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CASE STUDY

AECOM

MEMORANDUM

To	Stefanie Hom (MTC)
CC	Wendy Goodfriend (BCDC), Dick Fahey (Caltrans), Norman Wong (BART), Clair Bonham-Carter (AECOM)
Subject	San Francisco-Oakland Bay Bridge Touchdown Focus Area
From	Ricky Torres-Cooban, EIT, Michael Mak, P.E., Justin Vandever, P.E., Kris May, Ph.D., P.E.
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1. INTRODUCTION AND PURPOSE

The San Francisco-Oakland Bay Bridge touchdown (Bay Bridge Touchdown) was selected as a focus area for more detailed sea level rise exposure analysis and adaptation strategy development as part of the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study. Under the precursor MTC Vulnerability and Risk Assessment Project (BCDC et al. 2011), this area was shown to be vulnerable to inundation by sea level rise and coastal storm surge that could impact critical transportation assets and other adjacent assets that support the region, as identified by the Project Management Team (PMT). The purpose of this memorandum is to identify the key areas of vulnerability that exist within the focus area and assess the sources, mechanisms, and timing of inland inundation and flooding to inform the development of adaptation strategies.

This technical memorandum should be considered in tandem with other ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand sea level rise, storm surge, and shoreline vulnerabilities in Alameda County. The following sections provide a description of the Bay Bridge Touchdown Focus Area (Section 2), an assessment of exposure to inundation and flooding (Section 3), identification of key areas of vulnerability (Section 4), recommendations for timing of adaptation measures (Section 5), proposed adaptation measures (Section 6), and conclusions and next steps (Section 7).

2. FOCUS AREA DESCRIPTION

The Bay Bridge Touchdown focus area is located south of Emeryville Marina in the San Francisco Bay (Bay), along the northern boundary of the Oakland Outer Harbor (Figure 1). The area includes the Bay Bridge Touchdown and westbound toll plaza as well as the intersection of interstate highways I-580, I-80, and I-880. The northern portion of the focus area is mostly tidal wetlands with a small area immediately north of the Bay Bridge westbound tollbooths at Radio Beach where three radio towers are located. The core asset in this focus area is the Bay Bridge Touchdown. Several adjacent assets are also located within this focus area south of I-80, including a wastewater discharge transition structure and dechlorination facilities owned and operated by the East Bay Municipal Utility District

(EBMUD) at the western tip of the shoreline, the main EBMUD wastewater treatment plant farther inland (to the east), electrical substations, the Port of Oakland, and several other industrial buildings, temporary and permanent, of which some have historical value. The proposed site for Gateway Park is also within this focus area.

The area north of the Bay Bridge Touchdown (Areas A to C in Figure 1) is a tidal wetland and experiences regular tidal inundation under existing conditions. Approximately one third of the shoreline has some degree of rock protection. South of I-80, the Port of Oakland berths 7-10 (Areas G and H in Figure 1) are constructed of concrete and elevated several feet above typical high tides. Along the western portion of the focus area (Areas D to F in Figure 1), engineered rock protection exists along the majority of the shoreline and some tidal inundation occurs under existing conditions in low-lying areas along the shoreline.

The AECOM team performed a site visit on March 7, 2014 with BCDC, MTC, BART, and Caltrans staff. Visual inspection of shoreline protection structures and assets was performed along the northern and southern shorelines of the Bay Bridge touchdown and along Burma Road. Areas subject to tidal inundation under existing conditions were also verified. See Attachment A for site visit photos.

3. INUNDATION AND FLOODING EXPOSURE

In the discussion that follows, a clear distinction is made between the terms *inundation* and *flooding*. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. In contrast, *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. The term flooding, as it is used throughout this memorandum, is therefore a temporary inundation condition that results from a storm event rather than the permanent inundation due to daily high tides.

To assess portions of the shoreline that are exposed to inundation and flooding within the Bay Bridge Touchdown focus area, six sea level rise and inundation mapping scenarios were examined (Table 1). Inundation maps were created for each of the scenarios using the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (Marcy et al. 2011). The scenarios were developed by adding different amounts of sea level rise onto the elevation of the existing conditions daily high tide level (represented by the Mean Higher High Water (MHHW) tide). The MHHW reference water levels used in this analysis were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [1] (DHI 2011). The modeling study spanned a 31-year period from January 1, 1973 to December 31, 2003. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to compute tidal datums.

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[1] www.r9coastal.org

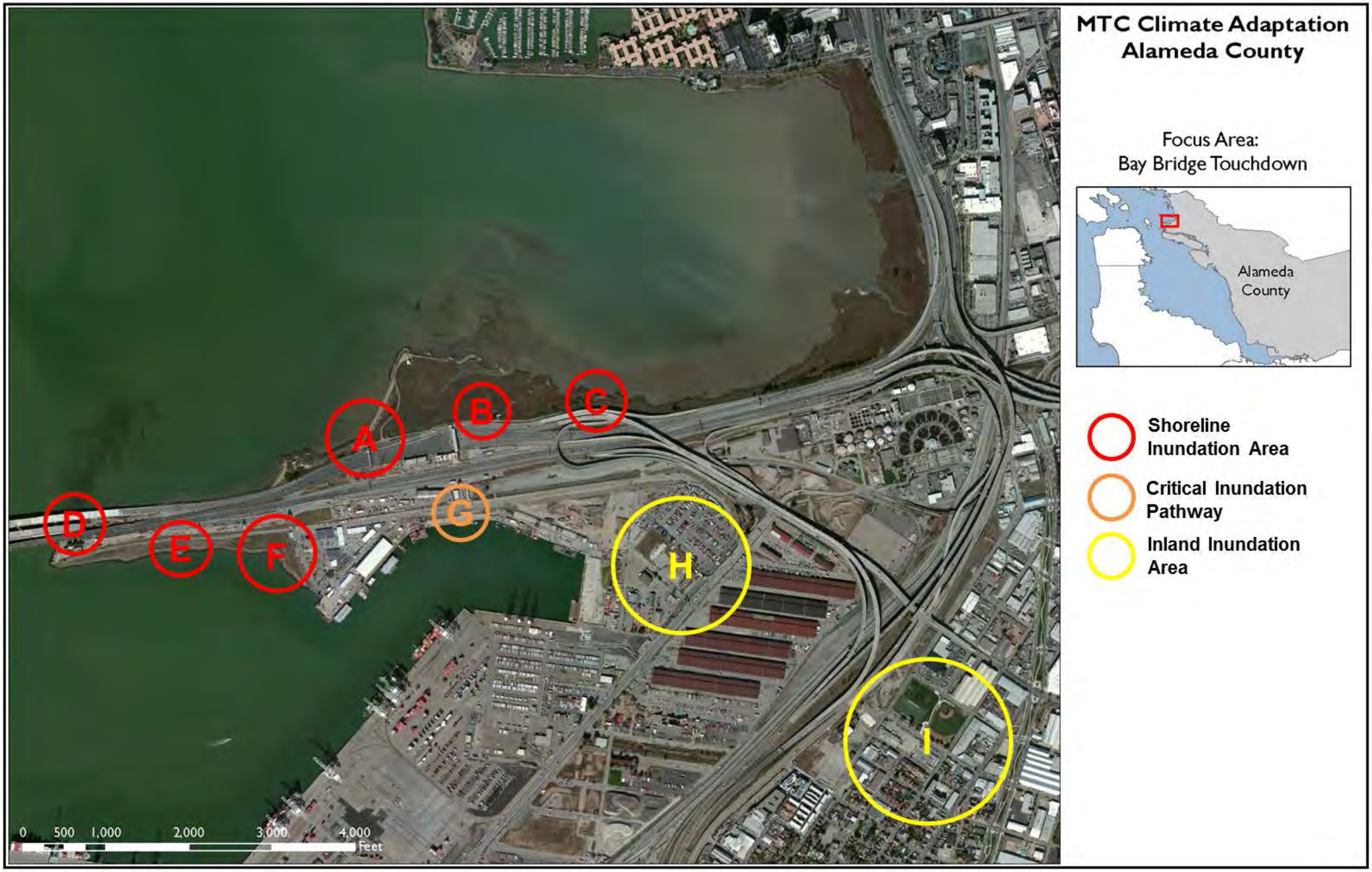

Figure 1. Bay Bridge Touchdown Focus Area Site Location Map and Inundation Areas

Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

In accordance with the most up-to-date sea level rise projections, the following scenarios were evaluated for the present study: 12-inch, 24-inch, 36-inch, and 48-inch. In addition to these scenarios, 72-inch and 96-inch scenarios were also evaluated; but these water levels are outside the range of current scientific predictions for sea level rise and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC 2012). Rather, these scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of sea level rise. Mapped scenarios are listed in Table 1**.** The inundation maps for this focus area were developed by AECOM as a part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD and are shown in Attachment B. The maps show inundation areas and depths as well as overtopping potential lines along the shoreline and the edges of the highway. “Overtopping potential” refers to the condition where the water surface elevation associated with a particular reference water level exceeds the elevation of the shoreline asset. The depth of overtopping potential at each shoreline segment is calculated by taking an average of several depths over the length of the segment. This assessment is considered a planning-level tool only, as it does not account for the physics of wave runup and overtopping. It also does not account for potential vulnerabilities along the shoreline protection infrastructure that could result in complete failure of the flood protection infrastructure through scour, undermining, or breach after the initial overtopping occurs.

Table 1. Sea Level Rise Inundation Mapping Scenarios

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12-inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24-inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36-inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48-inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72-inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96-inch	MHHW + 93 – 99 inch

It is important to understand that the reference water levels listed for each mapping scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of sea level rise with either a daily[2] or extreme high tide. For example, Scenario 3 (MHHW + 36-inch) represents a water level reached both by daily high tide with 36 inches of sea level rise or a 50-year extreme tide with no sea level rise (i.e., existing conditions). A +/- 3-inch tolerance was added to each reference water level to increase the applicable range of the mapped scenarios. For example, Scenario 3 (MHHW + 36-inch) 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. By combining

[2] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that. The actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 6.2 ft NAVD88 within this focus area.

different amounts of sea level rise and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map.

The matrix of sea level rise and tide scenarios is presented in Table 2. Values are shown in inches above the existing conditions MHHW level. The coloring shown matches the coloring in Table 1 and indicates the different combinations of sea level rise and extreme tide scenarios represented by each inundation map. Note that Scenarios 5 and 6 correspond only to extreme tide events as they are outside of the range of projections for probable sea level rise over the next century. The first row of the table shows values for existing conditions. For example, to read Table 2, the inundation map that represents MHHW + 36 inches (Scenario 3), would also represent a 1-yr event with 24 inches of sea level rise, a 2-yr event with 18 inches of sea level rise, a 5-yr event with 12 inches of sea level rise, etc. Equivalent water levels for the MHHW + 12-inch, MHHW + 24-inch, MHHW + 36-inch, MHHW + 48-inch, MHHW + 72-inch, and MHHW + 96-inch mapping scenarios can be determined similarly by tracking the color coding through the table. Alternatively, this matrix could be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of sea level rise, the MHHW + 48-inch mapping scenario could be examined. Using this approach, it is possible to assign flood risk to assets at various time scales and frequency of flooding.

Table 2. Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	14	19	23	27	33	37	42
MHHW + 6-inch	6	20	25	29	33	39	43	48
MHHW + 12-inch	12	26	31	35	39	45	49	54
MHHW + 18-inch	18	32	37	41	45	51	55	60
MHHW + 24-inch	24	38	43	47	51	57	61	66
MHHW + 30-inch	30	44	49	53	57	63	67	72
MHHW + 36-inch	36	50	55	59	63	69	73	78
MHHW + 42-inch	42	56	61	65	69	75	79	84
MHHW + 48-inch	48	62	67	71	75	81	85	90
MHHW + 54-inch	54	68	73	77	81	87	91	96
MHHW + 60-inch	60	74	79	83	87	93	97	102

Note: All values in inches above existing conditions MHHW at Bay Bridge Touchdown Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 1.

4. KEY AREAS OF VULNERABILITY

By combining the information available in the water level matrix (Table 2) with the results of the inundation mapping and overtopping potential calculations, shoreline exposure to inundation/flooding and the timing of exposure can be evaluated. This study identified nine key areas of vulnerability within the Bay Bridge Touchdown focus area based on the results of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 1 and labeled letters "A" through "I". These areas can be grouped into three categories -- *shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In Figure 1, shoreline inundation areas (A-F) are labeled in red, critical inundation pathways (G) in orange, and inland inundation areas (H-I) in yellow.

Shoreline inundation areas are immediately adjacent to the shoreline and are both the most vulnerable to flooding and the most likely to experience permanent inundation as a result of sea level rise. These areas are where the shoreline is first overtopped and from which floodwaters will propagate to areas immediately inland[3]. Six shoreline inundation areas were identified for the Bay Bridge Touchdown focus area and are discussed in Section 4.1. *Inland* inundation areas are not directly on the shoreline and require a hydraulic pathway to convey floodwaters from the Bay to the inland area. These areas are the least likely to experience the full extent of temporary flooding depicted in the inundation maps due to the typical duration of a coastal storm surge event and volume of water that would be required to fill these expansive low-lying areas during an episodic event. To determine the exact extent of inland flooding or permanent inundation, more sophisticated modeling is required; however, the exposure of these areas to potential inundation and flooding is well represented by the inundation maps for the purposes of this study. Two inland inundation areas were identified within the Bay Bridge Touchdown focus area and are discussed in Section 4.3. Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey floodwaters to inland areas. One critical inundation pathway was identified within the Bay Bridge Touchdown focus area and is discussed in Section 4.2.

4.1 SHORELINE INUNDATION AREAS

Six shoreline inundation areas were identified within the Bay Bridge Touchdown focus area (See Figure 1). Extensive shoreline inundation occurs in the earliest mapped scenario (MHHW + 12-inch); and inundated areas primarily include the tidal wetlands north of the Bay Bridge Touchdown and the radio towers located adjacent to Radio Beach (Areas A-C). The northernmost highway lane as well as the access road immediately adjacent to the toll plaza are partially inundated in the 12-inch and 24-inch scenarios though only with minimal inundation depths and limited extents. Critical portions of the westbound highway assets are extensively inundated at the 36-inch scenario. Access roads in both the northern and southern portions of the Bay Bridge touchdown are also extensively inundated at the

[3] The sea level rise scenario when the site is first overtopping has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12", 24", 36", 48"). The actual sea level rise scenario which results in overtopping may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

36-inch scenario. Additionally, partial inundation of the southwestern tip of the peninsula (Area D) endangers electrical and wastewater treatment facilities at the 36-inch scenario. Inundation maps for the 36-inch scenario are shown in Figure 2 and Figure 3. The six shoreline inundation areas are summarized below:

- Area A (Figure 2)
  - Limited inundation occurs near the toll plaza as early as 12-inch scenario
  - Inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet
- Area B (Figure 2)
  - Limited inundation occurs near the toll plaza as early as 24-inch scenario
  - Partial inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet
- Area C (Figure 2)
  - Partial inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - Inundation underneath elevated highway segments
- Area D (Figure 3)
  - Access road and buildings are partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet
  - Inundation underneath elevated highway segments
- Area E (Figure 3)
  - Burma Road is partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet
- Area F (Figure 3)
  - Burma Road and some nearby buildings are partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet

4.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway was identified at the Bay Bridge Touchdown focus area (Area G in Figure 1). This low-lying hydraulic pathway allows floodwaters to penetrate landward from the shoreline to the inland inundation Areas H and I (Figure 4). Given the relatively large extent of inland inundation observed, AECOM sought to verify the mechanism of flooding and accuracy of the digital elevation model (DEM)[4] upon which the inundation maps were based to confirm the likelihood of flooding depicted. The DEM was compared to the original topographic Light Detection and Ranging (LiDAR) data points for this area to confirm that the modeled terrain surface of the DEM accurately represented the raw LiDAR data. Additionally, the orthoimagery from the 2010 LiDAR data collection and aerial photography from Google Earth (2014) were examined to confirm the location of the pathway and its surrounding features. Based on these examinations, the pathway appears to be formed by an engineered stormwater drainage area along Burma Road, which most likely drains to

[4] A 2-meter digital elevation model (DEM) was developed from the 2010 LiDAR data collected by the United States Geological Survey (USGS) and National Oceanic Atmospheric Administration (NOAA) as part of the California Coastal Mapping Program (CCMP)

the Bay. Although intended for mitigating flooding due to precipitation and runoff, this stormwater drainage system is ineffective at preventing coastal floodwaters from propagating inland.

Figure 5 shows the elevation profile along the critical inundation pathway starting at the shoreline near Areas E and F and extending inland to Area H. The MHHW + 48-inch water level is shown for reference relative to the topography. As can be seen in Figure 5, the MHHW + 48-inch water level overtops both the shoreline protection infrastructure and the high point of the critical inundation pathway at an elevation of approximately 10 feet NAVD88. Once both of these features are overtopped, there is a continuous hydraulic connection from the shoreline to the inland inundation areas, which conveys floodwaters landward. Key observations for this critical inundation pathway are summarized below:

- Area G (Figure 4)
  - Inundation occurs at critical water level of approximately 10 feet NAVD88
  - Narrow drainage pathway along Burma Road at Port of Oakland Berth 8 connects the flooding from Areas E and F (Figure 3) to Areas H and I
  - Inundation first occurs at the 48-inch scenario with inundation depths of 0-3 feet

4.3 INLAND INUNDATION AREAS

Two key inland inundation areas were identified for the Bay Bridge Touchdown focus area. These areas are inundated via the critical inundation pathway (Area G) at the 48-inch scenario and are otherwise isolated from floodwaters for the lower sea level rise scenarios. Extensive inland flooding from multiple sources occurs at the 72-inch and 96-inch scenarios and extends northward towards the Emeryville Crescent. As stated in Section 3, these scenarios correspond with future extreme tide events and are unlikely to occur as permanent inundation before 2100. The inland inundation areas are summarized below:

- Area H (Figure 4)
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - Mostly industrial land uses

- Area I (Figure 4)
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - I-880, residential and commercial land uses

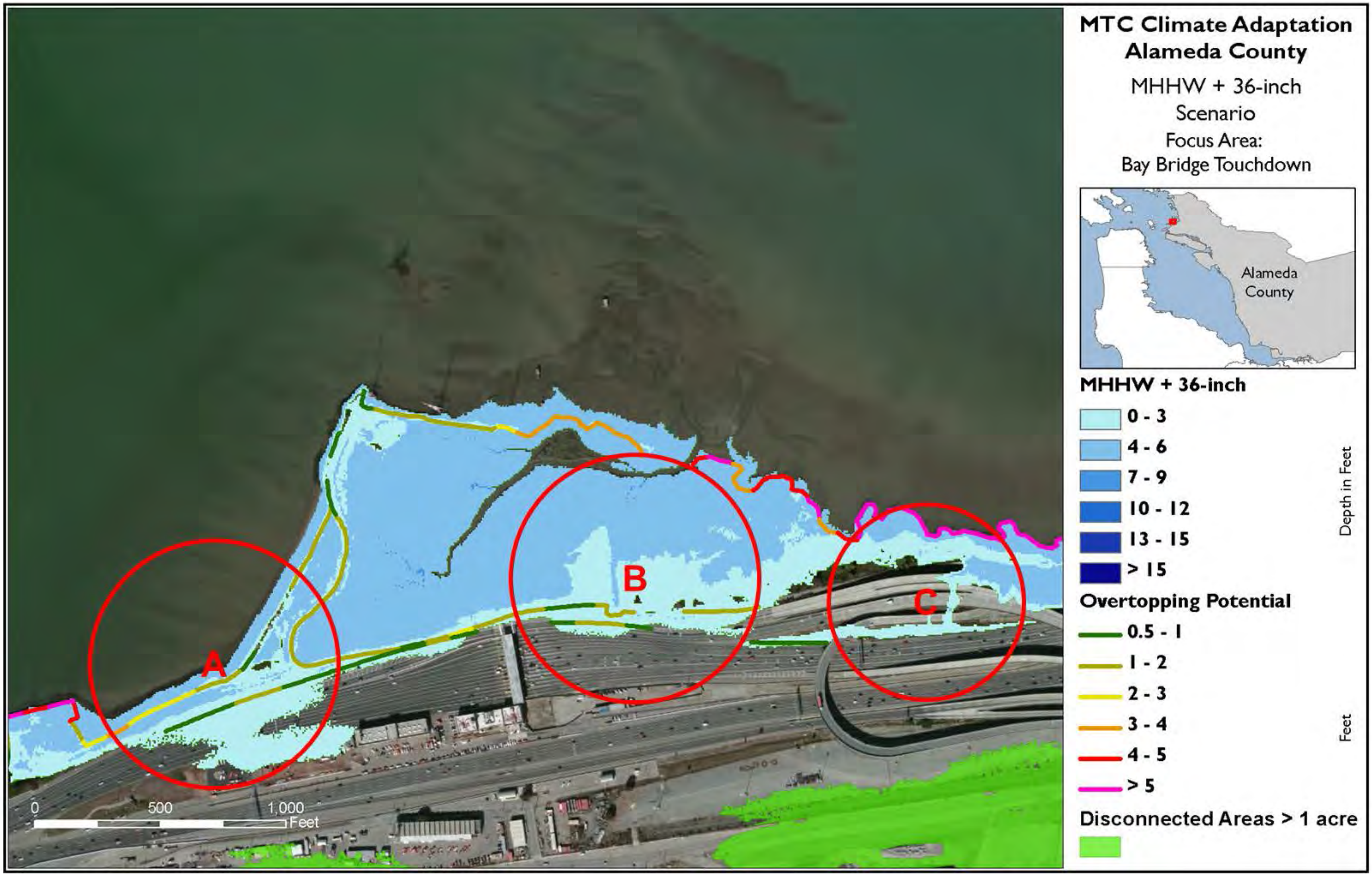

Figure 2. Shoreline Inundation Areas A, B, and C - MHHW + 36-inch Scenario

Figure 3. Shoreline Inundation Areas D, E, and F - MHHW + 36-inch Scenario

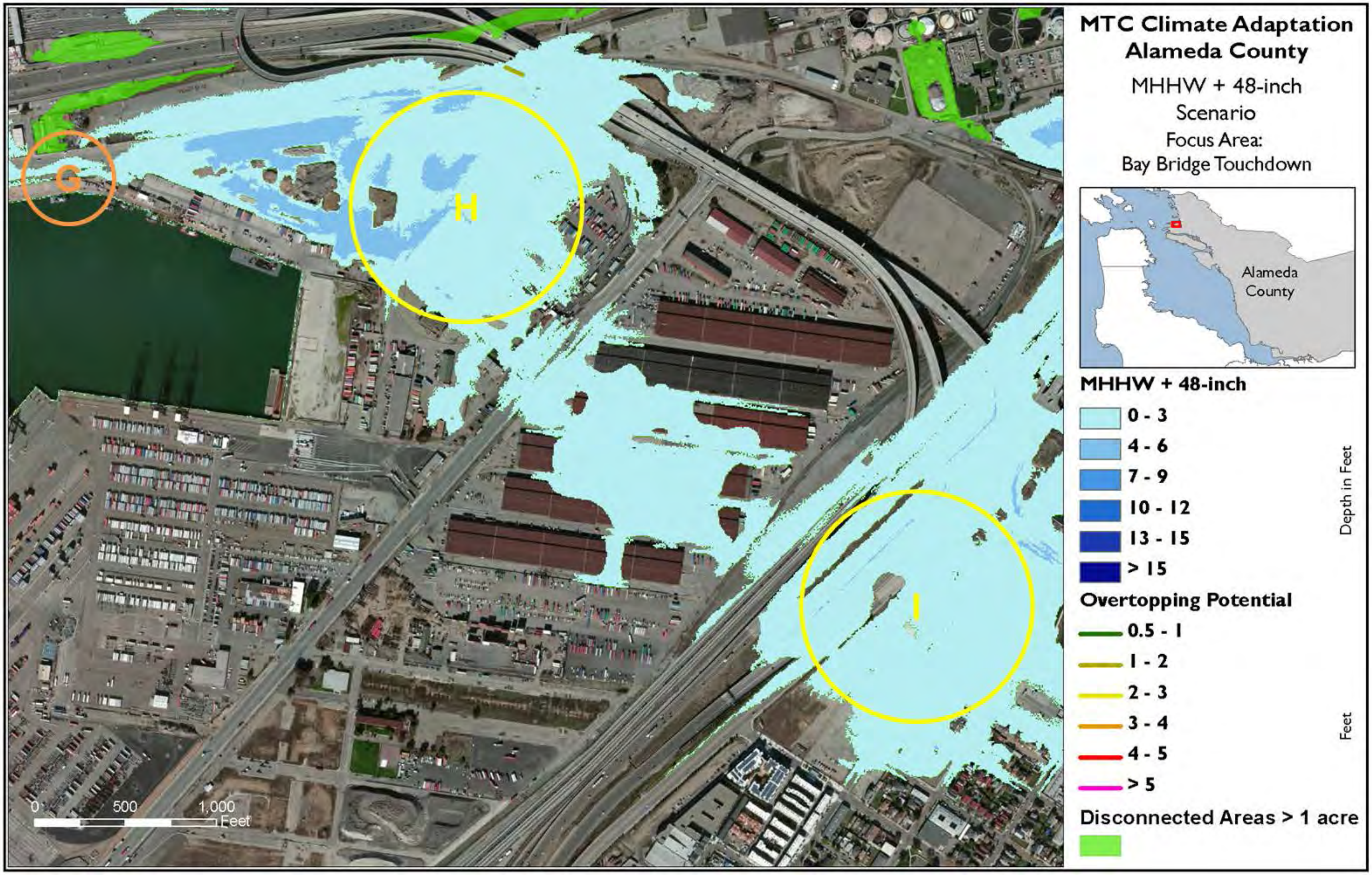

Figure 4. Critical Inundation Pathway (Area G) and Inland Inundation Areas (H-I) - MHHW + 48-inch Scenario

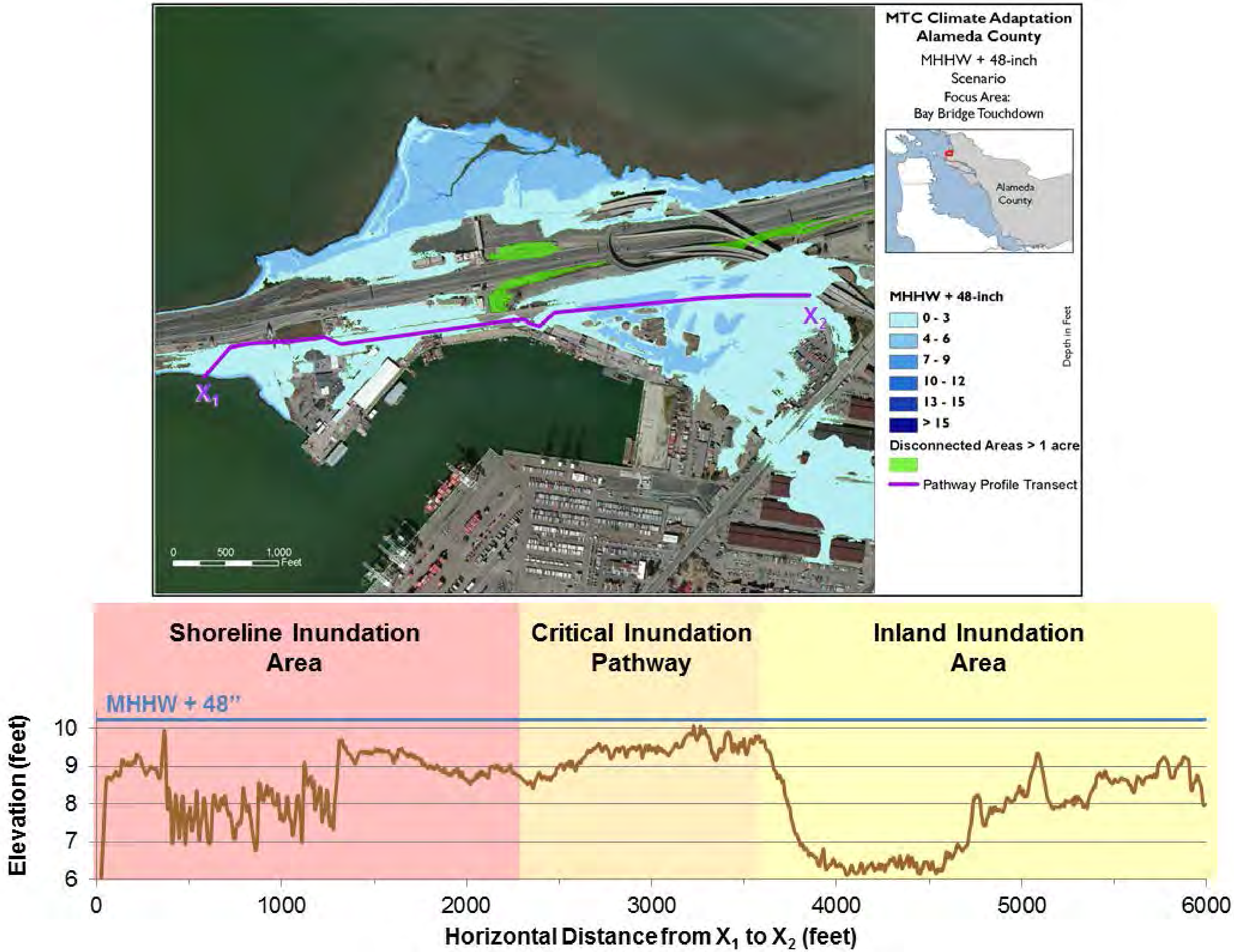

Figure 5. Plan and Profile View of Critical Inundation Pathway Connecting the Shoreline with Inland Inundation Areas

Notes: Profile outlined in purple in the plan view. Profile stationing reads from west (X_1) to east (X_2).

5. TIMING OF ADAPTATION MEASURES

The timing of adaptation measures is a key component of climate change adaptation planning. AECOM examined the timing of adaptation measures from the perspective of maintaining the existing level of flood protection in the face of rising sea level. The standard level of design for flood protection along the Bay shoreline is the 100-year (or 1-percent annual chance) flood[5], although in many areas this design criterion is not met. For the purposes of this study, the occurrence of various extreme tide levels under different sea level rise scenarios was evaluated. It should be noted that extreme tide levels presented in this memorandum do not include the effects of waves at the shoreline or the effects of precipitation based runoff and highway drainage and therefore may underestimate true flood risk. FEMA is currently in the process of updating Flood Insurance Rate Maps for this area which provide a more complete assessment of existing flood hazards.

Table 3 summarizes the timing of flooding for the shoreline inundation areas (A-F) and inland inundation areas (H-I) for various sea level rise scenarios. As discussed in Section 4, limited exposure to inundation occurs as early as the MHHW + 12-inch scenario along the northernmost highway lanes. The shoreline and inland inundation areas will be critically exposed to daily tidal inundation under the MHHW + 36-inch and MHHW + 48-inch sea level rise scenarios, respectively; however, these areas will be exposed to flooding by extreme tide events at much lower sea level rise scenarios. For example, core assets within the shoreline inundation area that will be exposed to daily tidal inundation under the MHHW + 36-inch sea level rise scenario could also be exposed to flooding once per year during 24 inches of sea level rise (24 inches of SLR + 1-year extreme tide), or repeatedly during El Niño[6] conditions with 6 inches of sea level rise (6 inches of SLR + 10-year extreme tide). The shoreline inundation areas (A-F) currently experience flooding under an existing 50-year extreme tide, while the inland inundation areas (H-I) require a coastal storm event greater than the 100-year level before they are flooded under existing conditions[7]. As sea levels increase over time, the level of flood protection for these areas will decrease and flooding will occur at a higher frequency. The reduction in level of flood protection due to sea level rise is shown in Table 3 for the shoreline and inland inundation areas. To maintain the existing level of flood protection along the shoreline areas, adaptation actions should be taken immediately. To maintain the existing level of flood protection (100-year) for the inland areas, adaptation actions should be considered before 6 inches of sea level rise occurs. Based on current guidance, 6 inches of sea level rise may occur by 2030 (NRC 2012). If no action is taken, sea level rise will continue to diminish the level of flood protection afforded by the existing shore protection infrastructure up until the point where the shoreline and inland areas are subject to daily tidal inundation.

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[5] The 100-year flood is typically applied by the Federal Emergency Management Agency (FEMA) for developing Flood Insurance Rate Maps for coastal communities.

[6] The 10-year storm surge elevation is comparable to a typical El Niño winter condition in the Bay.

[7] It should be noted that localized areas of shoreline flooding may occur at less extreme tides and that the quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk.

Table 3. Timing of Inundation and Flooding for Inundation Areas within the Bay Bridge Touchdown Focus Area

		Timing of Temporary Flooding from Extreme Tides (inches of SLR)						
Type	Permanent Inundation Scenario (inches of SLR)	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Shoreline Inundation Areas (A-F)	+ 36	+ 24	+ 18	+ 12	+ 6	+ 6	Existing	Existing
Inland Inundation Areas (H-I)	+ 48	+ 36	+ 30	+ 24	+ 18	+ 18	+ 12	+ 6
System-wide	+ 72	+ 60	+ 54	+ 48	+ 42	+ 42	+ 36	+ 30

Note: Localized areas of shoreline flooding may occur at less extreme tides. The quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk. “Existing” implies that a potential flooding scenario is possible under current conditions with no SLR.

In addition to the localized areas of inundation discussed in Section 4, the timing of system-wide inundation is also included in Table 3. System-wide inundation occurs when extensive inland areas are inundated by multiple sources, including the localized inundation areas and pathways identified for lower sea level rise scenarios. For example, along the northern shoreline, Areas A, B, and C result in daily tidal inundation of the highway at the 36-inch scenario. Although these areas are the earliest sources of inundation, the 72-inch and 96-inch scenarios reveal that almost the entire shoreline from Radio Beach to the Emeryville Crescent will ultimately be overtopped. For the timing of flooding indicated for the shoreline inundation areas (existing conditions), small-scale localized adaptation measures may be feasible. For the timing of flooding indicated for the system-wide flooding (30-36 inches), a large-scale integrated adaptation measure will be required.

6. PROPOSED ADAPTATION MEASURES

As a part of the overall MTC Climate Adaptation Pilot Project, several adaptation strategies have been outlined to address the existing and future flood vulnerabilities identified within the Bay Bridge touchdown focus area. Section 6.1 summarizes the proposed strategies for the northern portion of the focus area (Areas A-C) and Section 6.2 summarizes the proposed strategies for the southern portion of the focus area (Areas D-F).

6.2 NORTH OF BAY BRIDGE TOUCHDOWN (AREAS A – C)

To protect the vulnerable and low-lying areas on the north side of the touchdown, an engineered flood protection structure would likely be required. The flood protection structure could be more of a traditional levee structure, or it could be designed to be integrated within the existing wetland and beach habitats located on the north side of the touchdown. Suggested solutions include:

- Engineered berm with rock revetment: this structure would be located adjacent to the roadway along the entire length of the Bay Bridge touchdown. This structure could be a standalone structure that would provide sea level rise and storm protection to the roadway without providing any protection or linkages with the adjacent wetland habitats. Long-term maintenance would be required, and the structure may require the addition of periodic lifts to maintain the desired level of protection as sea levels rise. A feasibility assessment of roadway drainage collection, treatment, and discharge options would also be an important consideration in the development of this adaptation strategy.

- Engineered berm with habitat enhancements: this structure would provide protection from sea level rise and storm surge, but would be engineered to maintain the link with adjacent wetland habitats by maximizing the use of natural and living (vegetative) materials. Exposure to erosion and other natural processes in the Bay would require this strategy to include active long-term management (e.g., nourishment) and possibly restoration efforts to ensure adjacent habitats keep pace with sea level rise. A feasibility assessment of roadway drainage collection, treatment, and discharge options would also be an important consideration in the development of this adaptation strategy.

- Artificial dunes: constructing artificial dunes along the entire length of the low-lying section north of the Bay Bridge Touchdown is an adaptation strategy that retains habitat value in the area while protecting highway assets. The longer-term resiliency of this strategy may require the addition of an offshore breakwater to reduce erosion from wave action.

- Offshore breakwater: this structure has been proposed as a possible adaptation strategy that can be used in tandem with any of the suggested berm or dune strategies along the roadway. Although construction of such a structure would not mitigate sea level rise, it would serve to reduce damaging storm surge and wave effects, thereby prolonging the useful life of the berm or dune strategies, while also protecting valuable habitats north of the bridge.

6.3 SOUTH OF BAY BRIDGE TOUCHDOWN (AREAS D – F)

The vulnerabilities to flooding along the south side of the Bay Bridge touchdown are more complex, and the suggested adaptation strategies will provide protection to the Bay Bridge and adjacent assets within the focus area. Potential adaptation strategies include:

- Construction of a low berm or sea wall to separate the proposed Gateway Park site from the Port of Oakland assets to the east. This strategy would address the critical inundation pathway along Burma Road (Area G). This strategy would not provide protection for assets to the west and north, but it would prevent inland inundation to the east.

- Raising Burma Road. This strategy could mitigate the critical inundation pathway while also providing emergency access to the Bay Bridge touchdown area. Assets to the west would likely remain vulnerable to exposure while assets to the east and north would be protected from flooding and inundation by his strategy.

- Natural and/or engineered shoreline protection will be an essential part of the proposed construction of Gateway Park. The shoreline could include features at or near the existing grade with landscape elements that incorporate high marsh and riparian habitat features that readily accommodate flooding by extreme tides and storm surge. Terracing of the landscape and raising existing structures are also proposed as possible strategies to increase the resilience and protection provided by the proposed park.

7. CONCLUSIONS AND NEXT STEPS

Nine key inundation vulnerability areas were identified within the Bay Bridge Touchdown focus area (Figure 1). Six of these are shoreline inundation areas, one is a critical inundation pathway, and two are inland inundation areas. The threshold for critical localized daily tidal inundation along the shoreline (Areas A-F) occurs at the MHHW + 36-inch scenario; however, extreme tides (50-year or greater) already threaten assets immediately adjacent to the shoreline under existing conditions. The threshold for daily tidal inundation of inland areas (Areas G-I) occurs at the MHHW + 48-inch scenario; however, extreme tides (50-year or greater) will threaten these areas in the future with just 6 to 12 inches of sea level rise. In the short term (0-6 inches), small-scale localized shoreline adaptation measures may protect critical assets from flooding during extreme tides; however, over the long term (approximately 36 inches of sea level rise and greater), a large-scale integrated flood protection strategy for the Bay Bridge Touchdown focus area will be required to prevent extensive flooding during extreme tides. Any responsible adaptation measure should consider the combined impact of coastal storm surge, waves, and roadway drainage and runoff. The cumulative impacts of rainfall runoff storm events occurring during periods of extreme tide levels were not considered in this analysis; however, these events will further exacerbate flooding within this focus area. In addition, rising groundwater tables, primarily associated with static sea level rise, can impact flooding and drainage by reducing infiltration and sub-surface storage of runoff. The existing highway drainage systems will become less effective over time and they may become completely ineffective with higher levels of sea level rise. These additional considerations are outside the scope of our current study, but evaluation of these factors is recommended as a next step.

8. REFERENCES

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ATTACHMENT A
BAY BRIDGE FOCUS AREA SITE VISIT PHOTOS

Attachment A - Site Visit Photos (March 7, 2014)

Bay Bridge Touchdown Focus Area – Radio Beach (Area A)

Bay Bridge Touchdown Focus Area – Radio Beach (Area A)

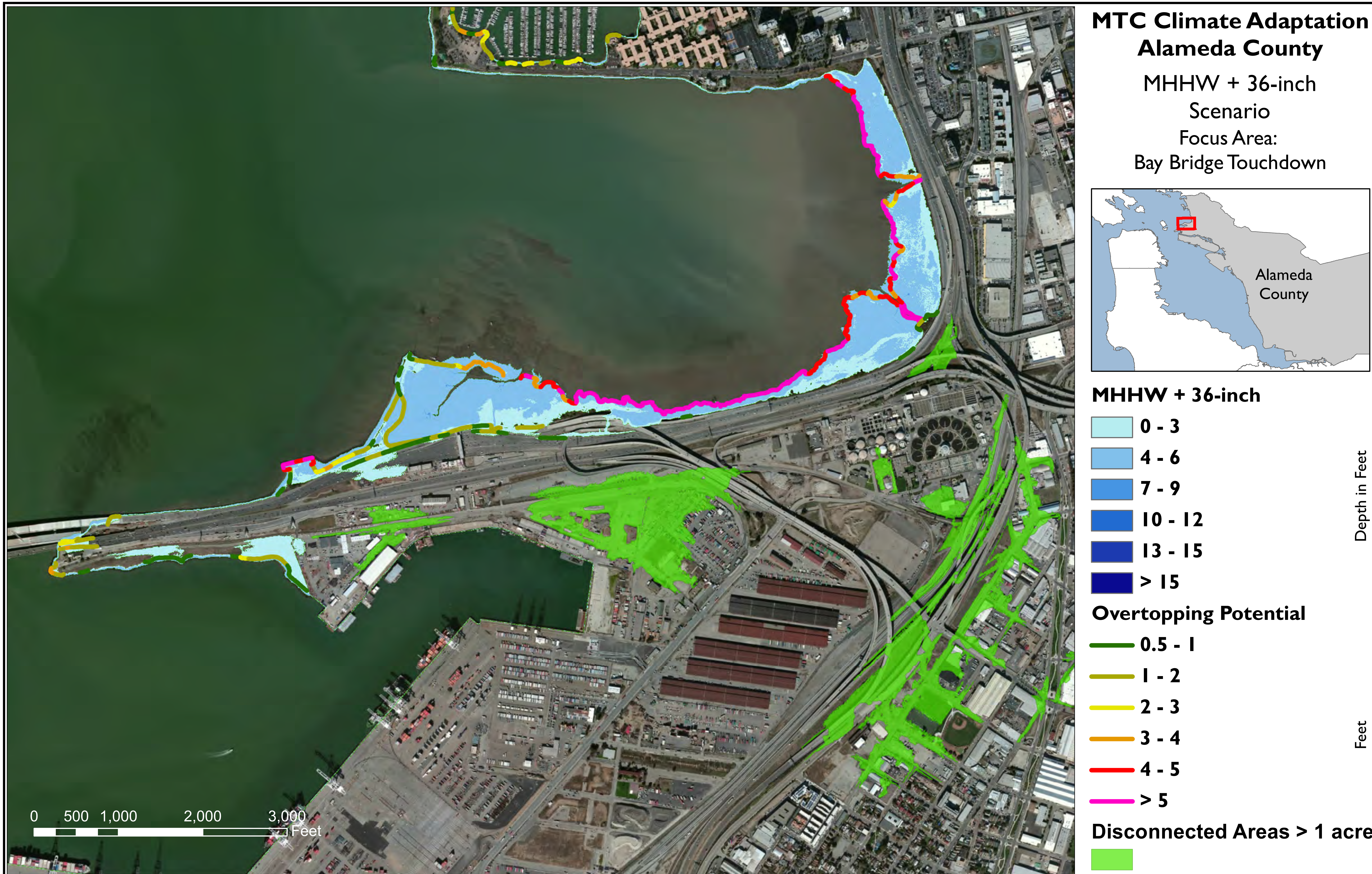
Bay Bridge Touchdown Focus Area – Western Tip of Burma Road (Area D)

Bay Bridge Touchdown Focus Area – Southern Shoreline along Burma Road (Area E)

ATTACHMENT B
FOCUS AREA INUNDATION MAPS

MTC Climate Adaptation
Alameda County
MHHW + 12-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 12-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
500
1,000
2,000
3,000
Feet

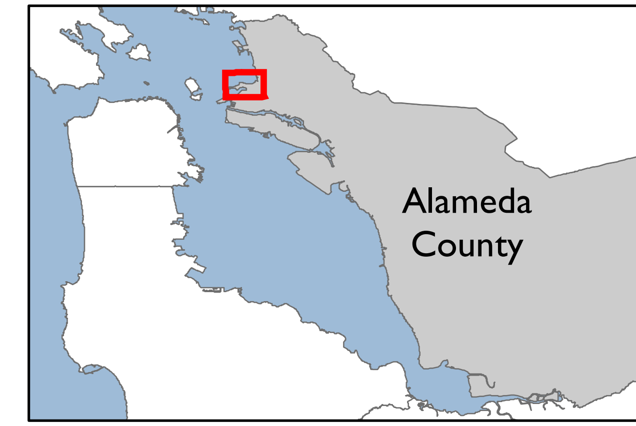

MTC Climate Adaptation
Alameda County
MHHW + 24-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 24-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
500
1,000
2,000
3,000
Feet


MTC Climate Adaptation
Alameda County
MHHW + 36-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 36-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0 500 1,000 2,000 3,000
Feet

MTC Climate Adaptation Alameda County

MHHW + 48-inch Scenario

Focus Area: Bay Bridge Touchdown



MHHW + 48-inch

Depth in Feet

- 0 - 3
- 4 - 6
- 7 - 9
- 10 - 12
- 13 - 15
- > 15

Overtopping Potential

Feet

- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- > 5

Disconnected Areas > 1 acre

MTC Climate Adaptation Alameda County

MHHW + 72-inch Scenario

Focus Area: Bay Bridge Touchdown

MHHW + 72-inch

Depth in Feet

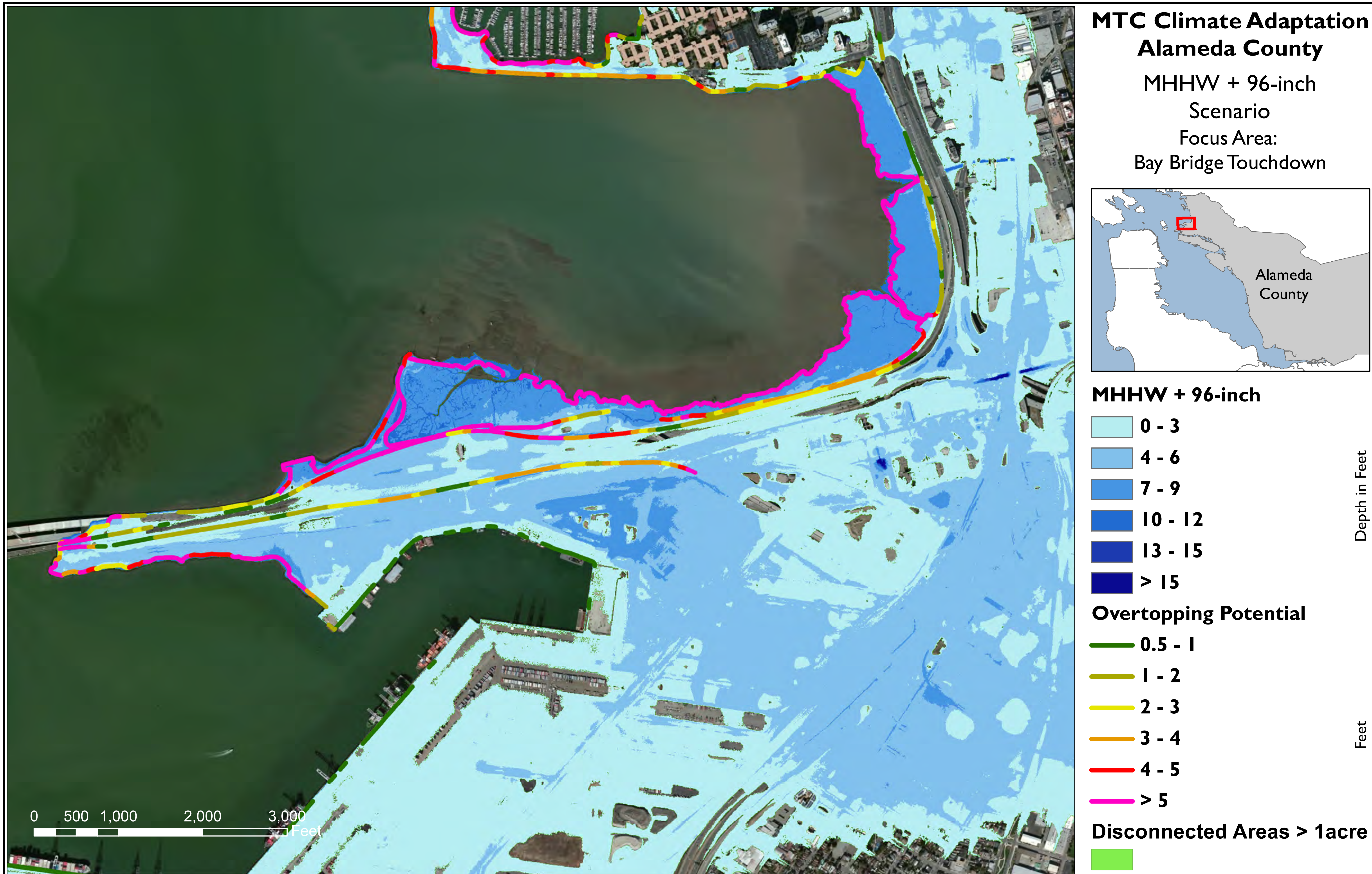
- **0 - 3**
- **4 - 6**
- **7 - 9**
- **10 - 12**
- **13 - 15**
- **> 15**

Overtopping Potential

Feet

- **0.5 - 1**
- **1 - 2**
- **2 - 3**
- **3 - 4**
- **4 - 5**
- **> 5**

Disconnected Areas > 1 acre


MTC Climate Adaptation
Alameda County
MHHW + 96-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 96-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1acre
0 500 1,000 2,000 3,000
Feet