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HAYWARD REGIONAL SHORELINE MASTER PLAN

FOR THE HAYWARD AREA SHORELINE PLANNING AGENCY (HASPA)

PART OF A JOINT POWERS AGREEMENT OF COH, HARD, AND EBRPD

TASK 2 DATA COLLECTION AND SEA LEVEL RISE MAPPING REPORT

SUBMITTED 11/26/2019

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INTRODUCTION

INTRODUCTION

This report describes the data sources and the approach used to update the inundation maps for the Hayward Shoreline area (project site) as part of the Hayward Regional Shoreline Master Plan project, commissioned by the Hayward Area Shoreline Planning Agency (HASPA). HASPA is a joint powers authority comprising the Hayward Area Recreation District (HARD), East Bay Regional Park District (EBRPD), and the City of Hayward. In 2015, sea level rise inundation maps for this area were released as part of the Adapting to Rising Tides study (ART). The 2015 maps represent the extent of bay-wide inundation resulting from the superposition of various sea level rise increments with the current high tide conditions, selected storm surge scenarios, and king tides.[1] This study expands on that previous effort by focusing on the Hayward shoreline area and by including the effect of sea level rise on the depth to groundwater in locations along the shoreline. The maps produced for this study represent both permanent inundation scenarios and temporary inundation scenarios caused by coastal storm events, for present and projected future conditions under various sea level rise increments.

OBJECTIVES

The main objective of inundation mapping is to identify potential future hazard areas for planning purposes in order to formulate appropriate adaptation strategies. The hazards considered in the inundation mapping effort are sea level rise, storm surge, and groundwater emergence. Various sea level rise increments are considered to represent different sea level rise probabilities, uncertainties and timelines. To assess future impacts of sea level rise in terms of inundation depth and extent, the selected sea level rise increment is added directly to the current hazard. No adjustments for increased storminess or other factors have been applied. The maps have been created based on best available existing information including:

- The anticipated inundation driven by sea level rise relative to mean higher high water has been obtained from the Adapting to Rising Tides Study.[2]
- Existing minimum depth to groundwater information was obtained from the Minimum Depth to Groundwater for the Coastal San Francisco Bay Area dataset.[3]
- The existing 1-percent annual chance coastal storm surge elevation (100-year return period stillwater elevation) has been obtained from FEMA's 06001CV2002B Flood Insurance Study.[4]

1. King Tides produce both the highest high tides and the lowest low tides of the year and typically occur in the winter months (December to February). They are astronomical tides that result from the combination of the closest proximity of the Earth to the Moon and Sun and a spring tide, which occurs twice a month after the new and full moon.
2. http://www.adaptingtorisingtides.org/maps-and-data-products/
3. https://dash.berkeley.edu/stash/dataset/doi:10.6078/D1W01Q
4. https://msc.fema.gov/portal/home

LIMITATIONS

The inundation maps produced in this study should be used for planning purposes only. Several factors contribute to a high level of uncertainty associated with the current assessment, including the pace of sea level rise, changes in frequency of storm events, precipitation changes, and other climate and anthropogenic effects. The variables and data sources selected for this study represent the best available science to date, but they are not predictions of what will happen. Rather, they represent possible, future scenarios that may be considered for planning purposes. Additional site-specific studies are recommended prior to implementing any projects or adaptive measures to ensure the uncertainty and risks are adequately addressed for the project's particular purpose.

It is acknowledged that adding sea level rise increments to the minimum depth to groundwater to determine the extent of future inundation is a simplified assumption. This assumption is likely conservative for some areas and overestimated for other areas. Geographically, this assumption is most uncertain furthest from the shoreline and in low-lying areas such as stream channels. This is due to the fact that water table maps do not reflect the process of discharge or other area-specific hydrogeological characteristics. Other potential groundwater impacts and effects that are not assessed as part of this study include saltwater intrusion, impacts on and effects of water supply/groundwater basin resources and management, subsurface utilities, and changes in precipitation. Additional certainty about future groundwater impacts would require a more detailed hydrogeological investigation, which is beyond the scope of this study.

Adding sea level rise increments to coastal storm surge elevations is also a simplified assumption, as it does not account for any local hydrodynamic or hydrologic conditions which could influence future inundation, nor does it account for potential increases in storm frequency and strength. However, this assumption is expected to provide results within a level of uncertainty aligned with the purpose of the overall assessment.

The hydrology and hydraulics of the existing stream and stormwater drainage systems are currently being studied by the Alameda County Flood Control and Water Conservation District ("District") (including potential impacts from sea level rise). The updated inundation maps presented here do not include any updates from the District study, and use instead information available from the effective FEMA Flood Insurance Study (FIS).

DATA COLLECTION

APPROACH

The following sections review the existing information considered by the design team in developing the updated inundation maps for the Hayward Shoreline Master Plan. This section will provide definitions of terms used, followed by a description of the available data sources for topography and bathymetry, coastal water levels, storm frequency trends, sea level rise trends, local hydrology, ground water, and wave climate.

DEFINITIONS

Return Periods

Flood events are typically classified based on a chance of occurrence. For example, a 1-percent annual chance of occurrence event has a 1% probability of happening in any given year. The common term is saying that the event has a return period of 100 years. As part of the evaluation process, the cumulative probability of occurrence of a given storm over a specific design life or planning period can be calculated as shown below. Some typical values for different annual exceedance probability (AEP) and planning periods are calculated according to the expression:

$$AEP = 1/T$$

Where:

- AEP is the annual exceedance probability;
- T is the return period of the event.

Tidal Datums

Tidal datums are specific ocean/estuary water level elevations based on observations and statistical analyses. Tidal datums are influenced by astronomical (predicted tides), hydrologic, climate, and meteorological factors, depending on the datum. They are used as a reference to measure, predict and define local water levels, and are defined in table 1.[5]

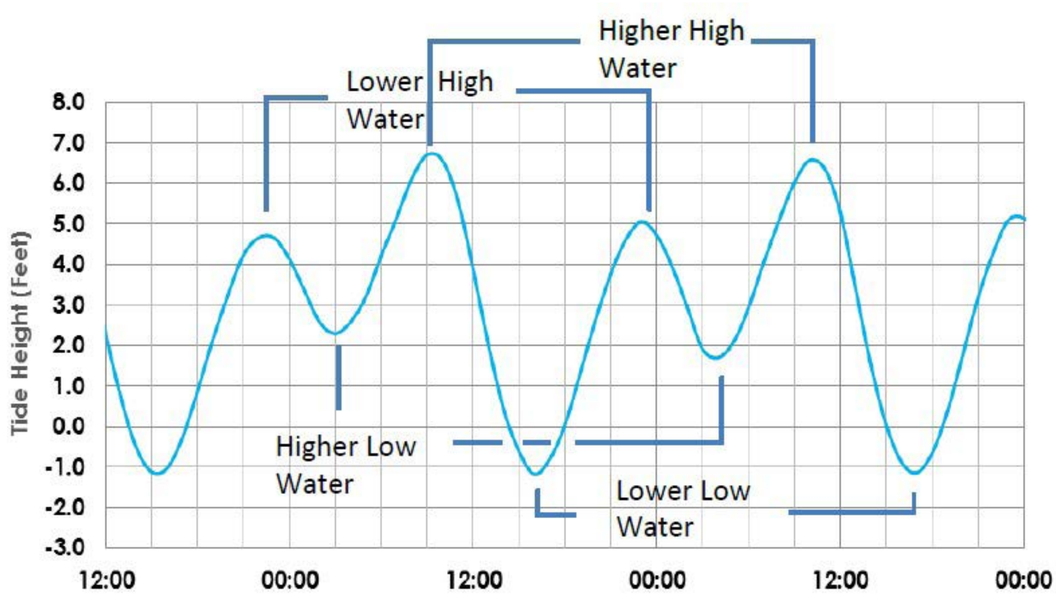

Figure 1: Daily high and low tide patterns in a mixed semidiurnal tide. Source: (AECOM, 2016)

5. https://tidesandcurrents.noaa.gov/datum_options.html

Table 1: Definitions of vertical datums. Source: (op. cit., p. 10)

Datum	Description	Definition
Max Tide	Highest Observed Tide	The maximum height reached by a rising tide. The high water is due to periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions.
HAT	Highest Astronomical Tide	The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the tidal epoch.
MHHW	Mean Higher High Water	The average of the higher high water height of each tidal day observed over the tidal epoch. (1)(2)(3)
MHW	Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch. (1)(2)(4)
MTL	Mean Tide Level	The arithmetic mean of mean high water and mean low water.
MSL	Mean Sea Level	The arithmetic mean of hourly heights observed over the tidal epoch.
MLW	Mean Low Water	The average of all the low water heights observed over the tidal epoch. (2)(4)
MLLW	Mean Lower Low Water	The average of the lower low water height of each tidal day observed over the tidal epoch. (2)(3)
NAVD88	North American Vertical Datum of 1988	Vertical datum for orthometric heights established for vertical control surveying in the United States of America based upon the General Adjustment of the North American Datum of 1988.
LAT	Lowest Astronomical Tide	The elevation of the lowest astronomical predicted tide expected to occur at a specific tide station over the tidal epoch.
Min Tide	Lowest Observed Tide	The minimum height reached by a falling tide. The low water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions.

Notes: (1) The National Tidal Datum Epoch or "Tidal Epoch" is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datums.
(2) In areas with perfectly identical semidiurnal tides, or in areas with a single tide, MHHW and MHW match. The same applies for the MLLW and MLW.
(3) High water is the maximum height reached by a rising tide. The high water is due to the periodic tidal forces and the effects of meteorological, hydrologic, and/or oceanographic conditions.
(4) Higher high water is the highest of the high waters (or single high water) for any specified tidal day due to the declinational effects of the Moon and Sun.

TOPOGRAPHY AND BATHYMETRY

Topography

USGS conducted a Lidar campaign of the area in 2010 and generated a Digital Elevation Model (DEM). The vertical datum used is NAVD88. A number of modifications to this DEM were conducted by the San Francisco Bay Conservation and Development Commission (BCDC) in 2015 to represent the changes to the shoreline between 2010 and 2015. Moreover, the topography of the Hayward Marsh has been updated as part of this study to reflect the latest information collected by CLE Engineering in 2014, and provided by HASPA to the project team.

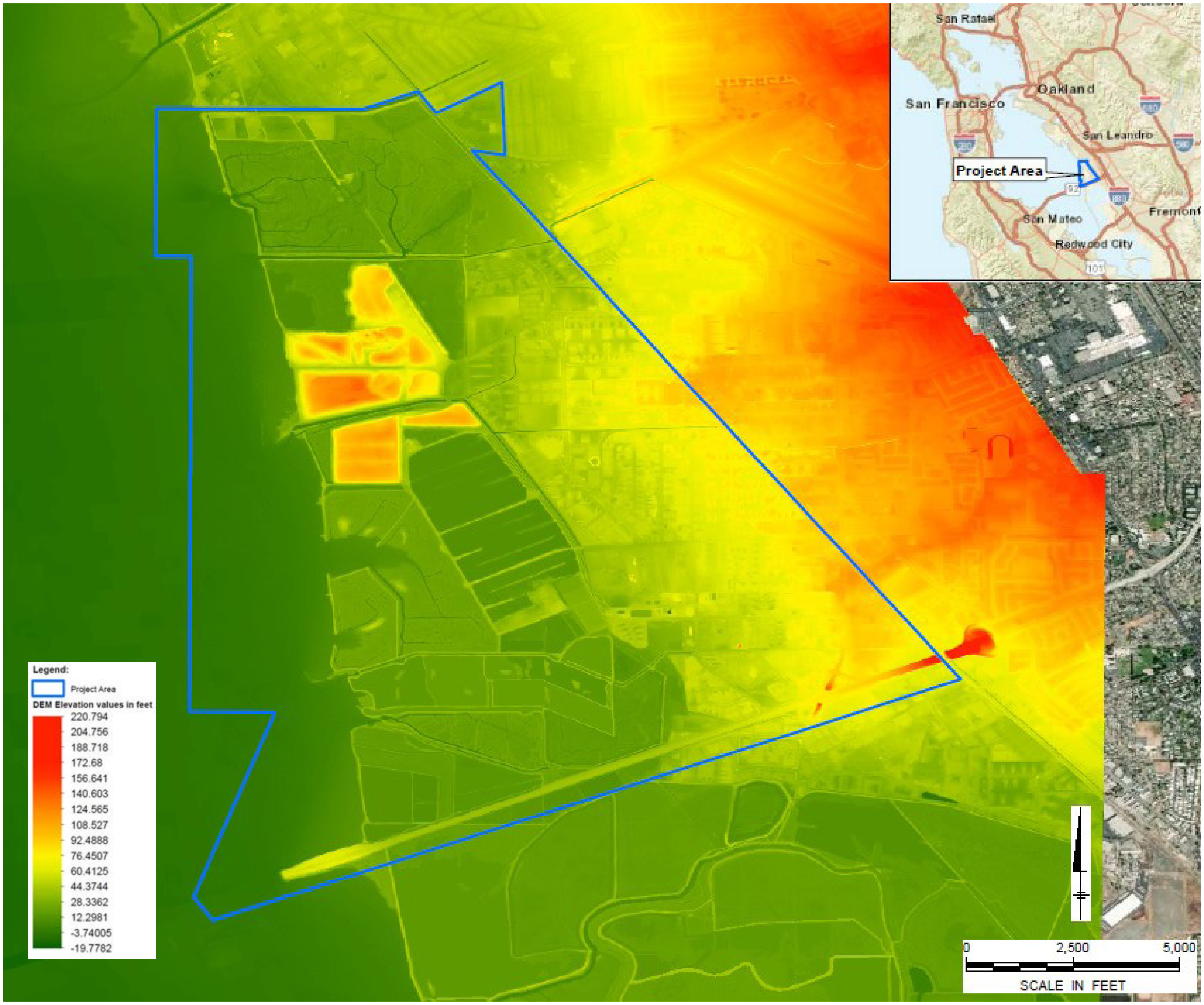

Figure 2: DEM elevations in the project area.

Bathymetry

The bathymetry of the San Francisco Bay is typical of a sheltered tidal estuary system with broad shallow waters, and mudflats exposed at low tide. Soundings range from 0 feet-MLLW at the mudflats away from the shoreline, to -0.5 feet-MLLW at an offshore distance of 1,000 feet. The bathymetry gets deeper closer to the navigation channel, eastern edge of which is located about 5.8 miles from the shoreline.

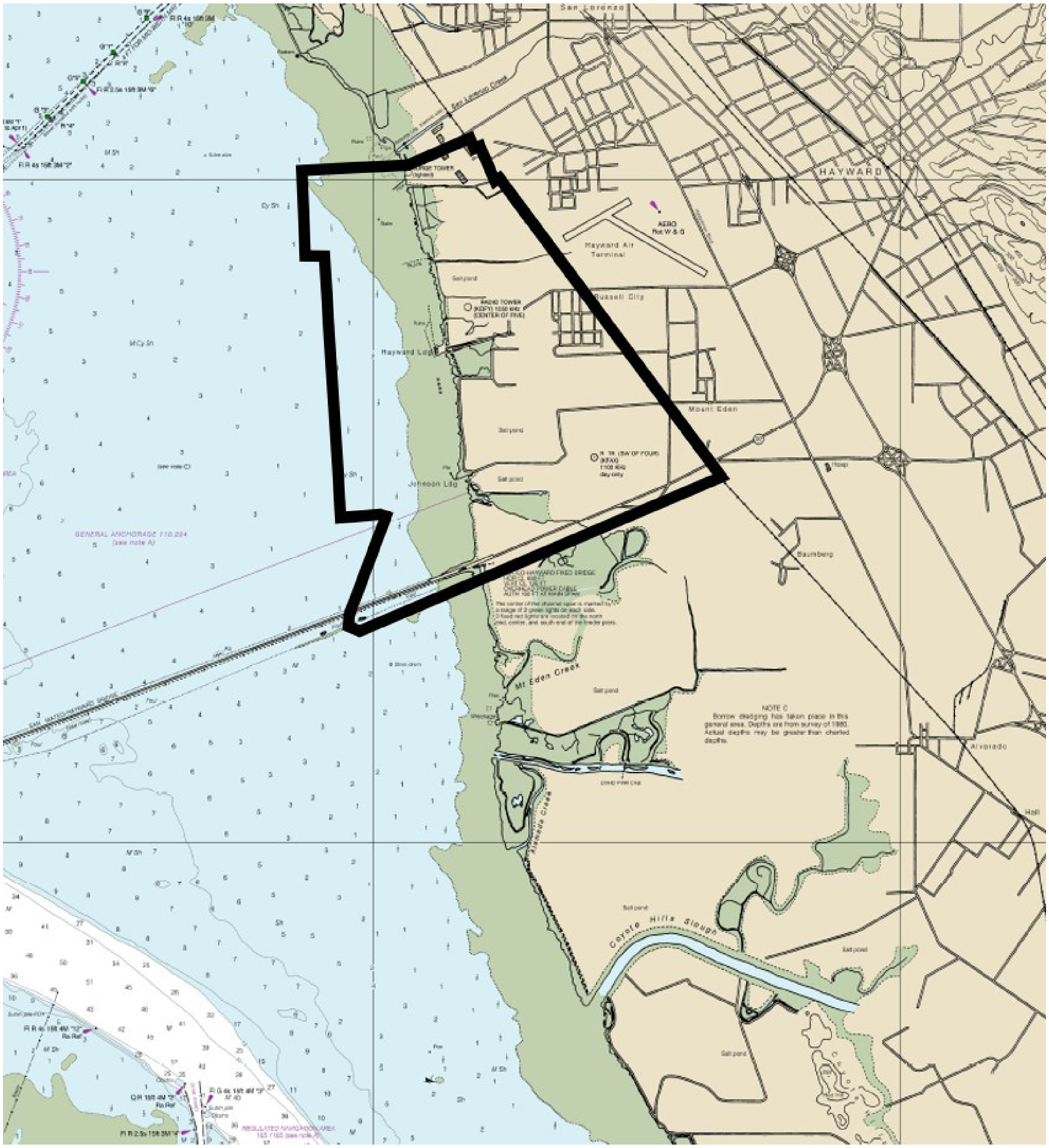

Figure 3: Excerpt of Nautical Chart 18651 highlighting the study area. Soundings of 0.5 feet can be seen offshore as the intertidal areas shown in green.

Vertical Elevation Variations: Areas of Land Subsidence

Shirzaei and Burgmann (Shirzaei, 2018) used synthetic aperture radar interferometric measurements and a global navigation satellite system data to show subsidence rates of less than 2 mm/year along most of the coastal areas along San Francisco Bay. However, rates exceeded 10 mm/year in some areas underlain by compacting artificial landfill and Holocene mud deposits. Given these estimates of ongoing land subsidence, it is possible that lager areas will be vulnerable to inundation increase in the future, as land subsidence progresses. Figure 4 shows that the subsidence rate in the project area is estimated to be between 0 mm/yr and -1 mm/yr. This translates into about 80 mm (0.3 in) in 80 years. Therefore, because this amount is negligeable, and because there are other factors of higher magnitude contributing to inundation, subsidence has been reviewed but not incorporated in the maps provided as a deliverable for this project.

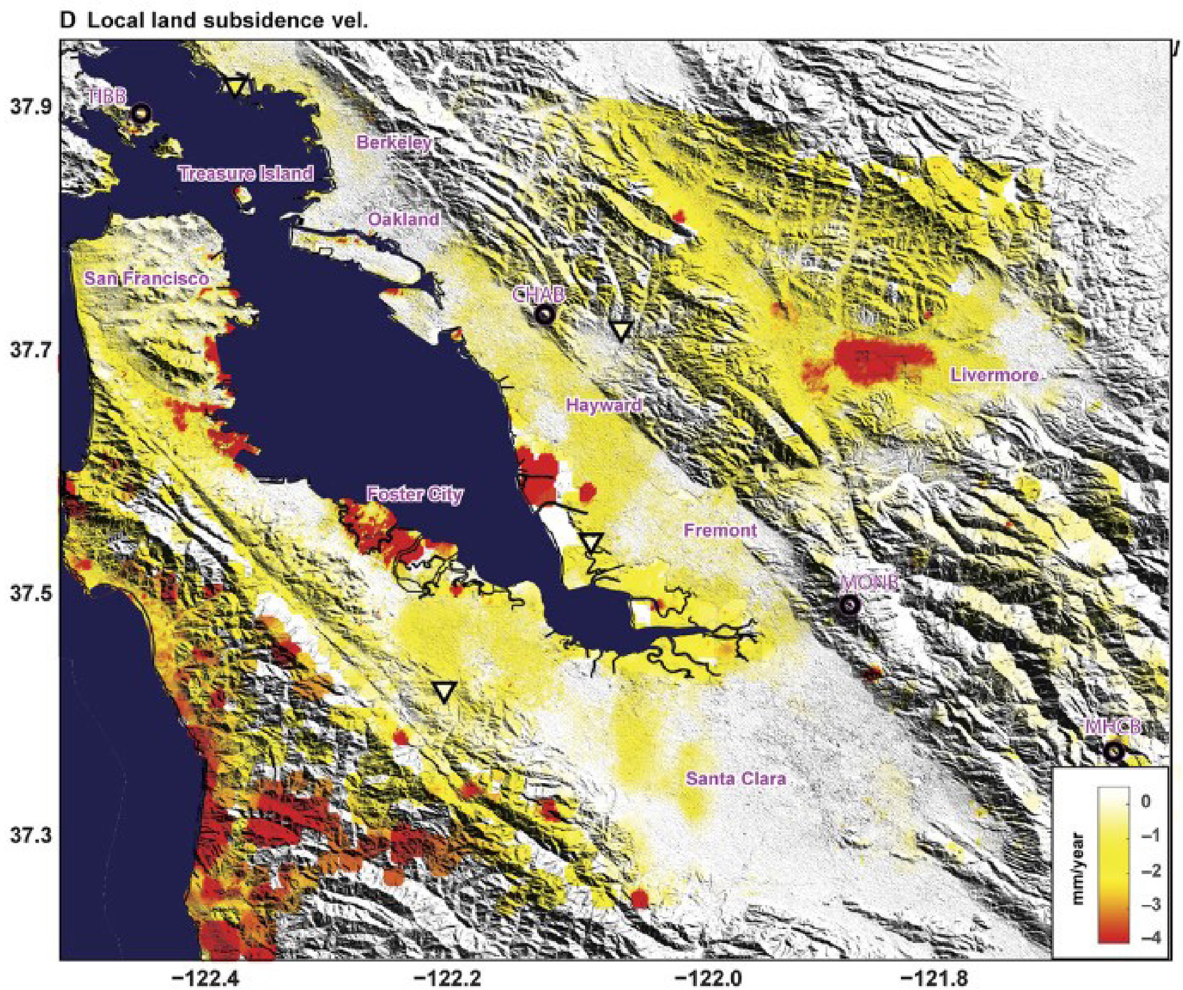

Figure 4: Average 3D velocity field across the SFBA from 13 July 2007 to 17 October 2010 (Shirzaei, 2018)

COASTAL WATER LEVELS

Extreme tide is a temporary increase (lasting hours to days) in the ocean water elevation that can be measured as the difference between the observed water elevation and the predicted astronomical tide. Extreme tides can be caused and influenced by:

- Storm surge: a temporary increase in the ocean water elevation due to low atmospheric pressure and wind effects that typically happens during storm events.
- El Niño: the Bay Area receives warm, high waters when El Niño is present in the Pacific Ocean. Water levels can be 0.5 to 1 foot above normal for periods that range between nine months and two years.
- The Pacific Decadal Oscillation: an atmospheric shift that varies over a time scale of decades (20 to 30 years).
- Freshwater Inflows: during precipitation events in California, water levels throughout San Francisco Bay may increase, particularly near freshwater sources.

If any, or a combination, of the above phenomena arises, the total water elevation at a given point of the shoreline will increase. Extreme tides are also referred to as stillwater slevation (SWEL)[6].

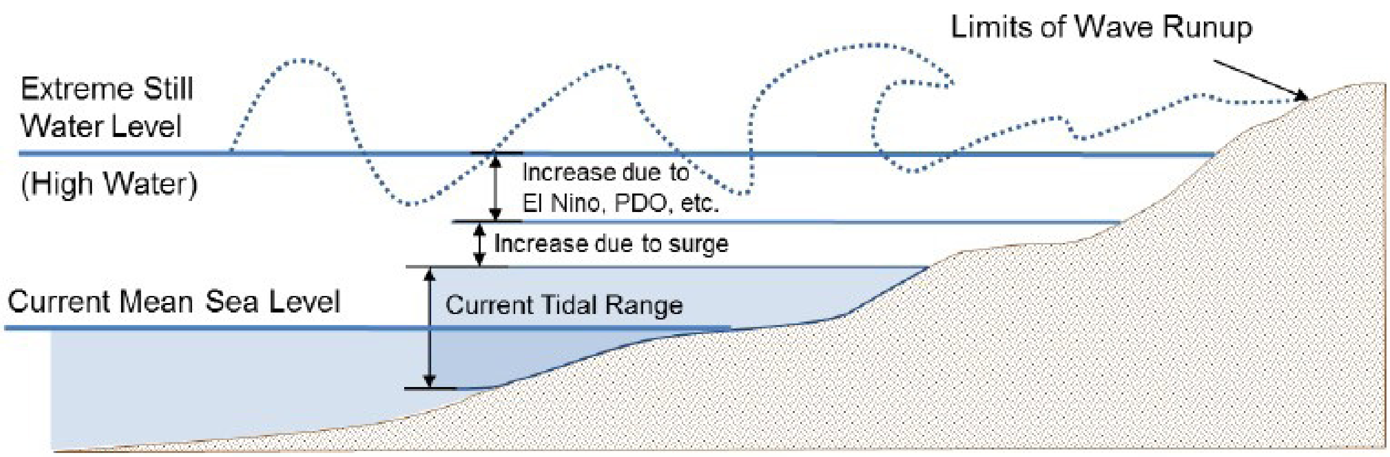

Figure 5: Extreme stillwater level components (California Coastal Commission, 2018)

Extreme Tides

The San Francisco Bay Tidal Datums and Extreme Tides Study (AECOM, 2016) is currently the best available source of extreme tides data for the Hayward shoreline area. The San Francisco Bay Tidal Datums and Extreme Tides Study provides tidal datums and extreme tide elevations for 900+ locations along the Bay shoreline, and for more than 30 points along the Hayward shoreline alone. The points were selected to capture local variations along the shoreline, such as changes in shoreline orientation, bathymetry, or riverine influences.

The San Francisco Bay Tidal Datums and Extreme Tides Study leveraged the extensive hydrodynamic modeling along the Bay performed by DHI[7] in 2011 (DHI, 2011) and 2013 as part as FEMA's San Francisco Bay Area Coastal Study. This study provided water level data (simulated) in 15-minute time intervals for each location, which was used to calculate extreme tide elevations for the 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year events. The results were compared with observations made by NOAA and the USACE study from 1984 (USACE, 1984). This comparison indicates that the extreme tide estimates compare well between all three studies for the 10-year event (0.2 to 0.3 ft difference), and all the 100-year extreme tides are within 1.0 ft of the USACE results.

6. Stillwater Elevation or SWEL Stillwater means the flood level not including the effects of waves (wave amplitude and wave setup) or tsunamis but including storm surge and astronomic tide.
7. DHI, the Danish Hydraulic Institute was previously known as the Institute for Water and Environment

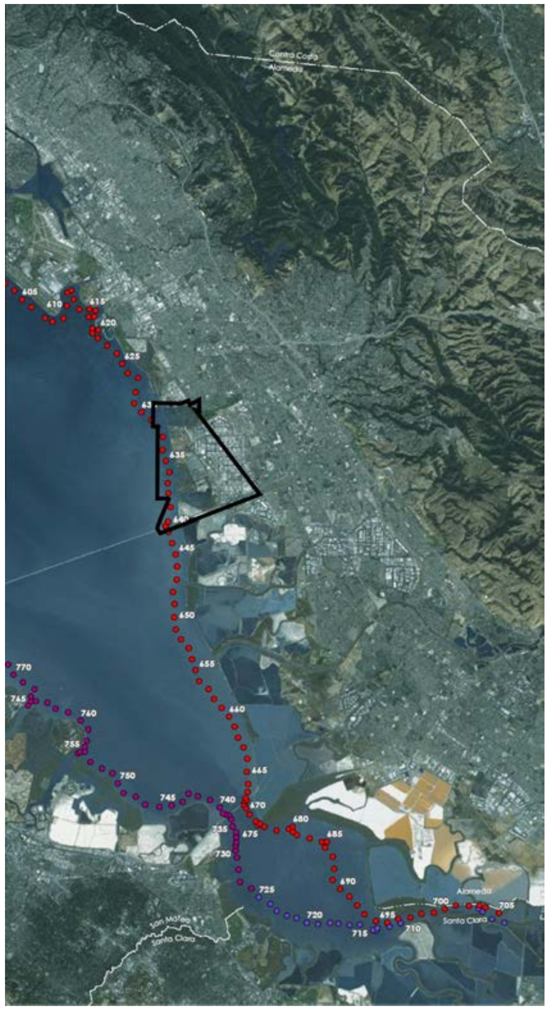

Figure 6: Locations along the Hayward shoreline where extreme tidal elevations were obtained as part of the San Francisco Bay Tidal Datums and Extreme Tides Study (AECOM, 2016)

Table 2 provides extreme tide elevations for the northernmost and southernmost points of the study area, and two intermediate locations.

Table 2: Tidal Datums (limited availability) and extreme tide elevations (ft-NAVD88) along the Hayward Shoreline Study area (AECOM, 2016).

	Tidal Datum [ft-NAVD88]		Extreme Tide Elevations [ft-NAVD88]							
Location	**MHW**	**MHHW**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**500-yr***
625 (northermost point of study area)	6.30	6.91	8.30	8.56	8.91	9.17	9.54	9.85	10.19	11.09
635	6.36	6.98	8.32	8.61	8.96	9.23	9.62	9.95	10.32	11.36
645 (southernmost point of study area)	6.43	7.04	8.35	8.67	9.02	9.30	9.71	10.07	10.48	11.65

** Note: Uncertainty in estimates of the 500-year extreme tide elevation is considerable, especially in the far South Bay due to the limited length of records available to develop the extreme value analysis.*

FEMA Flood Mapping

As part of its flood risk management program, FEMA provides Base Flood Elevations (BFE) for specific coastal locations in the U.S. The BFEs provide a basis for the regulation of the elevation or floodproofing of structures, as well as the flood insurance rates. The BFE is a compound quantity that reflects the influence of eustatic (e.g. tides, surge), hydraulic (e.g. wave run-up, wave action) and morphological (e.g. slope) characteristics for any coastal area. In order to model the base floods, FEMA applies the so-called "response-based approach." This method consists of simulating the complexity of the physical processes controlling flooding, and deriving flood statistics from the results at specific locations along the shoreline (transects). Therefore, FEMA FIRMs (Flood Insurance Rate Maps) do not necessarily display, even locally, the spatial variation of any realistic physical hydrologic event (FEMA, 2013). As a result, BFEs can differ significantly between two relatively close locations.

As illustrated in Table 3, FEMA's zone VE is also area subject to inundation from the base flood, but with additional hazards due to storm-induced wave action equal or greater than 3.0 feet (see Figure 7). Zone AE is the coatal area subject to inundation by the base (1-percent annual chance) flood event, including wave action generated by waves of up to 3.0 feet.

Table 3: Description of FEMA Designations. Source: https://www.fema.gov/glossary-terms

FEMA Designations	Description
VE Zone	Special Flood Hazard Area subject to coastal high hazard flooding.
AE Zone	Special Flood Hazard Area where base flood elevations are provided.
AH Zone	Areas of 1-percent annual chance shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet.
X Zone	Area of minimal flood hazard, usually depicted on Flood Insurance Rate Maps as at or above the 500-year flood level.
BFE	Base Flood Elevation – The computed elevation to which floodwater is anticipated to rise during the base flood. Base Flood Elevations (BFEs) are shown on Flood Insurance Rate Maps (FIRMs) and on the flood profiles. The base flood is typically set in the 1-percent annual chance flood event.
LiMWA	Limit of Moderate Wave Action – The inland limit of the area expected to receive 1.5-foot or greater breaking waves during the 1-percent annual chance flood event.
SFHA	Special Flood Hazard Area – Land area covered by the floodwaters of the base flood. The SFHA is the area where the National Flood Insurance Program floodplain management regulations must be enforced and the mandatory purchase of flood insurance applies.

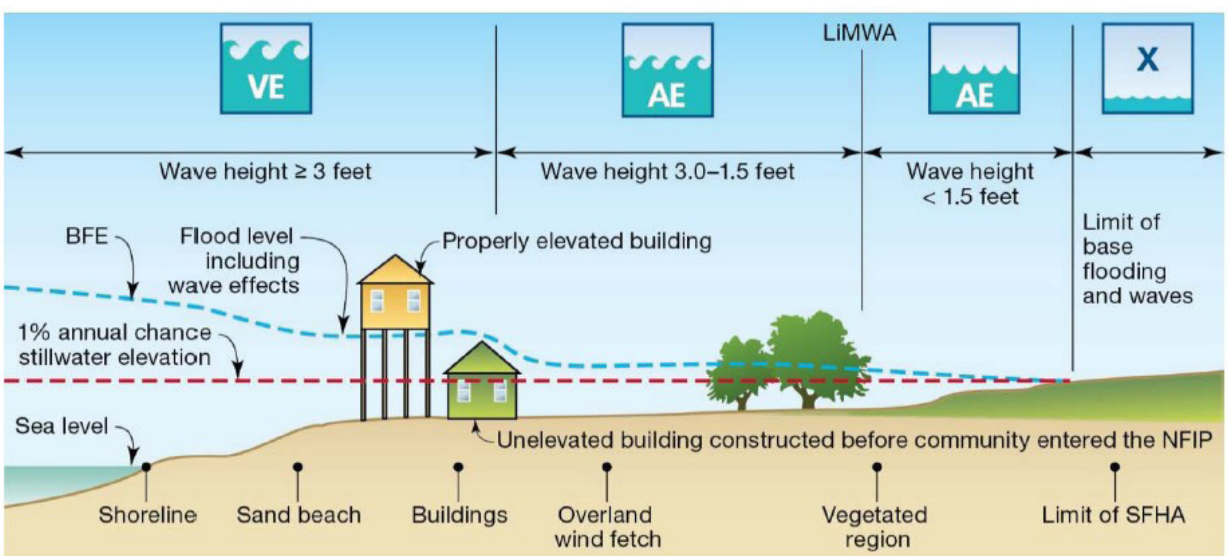

Figure 7: Transect schematic for FEMA flood elevation designations. Source: (FEMA, 2013).

FEMA maps, which represent coastal flood hazards, are based on existing shoreline characteristics, and on the wave and storm climatology at the time of the flood study. In accordance with the current Code of Federal Regulations, FEMA does not map flood hazards based on anticipated future sea levels or climate change. Stillwater elevations are shown in Table 4, located as shown in Figure 8.

Table 4: Stillwater Elevations (SWEL) per transect along the Hayward shoreline. Preliminary 2015 FEMA FIRMs for the Alameda County.

Transect No.	Longitude [deg-N]	Latitude [deg-E]	FEMA FIRM No.	1% Annual Chance SWEL (ft-NAVD88)
70	37.66117	-122.159	06001C0267H	10.2
71	37.65781	-122.158	06001C0267H	10.2
72	37.65435	-122.157	06001C0269H	10.2
73	37.6506	-122.156	06001C0269H	10.2
74	37.64733	-122.156	06001C0269H	10.3
75	37.64288	-122.153	06001C0269H	10.3
76	37.63709	-122.15	06001C0269H	10.3
77	37.63093	-122.153	06001C0269H	10.3
78	37.62725	-122.151	06001C0269H	10.4
79 (UTM)	6082344	2053432	06001C0407H	10.4

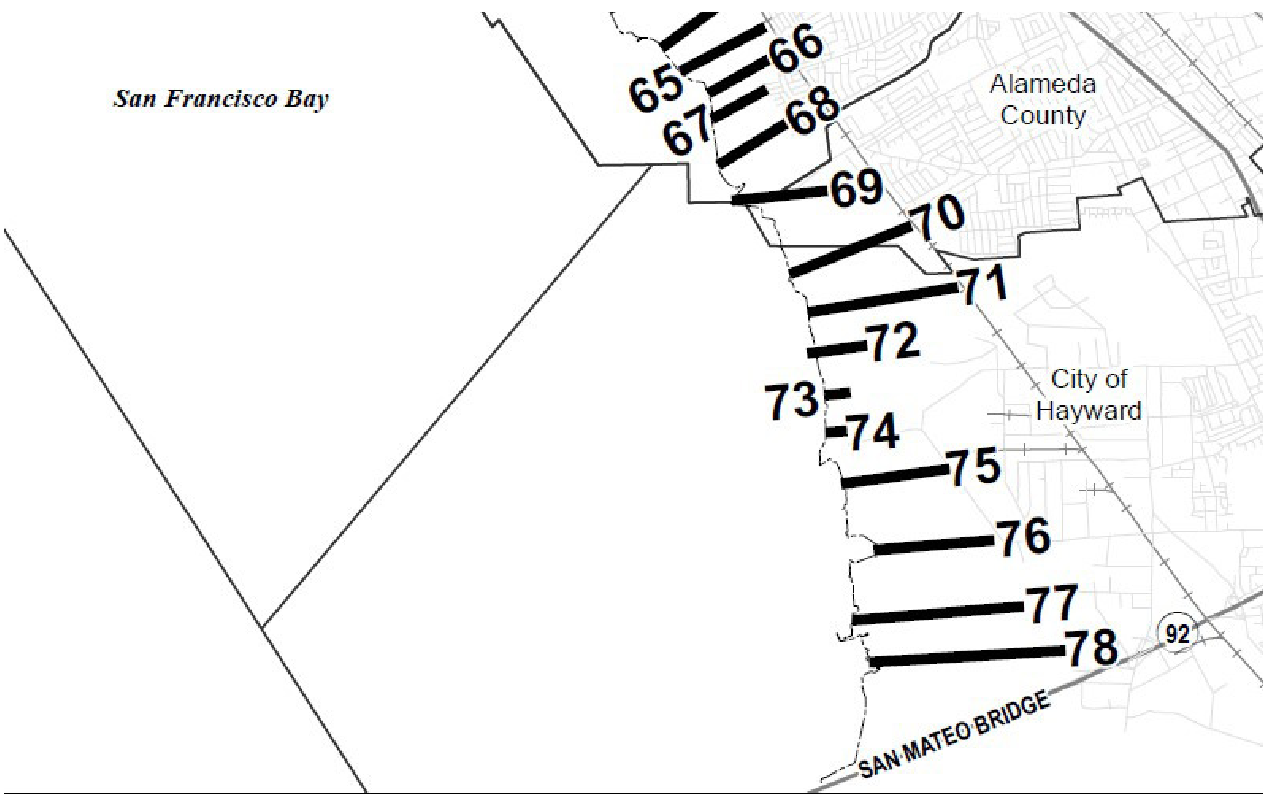

Figure 8: Location of FEMA's coastal transects on the project area (FEMA, 2018)

Wave Climate

The effects of met-ocean conditions (storm surge and waves) in the Hayward shoreline study area are captured in the information provided by the FEMA Flood Insurance Rate Maps (2015), so no further studies have been developed to analyze this contributing factor to flood elevation. FEMA's FIRM 06001C0269H shows that the wave action is limited in this area to less than 1.5 feet high, except for the open area to the Bay on the Cogswell Marsh (see Figure 9), and as such it does not appear to have a large impact for planning purposes.

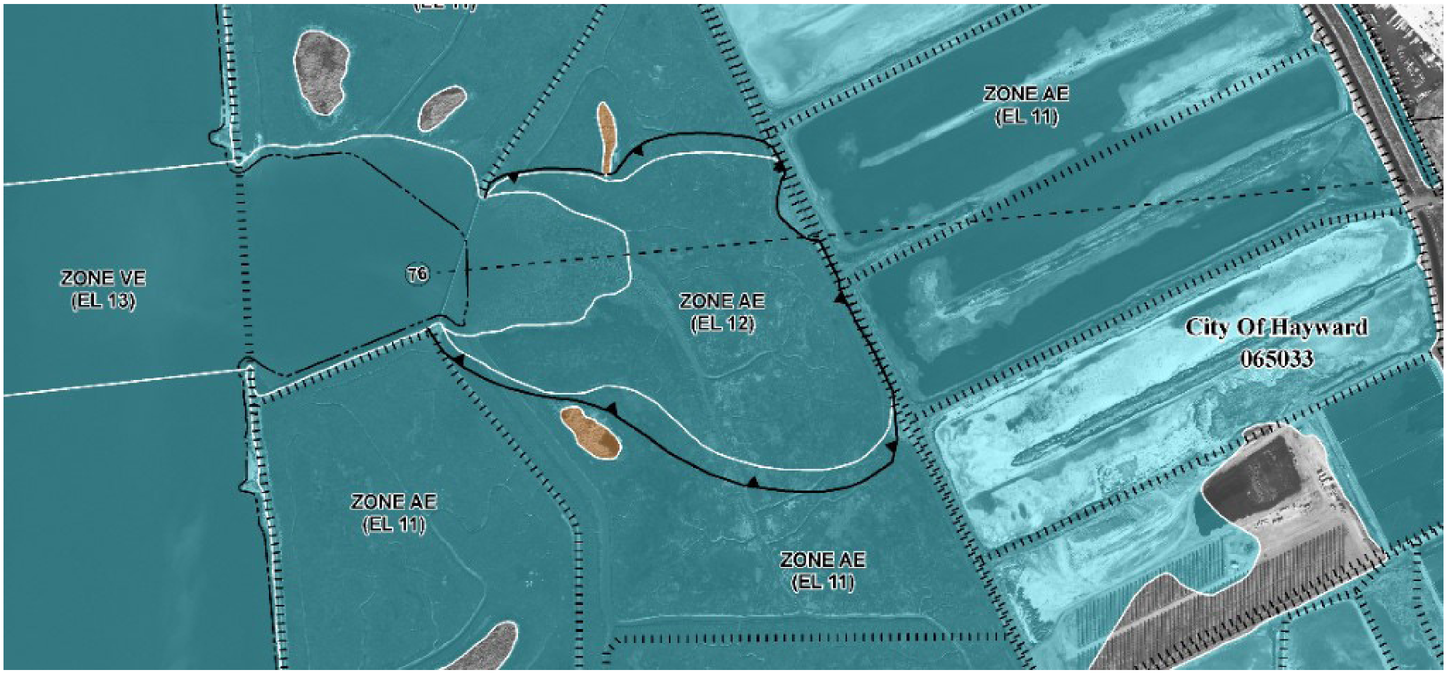

Figure 9: Excerpt of FEMA FIRM 06001C0269H showing the interface between the VE zones (wave heights greater than 1.5 feet high) and the AE zones (wave heights lower than 1.5 feet high).

FUTURE TRENDS

STORM EVENTS

PROJECTED CHANGES IN STORM FREQUENCY

Climate extremes are defined by the IPCC[8] as "a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variables" (IPCC, 2016).

In the North Pacific Ocean, the evidence that storminess (storm frequency) will change is conflicting and inconclusive (Cayan D. B., 2008, Lowe J, 2010, Dettinger, 2011) due to limitations in the models used to predict it.

The largest storms in the Bay Area are called "atmospheric rivers" (ARs). These storms contribute to, on average, 40% of the Sierra snowpack and can also produce heavy rainfall and consequently substantial flood risk. Atmospheric theory and climate models both indicate that in California, the largest individual storms are becoming more intense with climate change, and there is some evidence that this might be also accompanied by more frequent extremely dry precipitation periods, as well as more frequent "whiplash" events that swing from extremely dry to extremely wet conditions (Swain, 2018).

While the data around storm frequency increase is inconclusive, the data used in the studies mentioned above indicates that larger storms are getting stronger. As such, by the end of the century, what used to be a 20-year storm would become a 7-year storm, thus increasing the probability of occurrence by a factor of three.

PROJECTED CHANGES IN PRECIPITATION

The two emerging perspectives about how climate change is affecting precipitation in California indicate that:

- Changes in annual mean precipitation are expected to be relatively small compared to the range of natural variability experienced in the region (USGCRP, 2017);
- Atmospheric theory and climate models indicate that the largest individual storms are becoming more intense with climate change. This might also be paired by more frequent extremely dry precipitation periods, and more events that swing from extremely dry to extremely wet conditions. The increase in precipitation changes from 6% for RCP4.5 to up to 37% for RCP8.5.

Changes in Mean Precipitation

According to the San Francisco Bay Area Region Report (Ackerly, 2019), mean annual precipitation varied considerably from year to year during the period 1950-2005. The downscaled LOCA[9] data indicates that mean annual precipitation is likely to increase by a small amount, although these changes are nearly imperceptible relative to the high inter-annual variability observed in the past. Furthermore, the report indicates that across North America, even under the strongest emissions scenario (RCP8.5), little change is projected for summer and fall precipitation, but larger changes may occur in winter and spring (USGCRP, 2017).

Models indicate that precipitation in the northern regions of North America is projected to increase, while precipitation in the southern regions is projected to decrease. California straddles the boundary between these two regions, and so the uncertainty about what trend to expect is high. One factor that is still poorly understood is how much the expected northward shift in storm tracks is going to affect the local precipitation, as the horizontal resolution of the global climate models currently used is too large to resolve the shift.

8. International Panel on Climate Change
9. LOCA stands for Localized Constructed Analogues, a statistical downscaling technique used to downscale precipitation and temperature.

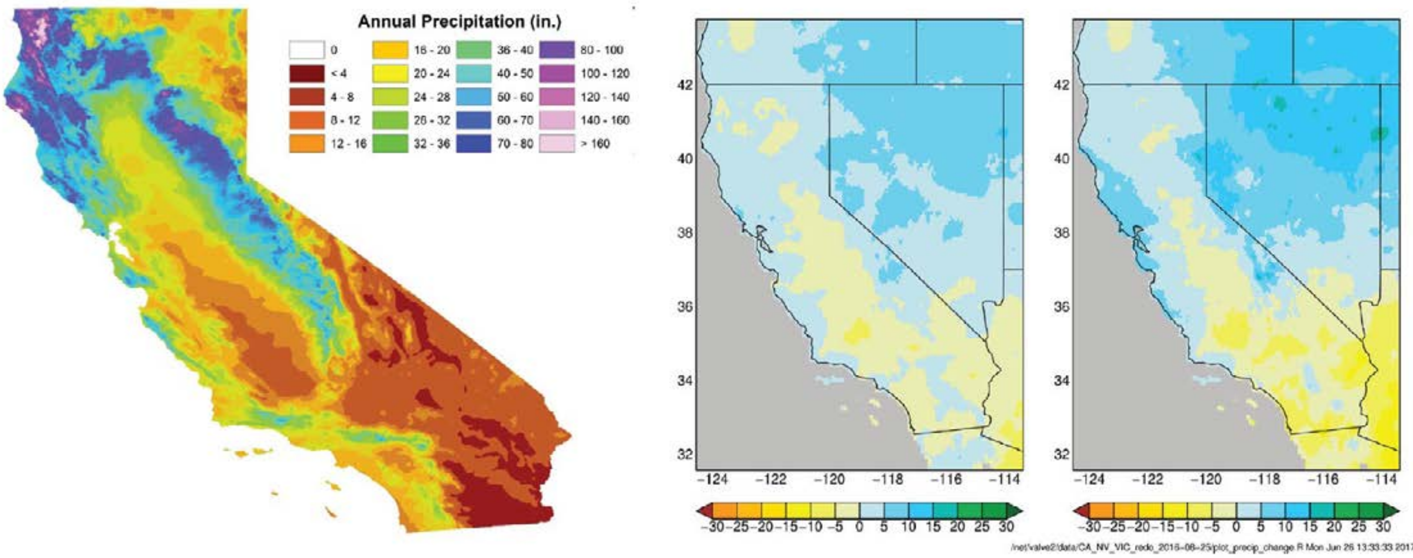

Figure 10: Left panel: Average annual precipitation in California. Right two panels: Projected percent changes (2070-2100 relative to 1950-2005) of annual precipitation, averaged over 10 LOCA downscaled GCMs selected for the Fourth Assessment for RCP 4.5 (left) and RCP 8.5 (right) scenarios. Source: Bedsworth, 2018.

Changes in Extreme Precipitation Events

Atmospheric rivers, the largest California storms, result in heavy rainfall over a narrow area, and may carry more water than seven to fifteen Mississippi Rivers combined (California's Fourth Climate Change Assessment, 2019). Both global climate models and downscaled LOCA projections suggest an increase in the magnitude of large precipitation events, as summarized in Table 5, measured in inches of rain per day.

Table 5: Range of increase in the magnitude of large precipitation events.

Emissions Scenario	Range of precipitation increase [%]
RCP4.5	6-15
RCP8.5*	Up to 37

** Note: Representative Concentration Pathways (RCPs) are scenarios that include time series of emissons and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics.*
RCP4.5 and RCP6.0 Two intermediate stabilisation pathways in which radiative forcing is stabilised at approximately 4.5 W m-2 and 6.0 W m-2 after 2100 (the corresponding ECPs assuming constant concentrations after 2150);
RCP8.5 One high pathway for which radiative forcing reaches greater than 8.5 W m-2 by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

SEA LEVEL RISE

REVIEW OF AVAILABLE GUIDANCE

This section provides a review of the most relevant guidance available regarding sea level rise projections and policies.

State of California Sea Level Rise Guidance: 2018 Update

The increased understanding of sea level rise projections and polar ice sheet loss warranted an update to the State's sea level rise guidance document to ensure decisions were based on the best available science. This document provides a science-based methodology for state and local governments to analyze and assess the risks associated with sea level rise, and to incorporate sea level rise into their planning, permitting, and investment decisions. The document also outlines the State's preferred coastal adaptation approaches.

This Guidance provides a step wise approach to help decision makers assess risk by evaluating a range of SLR projections and the impacts or consequences associated with these projections. Depending on the finite factors of a proposed project's location and lifespan, decision makers can evaluate the potential impacts and adaptive capacity of the project across a spectrum of SLR projections. This analysis enables state agencies and local governments to incorporate the latest SLR projections and related hazard information to consider into different types of decisions across California. This Guidance also describes and provides links to a variety of geospatial and visualization tools to assist decision makers in understanding the impacts of sea level rise. The document is accompanied by a library and database of additional resources, hosted on the State Adaptation Clearinghouse and the California Ocean Protection Council (OPC) website, to help visualize change, access funding opportunities, gather policy and scientific background related to specific jurisdictions, and provide additional support to address a challenge of this nature and magnitude.

California Coastal Commission Sea Level Rise Policy Guidance. Interpretive Guidelines for Addressing Sea Level Rise In Local Coastal Programs And Coastal Development Permits (2018)

Increasing global temperatures are causing significant effects at global, regional, and local scales. Sea level at the San Francisco tide gauge has risen eight inches (20 cm) over the past century, and reports developed by the California Ocean Protection Council (OPC) project that by the year 2100 sea levels may rise by approximately 2.4 to 6.9 feet, with the potential for rapid polar ice loss to result in an extreme scenario of 10.2 feet of sea level rise.

This document replicates the 2018 OPC set of projections for 12 tide gauges throughout California, which the Coastal Commission recommends using for planning purposes. This document also provides a step-by-step process for addressing SLR and adaptation planning in new and updated local coastal programs.

Climate Change Projections of Sea Level Extremes Along the California Coast (Cayan D. R., 2008)

This statistical study investigates the possible influence of SLR and other effects of climate change on future extreme sea levels. To accomplish this, they use a model of the combined contributions to hourly sea level of predicted tides and model-simulated weather, climate, and long-term global warming. The study concludes that in the San Francisco Bay estuary, sea level rise effects may be compounded by riverine floods that feed into the northern reaches of the Bay from the Sacramento/San Joaquin Delta.

NOAA TIDE DATA

The mean sea level at the Alameda tide gauge (9414750), which is the tide gauge closest to the project site, has been rising 0.82 mm/year (95% confidence interval), based on monthly sea level data from 1939 to 2018. This is equivalent to a change of 0.27 feet in 100 years. This trend is shown in Figure 11.

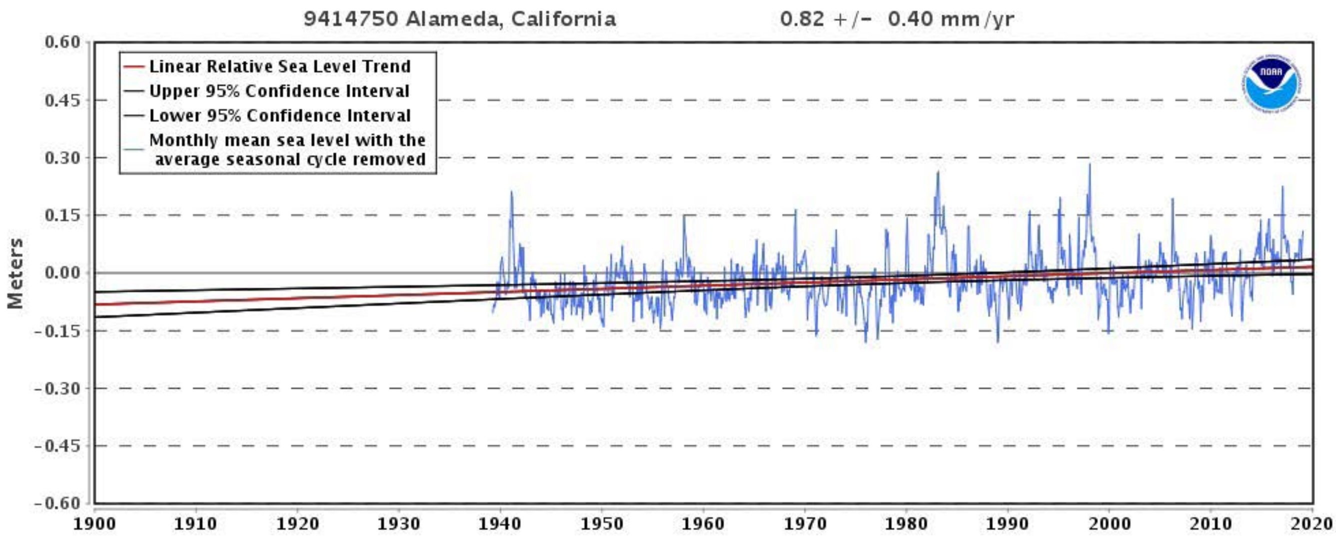

Figure 11: Relative sea-level trend at the Alameda, CA tidal gauge.

SEA LEVEL RISE PROJECTIONS FOR THE SAN FRANCISCO BAY

The California Coastal Commission Sea Level Rise Policy Guidance (California Coastal Commission, 2018) provides a summary of the best available science on sea level rise for California. It indicates that in the past century, global mean sea level (MSL) has increased by seven to eight inches, and that, with greater than a 95% probability, human influence has been the primary cause of the observed warming of the atmosphere and the ocean since the mid-20th century.

Relative average sea level rise is driven by:

- The expansion of ocean waters as they warm;
- The addition of freshwater to the ocean from melting land-based ice sheets and glaciers;
- Groundwater extraction contributing to land subsidence.

To capture regional and local factors (and thus to provide locally relevant data) that affect SLR variations, global-scale models are downscaled. The State of California Sea Level Rise Guidance: 2018 Update (State of California, 2018) provides SLR projections that have been refined for 12 tide gauges, including the San Francisco tide gauge. These projections are given for each decade from 2030 to 2150, and the OPC recommendations for their use are summarized in table 6.

Table 6: Recommendations by the CA Coastal Commission about the SLR scenarios to use depending on the sea-level-rise probability of exceedance.

Projection	Description	Likelihood	Use
Low-risk aversion scenario	Upper value for the "likely range"	17% probability of exceedance	Projects that would have limited consequences or a greater ability to adapt.
Medium-high risk aversion scenario		0.5% probability of exceedance or 1-in-200 chance	Projects with greater consequences and/or a lower ability to adapt.
Extreme risk aversion	Accounts for an extreme ice loss scenario	Not provided	Projects with little to no adaptive capacity that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts.

The projected SLR for the San Francisco tide gauge is shown in Figure 12.

Table 7: Projected SLR in San Francisco tide gauge.

Projected Sea Level Rise (in feet): *San Francisco*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.8	1.0
2040	0.8	1.3	1.8
2050	1.1	1.9	2.7
2060	1.5	2.6	3.9
2070	1.9	3.5	5.2
2080	2.4	4.5	6.6
2090	2.9	5.6	8.3
2100	3.4	6.9	10.2
2110*	3.5	7.3	11.9
2120	4.1	8.6	14.2
2130	4.6	10.0	16.6
2140	5.2	11.4	19.1
2150	5.8	13.0	21.9

LOCAL HYDROLOGY

MOST RECENT HYDROLOGIC AND HYDRAULIC ANALYSIS

The Alameda County Flood Control and Water Conservation District (ACFCWCD) is currently updating the hydrologic & hydrodynamic (H&H) models at the county level to incorporate the latest information about potential future increases in precipitation intensity, as well as sea level rise. This modeling effort is focused on understanding the capacity of the hydrologic system within the county to evaluate rainfall runoff under current and future precipitation scenarios and various sea level rise increments. These modeling results will be the best representation of the local hydrology in this area when study concludes in 2020 (expected).

The project team recommends updating the inundation maps after the ACFCWCD study is concluded, so that they reflect the most up-to-date information in relation to all the factors contributing to inundation in the Hayward Shoreline study area.

FEMA FLOOD INSURANCE STUDY

FEMA's FIS for Alameda County[10] provides flood profiles for the streams, channels, and rivers in the study area. These profiles are the modeled response to the 10%, 2%, 1%, and 0.2% annual chance (or annual exceedance probability, AEP) flood events, and although they were developed in the 1970s, they still constitute the most detailed publicly available information in this area to date. The profiles show the stream bed elevation relative to NAVD88, the distance above:

- the confluence with San Francisco Bay;
- river mouth;
- confluence with other rivers, the flood profiles for the return periods indicated;
- the location of singular structures along the transects.

The review of the FIRMs in the area reveals that there is just a one isolated instance where inundation due to the 1% rainfallrunoff event is observed. This area is along Line A channel (see Figure 12), in proximity to the railroad. Because of the limited extent of this area, this hazard zone will be considered a hazard zone for planning purposes, although it will not be reflected in the inundation maps.

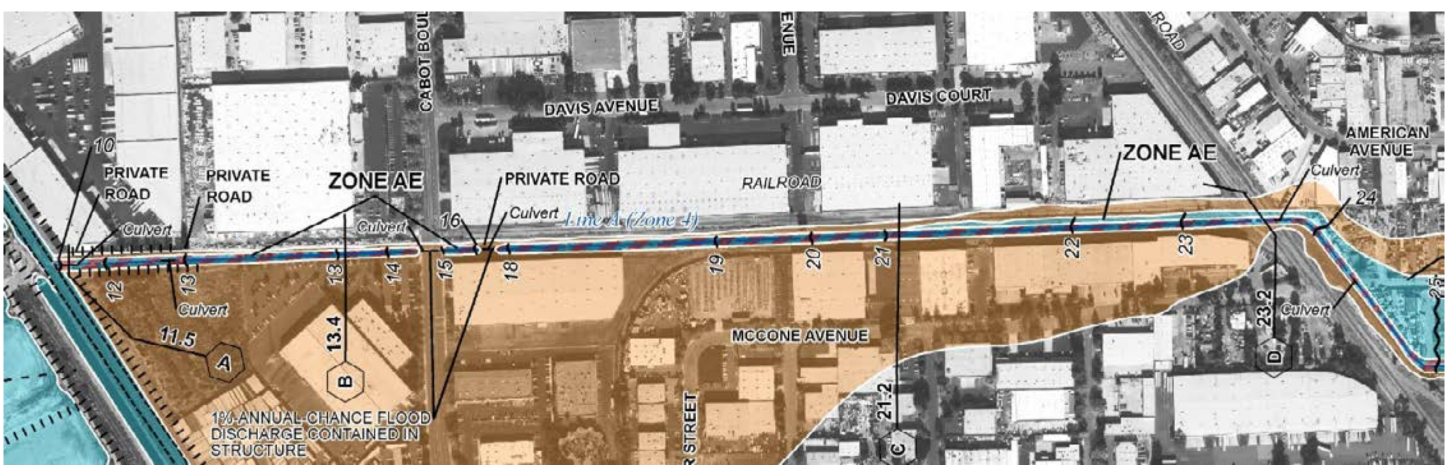

Figure 12: Areas identified as flooded by the 1%-annual chance rainfall-runoff event on FEMA's FIRM 06001C0269H, in blue.

10. https://viewer.nationalmap.gov/advanced-viewer/

GROUNDWATER

Groundwater resources in the Bay Region are supplied by both alluvial and fractured-rock aquifers. Alluvial aquifers are composed of sand and gravel or finer-grained sediments, with groundwater stored within the voids, or pore spaces, between the alluvial sediments. Fractured-rock aquifers consist of impermeable granitic, metamorphic, volcanic, or hard sedimentary rocks, with groundwater stored within cracks, fractures, or other void spaces. The distribution and extent of alluvial and fractured-rock aquifers and water wells vary within the region. The project area is located between the East Bay Plain and the Niles Cone sub-basins (see *Figure 13).*

Figure 13: Groundwater basins and sub-basins within the San Francisco East Bay relative to the project area (source: HASPA).

EFFECT OF SLR IN GROUNDWATER LEVELS

While the potential for coastal tidal inundation due to SLR is well documented, it is largely unrecognized that low-lying coastal areas may also be vulnerable to groundwater inundation, which is localized coastal-plain flooding due to a rise of the groundwater table with sea level (Rotzoll, 2013). Understanding the extent and response of the coastal aquifers to sea level rise is key in preparing for mitigation and adaptation measures (Hoover, 2016). The main factors that may determine the degree of sea-level-rise-driven groundwater inundation and shoaling in one specific location include:

- The proximity of the water table to the ground surface;
- The local geology (including distance to the shoreline);
- The local hydrology;
- Anthropogenic factors such as of groundwater extraction or addition.

Near the shoreline, the groundwater table in unconfined aquifers typically lies above mean sea level, fluctuates with daily tides and other low-frequency sources of ocean energy. Tidal influence decreases with distance from the shoreline. As sea level rises, the water table will likely rise simultaneously. For lower-lying interior areas this could mean that the groundwater may eventually break out above the land surface, causing inundation even though the area is not at, or directly connected to, the shoreline. The increased groundwater table could create new wetlands and expand others, change surface drainage, expand saturated soil conditions, and/or inundate the land, depending on local topography. This effect is expected to be more pronounced at the coastline and further inland. Flooding may be especially intense seasonally when high tide coincides with large rainfall events (Rotzoll, 2013).

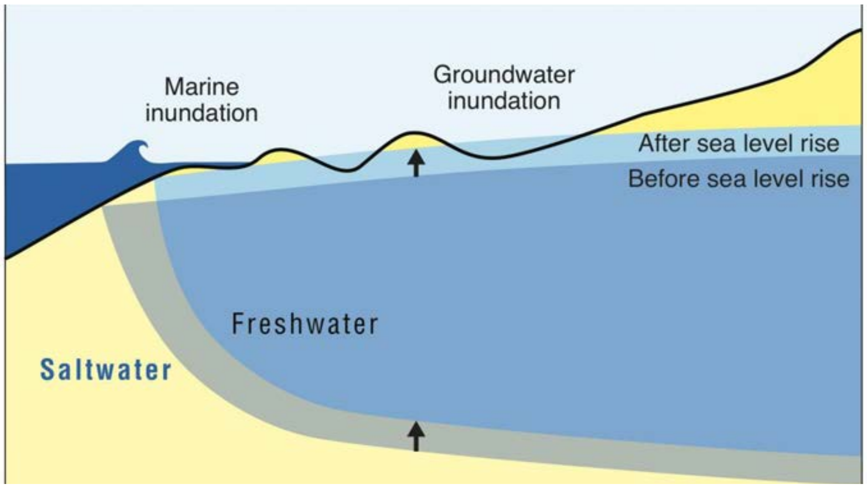

Figure 14: Illustration of the anticipated effect of sea-level rise on the groundwater table in coastal areas where shallow aquifers are connected to the bay/ocean.

The California State Water Board has a tool to visualize and download data, such as the minimum depth to water or maximum depth to water for each of the recorded wells, during a specific timeframe. This timeframe may be customized to show data from the last quarter to the last 10 years. Figure 15 shows the existing logged wells in the study area. County-wide data can be downloaded as well[11].

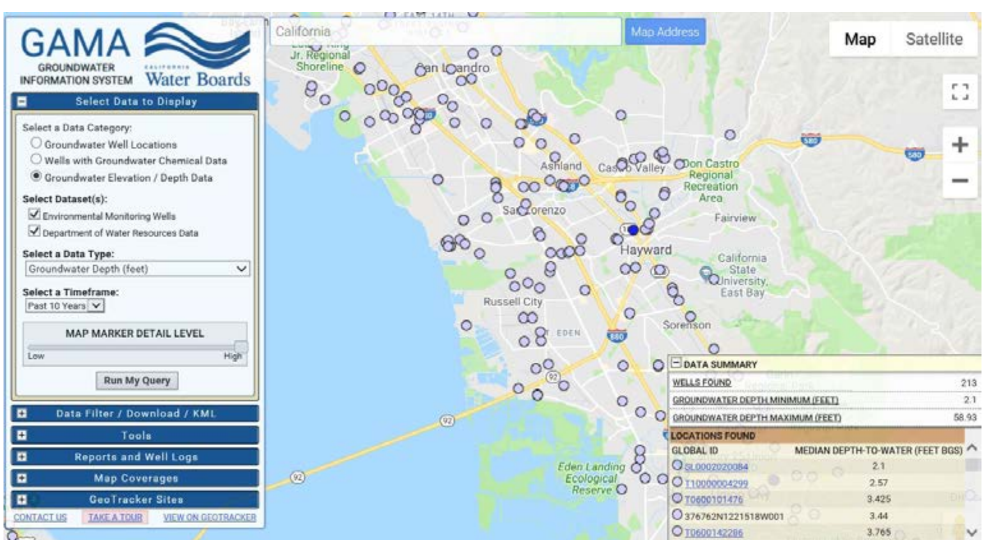

Figure 15: Location of monitoring wells, domestic wells, and public water systems wells in the study area [12].

....

11. http://geotracker.waterboards.ca.gov/data_download_by_county
12. https://gamagroundwater.waterboards.ca.gov/gama/gamamap/public/Default.asp

The San Francisco Bay Shoreline Adaptation Atlas (San Francisco Estuary Institute, 2019) provides a Bay-wide minimum depth-to-groundwater map (see Figure 16). This map was created by Plane, Hill, and May (2017), and updated in 2018, in an effort to describe the proximity of groundwater to the ground surface as another source of flooding in coastal areas.[13] Estimated values for minimum depth to groundwater were based on an interpolation that uses ground elevation data and minimum depth to water values measured at monitoring wells in the nine Bay Area counties over the past 20 years (1996-2016). Results from this effort are shown below for those areas within 1 Km of well points in the dataset.

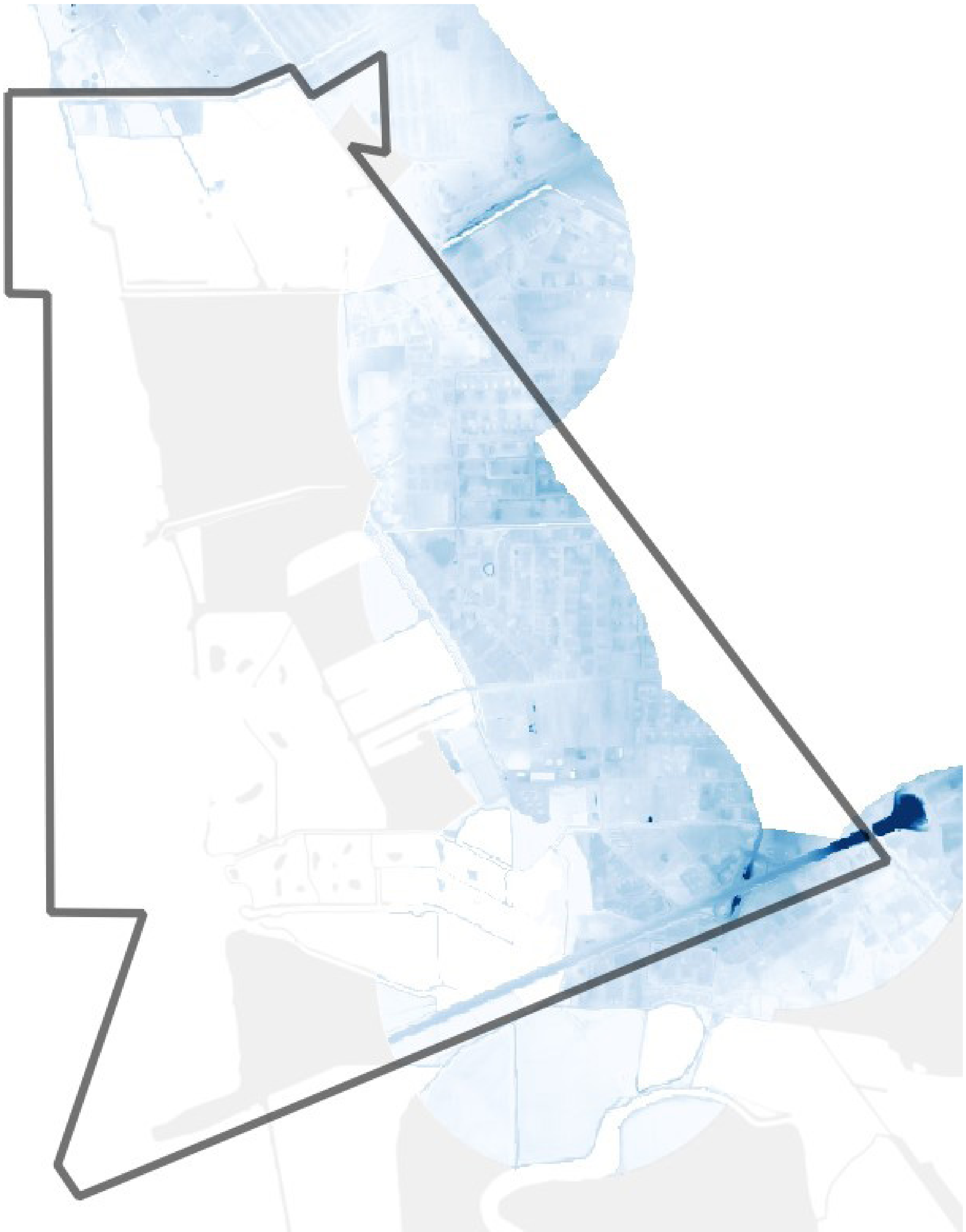

Figure 16: Minimum depth-to-groundwater map by Plane, Hill, and May (2017) for the project area. Lighter areas represent groundwater table to be closer to the ground surface.

13. https://www.mdpi.com/2073-4441/11/11/2228

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SEA LEVEL RISE MAPPING

OBJECTIVES

The main goal of this task is to generate digital versions of the inundation maps for the Hayward Shoreline project area. Resulting GIS data will be made available for display on the City of Hayward's web platform.

The maps produced are representative of both permanent and temporary flood conditions:

- Permanent Inundation is produced by rising sea levels. Sea level rise inundates coastal areas and exacerbates inland flooding as groundwater levels increase by the same amount as sea levels along the coastline, with the increment of groundwater level rise decreasing inland from the ocean. For the purposes of this study, this is represented by the Mean Higher High Water (MHHW), minimum depth to groundwater, and combination of MHHW and groundwater maps for each SLR increment;

- Temporary Inundation is the additional inundation that is produced by storm rainfall runoff and storm surge. For the purposes of this study, this is represented by the 100-year storm and groundwater map for each SLR increment.

METHODOLOGY

One of the key differences between the inundation maps generated as part of this project and those that have been generated in the past is that in these maps, groundwater elevation is incorporated as an additional factor contributing to potential flooding in coastal areas. Earlier sections describe how groundwater responds to rising seas, and this knowledge has been translated into the maps presented here. The specific details about the data considered in the analysis is described below.

DIGITAL ELEVATION MODEL

The Digital Elevation Model used is the most up-to-date representation of the Hayward Shoreline topo-bathymetry as of 2015. Elevations are in NAVD88.

Key Points

Data Source: USGS LiDAR (2010): San Francisco Point Cloud files with Orthometric Vertical Datum

Datum: NAVD88

Modifications: The elevations at the Hayward Marsh have been updated based on an existing condition study by CLE Engineering conducted in 2014 and provided by HASPA to the project team.

SEA LEVEL RISE

The sea level rise projections for the state of California used throughout this report define which SLR scenarios to evaluate. After careful consideration, the HASPA has decided to proceed with sea level rise increments of 2’, 4’, and 7’ to prepare the updated inundation maps. These sea level rise increments are representative of the expected sea level rise in 30, 60, and 80 years from 2019, according to the medium-high risk aversion sea-level rise curve provided by the California Coastal Commission. As the best available science progresses, the time horizons to which the sea level increments are provided may also change.

Table 8: Sea level rise increments by time horizon and level or risk aversion, based on the California Coastal Commission recommendations.

			17% Prob. SLR meets or exceeds	5% Prob. SLR meets or exceeds	0.5% Prob. SLR meets or exceeds	
# Years from now	**Year**	**Identifies areas that…**	*Low Risk Aversion*	*Medium Risk Aversion*	*Medium-High Risk Aversion*	
10	2030		0.5	0.6	**0.8**	
20	2040	are at **immediate** flood risk	0.8	1.0	**1.3**	
30	2050		1.1	1.4	**1.9**	**Up to 2 ft**
40	2060		1.5	1.8	**2.6**	
50	2070	are at **intermediate** flood risk	1.9	2.4	**3.5**	
60	2080		2.4	3.0	**4.5**	**Up to 4.5 ft**
70	2090	Will be **potentially** flooded	2.9	3.6	**5.6**	
80	2100		3.4	4.4	**6.9**	**Up to 7 ft**
90	2110		3.5	4.5	7.3	
100	2120		4.1		8.6	

Key Points

Data Source: GIS layers for Sea Level Rise - Overtopping and Inundation for Alameda County developed by AECOM (AECOM, 2017). Available at ART Bay Area Sea Level Rise and Shoreline Analysis Maps website (https://explorer.adaptingtorisingtides.org/download)

Methodology: Adopted the Adapting to Rising Tides SLR maps for selected SLR scenarios.

COASTAL STORM SURGE

To represent the inundation extent due to storm conditions, the average 1-percent annual chance stillwater elevation (SWEL) obtained from FEMA transects 70 through 79, resulting in 10.3 feet-NAVD88, has been adjusted up by 2', 4', and 7' to account for sea level rise. The resulting elevations have been projected inland in order to define the inundation extent. Disconnected areas have been removed from the maps, where applicable.

Key Points

Data Source: FEMA Flood Insurance Study 06001CV2002B. Available at FEMA's website (https://msc.fema.gov/portal/availabilitySearch?addcommunity=065033&communityName=HAYWARD,%20CITY%20OF#searchresultsanchor)

Methodology: The average 1-percent annual exceedance probability (100-year return period) stillwater elevation (SWEL) from FEMA transects 70 through 79 (10.3 feet-NAVD88) has been adjusted with the three sea-level rise increments to determine the updated stillwater elevation. Then, the inundation extent has been determined with each of the updated stillwater elevations of due to coastal storm events.

Caveats: No wave action, and therefore no total water level, has been mapped as FEMA has not released total water level maps for future sea-level rise scenarios, and the determination of waves into the maps warrants the use of numerical modeling (which is outside the scope of work for this study).

GROUNDWATER

The water table surface dataset created by Plane, Hill, and May (2017), which provides minimum depth-to-water in the project area, was adjusted to incorporate the effect of sea level rise as described in previous sections. A 1:1 sea level rise-to-groundwater ratio has been applied to the dataset, an assumption that is considered acceptable based on a literature review, for areas located within 1 Km from the shoreline. Although groundwater elevations are expected to also increase beyond 1 Km from the shoreline, these impacts are expected to be lower further inland, and so were not included in the current study. Furthermore, there was insufficient site specific information to determine the tapering coefficient that should be applied to determine the sea level rise to groundwater increase ratio in areas further inland. The interpolated water table surface was shifted up to account for sea level rise increases of 2', 4', and 7'. Groundwater emergence was calculated by subtracting the resulting water table surfaces from the ground elevation.

Key Points

Data source: Minimum Depth to Groundwater for the Coastal San Francisco Bay Area. https://www.mdpi.com/2073-4441/11/11/2228; https://datadryad.org/stash/dataset/doi:10.6078/D1W01Q

Time Period of Well Data Used: 20 years

Methodology: Adjusted the water table (minimum depth-to-groundwater) up by the sea-level rise increments of 2', 4' and, 7'. Areas where the groundwater table is higher than the existing topography are marked as susceptible for future groundwater emergence.

Result: Groundwater emergence extent for each of the sea-level rise scenarios considered, where water table data is available.

PRECIPITATION

The potential inundation extent due to rainfall runoff is reflected in FEMA's Flood Insurance Rate Maps, for the 1%-AEP and the 0.2%-AEP events (100- and 500-year return periods, respectively). Therefore, this data source has been used as the input to reflect temporary flooding conditions due to rainfall runoff.

As described earlier, future projections of storm frequency and intensity have, not yet been defined due to intrinsic limitations of the models used, and, even if more complete had been available, detailed hydraulic and hydrologic modeling would be needed to define the resulting inundation extent which goes beyond the scope of this project. The project team is aware that detailed hydraulic and hydrologic analyses are underway by the Alameda County Flood Control and Water Conservation District (ACFCWCD), and results will likely be made available by the end of year 2020. Therefore, there is the opportunity to update the maps generated as part of this project once the above-mentioned maps are made available.

In the study area, the flooding extent shown is primarily due to coastal storm surge and sea level rise rather than rainfall-runoff flooding as this happens in a very limited area along Line A, as described in the Local Hydrology section.

DELIVERABLES

The list below shows the inundation maps (or scenarios) that have been generated as part of this effort:

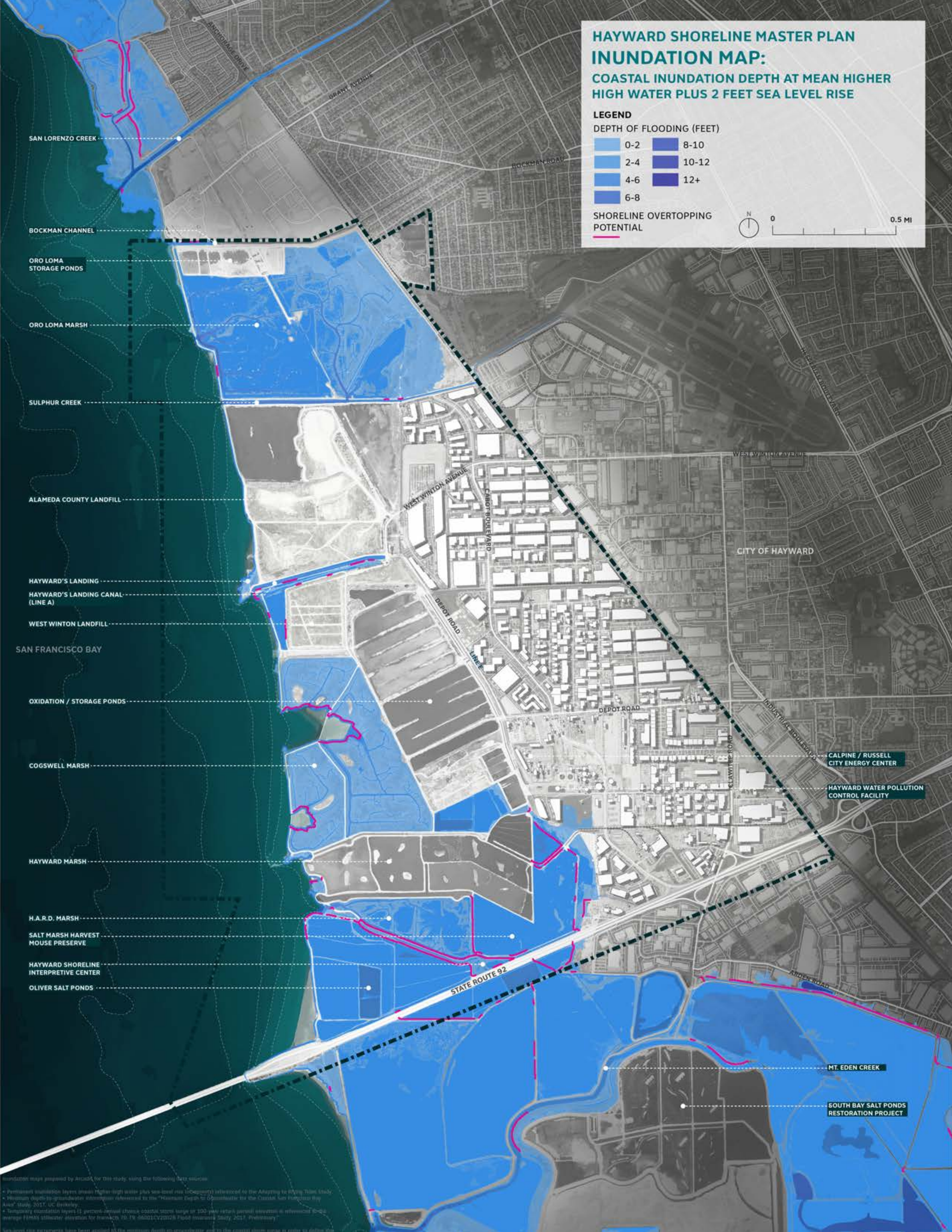
Map # Hazards Shown

1. Coastal inundation depth at MHHW plus 2 feet of sea level rise.
2. Minimum depth-to-groundwater emergence extent at 2 feet of sea level rise.
3. Combination of coastal inundation depth at MHHW and minimum depth-to-groundwater emergence extent at 2 feet sea level rise.
4. Combination of coastal inundation depth at 100-year storm surge conditions and groundwater emergence extent at 2 feet sea level rise.
5. Coastal inundation depth at MHHW plus 4 feet of sea level rise.
6. Minimum depth-to-groundwater emergence extent at 4 feet of sea level rise.
7. Combination of coastal inundation depth and minimum depth-to-groundwater emergence extent at 4 feet sea level rise.
8. Combination of coastal inundation depth at 100-year storm surge conditions and groundwater emergence extent at 4 feet sea level rise.
9. Coastal inundation depth at MHHW plus 7 feet of sea level rise.
10. Minimum depth-to-groundwater emergence extent at 7 feet of sea level rise.
11. Combination of coastal inundation depth and minimum depth-to-groundwater emergence extent at 7 feet of sea level rise.
12. Combination of coastal inundation depth at 100-year storm surge conditions and groundwater emergence extent at 7 feet of sea level rise.

The combinations shown above result in a total of 12 inundation maps. They represent the combination of the adjusted minimum depth-to-groundwater, adjusted FEMA 1% SWEL, and adjusted MHHW by the three sea-level rise scenarios chosen by HASPA.

SEA LEVEL RISE AND GROUNDWATER EMERGENCE MAPS

2’ SCENARIO



HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER PLUS 2 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
SHORELINE OVERTOPPING POTENTIAL
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
ALAMEDA COUNTY LANDFILL
HAYWARD'S LANDING
HAYWARD'S LANDING CANAL (LINE A)
WEST WINTON LANDFILL
SAN FRANCISCO BAY
OXIDATION / STORAGE PONDS
COGSWELL MARSH
HAYWARD MARSH
H.A.R.D. MARSH
SALT MARSH HARVEST MOUSE PRESERVE
HAYWARD SHORELINE INTERPRETIVE CENTER
OLIVER SALT PONDS
ANCHORAGE DRIVE
GRANT AVENUE
BOCKMAN ROAD
HESPERIAN BOULEVARD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE E
CLAWITER ROAD
INDUSTRIAL BOULEVARD
CITY OF HAYWARD
STATE ROUTE 92
ARDEN ROAD
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT
Inundation maps prepared by Arcadis for this study, using the following data sources:
• Minimum depth-to-groundwater information referenced to the "Minimum Depth to Groundwater for the Coastal San Francisco Bay Area" study, 2017, UC Berkeley.

HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
GROUNDWATER EMERGENCE EXTENT AT 2 FEET SEA LEVEL RISE
LEGEND
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
ALAMEDA COUNTY LANDFILL
HAYWARD'S LANDING
HAYWARD'S LANDING CANAL (LINE A)
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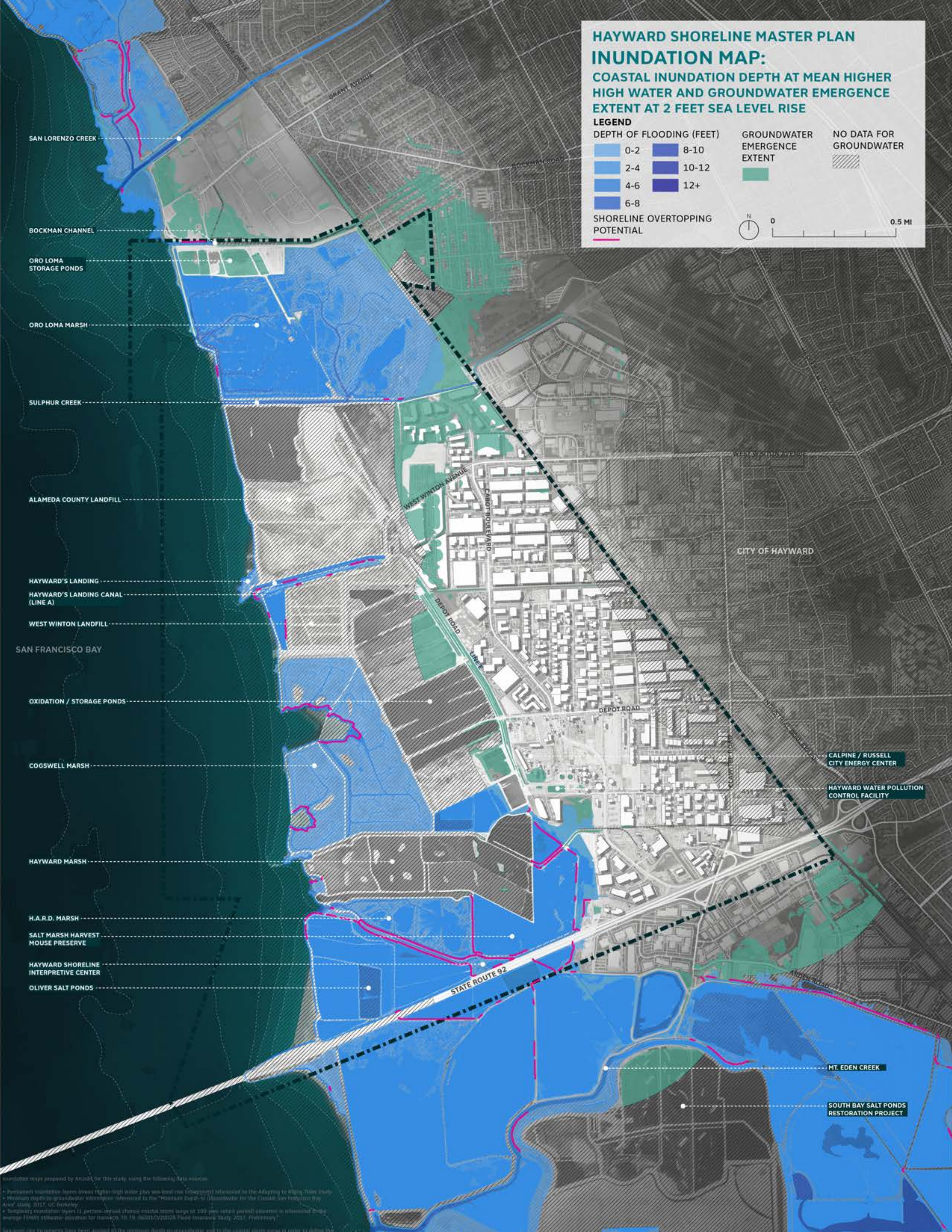
HAYWARD SHORELINE INTERPRETIVE CENTER
OLIVER SALT PONDS
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE A
CITY OF HAYWARD
STATE ROUTE 92
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER AND GROUNDWATER EMERGENCE EXTENT AT 2 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
SHORELINE OVERTOPPING POTENTIAL
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
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ORO LOMA MARSH
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STATE ROUTE 92
CITY OF HAYWARD
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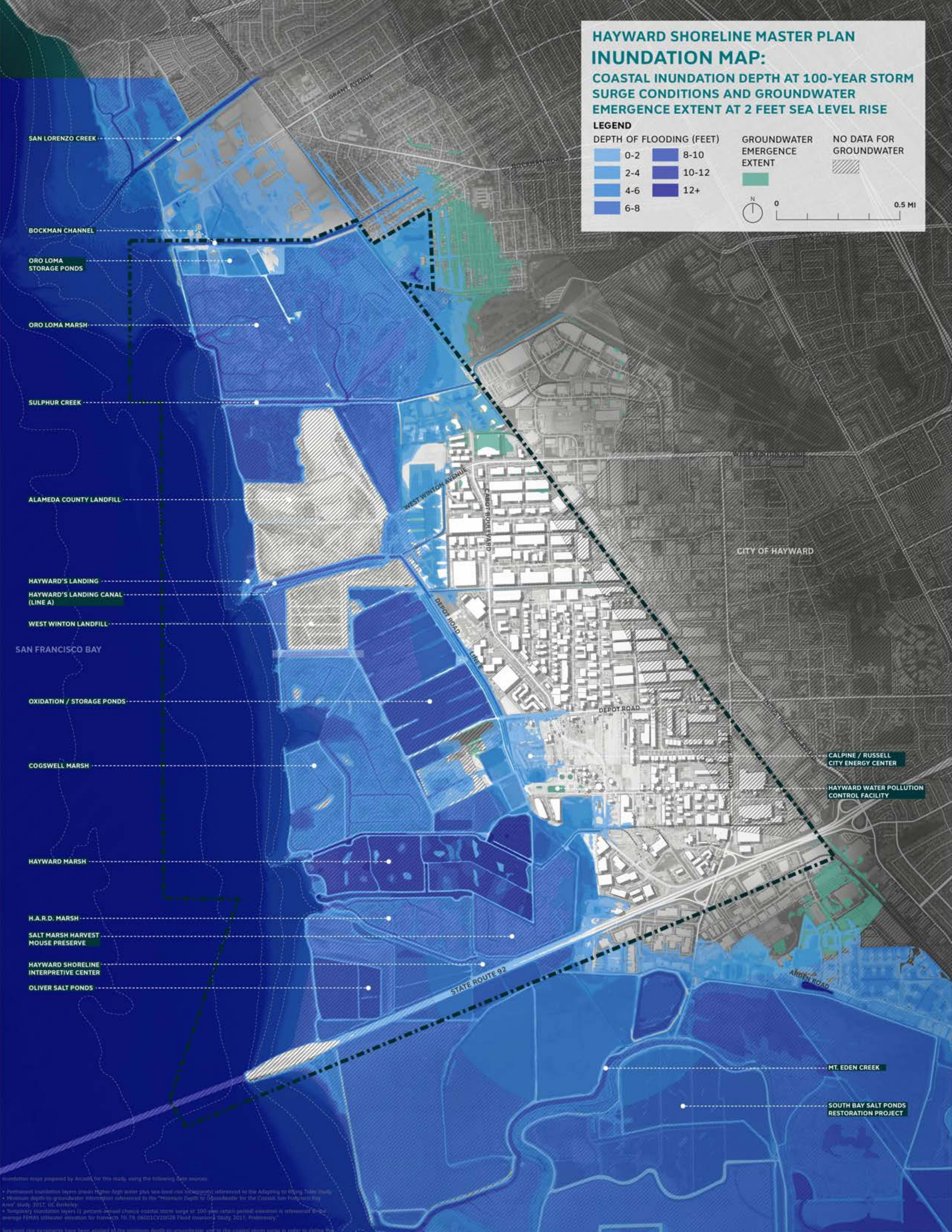
CABOT BOULEVARD
DEPOT ROAD
LINE I
GRANT AVENUE
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT 100-YEAR STORM SURGE CONDITIONS AND GROUNDWATER EMERGENCE EXTENT AT 2 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
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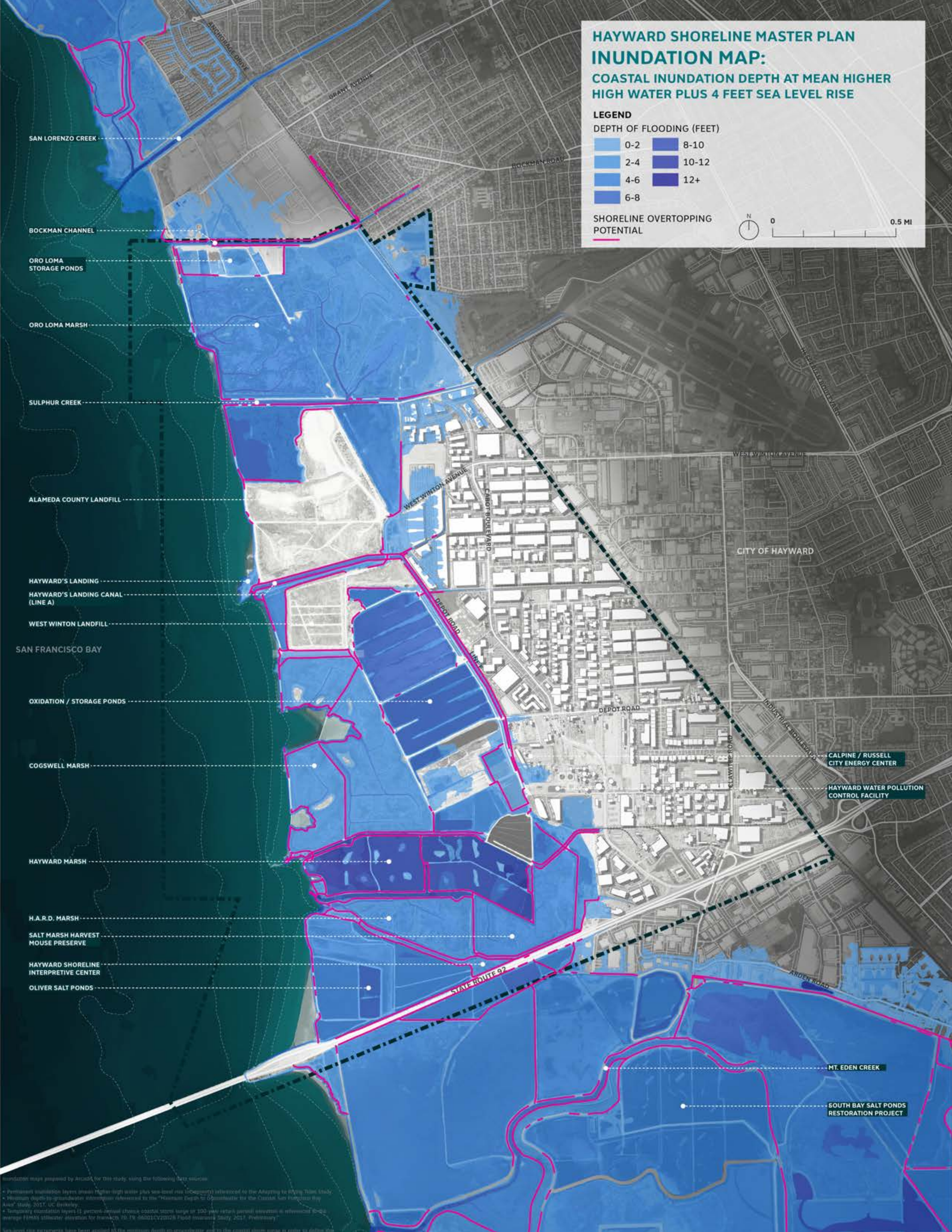
LINE
STATE ROUTE 92
ARDEN ROAD
Inundation maps prepared by Arcadis for this study, using the following data sources:
• Permanent inundation layers (mean higher high water plus sea-level rise increments) referenced to the Adapting to Rising Tides study.
• Minimum depth-to-groundwater information referenced to the "Minimum Depth to Groundwater for the Coastal San Francisco Bay Area" study, 2017, UC Berkeley.
• Temporary inundation layers (1 percent-annual chance coastal storm surge or 100-year return period) elevation is referenced to the average FEMA's stillwater elevation for transects 70-79 06001CV2002B Flood Insurance Study, 2017, Preliminary."

4’ SCENARIO



HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER PLUS 4 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
SHORELINE OVERTOPPING POTENTIAL
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0.5 MI
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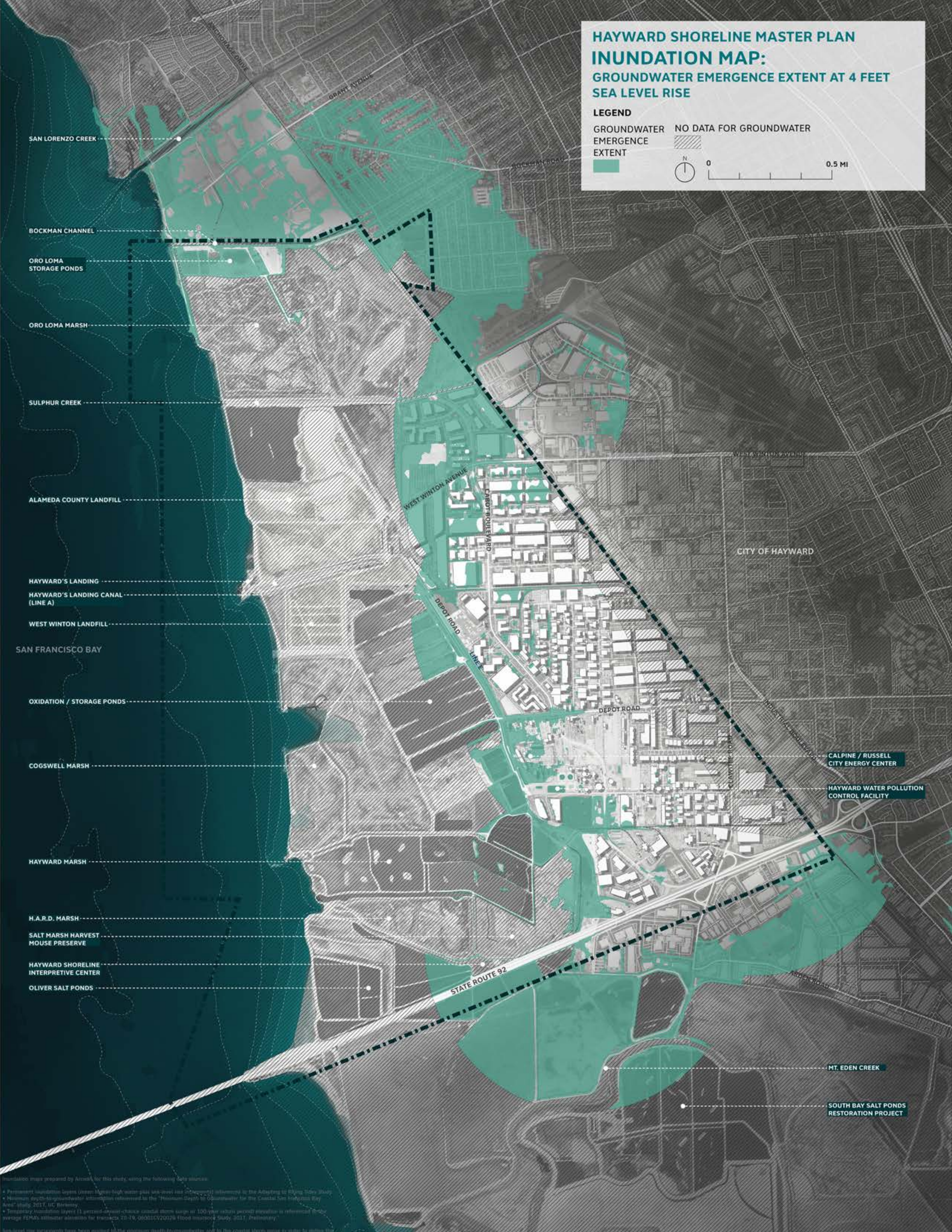
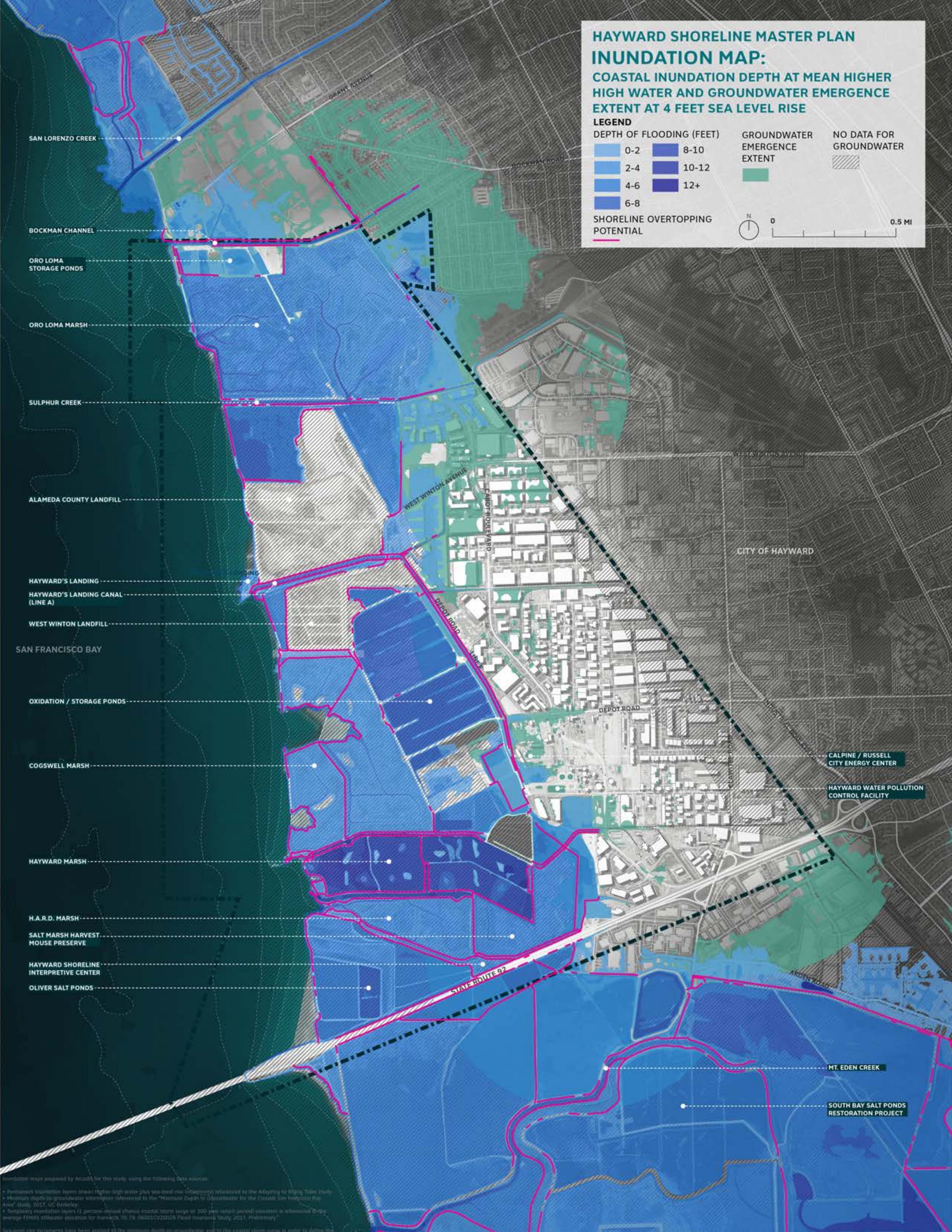
ANCHORAGE DRIVE
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
CLAWITER ROAD
INDUSTRIAL BOULEVARD
STATE ROUTE 92
ARDEN ROAD


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
GROUNDWATER EMERGENCE EXTENT AT 4 FEET SEA LEVEL RISE
LEGEND
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
ALAMEDA COUNTY LANDFILL
HAYWARD'S LANDING
HAYWARD'S LANDING CANAL (LINE A)
WEST WINTON LANDFILL
SAN FRANCISCO BAY
OXIDATION / STORAGE PONDS
COGSWELL MARSH
HAYWARD MARSH
H.A.R.D. MARSH
SALT MARSH HARVEST MOUSE PRESERVE
HAYWARD SHORELINE INTERPRETIVE CENTER
OLIVER SALT PONDS
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE E
CITY OF HAYWARD
STATE ROUTE 92
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER AND GROUNDWATER EMERGENCE EXTENT AT 4 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
SHORELINE OVERTOPPING POTENTIAL
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
ALAMEDA COUNTY LANDFILL
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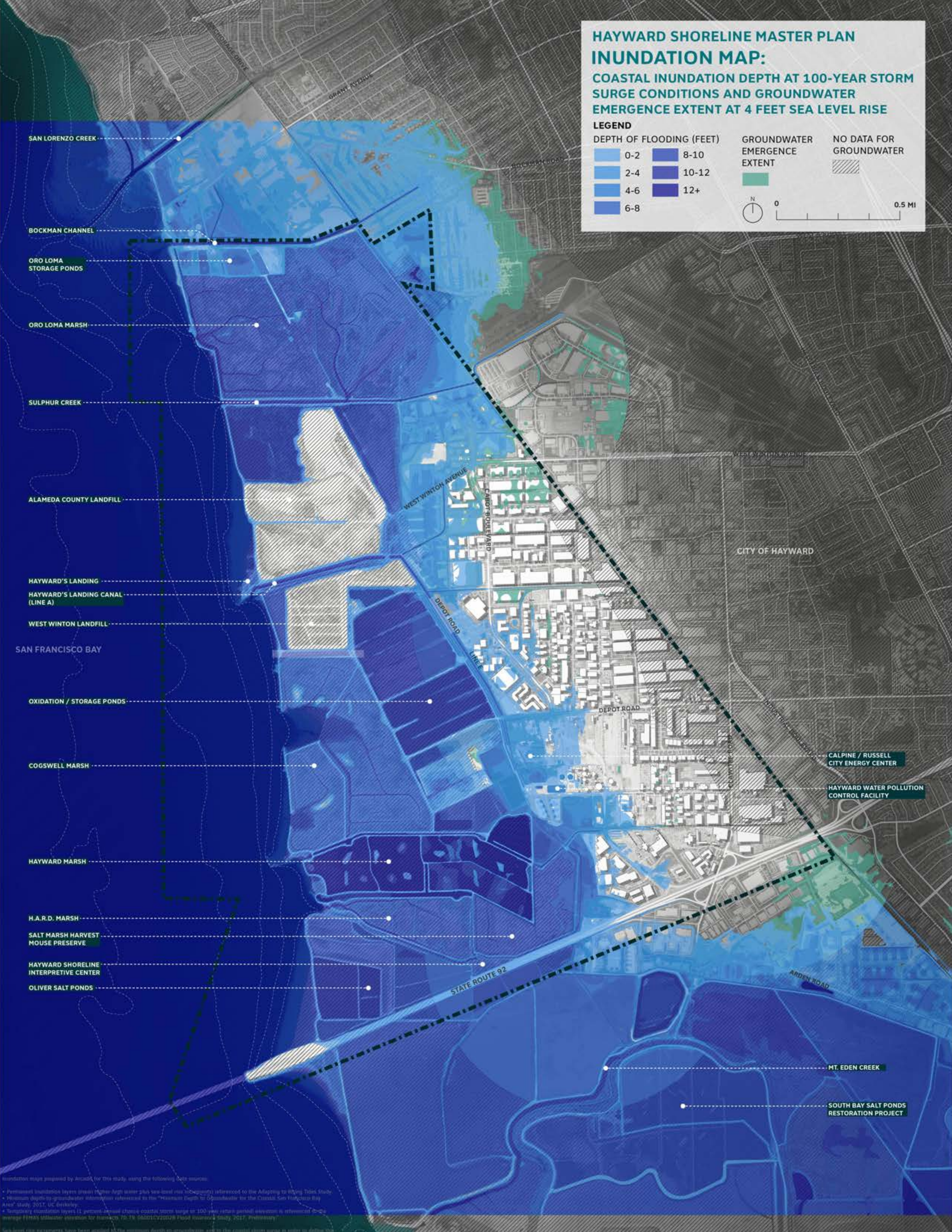
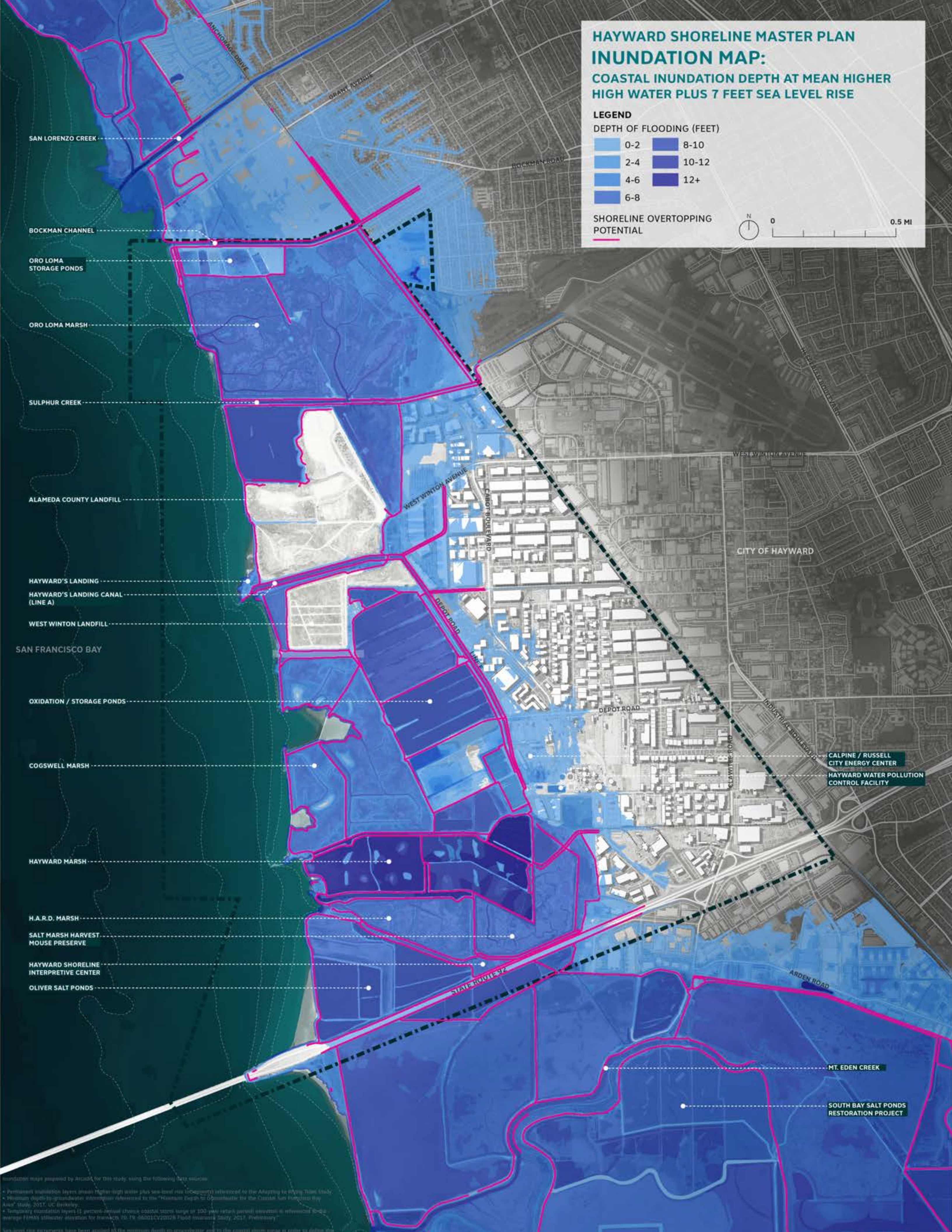
CITY OF HAYWARD
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE F
STATE ROUTE 92
ARDEN ROAD


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT 100-YEAR STORM SURGE CONDITIONS AND GROUNDWATER EMERGENCE EXTENT AT 4 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
ALAMEDA COUNTY LANDFILL
HAYWARD'S LANDING
HAYWARD'S LANDING CANAL (LINE A)
WEST WINTON LANDFILL
SAN FRANCISCO BAY
OXIDATION / STORAGE PONDS
COGSWELL MARSH
HAYWARD MARSH
H.A.R.D. MARSH
SALT MARSH HARVEST MOUSE PRESERVE
HAYWARD SHORELINE INTERPRETIVE CENTER
OLIVER SALT PONDS
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE E
CITY OF HAYWARD
STATE ROUTE 92
ARDEN ROAD
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT
Inundation maps prepared by Arcadis for this study using the following data sources:

7' SCENARIO


HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER PLUS 7 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
SHORELINE OVERTOPPING POTENTIAL
N
0
0.5 MI
SAN LORENZO CREEK
BOCKMAN CHANNEL
ORO LOMA STORAGE PONDS
ORO LOMA MARSH
SULPHUR CREEK
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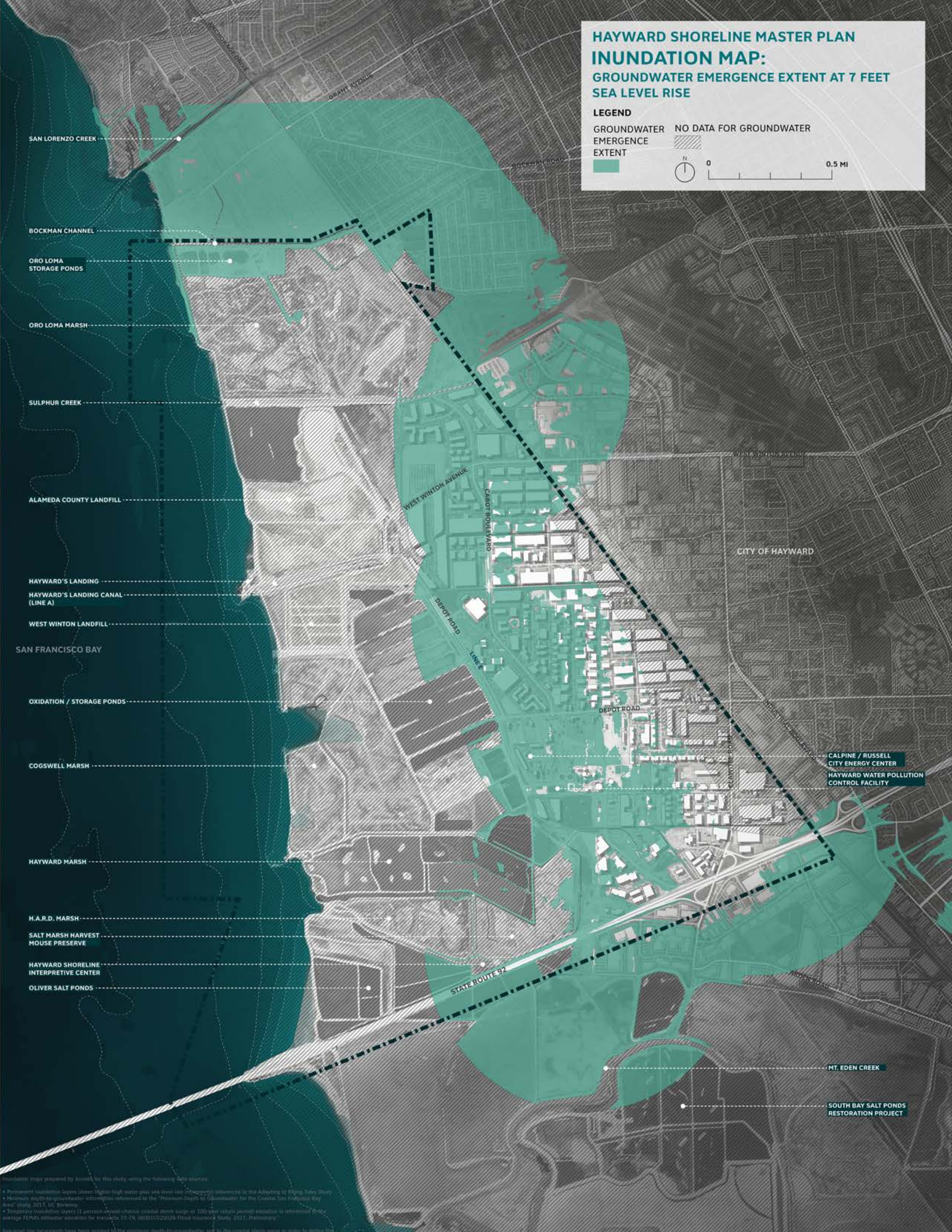
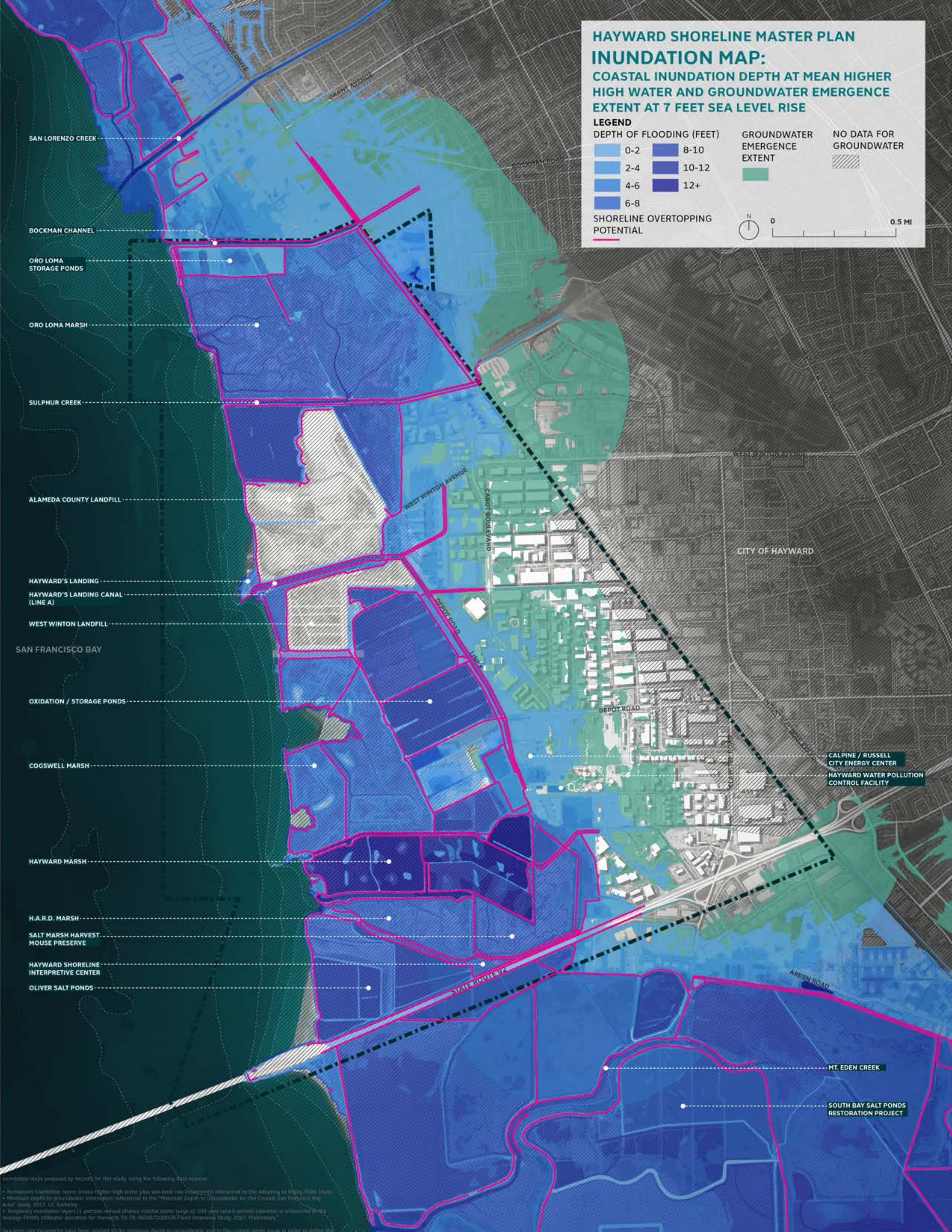
SALT MARSH HARVEST MOUSE PRESERVE
HAYWARD SHORELINE INTERPRETIVE CENTER
OLIVER SALT PONDS
ANCHORAGE DRIVE
GRANT AVENUE
BOCKMAN ROAD
WEST WINTON AVENUE
CABOT BOULEVARD
DEPOT ROAD
LINE I
CITY OF HAYWARD
INDUSTRIAL BOULEVARD
CLAWITER ROAD
CALPINE / RUSSELL CITY ENERGY CENTER
HAYWARD WATER POLLUTION CONTROL FACILITY
STATE ROUTE 92
ARDEN ROAD
MT. EDEN CREEK
SOUTH BAY SALT PONDS RESTORATION PROJECT

HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP: GROUNDWATER EMERGENCE EXTENT AT 7 FEET SEA LEVEL RISE




HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT MEAN HIGHER HIGH WATER AND GROUNDWATER EMERGENCE EXTENT AT 7 FEET SEA LEVEL RISE
LEGEND
DEPTH OF FLOODING (FEET)
0-2
2-4
4-6
6-8
8-10
10-12
12+
GROUNDWATER EMERGENCE EXTENT
NO DATA FOR GROUNDWATER
SHORELINE OVERTOPPING POTENTIAL
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0.5 MI
SAN LORENZO CREEK
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DEPOT ROAD
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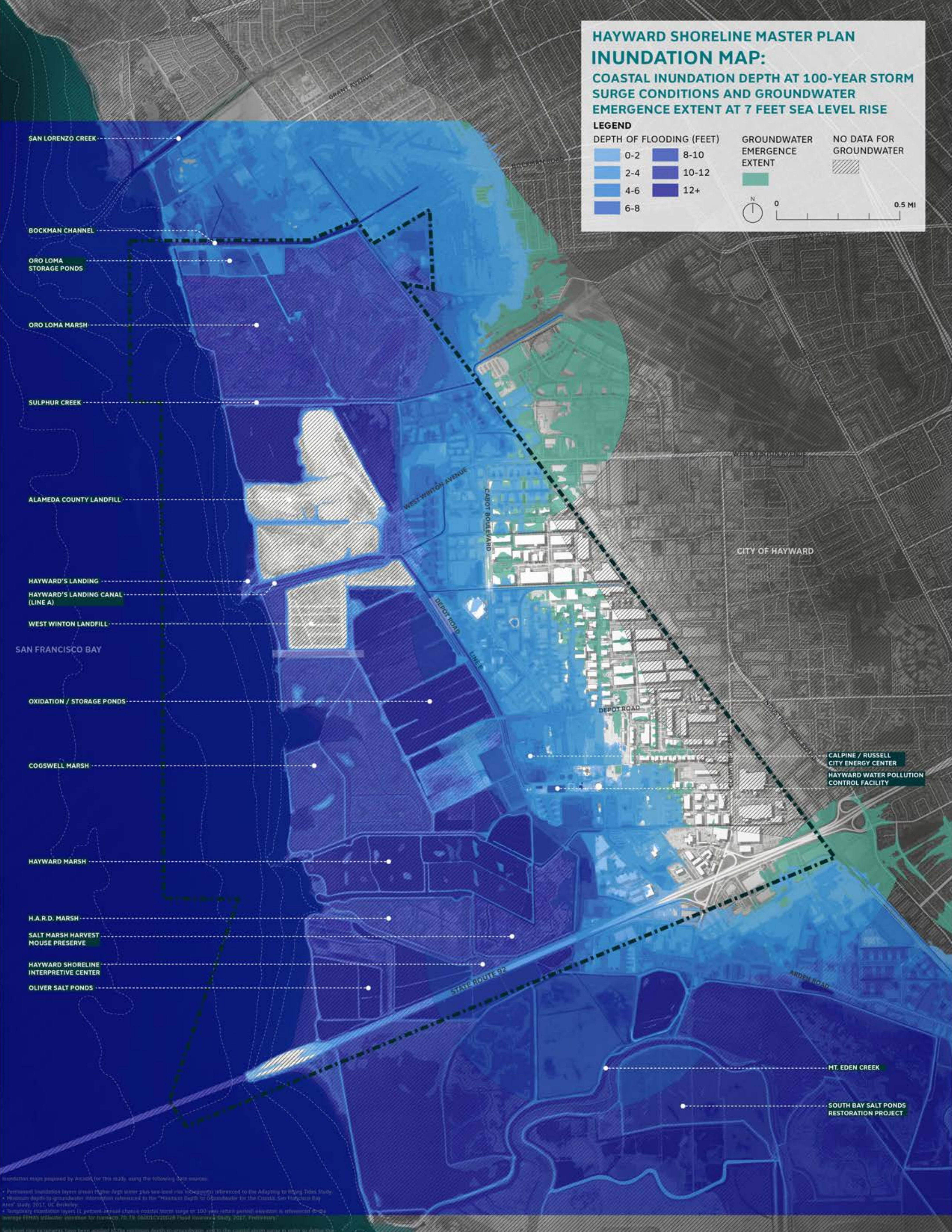
HAYWARD SHORELINE MASTER PLAN
INUNDATION MAP:
COASTAL INUNDATION DEPTH AT 100-YEAR STORM SURGE CONDITIONS AND GROUNDWATER EMERGENCE EXTENT AT 7 FEET SEA LEVEL RISE
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0
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LINE E
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ARDEN ROAD
Inundation maps prepared by Arcadis for this study, using the following data sources:
• Permanent inundation layers (mean higher high water plus sea-level rise increments) referenced to the Adapting to Rising Tides Study.
• Minimum depth-to-groundwater information referenced to the "Minimum Depth to Groundwater for the Coastal San Francisco Bay Area" study, 2017, UC Berkeley.
• Temporary inundation layers (1 percent-annual chance coastal storm surge or 100-year return period) elevation is referenced to the average FEMA stillwater elevation for transects 70-79, 06001CV2002B Flood Insurance Study, 2017, Preliminary.

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