CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING

FINAL TECHNICAL MEMORANDUM

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Technical Memorandum

Climate Stressors and Impacts: Bayside Sea Level Rise Mapping

Identification of Technical and Administrative Reviewers

Subtask	Deliverable	Technical Reviewer	Complete	Administrative Reviewer	Complete	PCTA Reviewer	Complete
04	DRAFT Climate Stressors and Impacts: Bayside Sea Level Rise Mapping Technical Memorandum (TM)	K. May; J. Vandever	x	S. Lowry	x	D. Donahue	x
04	FINAL Climate Stressors and Impacts: Bayside Sea Level Rise Mapping Technical Memorandum (TM)	K. May	x			D. Donahue	x

Quality Assurance and Quality Control Review Complete:

Kris May – Task Order Manager

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ACRONYMS/ABBREVIATIONS

AR5	Fifth Assessment Report
Bay Area	San Francisco Bay Area
CCAMP	California Coastal Analysis and Mapping Project
CCMP	California Coastal Mapping Program
CCSF	City and County of San Francisco
City	the City of San Francisco
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
GHG	greenhouse gas
GIS	Geographic Information System
IPCC	International Panel on Climate Change
LiDAR	light detection and ranging
MLLW	mean lower low water
MLW	mean low water
MTL	mean tide level
MSL	mean sea level
MHW	mean high water
MHHW	mean higher high water
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NTDE	National Tidal Datum Epoch
OCOF	Our Coast Our Future
SFCD	San Francisco City Datum
SFPUC	San Francisco Public Utilities Commission
SSIP	Sewer System Improvement Program
USGS	United States Geological Survey

TECHNICAL MEMORANDUM

To: Anna Roche, Climate Change Manager

From: Kris May, Task Order Manager

Subject: Climate Stressors and Impacts: Bayside Sea Level Rise Mapping

Date: 3/11/2015

1 INTRODUCTION

The San Francisco Public Utilities Commission (SFPUC), through the Sewer System Improvement Program (SSIP), is implementing a multi-billion dollar program over the next 20 years to upgrade the existing infrastructure and construct new infrastructure to improve the level of service and resiliency of the City of San Francisco's (City's) wastewater infrastructure. The SFPUC recognizes that climate conditions in the San Francisco Bay Area (Bay Area) will change over the next century, posing a unique challenge for this program. To address this challenge, the SFPUC is undertaking a comprehensive climate change vulnerability and risk assessment related to its wastewater and stormwater assets, culminating in an SSIP Climate Change Adaptation Plan. This plan will provide insight that can inform design and operational strategies, help manage climate change–related risks, and assist in identifying trigger points for implementing adaptation strategies so that a consistent level of service can be maintained over the coming decades and into the next century.

The primary tasks supporting the SSIP Climate Adaptation Plan are:

- **Climate Science Data Inventory** (Technical Memorandum, February 3, 2014): A summary of the relevant climate science data in order to establish the scientific basis for evaluating climate change impacts using the best, readily available, scientific information.
- **Asset and Operations Inventory** (Technical Memorandum, July 31, 2014): A summary of the SSIP assets and operations that will be evaluated for potential climate change impacts.
- **Climate Stressors and Impacts** (three Technical Memoranda): This memorandum is the first of three within the Climate Stressors and Impacts task. It presents the detailed sea level rise inundation mapping developed for the bayside of the City (from the Golden Gate Bridge and to the east along the San Francisco Bay shoreline, including Treasure Island, but excluding the San Francisco International Airport[1]). Separate memorandums present the detailed sea level rise inundation mapping for the Westside of the City (from the Golden Gate Bridge to the west and south along the open Pacific coast shoreline) and a detailed shoreline overtopping potential assessment along designated reaches near critical assets.

[1] The San Francisco International Airport is currently outside the SSIP program; however, SFPUC is coordinating efforts to complete mapping for the airport using consistent methods employed for SSIP.

- **Climate Vulnerability and Risk Assessment**: The climate change impacts, risks, opportunities and vulnerabilities will bring together the outputs of the previous tasks to explore, identify and assess the vulnerability and climate risks of SSIP assets and operations.
- **Adaptation Strategies:** This task will present a range of risk reduction solutions and recommendations for capital and operational improvements to adapt to future climate conditions. Adaptation strategy development will focus on the most at risk assets and operations identified during the Climate Vulnerability and Risk Assessment.

The sea level rise and storm surge inundation mapping presented in this memorandum will supplement the advancement of on-going SSIP projects and allow subsequent phases of the SSIP Climate Change Adaptation Plan to move forward, including the vulnerability and risk assessment and the formulation of adaptation strategies for a prioritized list of SSIP assets. In addition, the results presented in this memorandum provided the necessary information to update the existing Waste Water Enterprise Sea Level Rise Design Guidance with updated climate science and climate stressor and impacts information.

1.1 Overview of Memorandum

The following sections summarize the sea level rise science, describe the mapped sea level rise scenarios, and provide an overview of the detailed sea level rise inundation mapping methods. Appendix A presents a series of map books that depict the sea level rise inundation maps for the Bayside region.

- **Section 2: Sea Level Rise Science** provides an overview of the sea level rise and coastal hazards, a summary of the state of the science, and a discussion of sea level rise scenario selection.
- **Section 3: Inundation Mapping** describes the leveraged model data, water level analysis, topographic data, and the inundation mapping methods used to create the sea level rise inundation maps.
- **Section 4: Mapping Assumptions and Caveats** presents the underlying uncertainties and caveats that should be understood when using the developed inundation maps.

2 SEA LEVEL RISE SCIENCE

This section provides a brief overview of the primary sea level rise and coastal flood hazards, a summary of current sea level rise science, and a description of the approach used to select sea level rise scenarios for inundation mapping purposes. A comprehensive summary of the current state of the science regarding sea level rise and storm surge is presented within the Climate Science Data Summary Technical Memorandum (February 3, 2014).

2.1 Sea Level Rise and Coastal Hazards

San Francisco is susceptible to sea level rise, storm surge, and wave hazards along three sides of the city, with the open Pacific Ocean to the west and San Francisco Bay to the north and east. Several areas along the shoreline are already experiencing inundation and erosion due to coastal hazards, including Ocean Beach on the Pacific Coast, which is subjected to significant coastal storms and waves; the Port of San Francisco's Embarcadero, which is overtopped in several areas during the annual extreme high tides, or King Tides; and San Francisco International Airport, which experiences wave overtopping of flood protection structures and inundation of low-lying areas. Areas of the shoreline that have been filled, such as the Embarcadero, Mission Bay, and Treasure Island, are especially at risk, as rising sea levels may influence groundwater levels, resulting in increased subsidence and liquefaction hazards.

The following coastal flood hazards may increase due to sea level rise:

- **Daily tidal inundation:** As sea level rises, the amount of land and infrastructure subjected to daily inundation – also known as increases in mean higher high water (MHHW) – by high tides will increase. This would result in increased permanent future inundation of low-lying areas.
- **Annual high tide inundation (King Tides):** King tides are abnormally high, predictable astronomical tides that occur approximately twice per year. King Tides are the highest tides that occur each year during the winter and summer when the Earth, moon and sun are aligned. In the winter (December, January, and February), King Tides may be amplified by winter weather, making these events more dramatic. King Tides result in temporary inundation, particularly associated with nuisance flooding, such as inundation of low-lying roads, boardwalks, and waterfront promenades. The Embarcadero waterfront (Pier 14) and the Marina area in San Francisco experience inundation under current King Tide conditions.
- **Extreme high tide inundation (storm surge):** When Pacific Ocean storms coincide with high tides, storm surge due to meteorological effects can elevate Pacific Ocean and San Francisco Bay water levels and produce extreme high tides, resulting in temporary inundation. Such storm surge events have occurred in January 27, 1983, December 3, 1983, February 6, 1998, January 8, 2005, and December 31, 2006. Extreme high tides can cause severe inundation of low-lying roads, boardwalks, and promenades; can exacerbate coastal and riverine flooding and cause upstream flooding; and can interfere with stormwater outfalls. The Ocean Beach area is prone to inundation and erosion associated with extreme high tides and storm surge.

- **El Niño winter storms:** During El Niño[2] winters, atmospheric and oceanographic conditions in the Pacific Ocean produce severe winter storms that impact the San Francisco shorelines. Pacific Ocean storms follow a more southerly route and bring intense rainfall and storm conditions to the Bay Area. Tides are often elevated 0.5 to 1.0 feet above normal along the coast, and wind setup can elevate water levels even further. El Niño winter conditions prevailed in 1977–1978, 1982–1983, 1997–1998, and 2009–2010. Typical impacts include severe inundation of low-lying roads, boardwalks and waterfront promenades; storm drain backup; wave damage to coastal structures; and erosion of natural shorelines.
- **Ocean swell and wind-wave events (storm waves):** Pacific Ocean storms and strong thermal gradients can produce strong winds that blow across the ocean and the Bay. When the wind blows over long reaches of open water, large waves can be generated that impact the shoreline and cause damage. Typical impacts include wave damage to coastal structures such as levees, docks and piers, wharves, and revetments; backshore inundation due to wave overtopping of structures; and erosion of natural shorelines.

2.2 Summary of the Science

The science associated with sea level rise is continually being updated, revised, and strengthened. Although there is no doubt that sea levels have risen and will continue to rise at an accelerated rate over the coming century, it is difficult to predict with certainty what amount of sea level rise will occur at any given time. The uncertainties increase over time (e.g., the uncertainties associated with 2100 projections are greater than with 2050 projections) because of uncertainties in future greenhouse gas (GHG) emissions trends, the sensitivity of climate conditions to GHG concentrations, and the overall capabilities of climate models. The sea level rise projections presented in this document draw on the best available science on the potential effects of sea level rise in California as of March 2015.

In March 2013, the Ocean Protection Council adopted the 2012 National Research Council (NRC) Report *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* as the best available science on sea level rise for the state (Ocean Protection Council 2013). The California Coastal Commission also supported the use of the NRC 2012 report as best available current science, noting that the science of sea level rise is continually advancing and future research may enhance the scientific understanding of how the climate is changing, resulting in the need to regularly update sea level rise projections (California Coastal Commission 2013). The NRC report includes discussions of historic sea level rise observations, three sea level rise projections of likely sea level rise for the coming century, high and low extremes for sea level rise, and insight into the potential impacts of a rising sea for the California coast. After the release of the NRC report and the development of the draft Coastal Commission guidance, the International Panel on Climate Change (IPCC) released the Fifth Assessment Report (AR5), *Climate Change 2013: The Physical Science Basis*, which provides updated consensus estimates of global sea level rise (IPCC 2013).

Table 1 presents the NRC sea level rise projections for San Francisco relative to the year 2000. The table presents the local *projections* (mean ± 1 standard deviation). These projections (for example, 6 ± 2.0

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[2] El Niño–Southern Oscillation is a natural oceanic-atmospheric cycle. El Niño conditions are defined by prolonged warming in the Pacific Ocean sea surface temperatures. Typically, this happens at irregular intervals of two to seven years, and it can last anywhere from nine months to two years.

inches in 2030) represent the *likely* sea level rise values based on a moderate level of greenhouse gas emissions and extrapolation of continued accelerating land ice melt patterns, plus or minus one standard deviation[3]. The extreme limits of the *ranges* (for example, 2 and 12 inches for 2030) represent *unlikely but possible* levels of sea level rise using both low and very high emissions scenarios and, at the high end, including significant land ice melt that is not anticipated at this time but could occur. The NRC report is also notable for providing regional estimates of *net sea level rise* for the Oregon, Washington, and California coastlines that include the sum of contributions from the local thermal expansion of seawater, wind driven components, land ice melting, and vertical land motion. The chief differentiator among net sea level rise projections along the western coast derives from vertical land motion estimates, which show uplift (reducing net sea level rise) of lands north of Cape Mendocino and subsidence (increasing net sea level rise) of lands south of Cape Mendocino.

The NRC ranges are higher than the global estimates presented in IPCC AR5, while the projections in the NRC report are similar to IPCC estimates. At this time, the use of NRC projections and ranges is appropriate for SFPUC climate adaptation planning because they encompass the best available science, they have been derived considering local and regional processes and conditions, and their use is consistent with current state guidance. In addition, the sea level rise estimates presented in Table 1 are consistent with the recently adopted Capital Planning Commission guidance for incorporating sea level rise into capital planning in San Francisco[4].

Table 1: Sea Level Rise Estimates for San Francisco Relative to the Year 2000

Year	Projections	Ranges
2030	6 ± 2 in	2 to 12 in
2050	11 ± 4 in*	5 to 24 in
2100	36 ± 10 in	17 to 66 in

NRC. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*.

*As a simplifying assumption, the 2050 most likely value selected for the inundation mapping effort is 12 inches rather than the 11 inch value noted in the table.

Beyond sea level rise, consideration must also be given to storm surge and waves along the San Francisco shorelines. Understanding the additive impact of large waves and high tides to produce inundation and flooding is crucial for planning in the coastal environment. Table 2 provides an overview of factors affecting existing water levels on the San Francisco open Pacific Coast and in the San Francisco Bay.

3 One standard deviation roughly corresponds to a 15%/85% confidence interval, meaning that there is approximately 15% chance the value will exceed the high end of the projection (8 inches for the 2030 example given) and a 15% chance the value will be lower than the low end of the range (4 inches in the 2030 example).

4 The Capital Planning Commission guidance for incorporating sea level rise into capital planning in San Francisco is available at: http://onesanfrancisco.org/staff-resources/sea-level-rise-guidance/

Table 2: Factors That Influence Local Water Level Conditions in Addition to Sea Level Rise

Factors Affecting Water Level	Typical Range CCSF Pacific Shoreline[a]	Typical Range CCSF Bay Shoreline[b]	Period of Influence	Frequency
Tides	5 to 7 ft	5 to 7 ft	Hours	Twice daily
Storm Surge	0.5 to 3 ft	0.5 to 3 ft	Days	Several times a year
Storm Waves	10 to 30 ft	1 to 4 ft	Hours	Several times a year
El Niños (within the ENSO cycle)	0.5 to 3 ft	0.5 to 3 ft	Months to Years	2 to 7 years

[a] BakerAECOM. 2012. *Intermediate Data Submittal #1: Scoping and Data Review*. San Francisco County, California. California Coastal Analysis and Mapping Project / Open Pacific Coast Study. Federal Emergency Management Agency Region IX.

[b] DHI. 2010. *Regional Coastal Hazard Modeling Study for North and Central Bay*. Prepared for Federal Emergency Management Agency. September.

2.3 Sea Level Rise Scenario Selection

Sea level rise is often visualized using inundation maps; however, selecting the most appropriate sea level rise scenario to map for project planning, exposure analysis, and sea level rise vulnerability and risk assessment is not simple. Typically, a series of maps are created that represent specific sea level rise scenarios mapped on top of MHHW, as well as paired with a specific extreme tide or storm surge interval such as the 1% annual chance storm surge event (a.k.a., 100-year storm surge event). This approach requires pre-selecting specific sea level rise scenarios that will meet all project needs.

Rather than pre-selecting specific sea level rise scenarios for SFPUC and SSIP, ten individual inundation maps were developed to represent a range of possible scenarios associated with extreme tide levels and sea level rise, ranging from 6 inches to 66 inches of sea level rise, and the 1-year extreme tide event to the 100-year storm surge event (i.e., extreme tide). The scenario selection relied on the extreme tide water level analysis described in Section 3.1. The goal of the scenario selection was to identify ten scenarios that could represent the current NRC sea level rise projections and ranges, as presented in Section 2.2, as well as approximate a range of storm surge events. The first six scenarios relate directly to the NRC sea level rise estimates (sea level rise above MHHW), and capture a broad range of scenarios between the most likely scenario and the high of the uncertainty range at both mid- and end-of-century.

1. MHHW + 12” Reference Water Level[5] ≈ 2050 most likely sea level rise scenario
2. MHHW + 24” Reference Water Level = 2050 upper end sea level rise scenario; ≈ 2100 lower 15th percent confidence interval
3. MHHW + 36” Reference Water Level = 2100 most likely sea level rise scenario
4. MHHW + 48” Reference Water Level ≈ 2100 upper 85th percent confidence interval
5. MHHW + 52” Reference Water Level ≈ existing conditions 100-year extreme tide + 11” SLR (2050 most likely sea level rise scenario)
6. MHHW + 66” Reference Water Level = 2100 upper end sea level rise scenario; ≈ existing conditions 100-year extreme tide + 24” SLR (2050 upper end sea level rise scenario)

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[5] The reference water level can occur due to a variety of hydrodynamic conditions by combining different amounts of sea level rise with either a daily (MHHW) or extreme tide.

Each of the above scenarios can approximate either permanent inundation scenarios that are likely to occur before 2100, or temporary flooding events which would occur from specific combinations of sea level rise and extreme tides. For example, the water elevation associated with 36 inches of sea level rise is similar to the water elevation associated with a combination of 24 inches of sea level rise and a 1-year extreme tide (king tide). Therefore, a single map can be used to visualize either event. The primary difference between the two scenarios is that 36” of sea level rise above MHHW represent possible future *permanent* inundation by daily tides, and the 24” of sea level rise plus a 1-year extreme tide event represent the *temporary* inundation that would likely occur at least once in any given year.

Additional classification (Scenarios 7-10) of the range of sea level rise and the extreme tide conditions that the inundation mapping scenarios represent are presented below. These water levels do not represent permanent inundation scenarios that are likely to occur before 2100. They illustrate short term flooding that could occur when extreme tides are coupled with up to 66 inches of sea level rise.

7. MHHW + 77” Reference Water Level ≈ existing conditions 100-year extreme tide + 36” SLR (2100 most likely sea level rise scenario)
8. MHHW + 84” Reference Water Level ≈ existing conditions 50-year extreme tide + 48” SLR (2100 high end of most likely sea level rise scenario)
9. MHHW + 96” Reference Water Level ≈ existing conditions 25-year extreme + 66” SLR (2100 upper end sea level rise scenario)
10. MHHW + 108” Reference Water Level ≈ existing conditions 100-year extreme tide + 66” SLR (2100 upper end sea level rise scenario)

The water levels along the shoreline were binned using a tolerance of ± 3-inch to increase the applicable range of the mapped scenarios. For example, Scenario 1 (MHHW + 36 inches) is assumed to be representative of all extreme tide/sea level rise combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches (See Table 3).

While Table 3 presents the ten mapped scenarios, Table 4 presents over 55 combinations of sea level rise with extreme tides levels represented by the mapped scenarios. For example, from Table 4, the inundation map of Scenario 1 (MHHW + 36 inches), represents all of these combinations:

- a 1-year extreme tide coupled with 24 inches of sea level rise,
- a 2-year extreme tide coupled with 18 inches of sea level rise,
- a 5-year extreme tide event coupled with 12 inches of sea level rise,
- a 25-year extreme tide event coupled with 6 inches of sea level rise, and
- a 50-year extreme tide event under existing conditions (no sea level rise).

The colors shown in Table 3 are replicated in the matrix of water levels shown in Table 4 to indicate the combinations represented by each inundation map. As noted above, Scenarios 7-10 are outside the range of NRC permanent sea level rise estimates expected to occur by 2100. Table 4 also identifies the combinations of sea level rise and extreme tide which may produce flooding at the higher end of the spectrum at the end of the century. For example, Scenario 9 (96 inches above MHHW) approximates:

- 66 inches of sea level rise with a 25-year extreme tide event,
- 60 inches of sea level rise with a 50-year extreme tide event, and
- 54 inches of sea level rise with a 100-year extreme tide event.

These scenarios provide a rich data set with which to evaluate vulnerabilities and risk from sea level rise, and to better define the timing for effective adaptation strategies.

Table 3: Sea Level Rise Inundation Mapping Scenarios (inches above MHHW)

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario – (Reference ± 3 inches)
Scenario 1	MHHW + 12”	MHHW + 9 to 15”
Scenario 2	MHHW + 24”	MHHW + 21 to 27”
Scenario 3	MHHW + 36”	MHHW + 33 to 39”
Scenario 4	MHHW + 48”	MHHW + 45 to 51”
Scenario 5	MHHW + 52”	MHHW + 49 to 55”
Scenario 6	MHHW + 66”	MHHW + 63 to 69”
Scenario 7	MHHW + 77”	MHHW + 74 to 80”
Scenario 8	MHHW + 84”	MHHW + 81 to 87”
Scenario 9	MHHW + 96”	MHHW + 93 to 99”
Scenario 10	MHHW + 108”	MHHW + 105 to 111”

Table 4: Sea Level Rise and Extreme Tide Matrix

	Daily Tide ***Permanent Inundation***	**Extreme Tide (Storm Surge)** ***Temporary Flooding***						
Sea Level Rise Scenario	**+SLR**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
	Water Level above MHHW (in)							
Existing Conditions	0	12	19	23	27	32	36	41
MHHW + 6-inch	6	18	25	29	33	38	42	47
MHHW + 12-inch	12	24	31	35	39	44	48	53
MHHW + 18-inch	18	30	37	41	45	50	54	59
MHHW + 24-inch	24	36	43	47	51	56	60	65
MHHW + 30-inch	30	42	49	53	57	62	66	71
MHHW + 36-inch	36	48	55	59	63	68	72	77
MHHW + 42-inch	42	54	61	65	69	74	78	83
MHHW + 48-inch	48	60	67	71	75	80	84	89
MHHW + 52-inch	52	64	71	75	79	84	88	93
MHHW + 54-inch	54	66	73	77	81	86	90	95
MHHW + 60-inch	60	72	79	83	87	92	96	101
MHHW + 66-inch	66	78	85	89	93	98	102	107

Note: All values in inches above MHHW. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios showing in Table 3. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 3.

3 INUNDATION MAPPING

Inundation maps are a valuable tool for evaluating potential exposure to future sea level rise and extreme tide conditions, and the most up-to-date maps should be referenced during project planning and design. The maps are typically used to evaluate when (under what amount of sea level rise and/or storm surge) and by how much (what depth of inundation) an asset will be exposed. This section presents the overall method and data sources uses to develop the detailed inundation maps presented in Appendix A. The Bayside inundation mapping relied on two primary data sources:

- Modeled water levels from the FEMA San Francisco Bay Area Coastal Study[6]
- Topographic LIDAR from the USGS and NOAA California Coastal Mapping Program (CCMP)[7]

Water level data from the 31-year simulation of hydrodynamics and storm surge completed for FEMA's San Francisco Bay Area Coastal Study was leveraged at 70 points along the San Francisco shoreline. The modeled water level output was analyzed as part of this inundation mapping effort, as described in Section 3.1. The topographic LIDAR was leveraged directly from the USGS and NOAA for this study. The inundation mapping was completed on a 1-meter digital elevation model (DEM) for the technical memorandum, as described in Section 3.2.1.

3.1 Water Level Analysis

The sections below describe the modeling efforts leveraged for this analysis and present the model output analysis method and results.

3.1.1 Leveraged Water Level Model Studies

The inundation mapping effort leveraged existing and readily available model output from a large-scale San Francisco Bay modeling effort completed as part of FEMA's San Francisco Bay Area Coastal Study. This study leveraged hydrodynamic modeling data performed by DHI using the MIKE21 hydrodynamic model (DHI 2011). The FEMA modeling data was used to determine the daily MHHW tide levels throughout the SFPUC SSIP study area, which covers the Bayside shoreline of the City. The use of model data for this study was preferred over individual tide gage analyses because of the high spatial density provided in the model output data for the entirety of the project area. This data has been leveraged and used for several similar studies in San Francisco Bay, including the Adapting to Rising Tides project in Alameda County (San Francisco Bay Conservation and Development Commission 2011).[8]

The FEMA MIKE21 model output water level data was provided in 15-minute time steps; it consisted of water surface elevations relative to the North American Vertical Datum of 1988 (NAVD88), as described in the Regional Coastal Hazard Modeling Study for North and Central San Francisco Bay (DHI 2011). The water level and wave hindcast period extended from January 1, 1973, to December 31, 2003 (31 years).

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[6] www.r9coastal.org

[7] http://www.opc.ca.gov/2012/03/coastal-mapping-lidar-data-available/

[8] www.adpatingtorisingtides.org

3.1.2 Existing Conditions Daily and Extreme Tide Levels

Model output was extracted at 70 locations along the Bayside shoreline (see Figure 1). The extraction points were selected to adequately characterize the spatial variability of water levels along the shoreline. Figure 1 shows the model output locations used in the analysis. The FEMA MIKE 21 model output was used to assess existing conditions – both daily high tide water levels (i.e., MHHW) and extreme tide water levels (i.e., the 1-year to the 500-year extreme tide levels).

One of the fundamental assumptions in the inundation mapping was that the tidal hydraulics (e.g., the tidal range, amplitude, etc.) remain stationary over the 31-year simulation period (after historic sea level rise trends have been removed) – meaning sea level rise does not result in a significant change to the tidal hydraulics. For example, under stationary conditions, the daily tides levels for existing conditions can be projected into the future simply by adding a specific amount of sea level rise (e.g., 12 inches or 36 inches) to the MHHW elevation at a given point. This assumption does not account for factors that may modify the tidal hydraulics over the course of the 31-year simulation period. For example, as sea level rises, the mean water depth of the Bay will increase, which could affect the way in which the tidal wave propagates throughout the Bay, thereby increasing or decreasing the tide range at a particular location. Holleman and Stacey (2014) showed that this linear approach is appropriate within San Francisco Bay. Although small changes in the tidal range were observed, these changes were small compared to sea level rise (Holleman and Stacey 2014).

The MHHW tidal datum was selected to represent the typical daily high tide. The MHHW tide level for existing conditions was calculated using modeled hindcast data corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to perform tidal computations. The MHHW tide level is defined as the average of the higher high tides of each day recorded during the National Tidal Datum Epoch. MHHW elevations for existing conditions ranged from 5.9 feet to 6.7 feet NAVD88 along the Bayside shoreline. Results of the daily tide analysis are shown in Figure 2. In addition to the MHHW tidal datum, the MHW (mean high water), MTL (mean tide level), MSL (mean sea level), MLW (mean low water), and the MLLW (mean lower low water) tidal datums were computed for each model output point to provide detailed tidal datum information for other ongoing SFPUC and SSIP efforts along the shoreline.

Figure 1: FEMA Model Extraction Points

Elevations referenced to North American Vertical Datum of 1988.

Figure 2: FEMA Model Extraction Points and the Calculated Average Daily Tide Elevations (MHHW) for Existing Conditions

The extreme tide levels were computed using the 31-year period of record from the modeled water level time series. An example water level time series and the extracted annual maxima for one model output point are shown in Figure 3. Although the majority of the daily high tide levels are below 7.5 feet NAVD88 at this location, there are multiple times each year that exceed this level. The maximum annual tide that occurred each year is highlighted with a red square. The maximum high tide on record occurred in 1983, with an elevation of nearly 10.0 feet NAVD88, during a strong El Niño winter. In general, the maximum high tides typically occur in the winter months.

The following steps were used to calculate the extreme high tide levels:

1. Annual maxima water levels were extracted based on a July–June "storm year" consistent with the FEMA San Francisco Bay Area Coastal Study.
2. The generalized extreme value (GEV) probability distribution was fit to the annual maxima dataset, and extreme tide elevations were calculated for each return period.

The water level statistics used to represent the extreme tides include the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year extreme tide levels. The estimates of the 500-year tide level are only approximate, given the relatively short duration of the hydrodynamic model hindcast (31 years). However, these values are consistent with the values FEMA will use for the upcoming Flood Insurance Rate Maps and Flood Insurance Studies for the City; therefore the 500-year extreme tide levels are included in Appendix B, which provides the calculated extreme tide levels for each of the 70 points along the shoreline (referenced to NAVD88 and the San Francisco City Datum). The computed daily and extreme tide levels computed for each model output point are also available in a Geographic Information System (GIS) shapefile. The 500-year extreme tide levels were not extended to the development of the sea level rise and extreme tide matrix presented in Table 4.

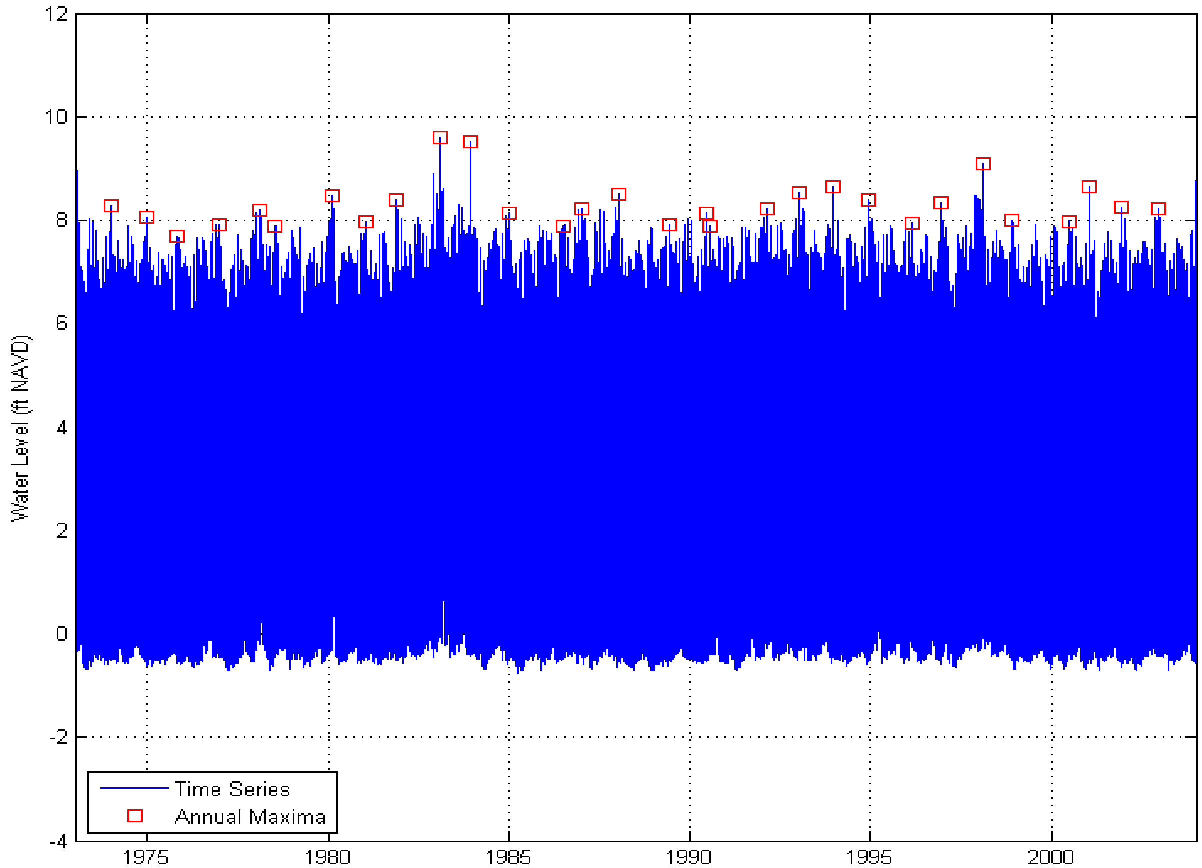

Figure 3: Example Water Level Time Series and Annual Maxima Dataset

3.2 Inundation Map Development

The inundation maps were created using the methods developed by the NOAA Coastal Services Center for the NOAA Coastal Flooding and Sea Level Rise Viewer (Marcy et al. 2011).

3.2.1 Leveraged Topographic Data

The inundation mapping effort used the best available topographic data for the study area – the USGS and NOAA LiDAR collected as part of the CCMP. This LiDAR set is also being used to support the FEMA San Francisco Bay Area Coastal Study, as well as several other large-scale regional modeling efforts. The USGS managed the LiDAR data collection in south San Francisco Bay. The South Bay LiDAR data were collected in June, October, and November 2010 and provide complete coverage of the bayside areas of the City and County of San Francisco shoreline, up to the 16-foot (5-meter) elevation contour. NOAA managed additional LiDAR collection for CCMP in northern San Francisco Bay from February to April 2010, as well as additional LiDAR collection in 2011 to provide enhanced coverage of many coastal shoreline areas, including areas along the City shoreline. The USGS and NOAA LiDAR data were delivered in point-cloud format at 1-meter point spacing.

The USGS and NOAA LiDAR and their associated DEMs provide the base topographic data for the inundation mapping effort. The bare-earth LiDAR was used for the inundation mapping. In the bare-earth LiDAR, all building and structures (i.e., bridges) have been removed. All vegetation has also been removed as part of the bare-earth LiDAR processing. The resultant DEM is of sufficient resolution and detail to capture the shoreline levees and flood protection assets. Although care was taken to capture all relevant topographic features and coastal structures that may impact coastal inundation, it is possible that structures narrower than the 1-meter horizontal DEM scale may not be fully represented.

3.2.2 Water Surface Digital Elevation Model Creation

The initial step in creating the inundation maps was to create the inundated MHHW water surface DEM using the calculated MHHW values from the FEMA model output points. The MHHW value at each output point was projected inland along shore perpendicular transects that extended beyond the expected extent of inundation under the highest sea level rise scenario. Transects were spaced at an appropriate density to capture the variation in tidal surface. The MHHW DEM was created with a grid spacing of 1-meter to match the resolution of the current topographic DEM. Sea level rise values (i.e., 12, 24, 36, 48, 66 inches, etc.) were added to the MHHW DEM to create a DEM for each of the ten inundation map scenarios.

The resulting water surface DEMs are an extension of the tidal water surface at the shoreline over the inland topography. This represents a conservative estimate of the inland inundated water surface. This exercise does not take into account the associated physics of overland flow, dissipation, levee overtopping, storm duration, or potential shoreline or levee erosion associated with extreme water levels and waves. To account for these processes, a more sophisticated modeling effort would be required. However, given the uncertainties associated with sea level rise, as well as future land use changes, development, and geomorphic changes that will occur over the next 100 years, a more sophisticated modeling effort may not necessarily provide more accurate or certain results.

3.2.3 Depth and Extent of Flooding

Depth of flooding raster[9] files were created by subtracting the land surface DEM from the water surface DEM. Both DEMs were generated using a 1-meter horizontal resolution with the same grid spacing to allow for grid cell to grid cell subtraction. The resultant DEM provides both the inland extent and the depth of inundation (in the absence of considering hydrologic connectivity).

The final step used in creating the depth and extent of flood maps relies on assessing hydraulic connectivity. The method described by Marcy et al. (2011) employs two rules for assessing whether a grid cell is inundated. A cell must be below the assigned water surface DEM elevation value, and it must be connected to an adjacent grid cell that was either flooded or open water. NOAA's method applies an "eight-side rule" for connectedness, where the grid cell is considered "connected" if any of its cardinal[10] or diagonal directions are connected to a flooded grid cell. This approach decreases the inundated area over earlier inundation mapping efforts that considered a grid cell to be inundated solely based on its elevation (i.e., even if there was no hydraulic pathway to the Bay to allow flooding).

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[9] A raster consists of an array of equally sized cells where each cell contains a value representing information (e.g., location and water depth values).

[10] Cardinal direction refers to North, South, East, and West.

The assessment of hydraulic connectivity removes areas from the inundation zone if they are protected by levees or other topographic features that are not overtopped. It also removes areas that are low-lying but inland and not connected to an adjacent flooded area.

3.2.4 Inundation Maps

The detailed inundation maps are presented in Appendix A. The scenarios each map can represent, either permanent inundation (MHHW + sea level rise) or temporary flooding (extreme tide scenarios) are noted on each map. The inundation maps are also available in GIS format.

The shades of blue represent various depths on inundation, shown in two-foot depth increments, ranging from 0 feet to greater than 12 feet of inundation. In addition, hydrologically disconnected low-lying areas are displayed in green. These areas do not have an effective overland flow path to allow water to reach the area, although these areas have topographic elevations below the inundated water surface. It is possible that the low-lying areas are connected through culverts, storm drains, or other hydraulic features which are not captured within the DEM; therefore it is important to note that there may be an existing or future flood risk within these areas. In addition, these low-lying areas may be associated with an increased risk due to rising groundwater elevations. The link between sea level rise and groundwater elevations is not well understood; however, it is likely that water table elevations will rise and sea levels rise.

4 MAPPING ASSUMPTIONS AND CAVEATS

The new inundation maps are intended as a screening-level tool to assess exposure to future sea level rise and extreme tide/storm surge induced coastal flooding. The inundation maps represent a "do nothing" future scenario assumption. Although the inundation maps do account for additional processes compared to the previous inundation maps created for San Francisco through other studies, and they rely on the best available and current information and data sources, they are still associated with a series of assumptions and caveats:

- The inundation scenarios associated with an increase in future MHHW (sea level rise above MHHW) represent areas that could be inundated *permanently* on a regular basis by tidal action. The inundation scenarios associated with extreme tide levels and storm surge represent *periodic* or temporary inundation associated with a coastal flooding condition. The inundation maps for extreme tide and storm surge scenarios do not consider the duration of flooding, or the potential mechanism for draining the floodwaters from the inundated land once the extreme high tide levels recede.
- The bathymetry of San Francisco Bay and the topography of the landward areas, including levees and other flood and shore protection features, are assumed to remain the same over time. No response to sea level rise and increased inundation is included in the analysis and mapping (e.g., the morphology of the region is constant over time).
- The maps do not account for the accumulation of organic matter in wetlands, or potential sediment deposition and/or resuspension that could alter San Francisco Bay hydrodynamics and/or bathymetry.
- The maps do not account for erosion, subsidence, future construction, or levee upgrades.
- The maps do not account for the existing condition or age of the shore protection assets. No degradation or levee failure modes have been analyzed as part of the inundation mapping effort.
- The maps do not account for water flow through water control structures such as culverts or tide gates.
- The levee heights and the heights of roadways and/or other topographic features that may affect floodwater conveyance are derived from the USGS and NOAA 2010 LiDAR data. Although this data set represents the best available topographic data, the data have not been extensively ground-truthed, and levee crests may be overrepresented or underrepresented by the LiDAR data.
- The inundation depth and extent shown on the MHHW maps are associated with the typical high tide, in an attempt to approximate the maximum extent of future daily tidal inundation. This level of inundation can also be referred to as "permanent inundation" because it represents the area that would be inundated regularly. Tides in San Francisco Bay exhibit two highs and two lows in any given day, and the daily high tide on any given day may be higher or lower than the MHHW tidal elevation.
- The depth and extent of inundation for an extreme coastal storm event (i.e., including local wind and wave effects) was not included in this study. These processes could have a significant effect on the ultimate depth of inundation associated with a large coastal wind/wave event, especially near the shoreline.
- The inundation maps do not account for localized inundation associated with rainfall-runoff events, or the potential for riverine overbank flooding in the local tributaries associated with large rainfall events.
- The maps do not account for inundation associated with changing rainfall patterns, frequency, or intensity as a result of climate change.

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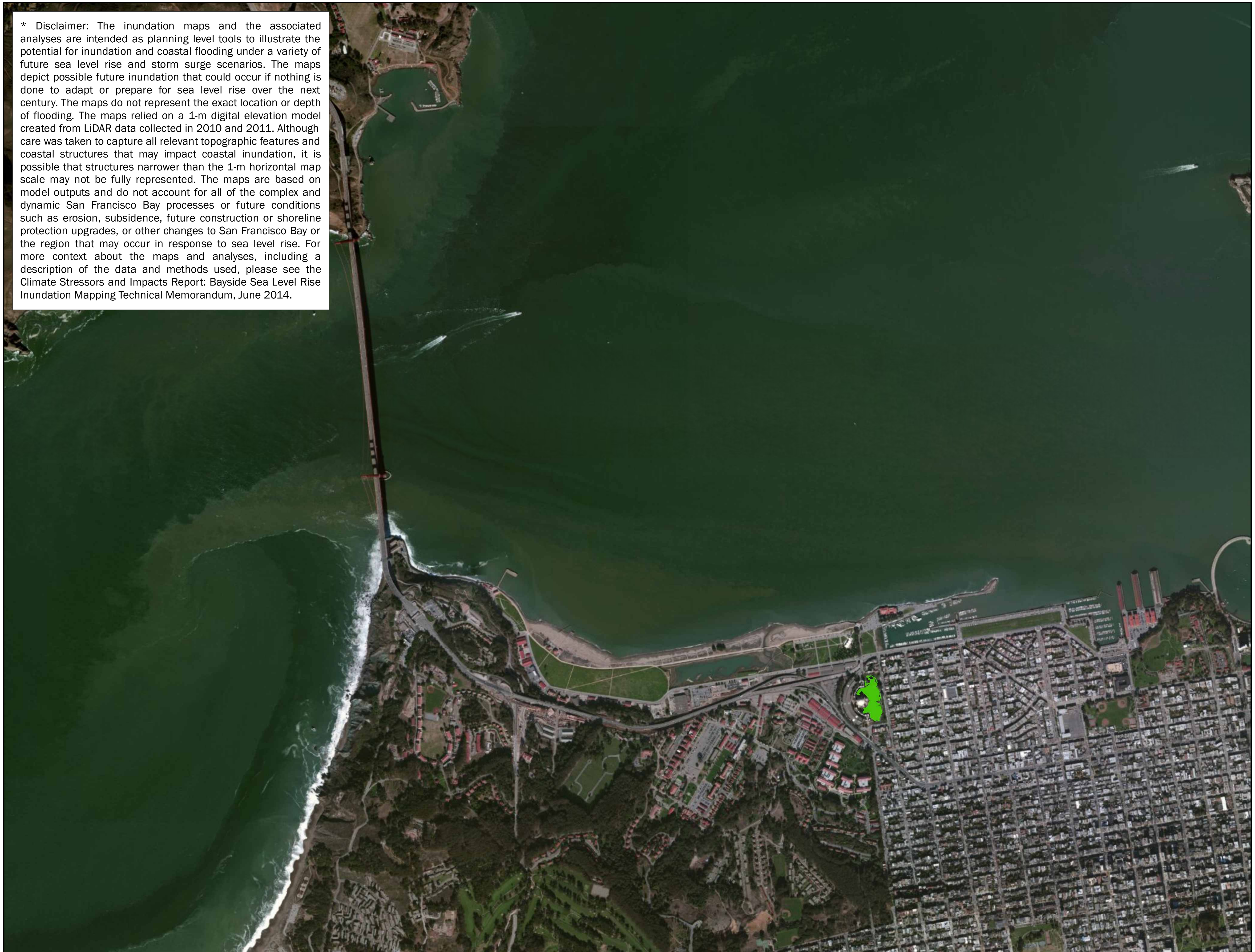
APPENDIX A – SEA LEVEL RISE INUNDATION MAPS – SFPUC SSIP BAYSIDE SHORELINE



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 12" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

0" SLR + 1-YEAR STORM SURGE

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12+
- Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles

1 inch = 0.3 miles

0 1,500 3,000 Feet

1 inch = 1,500 feet

San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015

SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 12" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

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Depth in Feet

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SFPUC SSIP BAYSIDE

Inundation Mapping

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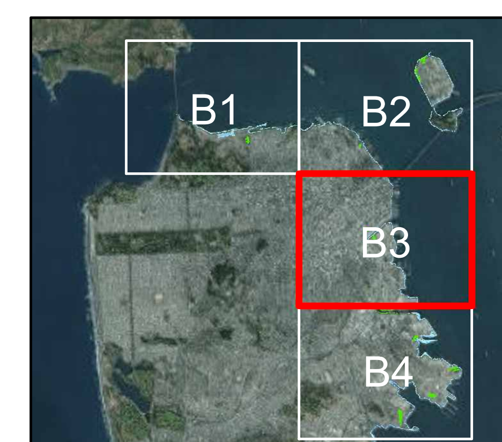

SFPUC SSIP BAYSIDE

Inundation Mapping

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MHHW + 12" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

0" SLR + 1-YEAR STORM SURGE

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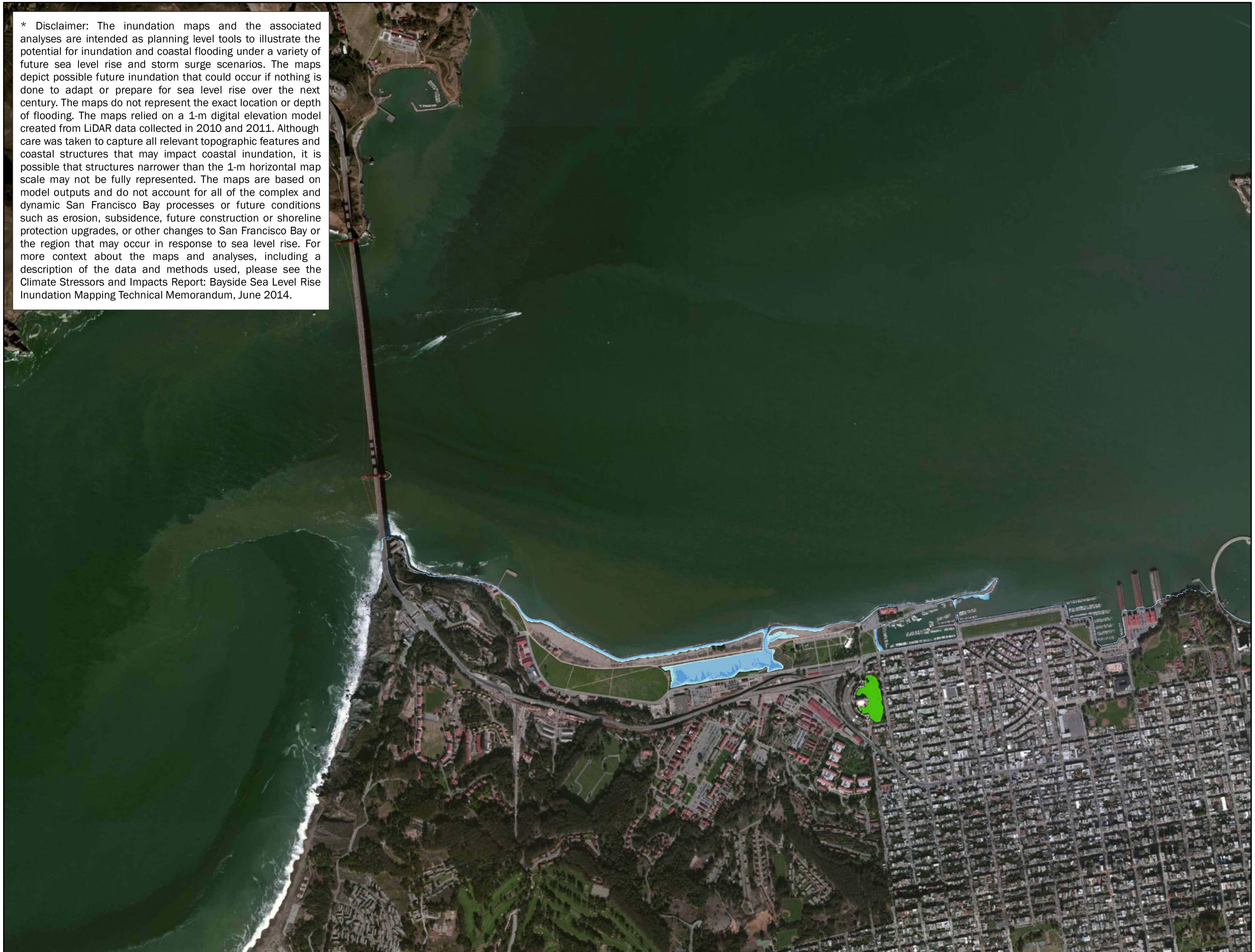

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 24" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

12" SLR + 1-YEAR STORM SURGE
6" SLR + 2-YEAR STORM SURGE
0" SLR + 10-YEAR STORM SURGE

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12+

Disconnected Areas > 1 Acre

N

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Projection:
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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 24" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

12" SLR + 1-YEAR STORM SURGE
6" SLR + 2-YEAR STORM SURGE
0" SLR + 10-YEAR STORM SURGE

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Services of the San Francisco Public Utilities Commission

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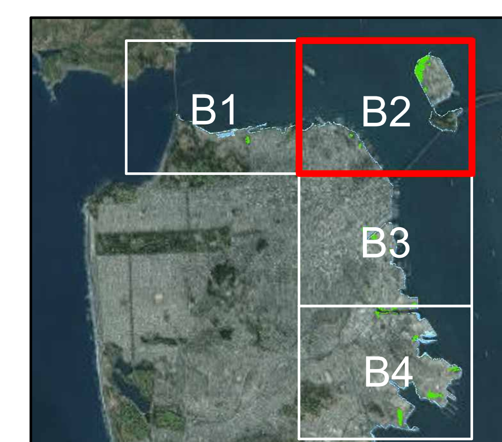

SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 24" SEA LEVEL RISE

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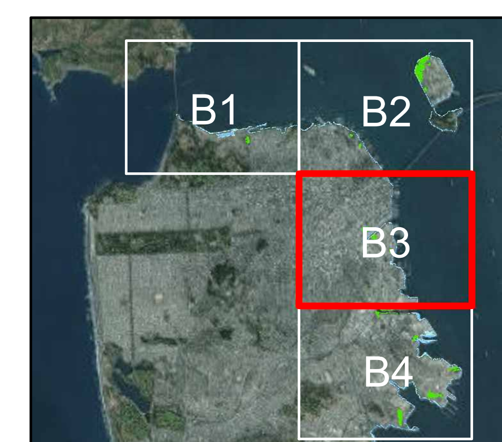

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 24" SEA LEVEL RISE

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12" SLR + 1-YEAR STORM SURGE
6" SLR + 2-YEAR STORM SURGE
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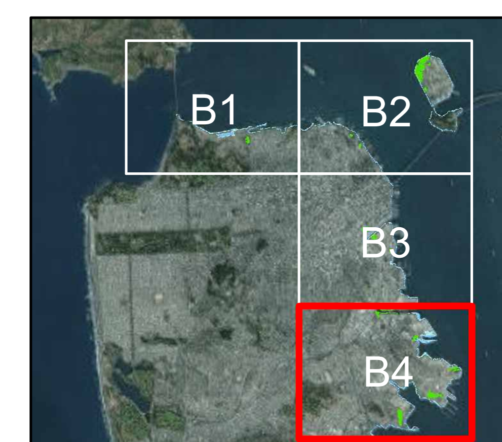

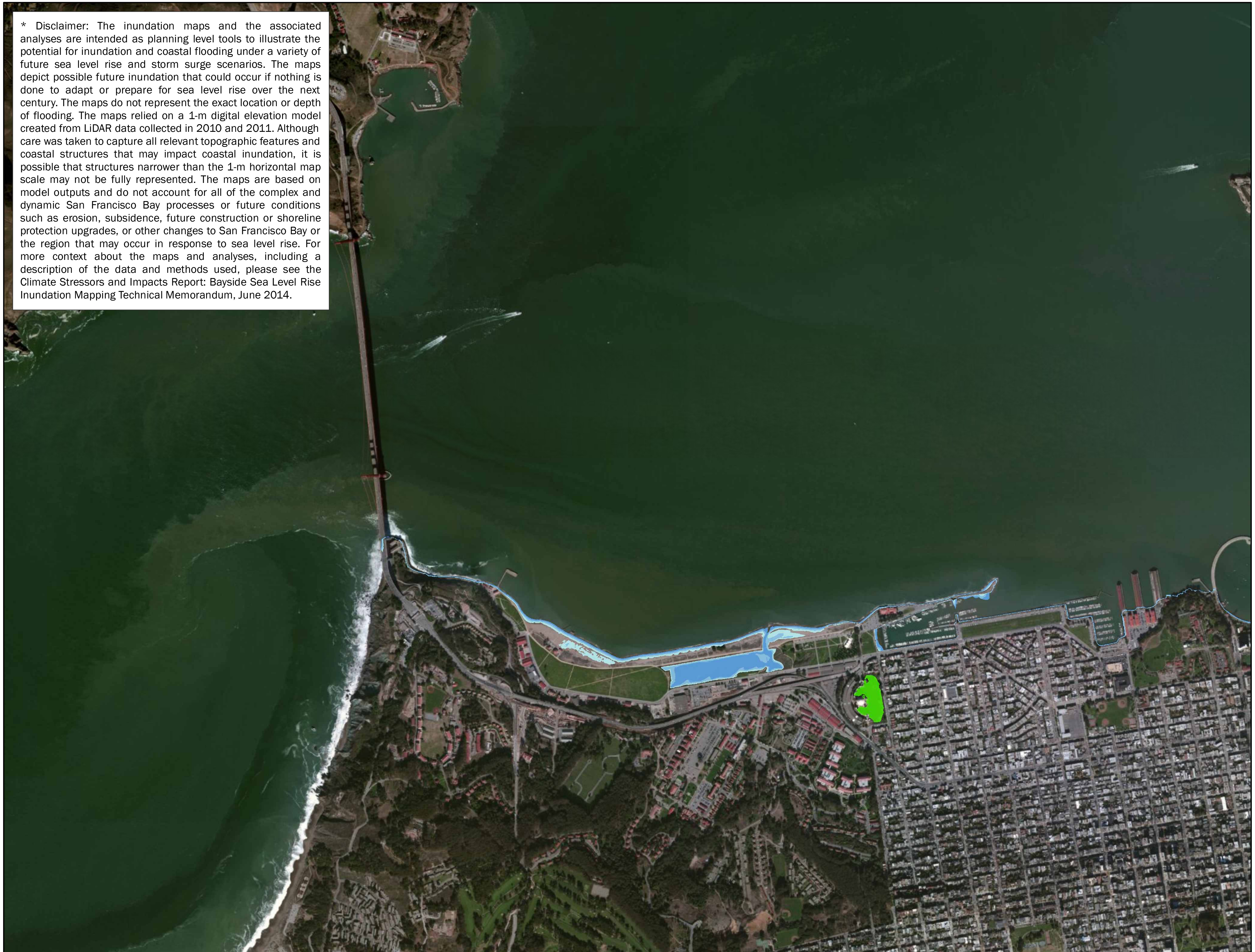

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 36" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

24" SLR + 1-YEAR STORM SURGE
18" SLR + 2-YEAR STORM SURGE
12" SLR + 5-YEAR STORM SURGE
6" SLR + 25-YEAR STORM SURGE
0" SLR + 50-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+
Disconnected Areas > 1 Acre

N

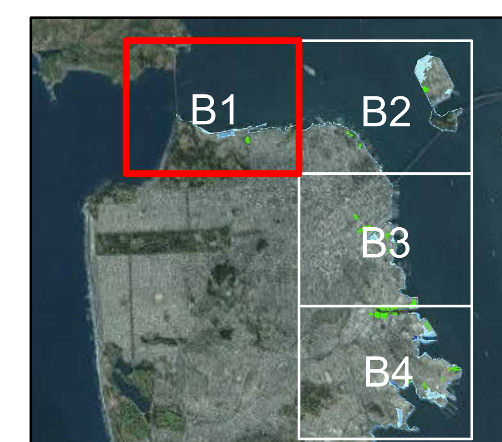
0 0.25 0.5 Miles
1 inch = 0.3 miles

0 1,500 3,000 Feet
1 inch = 1,500 feet

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 36" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

24" SLR + 1-YEAR STORM SURGE
18" SLR + 2-YEAR STORM SURGE
12" SLR + 5-YEAR STORM SURGE
6" SLR + 25-YEAR STORM SURGE
0" SLR + 50-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
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Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
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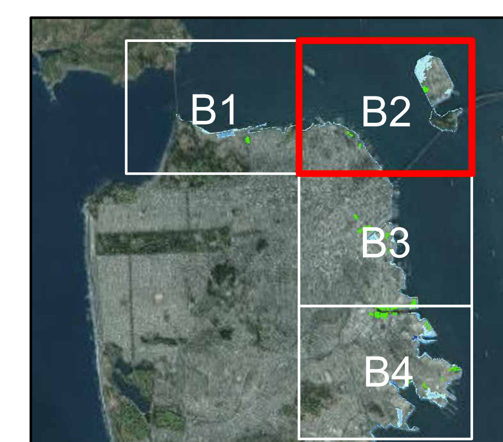
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 36" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

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Depth in Feet

Depth in Feet	
0 - 2	
2 - 4	
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6 - 8	
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12+	
	Disconnected Areas > 1 Acre

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San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
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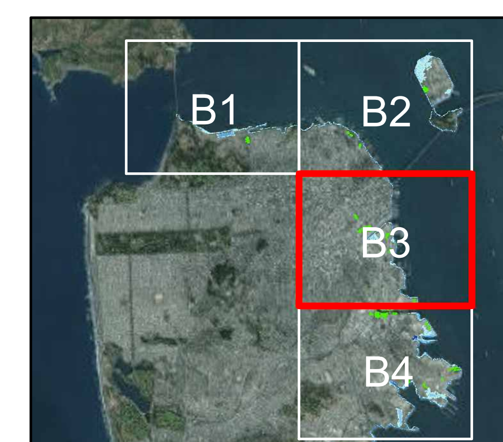

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 36" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

24" SLR + 1-YEAR STORM SURGE
18" SLR + 2-YEAR STORM SURGE
12" SLR + 5-YEAR STORM SURGE
6" SLR + 25-YEAR STORM SURGE
0" SLR + 50-YEAR STORM SURGE

Depth in Feet

Depth in Feet
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+
Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles

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0 1,500 3,000 Feet

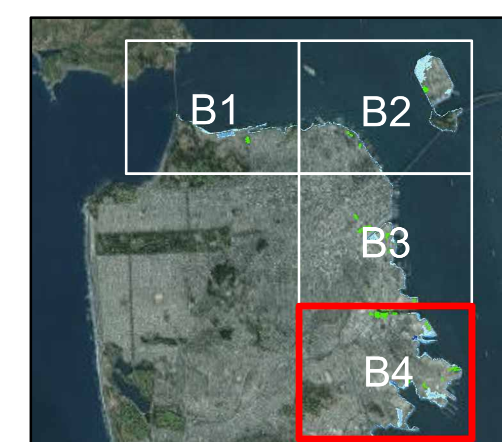
1 inch = 1,500 feet

San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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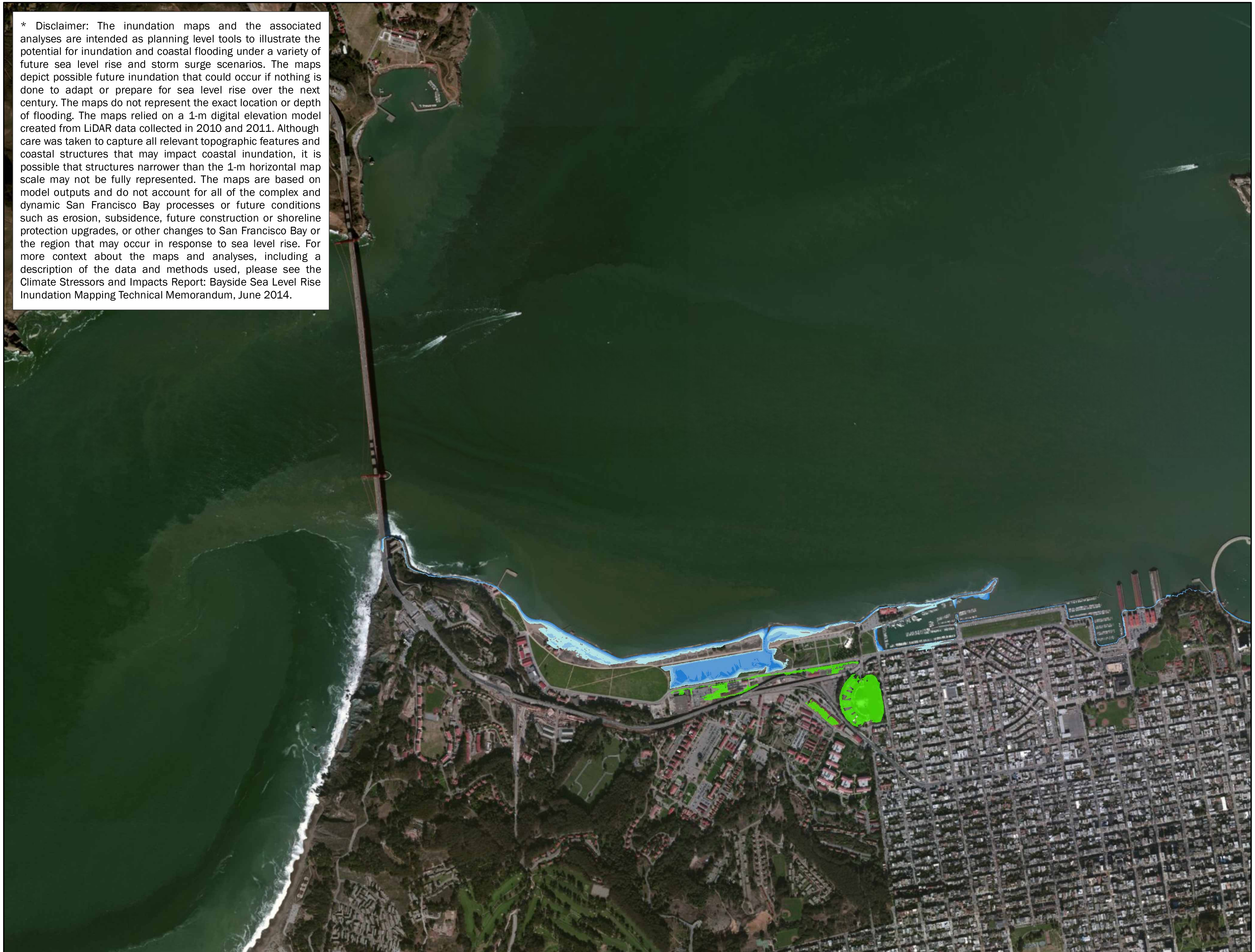

SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 48" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

36" SLR + 1-YEAR STORM SURGE
30" SLR + 2-YEAR STORM SURGE
24" SLR + 5-YEAR STORM SURGE
18" SLR + 25-YEAR STORM SURGE
12" SLR + 50-YEAR STORM SURGE
6" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+
Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
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0 1,500 3,000 Feet
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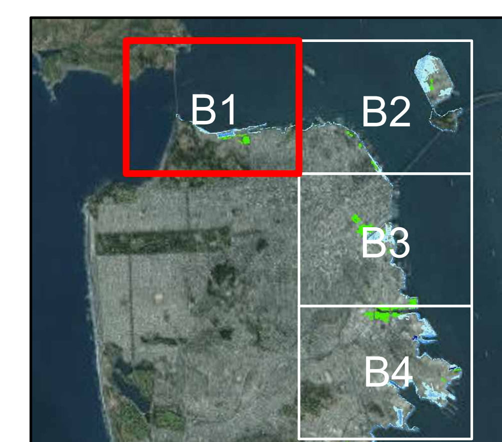
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 48" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

36" SLR + 1-YEAR STORM SURGE
30" SLR + 2-YEAR STORM SURGE
24" SLR + 5-YEAR STORM SURGE
18" SLR + 25-YEAR STORM SURGE
12" SLR + 50-YEAR STORM SURGE
6" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
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6 - 8
8 - 10
10 - 12
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Disconnected Areas > 1 Acre

N

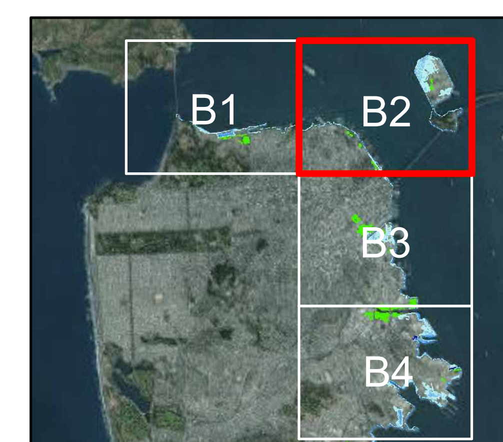
0 0.25 0.5 Miles
1 inch = 0.3 miles

0 1,500 3,000 Feet
1 inch = 1,500 feet

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 48" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

36" SLR + 1-YEAR STORM SURGE
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Depth in Feet

Depth in Feet
0 - 2
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6 - 8
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12+
Disconnected Areas > 1 Acre

0 0.25 0.5 Miles
1 inch = 0.3 miles
0 1,500 3,000 Feet
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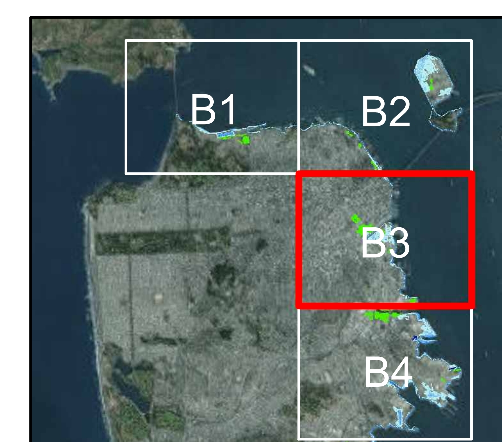
N

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 48" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

36" SLR + 1-YEAR STORM SURGE
30" SLR + 2-YEAR STORM SURGE
24" SLR + 5-YEAR STORM SURGE
18" SLR + 25-YEAR STORM SURGE
12" SLR + 50-YEAR STORM SURGE
6" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+

Disconnected Areas > 1 Acre

0 0.25 0.5 Miles
1 inch = 0.3 miles
0 1,500 3,000 Feet
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N

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
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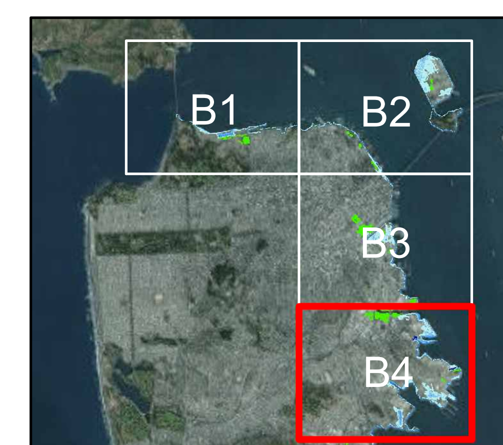
Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 52" SEA LEVEL RISE

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42" SLR + 1-YEAR STORM SURGE
36" SLR + 2-YEAR STORM SURGE
30" SLR + 5-YEAR STORM SURGE
24" SLR + 10-YEAR STORM SURGE
18" SLR + 50-YEAR STORM SURGE
12" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+

Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
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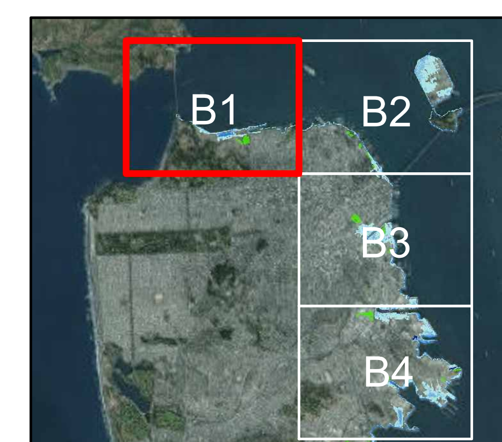
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 52" SEA LEVEL RISE

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42" SLR + 1-YEAR STORM SURGE
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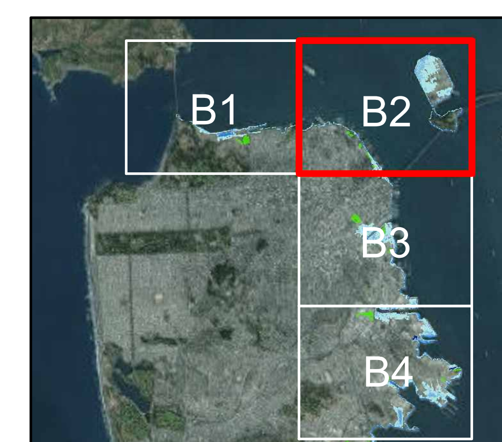
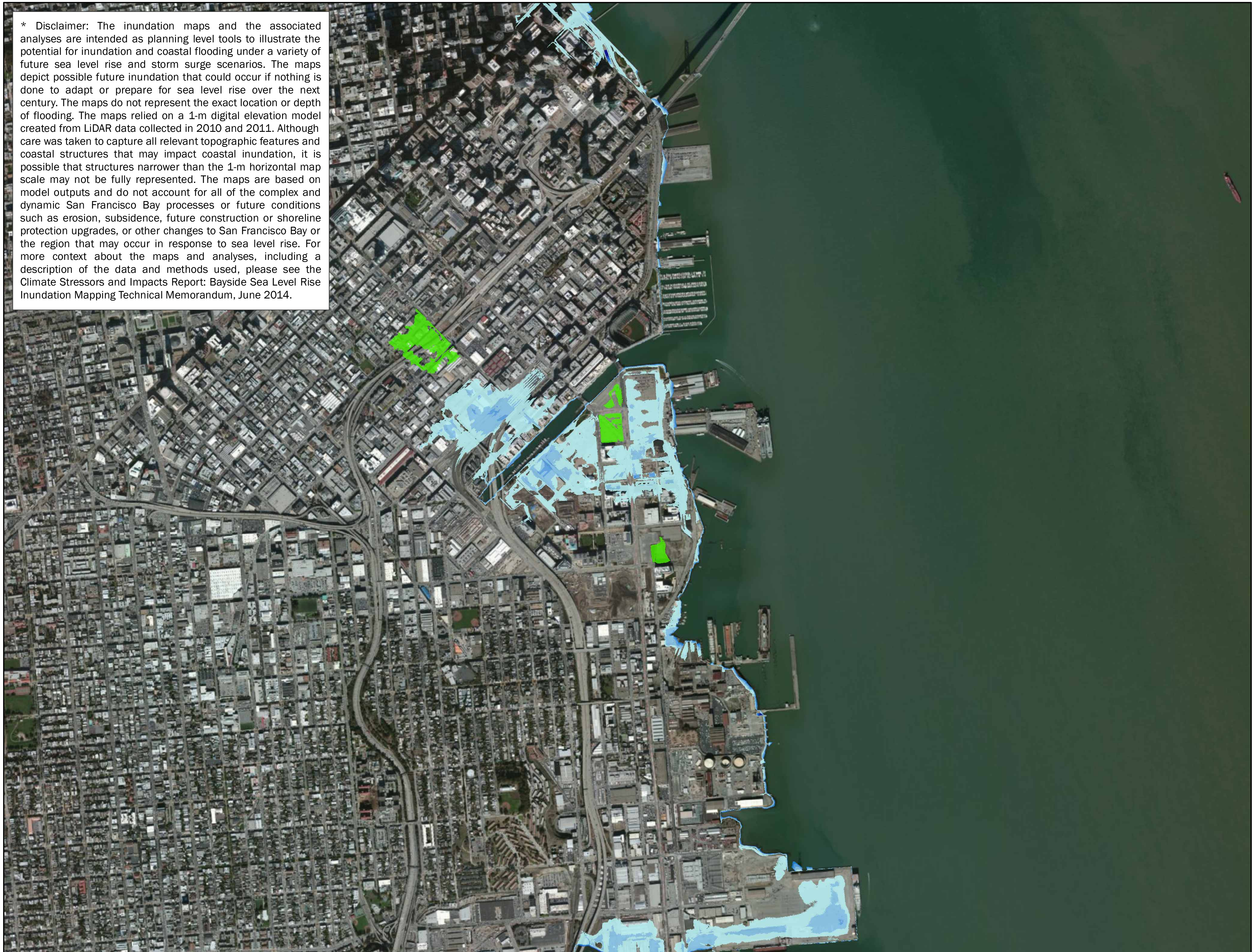


SFPUC SSIP BAYSIDE

Inundation Mapping



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MHHW + 52" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

42" SLR + 1-YEAR STORM SURGE
36" SLR + 2-YEAR STORM SURGE
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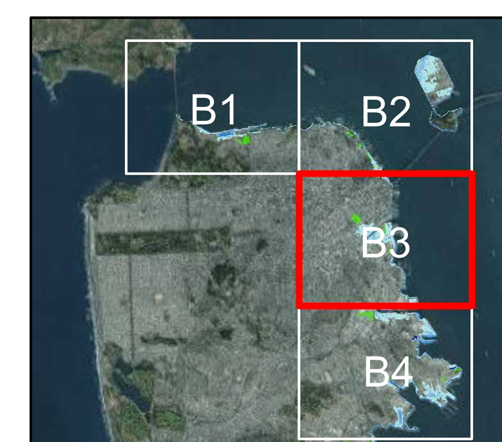
Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 52" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

42” SLR + 1-YEAR STORM SURGE
36” SLR + 2-YEAR STORM SURGE
30” SLR + 5-YEAR STORM SURGE
24” SLR + 10-YEAR STORM SURGE
18” SLR + 50-YEAR STORM SURGE
12” SLR + 100-YEAR STORM SURGE

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12+
- Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
1 inch = 0.3 miles

0 1,500 3,000 Feet
1 inch = 1,500 feet

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 66" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

54" SLR + 1-YEAR STORM SURGE
48" SLR + 2-YEAR STORM SURGE
42" SLR + 5-YEAR STORM SURGE
36" SLR + 25-YEAR STORM SURGE
30" SLR + 50-YEAR STORM SURGE
24" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+
Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
1 inch = 0.3 miles

0 1,500 3,000 Feet
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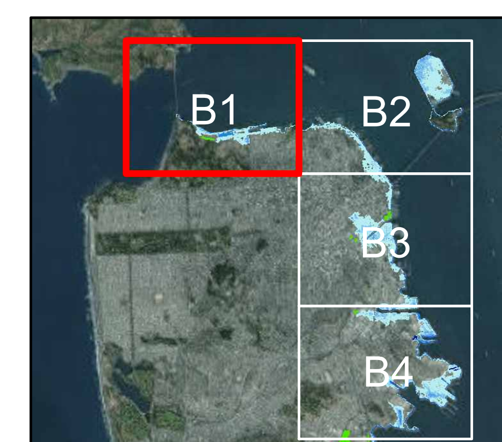
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 66" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

54" SLR + 1-YEAR STORM SURGE
48" SLR + 2-YEAR STORM SURGE
42" SLR + 5-YEAR STORM SURGE
36" SLR + 25-YEAR STORM SURGE
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24" SLR + 100-YEAR STORM SURGE

Depth in Feet

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4 - 6
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10 - 12
12+
Disconnected Areas > 1 Acre

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Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015

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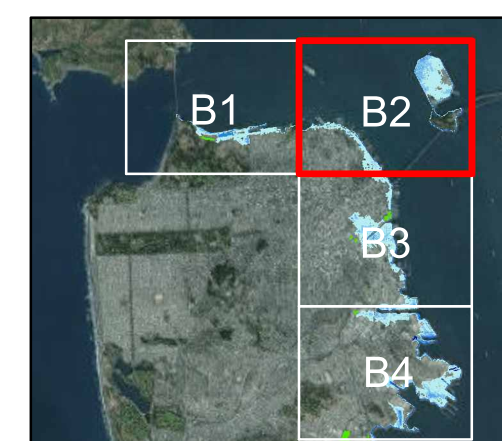

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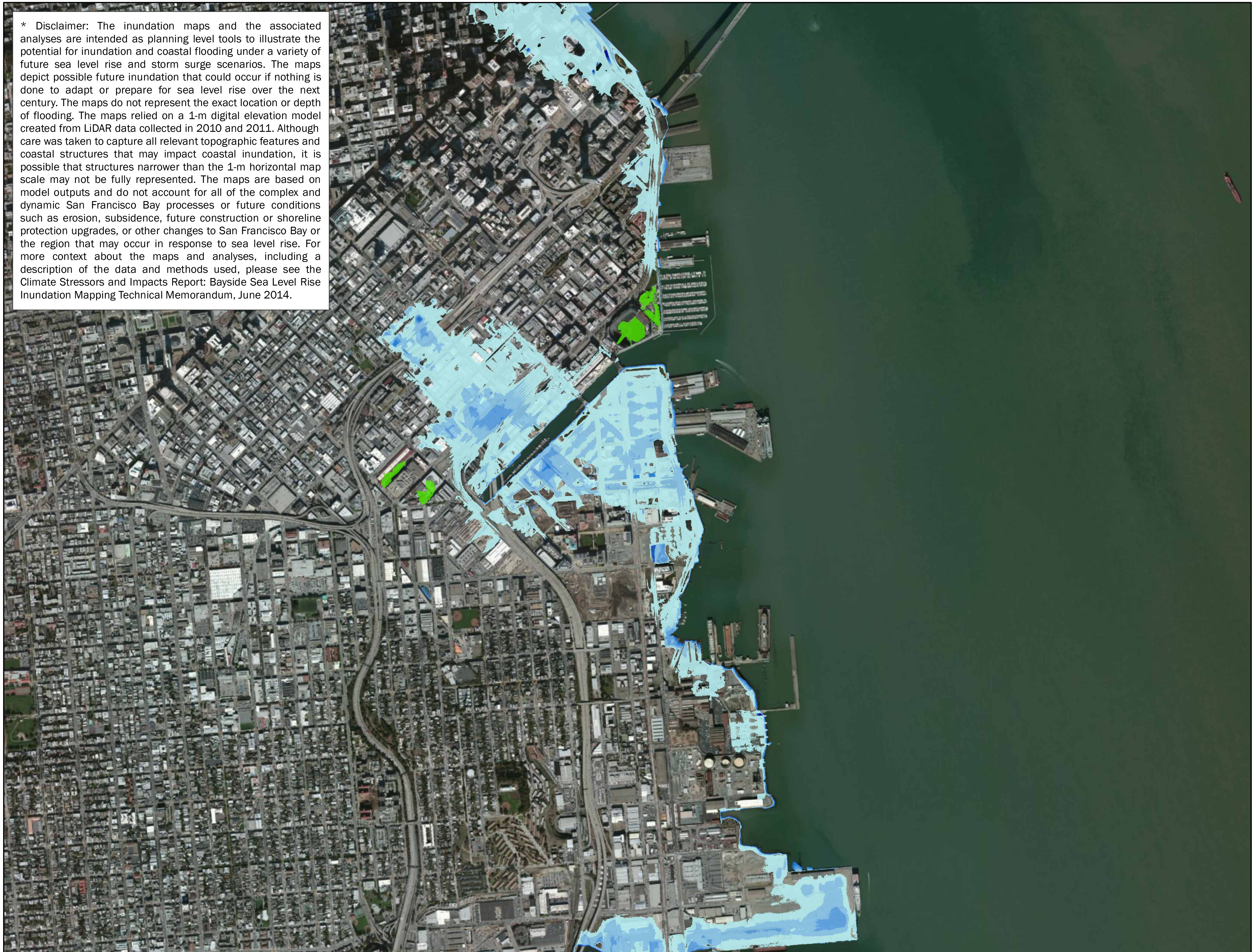

SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 66" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

54" SLR + 1-YEAR STORM SURGE
48" SLR + 2-YEAR STORM SURGE
42" SLR + 5-YEAR STORM SURGE
36" SLR + 25-YEAR STORM SURGE
30" SLR + 50-YEAR STORM SURGE
24" SLR + 100-YEAR STORM SURGE

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
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- Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
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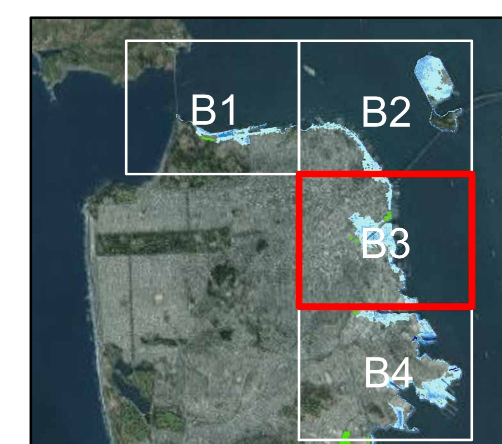
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 66" SEA LEVEL RISE

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

54" SLR + 1-YEAR STORM SURGE
48" SLR + 2-YEAR STORM SURGE
42" SLR + 5-YEAR STORM SURGE
36" SLR + 25-YEAR STORM SURGE
30" SLR + 50-YEAR STORM SURGE
24" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12+
Disconnected Areas > 1 Acre

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San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

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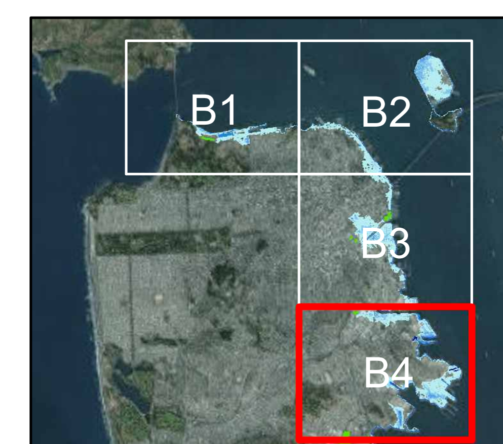

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 77" WATER LEVEL

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

66" SLR + 1-YEAR STORM SURGE
60" SLR + 2-YEAR STORM SURGE
54"SLR + 5-YEAR STORM SURGE
48"SLR + 10-YEAR STORM SURGE
42"SLR + 50-YEAR STORM SURGE
36"SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
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Disconnected Areas > 1 Acre

N

0 0.25 0.5 Miles
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San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
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66” SLR + 1-YEAR STORM SURGE
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Depth in Feet

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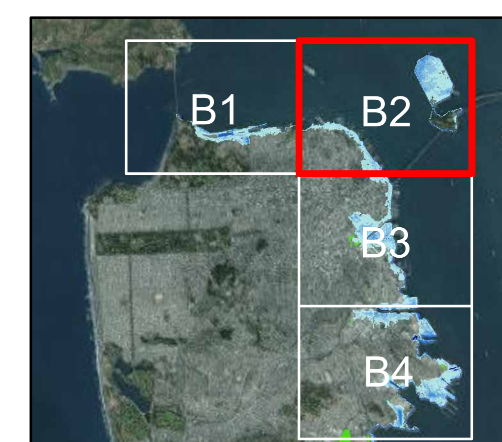

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SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 77" WATER LEVEL

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66" SLR + 1-YEAR STORM SURGE
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Inundation Mapping

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66" SLR + 1-YEAR STORM SURGE
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MHHW + 84" WATER LEVEL

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

66" SLR + 2-YEAR STORM SURGE
60" SLR + 5-YEAR STORM SURGE
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42" SLR + 100-YEAR STORM SURGE

Depth in Feet

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San Francisco Water Power Sewer
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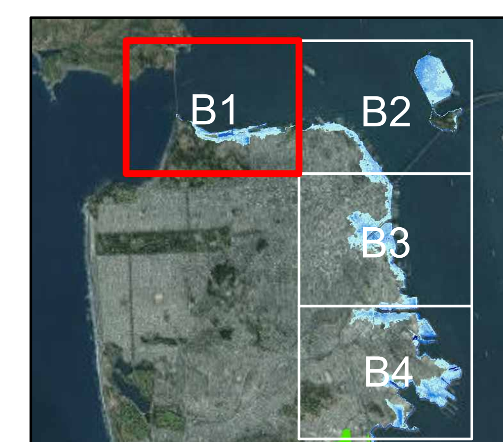

SFPUC SSIP BAYSIDE

Inundation Mapping

MHHW + 84" WATER LEVEL

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66" SLR + 2-YEAR STORM SURGE
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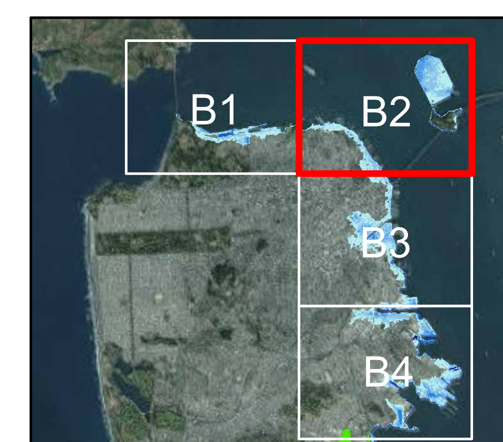

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MHHW + 84" WATER LEVEL

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66” SLR + 2-YEAR STORM SURGE
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42” SLR + 100-YEAR STORM SURGE

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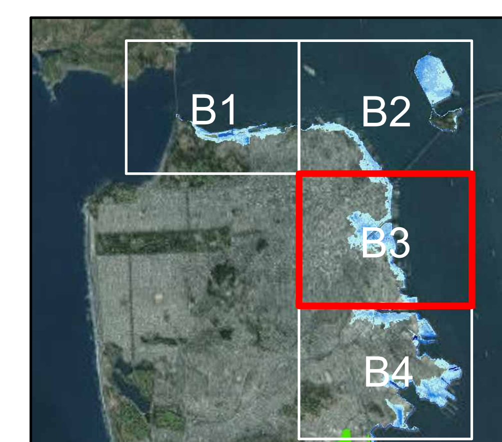

SFPUC SSIP BAYSIDE

Inundation Mapping

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MHHW + 84" WATER LEVEL

SLR + STORM SURGE SCENARIOS LISTED BELOW COULD BE APPROXIMATED BY THE INUNDATION SHOWN ON THIS MAP. FOR FUTHER INFORMATION, SEE TO19 - CLIMATE STRESSORS AND IMPACTS: BAYSIDE SEA LEVEL RISE MAPPING TM, JUNE 2014.

66" SLR + 2-YEAR STORM SURGE
60" SLR + 5-YEAR STORM SURGE
54" SLR + 25-YEAR STORM SURGE
48" SLR + 50-YEAR STORM SURGE
42" SLR + 100-YEAR STORM SURGE

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12+

Disconnected Areas > 1 Acre

N

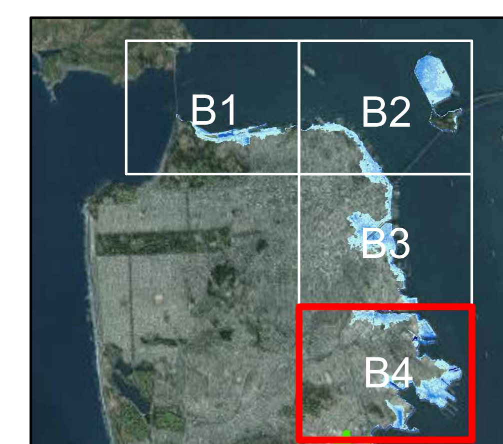
0 0.25 0.5 Miles
1 inch = 0.3 miles

0 1,500 3,000 Feet
1 inch = 1,500 feet

San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/11/2015



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Inundation Mapping

MHHW + 96" WATER LEVEL

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66" SLR + 25-YEAR STORM SURGE
60" SLR + 50-YEAR STORM SURGE
54" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2
2 - 4
4 - 6
6 - 8
8 - 10
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12+
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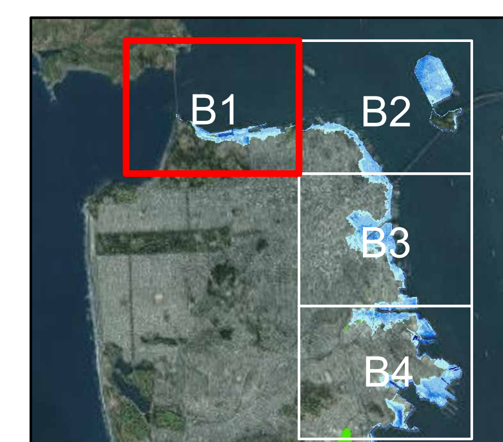

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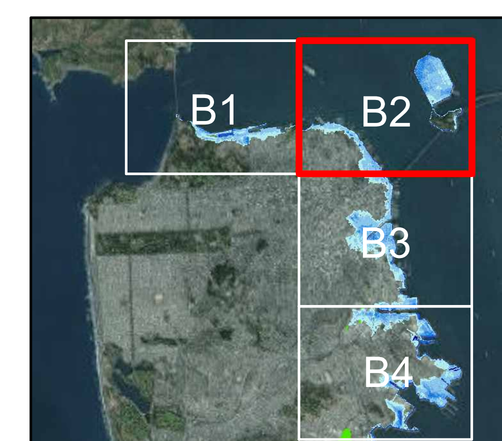

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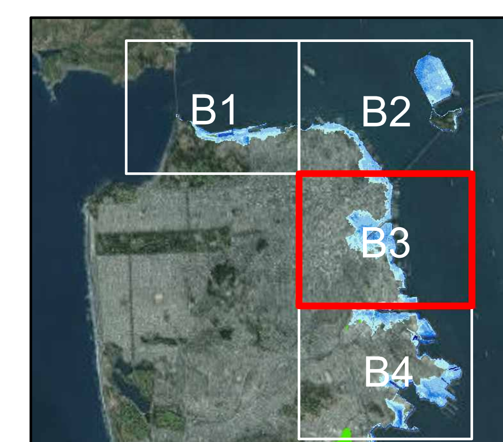

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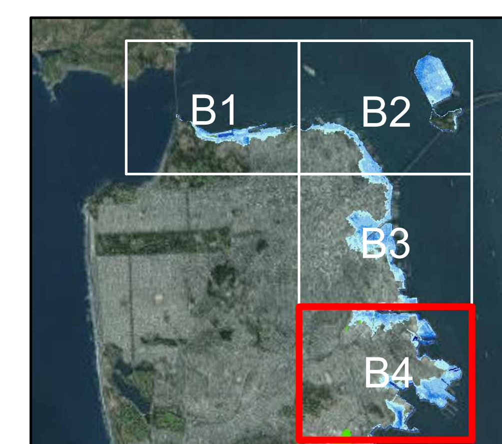

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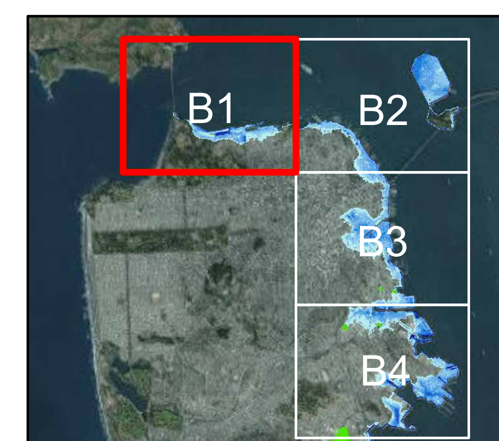

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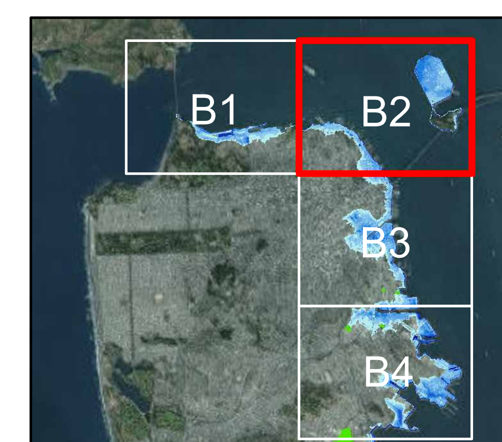

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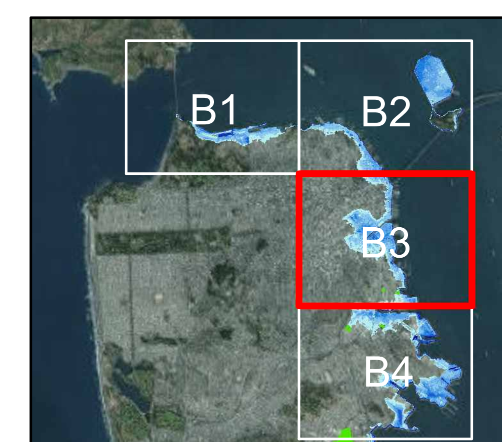

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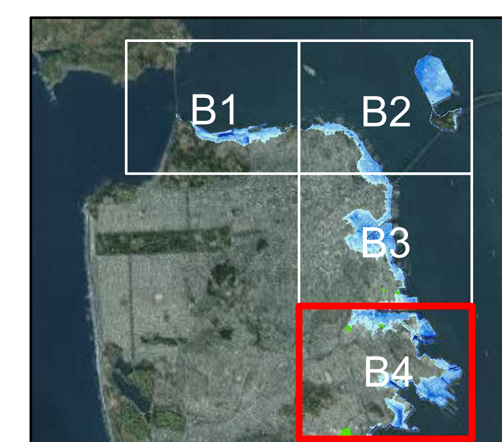

APPENDIX B – DAILY AND EXTREME TIDE LEVELS FOR SFPUC SSIP BAYSIDE SHORELINE

Description of Daily and Extreme Tide Levels

This appendix presents the detailed results of the water level analysis described in Section 3.1. Figure B-1 presents the locations and IDs of the FEMA model output points presented in Table B-1 and Table B-2. The extraction points were selected to adequately characterize the spatial variability of water levels throughout the study area. Table B-1 presents the daily and extreme tide water levels calculated for each model output point, referenced to North American Vertical Datum of 1988 (NAVD88). Table B-2 presents the daily and extreme tide water levels referenced to the San Francisco City Datum (SFCD). The daily tide water levels (tidal datums) were computed using the records observed during the current National Tidal Datum Epoch (NTDE), which is a specific 19-year period (1983-2001) adopted by NOAA to perform tidal computations. The following tidal datums were computed for each model output point using the current NTDE:

- MLLW (mean lower low water) – average of the lower low tides of each day.
- MLW (mean low water) – average of the higher low tides of each day.
- MSL (mean sea level) – average of all water levels.
- MTL (mean tide level) – average of average high water and average low water levels during the NTDE.
- MHW (mean high water) – average of the lower high tides of each day.
- MHHW (mean higher high water) – average of the higher high tides of each day.

In addition to the tidal datums, extreme tide levels calculated were for each model output point and are provided in Table B-1 and Table B-2. An extreme tide level is the increased elevation in water level during flood events, minus the contribution from waves due to wind or seismic effects. The extreme tide levels were computed using the 31-year record of the simulated time series. The generalized extreme value (GEV) probability distribution was fit to the annual maxima dataset derived at each model output point, and extreme tide elevations were calculated at each return period. The water level statistics used to represent the extreme tides include the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year extreme tide levels. The estimates of the 500-year tide level are only approximate, given the relatively short duration of the hydrodynamic model hindcast. The conversion from NAVD88 to SFCD was taken from the SFPUC's "Design Tides and Project Planning for Sea Level Rise" Draft Design Standard (SFPUC 2010). The following datum conversions listed in the SFPUC document were applied to the FEMA water levels: San Francisco City Datum is 11.336 feet above NAVD88.

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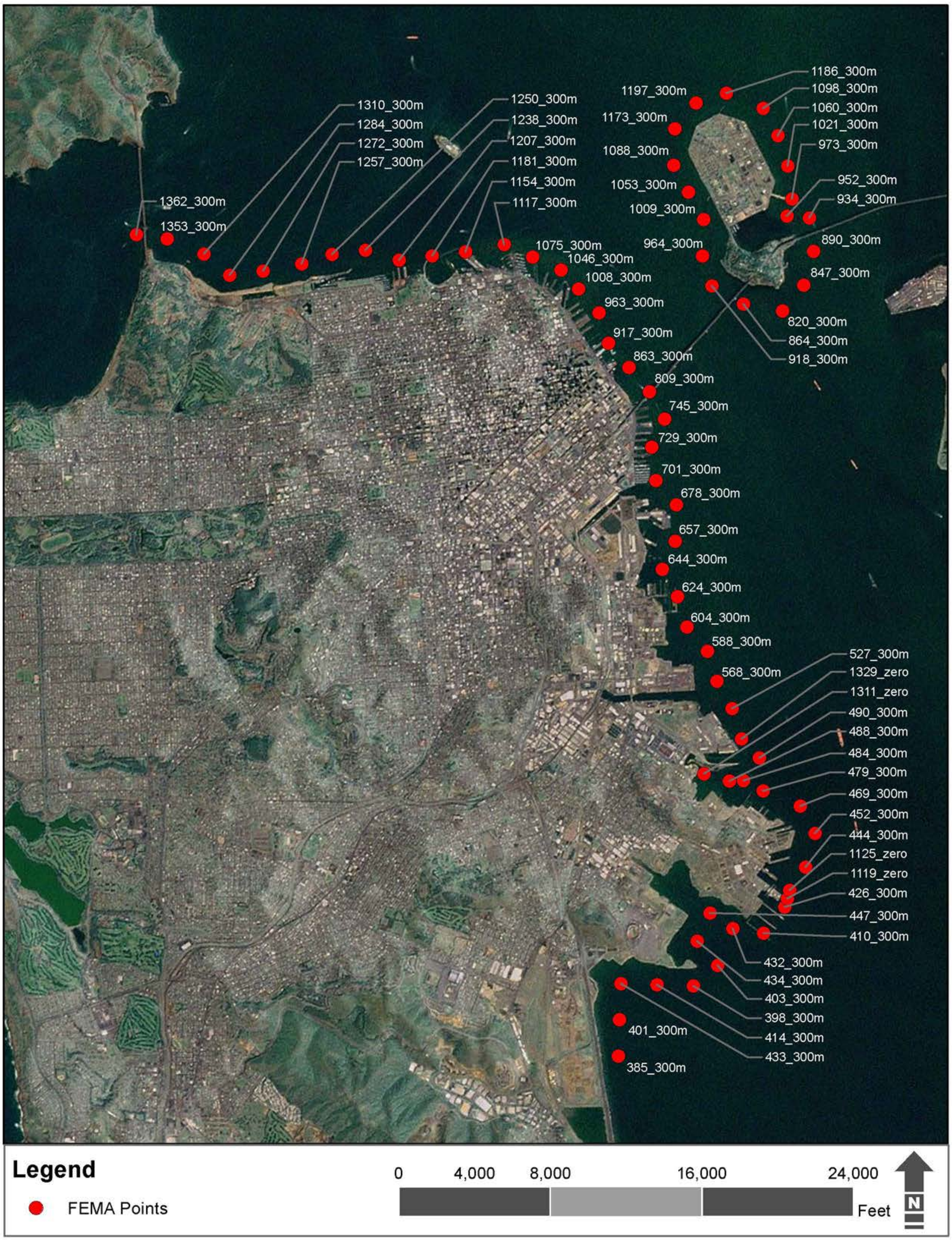

Figure B- 1: Federal Emergency Management Agency MIKE 21 Model Extraction Point IDs within the Project Area

Table B-1: San Francisco Existing Daily and Extreme Tide Levels (NAVD88-FT)

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	NAVD88-FT						NAVD88-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
385_300m	37.6955	-122.3886	2081213.5541	6015265.6925	-0.60	0.57	3.28	3.31	6.05	6.67	8.26	8.63	8.92	9.25	9.36	9.74	10.18	11.46
398_300m	37.7058	-122.3752	2084901.0139	6019225.5600	-0.57	0.59	3.28	3.31	6.03	6.64	8.23	8.60	8.89	9.21	9.32	9.70	10.13	11.36
401_300m	37.7007	-122.3885	2083125.3941	6015333.8026	-0.59	0.58	3.28	3.31	6.05	6.66	8.26	8.63	8.92	9.24	9.36	9.74	10.17	11.44
403_300m	37.7089	-122.3709	2085981.5236	6020502.6899	-0.55	0.61	3.27	3.31	6.01	6.63	8.21	8.58	8.87	9.19	9.30	9.67	10.09	11.30
410_300m	37.7137	-122.3626	2087696.7760	6022928.4725	-0.53	0.63	3.27	3.31	6.00	6.60	8.19	8.56	8.85	9.17	9.28	9.64	10.06	11.25
414_300m	37.7059	-122.3818	2084969.1240	6017313.7528	-0.58	0.58	3.28	3.31	6.04	6.66	8.25	8.62	8.91	9.24	9.35	9.73	10.16	11.41
426_300m	37.7175	-122.3588	2089064.4570	6024046.9086	-0.51	0.64	3.25	3.31	5.98	6.59	8.17	8.54	8.83	9.15	9.26	9.62	10.03	11.21
432_300m	37.7142	-122.3682	2087923.5472	6021303.8038	-0.54	0.62	3.27	3.31	6.01	6.62	8.21	8.57	8.86	9.18	9.29	9.66	10.08	11.27
433_300m	37.7060	-122.3884	2085037.2013	6015401.9127	-0.58	0.58	3.28	3.31	6.05	6.66	8.26	8.63	8.92	9.25	9.36	9.74	10.17	11.43
434_300m	37.7123	-122.3747	2087258.6536	6019422.1475	-0.54	0.61	3.27	3.31	6.01	6.62	8.21	8.58	8.87	9.19	9.30	9.67	10.09	11.29
444_300m	37.7233	-122.3552	2091165.1418	6025135.1938	-0.48	0.67	3.24	3.31	5.96	6.57	8.15	8.52	8.81	9.13	9.24	9.60	10.01	11.17
447_300m	37.7164	-122.3725	2088754.8448	6020094.7839	-0.54	0.61	3.27	3.31	6.01	6.62	8.21	8.58	8.87	9.19	9.30	9.67	10.09	11.29
452_300m	37.7283	-122.3535	2092948.4716	6025649.1363	-0.45	0.69	3.25	3.32	5.94	6.55	8.13	8.50	8.79	9.10	9.21	9.57	9.98	11.13
469_300m	37.7322	-122.3564	2094384.2955	6024855.7652	-0.43	0.70	3.25	3.32	5.93	6.53	8.10	8.48	8.77	9.08	9.19	9.55	9.96	11.09
479_300m	37.7343	-122.3632	2095185.3766	6022913.7416	-0.42	0.72	3.26	3.31	5.91	6.51	8.08	8.46	8.75	9.07	9.17	9.53	9.93	11.06
484_300m	37.7357	-122.3668	2095729.5356	6021863.3828	-0.41	0.73	3.26	3.32	5.90	6.50	8.08	8.46	8.75	9.06	9.17	9.53	9.93	11.05
488_300m	37.7356	-122.3694	2095699.3191	6021130.4118	-0.41	0.73	3.26	3.32	5.91	6.50	8.08	8.46	8.75	9.06	9.17	9.53	9.94	11.06
490_300m	37.7391	-122.3640	2096938.5227	6022694.6803	-0.40	0.73	3.26	3.31	5.89	6.49	8.07	8.44	8.73	9.05	9.16	9.51	9.91	11.02
527_300m	37.7461	-122.3692	2099522.9663	6021266.6320	-0.37	0.76	3.26	3.31	5.86	6.45	8.02	8.41	8.70	9.01	9.12	9.47	9.87	10.96
568_300m	37.7500	-122.3720	2100958.7902	6020473.2609	-0.35	0.77	3.26	3.31	5.85	6.44	8.01	8.39	8.68	9.00	9.11	9.46	9.86	10.95
588_300m	37.7543	-122.3739	2102553.2752	6019967.0283	-0.33	0.79	3.25	3.31	5.83	6.42	7.98	8.37	8.66	8.97	9.08	9.43	9.82	10.89
604_300m	37.7578	-122.3777	2103830.3724	6018886.5186	-0.31	0.80	3.25	3.31	5.81	6.40	7.97	8.35	8.64	8.96	9.06	9.42	9.80	10.86
624_300m	37.7621	-122.3795	2105424.8574	6018380.2861	-0.30	0.81	3.26	3.31	5.80	6.39	7.95	8.34	8.63	8.94	9.05	9.40	9.79	10.84
644_300m	37.7660	-122.3824	2106860.6813	6017586.9149	-0.28	0.82	3.26	3.31	5.80	6.38	7.94	8.33	8.62	8.94	9.04	9.39	9.78	10.83
657_300m	37.7702	-122.3802	2108356.8397	6018259.5514	-0.27	0.83	3.25	3.31	5.78	6.37	7.93	8.32	8.61	8.92	9.03	9.37	9.75	10.79
678_300m	37.7754	-122.3801	2110268.6797	6018327.6615	-0.24	0.85	3.23	3.30	5.75	6.34	7.89	8.28	8.58	8.89	8.99	9.34	9.71	10.73
701_300m	37.7789	-122.3839	2111545.8097	6017247.1190	-0.23	0.87	3.24	3.30	5.74	6.32	7.88	8.27	8.56	8.87	8.98	9.32	9.70	10.71

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	NAVD88-FT						NAVD88-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
729_300m	37.7837	-122.3848	2113298.9558	6017028.0578	-0.21	0.88	3.23	3.31	5.73	6.31	7.86	8.26	8.55	8.86	8.96	9.31	9.68	10.70
745_300m	37.7878	-122.3825	2114795.1142	6017700.6942	-0.19	0.89	3.22	3.30	5.71	6.29	7.84	8.23	8.53	8.84	8.95	9.29	9.68	10.71
809_300m	37.7917	-122.3854	2116230.9381	6016907.3231	-0.17	0.91	3.23	3.30	5.69	6.26	7.81	8.21	8.50	8.82	8.93	9.28	9.66	10.71
863_300m	37.7952	-122.3892	2117508.0681	6015826.7807	-0.15	0.93	3.23	3.30	5.68	6.25	7.79	8.19	8.48	8.80	8.91	9.26	9.65	10.71
917_300m	37.7986	-122.3930	2118785.1981	6014746.2382	-0.13	0.94	3.24	3.30	5.66	6.23	7.77	8.17	8.46	8.78	8.89	9.25	9.64	10.70
963_300m	37.8030	-122.3949	2120379.6503	6014240.0384	-0.12	0.94	3.20	3.29	5.64	6.20	7.74	8.14	8.44	8.76	8.87	9.23	9.62	10.70
1008_300m	37.8064	-122.3987	2121656.7803	6013159.4960	-0.10	0.95	3.21	3.29	5.62	6.18	7.72	8.12	8.42	8.74	8.85	9.21	9.60	10.68
1046_300m	37.8091	-122.4020	2122646.7718	6012237.6474	-0.08	0.96	3.20	3.28	5.60	6.16	7.69	8.09	8.39	8.72	8.83	9.19	9.59	10.69
1075_300m	37.8108	-122.4072	2123319.3754	6010741.4562	-0.07	0.97	3.20	3.28	5.58	6.14	7.67	8.07	8.37	8.70	8.81	9.17	9.58	10.69
1117_300m	37.8126	-122.4125	2123992.0119	6009245.2978	-0.06	0.97	3.19	3.27	5.56	6.11	7.64	8.04	8.34	8.67	8.79	9.16	9.58	10.73
1154_300m	37.8114	-122.4195	2123614.2567	6007204.9803	-0.04	1.00	3.22	3.27	5.54	6.09	7.62	8.01	8.32	8.65	8.76	9.14	9.56	10.75
1181_300m	37.8107	-122.4255	2123395.2283	6005451.8342	-0.03	1.01	3.22	3.27	5.52	6.08	7.60	7.99	8.30	8.63	8.74	9.12	9.55	10.74
1207_300m	37.8100	-122.4316	2123176.1670	6003698.6881	-0.01	1.02	3.23	3.26	5.51	6.06	7.58	7.97	8.28	8.61	8.73	9.11	9.54	10.74
1238_300m	37.8114	-122.4378	2123690.1096	6001915.3255	-0.01	1.02	3.22	3.26	5.50	6.05	7.56	7.95	8.26	8.60	8.71	9.10	9.53	10.74
1250_300m	37.8107	-122.4439	2123471.0483	6000162.1794	0.01	1.02	3.22	3.25	5.48	6.03	7.54	7.93	8.24	8.58	8.69	9.08	9.51	10.72
1257_300m	37.8092	-122.4493	2122964.8486	5998567.6944	0.01	1.03	3.22	3.25	5.46	6.01	7.52	7.91	8.22	8.56	8.67	9.06	9.49	10.70
1272_300m	37.8080	-122.4564	2122587.1262	5996527.4098	0.02	1.03	3.22	3.24	5.45	5.99	7.49	7.89	8.20	8.53	8.65	9.03	9.46	10.68
1284_300m	37.8073	-122.4624	2122368.0650	5994774.2637	0.03	1.04	3.22	3.23	5.43	5.97	7.47	7.87	8.18	8.51	8.63	9.02	9.45	10.66
1310_300m	37.8103	-122.4672	2123486.5339	5993406.5499	0.05	1.04	3.21	3.22	5.41	5.95	7.44	7.84	8.15	8.48	8.60	8.98	9.41	10.63
1353_300m	37.8124	-122.4740	2124287.6477	5991464.5262	0.07	1.05	3.21	3.22	5.39	5.93	7.41	7.81	8.12	8.46	8.57	8.95	9.38	10.58
1362_300m	37.8129	-122.4797	2124514.4189	5989839.8904	-0.06	0.90	3.06	3.13	5.37	5.89	7.36	7.76	8.07	8.40	8.51	8.89	9.31	10.47
1119_zero	37.7187	-122.3584	2089510.2895	6024175.3860	-0.50	0.65	3.25	3.31	5.98	6.58	8.17	8.54	8.83	9.14	9.25	9.62	10.03	11.20
1125_zero	37.7200	-122.3580	2089956.1219	6024303.8963	-0.49	0.65	3.24	3.31	5.97	6.57	8.16	8.53	8.82	9.13	9.24	9.61	10.01	11.18
1311_zero	37.7366	-122.3740	2096084.7842	6019792.8817	-0.35	0.76	3.26	3.33	5.90	6.50	8.08	8.46	8.75	9.07	9.18	9.54	9.94	11.07
1329_zero	37.7417	-122.3673	2097928.5141	6021772.8318	-0.38	0.74	3.25	3.31	5.88	6.47	8.05	8.43	8.72	9.03	9.14	9.50	9.89	10.99
820_300m	37.8038	-122.3614	2120484.9651	6023927.6503	-0.13	0.95	3.28	3.32	5.69	6.26	7.81	8.20	8.50	8.81	8.92	9.26	9.64	10.67
847_300m	37.8076	-122.3576	2121852.6461	6025046.1192	-0.14	0.94	3.27	3.31	5.68	6.25	7.80	8.20	8.49	8.81	8.91	9.26	9.64	10.65
864_300m	37.8046	-122.3686	2120840.2137	6021857.1492	-0.12	0.96	3.26	3.31	5.67	6.24	7.79	8.18	8.48	8.79	8.90	9.25	9.63	10.67
890_300m	37.8125	-122.3560	2123635.9758	6025560.0617	-0.12	0.95	3.27	3.31	5.67	6.25	7.79	8.19	8.49	8.80	8.91	9.26	9.64	10.68

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	NAVD88-FT						NAVD88-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
918_300m	37.8072	-122.3744	2121799.9887	6020202.2968	-0.11	0.95	3.23	3.30	5.66	6.22	7.76	8.16	8.46	8.77	8.88	9.23	9.61	10.66
934_300m	37.8173	-122.3568	2125389.1219	6025341.0005	-0.12	0.97	3.28	3.32	5.67	6.23	7.79	8.18	8.48	8.80	8.91	9.26	9.64	10.69
952_300m	37.8175	-122.3609	2125487.4157	6024162.1643	-0.11	0.97	3.28	3.32	5.66	6.24	7.79	8.18	8.48	8.80	8.91	9.26	9.65	10.70
964_300m	37.8115	-122.3762	2123394.4737	6019696.0971	-0.09	0.97	3.24	3.30	5.64	6.20	7.74	8.14	8.44	8.76	8.86	9.22	9.61	10.67
973_300m	37.8200	-122.3601	2126379.1134	6024419.1519	-0.10	0.97	3.28	3.32	5.66	6.23	7.78	8.18	8.48	8.80	8.90	9.26	9.64	10.69
1009_300m	37.8168	-122.3761	2125306.3137	6019764.2072	-0.07	0.99	3.26	3.31	5.62	6.19	7.73	8.12	8.42	8.74	8.85	9.21	9.61	10.68
1021_300m	37.8248	-122.3610	2128132.2595	6024200.0907	-0.09	0.98	3.27	3.31	5.65	6.22	7.76	8.16	8.47	8.79	8.89	9.25	9.64	10.70
1053_300m	37.8207	-122.3790	2126742.1048	6018970.8361	-0.06	1.00	3.27	3.30	5.61	6.17	7.71	8.11	8.41	8.73	8.84	9.20	9.60	10.68
1060_300m	37.8291	-122.3628	2129726.7445	6023693.8909	-0.07	0.99	3.27	3.31	5.64	6.21	7.75	8.15	8.45	8.77	8.88	9.24	9.64	10.71
1088_300m	37.8246	-122.3818	2128177.8959	6018177.4649	-0.04	1.01	3.27	3.30	5.60	6.16	7.69	8.09	8.40	8.72	8.83	9.19	9.59	10.69
1098_300m	37.8330	-122.3657	2131162.5356	6022900.5198	-0.06	1.00	3.27	3.31	5.63	6.19	7.73	8.13	8.44	8.76	8.87	9.24	9.64	10.73
1173_300m	37.8298	-122.3817	2130089.7359	6018245.5750	-0.03	1.03	3.28	3.31	5.59	6.15	7.69	8.09	8.40	8.73	8.84	9.21	9.63	10.77
1186_300m	37.8351	-122.3725	2131963.6495	6020958.4961	-0.04	1.01	3.27	3.31	5.61	6.17	7.71	8.11	8.42	8.75	8.86	9.24	9.65	10.80
1197_300m	37.8337	-122.3779	2131457.4169	6019364.0111	-0.03	1.02	3.29	3.31	5.60	6.17	7.70	8.10	8.41	8.74	8.85	9.23	9.65	10.83

1. Tidal data calculated based on National Tidal Datum Epoch (1983–2001)
2. Tidal data and surge elevations calculated using data from FEMA regional model (Central/North) of San Francisco Bay (DHI 2011)
3. Surge elevations calculated using generalized extreme value distribution – maximum likelihood method
4. SWEL_100 = 100-year SWEL, the 1% annual chance extreme tide elevation based on FEMA model simulations, determined from statistical analysis of modeled annual maximum water levels at each model output point

Table B-2: San Francisco Existing Daily and Extreme Tide Levels (San Francisco City Datum-FT)

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	SFCD-FT						SFCD-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
385_300m	37.6955	-122.3886	2081213.5541	6015265.6925	-11.93	-10.77	-8.05	-8.03	-5.29	-4.67	-3.08	-2.71	-2.42	-2.09	-1.98	-1.59	-1.16	0.12
398_300m	37.7058	-122.3752	2084901.0139	6019225.5600	-11.90	-10.74	-8.06	-8.03	-5.31	-4.70	-3.11	-2.74	-2.45	-2.12	-2.01	-1.64	-1.21	0.02
401_300m	37.7007	-122.3885	2083125.3941	6015333.8026	-11.92	-10.76	-8.05	-8.03	-5.29	-4.68	-3.08	-2.71	-2.42	-2.09	-1.98	-1.60	-1.16	0.10
403_300m	37.7089	-122.3709	2085981.5236	6020502.6899	-11.88	-10.73	-8.06	-8.03	-5.32	-4.71	-3.13	-2.76	-2.47	-2.15	-2.04	-1.67	-1.25	-0.04
410_300m	37.7137	-122.3626	2087696.7760	6022928.4725	-11.86	-10.71	-8.07	-8.02	-5.34	-4.74	-3.15	-2.78	-2.49	-2.17	-2.06	-1.69	-1.28	-0.09
414_300m	37.7059	-122.3818	2084969.1240	6017313.7528	-11.91	-10.76	-8.05	-8.02	-5.29	-4.68	-3.08	-2.72	-2.42	-2.10	-1.99	-1.61	-1.18	0.07
426_300m	37.7175	-122.3588	2089064.4570	6024046.9086	-11.84	-10.70	-8.08	-8.03	-5.36	-4.75	-3.17	-2.80	-2.51	-2.19	-2.08	-1.72	-1.30	-0.13
432_300m	37.7142	-122.3682	2087923.5472	6021303.8038	-11.87	-10.72	-8.07	-8.02	-5.33	-4.72	-3.13	-2.76	-2.47	-2.15	-2.04	-1.68	-1.26	-0.06
433_300m	37.7060	-122.3884	2085037.2013	6015401.9127	-11.92	-10.76	-8.05	-8.03	-5.29	-4.68	-3.08	-2.71	-2.42	-2.09	-1.98	-1.60	-1.16	0.09
434_300m	37.7123	-122.3747	2087258.6536	6019422.1475	-11.88	-10.72	-8.07	-8.03	-5.33	-4.72	-3.13	-2.76	-2.47	-2.15	-2.04	-1.67	-1.25	-0.04
444_300m	37.7233	-122.3552	2091165.1418	6025135.1938	-11.81	-10.67	-8.10	-8.02	-5.37	-4.77	-3.19	-2.82	-2.53	-2.21	-2.10	-1.74	-1.33	-0.17
447_300m	37.7164	-122.3725	2088754.8448	6020094.7839	-11.87	-10.72	-8.07	-8.02	-5.33	-4.71	-3.13	-2.76	-2.47	-2.15	-2.04	-1.67	-1.25	-0.05
452_300m	37.7283	-122.3535	2092948.4716	6025649.1363	-11.79	-10.65	-8.09	-8.02	-5.39	-4.79	-3.21	-2.84	-2.55	-2.23	-2.12	-1.76	-1.36	-0.21
469_300m	37.7322	-122.3564	2094384.2955	6024855.7652	-11.77	-10.63	-8.08	-8.02	-5.41	-4.81	-3.23	-2.86	-2.57	-2.25	-2.14	-1.78	-1.38	-0.25
479_300m	37.7343	-122.3632	2095185.3766	6022913.7416	-11.75	-10.62	-8.08	-8.02	-5.43	-4.83	-3.25	-2.88	-2.59	-2.27	-2.16	-1.80	-1.40	-0.28
484_300m	37.7357	-122.3668	2095729.5356	6021863.3828	-11.74	-10.61	-8.08	-8.02	-5.43	-4.83	-3.26	-2.88	-2.59	-2.27	-2.17	-1.81	-1.41	-0.28
488_300m	37.7356	-122.3694	2095699.3191	6021130.4118	-11.74	-10.61	-8.08	-8.02	-5.43	-4.83	-3.26	-2.88	-2.59	-2.27	-2.16	-1.80	-1.40	-0.27
490_300m	37.7391	-122.3640	2096938.5227	6022694.6803	-11.74	-10.61	-8.08	-8.02	-5.44	-4.85	-3.27	-2.89	-2.60	-2.29	-2.18	-1.82	-1.43	-0.32
527_300m	37.7461	-122.3692	2099522.9663	6021266.6320	-11.70	-10.58	-8.08	-8.03	-5.48	-4.88	-3.31	-2.93	-2.64	-2.33	-2.22	-1.86	-1.47	-0.37
568_300m	37.7500	-122.3720	2100958.7902	6020473.2609	-11.69	-10.56	-8.08	-8.03	-5.49	-4.90	-3.33	-2.94	-2.65	-2.34	-2.23	-1.87	-1.48	-0.39
588_300m	37.7543	-122.3739	2102553.2752	6019967.0283	-11.67	-10.55	-8.08	-8.03	-5.51	-4.92	-3.35	-2.97	-2.68	-2.36	-2.26	-1.90	-1.51	-0.44
604_300m	37.7578	-122.3777	2103830.3724	6018886.5186	-11.65	-10.54	-8.08	-8.03	-5.52	-4.93	-3.37	-2.98	-2.69	-2.38	-2.27	-1.92	-1.53	-0.47
624_300m	37.7621	-122.3795	2105424.8574	6018380.2861	-11.64	-10.52	-8.08	-8.03	-5.53	-4.94	-3.38	-3.00	-2.70	-2.39	-2.29	-1.94	-1.55	-0.50
644_300m	37.7660	-122.3824	2106860.6813	6017586.9149	-11.62	-10.51	-8.08	-8.03	-5.54	-4.95	-3.39	-3.01	-2.71	-2.40	-2.29	-1.94	-1.56	-0.51
657_300m	37.7702	-122.3802	2108356.8397	6018259.5514	-11.61	-10.50	-8.09	-8.03	-5.55	-4.97	-3.41	-3.02	-2.73	-2.42	-2.31	-1.96	-1.58	-0.55
678_300m	37.7754	-122.3801	2110268.6797	6018327.6615	-11.58	-10.48	-8.11	-8.03	-5.58	-5.00	-3.44	-3.05	-2.76	-2.45	-2.35	-2.00	-1.62	-0.61
701_300m	37.7789	-122.3839	2111545.8097	6017247.1190	-11.56	-10.47	-8.10	-8.03	-5.60	-5.02	-3.46	-3.07	-2.77	-2.46	-2.36	-2.02	-1.64	-0.62

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	SFCD-FT						SFCD-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
729_300m	37.7837	-122.3848	2113298.9558	6017028.0578	-11.54	-10.46	-8.10	-8.03	-5.61	-5.03	-3.47	-3.08	-2.79	-2.48	-2.37	-2.03	-1.65	-0.64
745_300m	37.7878	-122.3825	2114795.1142	6017700.6942	-11.53	-10.45	-8.12	-8.04	-5.62	-5.05	-3.50	-3.11	-2.81	-2.50	-2.39	-2.04	-1.66	-0.63
809_300m	37.7917	-122.3854	2116230.9381	6016907.3231	-11.51	-10.43	-8.10	-8.03	-5.64	-5.07	-3.52	-3.13	-2.83	-2.52	-2.41	-2.06	-1.67	-0.63
863_300m	37.7952	-122.3892	2117508.0681	6015826.7807	-11.48	-10.41	-8.11	-8.04	-5.66	-5.09	-3.54	-3.15	-2.85	-2.54	-2.43	-2.07	-1.69	-0.63
917_300m	37.7986	-122.3930	2118785.1981	6014746.2382	-11.47	-10.40	-8.10	-8.04	-5.68	-5.11	-3.57	-3.17	-2.87	-2.55	-2.45	-2.09	-1.70	-0.64
963_300m	37.8030	-122.3949	2120379.6503	6014240.0384	-11.45	-10.40	-8.13	-8.05	-5.70	-5.14	-3.59	-3.20	-2.90	-2.58	-2.47	-2.11	-1.72	-0.64
1008_300m	37.8064	-122.3987	2121656.7803	6013159.4960	-11.43	-10.39	-8.13	-8.05	-5.71	-5.15	-3.62	-3.22	-2.92	-2.60	-2.49	-2.13	-1.74	-0.66
1046_300m	37.8091	-122.4020	2122646.7718	6012237.6474	-11.42	-10.38	-8.13	-8.06	-5.74	-5.18	-3.65	-3.25	-2.94	-2.62	-2.51	-2.15	-1.74	-0.64
1075_300m	37.8108	-122.4072	2123319.3754	6010741.4562	-11.40	-10.37	-8.14	-8.06	-5.75	-5.20	-3.67	-3.27	-2.97	-2.64	-2.53	-2.16	-1.76	-0.65
1117_300m	37.8126	-122.4125	2123992.0119	6009245.2978	-11.39	-10.36	-8.14	-8.07	-5.78	-5.22	-3.70	-3.30	-2.99	-2.66	-2.55	-2.18	-1.76	-0.60
1154_300m	37.8114	-122.4195	2123614.2567	6007204.9803	-11.37	-10.34	-8.12	-8.07	-5.80	-5.24	-3.72	-3.33	-3.02	-2.69	-2.57	-2.19	-1.77	-0.59
1181_300m	37.8107	-122.4255	2123395.2283	6005451.8342	-11.36	-10.33	-8.11	-8.07	-5.81	-5.26	-3.74	-3.35	-3.04	-2.71	-2.59	-2.21	-1.79	-0.59
1207_300m	37.8100	-122.4316	2123176.1670	6003698.6881	-11.35	-10.32	-8.11	-8.07	-5.83	-5.28	-3.76	-3.36	-3.06	-2.72	-2.61	-2.23	-1.80	-0.60
1238_300m	37.8114	-122.4378	2123690.1096	6001915.3255	-11.34	-10.32	-8.12	-8.08	-5.84	-5.29	-3.78	-3.38	-3.07	-2.74	-2.62	-2.24	-1.81	-0.60
1250_300m	37.8107	-122.4439	2123471.0483	6000162.1794	-11.33	-10.31	-8.12	-8.09	-5.86	-5.31	-3.80	-3.40	-3.10	-2.76	-2.64	-2.26	-1.83	-0.62
1257_300m	37.8092	-122.4493	2122964.8486	5998567.6944	-11.32	-10.31	-8.12	-8.09	-5.87	-5.33	-3.82	-3.42	-3.11	-2.78	-2.66	-2.28	-1.85	-0.64
1272_300m	37.8080	-122.4564	2122587.1262	5996527.4098	-11.32	-10.30	-8.11	-8.10	-5.89	-5.35	-3.84	-3.45	-3.14	-2.80	-2.69	-2.30	-1.87	-0.66
1284_300m	37.8073	-122.4624	2122368.0650	5994774.2637	-11.31	-10.30	-8.12	-8.10	-5.91	-5.36	-3.86	-3.47	-3.16	-2.82	-2.71	-2.32	-1.89	-0.67
1310_300m	37.8103	-122.4672	2123486.5339	5993406.5499	-11.29	-10.30	-8.13	-8.11	-5.93	-5.39	-3.90	-3.50	-3.19	-2.85	-2.74	-2.35	-1.92	-0.71
1353_300m	37.8124	-122.4740	2124287.6477	5991464.5262	-11.27	-10.29	-8.13	-8.11	-5.94	-5.41	-3.92	-3.52	-3.22	-2.88	-2.77	-2.38	-1.96	-0.76
1362_300m	37.8129	-122.4797	2124514.4189	5989839.8904	-11.40	-10.44	-8.28	-8.20	-5.97	-5.45	-3.97	-3.58	-3.27	-2.94	-2.82	-2.45	-2.03	-0.87
1119_zero	37.7187	-122.3584	2089510.2895	6024175.3860	-11.84	-10.69	-8.09	-8.02	-5.36	-4.75	-3.17	-2.80	-2.51	-2.19	-2.08	-1.72	-1.31	-0.13
1125_zero	37.7200	-122.3580	2089956.1219	6024303.8963	-11.83	-10.68	-8.10	-8.03	-5.37	-4.77	-3.18	-2.81	-2.52	-2.20	-2.10	-1.73	-1.32	-0.16
1311_zero	37.7366	-122.3740	2096084.7842	6019792.8817	-11.68	-10.58	-8.07	-8.01	-5.43	-4.84	-3.26	-2.88	-2.59	-2.27	-2.16	-1.80	-1.40	-0.27
1329_zero	37.7417	-122.3673	2097928.5141	6021772.8318	-11.72	-10.59	-8.09	-8.03	-5.46	-4.86	-3.29	-2.91	-2.62	-2.30	-2.20	-1.84	-1.45	-0.35
820_300m	37.8038	-122.3614	2120484.9651	6023927.6503	-11.47	-10.38	-8.06	-8.02	-5.65	-5.08	-3.53	-3.13	-2.84	-2.53	-2.42	-2.07	-1.69	-0.67
847_300m	37.8076	-122.3576	2121852.6461	6025046.1192	-11.48	-10.39	-8.07	-8.02	-5.65	-5.08	-3.53	-3.14	-2.84	-2.53	-2.42	-2.08	-1.70	-0.68
864_300m	37.8046	-122.3686	2120840.2137	6021857.1492	-11.46	-10.38	-8.07	-8.02	-5.66	-5.10	-3.55	-3.15	-2.86	-2.54	-2.44	-2.09	-1.70	-0.67
890_300m	37.8125	-122.3560	2123635.9758	6025560.0617	-11.46	-10.38	-8.07	-8.02	-5.66	-5.09	-3.54	-3.15	-2.85	-2.53	-2.42	-2.07	-1.69	-0.66

Point ID	Coordinates (Northing/Easting in State Plane CAIII-FT)				Tidal Datums						Extreme Tide Levels							
	Lat.	Long.	Northing	Easting	SFCD-FT						SFCD-FT							
					MLLW	MLW	MSL	MTL	MHW	MHHW	SWEL_2	SWEL_5	SWEL_10	SWEL_20	SWEL_25	SWEL_50	SWEL_100	SWEL_500
918_300m	37.8072	-122.3744	2121799.9887	6020202.2968	-11.45	-10.39	-8.11	-8.03	-5.68	-5.12	-3.57	-3.18	-2.88	-2.56	-2.46	-2.11	-1.72	-0.68
934_300m	37.8173	-122.3568	2125389.1219	6025341.0005	-11.45	-10.37	-8.06	-8.02	-5.67	-5.10	-3.55	-3.15	-2.85	-2.54	-2.43	-2.08	-1.69	-0.65
952_300m	37.8175	-122.3609	2125487.4157	6024162.1643	-11.44	-10.37	-8.06	-8.02	-5.67	-5.10	-3.55	-3.15	-2.85	-2.54	-2.43	-2.07	-1.69	-0.63
964_300m	37.8115	-122.3762	2123394.4737	6019696.0971	-11.43	-10.37	-8.10	-8.03	-5.70	-5.13	-3.59	-3.20	-2.90	-2.58	-2.47	-2.12	-1.73	-0.67
973_300m	37.8200	-122.3601	2126379.1134	6024419.1519	-11.44	-10.37	-8.06	-8.02	-5.68	-5.10	-3.56	-3.16	-2.86	-2.54	-2.43	-2.08	-1.69	-0.64
1009_300m	37.8168	-122.3761	2125306.3137	6019764.2072	-11.41	-10.35	-8.08	-8.03	-5.71	-5.15	-3.61	-3.21	-2.91	-2.59	-2.48	-2.12	-1.73	-0.66
1021_300m	37.8248	-122.3610	2128132.2595	6024200.0907	-11.43	-10.36	-8.07	-8.02	-5.69	-5.12	-3.57	-3.17	-2.87	-2.55	-2.44	-2.09	-1.70	-0.63
1053_300m	37.8207	-122.3790	2126742.1048	6018970.8361	-11.39	-10.34	-8.07	-8.03	-5.73	-5.16	-3.63	-3.23	-2.93	-2.60	-2.50	-2.13	-1.74	-0.66
1060_300m	37.8291	-122.3628	2129726.7445	6023693.8909	-11.41	-10.35	-8.07	-8.02	-5.70	-5.13	-3.59	-3.19	-2.88	-2.56	-2.45	-2.09	-1.70	-0.63
1088_300m	37.8246	-122.3818	2128177.8959	6018177.4649	-11.38	-10.33	-8.07	-8.03	-5.74	-5.18	-3.64	-3.24	-2.94	-2.62	-2.51	-2.14	-1.74	-0.65
1098_300m	37.8330	-122.3657	2131162.5356	6022900.5198	-11.39	-10.34	-8.07	-8.02	-5.71	-5.14	-3.60	-3.20	-2.90	-2.57	-2.46	-2.10	-1.70	-0.60
1173_300m	37.8298	-122.3817	2130089.7359	6018245.5750	-11.36	-10.31	-8.05	-8.03	-5.74	-5.18	-3.65	-3.25	-2.94	-2.61	-2.50	-2.12	-1.71	-0.56
1186_300m	37.8351	-122.3725	2131963.6495	6020958.4961	-11.38	-10.32	-8.06	-8.02	-5.72	-5.16	-3.62	-3.22	-2.92	-2.59	-2.47	-2.10	-1.68	-0.53
1197_300m	37.8337	-122.3779	2131457.4169	6019364.0111	-11.36	-10.31	-8.05	-8.02	-5.73	-5.17	-3.63	-3.24	-2.93	-2.60	-2.48	-2.10	-1.68	-0.50

1. Tidal data calculated based on National Tidal Datum Epoch (1983–2001)
2. Tidal data and surge elevations calculated using data from FEMA regional model (Central/North) of San Francisco Bay (DHI 2011)
3. Surge elevations calculated using generalized extreme value distribution – maximum likelihood method
4. Conversions between SFCD, NGVD29, and NAVD88 were taken from the SFPUC's "Design Tides and Project Planning for Sea Level Rise" (Draft Design Standard, SFPUC Wastewater Enterprise, June 18, 2010). The following datum conversions listed in the SFPUC document were applied to the FEMA modeled water levels: San Francisco City Datum is 8.616 feet above NGVD29 and 11.336 feet above NAVD88
5. SWEL_100 = 100-year SWEL, the 1% annual chance extreme tide elevation based on FEMA model simulations, determined from statistical analysis of modeled annual maximum water levels at each model output point