Appendix A: Hayward Technical Memo

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Memorandum

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Subject	Hayward Focus Area		
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Date	July 1, 2014		

1. INTRODUCTION AND PURPOSE

The Hayward focus area was selected as a focus area for more detailed sea level rise (SLR) 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 SLR 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 SLR, storm surge, and shoreline vulnerabilities in Alameda County. The following sections provide a description of the Hayward 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 (Section 7).

2. FOCUS AREA DESCRIPTION

The Hayward focus area is located between Sulphur Creek and Alameda Creek along the eastern shoreline of San Francisco Bay (Bay) (Figure 1). The focus area includes a significant portion of the Hayward Regional Shoreline and Eden Landing Ecological Reserve as well as the San Mateo-Hayward Bridge touchdown. The shoreline of this focus area is comprised of a complex of fully tidal, muted tidal, and managed marshes and ponds. Bayfront and internal non-engineered berms separate the marshes, ponds, former oxidation ponds, and inland developed areas from direct exposure to the Bay (except for Cogswell Marsh and South Eden Landing Ecological Reserve, which have a natural marsh edge). This system of structural and natural shorelines acts as a buffer that reduces the risk of coastal flood hazard impacts on inland developments. The non-engineered berms were created from

Bay mud and fill, and although these structures are not certified or accredited flood protection structures[1], they do provide some level of flood protection and reduce wave hazards as they reach inland areas. Some of the berms also have integrated recreational trails that are part of the San Francisco Bay Trail system. The inland areas protected by the shoreline are primarily industrial land uses, with some small areas of residential and commercial uses. As shown on Figure 1, important assets in this focus area in addition to the San Mateo-Hayward Bridge touchdown include California State Route (SR) 92 (Area A), the Hayward Shoreline Interpretive Center, the Old West Winton Landfills (near Area B), and the City of Hayward Water Pollution Control Facility (Area H).

The fully tidal and muted tidal marshes experience regular tidal inundation under existing conditions. Managed marshes and ponds in the focus area have been engineered with water control structures (e.g., culverts, weirs, and tide gates) to control tidal flow. For the Hayward Marsh, which receives secondarily treated wastewater from Union Sanitary District, the water control structures assist in improving water quality prior to discharge to the Bay. Most of the shoreline in the focus area is protected to some degree by engineered protection (rock and rubble) except, most notably, in the southern extent of the focus area within the Eden Landing Ecological Reserve and in the northern extent along Cogswell Marsh.

The AECOM team performed a site visit on May 17, 2014. Visual inspection of shoreline protection structures, tide control structures, and assets was performed along the shoreline north of the San Mateo Bridge touchdown. See Attachment A for site visit photos.

[1] Flood protection structures can be certified by the United States Army Corps of Engineers and/or accredited by the Federal Emergency Management Agency for providing protection from the 100-year (1% annual chance) flood event

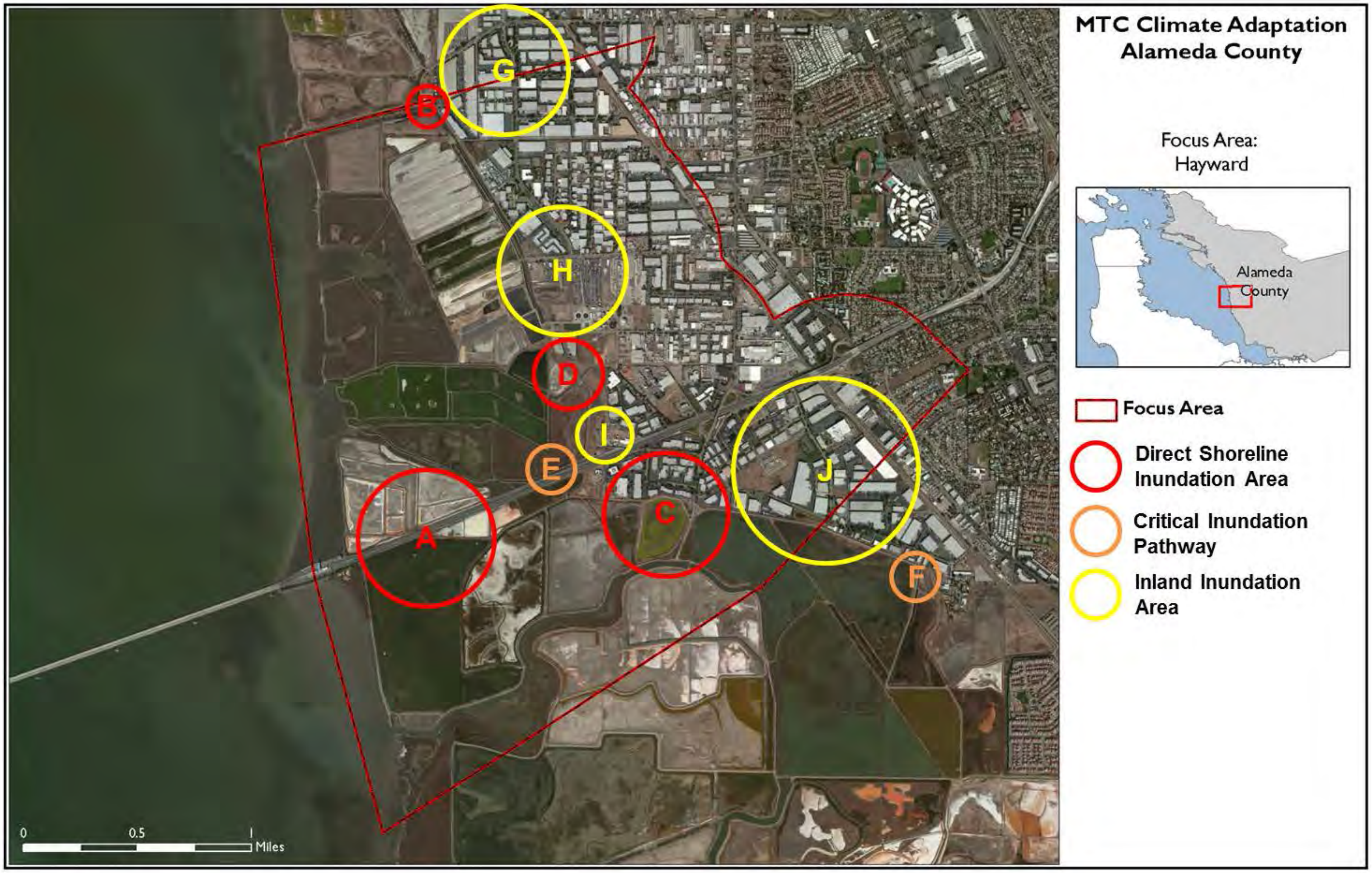

Figure 1. Hayward Focus Area Site Location Map and Inundation Areas

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

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 Hayward 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 SLR 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 [2] (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.

In accordance with the most up-to-date SLR projections from the National Research Council (NRC, 2012), the following scenarios were evaluated for the present study: 12-inch, 24-inch, 36-inch, and 48-inch above MHHW. In addition to these scenarios, 72-inch and 96-inch above MHHW were also evaluated, but these water levels are outside the range of current scientific predictions for SLR and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC, 2012). These scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of SLR. In general, though, the mapped scenarios can occur due to SLR, storm surge, or a combination of the two.

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.

[2] www.r9coastal.org

This assessment is considered a planning-level tool only, as it has some limitations. 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. The complex sediment transport processes of the managed marshes and ponds, in addition to the flow that may occur through the water control structures, are not included in this assessment. Marshes and ponds are assumed to maintain the elevations captured by the digital elevation model (DEM)[3], neglecting possible deposition or erosion that is likely to take place.

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 SLR with either a daily[4] or extreme high tide. For example, Scenario 3 (MHHW + 36-inch) represents both a daily high tide with 36 inches of SLR 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/SLR combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. By combining different amounts of SLR 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 SLR and tide scenarios is presented in Table 2. Values are in shown in inches above the existing conditions MHHW tidal level. The colors shown in Table 2 match the colors shown in Table 1. The colors indicate the different combinations of SLR and extreme tide scenarios represented by each inundation map. Note that Scenarios 5 and 6 correspond only to extreme tide

[3] 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)

[4] 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 7.0 ft NAVD88 within this focus area.

events as they are outside of the range of projections for probable SLR 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-inch (Scenario 3), would also represent a 1-yr event with 24 inches of SLR, a 2-yr event with 18 inches of SLR, a 5-yr event with 12 inches of SLR, 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. To reinforce these relationships, "X-inch scenario" and "MHHW + X-inch" will be used throughout this memorandum to refer to specific inundation maps and mapped scenarios (e.g., "48-inch scenario" or "MHHW + 48-inch" instead of "48 inches of SLR") since the scenario can be associated with multiple combinations of sea level rise and extreme tide events. Table 2 can also 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 SLR, the MHHW + 48-inch mapping scenario could be examined. Using this approach, it is possible to assess 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	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89
MHHW + 54-inch	54	69	74	78	81	86	90	95
MHHW + 60-inch	60	75	80	84	87	92	96	101

Note: All values in inches above existing conditions MHHW at Hayward 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 FOCUS AREA RESULTS

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. Floodwaters must first overtop the system of bayfront and internal berms before reaching the vast majority of inland development in this focus area. Since the marshes and ponds within the focus area are regularly inundated to some extent by tidal waters, the effects of temporary inundation are not likely to be significant with the exception of vegetation loss and drowning if floodwaters linger for extended periods and possible degradation of the overtopped berms and water control structures. As sea levels rise, this progressively overtopped shoreline system becomes an interconnected network of drowned marshes and ponds that can inundate adjacent areas at various thresholds. These thresholds are identified in Section 4.1. In some areas, successive internal berms need to be overtopped in order for storm surge events to have an impact. Estimating realistic flood volumes due to overtopping is not practical given the current level of information readily available; thus, the extent of temporary flooding depicted on the inundation maps, particularly when overtopping of successive internal berms occurs, may be overestimated. In addition, the water control structures that connect many of the ponds and adjacent areas are not considered in this analysis; these structures can both enhance and inhibit hydraulic connectivity. Topographic elevations within in the marshes and ponds may change significantly over time due to accumulation of organic matter and sediment transport processes, as mentioned in Section 3. These processes are not simulated as a part of this assessment and all topographic elevations are assumed to remain stationary.

In addition to conducting an evaluation of flood processes occurring within this system, this study identified ten key areas of vulnerability within the Hayward focus area based on a detailed review 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 Figure 2 and labeled letters "A" through "J." These areas can be grouped into three categories—*shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In both figures, shoreline inundation hazard areas are labeled in red (A-D), critical inundation pathways in orange (E-F), and inland inundation areas in yellow (G-J). Figure 2 below also shows a general overview of the sources of flooding and the pathways that allow floodwaters to progress inland.

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 SLR. These areas are where the shoreline is first overtopped and from which floodwaters propagate to areas immediately inland. Four shoreline inundation areas were identified for the Hayward focus area.

Inland inundation areas are not directly adjacent to the shoreline and require a hydraulic pathway to convey flood waters 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 the 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. Four inland inundation areas were identified within the Hayward focus area.

Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey flood waters to inland areas. Two critical inundation pathways were identified within the Hayward focus area.

To facilitate understanding, the Hayward focus area has been subdivided into three regions based on the flooding patterns within the focus area that occur with less than 36 inches of sea level rise (Figure 2): the area North of SR 92 (North); the area at and adjacent to SR 92 (SR 92); and the area South of SR 92 (South). Results for areas north of SR 92 are presented in Section 4.2; results for areas immediately adjacent to SR 92 are presented in Section 4.3; and results for areas south of SR 92 are presented in Section 4.4.

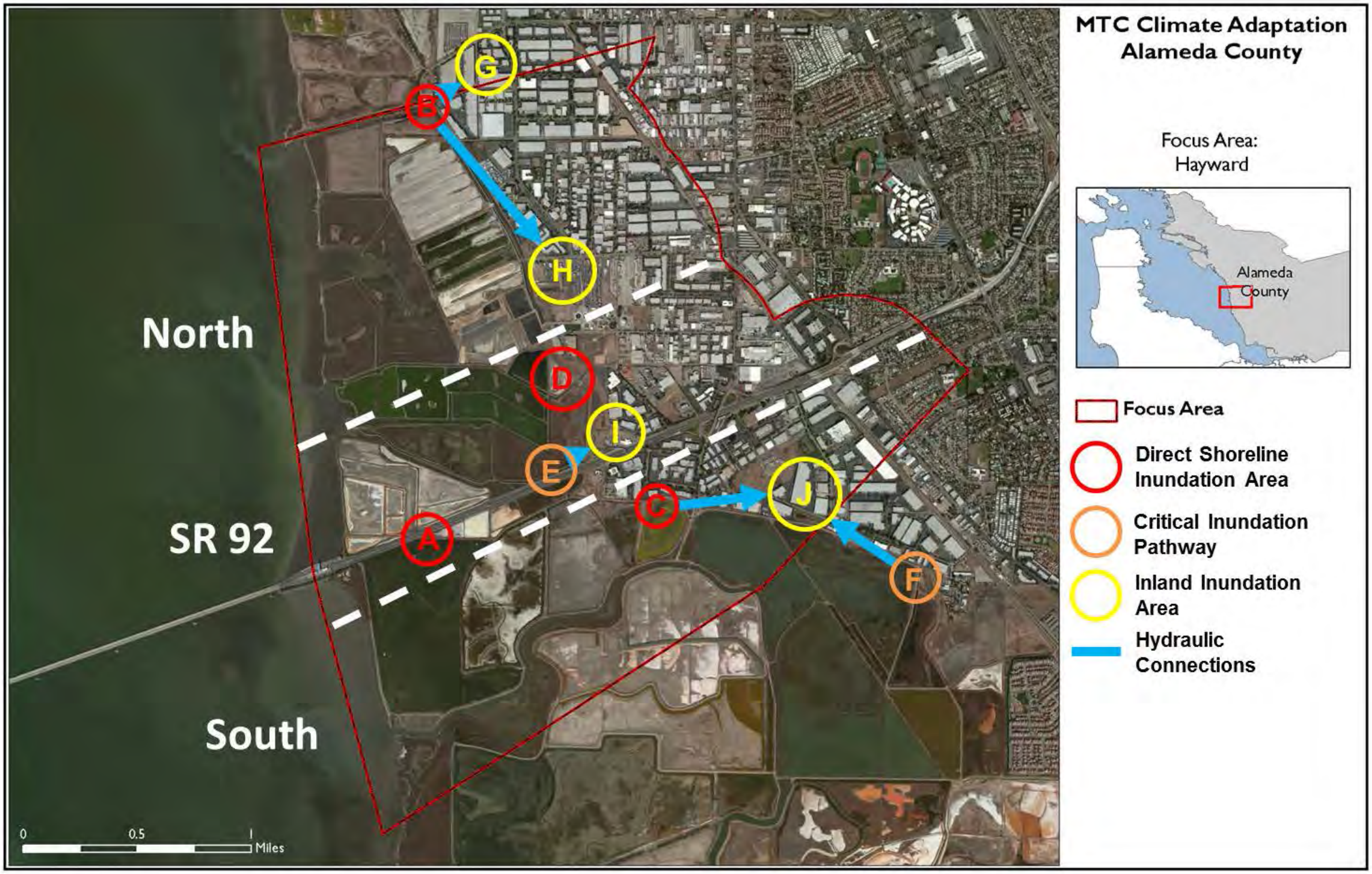

Figure 2. Delineation of Inundation Regions and Connections between Inundation Areas

4.1 MANAGED MARSHES AND PONDS

There are eight distinct marsh areas or ponds within the Hayward focus area, and these areas are typically separated by the network of internal and bayfront berms (Figure 3). The majority of this system is part of the Hayward Regional Shoreline, with the exception of Eden Landing Ecological Reserve, which is part of the Eden Landing system owned by the California Department of Fish and Wildlife. Figure 3 shows the timing of inundation throughout the system and the critical segments that will be overtopped, thereby inundating the adjacent area(s). Triangle Marsh, Cogswell Marsh, HARD Marsh and Eden Landing Ecological Reserve are directly connected to the Bay by natural and/or engineered inlets and are actively flooded under existing conditions. As expected, these areas are inundated in the 12-inch scenario[5]. In the 24-inch scenario, the internal berms surrounding HARD Marsh are overtopped and inundate the Salt Marsh Harvest Mouse Preserve and Oliver Salt Ponds. In the 36-inch scenario, the berm between Hayward Marsh and HARD Marsh is overtopped as well as the berm between Cogswell Marsh and the Oxidation Ponds. All internal berms are overtopped in the 72-inch scenario (which results in a level of inundation that could occur with 30 inches of SLR and a 100-year storm surge event, as shown in Table 2) and the entire system is inundated. The eight inundation areas are summarized below:

- Triangle Marsh (Figure 3)
    - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions
- Cogswell Marsh (Figure 3)
    - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions
- Hayward Marsh (Figure 3)
    - Inundation first occurs at the 36-inch scenario with inundation depths of 0-3 feet
- HARD Marsh (Figure 3)
    - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions
- Oliver Salt Ponds (Figure 3)
    - Inundation first occurs at the 24-inch scenario with inundation depths of 0-6 feet
- Oxidation Ponds (Figure 3)
    - Inundation first occurs in the south at the 36-inch scenario with inundation depths of 0-9 feet
    - The entire area is inundated at the 48-inch scenario with inundation depths of 0-9 feet
- Salt Marsh Harvest Mouse Preserve (Figure 3)
    - Inundation first occurs at the 24-inch scenario with inundation depths of 0-6 feet

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[5] The sea level rise scenario when the site is first overtopped 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 sea level rise 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.

- Eden Landing Ecological Reserve (Figure 3)
  - Partial inundation first occurs at the 12-inch scenario with inundation depths of 0-3 feet
  - The entire area is inundated at the 24-inch scenario with inundation depths of 0-9 feet

4.2 NORTH OF SR 92

North of SR 92, the primary sources of inundation are from natural and engineered flood control channels that are overtopped (Figure 4). One shoreline inundation area (Area B) was identified in this region as well as two inland inundation areas (Areas G and H). Shoreline inundation areas are presented in Section 4.2.1 and inland inundation areas are presented in Section 4.2.2.

4.2.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area B) was identified in the region north of SR 92. Overtopping of Zone 4 Line A flood control channel near the intersection of W Winton Avenue and Depot Road first occurs at the 36-inch scenario and results in the exposure of inland assets located in Area G, as summarized below:

- Area B (Figure 4)
  - Overtopping of the engineered flood control channels east of Triangle Marsh first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - W Winton Avenue is partially inundated from areas to the north and from overtopping of the flood control channel to the south
  - Industrial buildings and parking lots are partially inundated (Area G)

4.2.2 INLAND INUNDATION AREAS

Two inland inundation areas (Areas G and H) were identified in the region north of SR 92. Both are inundated as a result of overtopped natural and engineered channels. Area G is inundated first at the 36-inch scenario due to overtopping at Area B. Area H is inundated at the 48-inch scenario when the flood control channel east of the former oxidation ponds is overtopped at several places near Depot Road. A summary of the inland inundation areas for this region is included below:

- Area G (Figure 4)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 36-inch scenario with depths of 0-3 feet
  - Source of flooding is overtopped channels at Area B

- Area H (Figure 4)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 48-inch scenario with depths of 0-3 feet
  - Source of flooding is overtopped natural and flood control channels east of the oxidation ponds
  - City of Hayward Water Pollution Control Facility is partially flooded at the 72-inch scenario with depths of 0-3 feet

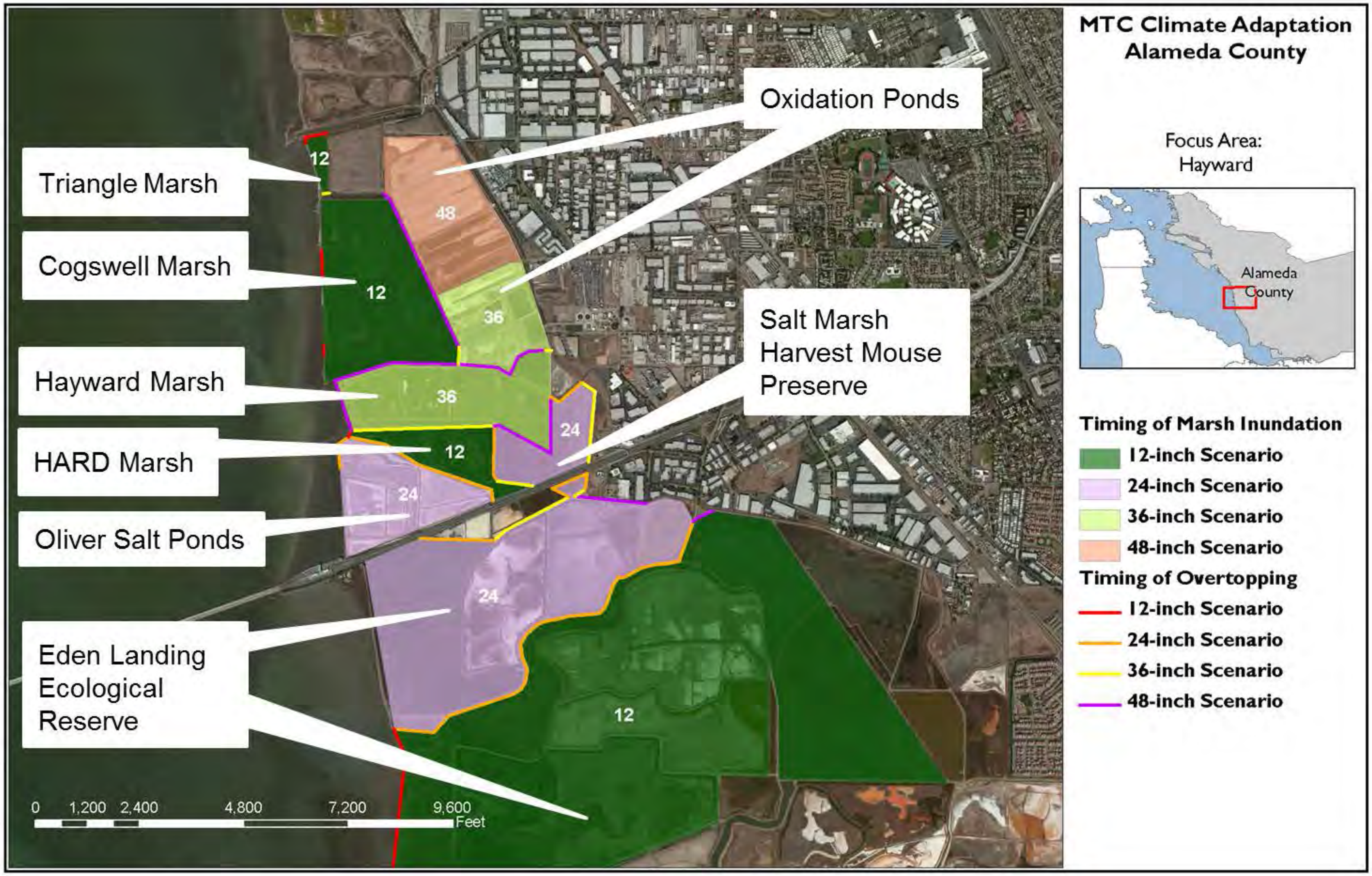

Figure 3. Timing of Bayfront Inundation and Locations of Overtopping at Non-Engineered Berms.
Note: Numbers denote the first sea level rise scenario that results in inundation (in inches above MHHW).

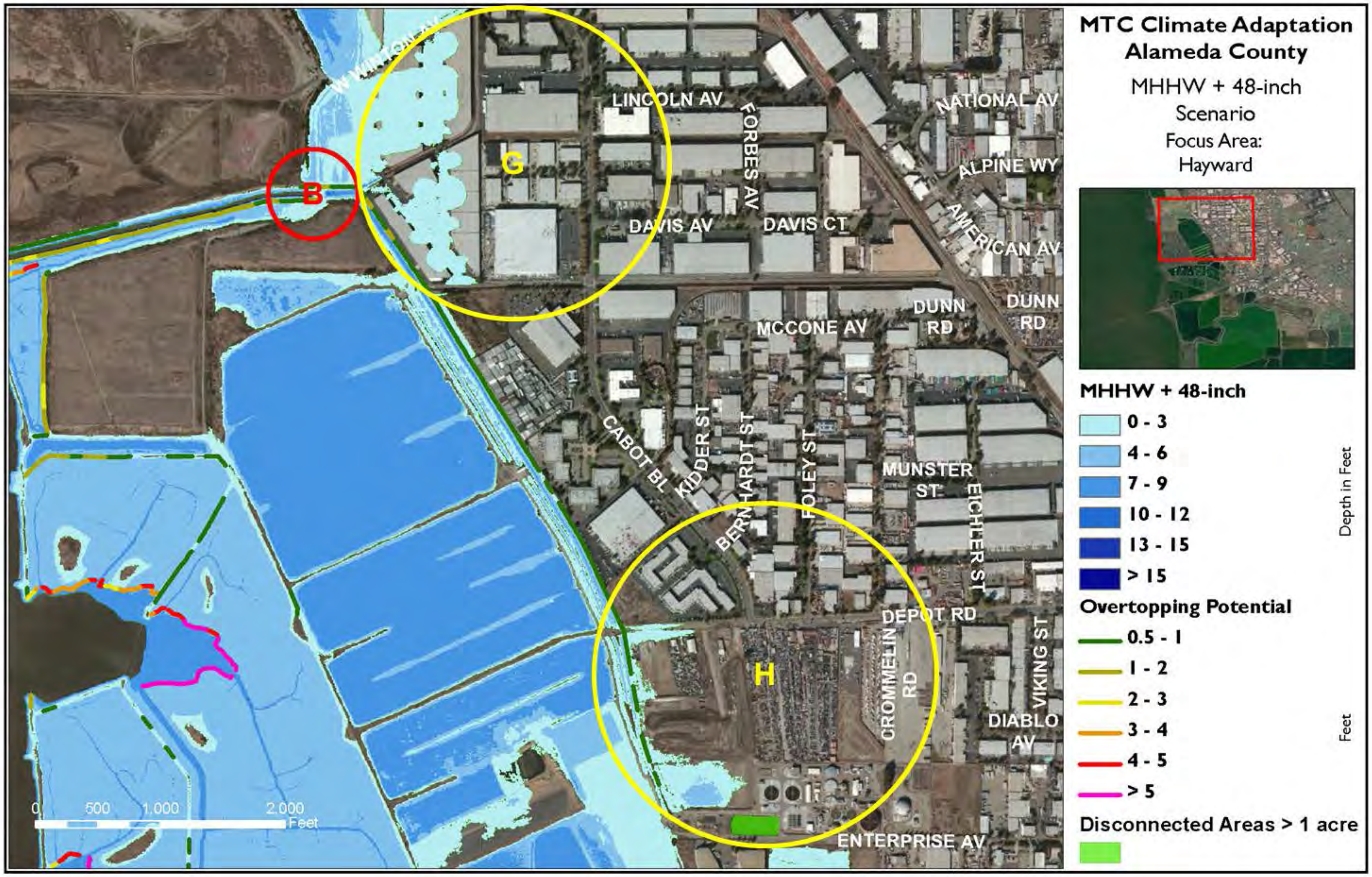

Figure 4. Inundation Areas North of SR 92 (MHHW + 48-inch Scenario)

4.3 SR 92

Inundation of SR 92 and adjacent areas occurs primarily from overtopping of non-engineered berms along Oliver Salt Ponds, HARD Marsh, and Salt Marsh Harvest Mouse Preserve (Figure 5 and Figure 6). Two shoreline inundation areas (Areas A and D) were identified in this region. Additionally, a critical inundation pathway (Area E) results in inundation of inland areas (Area I). Shoreline inundation areas within this region are discussed in Section 4.3.1; critical inundation pathways in this region are discussed in Section 4.3.2; and inland inundation areas within this region are discussed in Section 4.3.3.

4.3.1 SHORELINE INUNDATION AREAS

Two shoreline inundation areas (Areas A and D) were identified at SR 92. First, inundation and overtopping of HARD Marsh and the Salt Marsh Harvest Mouse Preserve at the 24-inch scenario results in limited shoreline inundation that reaches the antenna towers near Enterprise Avenue and several industrial buildings and parking areas near Johnson Road (Area D). Partial inundation of Breakwater Avenue, adjacent to SR 92, occurs at the 36-inch scenario (Area A). At the 48-inch scenario, Breakwater Avenue is completely inundated and significant areas on SR 92 are also inundated. A summary of the shoreline inundation areas is presented below:

- Area A (Figure 5)
  - ➢ Partial inundation of Breakwater Avenue first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - ➢ Partial inundation of the outermost highway lanes south of the Oliver Salt Ponds first occurs at the 48-inch scenario with inundation depths of 0-3 feet

- Area D (Figure 6)
  - ➢ Overtopping of the non-engineered berm in the north of Salt Marsh Harvest Mouse Preserve first occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - ➢ Antenna towers near Enterprise Avenue are partially inundated

4.3.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area E) was identified at SR 92. It is first overtopped at the 24-inch scenario (Figure 6). A single controlling feature was confirmed at the landward terminus of the channel along Breakwater Avenue at the Salt Marsh Harvest Mouse Preserve that results in extensive inland inundation of adjacent areas when overtopped. The high point of the critical inundation pathway occurs at an elevation of approximately 8 feet NAVD88. Figure 7 shows a representative transect of the elevation profile along Area E starting in the channel and extending inland over the non-engineered berm. The MHHW + 24-inch water level is shown for reference relative to the topography. Key observations for the critical inundation pathway are summarized below:

- Area E (Figure 6; Figure 7)
  - Narrow channel along Breakwater Avenue is inundated, overtopped at the southeast corner of Salt Marsh Harvest Mouse Preserve and connects the flooding from HARD Marsh to inland Area I
  - First occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - Immediately east of Hayward Shoreline Interpretive Center
  - Critical water level of approximately 8 feet NAVD88

4.3.3 INLAND INUNDATION AREAS

One inland inundation area (Area I) was identified at SR 92. Exposure occurs when the critical inundation pathway Area E is overtopped at the 24-inch scenario (Figure 6). More extensive flooding occurs at the 36-inch scenario when the non-engineered berm that forms the eastern boundary of Salt Marsh Harvest Mouse Preserve is overtopped almost entirely. A summary of the inland inundation areas is presented below:

- Area I (Figure 6)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 24-inch scenario with depths of 0-3 feet
    Source of flooding is HARD Marsh via Area E

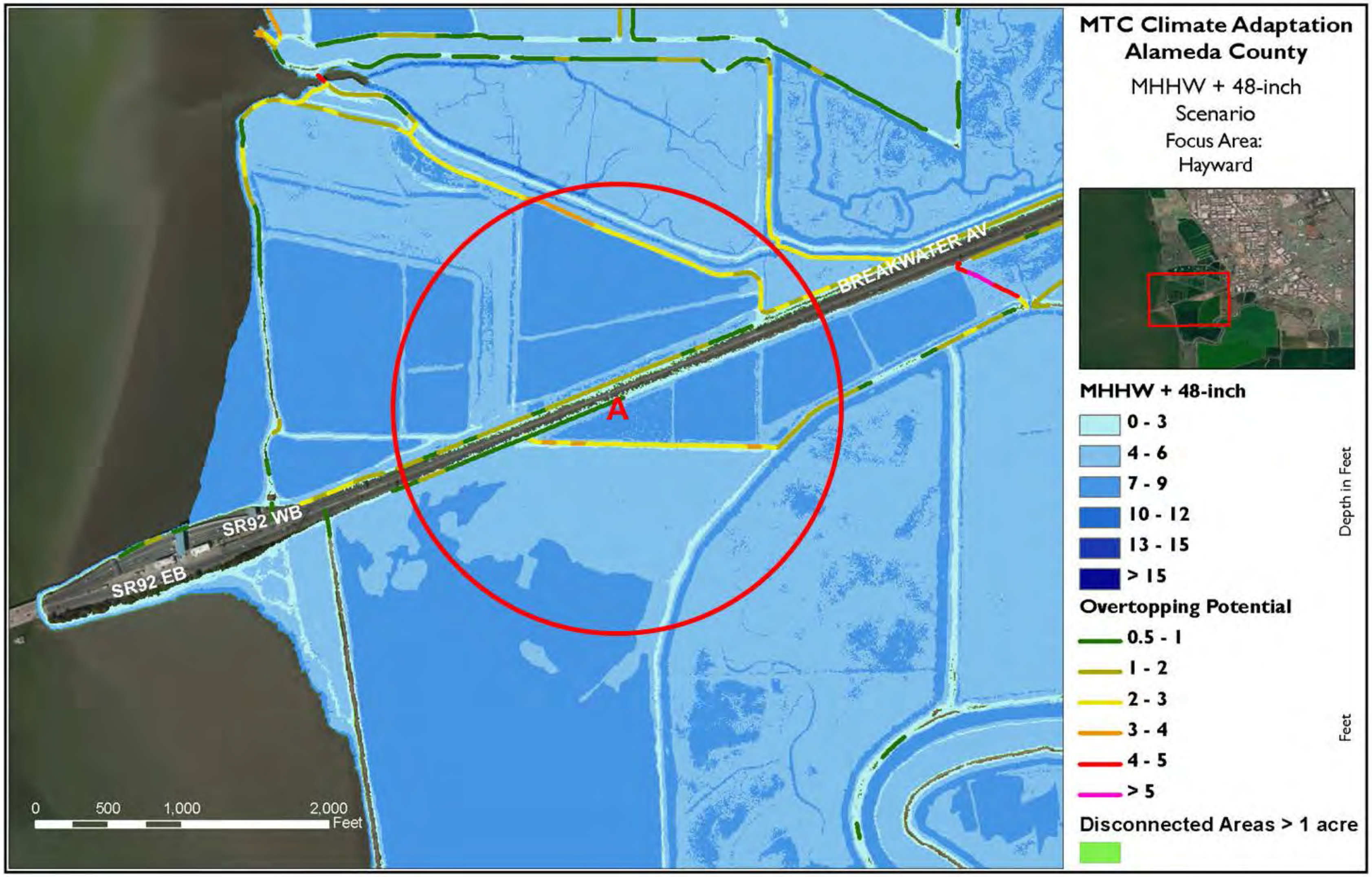

Figure 5. Inundation at Area A (MHHW + 48-inch Scenario)

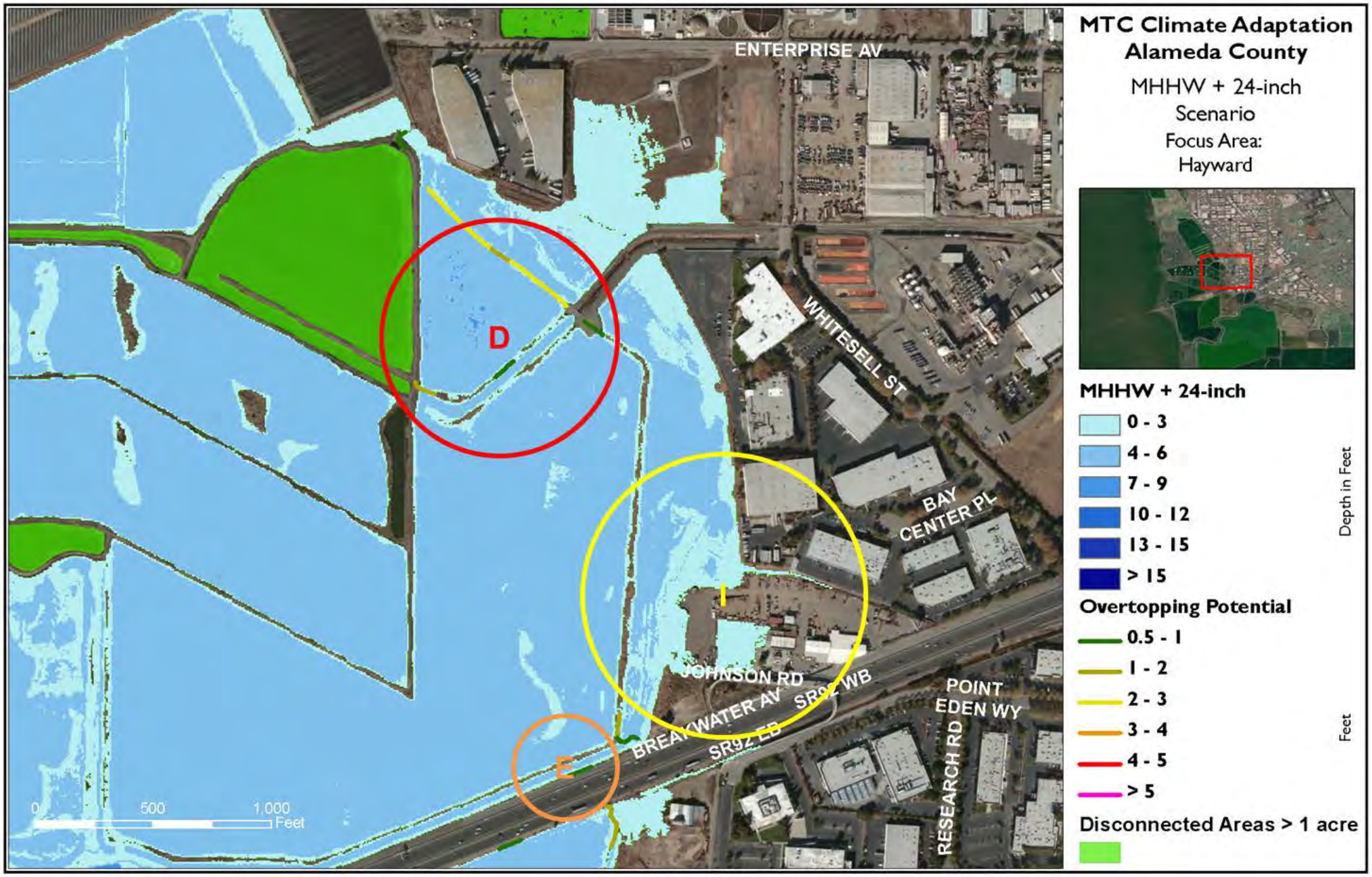

Figure 6. Areas of Inundation Adjacent to SR 92 (MHHW + 24-inch Scenario)

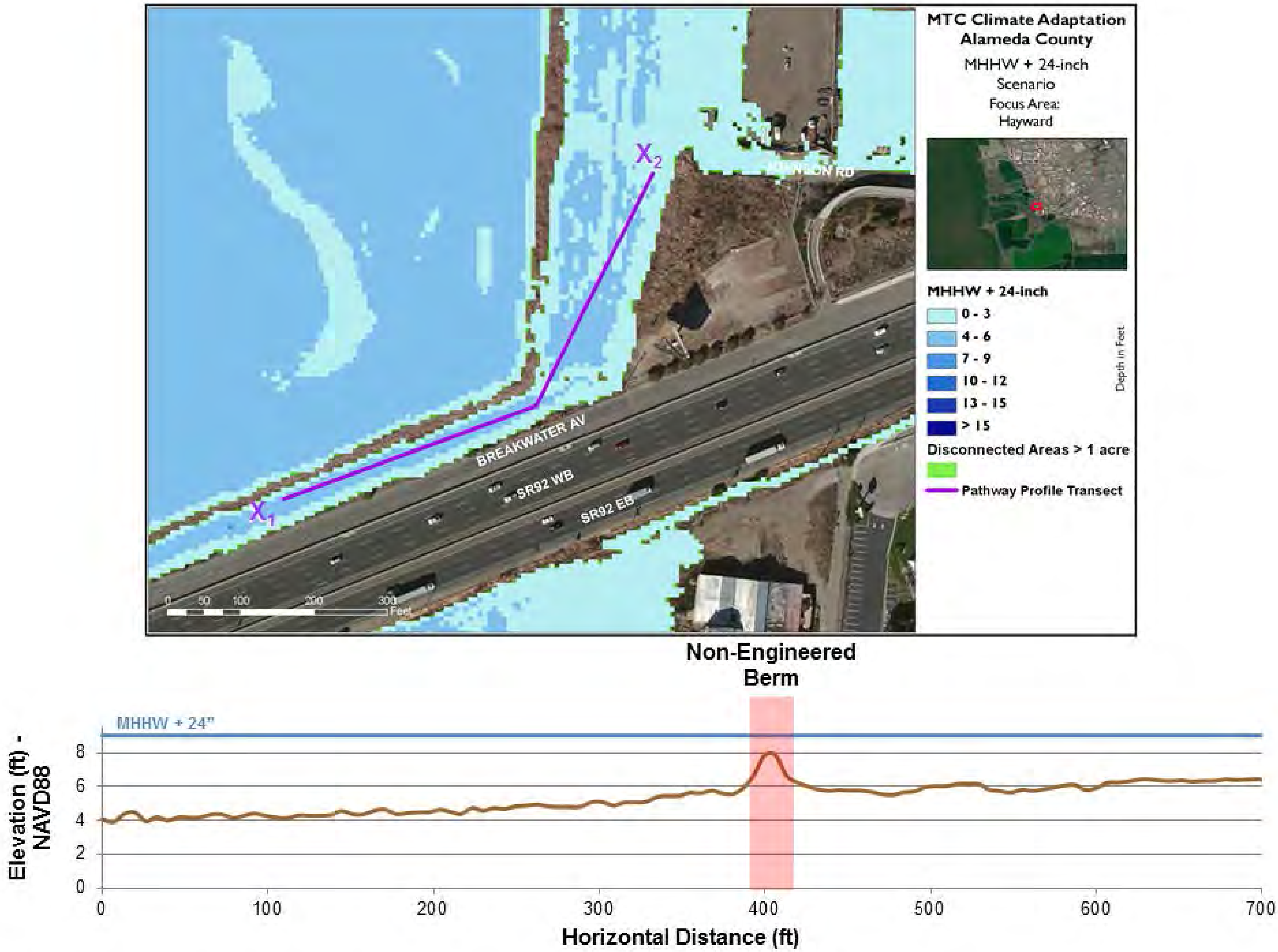

Figure 7. Plan and Profile of Critical Inundation Pathway (Area E) Connecting the Wetland Channel with Inland Inundation Areas

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

4.4 SOUTH OF SR 92

South of SR 92, inundation occurs primarily due to overtopping of non-engineered berms east of the Eden Landing Ecological Reserve. One shoreline inundation area (Area C), one critical inundation pathway (Area F), and one inland inundation area (Area J) were identified in this region. Shoreline inundation areas are presented in Section 4.4.1; critical inundation pathways are presented in Section 4.4.2; and inland inundation areas are presented in Section 4.4.3.

4.4.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area C) was identified for the region south of SR 92. Several segments of the non-engineered berm south of Point Eden Way are overtopped at the 48-inch scenario and inundate the industrial areas near Area C. A summary of the shoreline inundation areas is presented below:

- Area C (Figure 8)
    - Overtopping of the non-engineered berm in the northeast area of Eden Landing Ecological Reserve first occurs at the 48-inch scenario with inundation depths of 0-3 feet
    - Eden Landing Road and Arden Road are partially inundated
    - Industrial buildings and parking lots are partially inundated

4.4.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area F) was identified south of SR 92, with overtopping first observed in the 24-inch scenario. Given the relatively large extent of inland inundation observed as a result of overtopping at Area F, AECOM sought to verify the pathways of flooding and accuracy of the DEM 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 accurately represented the raw LiDAR data. Additionally, the 2014 ESRI World Imagery and aerial photography from Google Earth (2014) were examined to confirm the location of both pathways and surrounding features. These comparisons verified that the DEM adequately captures this area. The extensive inland inundation occurs when a berm located at the landward terminus of a channel near the intersection of Arden Road and Baumberg Avenue (east of Eden Landing Ecological Reserve) is overtopped. The high point of the critical inundation pathway occurs at an elevation of approximately 9 feet NAVD88 at Area F. Figure 10 shows a representative transect of the elevation profile along Areas F starting in the channel and extending inland over the non-engineered berm. The MHHW + 24-inch water level is shown for reference relative to the topography. Key observations for the critical inundation pathways are summarized below:

- Area F (Figure 9 and Figure 10)
  - Narrow channel along the inland side of the non-engineered berm fronting Eden Landing Ecological Reserve at Arden Road connects the flooding from southern areas of Eden Landing Ecological Reserve to inland Area J
  - First occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - Critical water level of approximately 9 feet NAVD88

4.4.3 INLAND INUNDATION AREAS

One inland inundation area (Area J) was identified south of SR 92 (Figure 7 and Figure 8). This extensive area along Arden Road and Trust Way is exposed due to overtopping of non-engineered berms at Area C (48-inch scenario) and overtopping of the critical inundation pathway at Area F (24-inch scenario). A summary of the inland inundation areas is presented below:

- Area J (Figure 8 and Figure 9)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 24-inch scenario with depths of 0-3 feet
  - Source of flooding is Eden Landing Ecological Reserve via Areas F and C

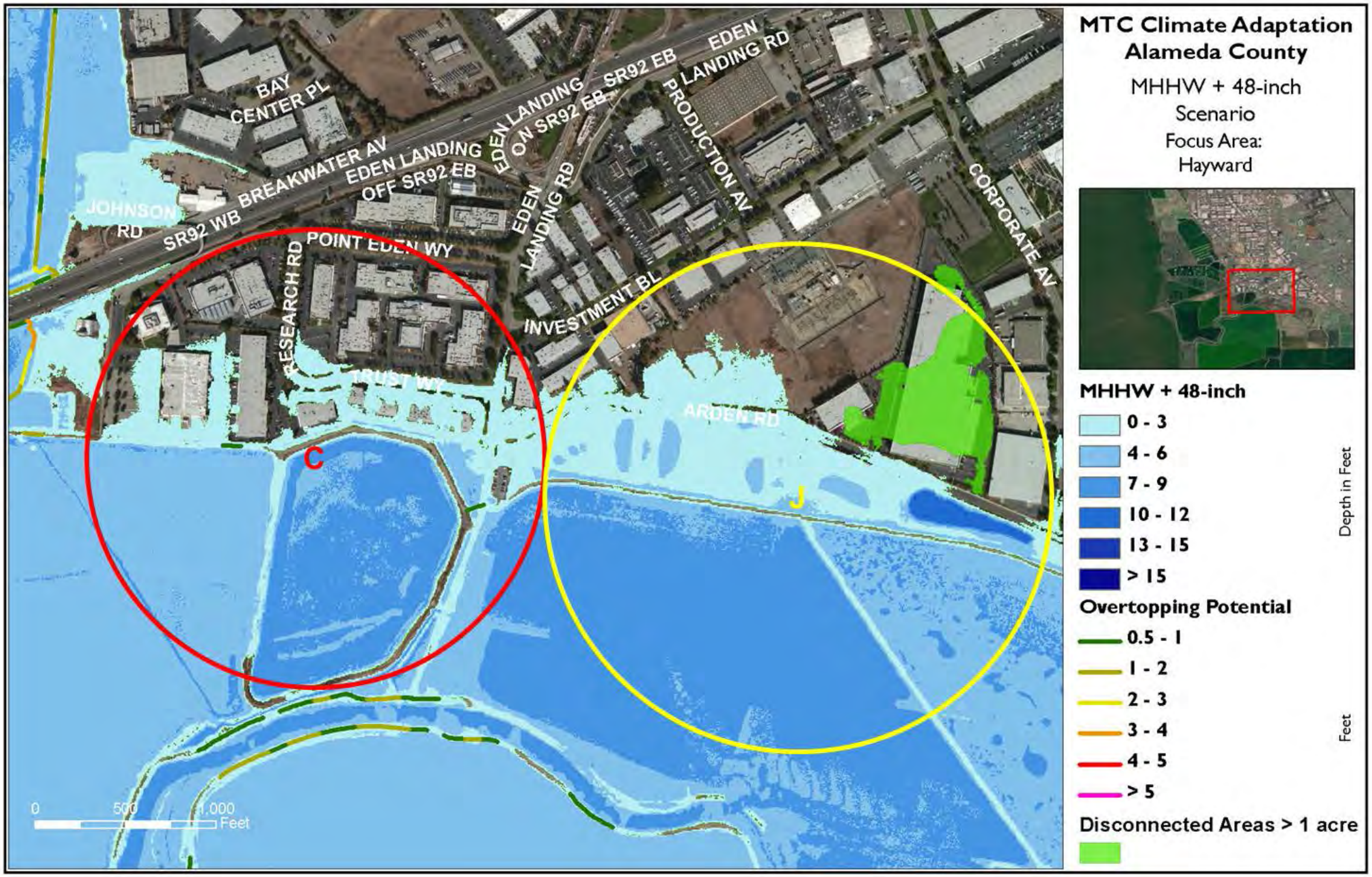

Figure 8. Inundation at Areas C and J (MHHW + 48-inch Scenario)

AECOM

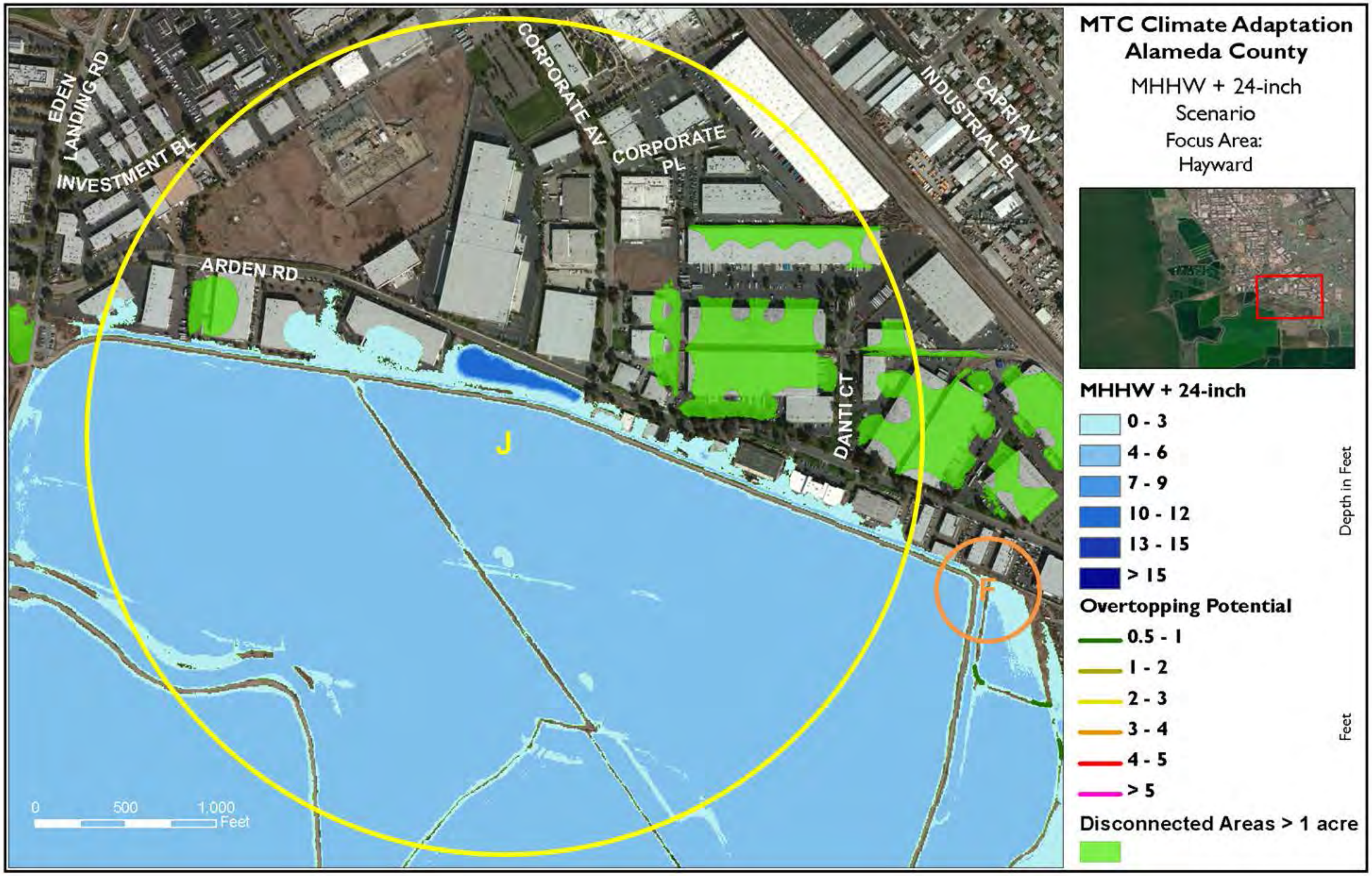

Figure 9. Critical Inundation Pathway F and Inland Inundation Area J (MHHW + 24-inch Scenario)

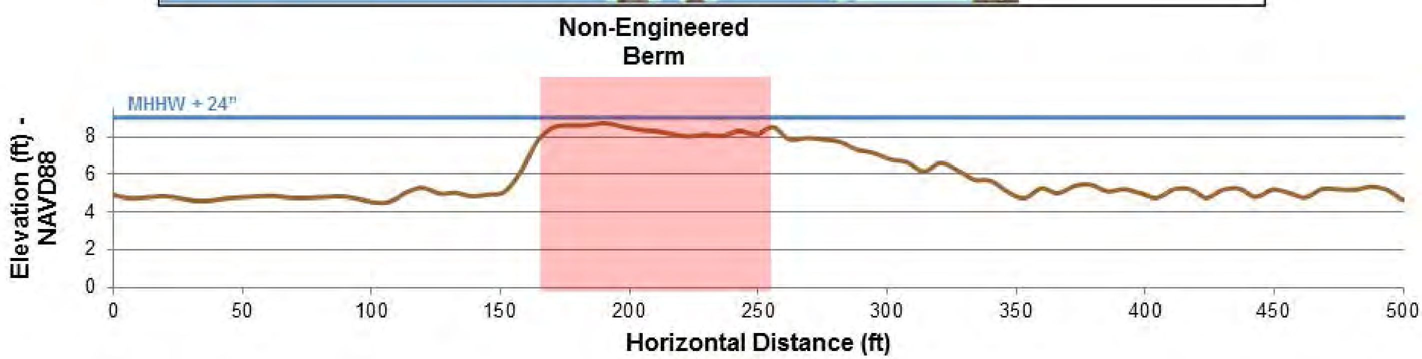

Figure 10. Plan and Profile View of Critical Inundation Pathway (Area F) Connecting the Wetland Channel with Inland Inundation Areas

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

5. TIMING OF ADAPTATION STRATEGIES

The timing of adaptation measure implementation 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[6], although in many areas this design criterion is not currently met. For the purposes of this study, the occurrence of various extreme tide levels under different SLR 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.

Tidal and managed marshes along the shoreline are exposed to daily inundation under existing conditions and are inundated in the earliest mapped scenario (MHHW + 12-inch) as shown in Table 3. For the managed ponds, if no action is taken to account for rising sea levels, the non-engineered berms that surround these ponds (providing ad-hoc flood protection to inland areas) will become more exposed to storm surge and wave-induced erosion. Over time, this could lead to lower thresholds for permanent inundation and flooding. Implementing adaptation strategies for these features can preserve the value of these natural areas while simultaneously providing flood protection for key assets in the inland areas. To be effective, however, an integrated system-wide approach will be required because of the interconnected nature of these systems.

Table 3 summarizes the timing of flooding for the managed wetlands, ponds, shoreline inundation areas (A-D), critical inundation pathways (E-F), and inland inundation areas (G-J) for various SLR scenarios. As discussed in Section 4, exposure of areas D, I, and J to daily tidal inundation first occurs under the MHHW + 24-inch SLR scenario; however, these areas will be exposed to flooding by extreme tide events at much lower SLR scenarios. For example, assets within areas D, I and J that will be exposed to daily tidal inundation under MHHW + 24-inch could also be exposed to flooding once per year during 12-inch of SLR, or every 5 years under existing conditions. The areas B and G currently experience flooding under an existing 50-year extreme tide while shoreline areas A and C 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 SLR is shown in Table 3. If no action is taken, SLR 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.

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

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

[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.

are inundated by multiple sources, including the localized inundation areas and pathways identified for lower SLR scenarios. For example, along the shoreline adjacent to the Eden Landing Ecological Reserve, overtopping occurs at two segments of the non-engineered berm in Area C, resulting in daily tidal inundation of the industrial developments at the 48-inch scenario. Although these areas are the earliest sources of inundation, the 72-inch and 96-inch scenarios reveal that the entire non-engineered berm from SR 92 to the southeastern extent of the study area will ultimately be overtopped. In the short term, small-scale localized adaptation measures may be feasible. However, larger-scale integrated adaptation measures will be required in the longer term.

Table 3. Timing of Inundation and Flooding for Inundation Areas within the Hayward Focus Area

Area	**Permanent Inundation Scenario (inches of SLR)**	**Timing of Temporary Flooding from Extreme Tides (inches of SLR)**						
		1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Trangle Marsh, Cogswell Marsh, HARD Marsh, Eden Landing Ecological Reserve South of Mt. Eden Creek	+ 12	Existing	Existing	Existing	Existing	Existing	Existing	Existing
D, E, F, H, I, J, Oliver Salt Ponds, Salt Marsh Harvest Mouse Preserve, Eden Landing Ecological Reserve North of Mt. Eden Creek	+ 24	+ 12	+ 6	Existing	Existing	Existing	Existing	Existing
B, G, Hayward Marsh, Oxidation Ponds South	+ 36	+ 24	+ 18	+ 12	+ 6	+ 6	Existing	Existing
A, C, Oxidation Ponds North	+ 48	+ 36	+ 30	+ 24	+ 24	+ 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.

6. PROPOSED ADAPTATION MEASURES

As a part of the MTC Climate Adaptation Pilot Project, several adaptation strategies have been proposed to address the vulnerabilities identified within the Hayward focus area. The following sections summarize the proposed physical strategies for the bayfront marshes and ponds north of SR 92 and for SR 92 itself. It should be noted that the strategies presented are not intended to comprise the full suite of potential strategies that could be implemented to address the physical vulnerabilities within the Hayward focus area.

6.1 MARSHES AND PONDS NORTH OF SR 92

Three potential adaptation strategies were proposed for the marsh and pond areas to the north of SR 92:

- Cooperative land retreat. If the assets are managed collectively, land uses could be shifted when necessary and appropriate protective measures and habitat goals could be established. This strategy requires delineating a segment of berms (existing or engineered) to serve as the landward extent of flood protection; areas outboard of this line of defense would be allowed to transgress naturally and possibly drown with rising sea levels. The outboard areas will attenuate waves and diminish erosion and flood risk; therefore they should be monitored so that additional flood protection elements can be considered and implemented as needed. Critical infrastructure such as landfills and wastewater treatment plants may require additional protection.
- Maintain the existing shoreline alignment by building up the height (and associated width) of the bayfront berms to keep pace with sea level rise. However, many of the existing berms are made of bay mud using local borrow and their maximum height may be limited by geotechnical stability and the availability of material. Water level management within the managed ponds will also become a challenge in the long term. Eventually, rising sea levels may completely surround the berms, leaving them particularly vulnerable to damage from storm surge and wave-induced erosion. Given the challenges associated with this strategy in the long term, this strategy can likely only be used in the short term until a more practical and cost-effective longer-term strategy can be put in place.
- Integrating the Bay trail with a levee alignment. The Bay trail alignment (or an alternate alignment) could be reinforced and raised to provide flood protection. This will provide a hydraulic barrier to the east throughout the focus area. The berm with the integrated Bay Trail alignment would be part of the overall flood defense of this area, assisting in providing multiple lines of defense. Increasing the height of the berm will also increase its width; therefore there may be impacts to surrounding habitats. It is recognized that there will be trade-offs associated with raising the berm and integrated Bay Trail and protecting it in place rather than re-routing the Bay Trail to a more inland location.

6.2 SR 92

Along the SR 92 bridge touchdown, the MTC Climate Adaptation Pilot Project proposed one informational strategy and two physical strategies aimed to reduce the overall physical vulnerabilities in this area:

- SR 92 drainage study (*informational strategy*). Any adaptation strategy that is implemented along the existing SR 92 corridor must take into account the existing SR 92 drainage system, and its interaction with the surrounding channels, ponds, and adjacent areas. The drainage study should quantify the capacity of the existing system, and also investigate how the capacity of the system may change as sea levels rise. Adaptation strategy development must include elements that can increase the drainage capacity of the system, while also considering water quality concerns associated with discharging highway runoff into habitat areas.
- Elevated SR 92 causeway. Constructing an elevated causeway for the SR 92 touchdown would require constructed new pile-supported road sections. Construction would need to be done in a staged manor to minimize traffic disruption, such as constructing the elevated sections on either side of the existing highway, and then removing the existing the highway once construction is complete (similar to the strategy employed for construction of the new Oakland – Bay Bridge span). Although this is a transportation-focused solution, it would also connect the habitat areas to the north and south of SR 92, and provide for a wider array of collective management strategies between the northern and southern areas. This strategy would also maintain view corridors with the Bay and surrounding habitats.
- Engineered structures adjacent to SR 92 touchdown. Engineered structures, such as embankments armored with rip-rap, sea walls, or levees could be constructed adjacent to the roadway. Armoring embankments would reduce wave-induced erosion, but would do little to mitigate rising sea levels. Levees and seawalls would visually cut off the road from views of the adjacent habitats. Levees would require regular maintenance, but could be integrated into the natural environment, unlike seawalls.

7. CONCLUSIONS

Ten key vulnerable areas were identified within the Hayward focus area (Figure 1). Four of these are shoreline inundation areas, two are critical inundation pathways, and four are inland inundation areas. The general hydraulic connections between the areas are presented in Figure 2. The threshold for localized daily tidal inundation of shoreline and inland areas occurs at the MHHW + 24-inch scenario; however, extreme tides (5-year or greater) already threaten assets immediately adjacent to the shoreline under existing conditions. Daily tidal inundation of SR 92 (Area A) as well as extensive inundation of the inland industrial developments occurs at the MHHW + 48-inch scenario; however, extreme tides (50-year or greater) will threaten these areas in the future with just 6 inches to 12 inches of SLR. Hayward Shoreline Interpretive Center is first exposed to inundation at the 24-inch scenario while the landfills near Triangle Marsh are not inundated in any of the mapped scenarios. Overtopped non-engineered berms and wetland channels are the key sources of inundation for these areas. Triangle Marsh, Cogswell Marsh, HARD Marsh, and Eden Landing Ecological Reserve south of Mt. Eden Creek are exposed to daily tidal inundation at the 12-inch scenario. The Oliver Salt Ponds, Salt Marsh Harvest Mouse Preserve, and the remainder of Eden Landing Ecological Reserve are permanently inundated at the 24-inch scenario. Hayward Marsh is exposed to inundation at the 36-inch scenario and the oxidation ponds are completely inundated at the 48-inch scenario. This assessment does not consider natural marsh processes such as marsh accretion, and the topography of the area is assumed to remain constant over time. However, some of the marsh and restoration areas may continue to accrete material and keep pace with sea level rise. If the marsh areas are able to keep pace with sea level rise, they will continue to provide some level of flood protection to the adjacent inland areas.

The earliest source of localized inundation within the Hayward focus area occurs when the banks of the engineered or natural drainage channels overtop; as the internal pond berms begin to overtop, system-wide inundation occurs. In the short term (0-6 inches of SLR), small-scale localized shoreline adaptation measures may protect critical assets from flooding during extreme tides; however, over the longer term (approximately 36 inches of SLR and greater), a large-scale integrated flood protection strategy for the Hayward focus area will be required to prevent extensive flooding during extreme tides.

Adaptation measures 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. Rainfall runoff events will further exacerbate flooding in the watershed. In addition, rising groundwater tables, primarily associated with static SLR, 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 the existing drainage systems may become ineffective with higher levels of SLR. Consideration and evaluation of these factors is recommended as a next step.

8. REFERENCES

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Attachment A – Hayward Focus Area Site Visit Photos

Attachment A - Site Visit Photos (March 17, 2014)

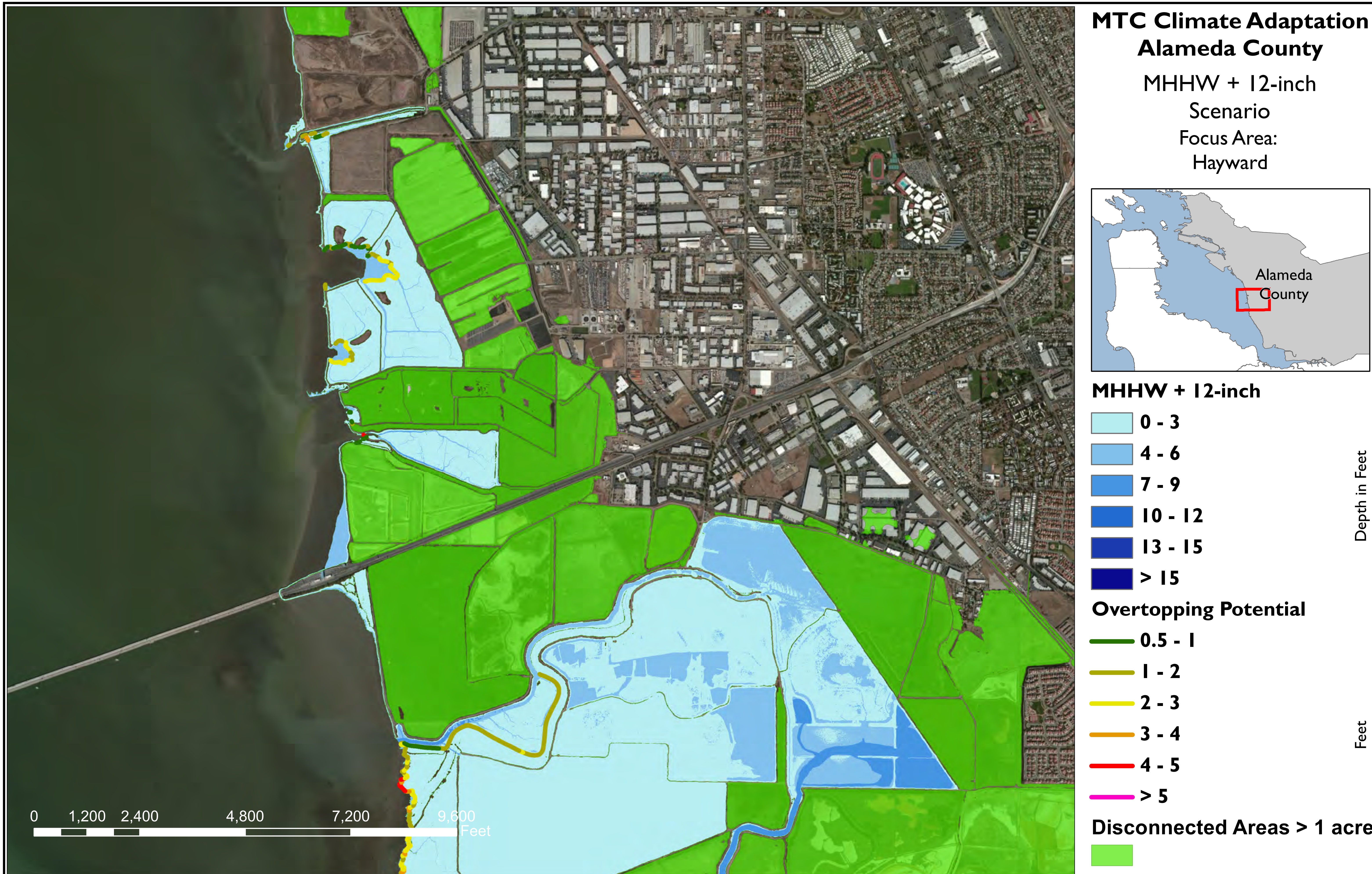
Hayward Focus Area – Shoreline Protection (Cogswell Marsh looking South)

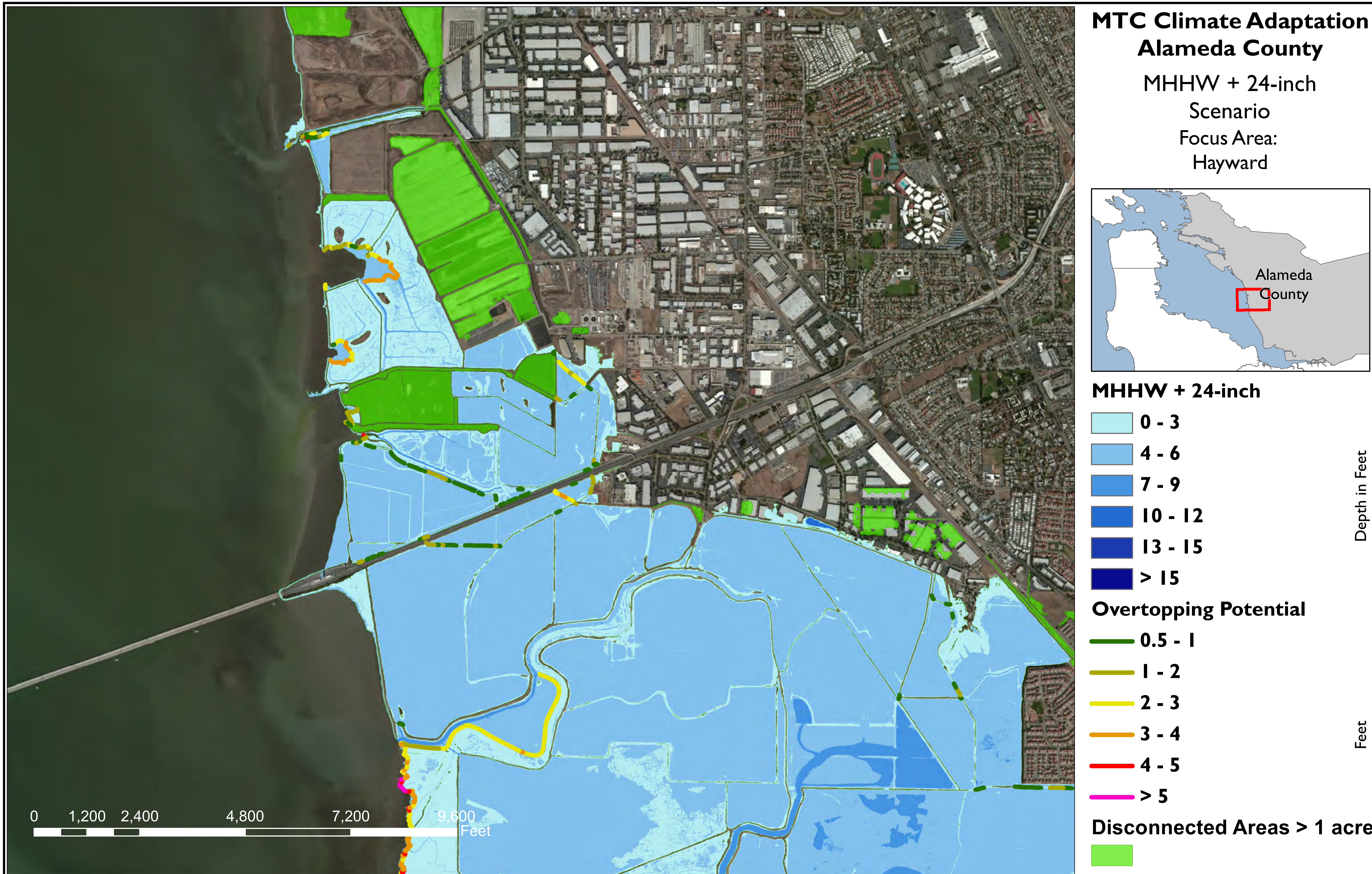
Hayward Focus Area – Shoreline Protection (Hayward Marsh looking South)

Hayward Focus Area – Tide Control Structures (Channel between Cogswell Marsh and Hayward Marsh looking inland)

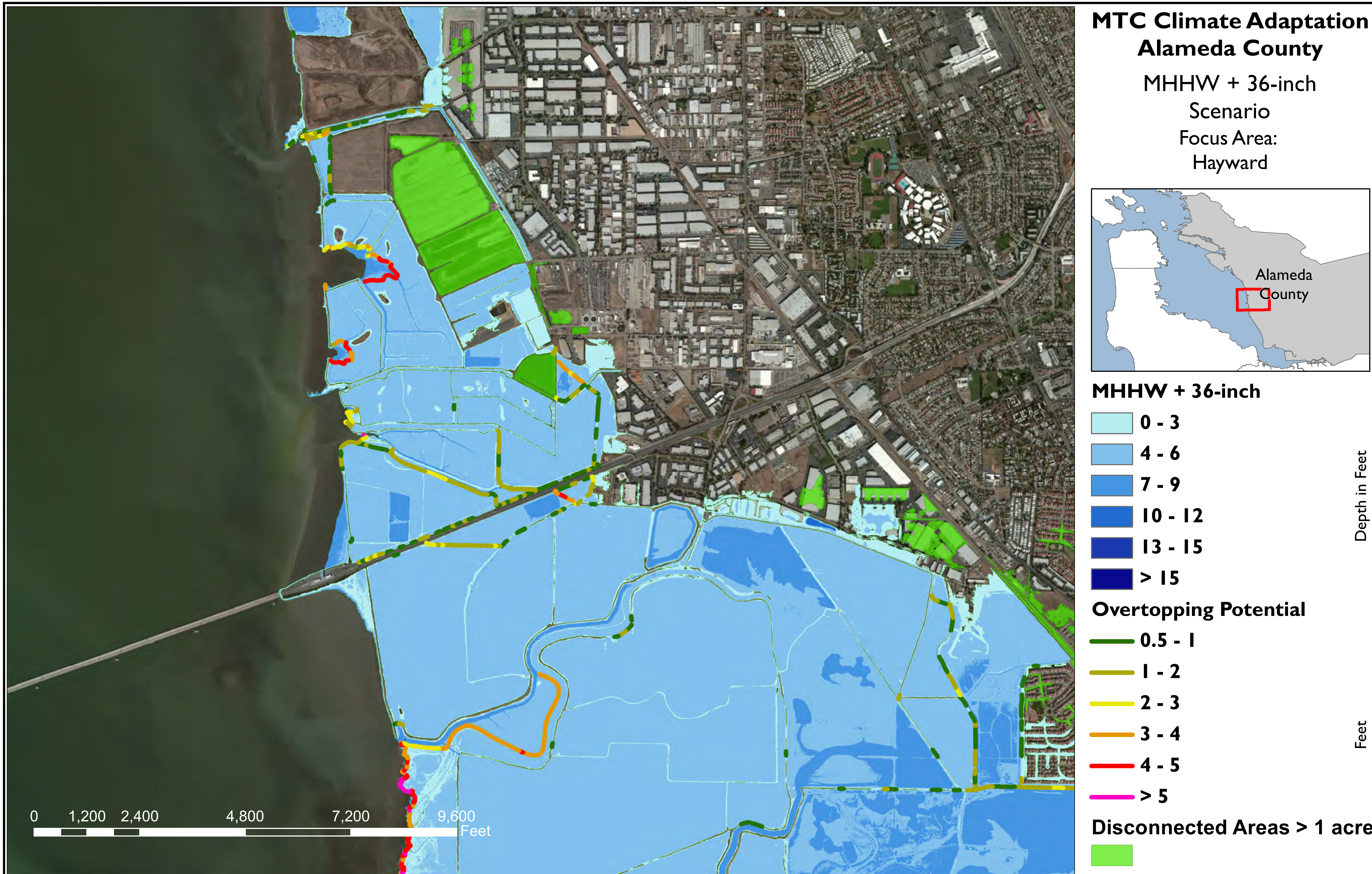
Hayward Focus Area – Tide Control Structures (Channel between Hayward Marsh and HARD Marsh looking towards the Bay)

Attachment B – Focus Area Inundation Maps


MTC Climate Adaptation
Alameda County
MHHW + 12-inch
Scenario
Focus Area:
Hayward
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
1,200
2,400
4,800
7,200
9,600
Feet



MTC Climate Adaptation
Alameda County
MHHW + 24-inch
Scenario
Focus Area:
Hayward
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
1,200
2,400
4,800
7,200
9,600
Feet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MHHW + 36-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 36-inch
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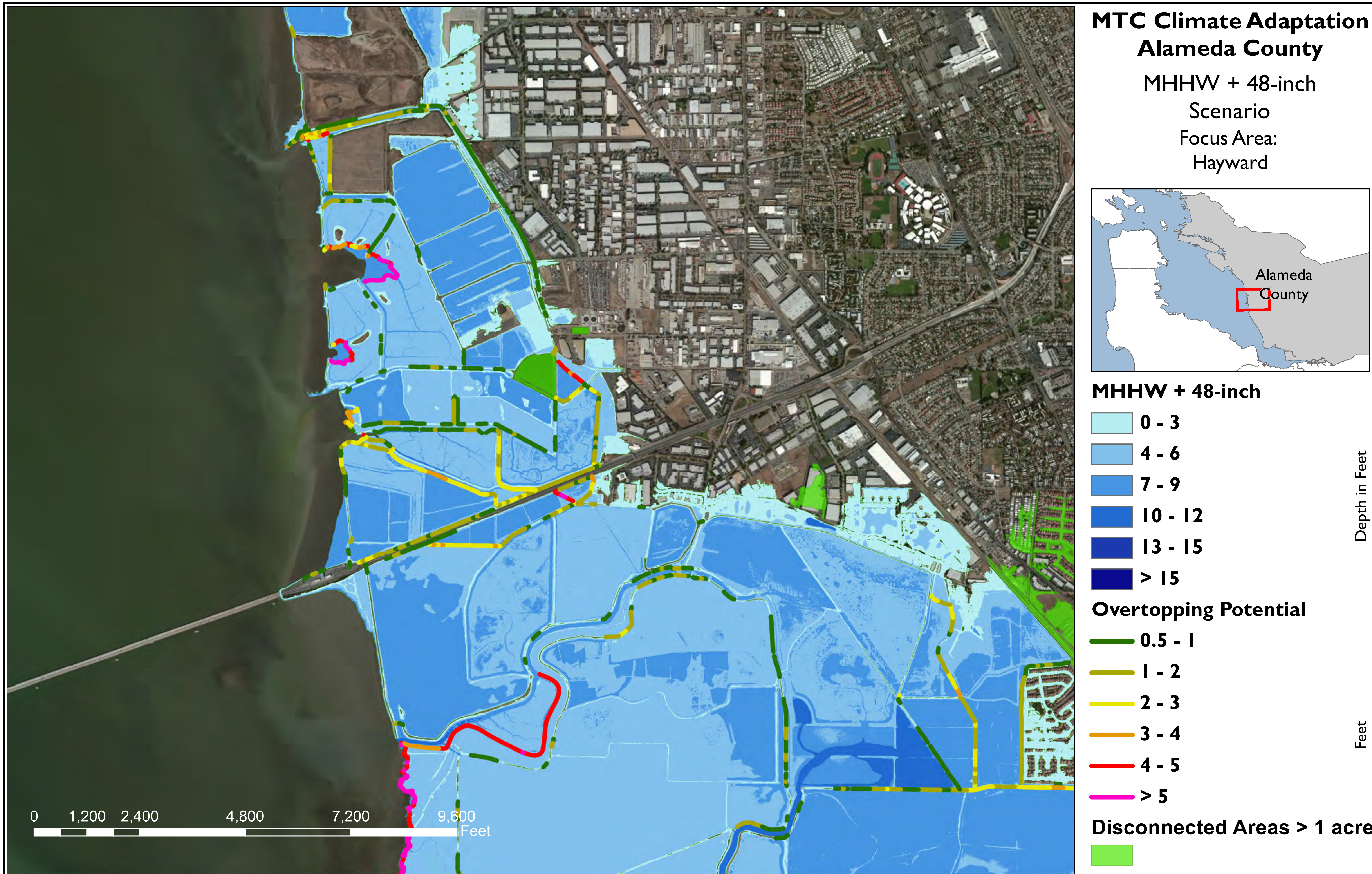
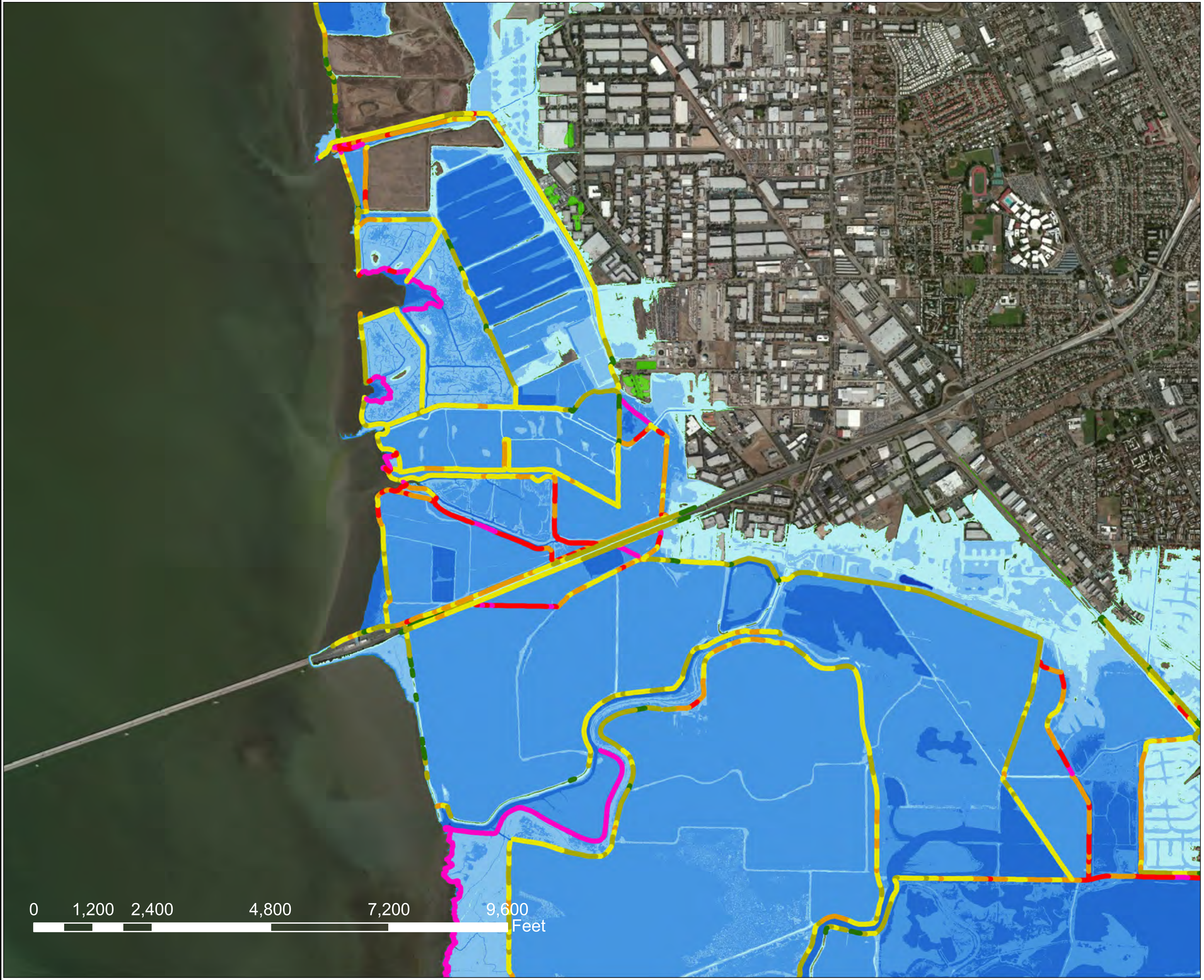
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet

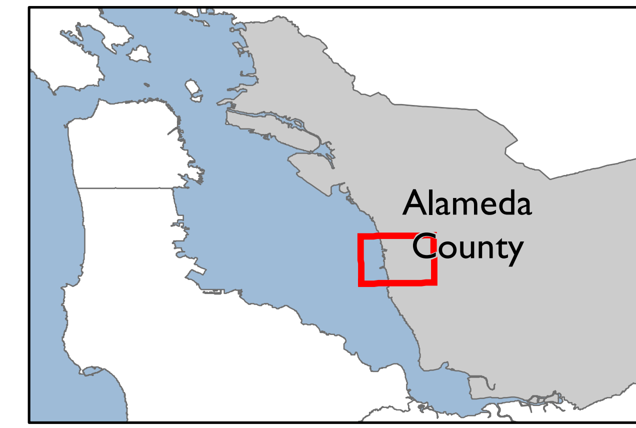

MTC Climate Adaptation
Alameda County
MHHW + 48-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 48-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet

MTC Climate Adaptation Alameda County

MHHW + 72-inch Scenario

Focus Area: Hayward





MHHW + 72-inch

Depth in Feet

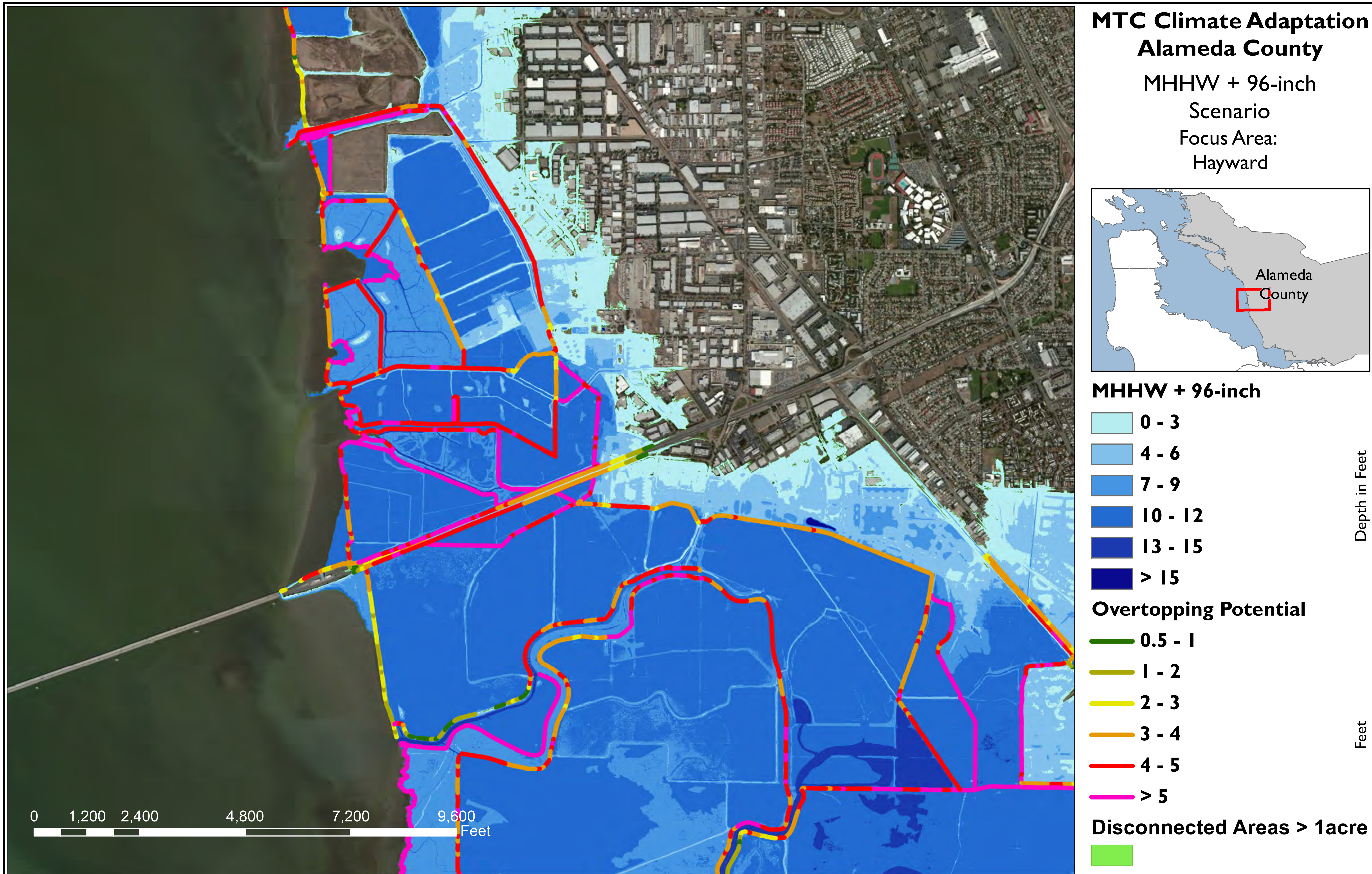
- **0 - 3**
- **4 - 6**
- **7 - 9**
- **10 - 12**
- **13 - 15**
- **> 15**

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:
Hayward
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
1,200
2,400
4,800
7,200
9,600
Feet