or setback levee to also restore portions of tidal wetlands	Large	Medium	City	No	$5,600,000-$12,000,000	Protect from 1% annual chance event[4]
Canal South									
CS-1	Shoreline adjacent to 15 Harbor St	Tidal overtopping of shoreline	Raise low-lying portion of shoreline	Large	Short	Private + City	No	$70,000-$150,000	Protect from 1% annual chance event[4]
Canal North									
CN-1	Mahon Creek	Mapped 1% annual chance floodplain.	Raise shoreline with levee and/or flood wall	Medium/ Large	Medium	Private + City	No	$18,500,000-$39,600,000	Protect from 1% annual chance event[4]
CN-2	Irwin Creek	Mapped 1% annual chance floodplain.	Raise shoreline with flood wall	Medium/ Large	Medium	Private + City	Yes	$7,800,000-$16,800,000	Protect from 1% annual chance event[4]

Focus Area #	Location	Likely/Potential Cause of Flooding	Potential Adaptation Strategy	Area affected[1]	Time-frame[2]	Land Owner-ship	Affects Primary or Secondary Evac. Route?	Cost[3]	Flood Hazard Reduction[4]
CN-3	Mooring Rd	Mapped 1% annual chance floodplain.	Raise roadway to maintain local evacuation route. Coordinate with homeowners on shoreline protection	Small	Medium	Private	No	--	Protect from 1% annual chance event[4]
CN-4	Intersection at 2nd and Irwin St	Tidal flooding through culvert outlet under Hwy 101 (Node HW195)	Install one-way flow valve on Node HW195	Small	Short	City	No	• $15,000-$20,000	Mitigate annual king tide flooding
CN-5	San Pedro Rd at Marin Yacht Club basin	Tidal flooding through culvert outlet (N477). Tidal overtopping at shoreline	• Install one-way flow valve on Node N477. • Raise low-lying portion of shoreline	Medium/ Large	Short	City	Primary	• $15,000-$20,000 • $1,000,000-$2,100,000	• Mitigate annual king tide flooding • Protect from 1% annual chance event[4]
CN-6	Summit Dr near intersection with Sommers Peterson Ln	Tidal flooding onto Summit Dr, possibly exacerbated by stormwater flooding from watershed north of San Pedro Rd and local culverts	• Raise low-lying portion of shoreline • Install one-way flow valve on Node N909	Medium	Short	City	No	• $1,100,000-$2,400,000 • $15,000-$20,000	• Protect from 1% annual chance event[4] • Mitigate annual king tide flooding
CN-7	Sea Way & Summit Neighborhood	SLR exacerbating flooding of low-lying areas	Adaptation strategy that combines engineered solutions for the Summit & Sea Dr communities and restoration of adjacent wetland parcel to the east	Medium	Medium	Private	No	--	• Variable
Loch Lomond									
LL-1	Intersection of San Pedro Rd	Tidal flooding through culvert outlets. Possible combined tidal and	Recommend further study of the cause of flooding at the	Medium	Short	City	Primary	• $30,000-$60,000	tbd

Focus Area #	Location	Likely/Potential Cause of Flooding	Potential Adaptation Strategy	Area affected[1]	Time-frame[2]	Land Owner-ship	Affects Primary or Secondary Evac. Route?	Cost[3]	Flood Hazard Reduction[4]
	and Lochinvar Rd	watershed runoff flooding	intersection to determine phasing of adaptation measures						
LL-2	Loch Lomond shoreline	Mapped 1% annual chance floodplain includes Point San Pedro Road and beyond, and increases with sea-level rise.	Identify alignment for future coastal flood levee that ties off to high ground before development encroaches on open space	Medium	Short	Private	No	--	Protect from 1% annual chance event[4]
LL-3	Loch Lomond eastern managed wetland	Levee erosion and flood overtopping causing unplanned breaching and marsh drowning	Develop wetlands resilience management plan for eastern wetland	Medium	Medium	Private	No	--	Provide 'living shoreline' to complement flood protection
Point San Pedro Road									
SP-1	Shoreline along Point San Pedro Rd from Main Dr to Riviera Dr	Wave overtopping already occurs during high Bay water levels and strong wind	Raise crest elevation via • levee widening (coordinated w/raising path and possible road re-alignment, OR • Floodwall	Large	Medium	City	Primary	• $12,000,000-$27,000,000 • $9,000,000-$20,000,000	Protect from 1% annual chance event[4]
SP-2	Tide gate at Glenwood	None documented. Potential for future flooding during high tides	• Install tide gate at culvert passing under Point San Pedro Rd (Node HW542)	Small	Medium	City	No	• $100,000-$210,000	Protect from 1% annual chance event[4]
Las Gallinas									
LG-1	Contempo Marin	Mapped 1% annual chance coastal floodplain.	• Conduct survey of levee crest and compare to flood water levels to refine flood hazard assessment • Consider (1) raising crest elevation with sheet pile wall or (2) set back mobile homes and raise earthen levee	Medium	Medium	Private	No	--	• n/a • Protect from 1% annual chance event[4]

Focus Area #	Location	Likely/Potential Cause of Flooding	Potential Adaptation Strategy	Area affected[1]	Time-frame[2]	Land Owner-ship	Affects Primary or Secondary Evac. Route?	Cost[3]	Flood Hazard Reduction[4]
LG-2	SMART rail	Mapped 1% annual chance coastal floodplain.	Coordinate with SMART on long-term resilience plan for exposed segment of rail	Large	Medium	Marin & Sonoma Counties	No	--	tbd
LG-3	Marin Lagoon Neighborhood levee	Mapped 1% annual chance coastal floodplain.	• Conduct survey of path crest and compare to flood water levels to refine flood hazard assessment • Consider raising crest elevation with (1) sheet pile wall and/or (2) earthen levee	Medium	Medium	Private	No	--	• n/a • Protect from 1% annual chance event[4]

1 Defined in Section 4.1.1
2 Defined in Section 4.1.2
3 See Appendix C
4 Flooding may still impact the focus area from other adjacent areas. More comprehensive protection needed to mitigate flood risk.

4.2.1 City-wide Measures

Several adaptation focus areas occur in more than one region and have implications across the City, as compared to local benefits to reducing flooding in one region. These city-wide measures include:

Focus Area CW-1: The San Rafael Canal runs through much of the City's low-lying area, and overtopping of the Canal's shoreline can cause inundation in three of the six shoreline regions: Bayfront, Canal North, and Canal South. These regions include substantial City and regional infrastructure, businesses, residences, and City services. In addition, stormwater from the hillside watersheds around the low-lying Canal area flows through the area to pump stations to reach the Bay. Particularly on the south side of the Canal, where there is a large area lower than daily high tides, inundations could be several feet or more during a flood. Substantial portions of the shoreline along the Canal are below the current 1% annual chance water level and will be below the 10% annual chance water level with only one foot of sea-level rise and below the 99% annual chance water level with two feet of sea-level rise. For these reasons, this measure is considered a city-wide measure even though some areas of the City would not be inundated by flooding from the Canal.

To address this flood exposure, there are two potential approaches, which are substantially different and costly. Therefore, the City should invest in a feasibility planning effort to evaluate and select a preferred approach for implementation.

Constructing flood barriers, such as levees and flood walls, is one approach. These barriers would be aligned along the existing shoreline, to raise the shoreline elevation and block overtopping. Many sections of the existing shoreline have encroaching buildings, which would complicate the completion of a continuous flood barrier crest. By keeping the footprint to the existing shoreline, this approach would be less disruptive to the hydraulic connectivity of the Canal, thereby preserving the existing conveyance for creek discharge, boat navigation access, and aquatic ecosystems.

The second approach consists of constructing a large hydraulic structure at the mouth of the Canal. This structure would have large gates which can be opened to allow water exchange when water levels do not threaten flooding and can be closed to block Bay water from entering when floods threaten. Because high Bay water levels and creek discharge are both associated with winter storms and may occur simultaneously, this approach would also require the construction of a very large pump station to convey creek discharge past the structure when it is closed. This approach was evaluated by the US Army Corps of Engineers in the early 1990s (USACE 1992), and while that study did not consider sea-level rise, the study could still be informative for a present-day feasibility study. This hydraulic structure would need to increase its frequency and duration of closure in response to sea-level rise. For example, a structure designed to close for the current 10% annual chance event would need to close nearly every day with two feet of sea-level rise. Other considerations for this approach would include disruptions to boat navigation and aquatic ecosystems.

Focus Area CW-2: As part of its General Plan update, the City's Community Development Department is considering a sea-level rise overlay for the City's zoning map. This overlay would identify properties along the City's shoreline which are vulnerable to sea-level rise and provide additional guidance for development which falls within this overlay. Guidance associated with the overlay zone may include elevation benchmarks for structures, setback from levees, and hazard disclosure. Elevation requirements for structures could be raised several feet higher than the minimum FEMA lowest floor elevation, to account for expected sea-level rise by 2050. Components of this overlay may be applied toward lowering FEMA flood insurance rates in the City via FEMA's Community Rating System program.

Focus Area CW-3: Many of the City's pump stations are located in and pump water from low-lying areas along the shoreline that face greater flood hazard due to sea-level rise. Some of these pump stations also manage runoff from portions of the City at higher elevations. The City should develop a protocol for assessing a pump station's capacity to meet its performance criteria in the face of climate change. Three key assessments are:

- What is the potential for increased inflow to the pump station due to more frequent levee overtopping due to sea-level rise, elevated groundwater levels caused by sea-level rise, and/or increased precipitation due to higher rainfall intensity and frequency?
- Can the pump station provide its design discharge capacity when pumping to Bay or Canal water levels elevated by sea-level rise?
- Is the pump station itself and its supporting infrastructure (e.g. power supply, maintenance access) vulnerable to inundation from greater flood hazards due to sea-level rise?

Once the assessment protocol is developed, the protocol can either be applied across the City's entire stormwater system at once or on a case-by-case basis as individual pump stations are slated for substantial repair and upgrade.

Nature-Based Approaches: Nature-based, or 'living shorelines' approaches include habitats (e.g. coarse beaches, ecotone or 'horizontal' levees, offshore oyster reefs) that complement shoreline flood protection measures by preserving or enhancing existing habitats, recreation, and/or public access. These measures may provide limited flood hazard reduction in the form of wave attenuation and scour protection. However, since nature-based approaches seldom provide enough flood hazard reduction on their own, these approaches are usually combined with structural flood protection such levees and floodwalls.

Since the focus of this study is adapting to flood hazards exacerbated by sea-level rise, these nature-based approaches, whose benefits are focused on habitat, are not detailed for all the focus areas. However, the City should continue to consider incorporating these approaches as flood protection planning advances. Ultimately, their feasibility will have to consider a range of factors including cost, constructability, effect on flooding, geomorphic sustainability, and regulatory considerations.

These approaches have been explored at a conceptual level for the San Rafael shoreline as part of the Resilient by Design Bay Area Challenge (Bionic 2018), by the San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019), by non-profit groups such as Resilient Shore, and as part of City planning efforts (City of San Rafael 2014) and county-wide planning efforts (Point Blue, SFEI, and County of Marin 2019). At Tiscornia Marsh (near the Al Boro Community Center), a planned restoration of the eroding offshore marsh is being considered using beneficially re-used dredge material (ESA 2018). Recent conceptual designs have proposed ecotone levees fronting the Bayfront South area, restoration of the Canalways and Spinnaker marsh areas, and coarse beaches fronting raised levees in front of the Bayfront South and Point San Pedro Road and Loch Lomond areas. A living shorelines test site including native oyster reefs and eelgrass beds near Spinnaker Point is also currently being monitored (Latta and Boyer 2015).

Managed Retreat: In its 2014 climate change white paper (City of San Rafael 2014), the City identified managed retreat as a potential approach for sea-level rise adaptation to be explored further. Retreat entails removing a portion of outboard Bay-fronting levees to allow tidal action in formerly diked areas that were separated from the Bay. Areas of diked wetlands where this could be explored further include the Canalways property (in the Bayfront South region) and the San Rafael Airport (in the Las Gallinas region). Managed retreat has been described by SFEI and SPUR (2019) and envisioned by Bionic (2018) and typically involves building setback levees and other measures to protect built assets situated behind the areas of retreat. This report does not consider managed retreat in detail, given its focus on the large numbers of City-owned areas that are vulnerable to sea-level rise in the short and medium term. Managed retreat should be considered as part of a long-term strategy to adapt to higher amount of sea-level rise anticipated for the end of this century and into the next century.

4.2.2 Bayfront South

The Bayfront South region includes a large portion of the City's Bay-fronting shoreline. Adaptations focus on improving flood protection from the unaccredited levee protecting the interior neighborhoods and businesses from elevated water levels and waves in the Bay. A number of conceptual nature-based approaches (e.g. ecotone levees, coarse beach fronting raised levee) have been proposed to complement flood protection measures for this shoreline and for the diked or muted tidal marshes immediately west of the shoreline trail. The feasibility of including these nature-based approaches should be considered as planning for flood protection advances.

Focus Area BF-1: The City should continue to coordinate with the Marin Audubon Society and the California State Coastal Conservancy on the restoration of Tiscornia Marsh, which includes improvements to about 1,600 feet of the adjacent levee. The conceptual design was funded by the Marin Community Foundation and the current phase, preliminary design and CEQA, is funded by a Measure AA grant. The Al Boro Community Center was also identified by Bionic (2019) as a site for protection and restoration of adjacent marsh areas, as part of its long-term vision for the Resilient by Design Challenge.

Focus Area BF-2: The northern shoreline from the Al Boro Community Center to Spinnaker point has a mix of City (pathway) and private ownership. The current shoreline levee is not

FEMA-accredited, and the City may consider improving this to meet FEMA accreditation standards and sea-level rise. Flooding along this portion of the shoreline would affect a relatively large area, but may be considered as a medium-term priority given the current crest elevation. It would cost approximately $2,200,000 to $4,800,000.

Focus Area BF-3: The eastern shoreline of the Spinnaker neighborhood has a City-owned, unaccredited levee protecting a large number of homes. The managed wetland just inboard of the levee presents an opportunity for a combined project improving both flood protection and wetland habitat. Long-term options include raising the existing outboard levee ($2,200,000 to $4,800,000) or consider pursuing Measure AA funding to set back the levee and improve wetland habitat via increased connectivity between the wetland and the Bay.

Focus Area BF-4: The Canalways property may present a long-term opportunity for protecting the shoreline and improving habitat. The City could collaborate with the landowner and other stakeholders to study the feasibility of alternatives that combine improved flood protection with development and wetlands restoration. Alternatives could consider different alignments for an improved levee, ranging from its present location to landward re-location that enables tidal restoration bayward of the levee. Implementation would be a longer-term effort.

Focus Area BF-5: The southern shoreline east of Kerner Way, between Shoreline Parkway and Grange Avenue, is primarily City-owned land. The existing shoreline levee is not FEMA-accredited, and the City may consider improving this to meet FEMA accreditation standards and sea-level rise. Flooding along this portion of the shoreline would affect commercial development and Interstate 580, but may be considered as a longer-term improvement item as it would have a high cost (at least $8,000,000) and other areas of the shoreline nearby are more vulnerable. Feasibility of setting back one or more sections of the levees that fronts the wetlands should be considered, as this approach offers the potential for restoring full tidal connectivity to the wetlands. This could offset wetlands impacts of levee improvements and also increase the resilience of the wetlands to sea-level rise by increasing sediment delivery to the wetlands.

4.2.3 Canal South

The Canal South region includes the highest density of private and public assets vulnerable to flooding due to the current 1% annual chance event. Developing an approach to this overall vulnerability is addressed in the City-wide measure CW-1 described above. The region may also be susceptible to flooding from the Bayfront South region. In addition, this region has a shoreline low spot which warrants its own adaptation measure:

Focus Area CS-1: The shoreline adjacent to 15 Harbor Street should be raised, in coordination with the local business owners who have already been taking measures in recent years to protect their structures from flood damage. Since this location was identified as one of the major pathways of flooding into the Canal District during high tides, this should be a high priority in the short-term. The length of the low-lying portion of the shoreline is limited, and the expected cost of raising the shoreline would be $70,000 to $150,000.

4.2.4 Canal North

Much of the shoreline in the Canal North region is currently vulnerable to the 1% annual chance event. Developing an approach to this overall vulnerability is addressed in the City-wide measure CW-1 described above. In addition, this region has several low spots which warrants their own adaptation measures:

Focus Area CN-1: Flooding along Mahon Creek should be mitigated by raising its banks. Since a significant portion of its length is laterally constrained, this may require vertical flood walls, although there may be room in some reaches for levees incorporated with the public trails and open space . The cost of improvement would be roughly $18,500,000 to $39,600,000. This assumes flood walls are erected from the Highway 101 crossing to B Street. There may also be restoration opportunities within this reach, although an assessment of restoration potential was not conducted for this study, nor included in the cost estimate.

Focus Area CN-2: Flooding along Irwin Creek should be mitigated by raising its banks. The entire length of the creek within the FEMA 1% SFHA is laterally constrained. Erecting flood walls would cost roughly $7,800,000 to $16,800,000, if placed between 3rd Street and Mission Avenue and minimal interference with the highway and its associated structures. There may also be restoration opportunities within this reach, although an assessment of restoration potential was not conducted for this study, nor included in the cost estimate.

Focus Area CN-3: Mooring Road should be an area for improvements to mitigate flood risk in the medium term. While the shoreline is privately-owned, actions can be taken by the City to preserve the evacuation route to Point San Pedro Road. The City may consider raising the portion of the roadway where possible to protect this evacuation route.

Focus Area CN-4: Flooding at the intersection of 2nd and Irwin streets should be mitigated by installing a one-way flow valve to the outlet that drains stormwater from the intersection to San Rafael Creek. The cost of the improvement would be roughly $15,000 to $20,000. This should be a high priority item, since flooding is already documented during events with high Bay water levels and/or heavy precipitation, and the intersection carries a high volume of traffic.

Focus Area CN-5: Flooding at Point San Pedro Road near the Marin Yacht Club should be mitigated by (1) installing a one-way flow valve on the culvert that drains the homes north of the road, and (2) considering raising low-lying portions of the road. These adaptations would cost $15,000 to 20,000 and $1,000,000-$2,100,000, respectively. Flooding of Point San Pedro Road blocks an emergency evacuation route. It should be considered a high priority for improvement by the City.

Focus Area CN-6: The portion of Summit Drive near its connection to Somers Peterson Lane should be an area of high priority for improvements to mitigate flood risk in the short term, since flooding of this area risks isolating homeowners from evacuation via Point San Pedro Road. We recommend that the City consider: (1) Raising either the roadway or the lowest-lying portion of the shoreline adjacent to the tidal channel, (2) Investigating flooding from the watershed north of Point San Pedro Road into the small drainage ditch on the eastern side of Summit Drive, and/or

(3) Installing a one-way flow valve at Node N909, which could eventually lead to flooding of Summit Drive through the existing stormwater system. The cost of these items is listed in Table 8.

Focus Area CN-7: Since both Summit Dr. and Sea Way are fronted by private homes with varying degrees of flood protection, we advise that the City coordinate with homeowners on a longer-term approach that could potentially tie into a larger project including the adjacent wetlands to the east and west. Given the setting, this could tie together engineering solutions (coordinated shoreline improvements of private properties, investigating feasibility of tide gate in front of the tidal channel), with habitat improvement of the wetland parcels immediately to the west and east (horizontal levees or other nature-based approaches), which could provide opportunities for additional funding mechanisms that would help the planning process (Measure AA grant or others listed in Section 5.3).

4.2.5 Loch Lomond

Much of the shoreline in the Loch Lomond region is currently vulnerable to the 1% annual chance event. Since the site is also the intersection of tides and stormwater drainage from neighborhoods north of Point San Pedro Road, potential measures may need additional study of the site's hydrology. The focus in this region is on a range of stormwater and shoreline protection measures.

Focus Area LL-1: The City should consider a stormwater study to identify the causes of flooding at the intersection of Point San Pedro and Lochinvar Roads and to assess the feasibility of potential flood mitigation measures. The stormwater network in this area collects runoff from neighborhoods north of Point San Pedro Road, includes drainage from the Village development south of Point San Pedro Road that is detained by subsurface storage, and ultimately discharged to the Bay. However, the details of the stormdrain network, the relative importance of watershed runoff versus Bay water levels, and causes of flooding, is not fully understood for present conditions. The gravity-dependent drainage will be further impeded by sea-level rise. Given the potential of the flooding at this location to disrupt emergency evacuation on Point San Pedro Road for nearby residents, this study is recommended as a short-term priority for the City. The cost of the study would be expected to range from $50,000 to $75,000.

Focus Area LL-2: Although recent development in the Village has been raised above the current BFE, these structures will become vulnerable to flooding with sea-level rise. In addition, there is no contiguous flood barrier to protect areas outside of the immediate footprint of the structures, such as Point San Pedro Road. Before development encroaches on the open space along the shoreline, the City should coordinate with the private landowners to determine an alignment for a contiguous flood barrier to address future coastal flood hazards. The ends of this barrier should tie off to high ground. The tradeoffs of aligning the levee landward or bayward of each area, such as the park to the west of the marina, should be considered. Since the breakwater fronting the Loch Lomond Marina provides protection from wind waves for the Village development, its ongoing maintenance and potential improvement to adapt to sea-level rise should be integrated into planning for this flood barrier.

Focus Area LL-3: In its current state, with levees blocking it off from daily tides, the wetland east of the marina and owned by the marina association will be limited in its capacity to naturally adapt to sea-level rise. Wetlands with continuous tidal connectivity can gradually sequester sediment and organic matter to naturally pace sea-level rise. The existing levees limit connectivity to only coastal flood events, which do not promote natural adaptation. With sea-level rise, the levees will face growing threat from erosion and flood overtopping until they eventually fail. An abrupt levee failure, particularly after some sea-level rise that leaves the wetland further lagging in its elevation relative to the tides, could result in excess inundation and marsh plant demise. A wetland adaptation plan should be developed for this wetland. With a planned increase in tidal connectivity, the marsh could more readily pace sea-level rise via its own natural adaptation processes. Enhancing this marsh with increased tidal connectivity could be used to offset wetland impacts from other nearby flood protection measures.

4.2.6 Point San Pedro Road

Adaptations for the Point San Pedro Road region (Figure 18) focus on improving flood protection from the unaccredited levee protecting the roadway and interior neighborhoods from elevated water levels and waves in the Bay. Table 8 summarizes the adaptation measures and rough costs for the region. Although the existing Dutra Quarry at Point San Pedro is not within the City boundaries, it may eventually become an opportunity area for shoreline enhancement and increased resiliency, as it includes an adjacent diked tidal marsh and a small beach.

Focus Area SP-1: Since the shoreline along Point San Pedro Road affects an emergency evacuation corridor and is already subject to wave overtopping when king tides coincide with high winds, improving the shoreline protection should be a near-term priority. The City should conduct further study of the feasibility of two measures: (1) raising the crest elevation via landward levee widening and potential realignment of the road, or (2) installing a flood wall on top of the existing levee. The first measure would likely be costlier and more difficult to plan, but would provide the City more flexibility in the long-term, as flood walls have limited long-term adaptability (i.e. a flood wall can only be raised to a point before they become structurally unsound and can no longer be accredited by FEMA).

Improving the existing shoreline levee to achieve FEMA accreditation would require raising the levee by several feet, increasing the lateral footprint of the shoreline protection, and re-aligning the roadway for a significant portion between Main Drive and Rivera Drive. The roadway appears to have some re-alignment capacity since it is four lanes wide with shoulders and a central median. Re-alignment could also include moving the sidewalk onto the levee crest, preserving some of the shoreline access that would be more impaired by a floodwall. Implementing the flood wall option may be complicated by the extent of removal needed for existing grouted riprap and the reduced visibility from the sidewalk. A rough order of magnitude cost for this effort would be $9,000,000 to $27,000,000. Also, this segment of the City's shoreline was identified by SFEI and SPUR (2019) as a potential area for including complementary nature-based approaches, such as a coarse beach fronting a raised shoreline. These options were not included in the cost estimate.

Focus Area SP-2: The portion of the Glenwood neighborhood that is mapped within the FEMA 1% annual chance floodplain could be better protected by installing a tide gate on the culvert that passes under Point San Pedro Road just west of Knight Drive. Installing a tide gate could limit the propagation of high Bay water levels into the neighborhood, and would be expected to cost $100,000 to $210,000.

4.2.7 Las Gallinas

Adapting to sea-level rise in the Las Gallinas region will require working with private owners of the assets at risk. Ownership of existing flood barriers are predominantly private landowners, and will require coordination between the City, landowners, the SMART Rail district, and the County. Although not analyzed in detail here, the San Rafael airport is surrounded by unaccredited levees and may present an opportunity for long-term adaptation in the future. In particular, less developed portions of the site may provide opportunities for managed retreat and marsh restoration.

Focus Area LG-1: The unaccredited levee protecting the western and northern sides of the Contempo Marin mobile home community has uncertain elevations, and should be surveyed to better understand the vulnerability of the community. Given the proximity of the levee to homes and to the wetlands immediately to the west, opportunities may be limited to raise the levee without encroaching on either space. The owner of the land could consider setting back homes to accommodate a larger levee, adding a flood wall to the existing levee, or a hybrid approach of enlarging the levee and adding a flood wall in more constrained areas. The eastern side of the community is protected by the SMART rail embankment and the levees surrounding the San Rafael Airport, so the community should coordinate both with the SMART Rail authority and the airport on management of these levees.

Focus Area LG-2: The SMART Rail tracks, managed by a joint Sonoma County and Marin County district, are raised on a low embankment. However, since much of this embankment is lower than flood water levels, the tracks also rely upon the Contempo Marin levee and the levee protecting the airport. The City should coordinate with SMART on the long-term resilience plan for this area.

Focus Area LG-3: The raised trail and bike path surrounding the Marin Lagoon neighborhood at the end of McInnis Parkway should be surveyed to better understand the level of flood vulnerability. Similar to the Contempo Marin community, space constraints between the homes and the wetlands along Las Gallinas Creek may limit the potential to raise the levee with additional earth fill. Floodwalls or a hybrid approach of levees and floodwalls may be preferred to protect the path and homes.

4.3 Potential Funding Sources

Implementing adaptation measures will require funding and will likely need to come from supplemental sources besides the City's general fund or local assessments. Collaboration with other stakeholders, such as the ongoing collaboration at Tiscornia Marsh with the Marin Audubon Society and the California State Coastal Conservancy, can support funding efforts. Other funding options to explore are summarized in Table 9 along with web links to the relevant resources.

TABLE 9
POTENTIAL FUNDING SOURCES

Potential Funding Source	Purpose	Additional Information
Flood Mitigation Assistance (FMA)	Reduce or eliminate claims against the NFIP by reducing long-term risk of flood damage to buildings insurable under NFIP	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation FEMA https://www.fema.gov/flood-mitigation-assistance-program
Pre-Disaster Mitigation (PDM)	National competitive program focused on mitigation project and planning activities that address multiple natural hazards	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation FEMA https://www.fema.gov/pre-disaster-mitigation-grant-program
Repetitive Flood Claims (RFC)	Reduce flood claims against the NFIP through flood mitigation; properties must be currently NFIP insured and have had at least one NFIP claim	FEMA https://www.fema.gov/media-library-data/20130726-1621-20490-8359/rfc_08_guidance_final_10_30_07.pdf
Severe Repetitive Loss (SRL)	Reduce or eliminate the long-term risk of flood damage to SRL residential structures currently insured under the NFIP	FEMA https://www.fema.gov/pdf/nfip/manual201205/content/20_srl.pdf
Hazard Mitigation Grant Program (HMGP)	Activated after a presidential disaster declaration; provides funds on a sliding scale formula based on a percentage of the total federal assistance for a disaster for long-term mitigation measures to reduce vulnerability to natural hazards	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/recovery/disaster-mitigation-technical-support/404-hazard-mitigation-grant-program FEMA https://www.fema.gov/hazard-mitigation-grant-program
Proposition 1 Climate Ready Grants	Climate Ready Grants are focused on supporting planning, project implementation and multi-agency coordination to advance actions that will increase the resilience of coastal communities and ecosystems	Coastal Conservancy http://scc.ca.gov/climate-change/climate-ready-program/
Measure AA	San Francisco Bay-specific program for restoring habitat, protecting communities from floods, and increasing shoreline public access	San Francisco Bay Restoration Authority http://sfbayrestore.org/sf-bay-restoration-authority-grants.php

Potential Funding Source	Purpose	Additional Information
Continuing Authorities Program (CAP)	CAP is to plan, design, and construct flood damage reduction projects. CAP projects do not require project-specific authorization from Congress.	U.S. Army Corps of Engineers, San Francisco District https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Continuing-Authorities-Program/
City of San Rafael Capital Improvement Plan (CIP)	Multi-year planning tool used to identify and implement the City's capital needs over the upcoming 3-year period	City of San Rafael: https://www.cityofsanrafael.org/capital-improvement-program/
Assessment District	An assessment district is a geographic area in which a governing body may apply a charge to real estate parcels to fund public projects that provide a direct benefit to the area.	City of San Rafael: https://www.cityofsanrafael.org/assessment-districts/
Potential Mitigation Fee	Fees that may be collected by the City for new development projects	City of San Rafael: https://www.cityofsanrafael.org/development-impact-fees-information/
Potential Tax Measures	Local tax measures that raise funds for specific public projects	Local; Example, Measure A – Transportation Sales Tax: https://www.cityofsanrafael.org/measure-a-transportation-sales-tax/
Geologic Hazard Abatement District (GHAD)	Independent, state-level public entity to oversee geologic hazard prevention, mitigation, abatement, and control. Typically funded through supplemental property assessments included within a property tax bill	Local; Example for Bay Area use of GHADs from BCDC: https://bcdc.ca.gov/fwg/20170601GeologicHazardAbatement.pdf

5 REFERENCES

AECOM. 2016. San Francisco Bay Tidal Datums and Extreme Tides Study. Prepared for FEMA and BCDC. February 2016.

BakerAECOM. 2015. IDS #4 – Draft Flood Hazard Mapping, prepared for the Federal Emergency Management Agency.

Ballard, G., Barnard, P., Erikson, L., Fitzgibbon, M., Moody, D., Higgason, K., Psaros, M., Veloz, S., and Wood, J. 2016. Our Coast Our Future (OCOF). Petaluma, California. Available at: http://www.ourcoastourfuture.org.

Bionic. 2018. San Rafael Elevate: Resilient by Design Bay Area Challenge Design Report. Version 2. Issued May 31, 2018.

BVB Consulting LLC (BVB). 2017. Bay Waterfront Adaptation & Vulnerability Evaluation (BayWAVE). Prepared by BVB Consulting LLC for Marin County Department of Public Works, June 2017.

City of San Rafael. 2007. Resolution of the San Rafael City Council Approving a Master Use Permit (UP 04-007) Environmental Design and Review Permit (ED 04-063) and Vesting Tentative Map (TM 04-001) for The Village at Loch Lomond Marina Development. Resolution #12332.

City of San Rafael. 2014. Climate Adaptation – Sea Level Rise: San Rafael, CA. White paper prepared by the City of San Rafael Dept. of Community Development. Lead author Paul Jensen, with assistance of Anais Hall. Dept. of Public Works File No. P13-002.

Danish Hydraulic Institute (DHI). 2011. Regional Coastal Hazard Modeling Study for North and Central San Francisco Bay. Final Draft Report. Prepared for Federal Emergency Management Agency, Region IX.

Environmental Science Associates (ESA). 2018. Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project: Conceptual Design Report. Prepared for Marin Audubon Society. July 2018.

ESA. 2019. McInnis Marsh Restoration Project: Hydraulic Monitoring Report. Prepared for Marin County Parks. September 2, 2019.

Federal Emergency Management Agency (FEMA). 2017. Flood Insurance Study Marin County, California and Incorporated Areas. Study Number 06041CV001D. August, 2017.

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

Latta, M, and Boyer, K. 2015. San Francisco Bay Living Shorelines: Nearshore Linkages Project Summary of Key Findings Two Years Post-Installation. April 30, 2015.

National Oceanic and Atmospheric Administration (NOAA). 2003. Computational Techniques for Tidal Datums Handbook. National Ocean Service Center for Operational Oceanographic Products and Services. NOAA Special Publication NOS CO-OPS 2.

National Oceanic and Atmospheric Administration (NOAA). 2018. U.S. Linear Relative Sea Level (RSL) Trends and 95% Confidence Intervals in mm.year and in ft/century for Station ID 9414290 San Francisco, California. https://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.html

Ocean Protection Council (OPC). 2018. State of California Sea-Level Rise Guidance 2018 Update. Prepared by the California Natural Resources Agency and the California Ocean Protection Council. March 2018.

Olofson Environmental. 2018. California Ridgeway's Rail Surveys for the San Francisco Estuary Invasive Spartina Project 2018. Prepared for California Coastal Conservancy.

Point Blue Conservation Science (Point Blue). 2019. Our Coast Our Future. Northern California Flood Maps. http://data.pointblue.org/apps/ocof/cms

Point Blue Conservation Science (Point Blue), San Francisco Estuary Institute (SFEI), and County of Marin. 2019. Sea Level Rise Adaptation Framework – A user guide to planning with nature as demonstrated in Marin County. Point Blue Conservation Science (Contribution #2239), Petaluma, CA. San Francisco Estuary Institute (Publication #946), Richmond, CA. Version: 1.0, August 2019.

San Francisco Bay Conservation Development Commission (BCDC). 2012. Adapting to Rising Tides Project. Available from: http://www.adaptingtorisingtides.org

San Francisco Estuary Institute (SFEI) and San Francisco Bay Area Planning and Urban Research Association (SPUR). 2019. San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units.

Siegel Environmental. 2016. East Spinnaker Point Lagoon Conceptual Enhancement and Management Alternatives Report. Prepared for the City of San Rafael. February 9.

Smith, Katherine R., Melissa K. Riley, Laureen Barthman–Thompson, Isa Woo, Mark J. Statham, Sarah Estrella, and Douglas A. Kelt. Toward Salt Marsh Harvest Mouse Recovery: A Review. San Francisco Estuary and Watershed Science, 16(2). https://escholarship.org/uc/item/2w06369x

Swain, D.L., Langenbrunner, B., Neelin, J.D. and Hall, A., 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change, 8(5), pp.427-433.

U.S. Army Corps of Engineers (USACE). 1984. San Francisco Bay Tidal Stage vs. Frequency Study. San Francisco District.

USACE. 1992. Marin County Shoreline, San Rafael Canal Final Feasibility Report and Environmental Impact Statement. San Francisco District.

USACE. 2011. Las Gallinas Creek Hydrologic Analysis Final Report. San Francisco District. August 2011.

U.S. Coast Survey (USCS). 1853. Coastal Topographic Sheet #415.

6 STUDY CONTRIBUTORS

ESA

- Matt Brennan, PE
- Dane Behrens, PE

City of San Rafael

Department of Public Works

- Hunter Young, Assistant Public Works Director/City Engineer
- Kevin McGowan, former Assistant Public Works Director/City Engineer
- Theo Sanchez, Associate Civil Engineer
- Mark Wright, Operations & Maintenance Manager

Department of Community Development

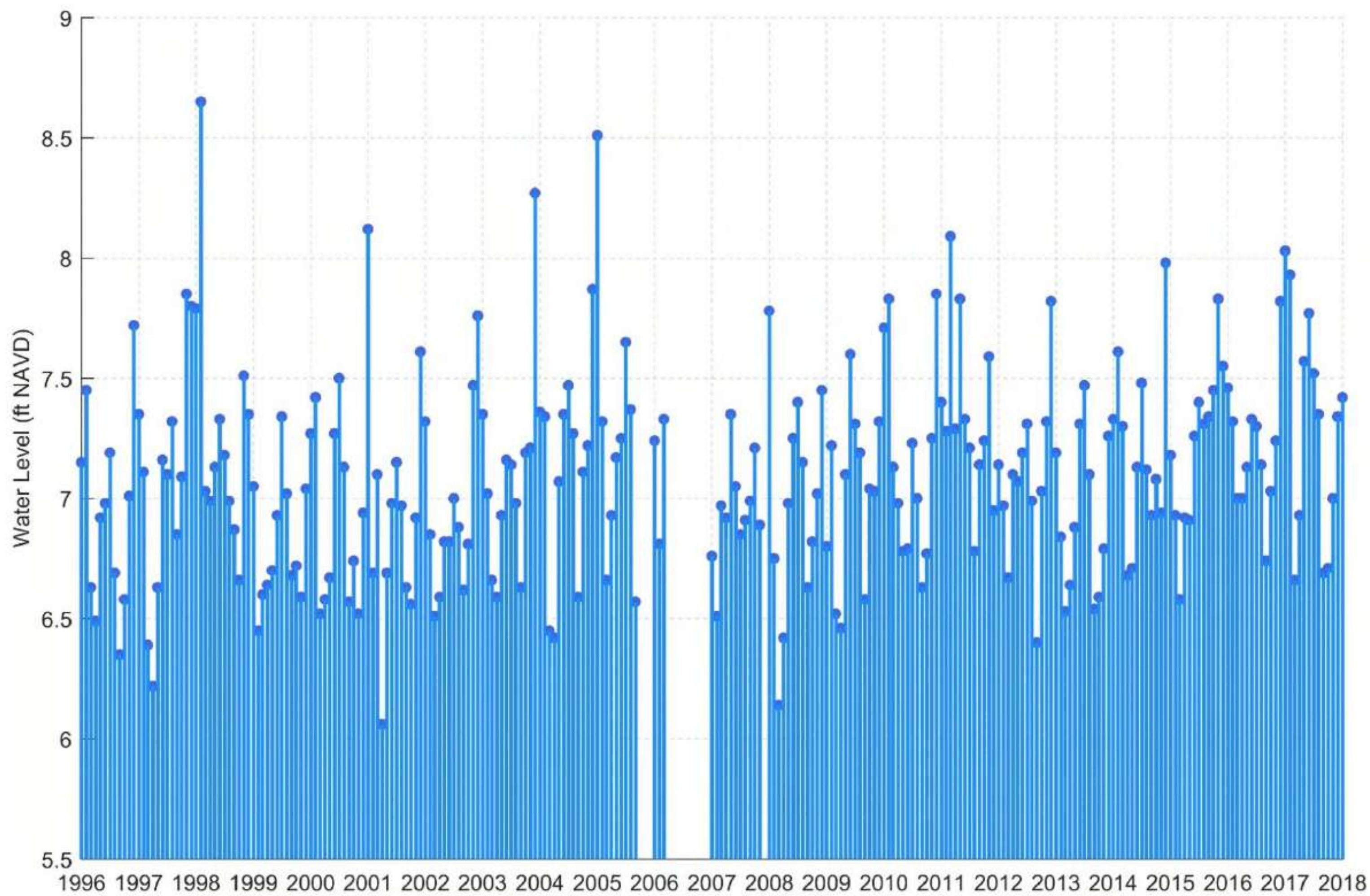
- Paul Jensen, Director
- Cory Bytof, Sustainability and Volunteer Program Coordinator

Marin County

Water Resources Division

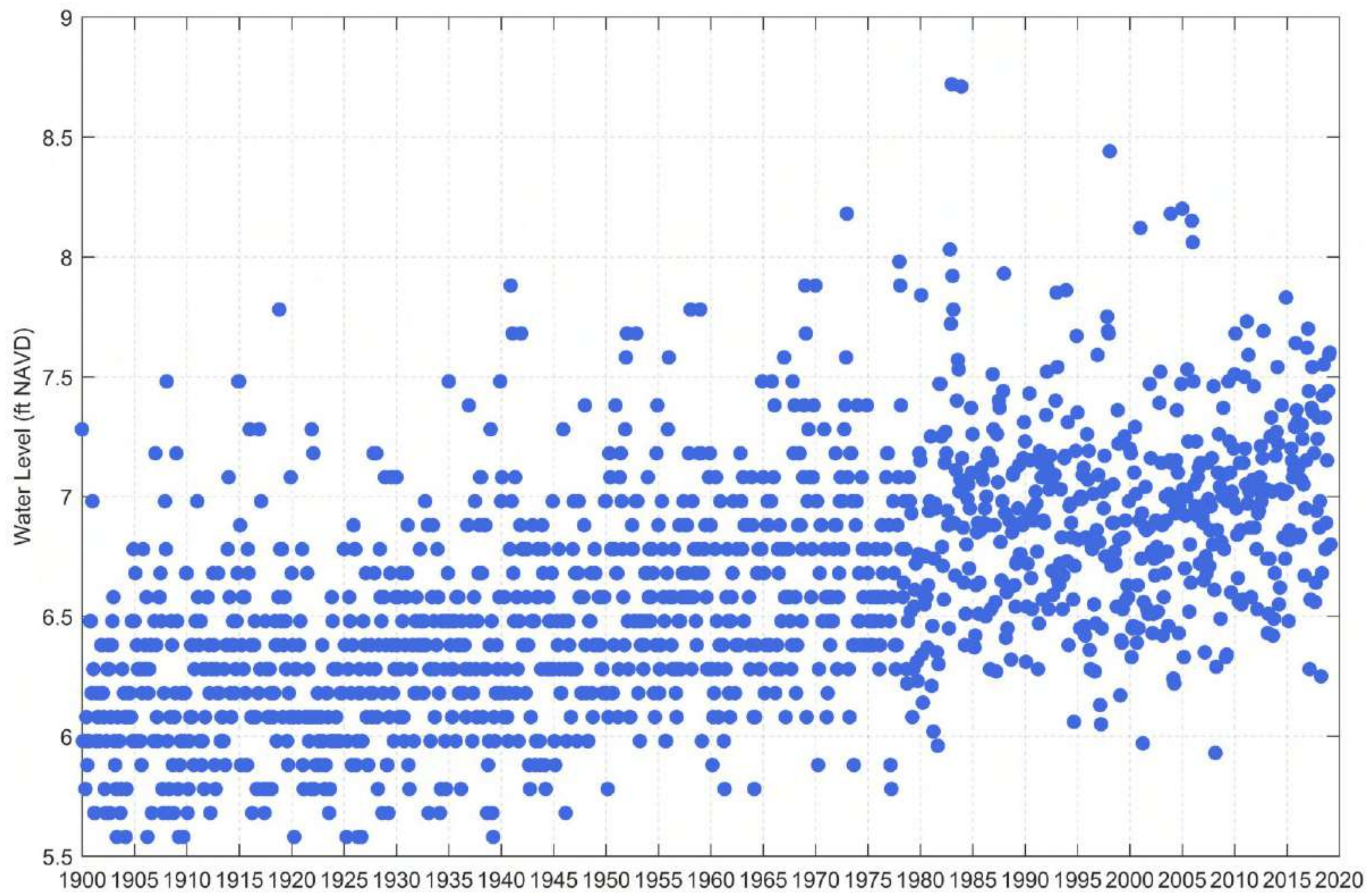
- Chris Choo, Principal Planner

7 FIGURES



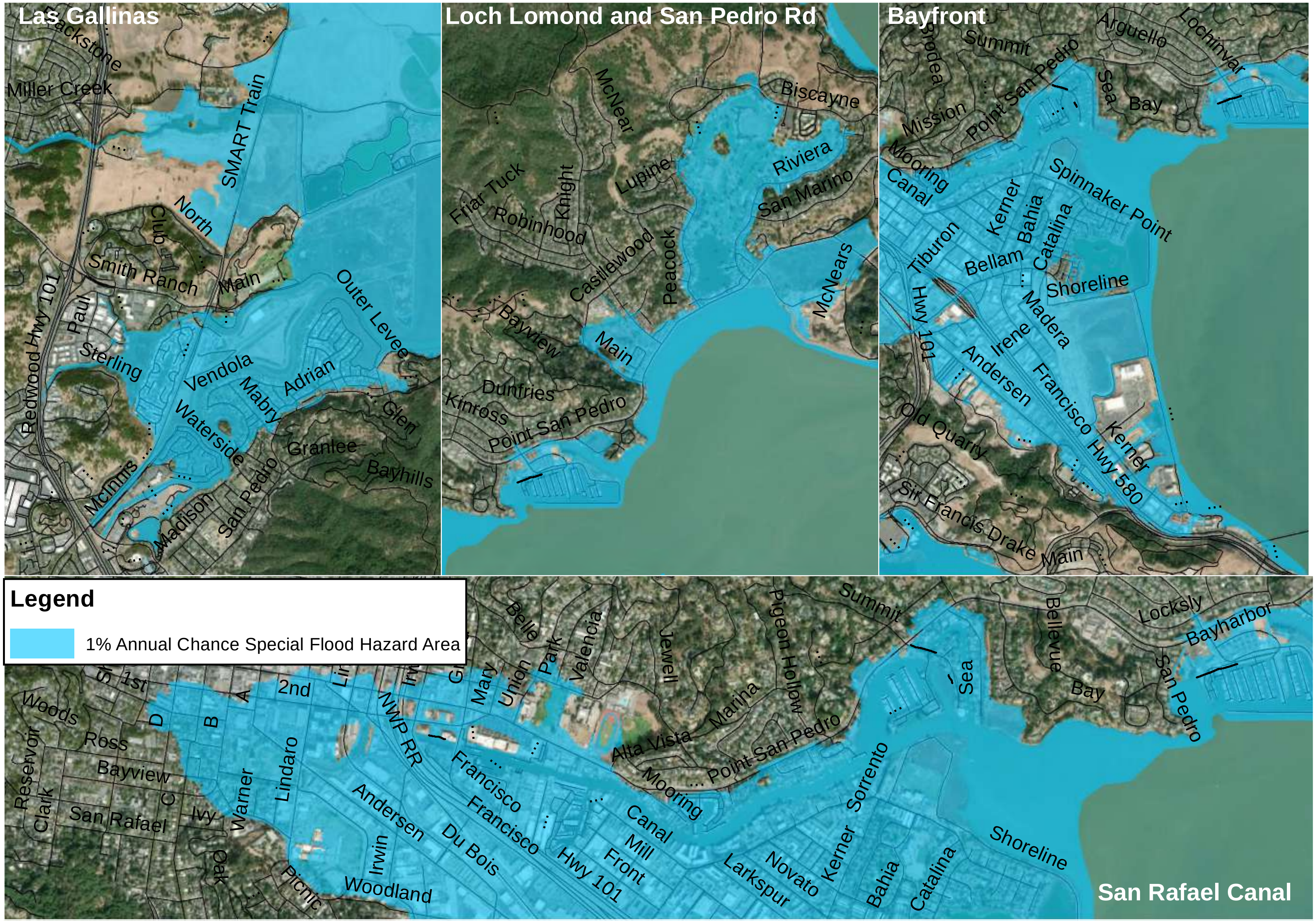
SOURCE: NOAA Station 9414863

Figure 1
Monthly peak water levels measured at NOAA Richmond tide station, 1996-2018



SOURCE: NOAA Station 9414290

Figure 3
Monthly peak water levels at NOAA San Francisco tide station, 1900-2019

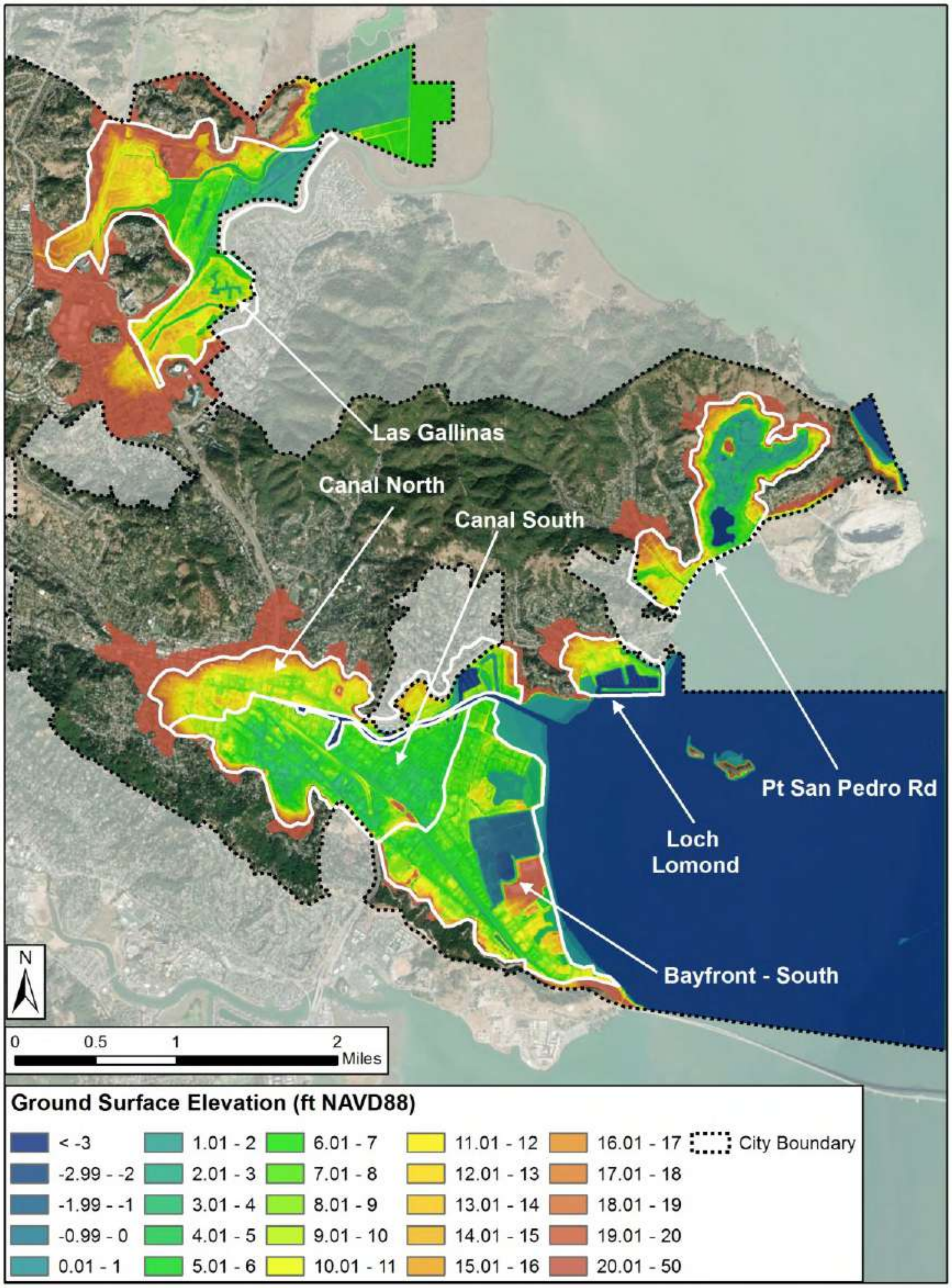


SOURCE: FEMA (Effective March 2016)

San Rafael Sea Level Rise Adaptation Study . D180140.00

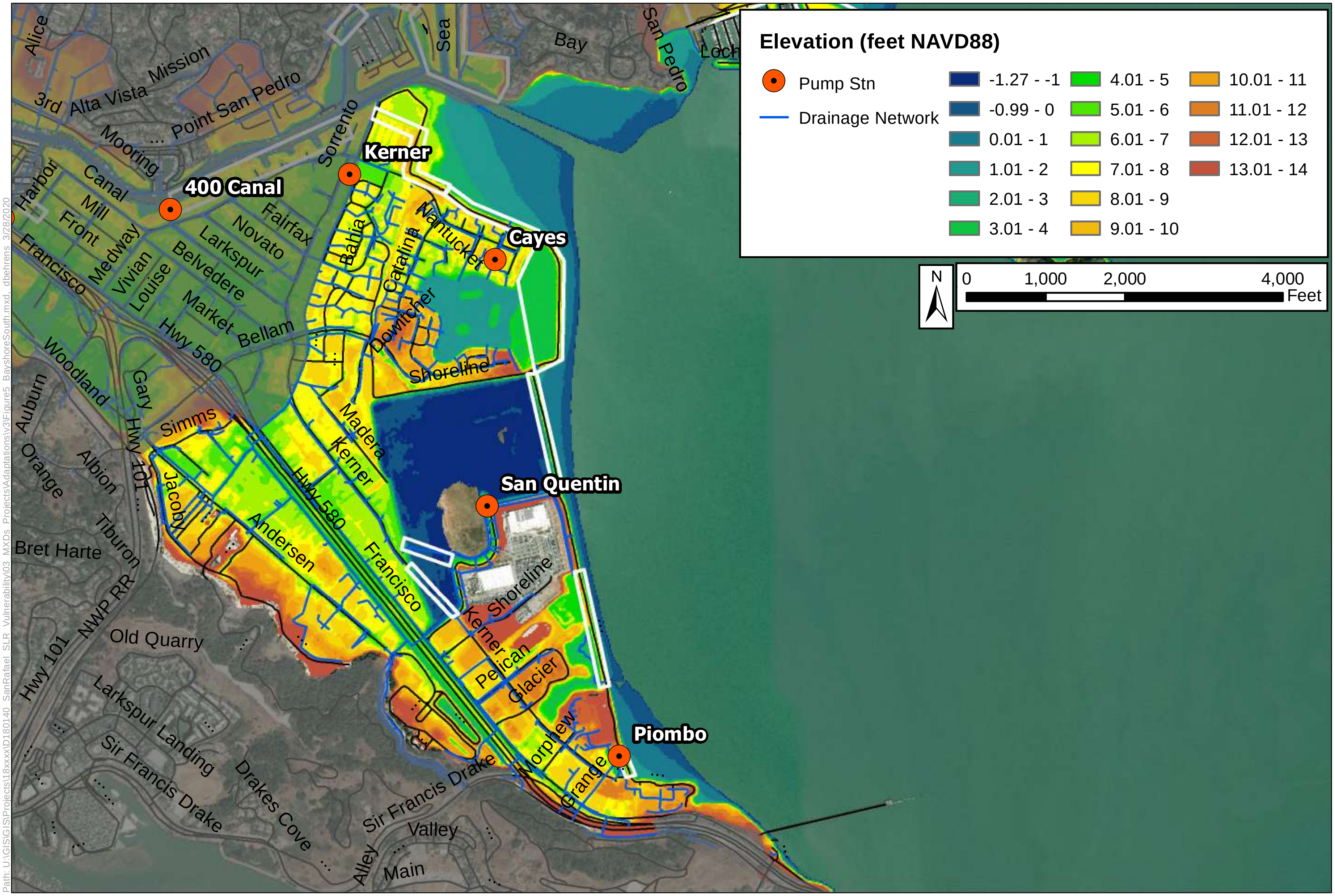
Figure 3
FEMA 1% Annual Chance Special Flood Hazard Area

ESA



SOURCE: NOAA SLR Viewer Topography (2010)

Figure 4
Site map and flood vulnerability regions



SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 5
Site Map: Bayfront South Region

ESA

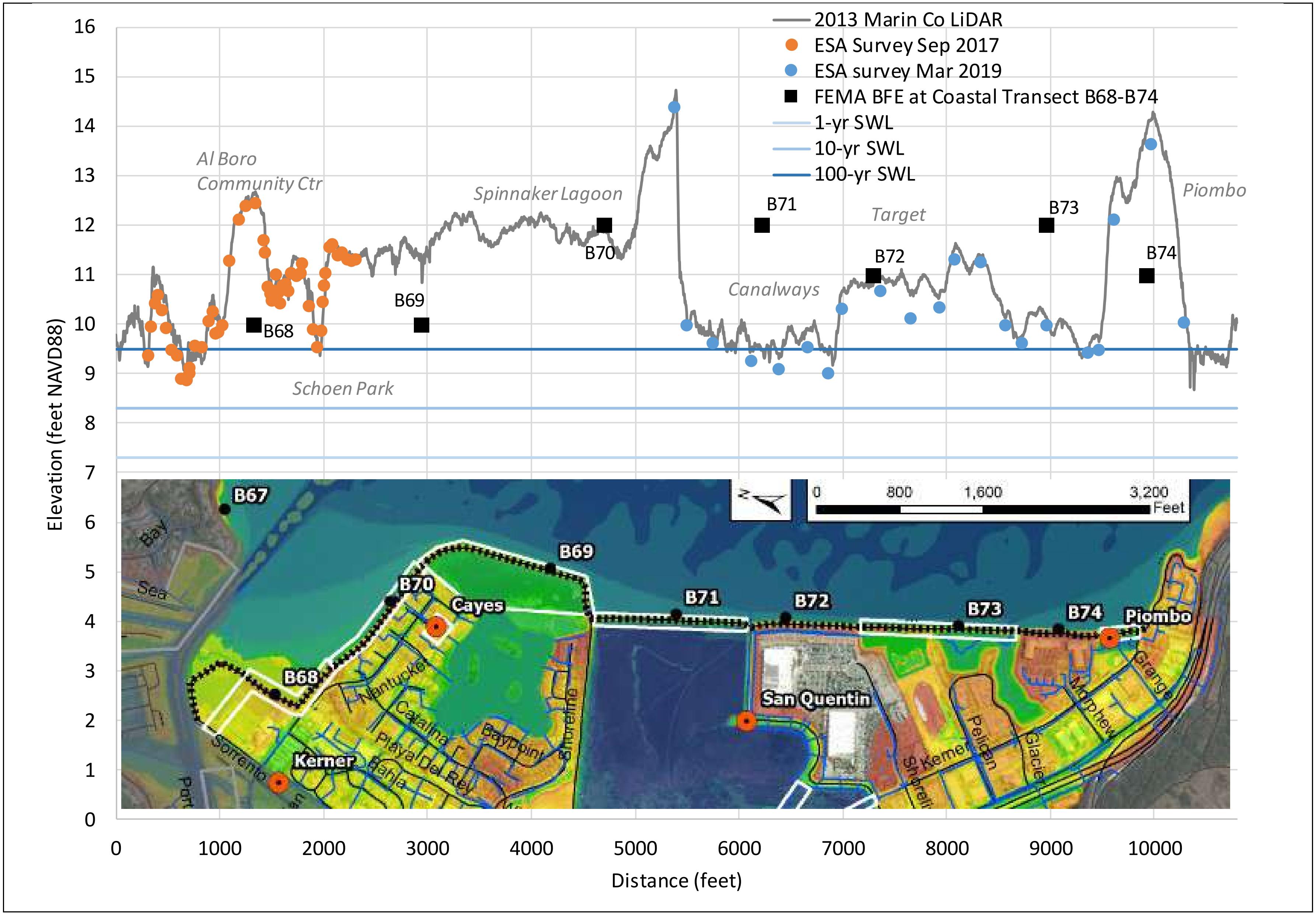
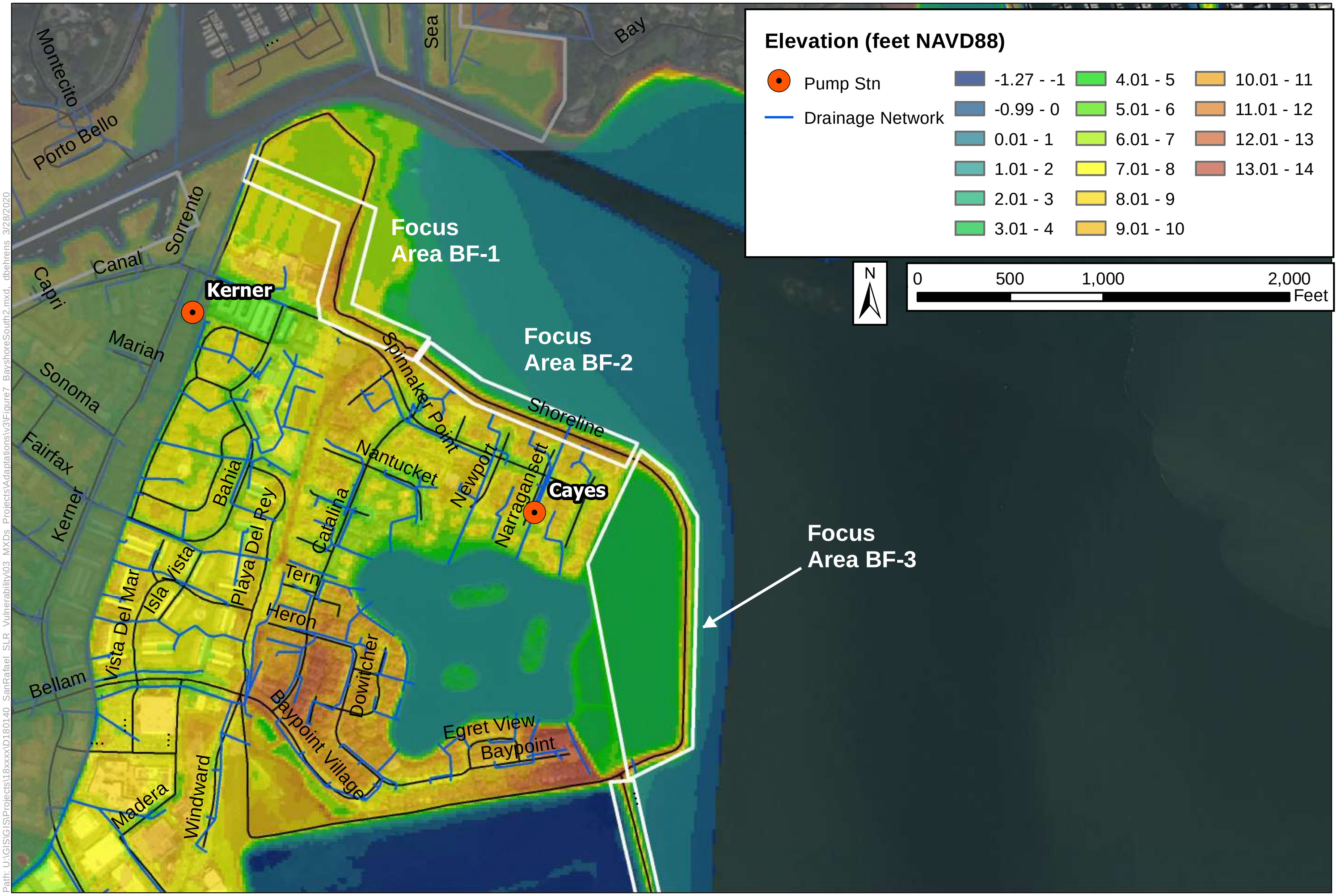


Figure 6
Shoreline elevations and extreme flood elevations: Bayfront South Region



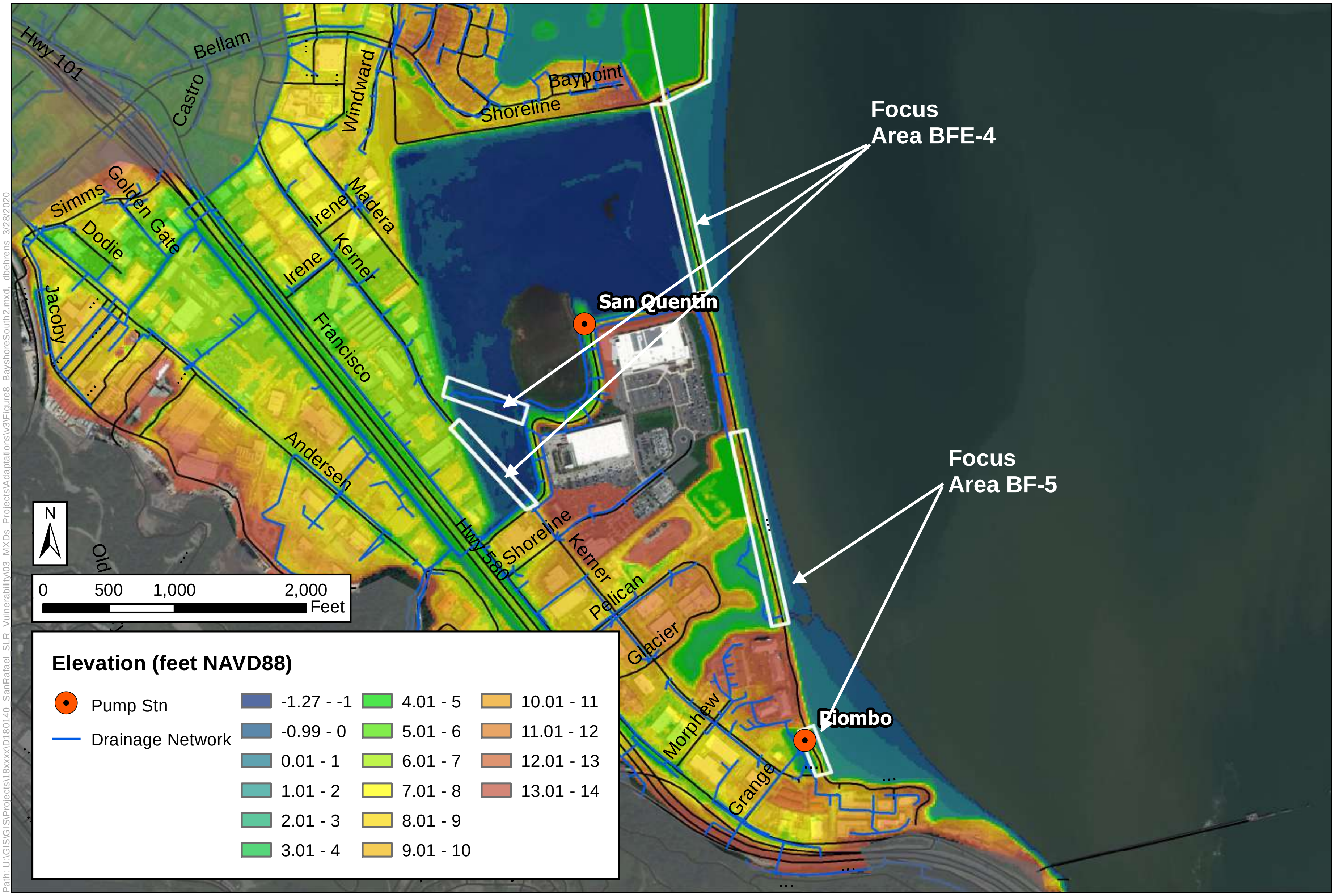
SOURCE: NOAA SLR Viewer Topography (2010)

Path: U:\GIS\GIS\Projects\18xxxx\D180140_SanRafael_SLR_Vulnerability\03_MXDs_Projects\Adaptations\v3\Figure7_BayshoreSouth2.mxd, dbehrens 3/28/2020

San Rafael SLR Adaptation Study . D180140.00

Figure 7
Site Map: Bayfront South Region: near Spinnaker Point

ESA

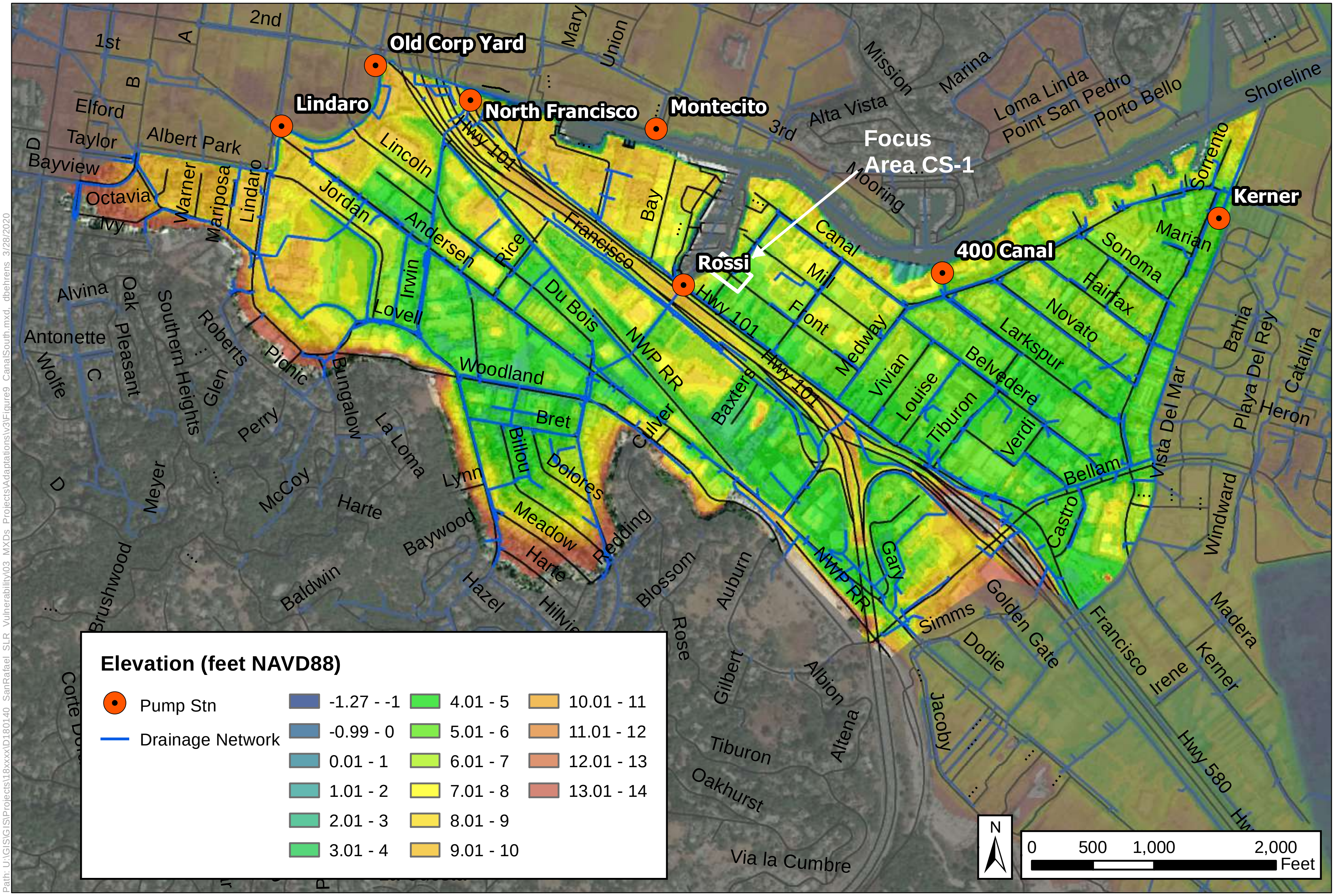


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D190002.00

Figure 8
Site Map: Baysfront South Region: near Morphew Street

ESA

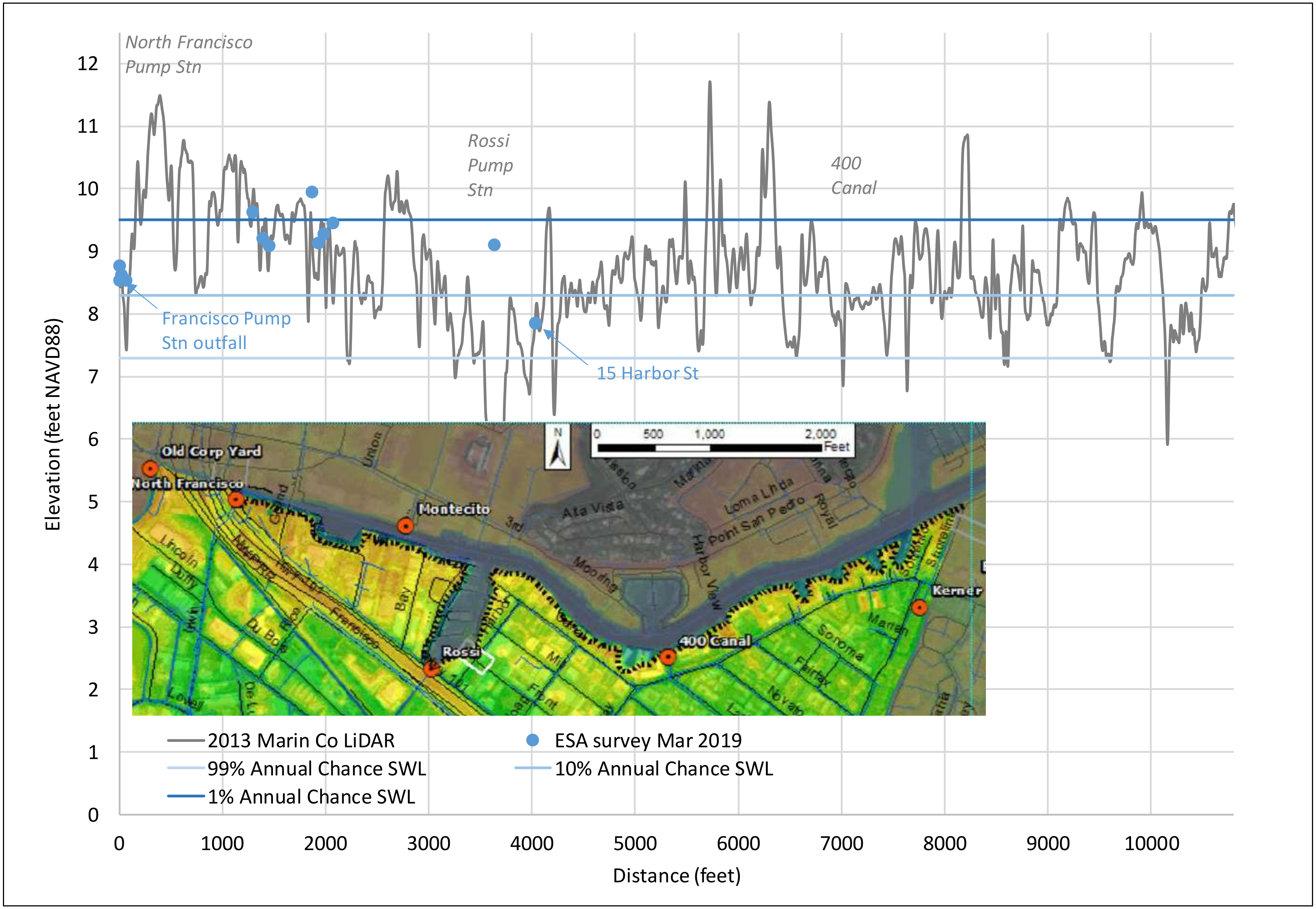


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study. D180140.00

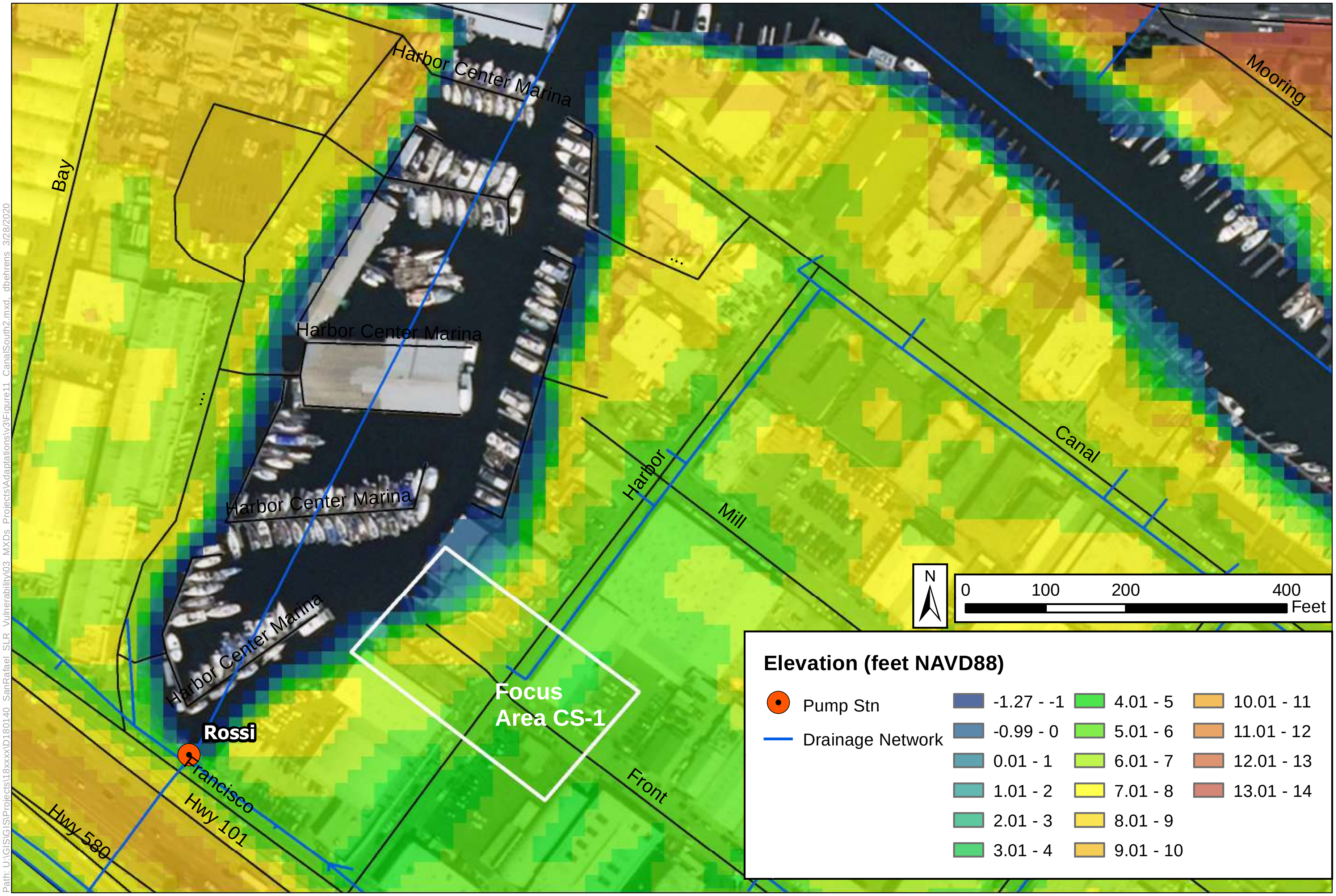
Figure 9
Site Map: Canal South Region

ESA



SOURCE: Marin County (2013) LiDAR and 2017 and 2019 ESA RTK GPS surveys

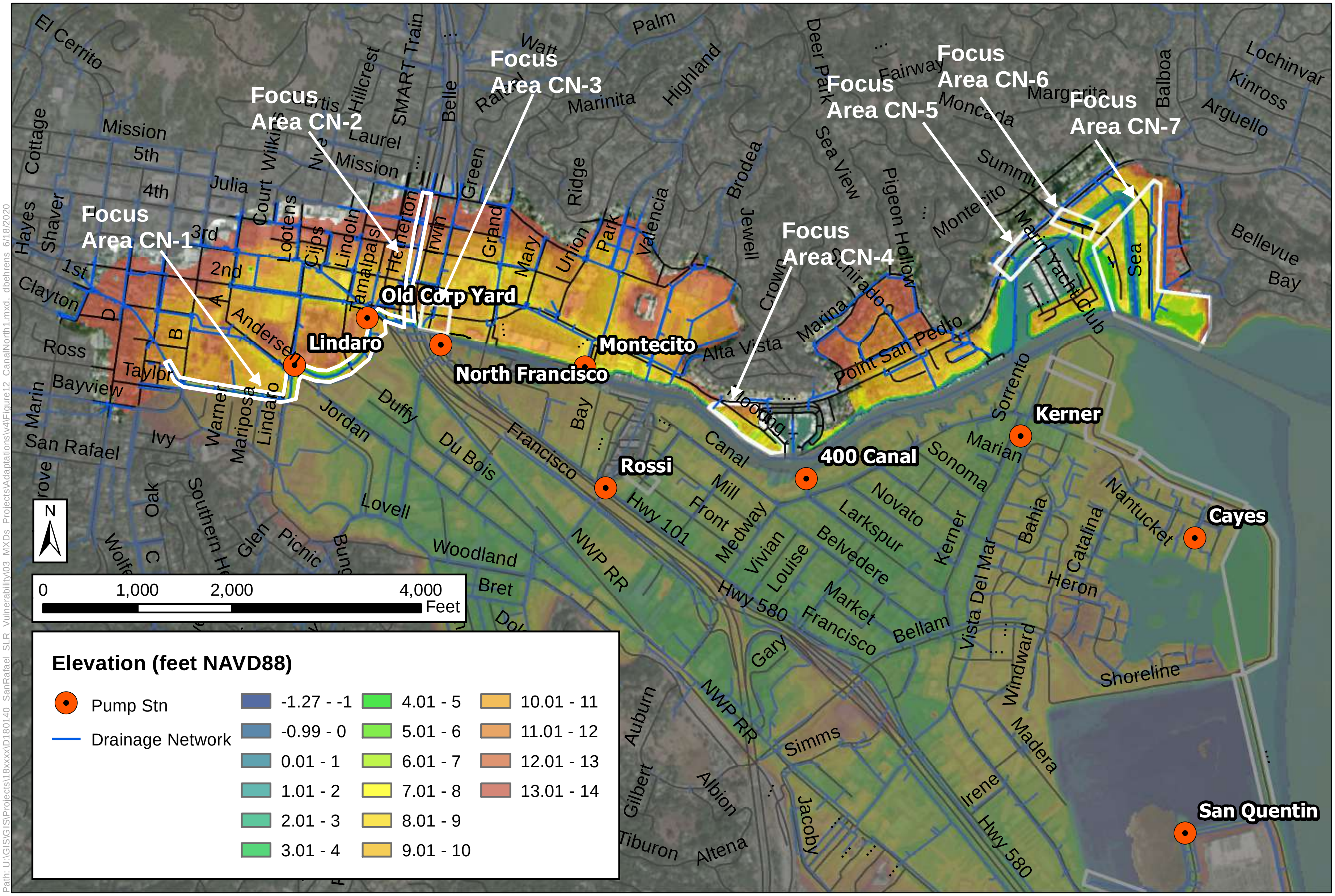
Figure 10
Shoreline elevations and extreme flood elevations: Canal South Region



SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 11
Site Map: Canal South Region: near Harbor Street

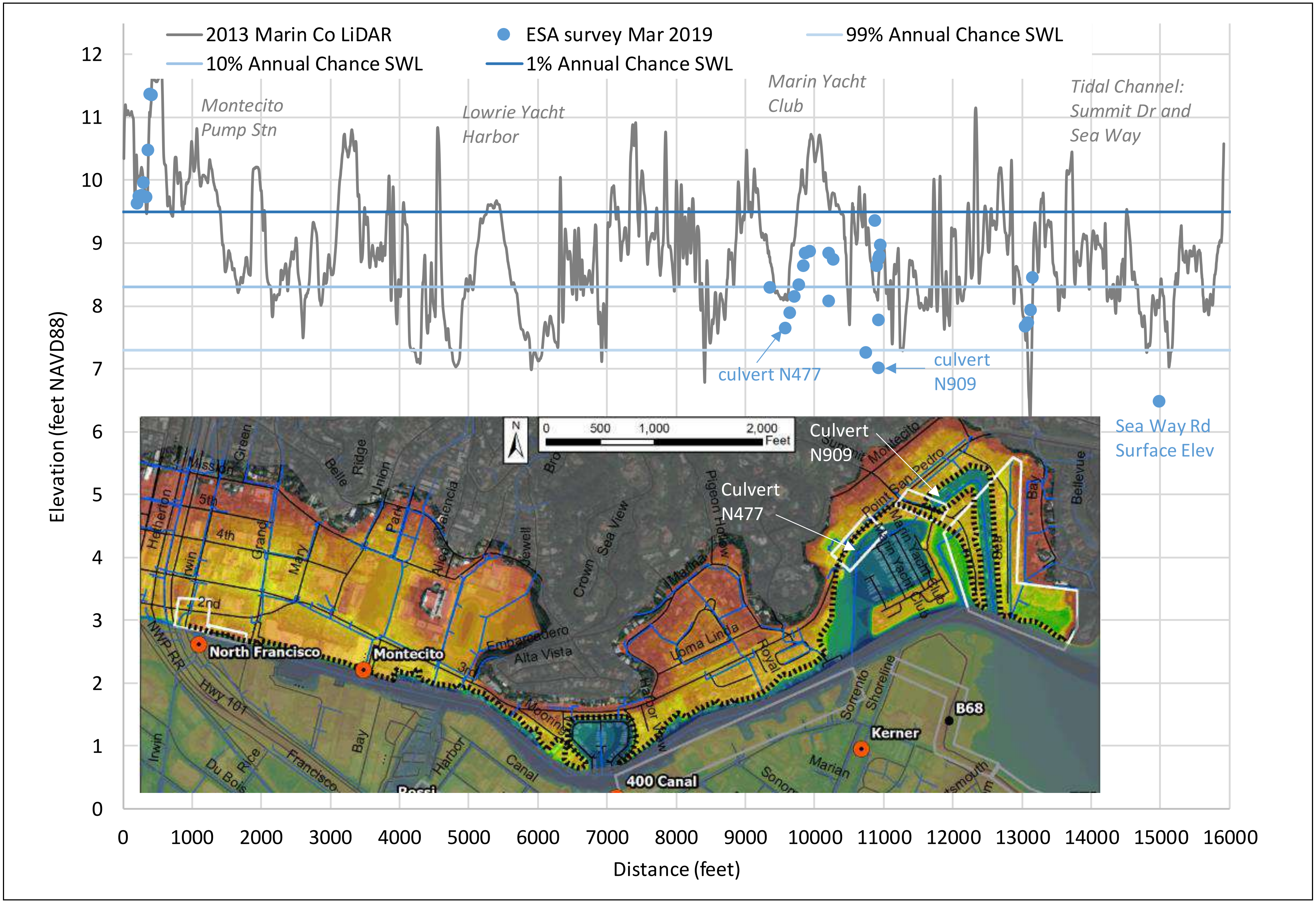


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 12
Site Map: Canal North Region

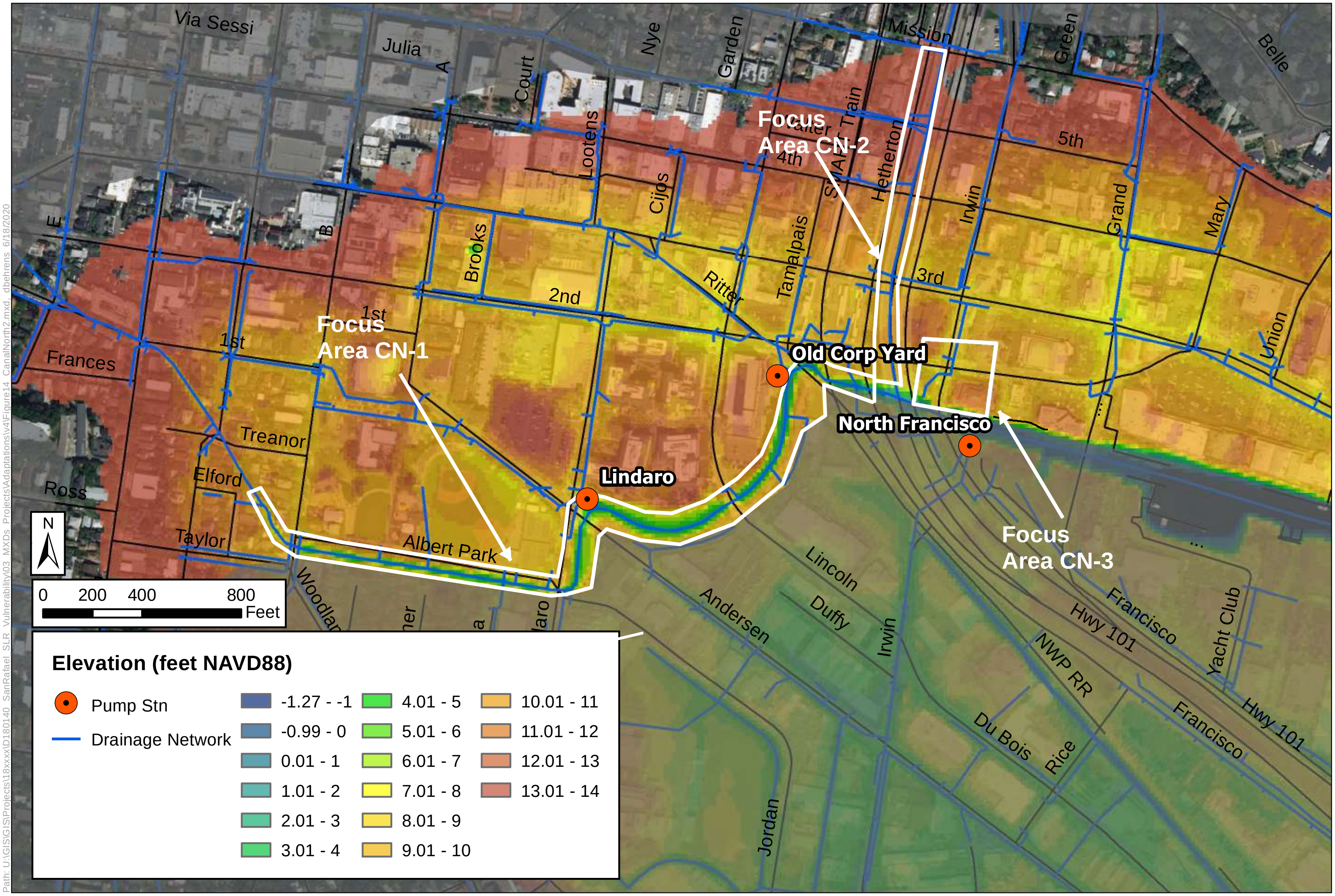
ESA



SOURCE: Marin County (2013) LiDAR and 2017 and 2019 ESA RTK GPS surveys

San Rafael Sea Level Rise Adaptation Study . D180140.00

Figure 13
Shoreline elevations and extreme flood elevations: Canal North Region

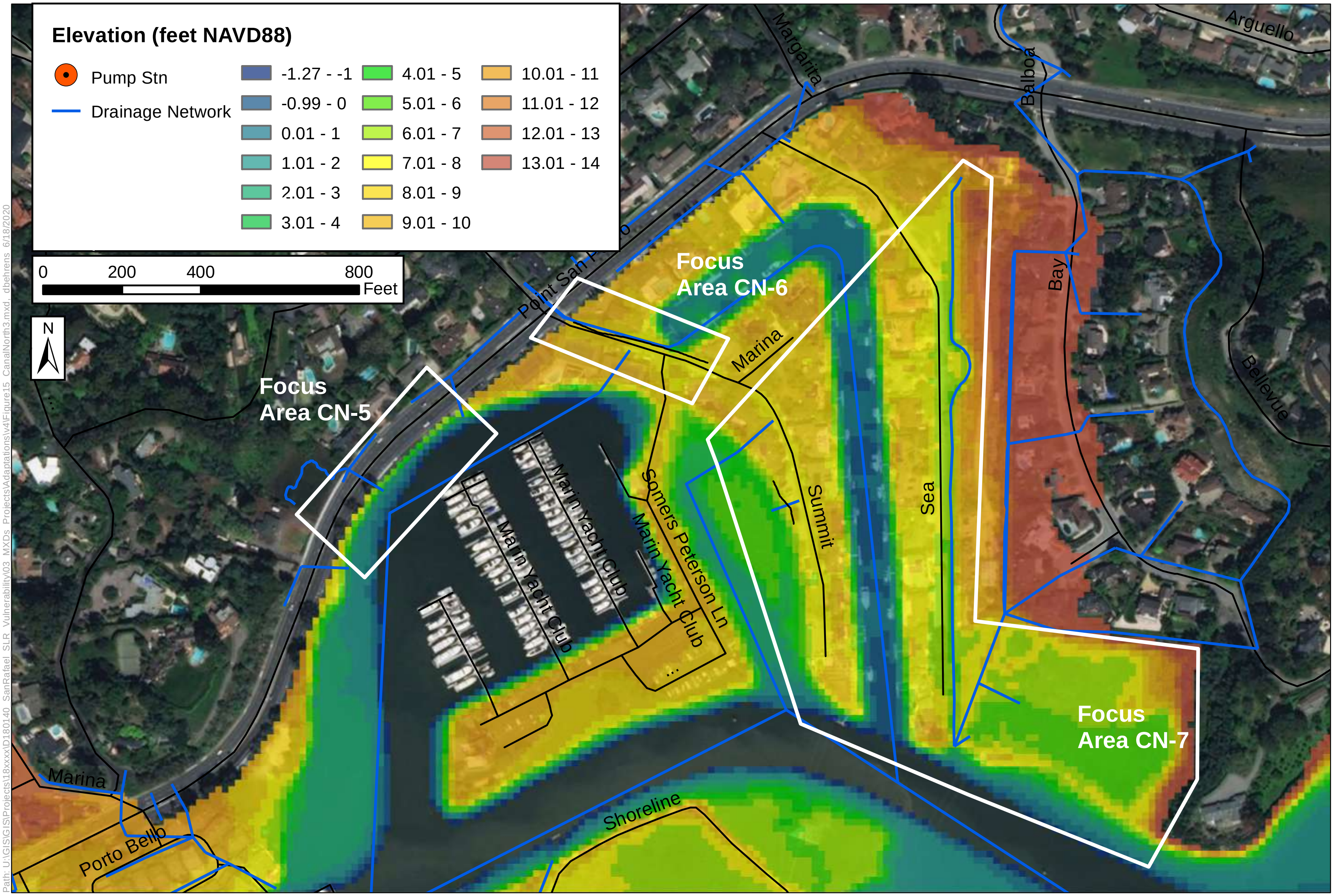


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 14
Site Map: Canal North Region: near Highway 101

ESA



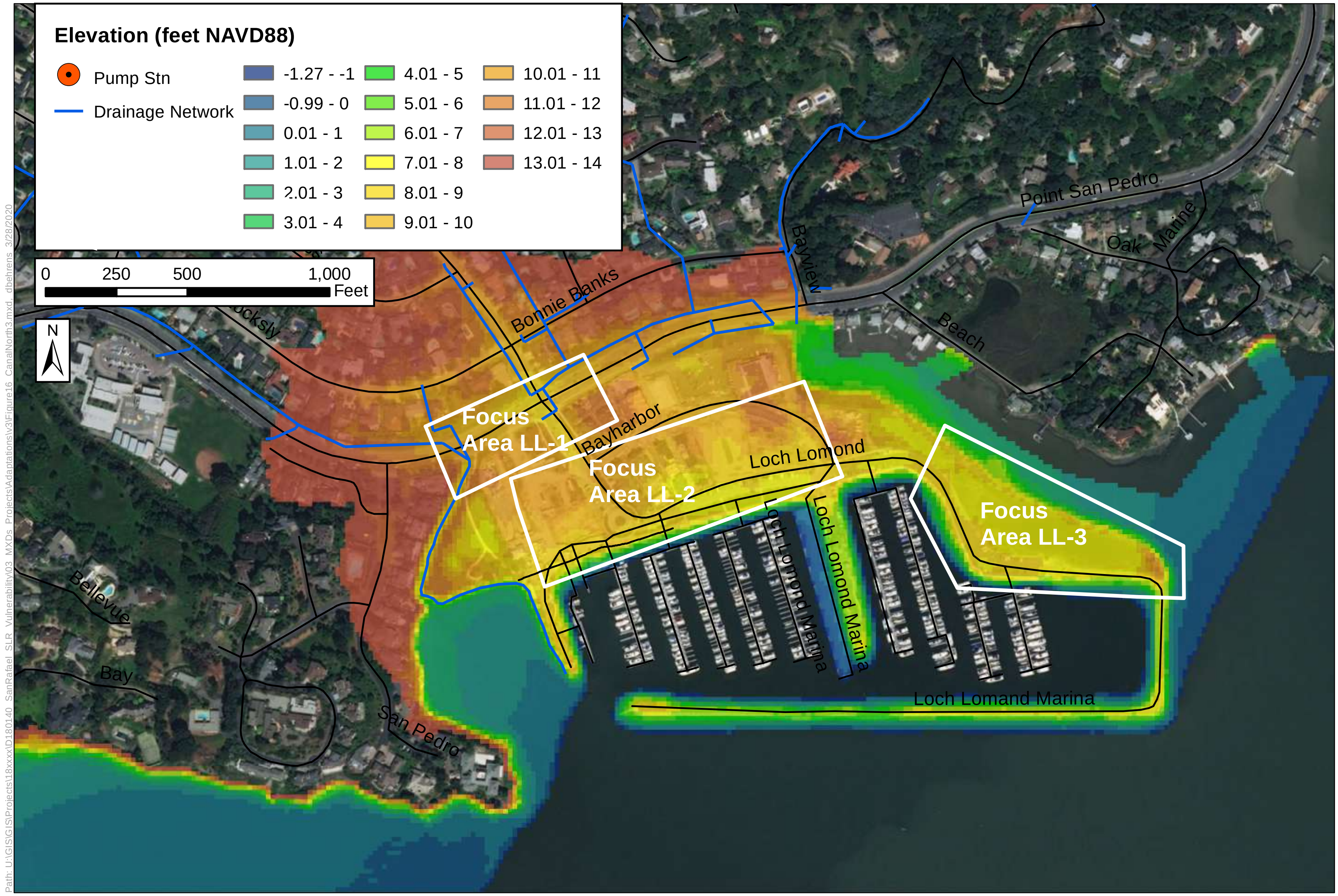
SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 15

Site Map: Canal North Region: near Marin Yacht Club

ESA

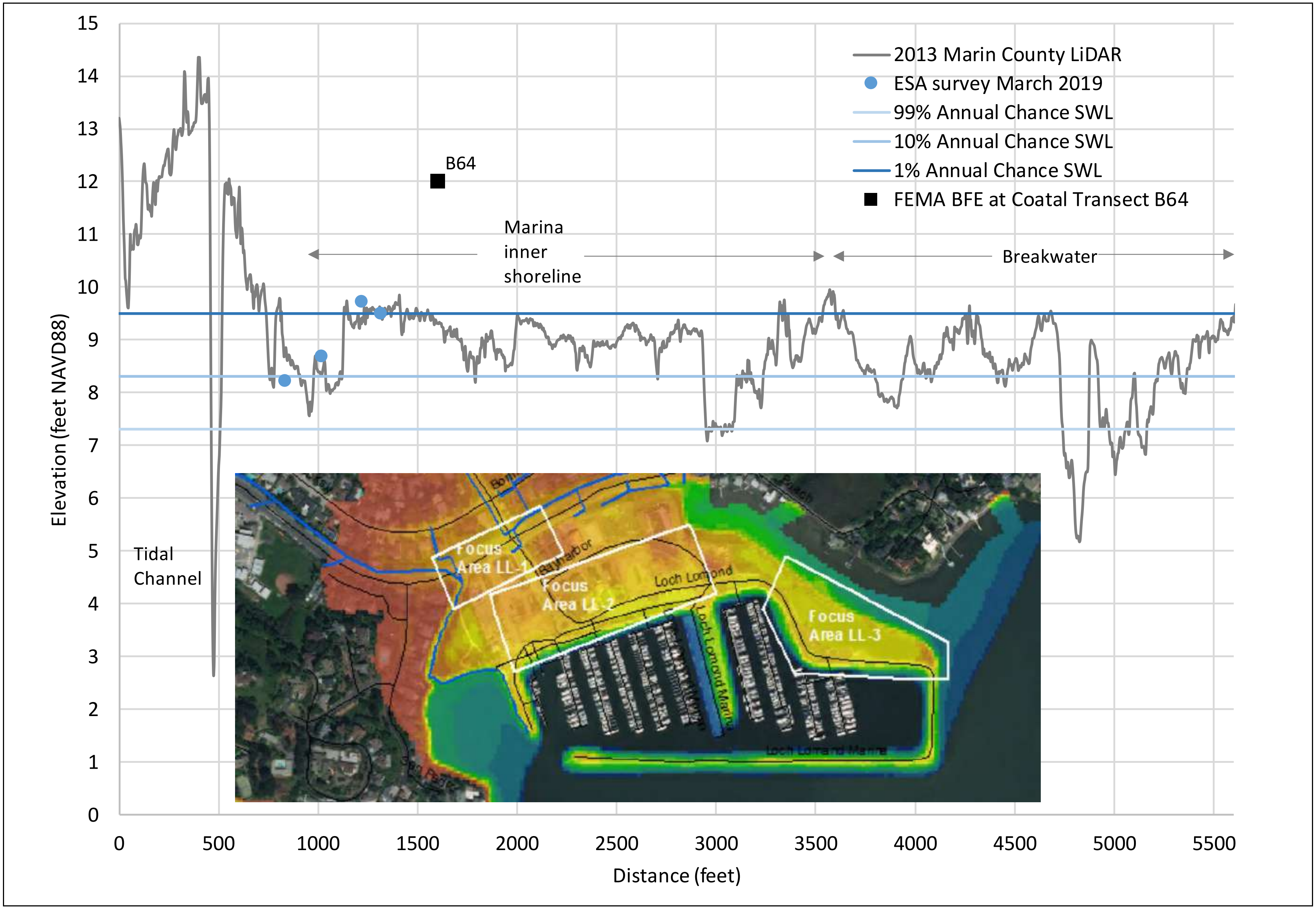


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 16
Site Map: Loch Lomond Region

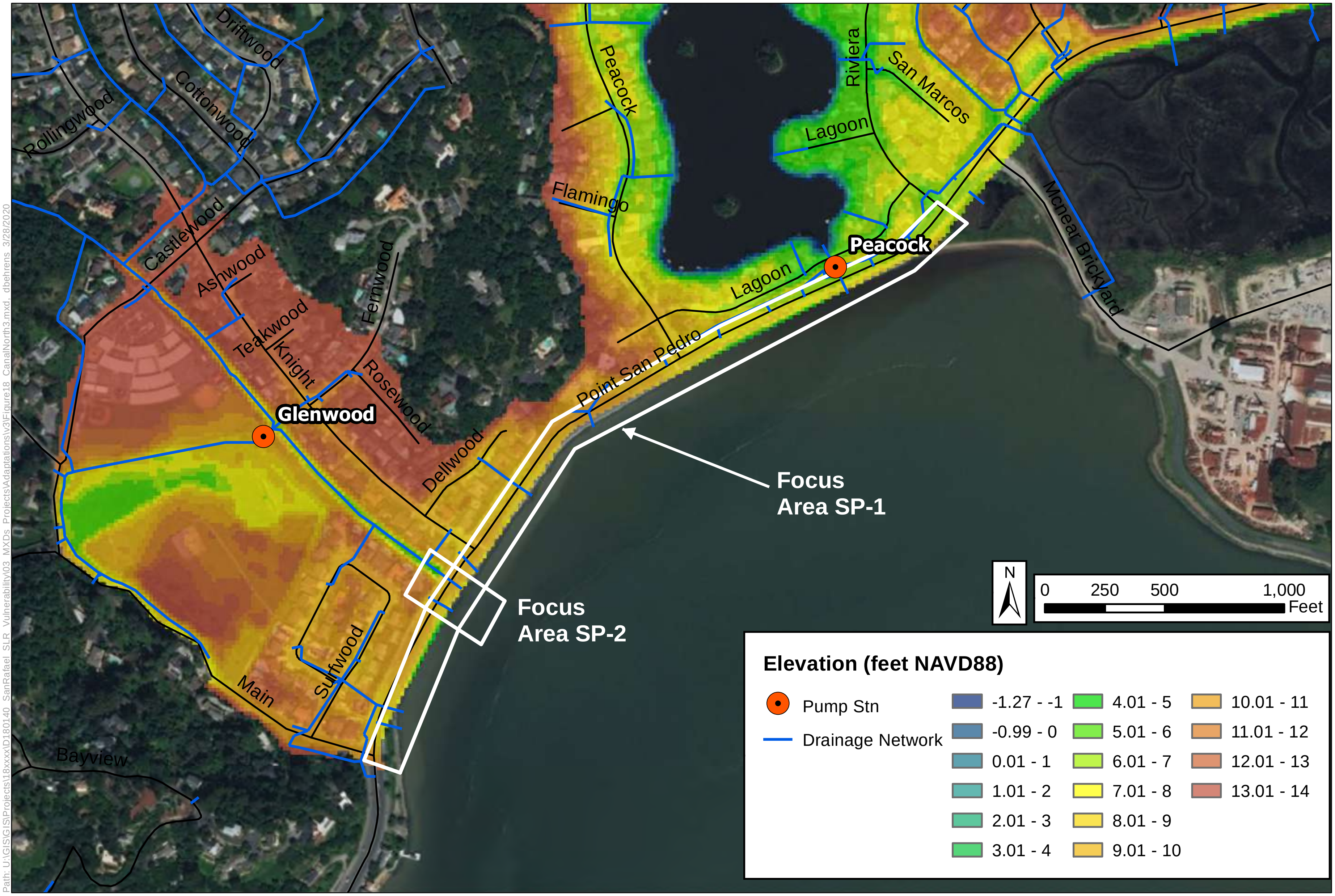
ESA



SOURCE: Marin County (2013) LiDAR and 2019 ESA RTK GPS surveys

San Rafael Sea Level Rise Adaptation Study . D180140.00

Figure 17
Shoreline elevations and extreme flood elevations: Loch Lomond Region

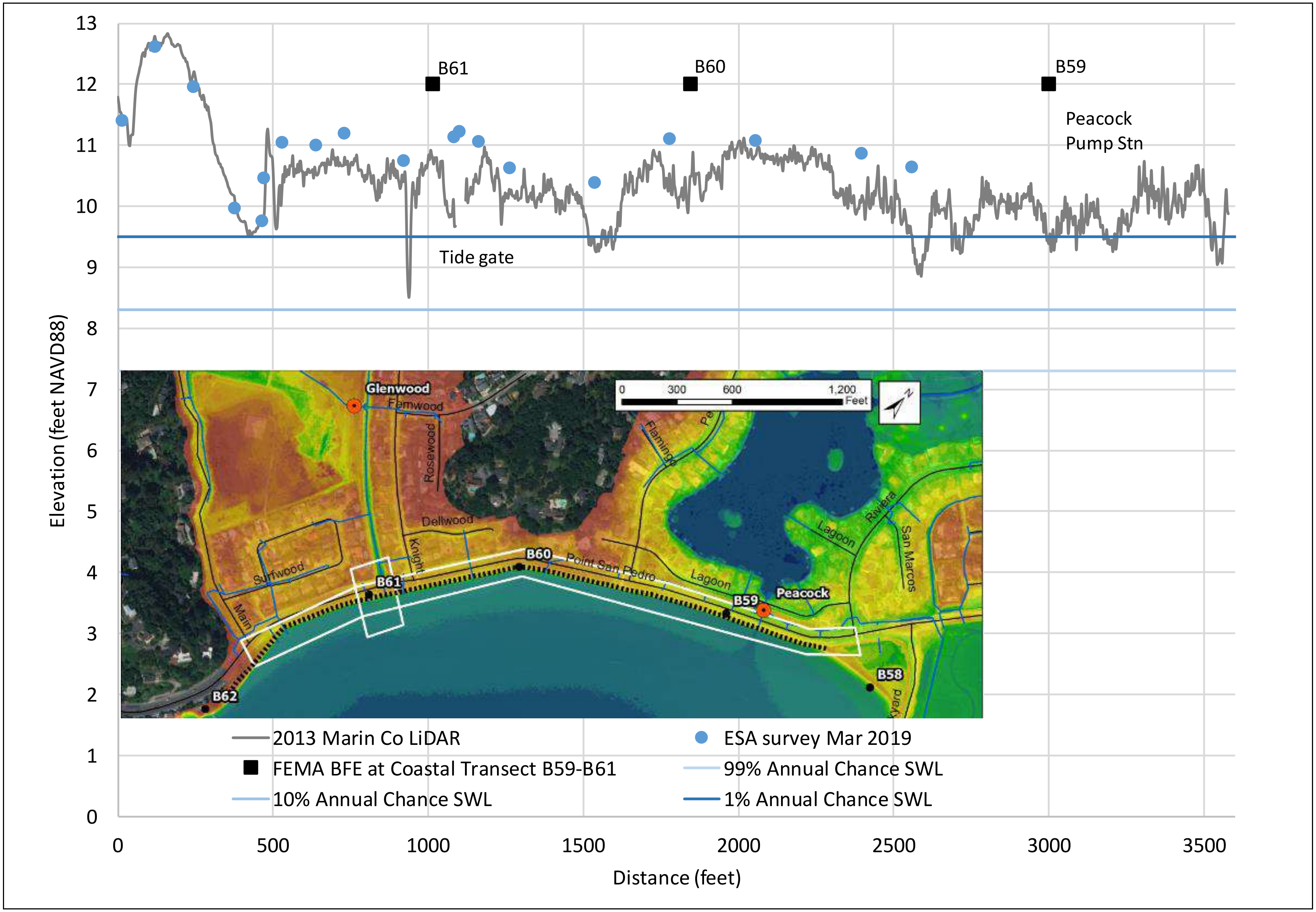


SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

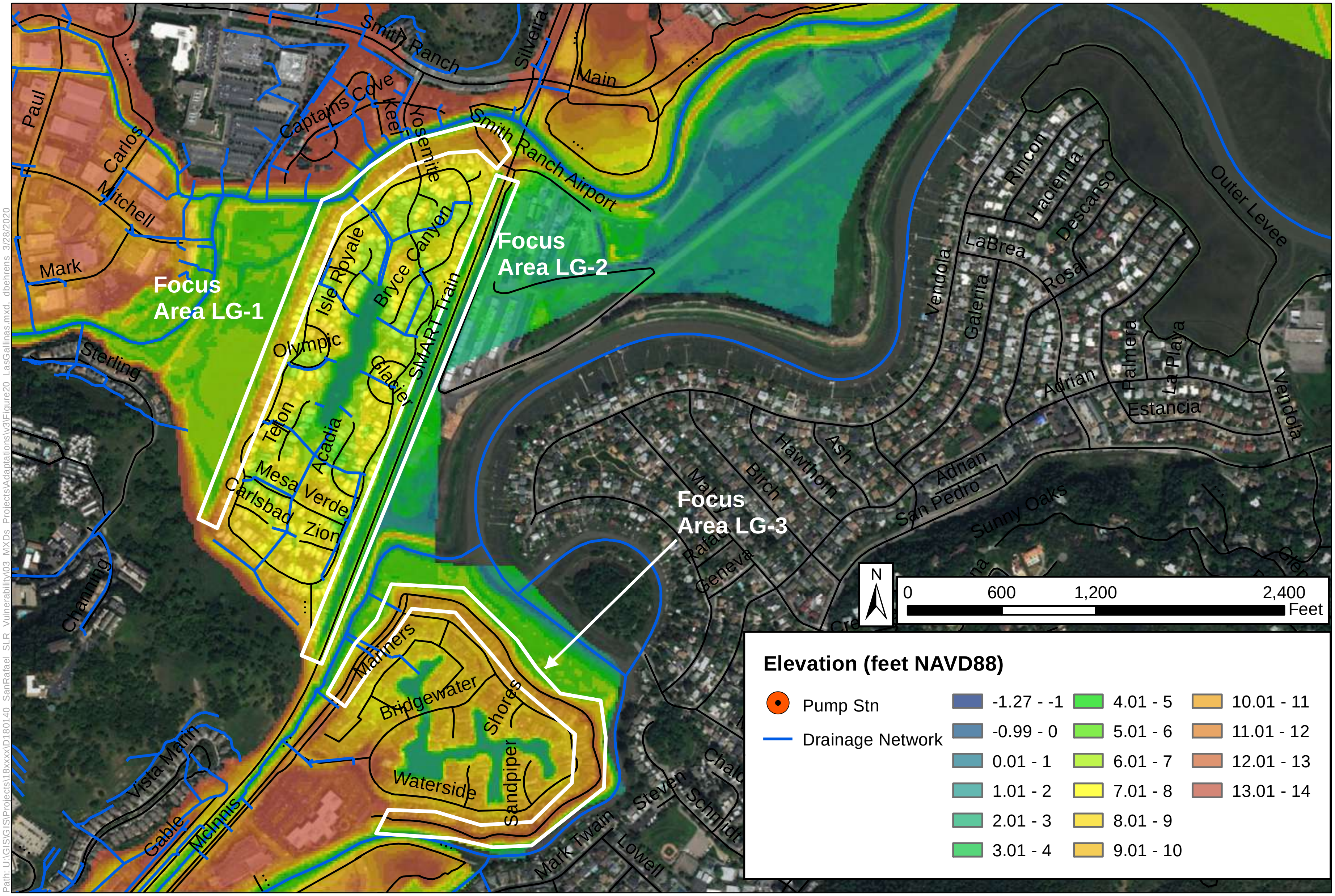
Figure 18
Site Map: Point San Pedro Rd Region

ESA



SOURCE: Marin County (2013) LiDAR and 2019 ESA RTK GPS survey

Figure 19
Shoreline elevations and extreme flood elevations: Point San Pedro Rd Region



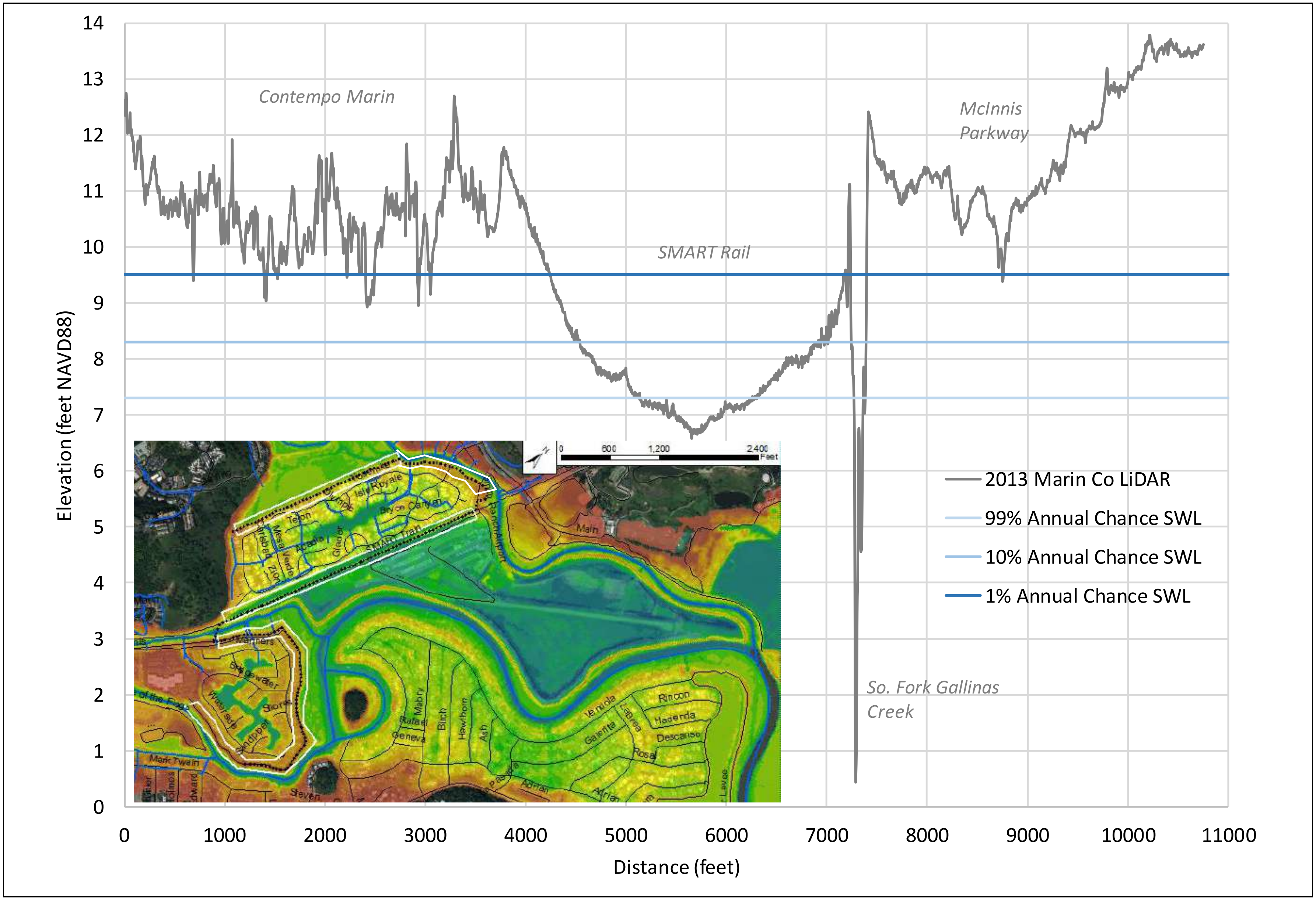
Path: U:\GIS\GIS\Projects\18xxxx\D180140_SanRafael_SLR_Vulnerability\03_MXDs_Projects\Adaptations\v3\Figure20_LasGallinas.mxd, dbehrens 3/28/2020

SOURCE: NOAA SLR Viewer Topography (2010)

San Rafael SLR Adaptation Study . D180140.00

Figure 20
Site Map: Las Gallinas Region

ESA



SOURCE: Marin County (2013) LiDAR and 2019 ESA RTK GPS surveys

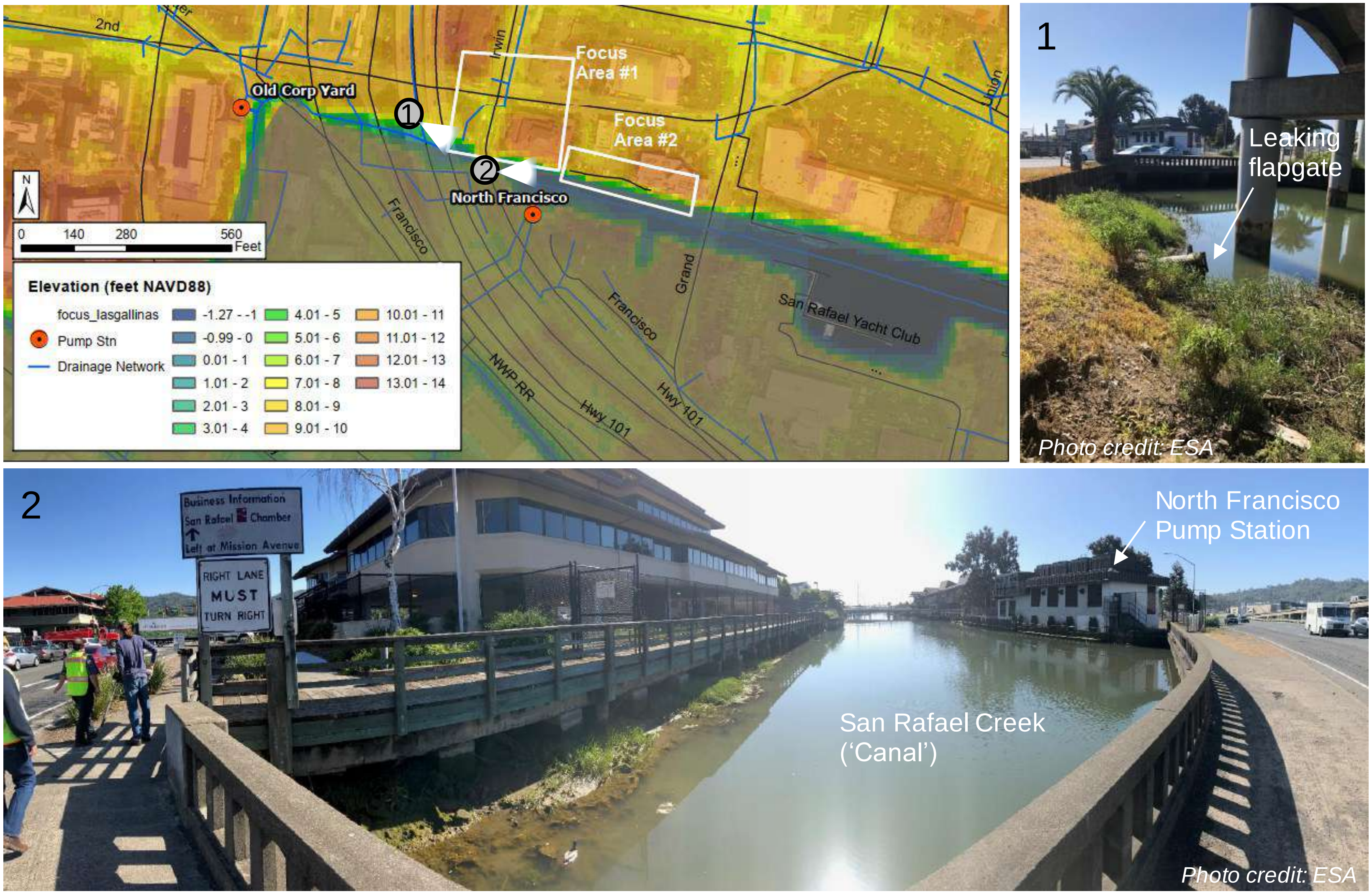
San Rafael Sea Level Rise Adaptation Study . D180140.00

Figure 21

Shoreline elevations and extreme flood elevations: Las Gallinas Region

Appendix A
Site Photographs

ESA

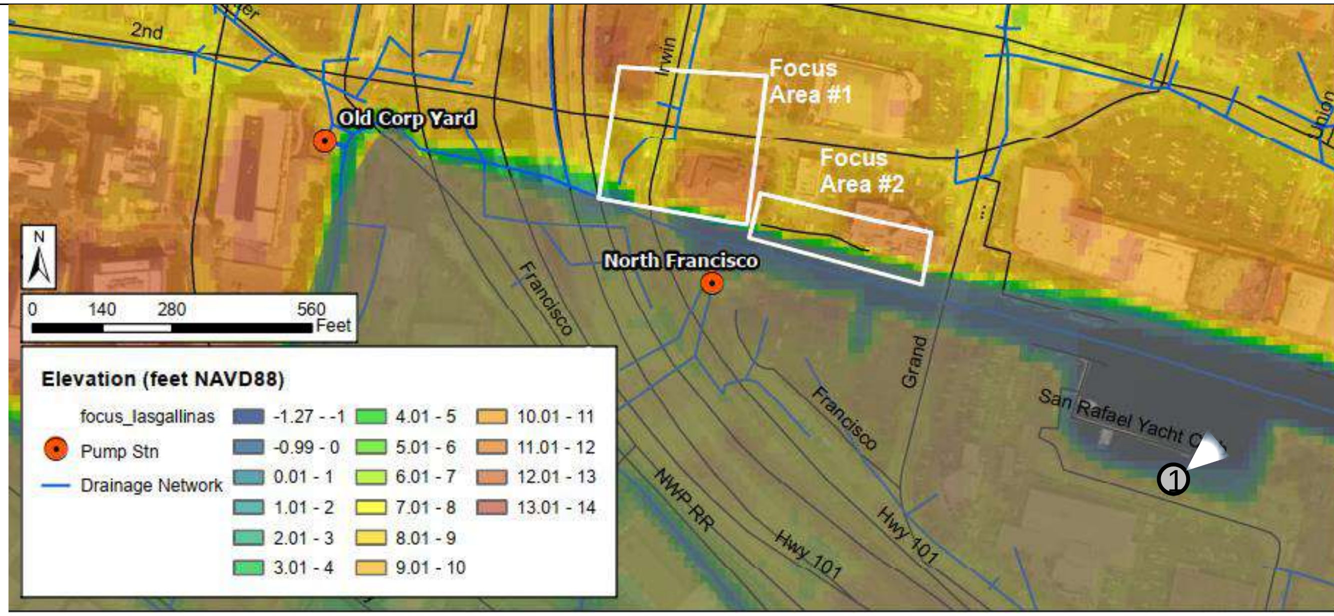


SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

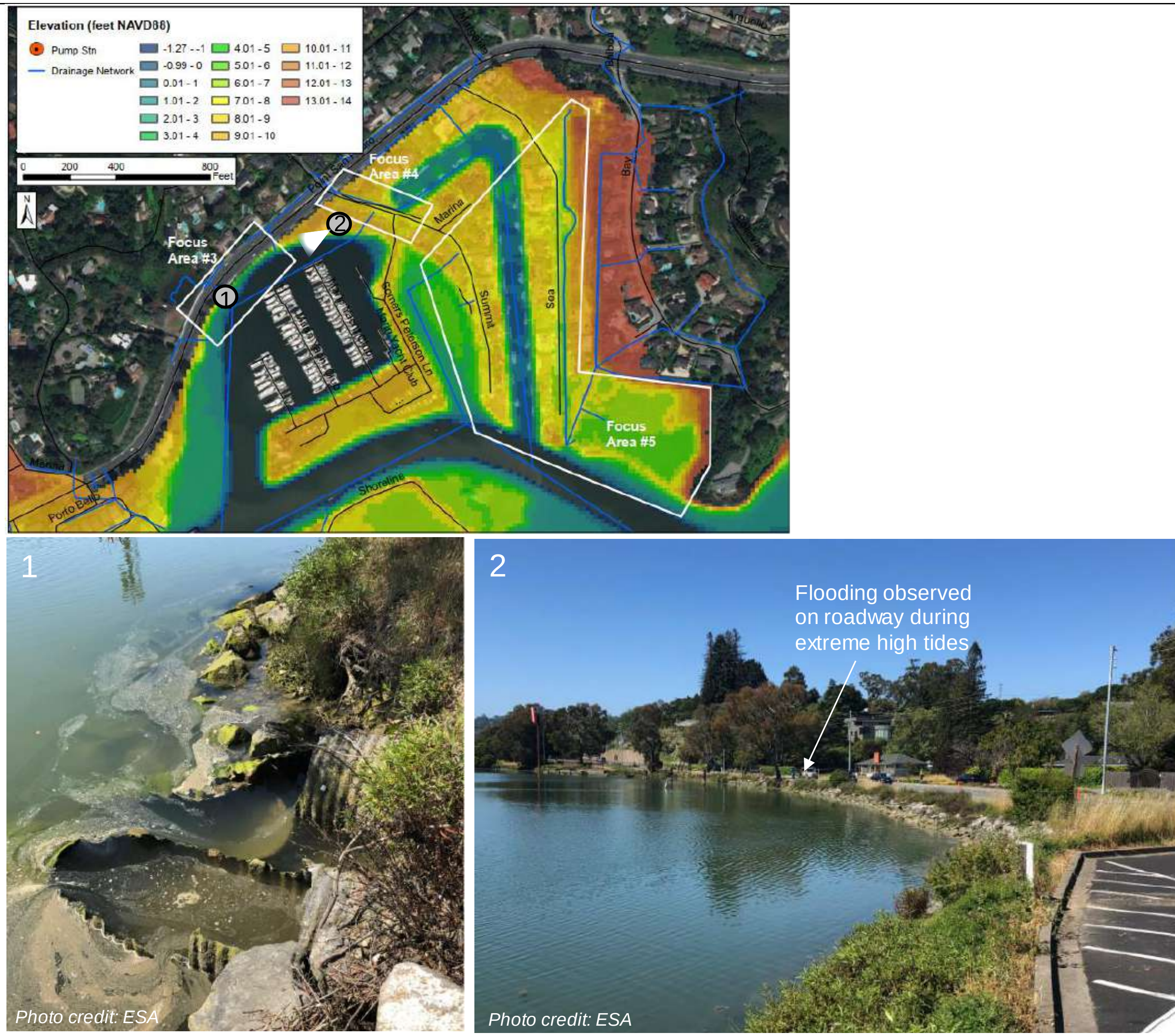
Figure A1

Focus areas near Highway 101 overpass of San Rafael Creek



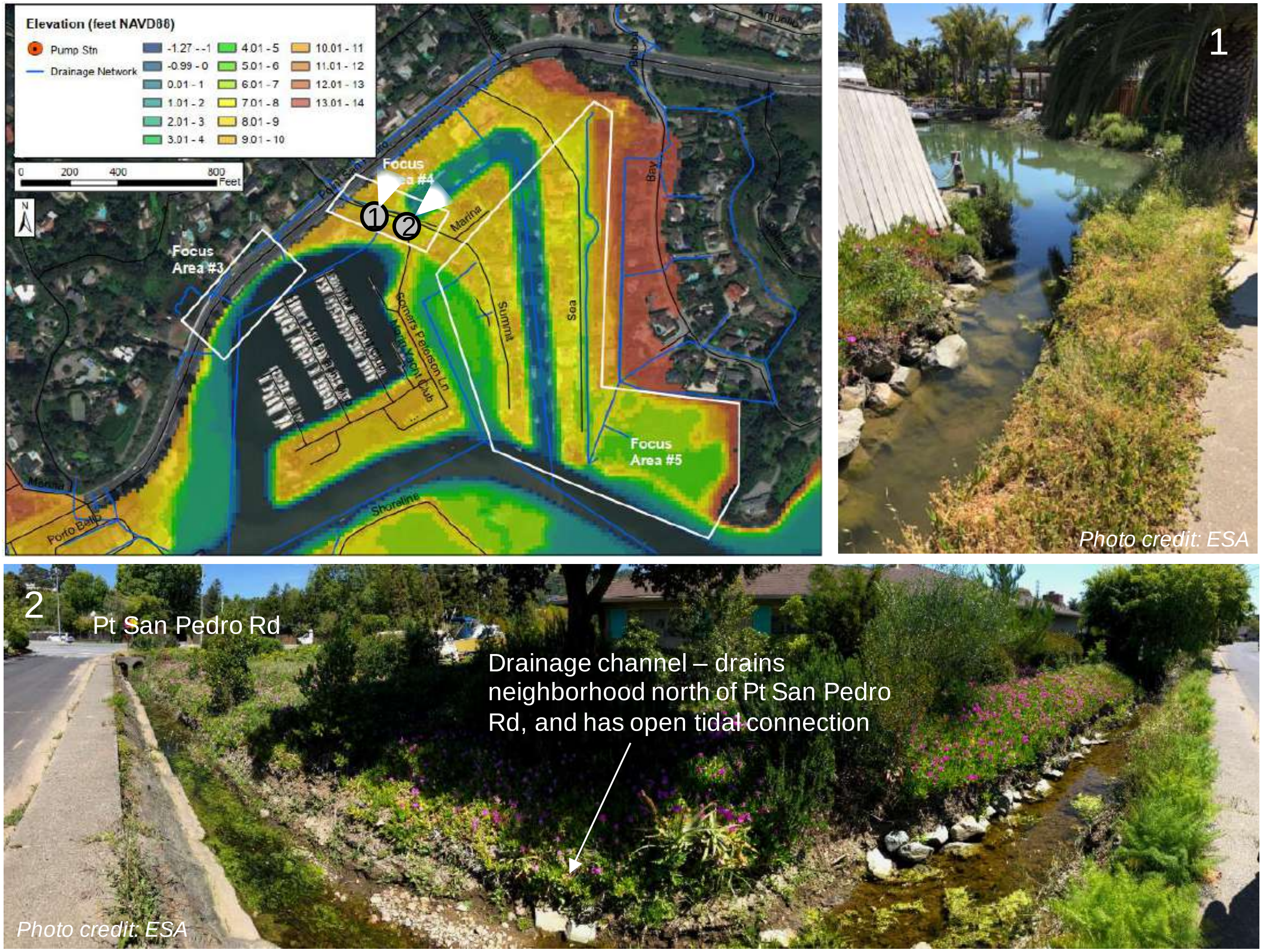
SOURCE: ESA

Figure A2
Shoreline walkway along the northern shoreline of San Rafael Creek (adjacent to Montecito Plaza)



SOURCE: ESA

Figure A3
Focus area within Marin Yacht Club



SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

Figure A4
Drainage channel with open connection to the Bay along Summit Drive

SOURCE: ESA

Figure A5

Photos of Focus Area 5, adjacent to Sea Way and Summit Drive

SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

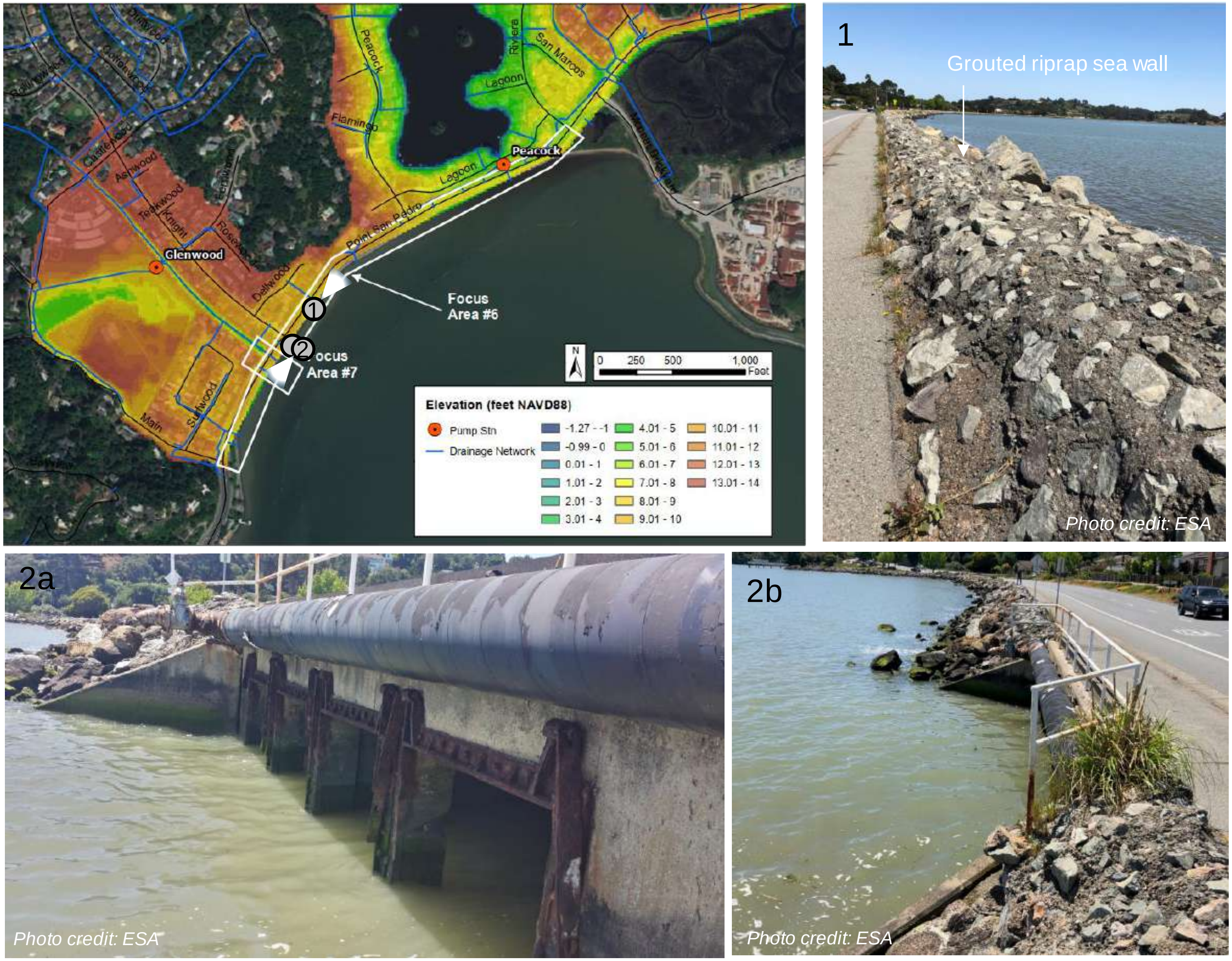
Figure A6

Photos of focus areas within Loch Lomond region

SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

Figure A7
Loch Lomond Jetty



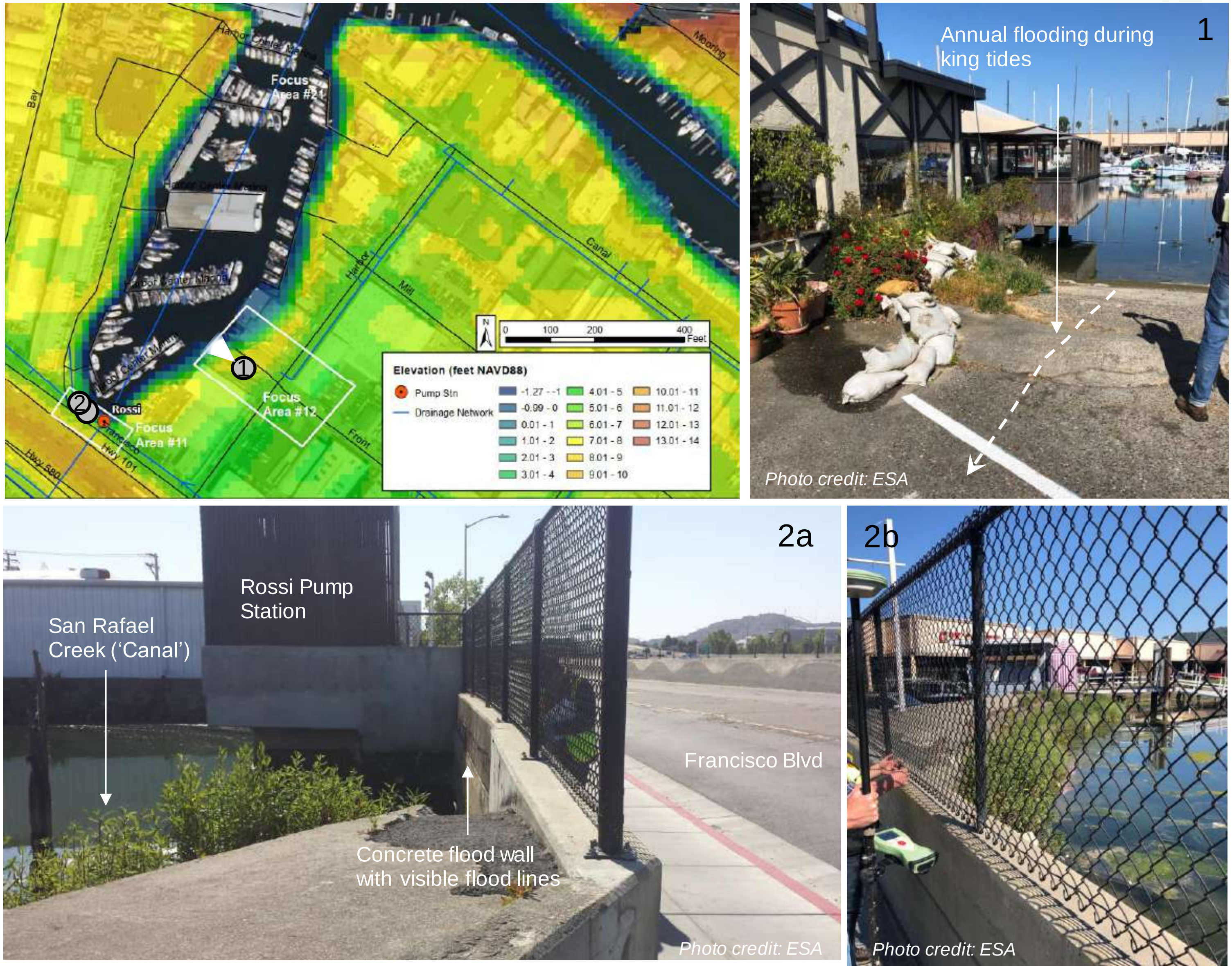
SOURCE: ESA

Figure A8
Focus areas along Pt San Pedro Road

SOURCE: Stephen Sarhad

San Rafael SLR Vulnerability Study . D180140.00

Figure A9
Flooding observed from combined high tides and wave runup at Pt San Pedro Road

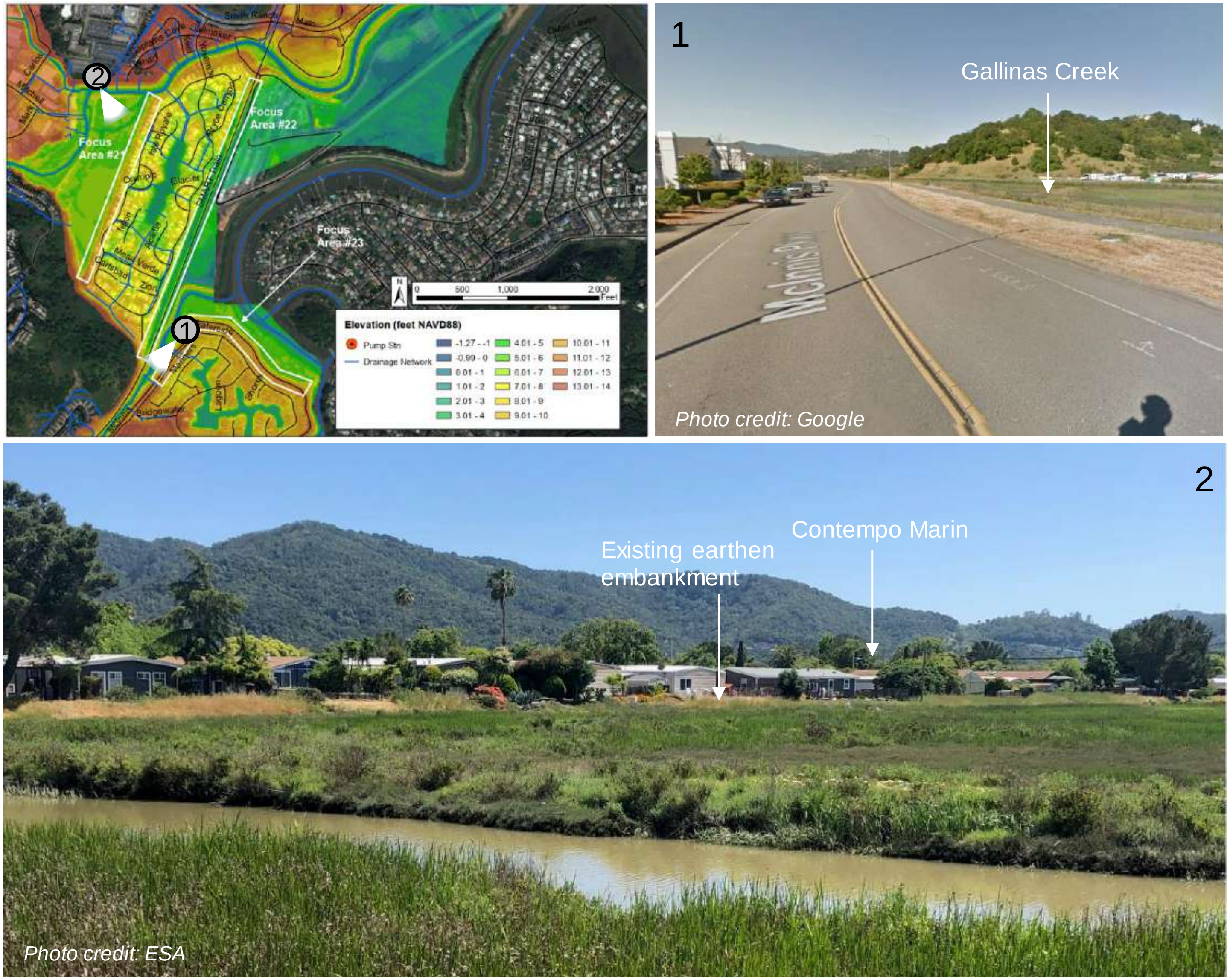


SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

Figure A10

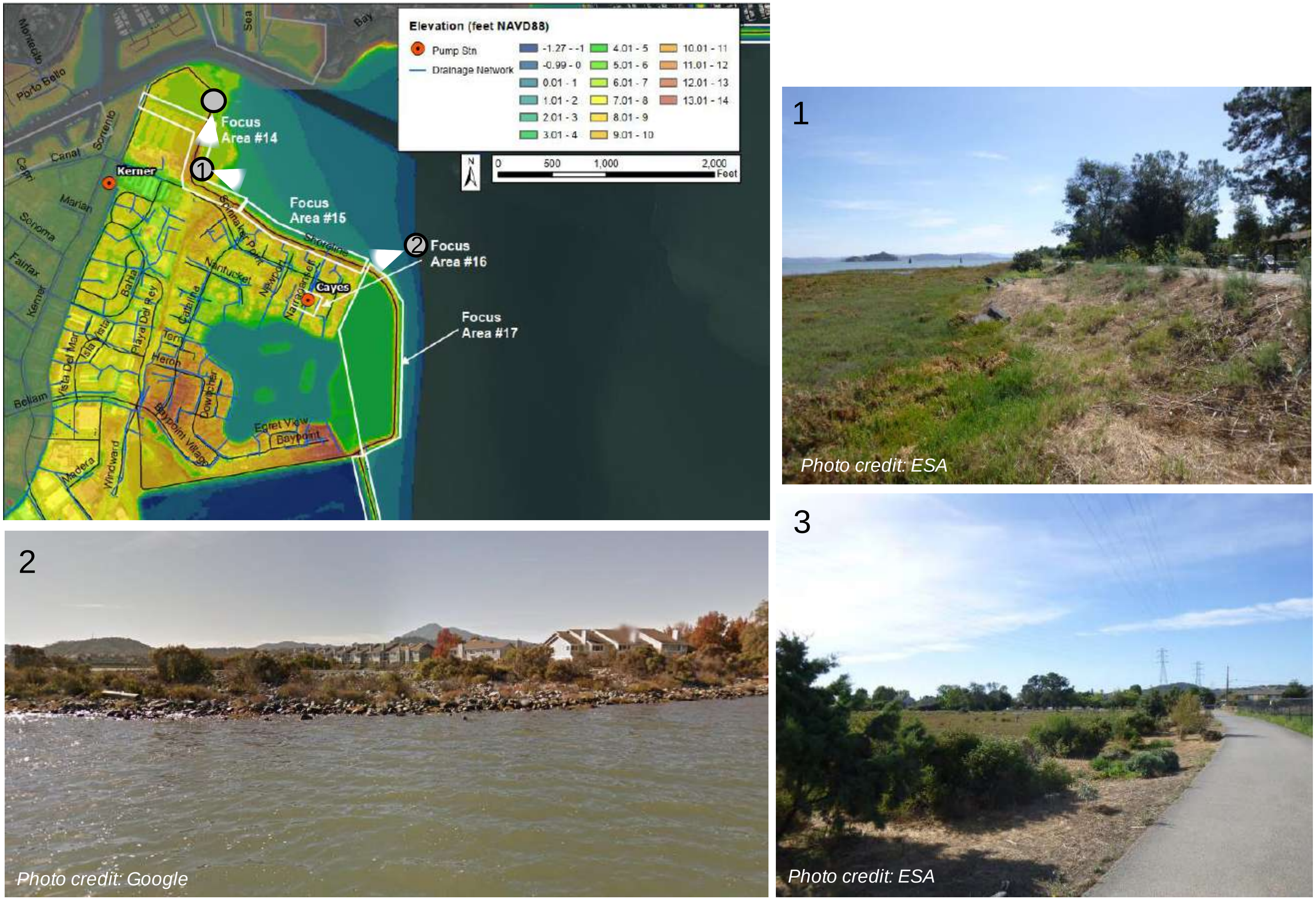
Focus areas along the southern shore of San Rafael Creek



SOURCE: ESA

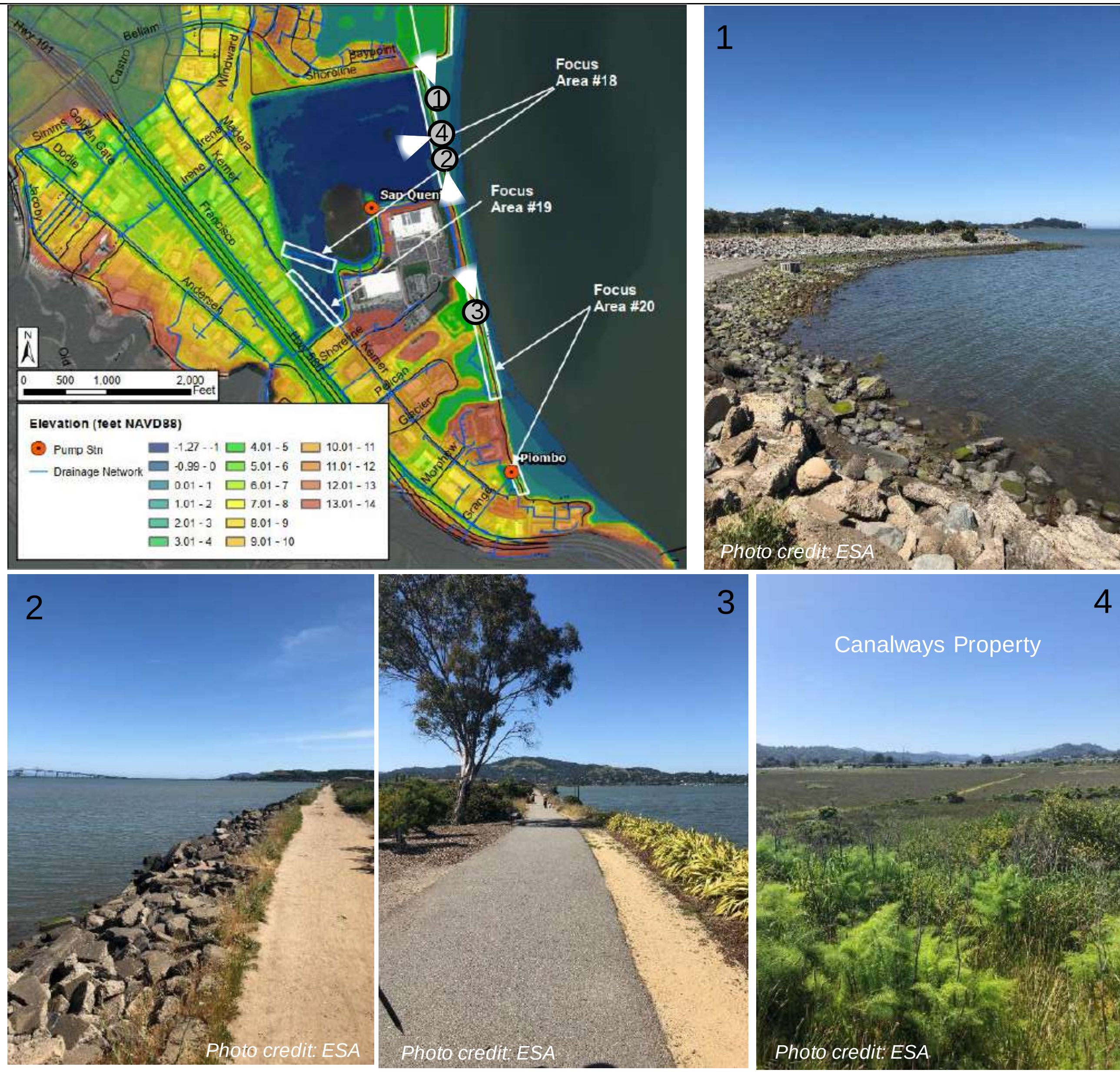
San Rafael SLR Vulnerability Study . D180140.00

Figure A11
Focus areas within the Las Gallinas region



SOURCE: ESA

Figure A12
Focus areas near Tiscornia Marsh

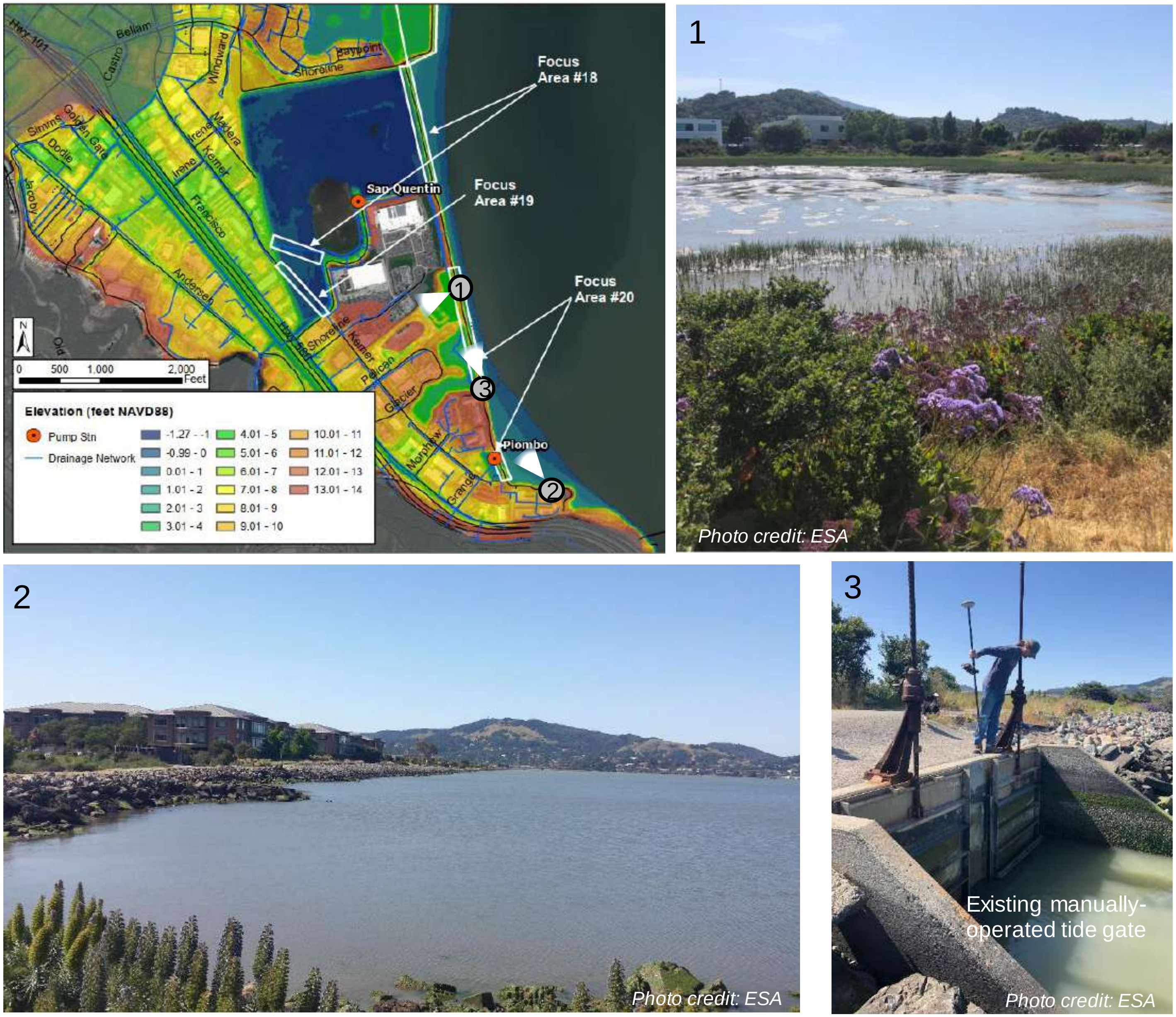


SOURCE: ESA

San Rafael SLR Vulnerability Study . D180140.00

Figure A13

Focus areas near Canalways



SOURCE: ESA

Figure A14
Focus areas near Piombo Marsh

Appendix B
Vulnerability Assessment

ESA

BVB Consulting LLC

San Rafael, CA Sea Level Rise Vulnerability Assessment

A Scenario-based analysis sea level rise and 100-year storm surge flooding along the shoreline

BRIDGIT VAN BELLEGHEM

Introduction

Climate change is affecting natural and built systems around the world. In the past century, the average global temperature has increased about 1.4°F, and average global sea level has increased 7 to 8 inches.[1] Locally, sea level at the San Francisco tide gauge has risen 8 inches over the past century. The two major causes of sea level rise are expanding warming oceans and land-based glacial and polar ice cap melt.[2]

According to the Marin County BayWAVE Vulnerability Assessment addressing sea level rise, the City of San Rafael is one of the most vulnerable jurisdictions in Marin County. Sea level rise will exacerbate the erosion, flooding, and storm impacts that already disrupt and damage San Rafael, leading to significant social, environmental, and economic impacts.

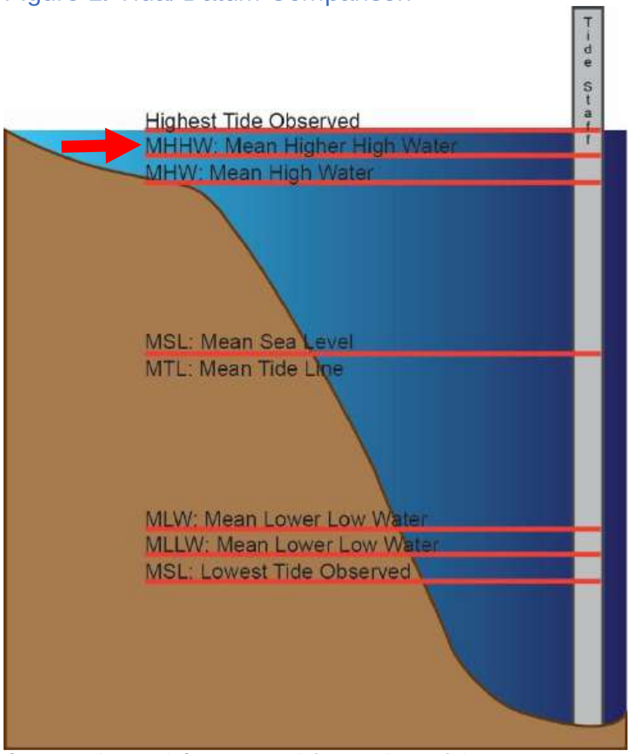
This assessment follows the BayWAVE assessment approach to refine potential flooding impacts from sea level rise on the City of San Rafael. This San Rafael Vulnerability Assessment seeks to provide context and estimates of the physical and fiscal impacts to shoreline over the coming decades. The data presented can be used to prioritize efforts, seek funding, and inform policy and development decisions. This Vulnerability Assessment is advisory and not a regulatory document or legal standard of review for action of San Rafael or other involved special government may take. Such actions are subject to the applicable local and state regulations.

Methods

Projecting and Mapping Sea Level Rise

Predicted Bay water levels used in this analysis are from the USGS Coastal Storm Modeling Systems (CoSMoS). CoSMoS scales down global and regional climate and wave models[3] and applies it to a 2010 digital elevation model (DEM) with 2-meter horizontal grid resolution elevations (North American Vertical Datum of 1988, NAVD88). CoSMoS references flood levels to mean higher high water (MHHW) tidal elevation. Mean higher high water is the average of the higher high-water level of each tidal day observed over the National Tidal Datum Epoch.[4,5] CoSMoS also provides the option to add higher water levels due to storm surges and sea level rise of different magnitudes, yielding up to 40 different possible scenarios.

Figure 1. Tidal Datum Comparison



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

CoSMoS does not incorporate flooding from upstream or draining from pump stations. The DEM does not account for shoreline improvements made after 2010. For example, portions of the Strand and Loch Lomond Marina were elevated to meet 2015

[1] 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.

[2] 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.

[3] 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]).

[4] 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 to obtain mean values (e.g., mean lower low water) for tidal data.

[5] 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.

FEMA standards, thus, the model and maps overestimate flood vulnerabilities in these areas. Finally, the model does not incorporate planned projects and assumes no action taken to prepare or adapt for sea level rise.

Selecting the Sea Level Rise Scenarios

Because of uncertainty in the magnitude and timing of future sea level rise[6], this analysis uses a scenario approach to assess a range of tidal, storm surge, and sea level rise exposures. Both typical tidal water levels (MHHW) and the 1% annual chance storm surge were considered. The sea level rise projected for the six scenarios in Table 1 align with the upper end of the ranges from the National Research Council (2012) for San Francisco and the medium-high risk aversion scenarios from OPC (2018). San Francisco region sea level estimates as follows:

- Scenarios 1 and 2 represent the near-term projection, 10 inches, projected to occur between 2030-2040
- Scenarios 3 and 4 represent the medium-term projection, 20 inches, projected to occur between 2050-2070
- Scenarios 5 and 6 represent the long-term projection, 60 inches, projected to occur between 2090-2140

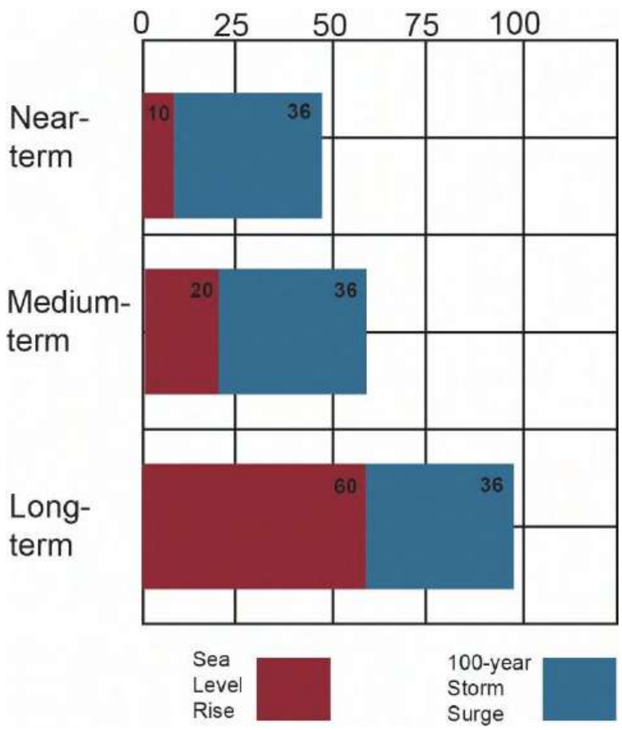
Table 1. Sea Level Rise & Storms Scenarios

Sea Level Rise Scenario		Term
1	MHHW + 10 inches SLR	Near 2030-2040
2	100-year storm + 10 inches SLR	
3	MHHW + 20 inches SLR	Medium 2050-2070
4	100-year storm + 20 inches SLR	
5	MHHW + 60 inches SRL	Long 2090-2140
6	100-year storm + 60 inches SLR	

Source: BayWAVE Vulnerability Assessment, 2017

Error! Not a valid bookmark self-reference. presents another view of the scenarios where the red lengths represent tidal MHHW flooding in sea level rise scenarios 1, 3, and 5, and the blue lengths represent the additional storm surge water level associated with a 100-year storm in scenarios 2, 4, and 6.

Figure 2. Scenarios' Associated Water Levels, in Inches



Source: BayWAVE Vulnerability Assessment, 2017

The 100-year storm surge was selected because it is a standard scenario typically used in Federal Emergency Management Agency (FEMA) mapping. A 100-year storm surge has one percent chance of being exceeded in a given year. Within the time frame of a 30-year mortgage, a 100-year storm has a nearly 30 percent chance of occurring.

Assessing Asset Flooding Vulnerability

As described in CalAdapt, sea level rise vulnerability is based on an asset's exposure, sensitivity, and adaptive capacity to higher high tides and bay surge threats. The assets identified as vulnerable for San Rafael in the BayWAVE process are represented here. The methods used in the BayWAVE Vulnerability Assessment (2017) are summarized as:

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

Available digitized assets were identified using MarinMap geographic data layers for roads, trails, parks, public facilities, utility districts, buildings, and parcels. Department of Fish and Wildlife provided fishing piers, marinas, and ports. Local utility data was provided by government agencies and the California Energy Commission. The absence of an asset does not imply that an asset is not vulnerable, as the lists here in are not exhaustive. Asset data layers were generated over several years and changes to the built environment may have occurred since the asset data was updated. Thus asset counts, and associated calculations, may be off.

To determine what could be exposed to sea level rise at MHHW and/or a 100-year storm surge, CoSMoS flood hazard layers and asset data points were overlaid in a geographic computer program. Asset data points within the geographic extent of the CoSMoS layers were marked as exposed.[7] BVB Consulting LLC compiled interviews with professional managers to determine if exposed assets would be sensitive and/or adaptable to:

- Flooding during annual highest tides and/or storm surges that cause nuisance flooding,
- Inundation at one high tide a day, several days a month, that causes chronic flooding,
- Erosion and other physical changes from higher high tides and storms,
- Saltwater intrusion, and/or
- Rising water table

without human intervention. [8, 9,10, 11]

Additionally, CoSMoS flood depth at 10 inch, three feet, and five feet MHHW layers were spatially joined with assets to determine average flood depths for scenarios 1, 3, and 5 respectively. Flood depth was calculated by converting GIS vector data to raster cells, each with a flood level. For buildings, all cells underlying its footprint are averaged. Where buildings are presented as a neighborhood, a maximum building flood depth is listed. Where data is available, additional analysis summarizes how many buildings could flood in one-foot flood depth intervals ranging from 0-6 feet for scenarios 1, 3, and 5. For roads, a high and low value was calculated on the flooded line segment. Exposed road mileage is road miles. Note that flood depth data is not available for all areas and may not match exposure figures.

Additional calculations were completed using the FEMA HAZUS parameters to determine the potential monetary losses from storm damages. Losses from minor damage range from $5,000-17,000, moderate damage are assessed at $17,001+, and finally, complete loss of value if a building is destroyed.[12, 13]

Understanding full physical vulnerability requires, at a minimum, onsite inspections of utilities and base floor elevations for each building as the CoSMoS data does not account for raised floor elevations. Recording building base floor elevations is beyond the scope of this report. The city may consider doing such an assessment to determine how deep of flood waters each structure could withstand and to inform individual property elevations and the regulations that guide them.

Coastal Flood Vulnerabilities in San Rafael

Map 1 shows the furthest inland extent of the six sea level rise scenarios. Most built assets within these areas are vulnerable to 100-year storm surge and/or tidal flooding before 2100. San Rafael is the most vulnerable city in Marin County to sea level rise with respect to both land area and population affected.

The vulnerable places and assets reported in this assessment are divided into near-, medium-, and long-term time frames, each presenting potential tidal flooding impacts and storm surge impacts. Each

[7] Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco. 2014. Appen 5. OneSF Checklist

[8] 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

[9] 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

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

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

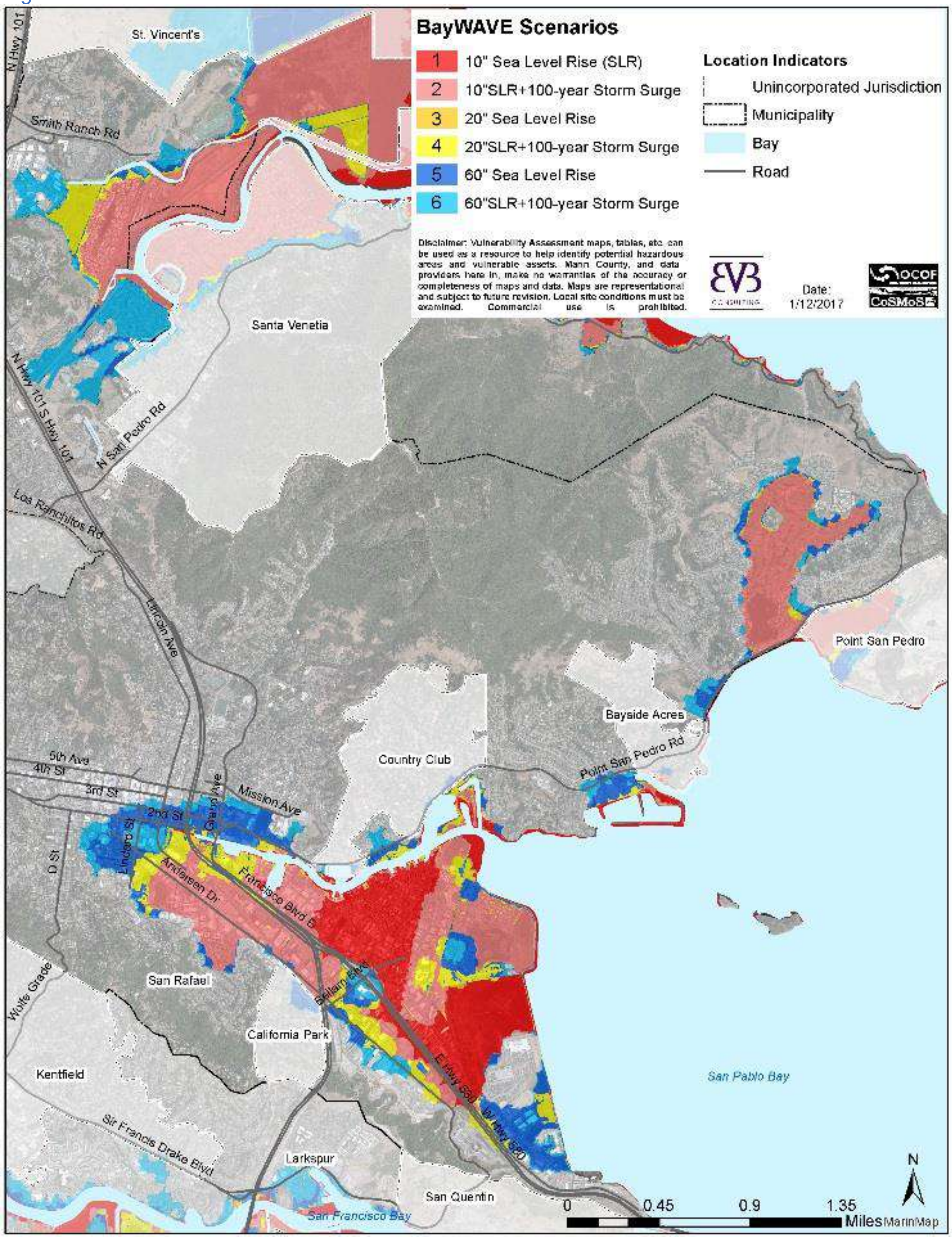
[12] Federal Emergency management Agency (FEMA) Website. Hazus. Last updated July 8, 2015. http://www.fema.gov/hazus.

[13] 2016 dollars

scenario is cumulative with the previous with the exception scenarios 2 and 3, where the extent of storm surge flooding by 2030 exceeds the extent tidal flooding could reach by 2050 in most locations. Areas flooded by 2030 experience more frequent and more severe flooding as sea levels rise to five feet.

Within each time frame, vulnerable areas are divided into sub-areas. In central San Rafael these are the Canal, Kerner, San Pedro (include Montecito and Happy Valley neighborhoods), Shoreline, Anderson/Francisco West (includes Picnic Valley and Bret Harte neighborhoods), and Downtown (includes Gerstle Park neighborhood). Near Point San Pedro is the Peacock Gap neighborhood, and in northern San Rafael the Las Gallinas area.

Map 1. San Rafael Sea Level Rise and 100-year Storm Surge Scenarios



Source: CoSMoS, Marin Map

Near-term Vulnerable Assets

In the near-term, sea level rise and storm surge impacts are concentrated in the low-lying areas in central and northern San Rafael. Several models predict flooding well beyond the shoreline into the Canal and Kerner areas, compromising multi-family housing, commercial, industrial, and recreational lands. A 100-year storm surge could also impact portions of the Anderson and Las Gallinas areas.

Tidal Flooding (MHHW) + 10 inches SLR

Tidally flooded lands at ten inches MHHW account for 449 acres, or three percent of San Rafael's land area. Affected areas are either next to the bay, estuaries, and/or surrounded by marshes bayside of Interstate 580 and US Highway 101 in central San Rafael Canal, Kerner, and San Pedro areas.

On the southern banks of the San Rafael Canal, water could reach land on both sides of the Harbor Center Marina and Harbor 555. Traveling towards the bay, tidal flooding can affect properties between San Rafael Creek and Canal Street starting at Hoag Street. These buildings include commercial and residential uses, including several apartment buildings. About midway through the block between Hoag Street and Medway Road. Kerner Boulevard marks the limit of tidal flooding north of Irene Street in the Canal area. However, at Irene Street, flooding originating from the shoreline marsh south of Spinnaker Point merges with flooding from the Canal area, impacting the area between Francisco Boulevard East and the bay to the Shoreline Path access off Francisco Boulevard East to the south at the border of the Shoreline area.

The Canal area population is about 70 percent Central and South American origin. Residents are young with larger families, lower incomes, and primarily renters compared to the rest of the city.[14] Almost one-half of residents are housing cost burdened,[15] are less likely to own cars, and more likely to ride transit.[16] These residents are not only disproportionately vulnerable to sea level rise, they will also be the first to experience the destructive forces of storm surges and higher high tides. Tidal flooding also jaunts inland beyond Francisco Boulevard East, over State Route 580 and into the rear portions of development facing Anderson Drive in the Anderson area.

As shown in Table 2, the impacted land in the Canal, Kerner, San Pedro, and Anderson a reas is broken up into 492 residential, 132 commercial, and 42 industrial parcels. These parcels contain 410 buildings, or two percent of all buildings in San Rafael. Many of these parcels contain large numbers of low-income renter households. In fact, 78 parcels covering 34 acres provide apartment homes in the Canal area. Bahia Vista Elementary School, San Rafael Fire Station 54, the Marin County Health Innovation Campus, San Rafael Municipal Marina are some of the public facilities that could flood.

Table 2. Vulnerable Parcels, Scenario 1: MHHW + 10" SLR

Land Use	#	Acres	%
Commercial	**132**	**187**	**11**
Improved	116	98	-
Unimproved	16	89	
Industrial	**48**	**22**	**17**
Residential	**492**	**46**	**3**
Multi-Family Improved	78	34	-
Multi-Family Unimproved	2	0.2	
Single Family Attached	382	5	
Single Family Improved	20	4	
Single Family Unimproved	8	3	
Tax Exempt	35	59	-

Source: MarinMap, CoSMoS

Table 3. Building Flood Depth Estimates, Scenario 1: MHHW + 10" SLR

Flood Depth (feet)	# of Buildings
0.1-1	90
1.1-2	140
2.1-3	180
3.1-4	250
4.1-5	3
5.1-6	1

[14] Census 2010

[15] Human Impact Partners. 2013. Community Health Needs Assessment Sub-County Health Indicators.

[16] Census 2010

Flood Depth (feet)	# of Buildings

Source: MarinMap, CoSMoS

The analysis presented in Table 3 divides vulnerable buildings into one-foot flood depth intervals. Most vulnerable buildings could experience flood depths less than or equal to three feet.

As see in Table 4, major roads potentially impacted by 0.8 ft sea level rise and tidal flooding if there were no levees are Bellam Boulevard, Francisco Boulevard East, Kerner Boulevard, Grand Avenue and Irwin Street. In the San Pedro area, roads bayside of Pt. San Pedro Road, such as Mooring Road, could also flood at MHHW. In total, eight road miles could experience tidal flooding, becoming impassable at least once, if not twice, a day for several hours. Drivers that venture through the salt water could damage their vehicle's mechanical and electronic systems.

US Highway 101 on- and off-ramps could flood along most of its course through the city center and at low spots of US Highway 101 where it connects with State Route 580 south of San Rafael Harbor. Preliminary conversations indicate that Caltrans is aware of the existing and arising concerns in San Rafael.17

The San Rafael Airport could experience flooding in low-lying areas. Several miles of trails, including the Bay Trail and Shoreline Path, McNear's Beach, Gallinas Creek, Pickleweed Park, and Starkweather Shoreline Park could anticipate impacts at the shoreline edges.

Utility assets, such as transmission lines, wires above and below ground, and pipelines below ground in the affected areas are vulnerable in the following ways:

- Poles and pipes could sink due to subsidence,
- Underground pipes can bend from compounding pressure forces between the water and road, or get damaged if roads erode or collapse,
- Saltwater inflow and infiltration can cause inefficiencies in wastewater treatment,
- Flood waters could prevent employees from reaching work sites.

[17] Sea Level Rise Vulnerability Assessment Interview. Caltrans. April 30, 2015. J. Peterson. D. Fahey. Marin County Development Agency. BVB Consulting LLC.

Table 4. Roads Flooded, Scenario 1: MHHW + 10” SLR

Scenario 1: Tidal Flooding 8 road miles	
Canal	**San Pedro**
Hwy 101 [C]	Bay Harbor Wy [P]
Hwy 580 [C]	Mooring Rd [L]
Bellam Blvd [L]	Sea Wy [L]
Francisco Blvd E [L]	Summit Ave [L]
Grand Ave [L]	**Kerner**
Irwin St. [L]	Hwy. 580 [C]
Canal St. [L]	Bellam Blvd. [L]
Alto St. [L]	Francisco Blvd. E [L]
Amalfi Pl. [L]	Kerner Blvd. [L]
Belvedere St. [L]	Bahia Pl. [L]
Capri Ct. [L]	Bahia Wy. [L]
Castro Ave. [L]	Bahia Cir. [L]
Charlotte Dr. [L]	Irene St. [L,P]
Elaine Wy. [L]	Market St. [L]
Fairfax St. [L]	**Las Gallinas**
Front St. [L]	Smith Ranch Airport Rd. [L]
Larkspur St. [L]	
Lido Ln. [L]	
Lisbon St. [L]	
Louise St. [L]	
Medway Rd. [L]	
Mill St. [L]	
Novato St. [L]	**Anderson**
Portofino Rd. [L]	Golden Gate Dr. [L]
Shoreline Path	
Sonoma St. [L]	
Sorrento Wy. [L]	
Tiburon St. [L]	
Verdi St. [L]	
Vivian St. [L]	

M = Marin County; C = State; L = Local; P = Private.
Source: MarinMap, CoSMoS

Table 5 lists the flooding potential for several critical assets mentioned across all sectors of daily life from deepest to shallowest levels of MHHW flood waters measured at that asset. These assets could flood at least once a day several days a month.

Table 5. Flood Inundation Depths for Representative Assets Vulnerable, Scenario 1: MHHW + 10” SLR

Asset	Scenarios		
	Near-term	Medium-term	Long-term
	1	3	5
Canal area Bay Trail & open space	10’3”	11’1”	25’4”
McInnis Park	7’6”	8’6”	10’6”
Starkweather Shoreline Park	5’4”	6’	16’3”
Pickleweed Park	5’	5’8”	8’9”
Hwy. 580 East	0-4’	0-4’10”	4”-7’8”
Kerner Blvd.	0-4’	0-4’7”	8”-7’5”
Francisco Blvd. E	0-3’10”	0-4’7”	1’-7’5”
Bellam Blvd.	0-3’5”	0-4’	0-7’3”
Canal St.	0-3’4”	1’2”-4’2”	2’-7’11”
Bahia Way	2’-3’3”	2’4”-3’11”	5’2”-6’10”
Hwy. 580 West	1”-2’10”	1”-3’7”	1”-6’5”
Bay Trail	0-2’3”	0-3’	0-10’3”
Fire Station 54	1'6"	2'7"	6'7"
San Rafael Yacht Harbor	1’2”	4’	10’4”
Municipal Harbor	1’	2’	6’
Lowrie Yacht Harbor	9”	3’7”	8’5”
Bahia Vista Elem. School/ Trinity Preschool	8”	2’3”	4’8”
Hi-Tide Boat	6”	3’4”	8’5”
Marin Yacht Club	1”	1’6”	3’9”
Health Innovation Campus/Clinics	1”	1’3”	3’
~~**San Rafael Canal**~~	~~Water resource~~		
Marin Lagoon	Water resource		

Source: MarinMap, CoSMoS

100-year Storm Surge + 10 inches SLR

A 100-year storm surge combined with ten inches of sea level rise, scenario 2, could flood, either in addition to or temporarily, three times as many acres than just tidal flooding alone. Roughly 1,300 acres, 1,940(10%) buildings, and 22 road miles could experience 100-year storm surge flooding. Storm surges can cause up to 3 feet of flooding. In addition to areas tidally flooded at 10 inches of sea level rise, areas flooded under 100-year storm surge conditions are:

- All areas that experience 100-year storm surge flooding in scenario 2
- Canal south to Shoreline area- Lands from Grand Avenue to Shoreline Parkway (about 2 miles south) could flood leaving a few temporary islands including Grand Ave to Bay Street, Spinnaker Point west of Baypoint Lagoon and near Shoen Park, Marin County Health Clinics, Mi Pueblo Food Center, and Target and Home Depot properties,
- San Pedro area- Along the San Rafael Canal at the Marin Yacht Club on Summit Avenue and Marina Way, and ends of Sea Way, Porto Bello Drive, and Harbor View Court, Mooring Road, and 3rd Street just before Embarcadero Way,
- Anderson area- a greater extent over and under State Route 580, US Highway 101, all of Francisco Boulevard West shopping and industrial areas into the Bret Harte neighborhood, Woodland Avenue up to Davidson Middle School, and development from State Route 580 to Anderson Drive, leaving only Simms Island dry,
- Peacock Gap area- Homes adjacent to San Pedro Lagoon and Peacock Gap golf course holes 5, 12, 14, 15, 16, and
- Las Gallinas area- Contempo Marin neighborhood and San Rafael Airport.

Of note, the Golden Gate Transit and Marin Airporter facilities and several Francisco Boulevard West shopping centers could flood. In addition, two of San Rafael's historic resources, the Litchfield Sign and French Quarter could be experience flooding.

If all the buildings exposed under this scenario are damaged, a minimum of $9.2 million in damages could occur. Damages could exceed $31.4 million if damages are more severe. Finally, assuming an average assessed value of $460,750/building, over $850 million (2016 dollars) in property could be lost.

Table 6. Roads Flooded in Near-Term Scenario 2

Scenario 2: 22 road miles	
Kerner	**Canal**
Roads in scenario 1	Roads in scenario 1
Bahia Ln. [L]	Hoag St. [L]
Bedford Cv. [L]	
Catalina Blvd. [L]	**Las Gallinas**
Duxbury Cv. [L]	Roads in scenario 1
Falmouth Cv. [L]	Acadia Ln. [L]
Gloucester Cv. [L]	Bryce Canyon Rd. [L]
Hingham Cv. [L]	Carlsbad Ct. [L]
Isla Vista Ln. [L]	Crater Lake Wy. [L]
Loma Vista Pl. [L]	Glacier Wy. [L]
Nantucket Cv. [L]	Isle Royale Ct. [L]
Narragansett Cv. [L]	McNear Dr. [L]
Newport Wy. [L]	Mesa Verde Wy. [L]
Playa Del Rey [L]	Olympic Wy. [L]
Plymouth Cv. [L]	Shenandoah Pl. [L]
Rockport Cv. [L]	Tahoe Pl. [L]
Salem Cv. [L]	Teton Ct. [L]
Spinnaker Point Dr. [L]	Yellowstone Ct. [L]
Vista Del Mar [L]	Zion Ct. [L]
Windward Wy. [L]	
San Pedro	**Anderson**
Roads in scenario 1	Roads in scenario 1
Marina Wy. [L]	Baxters Ct. [P]
Porto Bello Dr. [L]	Billou St. [L]
Pt. San Pedro Rd. [L, C]	Bret Ave. [L]
	De Luca Pl. [L]
Peacock Gap	Dolores St. [L]
Peacock Dr. [L]	Du Bois St. [L]
Lagoon Pl. [L]	Duffy Pl. [L]
Lagoon Rd. [L]	Gary Pl. [L]
Riviera Dr. [L]	Jordon St. [L]
San Marcos Pl. [L]	Lincoln Ave. [L]
Shoreline	Lovell Ave. [L]
Shoreline Pkwy. [L]	Rice Dr. [L]
	Woodland Ave. [L]

M = Marin County; C = State; L = Local; P = Private.
Source: Marin Map, COSMOS

Table 6 lists the roads that could suffer temporary storm surge flooding. Recent precedent indicates that temporary could mean days at a time, especially if coinciding with king tides. Roads that are named below would only flooding under storm conditions. San Rafael Municipal Marina and several private marinas could experience flooded facilities if barrier walls are not adequately elevated or if pier and dock pilings are not tall enough for the highest water level boats could become dislodged and damaged.

Utility assets in the affected areas would now also be vulnerable to storm damages to roads. Above ground utilities are especially vulnerable during storms due to high water and wind forces. floating debris, high winds, and falling and/or uprooting trees. In addition, several of these areas depend on storm water pump stations to remove stormwater flowing down from the uplands. Stormwater combined with higher tides and storm surges would require the pumps to work harder, increasing wear and the potential to fail.

Medium-term Vulnerable Assets

In the medium-term, impacts to the areas and assets affected by high tides in the near-term worsen. Water levels are higher, and flooding reaches properties more often. Additionally, most areas that previously flooding under 100-year storm surge conditions under scenario 2 could experience tidal flooding at MHHW.

Tidal Flooding (MHHW) + 20 inches SLR

At this level of flooding, nearly 900 acres could be wet at MHHW. These tidally flooded lands contain 883 residential, 234 commercial, and 104 industrial parcels with 1,088 (16%) buildings. These figures indicate 20 percent of commercial parcels and an alarming 40 percent of industrial parcels in central San Rafael areas would be vulnerable to tidal flooding. Most vulnerable buildings could experience inundation depths up to three feet, though some buildings could experience up to six feet of tidal flooding.

In addition to the areas that experienced tidal flooding in scenario 1 and 100-year storm surge flooding in scenario 2, the following could now experience flooding at MHHW:

- Canal area- Pickleweed Park up to the Albert J. Boro Community Center,
- Shoreline area- Starkweather Shoreline Park,
- San Pedro area- Montecito buildings on Irwin, 2^{nd}, and 3^{rd} Streets including gas stations, grocery stores, offices, and several businesses; east of the Montecito Shopping Plaza and over San Pedro Road fronting San Rafael High School,
- Downtown area- Up to Albert Park at the edges of Gerstle Park neighborhood
- Peacock Gap area- Point San Pedro Road at Peacock Drive extending over the lower portion of Peacock Gap Golf Course and more of the homes adjacent to it, and
- Las Gallinas area- Contempo Marin.

Table 7. Scenario 3: Vulnerable Parcels

Land Use	#	Ac.	%
Commercial	**224**	**375**	**19**
Improved	213	267	-
Unimproved	21	108	
Industrial	**104**	**51**	**37**
Improved	**97**	**50**	-
Unimproved	**7**	**1**	
Residential	**883**	**88**	**6**
Multi-Family Improved	104	44	-
Multi-Family Unimproved	3	0.6	
Single Family Attached	634	10	
Single Family Improved	127	31	
Single Family Unimproved	12	3	
Tax Exempt	75	203	

Source: MarinMap, CoSMoS

Table 8. Flood Depth Estimates at MHHW + 3 ft SLR

Flood Depth (feet)	# of Buildings
0.1-1	212
1.1-2	251
2.1-3	206
3.1-4	102
4.1-5	9
5.1-6	1
6.1-7	212

Source: MarinMap, CoSMoS

Table 9. Scenario 3: Vulnerable Roads

Scenario 3: 15 road miles
Roads in scenario 1 Francisco Blvd W [L]

L = Local
Source: MarinMap, CoSMoS

Francisco Boulevard West is the only new addition to roads vulnerable to tidal flooding in this scenario. The roads identified under scenario 1 would become impassable for longer periods with deeper waters. Emergency services will continue to face challenges accessing those in need in vulnerable areas, especially service from Fire Stations 54, 52 and 55.

Table 10 provides flood depths at MHHW for example vulnerable assets in scenario 3.

Table 10. Scenario 3: Example Vulnerable Assets

Asset	Scenarios		
	Near-term	Medium-term	Long-term
	1	3	5
Beach Park		8'11"	11'10"
Peacock Gap Park		6'3"	9'
Grand Ave.		0-6'	7"-9'
Andersen Dr.		0-5'	3"-8"
Francisco Blvd. W		0-4'9"	1'8"-9'5"
Peacock Dr.		0-4'	9"-6'8"
SMART Rail		1'8"-3'9"	1'2"-6'8"
Loch Lomond Marina		3'7"	9'7"
Peacock Gap homes		1"-3'6"	2"-8'9"
San Rafael Airport		3'5"	8'10"
Canal Neighborhood		1"-3'	2"-7'8"
Marin Lagoon		5"-2'5"	1'-6'
US 101 North		0-2'5"	6"-5'3"
Davidson Middle School		2'3"	5'9"
Pt. San Pedro Rd.		0-2'2"	4"-5'10"
San Rafael Yacht Club		2'2"	5'7"
US 101S off ramp		0-2'	1'4"-5'
GGBHTD Depot/ Headquarters		1'8"-2'	4'2"-5'
Downtown		1"-1'3"	3"-3'3"
PG&E Office/ Yard		1'2"	3'
Pickleweed Park facilities		1'2"	3'
Montecito Plaza		1'	2'3"
Transit Center		11"	2'5"
Marin Community Clinic		10"	3'8"
San Rafael High School		10"	2'
3rd Street		5"	10"-3'10"

Source: Marin Map, COSMOS

100-year Storm Surge + 20 inches SLR

Roughly 1,500 acres, 2,100 (11%) buildings, and 27 road miles could be vulnerable at three feet of sea level rise and a 100-year storm surge is the already vulnerable areas. Recovering from these storm damages would be costly. According to the

FEMA Hazus model, minor damage to buildings could reach almost $11 million, while moderate damage could exceed $35 million. Destruction would cost nearly $1 billion. Storm surge flooding would flood all previously identified areas and reach:

- Downtown area- Further downtown to C Street and in to the Gerstle Park neighborhood,
- San Pedro area- Further into Montecito to nearly 4th Street, including the Montecito Shopping Plaza, along San Pedro Road after Country Club (unincorporated), north of Marin Yatch Club, and just after Bayside Acres (unincorporated) in Glenwood, and
- Peacock Gap area- Larger segment of San Pedro Road, golf course, and adjacent homes.

Table 11 lists the roads that could suffer in scenario 4. Roads identified by name would only experience flooding in combination with storm surges, avoiding tidal flooding at this water level.

Table 11. Scenario 4: Vulnerable Roads

Scenario 4: 27 road miles	
Canal	**San Pedro**
Roads in scenarios 1-3 Yacht Club Dr [P]	Roads in scenarios 1-3 3rd St [L] Aqua Vista Dr [L] Loch Lomond Dr [L] Royal Ct [L]
Kerner	
Roads in scenarios 1-3 Baypoint Dr [L] Baypoint Village Dr [L] Egret View [L] Pelican Wy [L]	
Anderson	**Peacock Gap**
Simms St [L] Dodie St [L] Lindaro St [L]	Roads in scenarios 1-3 Biscayne Dr [L]
	Las Gallinas
	Roads in scenarios 1-3
	Downtown
	2nd St [L] 3rd St [L]

M = Marin County; C = State; L = Local; P = Private.
Source: Marin Map, COSMOS

Long-term Vulnerable Assets

By 2100, significant portions of San Rafael could experience tidal flooding, and an even larger area could experience 100-year storm surge flooding. The areas closest to the shoreline could become undevelopable without intervention, and in some cases relocation may be warranted.

During a storm-surge, these areas experience significantly more flooding, and could reach further inland, especially in the Gerstle Park and Marin Lagoon neighborhoods.

Tidal Flooding (MHHW) + 60 inches SLR

At five feet of sea level rise, 1,856 acres, roughly 13 percent of San Rafael's land area, could be exposed to tidal flooding. At this level of flooding, 40 percent of commercial and 60 percent of industrial parcels in the city could experience tidal flooding and potentially become unusable. Nearly 15 percent of residential parcels could flood, affecting thousands of homes, many of them the most affordable neighborhoods. For instance, 136 parcels on 54 acres of multi-family housing could experience tidal flooding.

Table 12. Parcels Vulnerable to Tidal Flooding At 5 feet of Sea Level Rise

Land Use	#	Ac.	%
Commercial	**473**	**676**	**40**
Improved	419	527	
Unimproved	54	149	
Industrial	**170**	**88**	**61**
Improved	153	83	
Unimproved	17	5	
Residential	**1,798**	**196**	**12**
Mobile Home	154	1	
Multi-Family Improved	136	54	
Multi-Family Unimproved	4	1	
Single Family Attached	1,084	38	
Single Family Improved	390	76	
Single Family Unimproved	27	26	
Tax Exempt	182	65.5	

Source: MarinMap, CoSMoS

Table 13. Flood Level Estimates* at 5 feet MHHW

Flood Depth (feet)	# of Buildings
0.1-1	108
1.1-2	228
2.1-3	346

Flood Depth (feet)	# of Buildings
3.1-4	548
4.1-5	401
5.1-6	360
6.1-7	215
7.1- 8	190
8.1-9	26

Source: Marin Map, COSMOS

Nearly 2,500 buildings, or 13 percent of buildings in San Rafael, could face some level of tidal flooding. More than 600 buildings could flood with up to three feet, more than 1,000 could flood with between three and six feet, and more than 400 could flood with up to nine feet of saltwater at mean higher high water. Buildings that flood to these extremes on a regular basis are not useable.

High tides would bring chronic flooding all areas and neighborhoods presented under previous tidal and 100-year storm surge scenarios and could extend further in to the low-lying inland areas in central and northern San Rafael and Peacock Gap. Areas that could experience tidal flooding that did not experience it in scenario 3 include:

- Kerner area- Housing on Spinnaker Point,
- Anderson area- Northern edge of Picnic Valley at Woodland Avenue,
- Downtown area- Downtown and Gerstle Park from A to C streets to the west and nearly Bayview Street to the south, leaving a small island of development west of San Rafael Creek to where A Street turns into Anderson Drive, US Highway 101 when Mahon Creek overflows its banks,
- San Pedro area- Up to 4th Street, over Point San Pedro Road into San Rafael High School, north of Loch Lormond Marina (may have been resolved in 2016 by elevation increases to property),
- Peacock Gap area- over Point San Pedro Road from Glenwood to Chapel Cove Road, and
- Las Gallinas area- McInnis Park soccer fields.

lists the roads and Table 15 lists a few assets and the flood depths that could flood at MHHW on a regular basis in scenario 5 within these areas.

Table 14. Scenario 5: Vulnerable Roads

Scenario 5: 35 road miles	
Canal	**San Pedro**
Roads in scenarios 1-4 Lido Ln [L] **Kerner** Roads in scenarios 1-4 Avocet Ct [P] Dowitcher Wy [P] Glacier Pt [L] Grange Ave [L] Morphew St [L] Piombo Pl [L] Portsmouth Cv [L] Tern Ct [P] Turnstone Dr [P]	Roads in scenarios 1-4 4th St [L] Embarcadero Wy [L] Leith Ln [L] Lochinvar Rd [L] Mary St [L] Park St [L] Summit Ave [L] Surfwood Cir [L] Union St [L] **Peacock Gap** Roads in scenarios 1-4 Chapel Cove Dr [L] Knight Dr [L] Peacock Ln [L] Riviera Pl [L] Silk Oak Cir [L]
Anderson	**Downtown**
Roads in scenarios 1-4 Albert Park Ln [L] Jacoby St [L] Warner Ct [L] **Las Gallinas** Roads in scenarios 1-4	Roads in scenarios 1-4 A St [L] B St [L] Hetherton St [L] Brooks St [L] Cijos St [L] Mission Ave [L] Lootens Pl [L] Ritter St [L]

M = Marin County; C = State; L = Local; P = Private.
Source: Marin Map, COSMOS

Table 15. Scenario 5: Example Vulnerable Assets

Asset	Scenarios		
	Near-term	Medium-term	Long-term
	1	3	5
SMART rail	-	-	1”-10’3”
Lincoln Ave.	-	-	10”-7’4”
Schoen Park	-	-	4’2”
4th St.	-	-	1’-3’5”
2nd St.	-	-	1’-3’4”
Ritter Clinic	-	-	2’10”
Hetherton St.	-	-	1’4”-2’4”
Marin County Emergency Services	-	-	2’2”
Peacock Ln.	-	-	1’4”-1’11”

Source: MarinMap, CoSMoS

100-year Storm Surge + 60 inches SLR
By scenario 6, 2,120 acres could be exposed to flooding, and all but about 300 acres would also experience tidal flooding. This flooded area in central San Rafael contains 75 percent of San Rafael's industrial parcels. Moreover, about 3,250 existing buildings (18%) could experience flood damage. Many could expect at least 1 to 3 feet of storm surge flooding. Downtown, buildings are older and not reinforced to withstand flooding. These buildings are primarily mixed-use, with businesses and housing, or commercial. Most single-family homes in the low-lying areas of San Rafael are one- and two-story homes, built in the Victorian era, the earlier part of the 20th century, post-WWII, with some modern homes interspersed and concentrated along the shoreline.[18]

FEMA Hazus post-disaster cost estimates for damage to buildings and their contents estimates that if all the buildings vulnerable in scenario 6 experience minor damage up to $16 million in damages could occur. If all these buildings were to be destroyed, the worst possible outcome, up to $1.5 billion (2016 dollars) in assessed structural value could be lost. By the time these impacts occur, the values would likely be higher, especially market value.

Areas that could experience flooding under this scenario that avoided flooding under previous scenarios are:

- San Pedro area- After Country Club over Pt. San Pedro Road south of Marin Boulevard,
- Downtown area- Bayview Street in Gerstle Park
- Anderson area- further into the Bret Harte and Picnic Valley neighborhoods.
- Las Gallinas area- Marin Lagoon and the commercial light industrial area north of Contempo Marin

lists the roads that could experience nuisance flooding in scenario 6. Named roads would only flood under storm surge conditions in this time period. Those that fall under previous scenarios have already experienced flooding under the previous scenarios.

Table 16. Scenario 6: Vulnerable Roads

Scenario 6: 41 road miles	
Canal	**San Pedro**
Roads in scenarios 1-5	Roads in scenarios 1-5 Loma Linda Rd. [L] Main Dr. [L] San Pedro Cv. [P]
Kerner	
Roads in scenarios 1-5 Newport Wy. [L]	**Peacock Gap**
Downtown	Roads in scenarios 1-5 Milano Pl. [L] Riviera Manor [L]
Roads in scenarios 1-5 Bayview St. [L] C St. [L] Commercial Pl. [L]	
Anderson	**Las Gallinas**
Roads in scenarios 1-5 Octavia St. [L] Taylor St. [L] Willow St. [L]	Roads in scenarios 1-5 Smith Ranch Rd. [L] Bridgewater Dr. [L] Mariners Cir. [L] Mark Dr. [L] McInnis Pkwy. [L] Mitchell Blvd. [L] Waterside Cir. [L] Paul Dr. [L] Sandpiper Ct. [L] Shores Ct. [L]

M = Marin County; C = State; L = Local; P = Private.
Source: Marin Map, COSMOS

This level of flooding would be highly destructive and devastating to thousands of residents, business owners, and workers who depend on the roads, buildings, and utilities in the vulnerable areas.

[18] BCDC. March 2015 Stronger Housing Safer Communities. Strategies for Seismic and Flood Risk. Summary Report. San Rafael Profile: http://resilience.abag.ca.gov/wp-content/documents/housing/San%20Rafael%20Community%20Profile_final_v2.pdf

Appendix C
Cost Estimates

Measure BF-2

Raise levee to FEMA-accredited level

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Raise flood wall	1600	LF	$1,000	$1,600,000
Contingency				30%	$480,000
Subtotal: Construction					$2,080,000

Other Costs

Design	20%	$416,000
Environmental Compliance & Permitting	20%	$416,000
Project Management	2%	$41,600
Construction Admin/Inspection	2%	$41,600
Project Contingency	10%	$208,000

Total cost	**$3,200,000**

Measure BF-3

Raise levee to FEMA-accredited level

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Raise shoreline levee	1600	LF	$1,000	$1,600,000
Contingency				30%	$480,000
Subtotal: Construction					$2,080,000

Other Costs

Design	20%	$416,000
Environmental Compliance & Permitting	20%	$416,000
Project Management	2%	$41,600
Construction Admin/Inspection	2%	$41,600
Project Contingency	10%	$208,000

Total cost	**$3,200,000**

Measure BF-5

Raise portions of Kerner Dr to prevent flooding within Target and Piombo marshes

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Raise shoreline levee	4000	LF	$1,000	$4,000,000
Contingency				30%	$1,200,000
Subtotal: Construction					$5,200,000

Other Costs

Design	20%	$1,040,000
Environmental Compliance & Permitting	20%	$1,040,000
Project Management	2%	$104,000
Construction Admin/Inspection	2%	$104,000
Project Contingency	10%	$520,000

Total cost	**$8,000,000**

Measure CS-1

Raise low-lying portion of shoreline

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Raise shoreline	50	LS	$1,000	$50,000
Contingency				30%	$15,000
Subtotal: Construction					$65,000

Other Costs

Design	20%	$13,000
Environmental Compliance & Permitting	20%	$13,000
Project Management	2%	$1,300
Construction Admin/Inspection	2%	$1,300
Project Contingency	10%	$6,500

Total cost	**$100,000**

Measure CN-1

Install flood walls on Mahon Creek from San Rafael Canal to B St

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Install new floodwall	6600	LF	$2,000	$13,200,000
Contingency				30%	$3,960,000
Subtotal: Construction					$17,160,000

Other Costs

Design	20%	$3,432,000
Environmental Compliance & Permitting	20%	$3,432,000
Project Management	2%	$343,200
Construction Admin/Inspection	2%	$343,200
Project Contingency	10%	$1,716,000

Total cost	**$26,400,000**

Measure CN-2

Install flood wall on Irwin Creek from San Rafael Canal to Mission Ave

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Install new floodwalls	2800	LF	$2,000	$5,600,000
Contingency				30%	$1,680,000
Subtotal: Construction					$7,280,000

Other Costs

Design	20%	$1,456,000
Environmental Compliance & Permitting	20%	$1,456,000
Project Management	2%	$145,600
Construction Admin/Inspection	2%	$145,600
Project Contingency	10%	$728,000

Total cost	**$11,200,000**

Measure CN-4

Install one-way flow valve on Node HW195

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	Underground pipeline inspection	1	LS	$5,000	$5,000
2	Retrofit storm drain	1	EA	$6,000	$6,000
Contingency				30%	$1,500
Subtotal: Construction					$12,500

Other Costs

Design	20%	$2,500
Environmental Compliance & Permitting	20%	$2,500
Project Management	2%	$250
Construction Admin/Inspection	2%	$250
Project Contingency	10%	$1,250

Total cost	**$19,000**

Measure CN-5

a) Install one-way flow valve on Node N477

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	Underground pipeline inspection	1	LS	$5,000	$5,000
2	Retrofit storm drain	1	EA	$6,000	$6,000
Contingency				30%	$1,500
Subtotal: Construction					$12,500

Other Costs

Design	20%	$2,500
Environmental Compliance & Permitting	20%	$2,500
Project Management	2%	$250
Construction Admin/Inspection	2%	$250
Project Contingency	10%	$1,250

Total cost	**$19,000**

b) Raise low-lying portion of shoreline

Construction Costs

Line #	Item	Length (FT)	Unit	Unit Cost	Cost
1	Raised levee	700	LF	$1,000	$700,000
Contingency				30%	$210,000
Subtotal: Construction					$910,000

Other Costs

Design	20%	$182,000
Environmental Compliance & Permitting	20%	$182,000
Project Management	2%	$18,200
Construction Admin/Inspection	2%	$18,200
Project Contingency	10%	$91,000

Total cost	**$1,400,000**

Measure CN-6

a) Raise low-lying portion of shoreline

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Raised levee	800	LF	$1,000	$800,000
Contingency				30%	$240,000
Subtotal: Construction					$1,040,000

Other Costs

Design	20%	$208,000
Environmental Compliance & Permitting	20%	$208,000
Project Management	2%	$20,800
Construction Admin/Inspection	2%	$20,800
Project Contingency	10%	$104,000

Total cost		**$1,600,000**

b) Install one-way flow valve on Node N909

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	Underground pipeline inspection	1	LS	$5,000	$5,000
2	Retrofit storm drain	1	EA	$6,000	$6,000
Contingency				30%	$1,500
Subtotal: Construction					$12,500

Other Costs

Design	20%	$2,500
Environmental Compliance & Permitting	20%	$2,500
Project Management	2%	$250
Construction Admin/Inspection	2%	$250
Project Contingency	10%	$1,250

Total cost		**$19,000**

Measure LL-1

Study of flooding at the intersection to determine adaptation measures

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	Topographic survey and review of subgrade storage information from EIR/EIS	1	LS	$10,000	$10,000
2	Hydrologic study with HEC-RAS	1	LS	$25,000	$25,000
Contingency				30%	$3,000
Subtotal: (	Study				$38,000

Other Costs

Design	0%	$0
Environmental Compliance & Permitting	0%	$0
Project Management	2%	$760
Construction Admin/Inspection	0%	$0
Project Contingency	10%	$3,800

Total cost	**$43,000**

Measure SP-1

a) Levee widening with road re-alignment

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	re-align road	3200	LF	$2,000	$6,400,000
2	construct new levee at shore edge	3200	LF	$1,000	$3,200,000
Contingency				30%	$1,920,000
Subtotal: Construction					$11,520,000

Other Costs

Design	20%	$2,304,000
Environmental Compliance & Permitting	20%	$2,304,000
Project Management	2%	$230,400
Construction Admin/Inspection	2%	$230,400
Project Contingency	10%	$1,152,000

Total cost	**$17,700,000**

b) Install new floodwall

Construction Costs

Line #	Item	Quantity (FT)	Unit	Unit Cost	Cost
1	Install new floodwall	3200	LF	$2,000	$6,400,000
Contingency				30%	$1,920,000
Subtotal: Construction					$8,320,000

Other Costs

Design	20%	$1,664,000
Environmental Compliance & Permitting	20%	$1,664,000
Project Management	2%	$166,400
Construction Admin/Inspection	2%	$166,400
Project Contingency	10%	$832,000

Total cost	**$12,800,000**

Measure SP-2

Install new side-hinge tide gates (Node HW542)

Construction Costs

Line #	Item	Quantity	Unit	Unit Cost	Cost
1	Install new HDPE pipeline under roadway	100	LF	$350	$35,000
2	Install new tide gates	2	LS	$7,000	$14,000
3	allowance for new RSP, concrete headwall	1	LS	$30,000	$30,000
Contingency				30%	$10,500
Subtotal: Construction					$89,500

Other Costs

Design	20%	$17,900
Environmental Compliance & Permitting	20%	$17,900
Project Management	2%	$1,790
Construction Admin/Inspection	2%	$1,790
Project Contingency	10%	$8,950

Total cost	**$140,000**