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Memorandum

To	Wendy Goodfriend, BCDC	Page	1
CC	Claire Bonham-Carter, AECOM		
Subject	Bay Farm Island Focus Area		
From	Jeremy Mull, P.E., Michael Mak, P.E., Kris May, Ph.D., P.E.		
Date	June 25, 2014		

1. INTRODUCTION AND PURPOSE

Bay Farm Island was selected as a focus area for more detailed sea level rise (SLR) exposure analysis and adaptation strategy development as part of the 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. Under a separate project named the Adapting to Rising Tides (ART) Transportation Vulnerability and Risk Assessment Pilot Project (ART) (BCDC et al. 2011), this area was identified as vulnerable to inundation by SLR and coastal storm surge that could impact critical transportation assets and other adjacent assets that support the region. Additional sea level rise inundation maps were created for the Alameda County Sea Level Rise Shoreline Vulnerability Assessment (in progress), which includes the Bay Farm Island focus area within the mapping extent. These inundation maps were examined to better understand the timing of when sea level rise is expected to impact the shoreline and inland areas. The inundation maps showed that an extensive portion of Bay Farm Island, including facilities associated with the Oakland International Airport, would be inundated with as little as 12 inches of SLR (see Figure 1). Prior to identifying key vulnerabilities within the focus area, a first step was taken to verify the accuracy of the initial inundation maps and confirm the likelihood of inundation shown during 12 inches of SLR. Refinements to the inundation maps were made where necessary and are presented in this memorandum.

The purpose of this memorandum[1] 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 measures, some of which are presented in this memorandum. This technical memorandum should be considered in tandem with other ongoing work in Alameda County, including the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study, which is conducting a similar level of vulnerability assessments in other areas that have been identified as vulnerable. The following sections provide a description of the Bay Farm Island Focus Area (Section 2), an assessment of exposure to inundation and flooding (Section 3), the verification of topographic features and elevations at several locations (Section 4), identification of key areas of vulnerability (Section 5), recommendations for the timing of adaptation measures (Section 6), potential adaptation measures (Section 7), and conclusions and next steps (Section 8).

[1] This memorandum is funded with qualified outer continental shelf oils and gas revenues by the Coastal Impacts Assessment Program, Fish and Wildlife Service, U.S. Department of the Interior.

Figure 1. Initial Inundation Maps Showing Inundation of Bay Farm Island with 12 inches of SLR

Note: Inundated areas, including the Oakland International Airport, are shaded in blue.

2. FOCUS AREA DESCRIPTION

Bay Farm Island is a relatively low-lying peninsula that extends from the eastern shoreline of San Francisco Bay. It was historically an island surrounded by several marsh complexes but is now connected to the San Francisco Bay shoreline by artificial land fill and a majority of the marshes have been developed with fill. Located within the City of Alameda and the City of Oakland, key assets include the Oakland International Airport, Oakland Raiders headquarters, the Chuck Corica Golf Complex, and several residential neighborhoods. Bay Farm Island is currently protected from coastal flooding and inundation by several standalone structures and tide gates along the shoreline. In addition, there is a system of levees that protects the shoreline in several areas, most notably around the Oakland International Airport. Placements of rip-rap and revetments protect areas of the shoreline from erosion. The key areas in this assessment include the northern and eastern portions of the Bay Farm Island shoreline along San Francisco Bay and San Leandro Bay, where inundation is first expected to occur during sea level rise and storm surge events. Several sections along this shoreline are known low-lying areas that are already vulnerable to flooding during storm surge events. The section of the shoreline investigated in this focus area is highlighted in Figure 2. Key areas of inundation that needed to be verified during the assessment are presented in Section 4.

Figure 2. Focus Area Shoreline

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 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 Farm Island focus area, six sea level rise 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 [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 sea level rise projections, the following scenarios were evaluated for the present study: 12 inches, 24 inches, 36 inches, and 48 inches of sea level rise above existing MHHW. In addition to these scenarios, 72 inches and 96 inches above MHHW were also evaluated, but these water levels are outside the range of current scientific predictions for sea level rise within this century 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 sea level rise.

The initial inundation maps for this focus area were developed by AECOM as part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD. The maps show the extent of inland inundation, inundation depths, and the depth of “overtopping potential” along the shoreline. 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. Note that the overtopping calculations represent an average of inundation depths over a specified length of the shoreline and do not show depths less than 0.5 feet to account for the limits in the vertical accuracy of the DEM and the sea level rise inundation mapping process. Therefore in some areas on the inundation maps, inundation over a shoreline feature may be shown with no corresponding overtopping depth, if the overtopping depth is

[2] www.r9coastal.org

less than 0.5 feet. 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. The mapping scenarios are listed in Table 1. The revised inundation maps created for this assessment are presented in Attachment A**.**

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[3] or extreme high tide. For example, Scenario 3 (MHHW + 36 inch) represents a water level reached by a daily high tide with 36 inches of sea level rise, and we subsequently refer to this scenario as 36 inches of SLR. This scenario also represents a 50-year extreme tide with no sea level rise (i.e., existing conditions). To expand the range of extreme tide and sea level rise scenarios represented by each of the six mapping scenarios, a +/- 3 inches tolerance was added to each reference water level to increase its applicable range. 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 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,

[3] 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 6.6 ft NAVD88 within this focus area.

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 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	14	19	23	27	32	36	41
MHHW + 6 inch	6	20	25	29	33	38	42	47
MHHW + 12 inch	12	26	31	35	39	44	48	53
MHHW + 18 inch	18	32	37	41	45	50	54	59
MHHW + 24 inch	24	38	43	47	51	56	60	65
MHHW + 30 inch	30	44	49	53	57	62	66	71
MHHW + 36 inch	36	50	55	59	63	68	72	77
MHHW + 42 inch	42	56	61	65	69	74	78	83
MHHW + 48 inch	48	62	67	71	75	80	84	89
MHHW + 54 inch	54	68	73	77	81	86	90	95
MHHW + 60 inch	60	74	79	83	87	92	96	101

Note: All values in inches above existing conditions MHHW at Bay Farm Island 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 SITE ASSESSMENTS

By combining the information available in the SLR and tide scenarios 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. The initial inundation maps from the Alameda County Sea Level Rise Shoreline Vulnerability Assessment indicated that wide-spread inundation could occur with 12 inches of SLR. According to the matrix, the inundation that occurs with 12 inches of sea level is similar to what could occur annually under existing conditions during a King Tide Event (1-year event). However, this degree of flooding does not currently occur during typical Kind Tide conditions. AECOM therefore sought to verify the pathways of flooding as well as the accuracy of the 2-meter resolution digital elevation model (DEM) and 2010 LiDAR data[4]. A detailed review of the inundation maps, inundation depth grids, and overtopping potential calculations revealed low elevations in the DEM at five sites that were acting as critical pathways for inland inundation at low SLR scenarios (Figure 3). The AECOM team performed site visits on March 5, 2014 and March 30, 2014 to verify the elevation of these areas with a visual inspection of the shoreline (see Attachment B for the site visit photos). Only areas with localized inundation pathways or distinct topographic features (e.g., vertical walls) were examined in this verification step. Broad stretches of shoreline that were shown as inundated on the inundation maps were not evaluated.

The site visits and a review of the orthoimagery (2010) from the LiDAR data collection and aerial photography from Google Earth (2014) revealed two vertical structures (one seawall and one wing-wall) that were not fully captured in the DEM at Sites A and B. It is important to note that the bare-earth (Class 2) LiDAR data were used exclusively to generate the DEM. In the bare-earth LiDAR, all vegetation, buildings, bridges, and many coastal protection structures (e.g., standalone seawalls) are typically removed. Furthermore, any seawalls or narrow structures that are not removed from the bare earth data may be too narrow to be fully resolved by the 1-m spaced LiDAR data points. A review of the inundation depth grids further indicated that low elevations in the DEM at Sites C, D, and E along Doolittle Drive were pathways for inland inundation at low SLR scenarios. Although accurate, the 2-m resolution DEM is coarse enough to smooth over high elevation features, including the crests of small levees or the crown of a road, that also provides flood protection.

Although the exact dimensions of these features were not fully captured in the bare-earth LiDAR and/or DEM, there were enough raw LiDAR data points to accurately determine the high point elevations. The DEM at these five sites was compared to the original topographic LiDAR data points in these areas to confirm that the modeled terrain surface of the DEM accurately represented the LiDAR data. If there were distinct differences found between the elevations in the DEM, the elevations in the LiDAR data, and the observations from the site visit, the DEM at each site was modified to reflect the most reasonable or more accurate elevations. After modifying the DEM, the shoreline delineation used for the overtopping potential assessment was adjusted to coincide with the vertical structures and high points of Doolittle Drive. The inundation mapping and overtopping analyses were redone for each sea level rise scenario with the revised DEM to verify how these modifications affected the inundation mapping, and to review and confirm the revised exposure level and shoreline vulnerabilities. The revised inundation maps are found in Attachment A.

[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).

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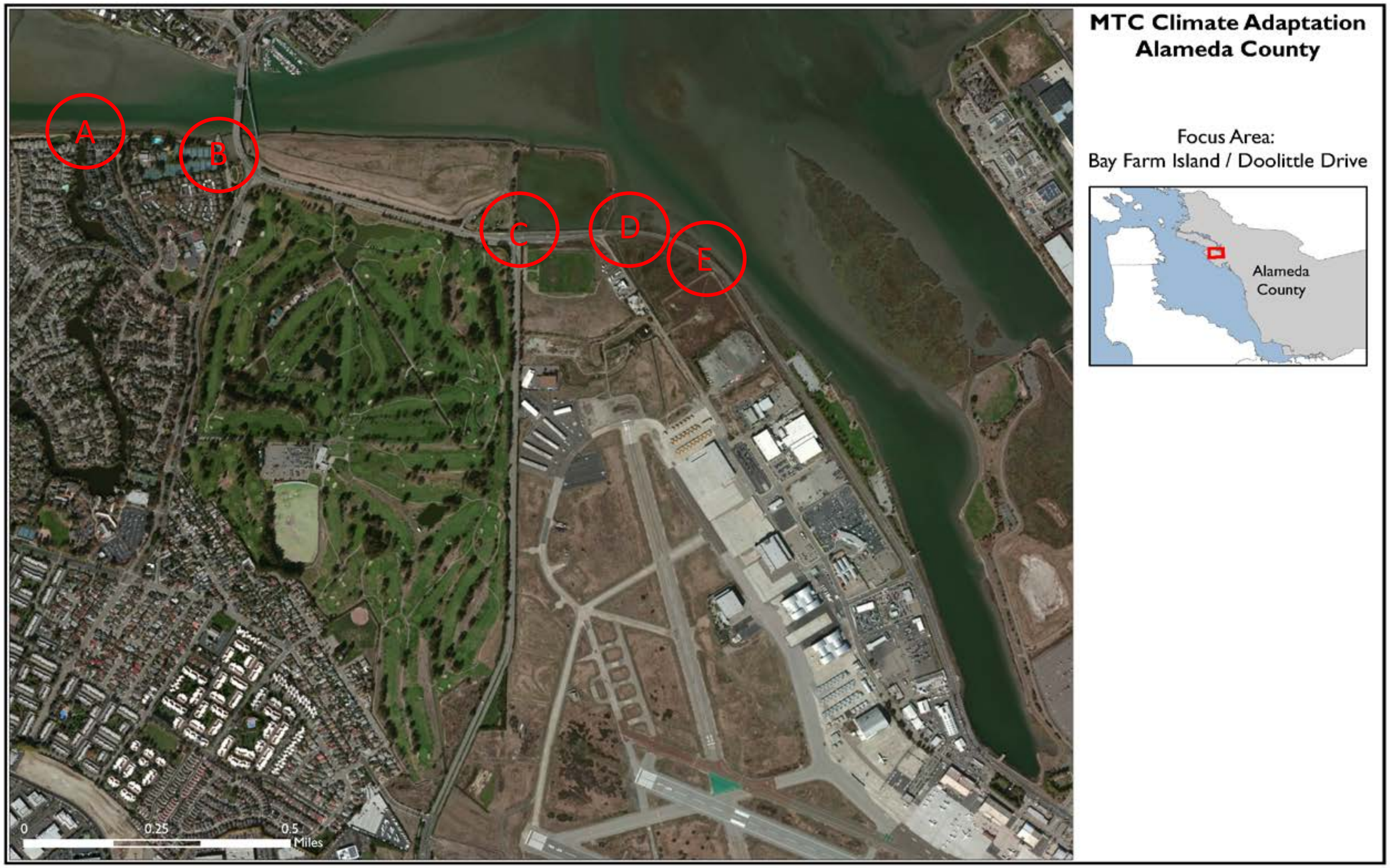

Figure 3. Sites In The DEM Contributing To Inundation In Low SLR Scenario

A summary of the modifications to the topographic DEM are presented in Table 3. For each site that was reviewed, the original DEM elevations, average elevations in the LiDAR data, modified DEM elevations, and the first SLR scenario when the site is overtopped[5] is listed in Table 3. A detailed description of the modifications made to the DEM at each site is provided in the following sections.

Table 3: Modified Low-Lying Areas in the DEM Contributing to Inundation

Site	Average DEM Elevation (feet NAVD88)	SLR Scenario of First Overtopping (inches SLR)	Approximate Wall Height from Ground (feet)	Average LiDAR Elevation (feet NAVD88)	Modified Elevation (feet NAVD88)	Revised SLR Scenario of First Overtopping (inches SLR)
A. Tide Gate Structure						
West Segment	10.0	36	2.0	10.0	NA	36
East Segment	9.0	36	2.0	9.5	9.5	36
B. Veterans Court Seawall						
North Segment	7.2	24	3.0	10.0	10.0	48
Middle Segment	5.9	12	3.0	10.0	10.0	48
South Segment	7.5	12	3.0	10.0	10.0	48
C. Doolittle Drive/Harbor Bay Parkway Intersection	8.5	24	NA	9.0	9.0	36
D. Doolittle Drive	8.5	24	NA	9.0	9.0	36
E. East Doolittle Drive	8.5	24	NA	9.0	9.0	36

NA = No change or not applicable

Note: Average DEM elevations indicate the average of elevation multiple DEM grid cells along each feature. Average LiDAR elevations indicate the average of multiple elevation points along each feature.

4.1 Site A - Tide Gate Structure

Site A is a tide gate structure with low wing-walls located nearly 0.3 miles west of the Doolittle Road/Bay Farm Island Bridge (Figure 4). The berm behind the tide gate structure and wing-walls is at a lower elevation than the top of the wing-walls and the adjacent shoreline. The wing-walls are an engineered structure which protects the backshore area and lagoon from wave action. It also

[5] 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.

protects the backshore area from scour during periods of discharge from the lagoon. Overtopping at this location will expose the adjacent residential neighborhood to flooding, and during permanent inundation above the wall, the discharge point for stormwater runoff out of the lagoon will be eliminated.

Figure 4. Site A – Tide Gate Structure west of the Doolittle Road/Bay Farm Island Bridge

The wing-walls consist of two segments which are constructed approximately 2 feet above the backshore ground elevation. The average DEM elevation of the west segment was 10.0 feet NAVD88, and overtopping was expected to begin occurring at 36 inches of SLR based on the initial inundation maps. The average DEM elevation of the east segment was 9.0 feet NAVD88, and overtopping was also expected to begin occurring at 36 inches of SLR. The average LiDAR elevations of the walls are approximately 9.5 feet NAVD88, so low DEM elevations on the east segment were modified to reflect this elevation. The low-lying elevations of the backshore area on the DEM were verified to be represented correctly and were not adjusted. After modifications to the topographic DEM were completed, the inundation maps were revised using the new DEM. The new inundation maps in Attachment A show that the east section of the wing-wall is still expected to be overtopped at 36 inches of SLR (approximately 9.6 feet NAVD88). The overtopping potential lines on the inundation maps do not show overtopping over both segments of the wing-wall until 48 inches of SLR. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site A are listed in Table 3.

Inundation of the residential areas adjacent to the lagoon will begin at 36 inches of SLR. Inundation will occur from overtopping of the tide gate wing-walls and also via pathways originating from the adjacent Corica Golf Course that is also flooded during this scenario. Residential neighborhoods located more inland will be protected from 36 inches of SLR but will begin to experience inundation at 48 inches of SLR.

4.2 Site B - Veterans Court Seawall

Site B includes a 3 feet-high seawall located immediately west of the Doolittle Drive/Bay Farm Island Bridge along the seaward side of Veterans Court (Figure 5), and a stretch of shoreline just west of the seawall in front of the Harbor Bay Club (Figure 6) with loose rock protection from a former seawall. A detailed review of the DEM and inundation mapping in this area showed that the site served as a critical inundation pathway with 12 inches of SLR.

In the DEM, the average elevation of the north segment of the seawall was 7.2 feet NAVD88, and it was projected to begin overtopping at 24 inches of SLR based on the initial inundation maps. The average elevations of the middle and south segments of the seawall were 5.9 feet and 7.5 feet NAVD88 respectively, and they were projected to begin overtopping with 12 inches of SLR. This location is the primary pathway for all of the inundation in the Bay Farm Focus area with 12 inches of SLR under the initial inundation mapping. However, from the site visit and the initial review of the DEM, it was apparent that the elevations of the seawall were not fully captured. A review of the LiDAR data showed that the elevations at the wall are approximately 10 feet NAVD88, approximately 2.5 to 3.0 feet higher than the elevation on the DEM. To better represent the seawall, the DEM elevations at the location of the seawall were modified to reflect this elevation. The Harbor Bay Club shoreline elevations were confirmed by reviewing the topographic elevations in the DEM, and no changes were necessary. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site B are listed in Table 3.

After the modifications to the DEM representing the Veterans Court area were completed and the inundation maps were updated, the new inundation maps (Attachment A) showed that overtopping of the seawall is not observed until 48 inches of SLR (approximately 10.6 feet NAVD88). However, overtopping still occurs over the Harbor Bay Club shoreline with 36 inches of SLR (approximately 9.6 feet NAVD88), and this inundation impacts the Veterans Court area and Island Drive to the south of Veterans Court.

Figure 5. Site B - Veterans Court Seawall

Figure 6. Site B - Shoreline Adjacent to Harbor Bay Club Looking East at Veterans Court

4.3 Site C - Doolittle Drive at Intersection with Harbor Bay Parkway

Further review of the initial inundation maps and DEM revealed inundation pathways at three sites along Doolittle Drive with 24 inches of SLR. Site C is a section of road built on fill along Doolittle Drive at the intersection of Doolittle Drive and Harbor Bay Parkway. At the intersection, the inundation with 24 inches of SLR occurs via a flow pathway created by a single low-lying elevation on the DEM (see Figure 7). The 2-m resolution DEM had over-smoothed the crown of the road in the intersection, allowing water levels during the MHHW + 24 inch scenario to just exceed the crown and inundate the inland areas behind Doolittle Drive (see Figure 8). The average DEM elevation of the road at the intersection was 8.5 feet NAVD88. To verify the crown elevation of the road, the LiDAR data was overlaid over the DEM. The average LiDAR elevations of the street are approximately 9.0 feet NAVD88, or approximately 0.5 feet higher than the elevations identified on the DEM. The elevations in the DEM were modified to reflect the higher elevation, and the inundation maps were revised. After remapping this focus area using the modified DEM, all sections of Doolittle Drive provide flood protection up to 36 inches of SLR (approximately 9.6 feet NAVD88; See Attachment A). The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site C are listed in Table 3.

Figure 7. Site C – Inundation Across the Intersection of Doolittle Drive / Harbor Bay Parkway

Note: A low-lying elevation on the DEM at the intersection of Doolittle Drive and Harbor Bay Parkway was found to be a pathway to inundation of inland areas during 24 inches of SLR.

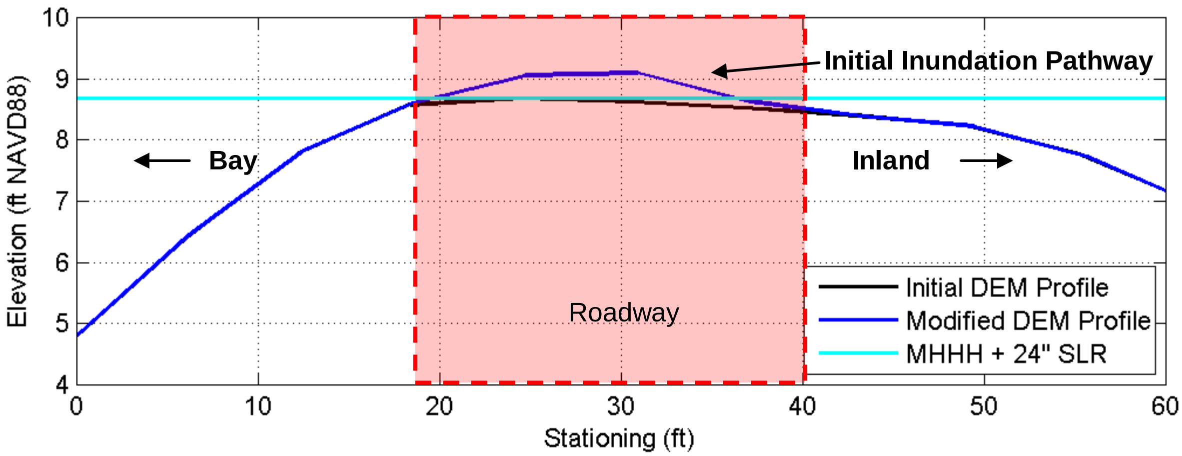

Figure 8. Roadway Cross Section of Intersection at Doolittle Drive and Harbor Bay Parkway

Note: The over-smoothed crown in the original DEM was allowing inundation with 24 inches of SLR (blue line).

4.4 Site D – Doolittle Drive

Site D is a section of Doolittle Drive built on fill approximately 0.2 miles east of the intersection of Doolittle Drive and Harbor Bay Parkway (Figure 9). At Site D, the initial maps showed inundation across Doolittle Drive during 24 inches of SLR via a flow pathway across several low-lying elevations in the DEM, similar to Site C. The 2-m resolution DEM had over-smoothed the highest elevations near the center line of the road allowing water levels during the MHHW + 24 inch scenario to inundate the island in the inundation analysis. The average DEM elevation of the road at this site was 8.5 feet NAVD88 (see Figure 10). The average LiDAR elevations of the street are approximately 9.0 feet NAVD88, so the elevations in the DEM were raised approximately 0.5 feet in this area. The revised inundation mapping for this focus area using the modified DEM shows that all sections of Doolittle Drive provide flood protection until 36 inches of SLR is reached (approximately 9.6 feet NAVD88; See Attachment A). The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site D are listed in Table 3.

Figure 9. Site D – Doolittle Drive Looking Southeast

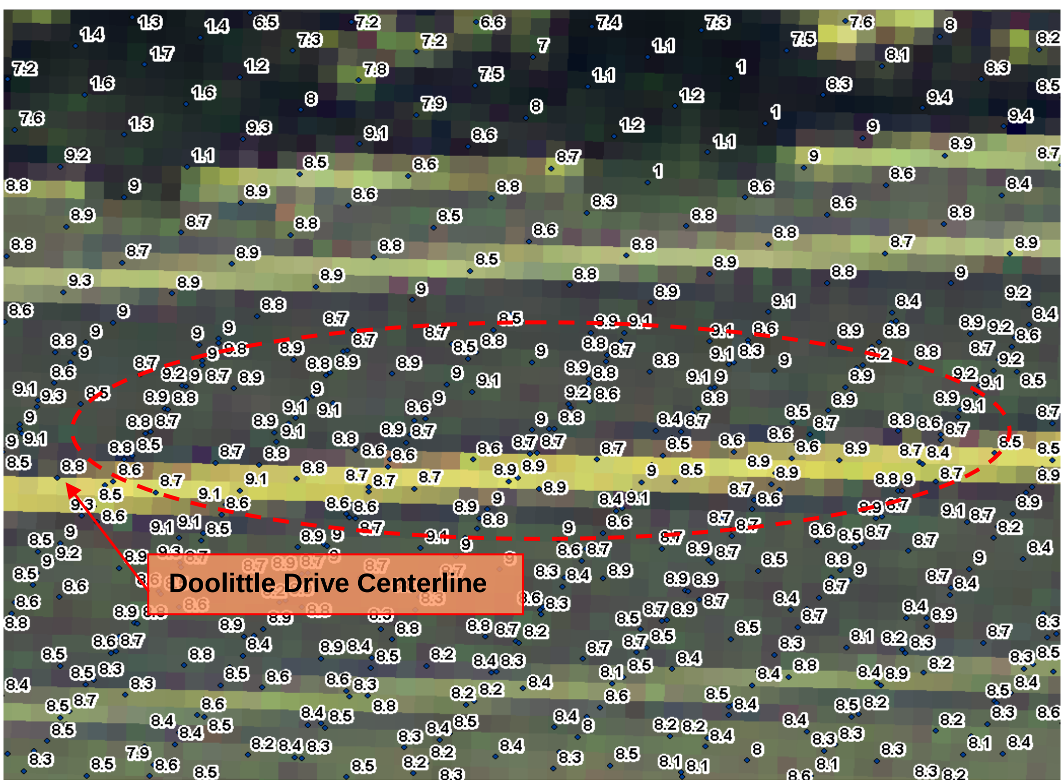

Figure 10. LiDAR Elevations at Site D

Note: The measured LiDAR elevations at the high point in the road are approximately 8.5-9.5 feet NAVD88. The DEM grid cells in the same locations were modified to a minimum elevation of 9 feet NAVD88.

4.5 Site E – Doolittle Drive

Site E on Doolittle Drive is a section of the roadway built on fill, approximately 0.3 miles southeast of the intersection of Doolittle Drive and Harbor Bay Parkway (see Figure 11). At Site E, inundation over Doolittle Drive with 24 inches of SLR was generated via a flow pathway across several low-lying elevations in the DEM, similar to Sites C and D. The 2-m resolution DEM had over-smoothed the highest elevation in the road allowing water levels during the MHHW + 24 inch scenario to inundate inland areas. The average DEM elevation of the road at this site was 8.5 feet NAVD88. The average LiDAR elevations of the street are approximately 9 feet NAVD88, so the elevations in the DEM were raised approximately 0.5 feet in this area. After remapping this focus area using the modified DEM, all sections of Doolittle Drive provide flood protection until 36 inches of SLR (approximately 9.6 feet NAVD88; See Attachment A). Areas further south on Doolittle Drive were also reviewed to confirm the elevations in the DEM, and no changes were warranted. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site D are listed in Table 3.

Figure 11. Site E – South Doolittle Drive, Looking Northwest

5. FOCUS AREA VULNERABILITIES

The initial inundation maps for the Alameda County Sea Level Rise Shoreline Vulnerability Assessment indicated that a majority of the Bay Farm Island focus area would be permanently inundated with only 12 inches of SLR. Modifications to the DEM at Sites A-E and subsequent re-analysis verified that system-wide inundation of the focus area will now first occur with 36 inches of SLR (approximately 9.6 feet NAVD88; see Figure 12). In this scenario, overtopping will occur along the low-lying shoreline just west of the Veterans Court seawall in front of the Harbor Bay Club (Site B) and along the northern and eastern sections of Doolittle Drive (Sites C-E). Overtopping at the tide gate wing-wall (Site A) will also occur with 36 inches of SLR. Two additional low areas have been identified on southeast Doolittle Drive (Sites F and G). These sites are low spots on the roadway that can serve as hydraulic connections for floodwaters to reach inland areas with 36 inches of SLR. These sites are also critical pathways to extensive inland inundation at this water level scenario. The areas along the Bay Farm Island shoreline that lead to system-wide inundation during 36 inches of SLR are shown on Figure 12.

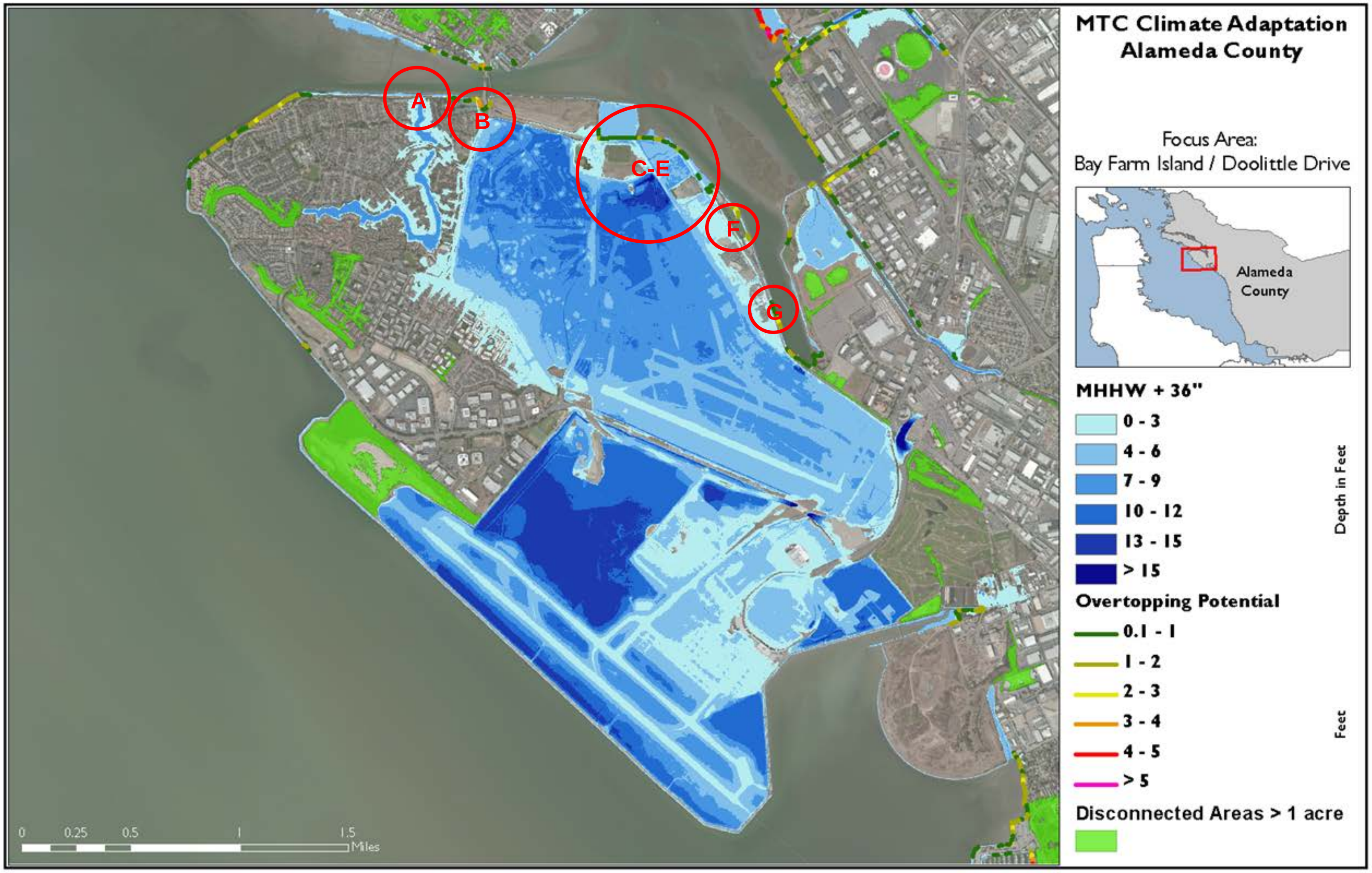

Figure 12. Updated Inundation and Flooding Analysis Using the Modified DEM

Note: System-wide inundation of Bay Farm island is expected at 36 inches of SLR. The tide gate wing-wall (Site A), the Harbor Bay Club shoreline (Site B), and sites along Doolittle Drive (Sites C-G) are the critical inundation pathways in this scenario.

6. TIMING OF POTENTIAL ADAPTATION MEASURES

One of the most important aspects of adaptation planning is determining when and where adaptation measures must be employed in order to prevent inland inundation and flooding. The previous sections have addressed the vulnerable locations that will likely require adaptation strategies. This section focuses on evaluating when, in time, these strategies should be implemented. AECOM examined the timing of adaptation measures from the perspective of maintaining the *existing* level of flood protection in the face of SLR. Although the standard level of design for flood protection features is typically the 100-year (or 1-percent annual chance) flood[6], this level of protection is currently not provided under existing conditions within the Bay Farm Island focus area. The timing of daily inundation, annual flooding events, and less frequent flooding events (in terms of water levels) for the vulnerable sites (A – G) are summarized in Table 4. Under existing conditions, these areas are all expected to be overtopped by a 50-year or greater extreme tide event. Adaptation strategies are therefore required now if this level of protection is to be increased for the 100-year flood event and for SLR over the coming decades.

It should be noted that the extreme tide levels presented in this memorandum do not include the effects of waves at the shoreline which can result in erosion and undermining of existing shoreline protection, or the effects of precipitation-based runoff and current highway drainage were not evaluated which can also result in flooding that will be exacerbated with sea level rise. Bay Farm Island is also largely constructed on fill over former marshlands and the groundwater table is high. Increases in sea level will likely correlate to similar increases in the groundwater table, thereby increasing the potential for flooding and other hazards associated with fill (e.g., saturation and settlement). These compounding circumstances and additional flood risks are not addressed within this study, but they should be considered before implementing adaptation strategies.

Although 36 inches of SLR (approximately 9.6 feet NAVD88) has been identified as the critical threshold for system-wide inundation of the focus area, these areas will also be exposed to flooding by extreme tide events coupled with lower sea level rise scenarios. The cells highlighted in green in Table 2 show the range of potential SLR and storm surge scenarios that could impact Bay Farm Island and could result in a similar overall inundation extent as MHHW + 36 inches of SLR. For example, assets within the inundation zone that will be exposed to daily tidal inundation under the MHHW + 36 inches of SLR scenario could also be exposed to flooding once per year with 24 inches of sea level rise (24 inches of SLR + 1-year extreme tide), or during El Niño[7] conditions with 6 inches of sea level rise (6 inches of SLR + 10-year extreme tide). Based on current NRC (2012) SLR projections, 6 inches of sea level rise is likely to occur by 2030 (NRC 2012).

It should be noted that the previous inundation mapping effort demonstrated that the primary pathway for inundation of Bay Farm Island with 12 inches of SLR was over the Veterans Court seawall (Site B). Although overtopping of this seawall under an temporary extreme tide event is not likely to result

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

in wide-scale inundation of Bay Farm Island, overtopping due to long-term SLR could result in significant inundation. Although modifications were made to the DEM to better represent the height of this structure based on orthoimages, LiDAR data, and site visits, it is recommended that the integrity of this structure for providing flood protection be reviewed. Adaptation strategies at Site B may be the highest priority for existing and future flood protection if this structure is deemed insufficient.

Table 4. Timing of Inundation and Flooding

		Timing of Temporary Flooding from Extreme Tides (inches of SLR)						
Site	**Permanent Inundation Scenario (inches of SLR)**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
A	36	24	18	12	6	6	Existing	Existing
B	36	24	18	12	6	6	Existing	Existing
C-G Doolittle Drive	36	24	18	12	6	6	Existing	Existing
System-wide	**36**	**24**	**18**	**12**	**6**	**6**	**Existing**	**Existing**

Note: Localized areas of shoreline flooding may occur at less extreme tides and 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.

7. POTENTIAL ADAPTATION MEASURES

Bay Farm Island will require multiple adaptation measures to prevent flooding and inundation, because inundation results from concurrent overtopping at several low-lying areas along the shoreline. The strategies suggested below could be implemented to help reduce existing and future flood risks at Sites A, B, and C – G.

7.1 Tide Gate Structure (Site A)

To provide flood protection for the neighborhoods adjacent to the Bay Farm lagoon for SLR greater than 36 inches (or comparable SLR and storm surge scenarios as shown in Table 2, the elevation of the tide gate, associated wing-wall structure, backshore berm behind the wing-wall, and adjacent shoreline should be raised by at least 1 to 2 feet (to approximately 10.5 - 11.5 feet NAVD88). The Bay Farm Lagoon serves as a stormwater retention pond during heavy rainfall events, and the lagoon water levels are typically drawn down before storms to increase the storage capacity. SLR will impact this process so to maintain this function, the entire tide gate structure should be raised. Future adaptation measures should consider the addition of pump systems to draw down the lagoon water levels. The adjacent shorelines should also be improved to provide sufficient freeboard (i.e., additional structure height above the flood hazard water level) above the design water levels (e.g., 36 inches of sea level rise and a 100-year extreme tide level). Additional benefits[8] can be achieved for the neighborhood communities if the structure is designed and constructed to provide protection from the 100-year extreme tide level (including waves) and then accredited by FEMA for providing flood protection.

7.2 Veterans Court Seawall and Harbor Bay Club Shoreline (Site B)

The seawall at Veterans Court should be strengthened and raised to provide a higher level of flood protection. It is recommended that the seawall be raised to meet FEMA standards with sufficient freeboard (i.e., additional structure height above the flood hazard water level) to provide additional protection to accommodate future SLR. However, due to the system-wide inundation that occurs throughout Bay Farm Island with 36 inches of SLR, implementing an adaptation strategy solely for this location will not significantly reduce the overall flood risk to Bay Farm Island. A strategy at this location is needed in tandem with strategies at Site A and Sties C – G.

The shoreline in front of the Harbor Bay Club should also be strengthened and raised by a minimum of 2 feet to approximately 11.0 feet NAVD88 to provide a higher level of flood protection. A higher elevation may be necessary based on freeboard criteria to meet FEMA standards. Additional wave runup analyses are necessary to determine this minimum elevation. An adaptation measure for this shoreline could include retrofitting and raising the existing seawall in addition to raising the berm along the shoreline from the seawall to a location west of the tide gate structure at Site A.

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[8] Flood insurance premiums can be reduced, or eliminated, if the flood protection features remove the structures (e.g., homes) from the FEMA 100-year floodplain.

Alternatively, a living levee[9] could be developed for this location to provide a more natural shoreline aesthetic and valuable habitat transitioning from uplands, to marsh, to mudflat. Depending on the accommodation space available, and the desired level of flood protection, the living levee may require inland land acquisition or encroachment into the bay and existing mudflat areas. The design would also need to accommodate the wave exposure along this shoreline. This adaptation measure will require active long-term management in order to maintain an adequate level of freeboard in response to continually rising sea levels.

7.3 Doolittle Drive (Sites C – G)

Between Sites C and G, the primary flood protection element along Doolittle Drive is the roadway itself. The Bay is located to one side of the roadway, and marshlands and industrial areas are located to the other side. Many of the inland areas are at elevations below the crown of Doolittle Drive. Large sections of Doolittle Drive will be overtopped by water levels of MHHW + 36 inches and higher. Figure 13 shows an elevation profile Doolittle Drive compared to water levels associated with 12-, 24-, 36-, 48-, and 60-inches of SLR. With 24 inches of SLR, the Bay water levels at MHHW will be very near the crown of Doolittle Road, likely compromising its ability to function in its current capacity. With 36 inches of SLR, the overtopping depth along the roadway would be less than 1 foot between Sites C and F. Increasing the existing grade of Doolittle Drive by 1 foot to approximately 10 feet NAVD88, or more, and providing additional shoreline protection features to prevent erosion would provide additional protection for the inland areas from inundation and flooding. However, a strategy that considers the entire length of Doolittle Drive would be more effective at addressing the shoreline vulnerabilities in this area. To provide flood protection up to 48 inches of SLR, or a 100-year storm surge event coupled with 6 inches of SLR, some portions of Doolittle Drive would need to be elevated by 3 feet to approximately 12.0 feet NAVD88. Elevating the roadway should be coupled with shoreline improvements and habitat enhancements such as a living levee, to retain the natural aesthetic and habitat value in this area.

As an alternative to raising the elevation of Doolittle Drive, a levee or seawall could be constructed on the seaward edge of Doolittle Drive. The levee or seawall could be designed and implemented in an adaptable manner that allows the elevation to be increased over time as sea level rise and flood risks increase. However, this strategy would encroach into the bay and require wetland mitigation.

[9] A living levee is a structure which couples multiple benefits, including flood protection and habitat restoration or creation. Typical flood protection levee do not incorporate “living” vegetated elements; whereas a living levee seeks to maximize the inclusion of vegetation in order to create valuable habitats and create habitat corridors which can link critical habitat areas together. Living levees can be found in both coastal and riverine environments.

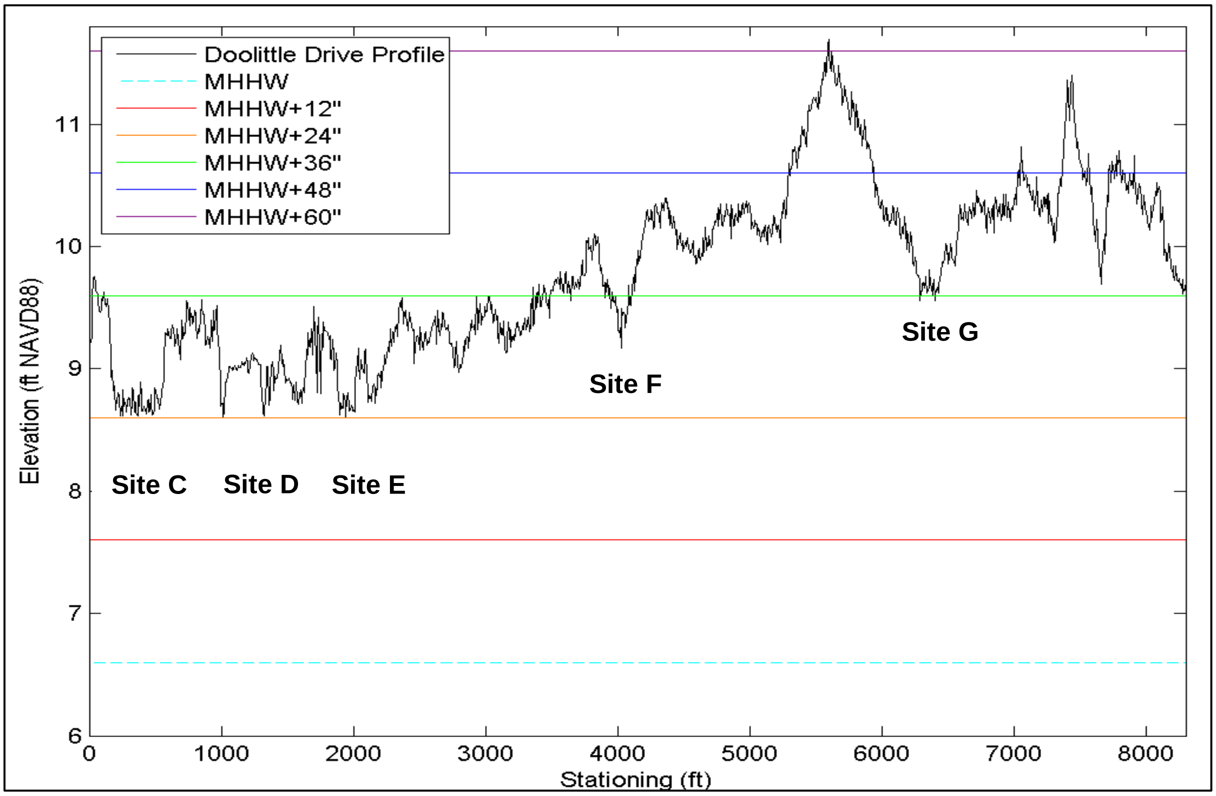

Figure 13. Elevation Profile of Doolittle Drive with Water Level Scenarios

Note: Significant portions of the road are first overtopped with 36 inches of SLR and equivalent flooding scenarios. Each additional foot added to the elevation of the road will increase the flood protection capacity to a successively higher water level. See Figure 12 for site locations.

8. CONCLUSIONS AND NEXT STEPS

Five sites were evaluated in the Bay Farm Island focus area with respect to more detailed SLR exposure in order to confirm the vulnerabilities identified within the previous ART Pilot Project (BCDC et al. 2011). As part of the focus area analysis, the most vulnerable locations were identified, field site visits were performed to confirm the vulnerabilities, and the accuracy of the DEM was verified. The selected sites were distinct areas where an initial assessment of the overtopping potential and inundation maps highlighted possible low-lying areas that led to system-wide inundation of the focus area. The DEM elevations at several locations detailed in this memorandum (Sites A – E) were modified using the source LiDAR data, orthoimages, and site observations as a reference. The revised DEM was used to create new inundation maps and overtopping potential lines so that a more accurate assessment of the critical inundation pathways and flood risk could be evaluated.

Localized shoreline overtopping within the focus area is expected to occur with 24 inches SLR, or may occur under existing conditions with a 5-year extreme tide event. System-wide inundation is expected to occur with 36 inches of SLR – or a lesser amount of SLR coupled with a storm surge scenario. The Bay Farm Island focus area is at risk of flooding under existing conditions with a 50-year extreme tide event. The inundated area includes the Oakland International Airport and the adjacent industrial areas, as well as residential neighborhoods, two elementary schools, and the Chuck Corica Golf Course. To provide a 100-year level of protection under existing conditions, several areas along the shoreline should be raised, strengthened, and improved. Specific adaptation strategies include raising the shoreline in front of the Harbor Bay Club and the Veterans Court seawall to the Bay Farm Lagoon tide gate, raising the Bay Farm Lagoon tide gate and adjacent wing-walls, and raising Doolittle Road.

Shoreline erosion, degradation of coastal protection structures, land subsidence, increasing groundwater levels, and runoff-driven flooding from rainfall were not considered as part of this focus study assessment. The cumulative impacts of rainfall runoff events occurring during periods of extreme tide levels were also not considered in this analysis. However, given the low-lying nature of Bay Farm Island, and that fact that it is constructed primarily of fill over former marshlands, these additional risk factors should be seriously considered and evaluated when developing and implementing adaptation strategies – particularly strategies that focus on solely on providing improved shoreline protection. Although shoreline structures and strategies can prevent or inhibit overtopping and inland inundation of Bay waters, rising groundwater levels and rainfall-driven flooding could result in compounded flood risk for this area. Areas developed with fill will be particularly susceptible to groundwater intrusion and subsidence. An increase in soil saturation, coupled with increased rainfall and runoff, will further exacerbate flooding. Existing inland drainage systems will become less effective with higher groundwater levels and they may become completely ineffective with higher levels of SLR. Though outside the scope of our current study, evaluation of these mechanisms is recommended as a next step.

9. REFERENCES

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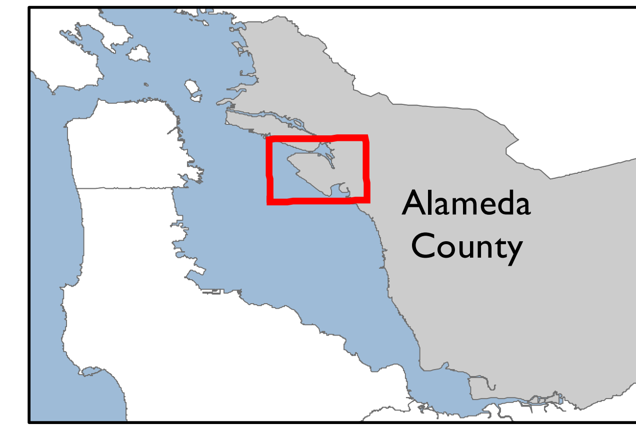
Attachment A – Focus Area Inundation Maps

Alameda County Inundation Mapping

MHHW + 12"
SLR Scenario

Focus Area: Bay Farm Island



Overtopping Potential

Depth in Feet

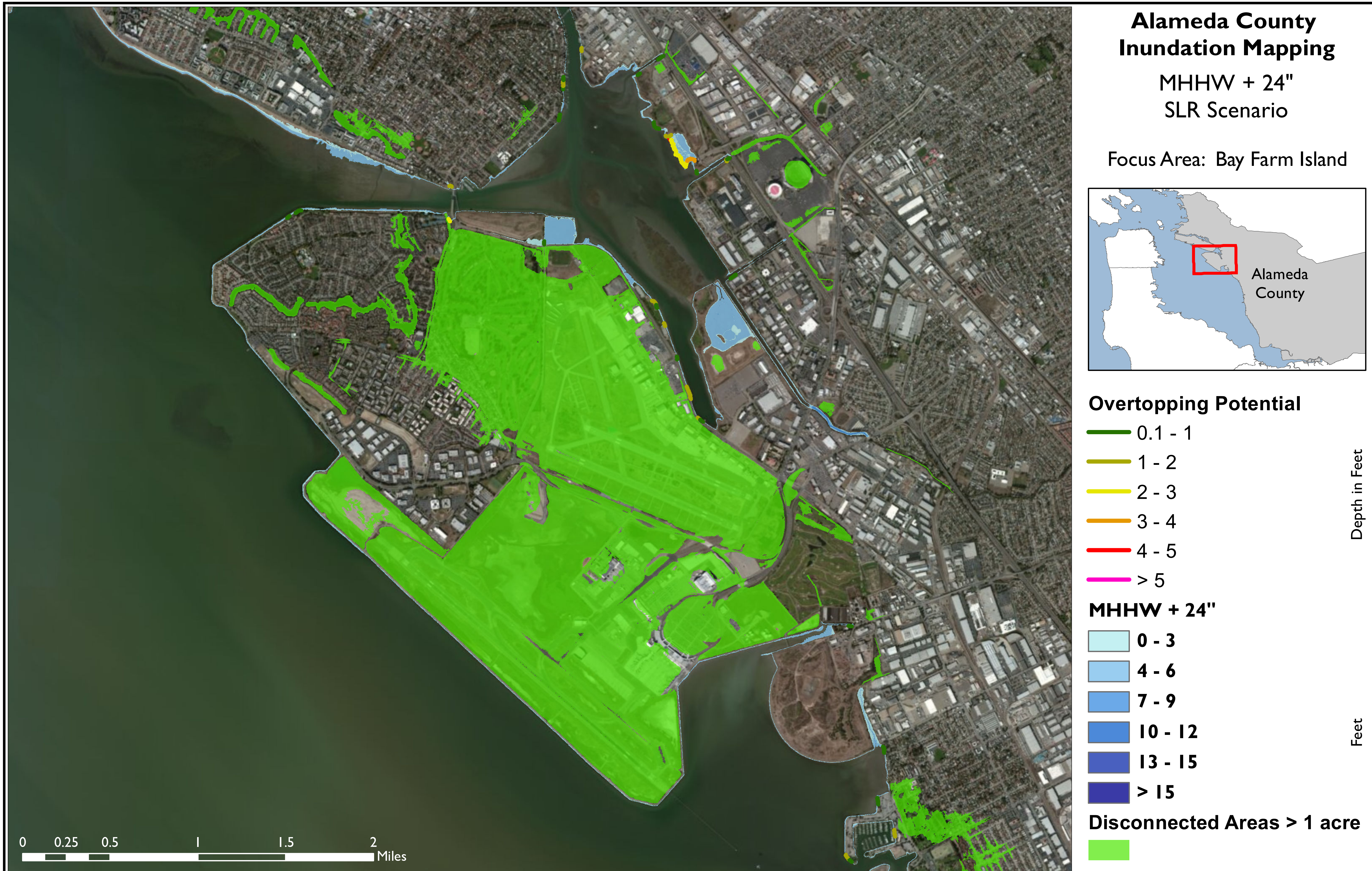
- 0.1 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- > 5

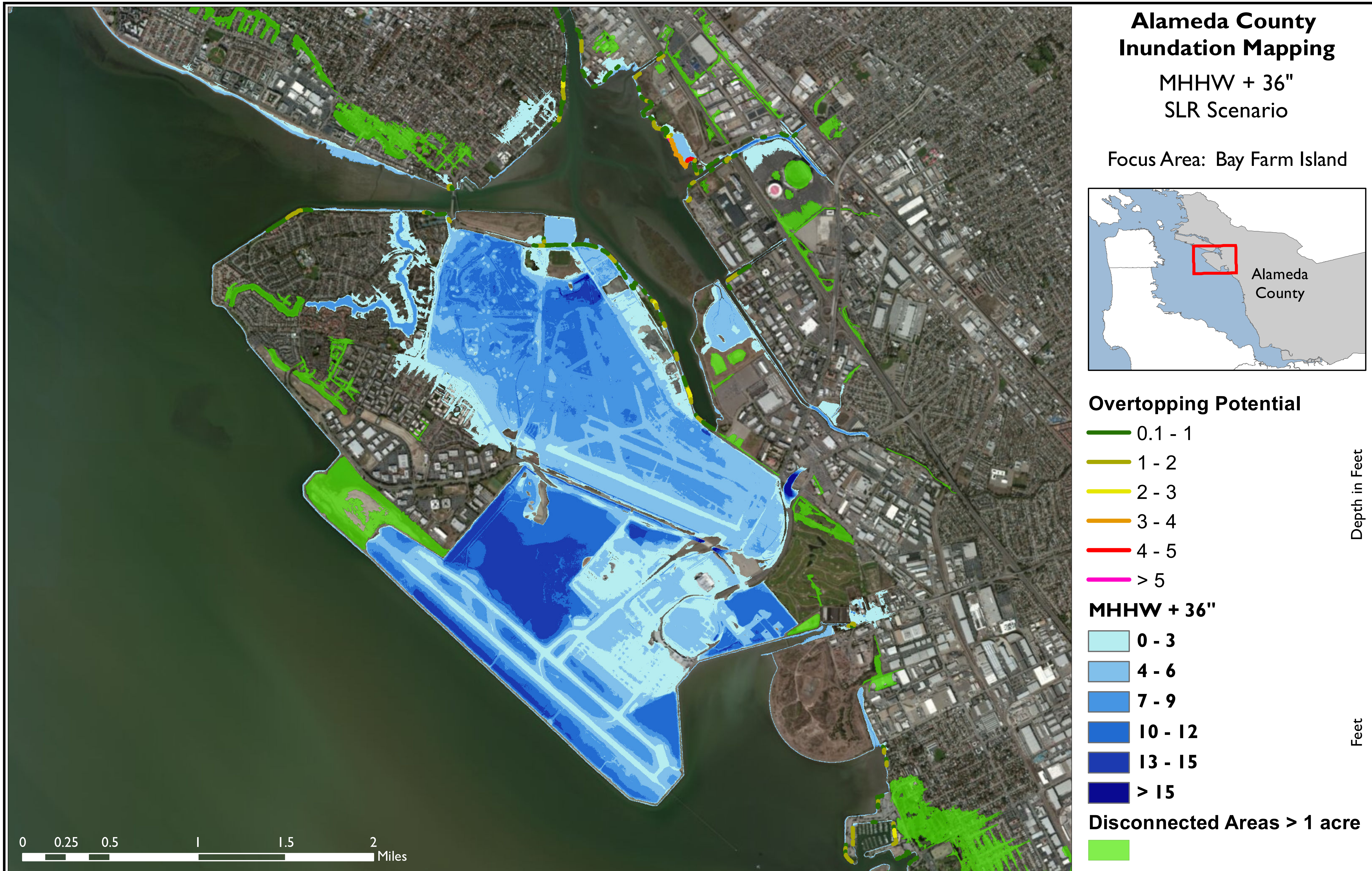
MHHW + 12"

Feet

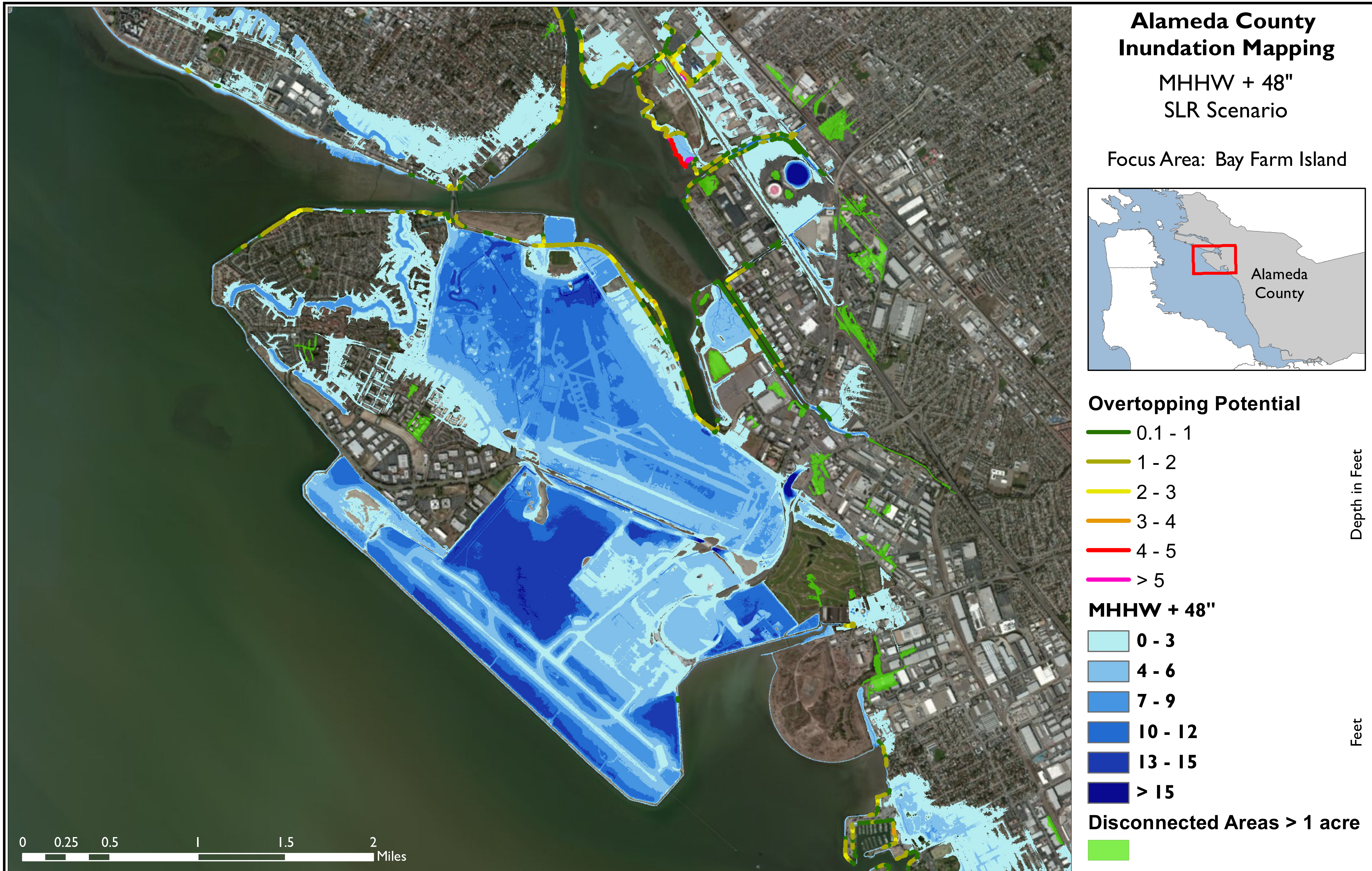
- **0 - 3**
- **4 - 6**
- **7 - 9**
- **10 - 12**
- **13 - 15**
- **> 15**

Disconnected Areas > 1 acre

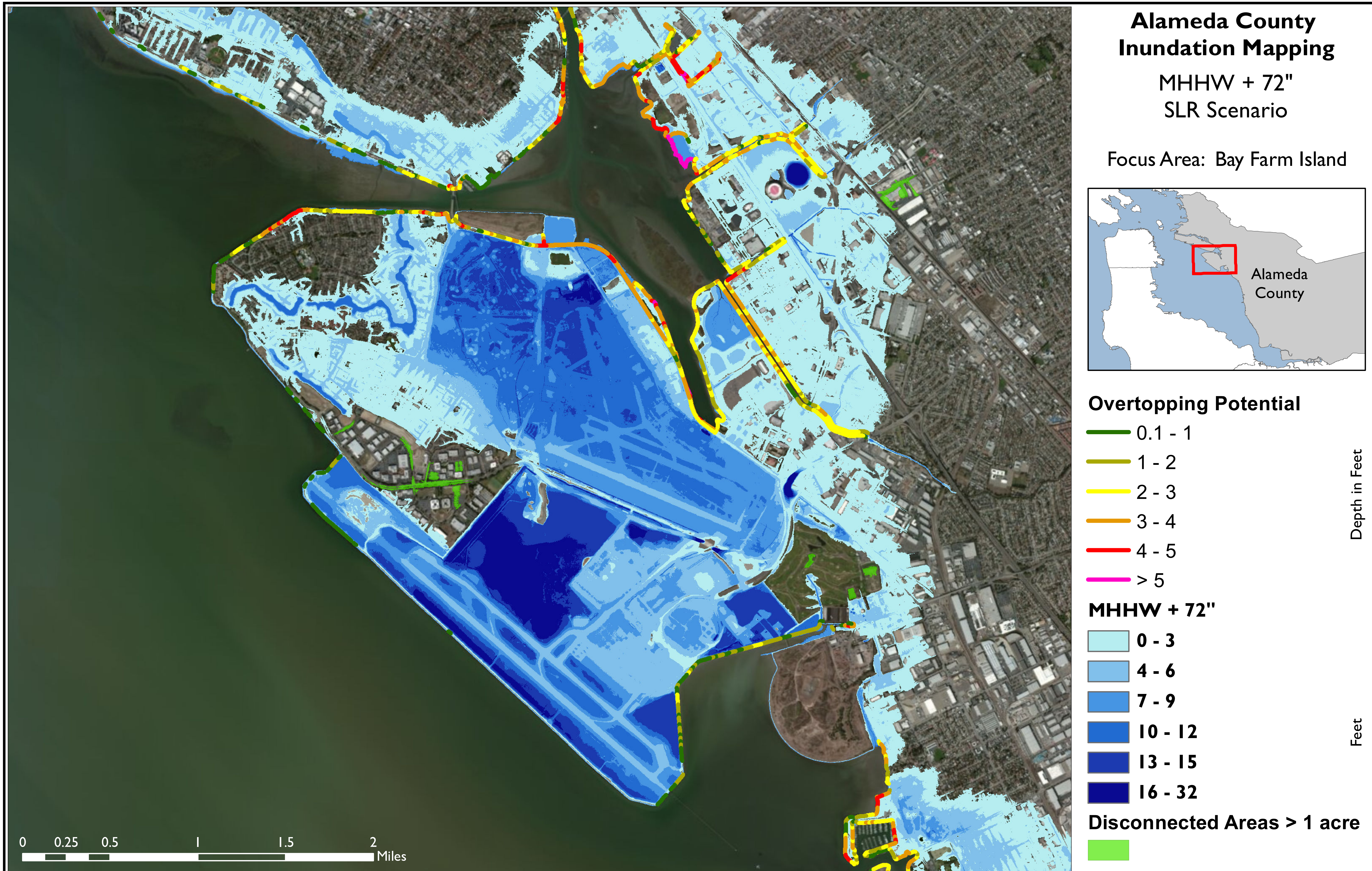

Alameda County
Inundation Mapping
MHHW + 24"
SLR Scenario
Focus Area: Bay Farm Island
Alameda
County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 24"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0 0.25 0.5 1 1.5 2
Miles



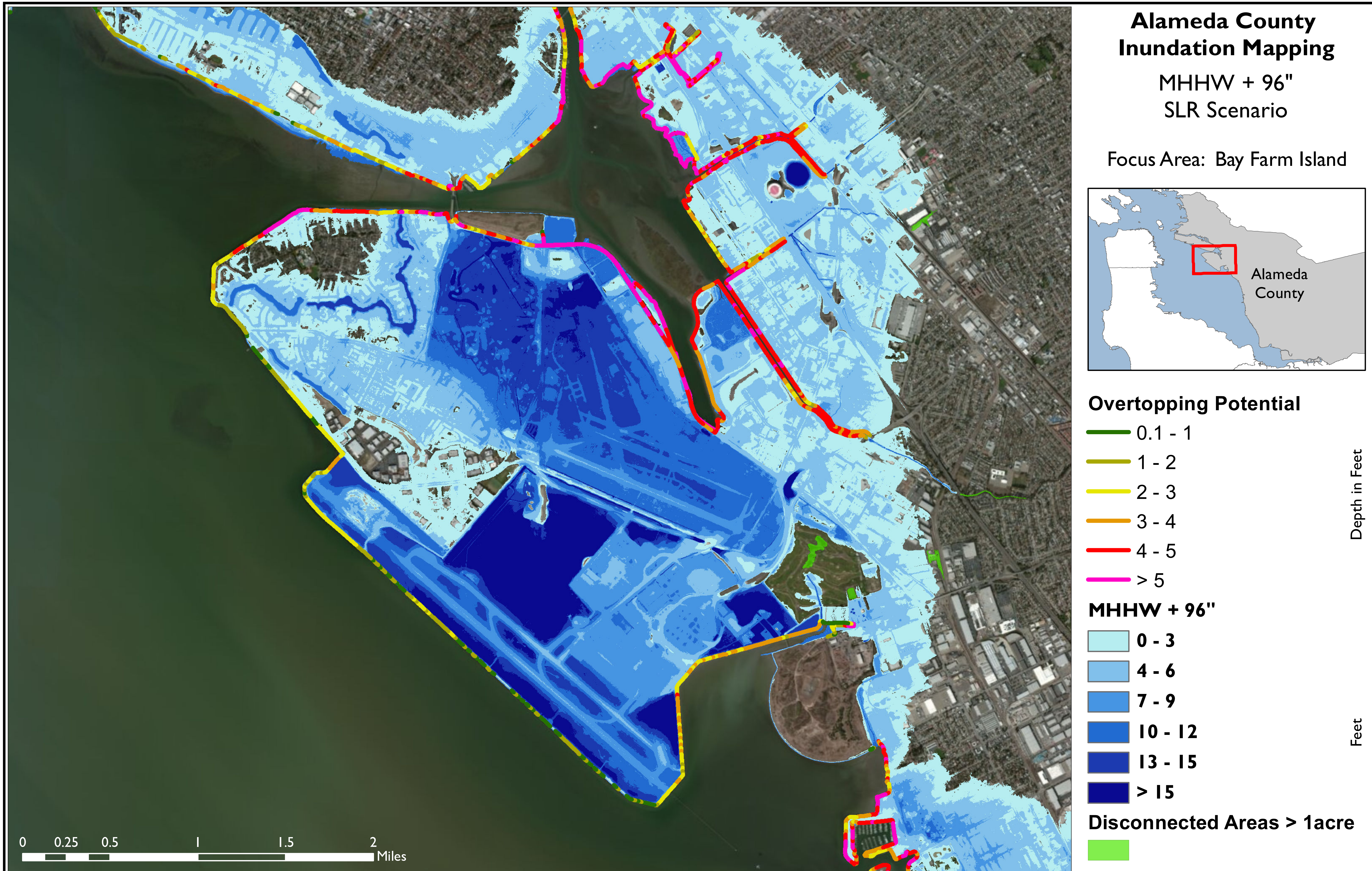
Alameda County
Inundation Mapping
MHHW + 36"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 36"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles



Alameda County
Inundation Mapping
MHHW + 48"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 48"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles



Alameda County
Inundation Mapping
MHHW + 72"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 72"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
16 - 32
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles



Alameda County
Inundation Mapping
MHHW + 96"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 96"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1acre
0
0.25
0.5
1
1.5
2
Miles

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Attachment B – Bay Farm Island Focus Area Site Visit Photos

Attachment B - Site Visit Photos (March 05 and March 07, 2014)

Bay Farm Island Focus Area– Looking East along Harbor Bay Club Shoreline (Site B)

Bay Farm Island Focus Area– Looking East along Harbor Bay Club Shoreline (Site B)

Bay Farm Island Focus Area– Doolittle Drive Shoreline Looking North

Bay Farm Island Focus Area– Doolittle Drive Shoreline Looking North (Site G)