Port of San Francisco Sea Level Rise Inundation Mapping Technical Memorandum

March 2016

60405532

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List of Acronyms

CCMP	California Coastal Mapping Program
CCSF	City and County of San Francisco
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
FIRMs	FEMA Flood Insurance Rate Maps
LIDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
Port	Port of San Francisco
PUC	San Francisco Public Utilities Commission

1 Introduction

The Port of San Francisco (Port) has jurisdiction over the lands adjacent to the San Francisco Bay shoreline between the Hyde Street Pier and India Basin, including the piers and wharves that extend overwater. When the San Francisco Public Utilities Commission (PUC) commissioned detailed sea level rise and storm surge inundation mapping, the Port's piers and wharves were excluded from the analysis and mapping because they had been removed from the bare earth topographic LIDAR. Structures over open water are commonly removed from LIDAR datasets during the bare earth post-processing phase, so this exclusion was expected. The PUC does not own any assets on these structures; therefore incorporating these structures within the inundation mapping was not required at the time the maps were developed. However, the PUC's inundation mapping is currently being used by all City and County of San Francisco (CCSF) departments in support of sea level rise vulnerability and risk assessments, and for compliance with the CCSF's Capital Planning Committee guidance for incorporating sea level rise into capital planning in San Francisco; therefore it is important to include the pier and wharf structures within the inundation mapping so that the structures are not inadvertently assumed to have zero sea level rise risk.

AECOM has extracted elevation data associated with the top of the pier and wharf decks from the raw 2010/2011 LIDAR, and used this data to build the pier and wharf structures into the digital elevation model (DEM). The sea level rise and storm surge inundation maps where then updated to account for the appropriate exposure level of the piers and wharves.

The memorandum provides a brief overview of the mapping process, and provides detail on how the elevation data was extracted from the LIDAR so that it could be incorporated within the DEM. Additional details on the methods is presented in the PUC's Bayside Sea Level Rise Inundation Mapping Technical Memorandum (2014b). The final map products are included in Appendix A, and they are also included in the recent county-wide CCSF Sea Level Rise Action Plan.

2 Sea Level Rise Science

This section provides a brief overview of the best available sea level rise projections for CCSF, and a description of the approach used to select sea level rise scenarios for inundation mapping purposes. A detailed overview of the state of sea level rise science is presented in the PUC's Climate Science Data Inventory Technical Memorandum (2014a), and is not reproduced here.

2.1 Sea Level Rise Projections

The PUC's work and the CCSF Sea Level Rise Action Plan agree with local and state agencies that the National Research Council's 2012 report (NRC 2012) *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* is the best available science on sea level rise for the state and for CCSF.

Table 2-1 presents the NRC sea level rise projections for San Francisco relative to the year 2000. The table presents the local *projections* (mean ± 1 standard deviation). These projections (for example, 6 ± 2.0 inches in 2030) represent the *likely* sea level rise values based on a moderate level of greenhouse gas emissions and extrapolation of continued accelerating land ice melt patterns, plus or minus one standard deviation[1]. The extreme limits of the *ranges* (for example, 2 and 12 inches for 2030) represent *unlikely but possible* levels of sea level rise using both low and very high emissions scenarios and, at the high end, including significant land ice melt that is not anticipated at this time but could occur. The NRC report is also notable for providing regional estimates of *net sea level rise* for the Oregon, Washington, and California coastlines that include the sum of contributions from the local thermal expansion of seawater, wind driven components, land ice melting, and vertical land motion. The chief differentiator among net sea level rise projections along the western coast derives from vertical land motion estimates, which show uplift (reducing net sea level rise) of lands north of Cape Mendocino and subsidence (increasing net sea level rise) of lands south of Cape Mendocino.

Table 2-1: Sea Level Rise Estimates for San Francisco Relative to the Year 2000

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

NRC. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.
*As a simplifying assumption, the 2050 most likely value selected for the inundation mapping effort is 12 inches rather than the 11 inch value noted in the table.

2.2 Sea Level Rise Scenario Selection

Sea level rise is often visualized using inundation maps. Typically, maps represent specific SLR scenarios (e.g., 16 inches of SLR above MHHW) or extreme tide water level (e.g., the 1 percent annual chance tide, also referred as the 100-year stillwater elevation [SWEL], or 100-year extreme tide). However, selecting the most appropriate SLR scenario to map in support of project planning, exposure analyses, or SLR vulnerability and risk assessments is not simple. This approach requires pre-selecting appropriate SLR and extreme tide scenarios that meet all project needs.

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

Eleven inundation maps were created to update the original CCSF maps created for the PUC. These eleven inundation maps illustrate a range of possible scenarios associated with both extreme tide levels and sea level rise. This includes inundation which would occur from 12 inches to 66 inches of sea level rise, and from the 1-year extreme tide event to the 100-year extreme tide event. For ten scenarios, the specified amounts of sea level rise were added directly to the existing MHHW elevations calculated along the shoreline. One additional scenario represents the 100-year extreme tide event under current conditions (no sea level rise).

The scenario selection relied on the extreme water level analysis described in detail in the PUC Bayside Sea Level Rise Mapping Technical Memorandum (2014b). The goal of scenario selection was to identify six scenarios that could represent the current NRC SLR projections, as presented in Section 2.1, and additional scenarios to approximate a range of sea level rise combined with storm surge events.

Each of the following scenarios approximates either (1) permanent inundation scenarios likely to occur before 2100 or (2) temporary flood conditions from specific combinations of SLR and extreme tides. For example, the water elevation associated with 36 inches of SLR is similar to the water elevation associated with a combination of 24 inches of SLR and a 1-year extreme tide (King Tide). Therefore, a single map can be used to visualize either event. Although inundation maps can be used to approximate the temporary flood extent associated with an extreme tide, they illustrate neither the duration of flooding nor the potential mechanism(s) for draining floodwaters once the extreme tide recedes. Figure 2-1 presents a representative cross section of a shoreline that illustrates the distinction between permanent inundation and temporary flooding.

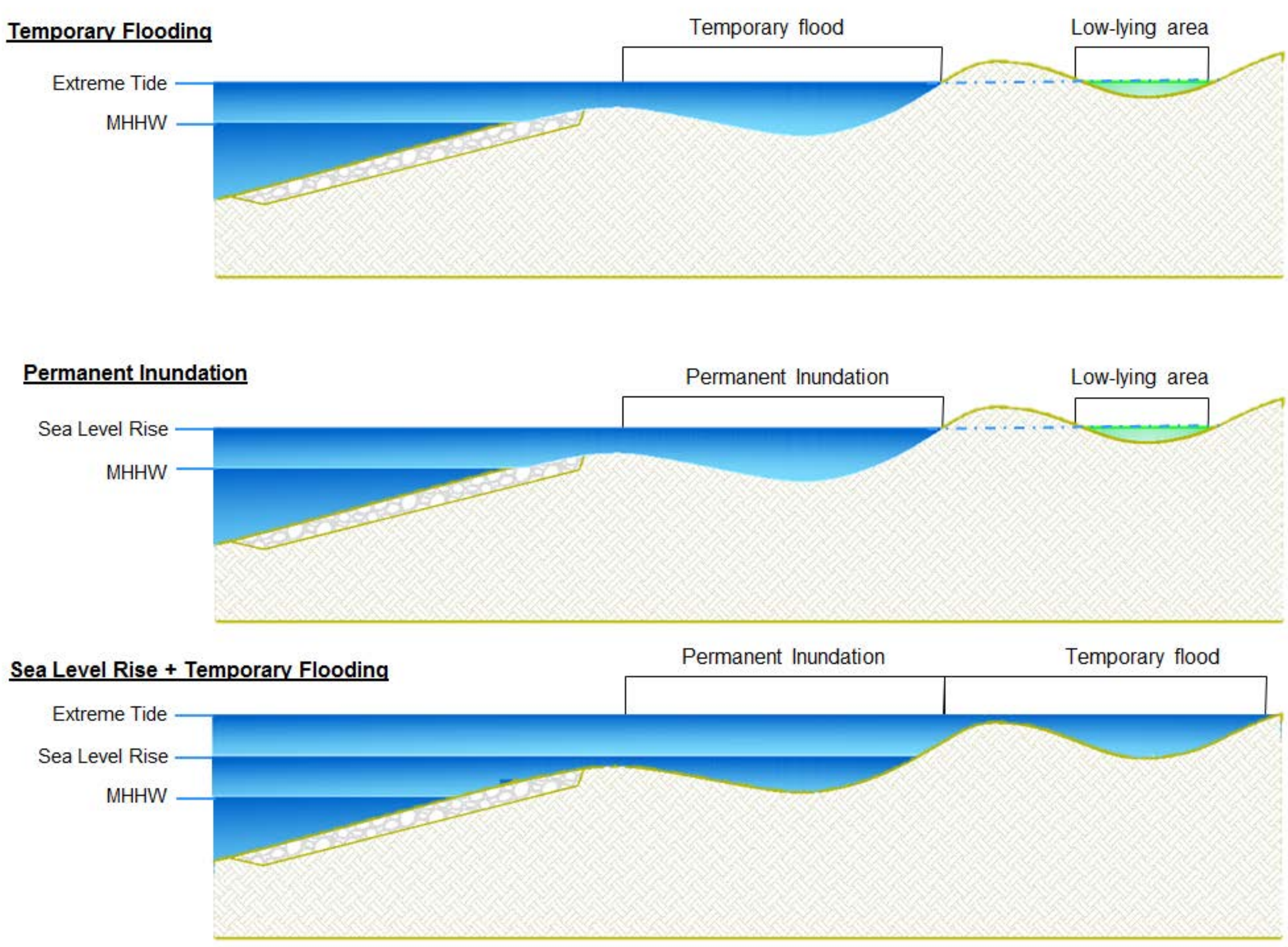

Figure 2-1. Shoreline Cross Section Showing Permanent Inundation and Temporary Flooding

The first six scenarios (12, 24, 36, 48, 52, and 66 inches of SLR above MHHW) relate directly to the NRC SLR estimates, and they capture a broad range of scenarios between the most likely scenario and the high-end of the uncertainty range at both mid- century and at the end of the century.

1. 12-inch sea level rise ≈ 2050 most likely SLR scenario
2. 24-inch sea level rise = 2050 high end of the range; or an existing 5-year extreme tide
3. 36-inch sea level rise = 2100 most likely SLR scenario; or an existing 50-year extreme tide
4. 48-inch sea level rise ≈ 2100 upper 85% confidence interval; or 6 inches of SLR plus a 100-year extreme tide
5. 52-inch sea level rise ≈ existing conditions 500-year extreme tide; or 12-inch SLR plus 100-year extreme tide
6. 66-inch sea level rise = 2100 upper end SLR scenario; or 24-inch SLR plus 100-year extreme tide

In addition to the scenarios listed above, Bay water elevations 77, 84, 96, and 108 inches above MHHW were mapped. These levels are above current predictions for SLR likely to occur before 2100, but they illustrate short-term flooding that could occur in that time frame when extreme tides are coupled with SLR.

7. 77-inches above MHHW ≈ 36-inch SLR plus 100-year extreme tide
8. 84-inches above MHHW ≈ 42-inch SLR plus 100-year extreme tide
9. 96-inches above MHHW ≈ 54-inch SLR plus 100-year extreme tide
10. 108-inches above MHHW ≈ 66-inch SLR plus 100-year extreme tide

The final scenario illustrates the water levels reached by a 100-year extreme tide under current conditions, without sea level rise. The water levels used to map the 100-year extreme tide are consistent with the values the Federal Emergency Management Agency (FEMA) used for the preliminary FEMA Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies released on November 14, 2015 for CCSF.

11. 100-year extreme tide (existing conditions) ≈ 42-inches plus MHHW

The extreme tide/SLR combinations that each inundation map represent are listed on the map pages in Appendix A. The 11 inundation maps represent a total of 52 extreme tide and SLR combinations.

Additional detail on how these combinations were developed can be found in the PUC Bayside Sea Level Rise Mapping Technical Memorandum (2014b).

3 Inundation Mapping

This section presents the overall method and data sources used to develop the 11 inundation maps presented in Appendix A, with a focus on the topographic data sets and the work required to include the Port's pier and wharf structures within the inundation maps.

The inundation maps were created using the methods developed by the NOAA Coastal Services Center for the NOAA Coastal Flooding and Sea Level Rise Viewer (Marcy et al., 2011). Additional detail on the inundation mapping methodology is located in the PUC Bayside Sea Level Rise Mapping Technical Memorandum (2014b). The inundation mapping relied on two primary data sources:

- Modeled water levels from the FEMA San Francisco Bay Area Coastal Study[2]
- Topographic LIDAR from the USGS and NOAA California Coastal Mapping Program (CCMP)[3]

Water level data from the 31-year simulation of hydrodynamics and storm surge completed for FEMA's San Francisco Bay Area Coastal Study was leveraged at 70 points along the San Francisco shoreline. The modeled water level output were analyzed in the previous inundation mapping effort for the PUC. Details on the methods and data sources behind the modeled water levels and calculation of extreme tide elevations are described in the PUC Bayside Sea Level Rise Mapping Technical Memorandum (2014b).

The inundation mapping effort used the best available topographic data for the study area – the USGS and NOAA LIDAR collected as part of the CCMP. For the PUC inundation mapping, the USGS and NOAA topographic LIDAR were merged and converted into a 1-meter digital elevation model (DEM). For this update, modifications were completed on the existing 1-meter DEM to include the ground elevations of the Port's pier and wharves that were missing in the original DEM. This DEM was sufficient for the PUC, but did not capture key structures along the CCSF shoreline. Piers and wharves that were captured in the original DEM were left as-is.

3.1 Leveraged Topographic Data

The USGS managed the LIDAR data collection in south San Francisco Bay. The South Bay LIDAR data were collected in June, October, and November 2010 and provide complete coverage of the bayside areas of the CCSF shoreline, up to the 16-foot (5-meter) elevation contour. NOAA managed additional LIDAR collection for CCMP in northern San Francisco Bay from February to April 2010, as well as additional LIDAR collection in 2011 to provide enhanced coverage of many coastal shoreline areas, including areas along the CCSF shoreline. The USGS and NOAA LIDAR data were delivered in point-cloud format at 1-meter point spacing.

3.1.1 Bare Earth DEM

The USGS and NOAA bare-earth LIDAR was used for the PUC inundation mapping. In the bare-earth LIDAR, all buildings, structures (i.e., bridges), and vegetation have been removed from the original raw LIDAR dataset. All of the piers and wharfs along the CCSF shoreline have also been removed during the bare-earth LIDAR processing. The resultant DEM was of sufficient resolution and detail to capture the shoreline levees and flood protection assets within the interior of CCSF, but because the DEM did not include the piers and wharves, the DEM could not be used to assess inundation over the existing pier and wharf structures.

3.1.2 Raw LIDAR

At the time of this inundation mapping effort, a detailed survey of pier and wharf deck elevations was not available. To update the maps in time to support the CCSF Sea Level Rise Action Plan, the bare top of pier and wharf deck elevations were extracted from the original raw LIDAR dataset (that also includes all buildings and structures). Although this approach requires several steps, it was selected because it allowed elevations of structures to be obtained quickly.

[2] www.r9coastal.org

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

3.2 Pier and Wharf Boundaries

A boundary delineation of the Port's piers and wharves was provided by Farallon Geographics in GIS shapefile format to guide the extent of the DEM modifications. After comparison of the pier and wharf outlines to the extents observed in the original raw LIDAR dataset and aerial imagery (ESRI World Imagery [2014]), the Farallon Geographics GIS shapefile was modified to align the datasets. The extents of the piers and wharves in the boundary delineation were modified using the original raw LIDAR points and the aerial imagery as a guide. Piers that were demolished (or no longer exist in 2016) were removed from the boundary layer. Figure 3-1 shows the boundary of each pier/wharf along the CCSF shoreline.

Figure 3-1: Extent of Port Piers and Wharves

Note: Aerial imagery from 2014 ESRI World Imagery layer

3.3 Elevation Data Extraction

Each pier and wharf structure along the Port's jurisdictional shoreline that was not captured in the original DEM was assigned a single elevation that represents the average elevation of the bare top of deck. The elevations were extracted from the original raw LIDAR points from either the USGS or NOAA dataset. This is similar to the bare earth DEM processing, where all structures are removed down to the bare earth elevation. Since the raw LIDAR points may capture the elevation of any structure (e.g., buildings, vehicles, utility poles), the average elevation for each deck was calculated by either extracting a ground profile using GIS and averaging the elevations, or manually averaging individual points. It was not feasible to create a varying DEM surface based on all of the deck elevations (similar to the creation of the landward bare earth DEM) due to the time consuming processing of removing miscellaneous structures on each pier or wharf deck. Therefore a single representative elevation was assigned to each missing pier or wharf, which is sufficient for inundation mapping. Table 4-1 in Section 4 shows the average elevations assigned to each Port pier/wharf structure.

Figure 3-2 shows an example of the area where the bare top of deck elevations were extracted for Pier 33.

3.4 DEM Development

Once an average top of deck elevation was calculated for each pier and wharf structure, the original CCSF DEM was modified to include these elevations. Both the USGS and NOAA LIDAR datasets were used for the elevation extraction, but in areas of overlap the NOAA dataset was selected for consistency. The pier and wharf boundary GIS layer was used as the footprint for stamping in the corresponding elevations for each pier into the existing DEM. Since the elevation of each pier or wharf deck represents a single average elevation, there were locations at the pier/wharf transition to the landward shoreline where sharp changes in elevations occurred. In locations with significant changes, the landward DEM was adjusted to create a smoother transition.

At many locations where the piers and wharves were removed to create the original bare earth DEM, a false transition between the existing shoreline and the Bay remained. When the piers and wharf footprints were stamped into the DEM, these residual elevations surrounding the footprint were left as-is, since it does not impact the inundation extents over the piers and wharves or over the existing shoreline areas.

Figure 3-3 shows a comparison of the original CCSF DEM with the piers absent, and the modified DEM with the piers reconstructed, for one example location.

Figure 3-2: Example Area of Elevation Extraction at Pier 33

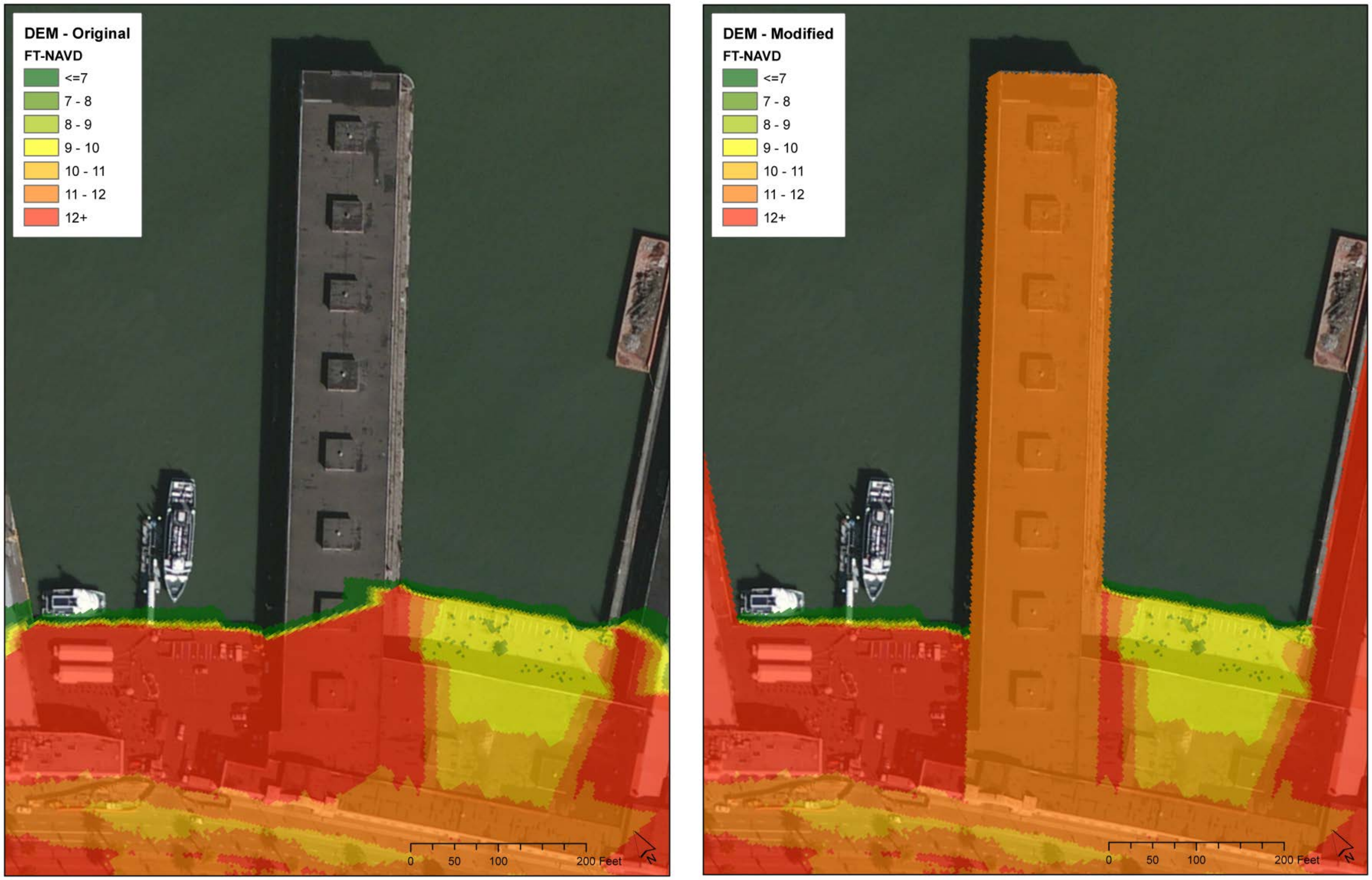

Figure 3-3: Comparison of Existing and Updated CCSF DEM

3.5 Inundation Maps

The detailed inundation maps are presented in Appendix A. The scenarios each map can represent, either permanent inundation (MHHW + sea level rise) or temporary flooding (extreme tide scenarios + sea level rise), are noted on each map. The inundation maps are also available in GIS format. Note that the maps presented in Appendix A focus on the Port shoreline, although the full GIS layers include the entire CCSF shoreline, including the San Francisco International Airport. The inundation map revisions completed for the Port have also been compiled with the PUC dataset, which is considered the master dataset for CCSF sea level rise planning.

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

4 Results

As discussed in Section 3, the 11 inundation maps represent range of sea level rise and extreme tide scenarios. The relevant combinations are listed on each map in Appendix A. Table 4-1 shows the average elevations assigned to each pier/wharf structure missing in the original DEM and the associated daily and extreme tide elevations at each structure: MHHW, 100-year SWEL, and 100-year SWEL + 12-, 24-, 36-, and 66-inches of SLR. Cells in Table 4-1 are shaded in red to show the timing of impact from temporary flooding from a 100-year storm surge event plus the specified amount of SLR. For example, Table 4-1 shows that the Ferry Building footprint would not be impacted by a 100-year storm surge event until 24 inches of SLR or higher.

Table 4-1: Average Bare Earth Top of Deck Elevations for Piers/Wharves

Structure Name	Structure Avg. Elevation FT-NAVD88	MHHW 0-inch SLR	SWEL (Storm Surge) 100-year 0-inch SLR	100-year +12-inch SLR	100-year +24-inch SLR	100-year +36-inch SLR	100-year +66-inch SLR
		FT-NAVD88					
Aquatic Park Pier	12.5	6.1	9.5	10.5	11.5	12.5	15.0
Ferry Building	11.3	6.2	9.7	10.7	11.7	12.7	15.2
Fort Mason 1	16.5	6.1	9.5	10.5	11.5	12.5	15.0
Fort Mason 2	16.5	6.1	9.5	10.5	11.5	12.5	15.0
Fort Mason 3	16.5	6.1	9.5	10.5	11.5	12.5	15.0
Hyde St Pier	11.2	6.1	9.6	10.6	11.6	12.6	15.1
Pier 1	12.0	6.2	9.6	10.6	11.6	12.6	15.1
Pier 1 1/2	10.0	6.2	9.6	10.6	11.6	12.6	15.1
Pier 14	14.5	6.2	9.7	10.7	11.7	12.7	15.2
Pier 15	12.5	6.2	9.6	10.6	11.6	12.6	15.1
Pier 17	12.5	6.2	9.6	10.6	11.6	12.6	15.1
Pier 19	12.5	6.2	9.6	10.6	11.6	12.6	15.1
Pier 22 1/2	10.5	6.3	9.7	10.7	11.7	12.7	15.2
Pier 23	12.3	6.2	9.6	10.6	11.6	12.6	15.1
Pier 24 Annex	12.5	6.3	9.7	10.7	11.7	12.7	15.2
Pier 26	12.5	6.3	9.7	10.7	11.7	12.7	15.2
Pier 27	13.2	6.2	9.6	10.6	11.6	12.6	15.1
Pier 28	12.2	6.3	9.7	10.7	11.7	12.7	15.2
Pier 29	13.0	6.2	9.6	10.6	11.6	12.6	15.1
Pier 3	12.0	6.2	9.6	10.6	11.6	12.6	15.1
Pier 30	12.4	6.3	9.7	10.7	11.7	12.7	15.2
Pier 31	12.0	6.2	9.6	10.6	11.6	12.6	15.1
Pier 32	12.4	6.3	9.7	10.7	11.7	12.7	15.2
Pier 33	12.5	6.2	9.6	10.6	11.6	12.6	15.1
Pier 35	12.5	6.1	9.6	10.6	11.6	12.6	15.1
Pier 38	12.5	6.3	9.7	10.7	11.7	12.7	15.2
Pier 39	10.5	6.1	9.5	10.5	11.5	12.5	15.0
Pier 40	12.5	6.3	9.7	10.7	11.7	12.7	15.2
Pier 41	12.4	6.1	9.6	10.6	11.6	12.6	15.1
Pier 41 1/2	12.0	6.1	9.6	10.6	11.6	12.6	15.1
Pier 43	10.5	6.1	9.6	10.6	11.6	12.6	15.1
Pier 43 1/2	11.0	6.1	9.6	10.6	11.6	12.6	15.1
Pier 45	12.0	6.1	9.6	10.6	11.6	12.6	15.1
Pier 47	10.5	6.1	9.6	10.6	11.6	12.6	15.1
Pier 48	11.9	6.3	9.7	10.7	11.7	12.7	15.2

Table 4-1: Average Bare Earth Top of Deck Elevations for Piers/Wharves

Structure Name	Structure Avg. Elevation FT-NAVD88	MHHW 0-inch SLR	SWEL (Storm Surge) 100-year 0-inch SLR	100-year +12-inch SLR	100-year +24-inch SLR	100-year +36-inch SLR	100-year +66-inch SLR
		FT-NAVD88					
Pier 50	12.0	6.3	9.7	10.7	11.7	12.7	15.2
Pier 52	10.5	6.4	9.8	10.8	11.8	12.8	15.3
Pier 54	12.2	6.4	9.8	10.8	11.8	12.8	15.3
Pier 7	11.3	6.2	9.6	10.6	11.6	12.6	15.1
Pier 7 1/2	10.5	6.2	9.6	10.6	11.6	12.6	15.1
Pier 70	13.0	6.4	9.8	10.8	11.8	12.8	15.3
Pier 9	12.5	6.2	9.6	10.6	11.6	12.6	15.1
Wharf 3 / 4	11.0	6.4	9.8	10.8	11.8	12.8	15.3

Note: Several piers and wharves were not modified in this update because the bare earth top of deck elevations were sufficiently captured in the original DEM. This includes Piers 35 ½, 31 ½, 29 ½, 19 ½, 17 ½, 9 ½, 5, 26 ½, 54 ½, 68, 80, 90, 92, 94, and 96. The elevations for these piers are not shown in Table 4-1.

Looking at the range of maps and scenarios shown in Appendix A, significant permanent inundation appears along the Embarcadero shoreline starting at 48 inches of SLR above MHHW. This inundation extent is similar to the temporary flooding that could occur with 100-year storm surge condition with 6 inches of SLR. While the top of other pier decks may not be directly inundated under this scenario, sidewalks, streets, and open spaces will be inundated; therefore access to the pier and wharf facilities will be impacted. Note that this water level does not include waves, which will cause temporary inundation directly along the shoreline earlier due to wave overtopping. Some sections of the Embarcadero currently experience minor inundation due to wave overtopping under existing conditions when Bay tide levels are high. Several other piers to the south of the Embarcadero (including Pier 68 near the dry docks) and piers adjacent to Islais Creek (including Piers 90, 92, 94, and 96) also experience inundation during this scenario.

With 52 inches of SLR above MHHW, additional piers become inundated including Piers 7 ½, 22 ½ , 52, 54 ½, and 80. This corresponds to a 100-year storm surge condition with 12 inches of SLR.

Piers 47, 43 ½, 43, 39, 23, 7, 70, the Hyde St. pier, Wharf ¾, and the Ferry Terminal area are inundated with 66 inches of SLR above MHHW, or a 100-year storm surge condition with 24 inches of SLR.

At a water level of 77 inches above MHHW (100-year storm surge + 36 inches of SLR), almost all piers and wharves are impacted by flooding.

It is important to note that the elevations of the piers and wharves updated in the DEM represent the top of deck elevation, and the lowest horizontal members of each structure would be inundated at a much earlier scenario than shown in the maps. Wave impacts and wave overtopping were not evaluated as part of this analysis, and waves could cause additional damage to structures prior to impacts from daily inundation from permanent sea level rise.

5 Mapping Assumptions and Caveats

The inundation maps are intended as a screening-level tool to assess exposure to future SLR and extreme tide/storm surge-induced coastal flooding. These maps represent a "do nothing" future scenario, and although they rely on the best available and current information and data sources, they are still associated with a series of assumptions and caveats as detailed below.

- The inundation maps rely on the top of the pier and wharf deck elevations, and these structures may become vulnerable at earlier scenarios, such as when the lowest horizontal members become regularly exposed to inundation.
- The inundation scenarios associated with an increase in future MHHW (SLR above MHHW) represent areas that could be inundated permanently on a regular basis by tidal action. The inundation scenarios associated with extreme tide levels and storm surge represent periodic or temporary inundation associated with a coastal flooding. The inundation maps for extreme tide scenarios do not consider the duration of flooding or the potential mechanism for draining the floodwaters from the inundated land once the extreme high tide levels recede.
- The bathymetry of San Francisco Bay and the topography of the landward areas, including levees and other flood and shore protection features, are assumed to remain constant. No potential physical shoreline changes are included in the analysis and mapping. The accumulation of organic matter in wetlands, potential sediment deposition and/or resuspension, and subsidence that could alter San Francisco Bay hydrodynamics and/or bathymetry are not captured within the SLR scenarios.
- The maps do not account for future construction or levee upgrades. The mapping methods also do not consider the existing condition or age of the shore protection assets. No degradation or levee failure modes have been analyzed as part of the inundation mapping effort.
- The maps do not account for flooding from potential increases in the groundwater table as sea levels rise.
- The maps do not account for water flow through water control structures such as culverts or tide gates.
- The levee heights and the heights of roadways and/or other topographic features that may affect floodwater conveyance are derived from the USGS and NOAA 2010/2011 LIDAR data. Although this data set represents the best available topographic data, the data have not been extensively ground-truthed, and levee crests may be overrepresented or underrepresented by the LIDAR data. It is possible that features narrower than the 1-m horizontal map scale may not be fully represented.
- The inundation depth and extent shown on the MHHW maps are associated with the typical high tide to approximate the maximum extent of future daily tidal inundation. This level of inundation can also be referred to as "permanent inundation" because it represents the area that would be inundated regularly. Tides in San Francisco Bay exhibit two highs and two lows in any given day, and the daily high tide on any given day may be higher or lower than the MHHW tidal elevation.
- The depth and extent of inundation for an extreme coastal storm event (i.e., including local wind and wave effects) was not included in this study. These processes could have a significant effect on the ultimate depth of inundation associated with a large coastal wind/wave event, especially near the shoreline.
- The inundation maps do not account for localized inundation associated with any freshwater inputs, such as rainfall-runoff events, or the potential for riverine overbank flooding in the local tributaries associated with large rainfall events. Inundation associated with changing rainfall patterns, frequency, or intensity as a result of climate change is also not included in this analysis.
- The science of climate change is constantly evolving, and SLR projections have a wide range of values.

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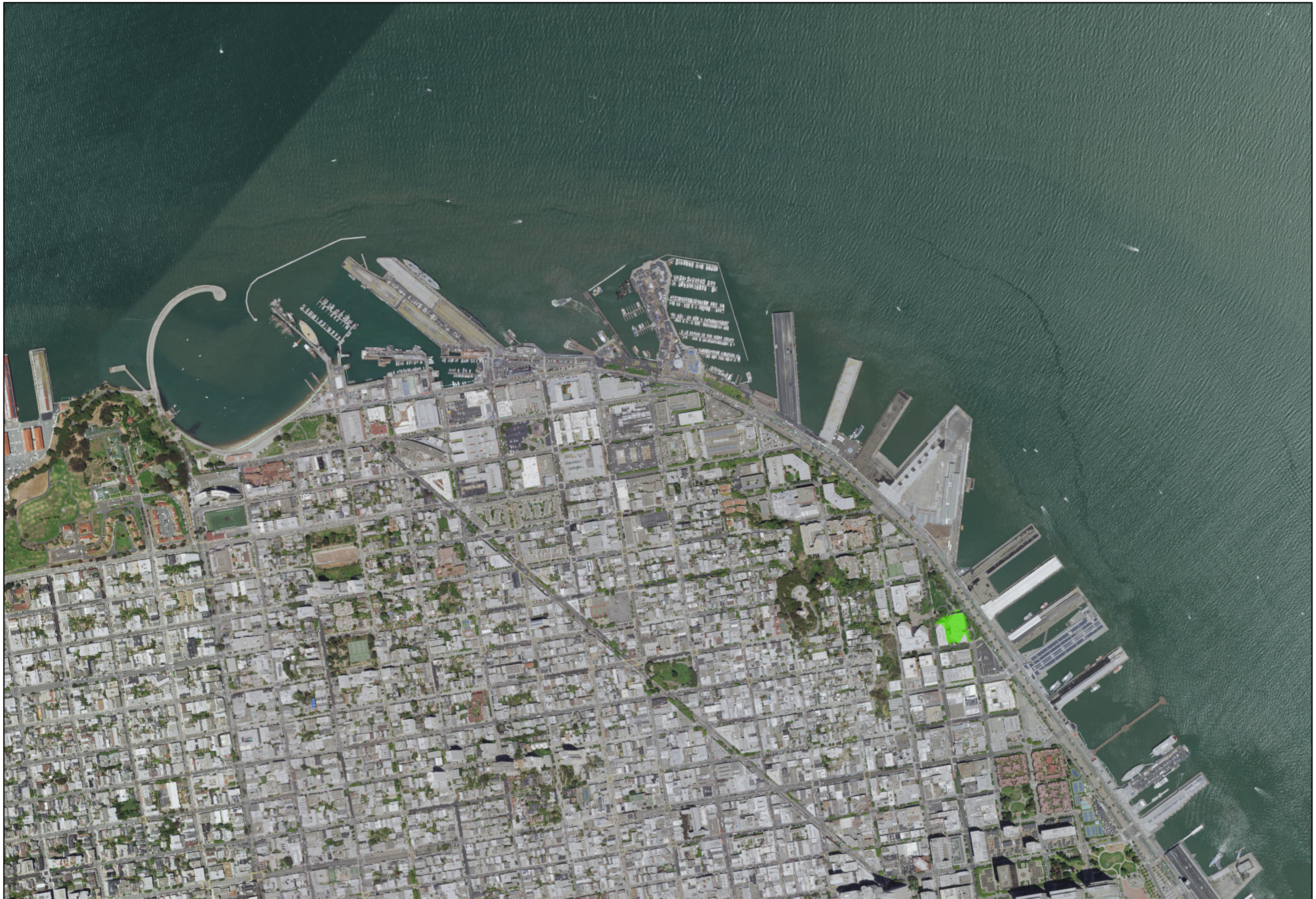
Appendix A.
Port of San Francisco Sea Level Rise Inundation Maps



PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 12" SEA LEVEL RISE

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

0” SLR + 1-YEAR STORM SURGE

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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0" SLR + 1-YEAR STORM SURGE

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12+
Disconnected Areas > 1 Acre

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0 0.1 0.2 0.3 Miles

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PORT OF SAN FRANCISCO

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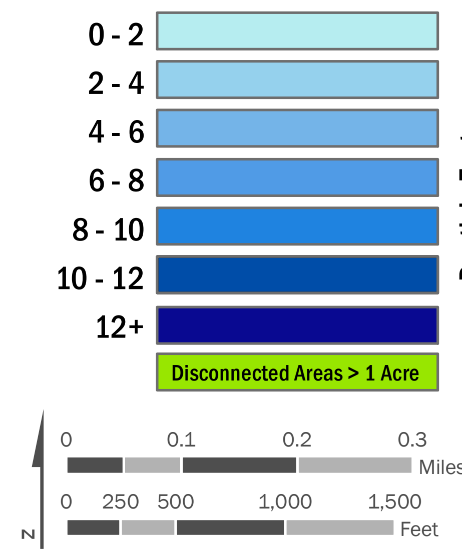
0" SLR + 1-YEAR STORM SURGE



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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 24" SEA LEVEL RISE

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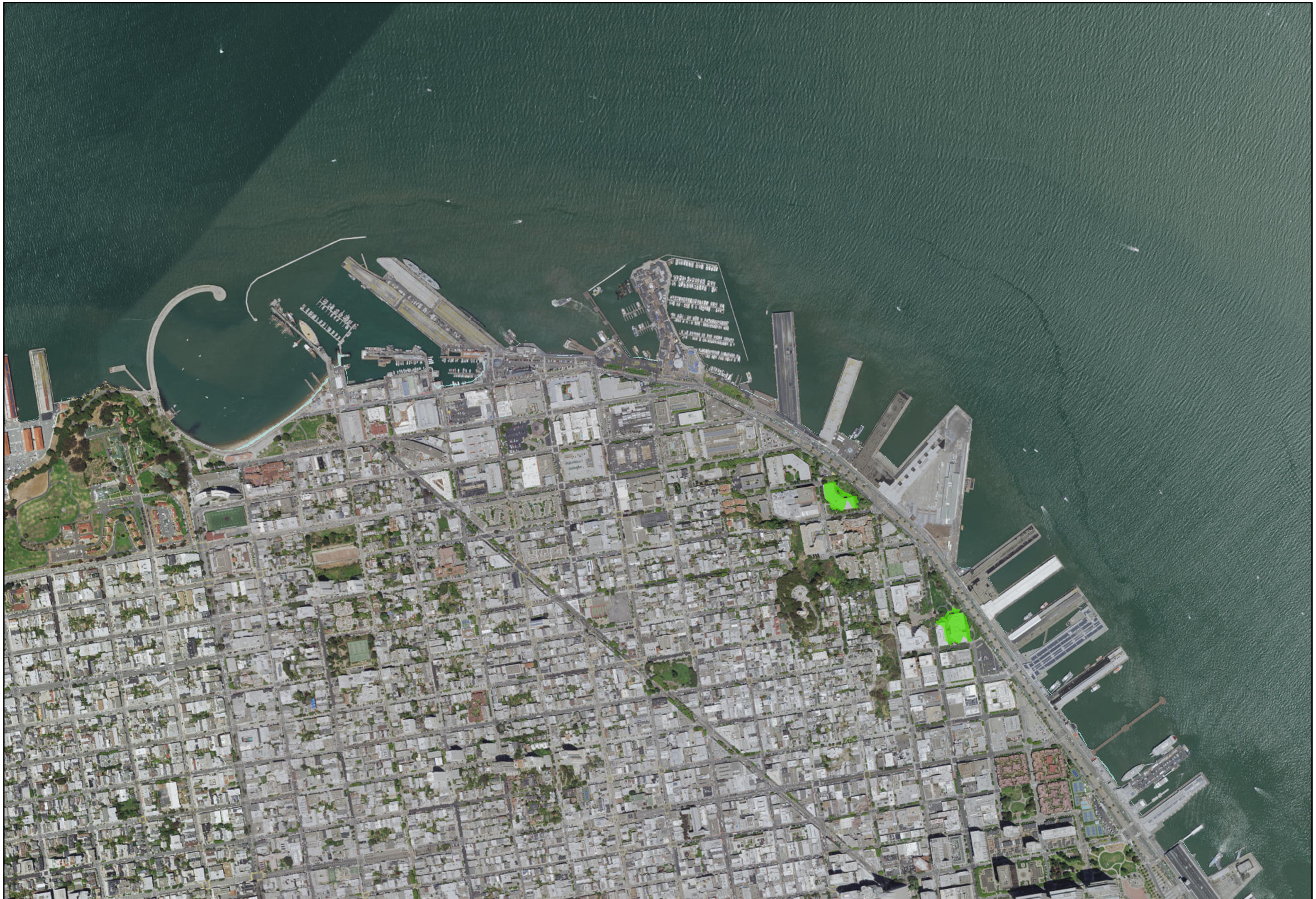
12” SLR + 1-YEAR STORM SURGE
6” SLR + 2-YEAR STORM SURGE
0” SLR + 10-YEAR STORM SURGE



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

0 0.1 0.2 0.3 Miles
0 250 500 1,000 1,500 Feet
N

PORT OF SAN FRANCISCO

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UTM Zone 10N; North American Datum 1983

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 36" SEA LEVEL RISE

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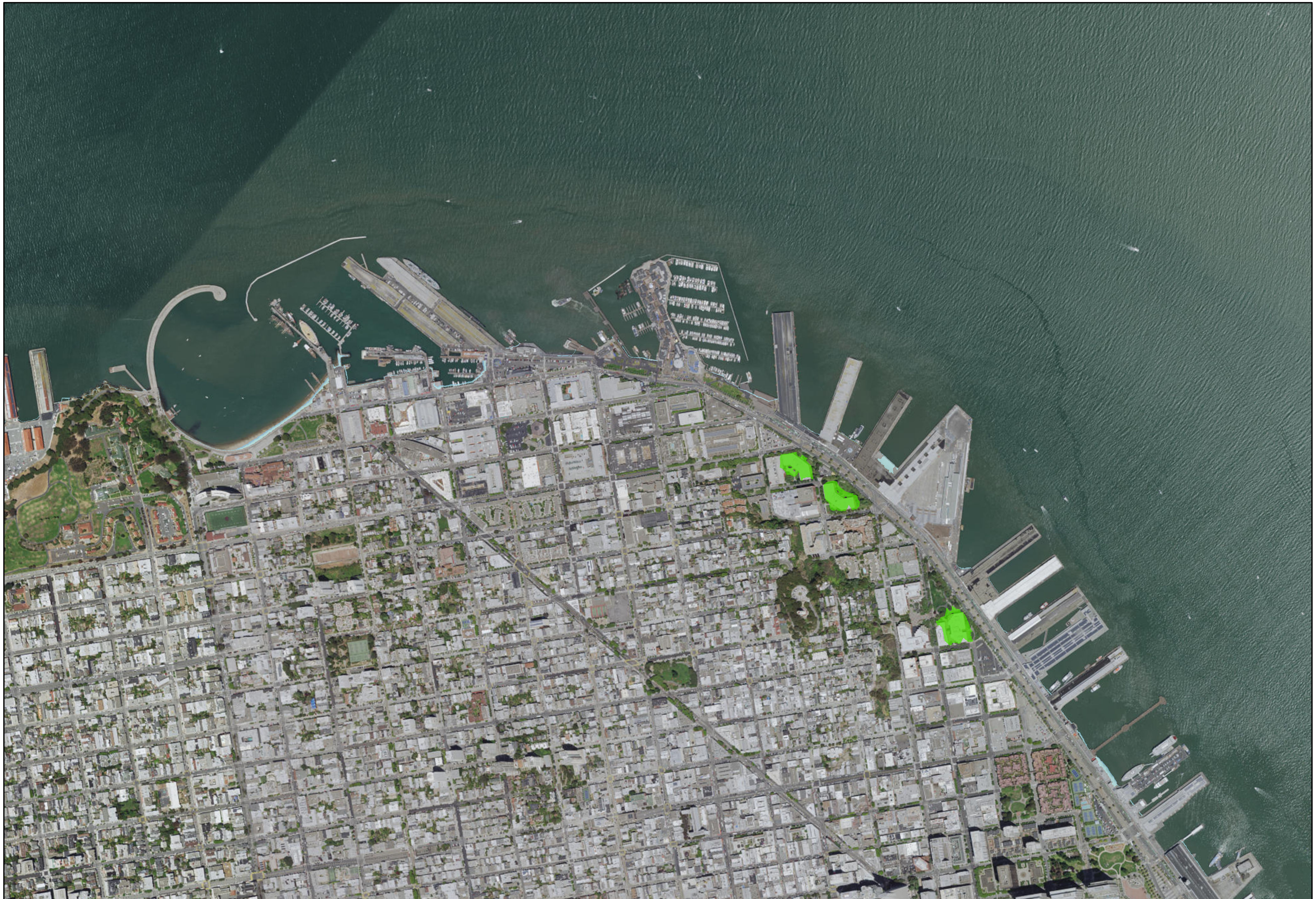
24" SLR + 1-YEAR STORM SURGE
18" SLR + 2-YEAR STORM SURGE
12" SLR + 5-YEAR STORM SURGE
6" SLR + 25-YEAR STORM SURGE
0" SLR + 50-YEAR STORM SURGE



Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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24" SLR + 1-YEAR STORM SURGE
18" SLR + 2-YEAR STORM SURGE
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0" SLR + 50-YEAR STORM SURGE

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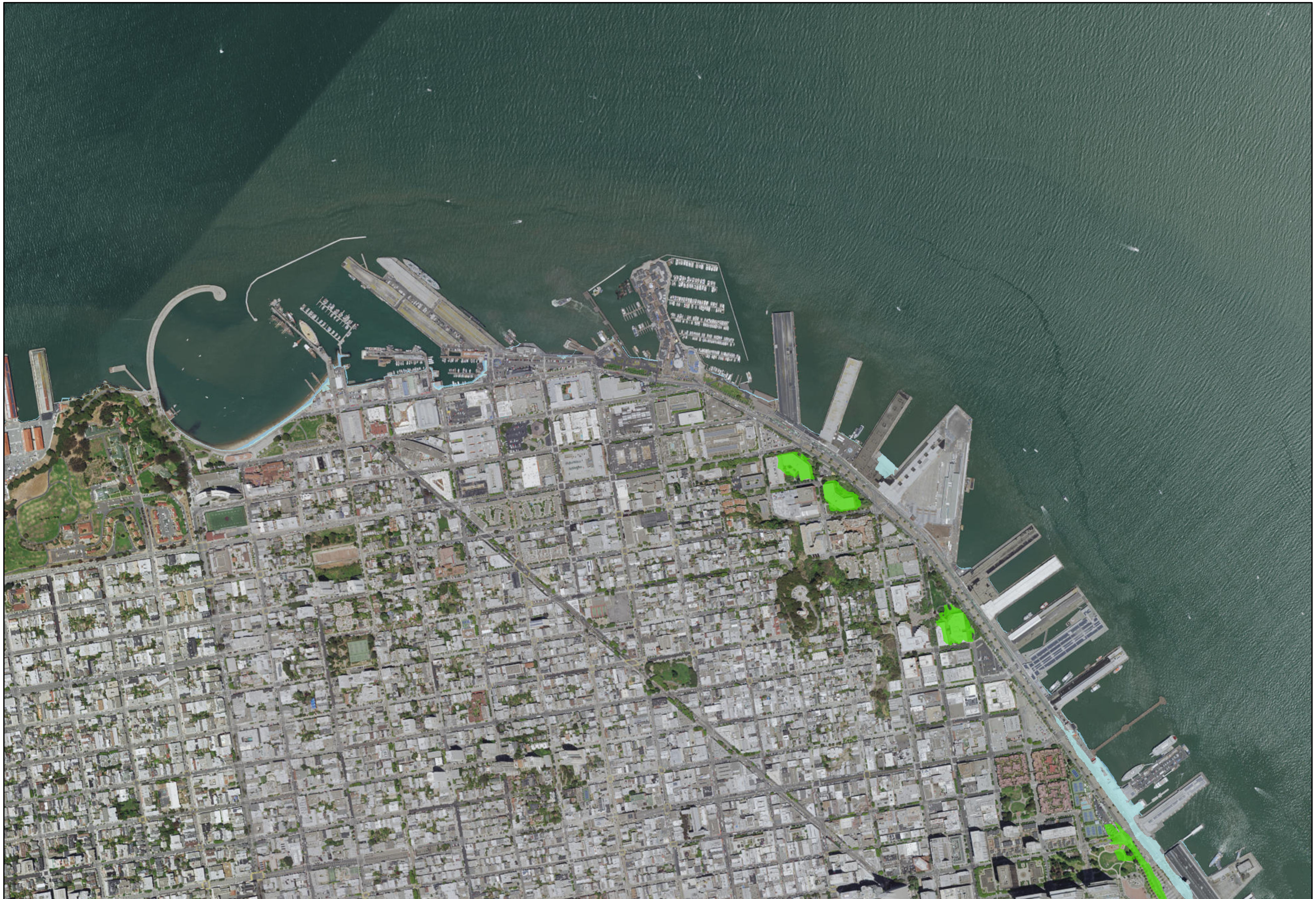

PORT OF SAN FRANCISCO
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MHHW + 48" SEA LEVEL RISE

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

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PORT OF SAN FRANCISCO

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36” SLR + 1-YEAR STORM SURGE
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12” SLR + 50-YEAR STORM SURGE
6” SLR + 100-YEAR STORM SURGE

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4 - 6
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12+

Disconnected Areas > 1 Acre

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0 0.1 0.2 0.3 Miles

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10 - 12
12+
Disconnected Areas > 1 Acre

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 48" SEA LEVEL RISE

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

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

Depth in Feet

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

Disconnected Areas > 1 Acre

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

N

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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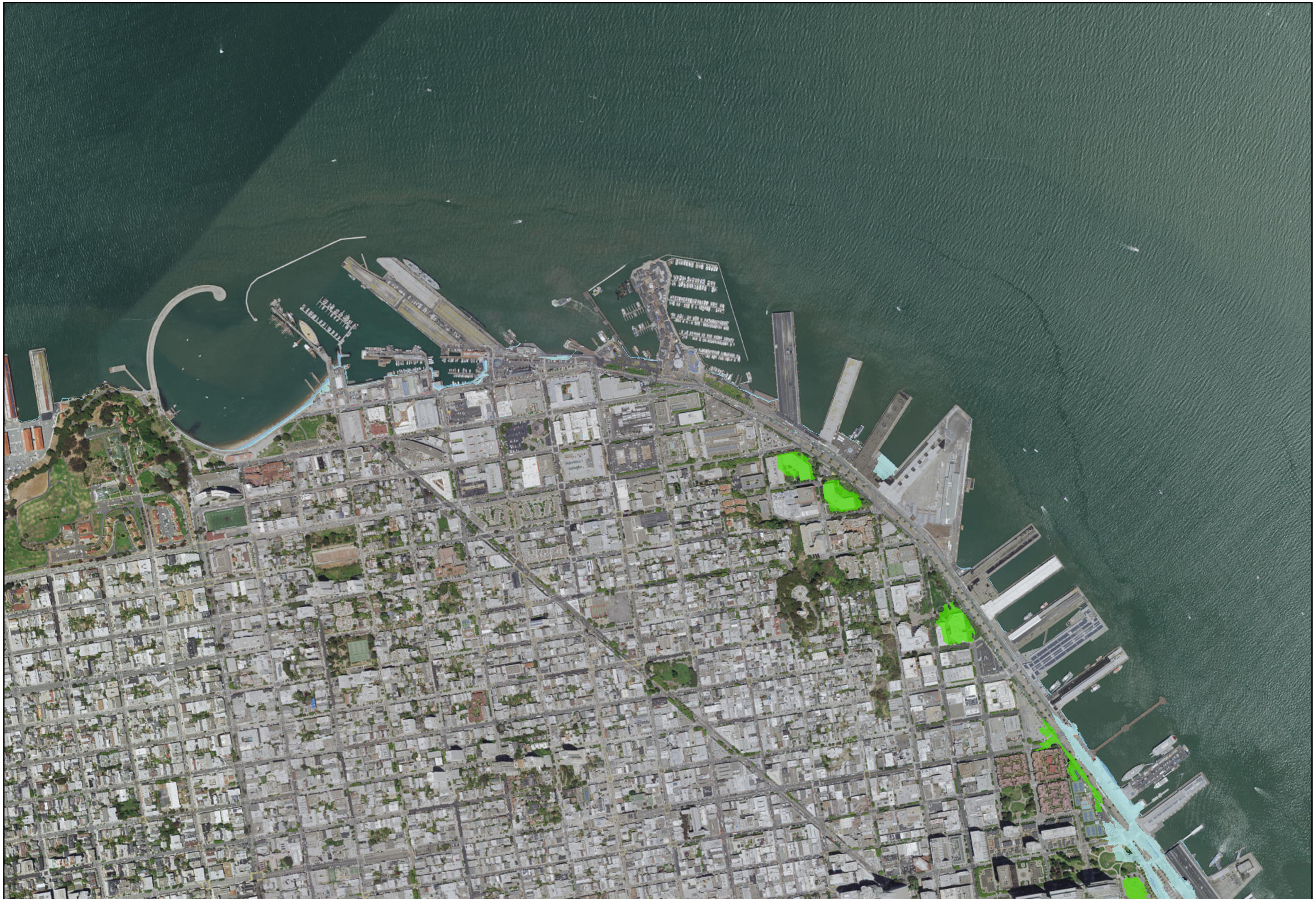


PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 52" SEA LEVEL RISE

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

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

Depth in Feet

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

Disconnected Areas > 1 Acre

N

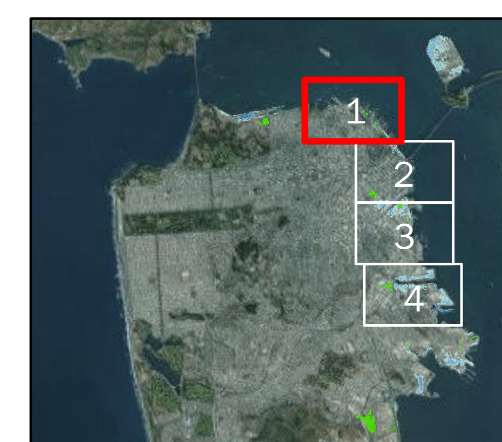
0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016



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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 52" SEA LEVEL RISE

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

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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

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Disconnected Areas > 1 Acre

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

Depth in Feet

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

N
0 0.1 0.2 0.3 Miles
0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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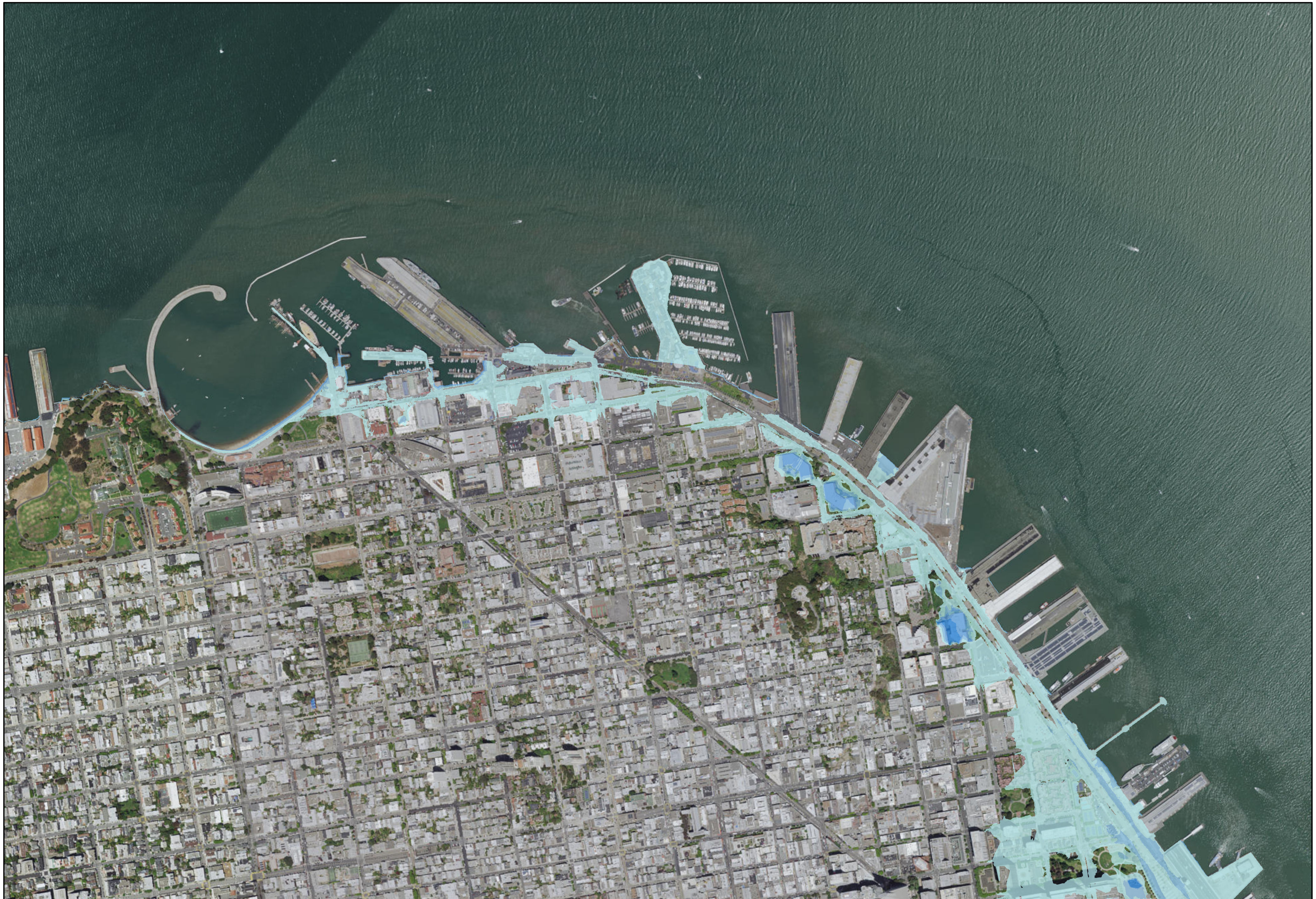
PORT OF SAN FRANCISCO

Inundation Mapping

MHHW + 66" SEA LEVEL RISE

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

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



Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 66" SEA LEVEL RISE

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

54" SLR + 1-YEAR STORM SURGE
48" SLR + 2-YEAR STORM SURGE
42" SLR + 5-YEAR STORM SURGE
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Depth in Feet

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Disconnected Areas > 1 Acre

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

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PORT OF SAN FRANCISCO

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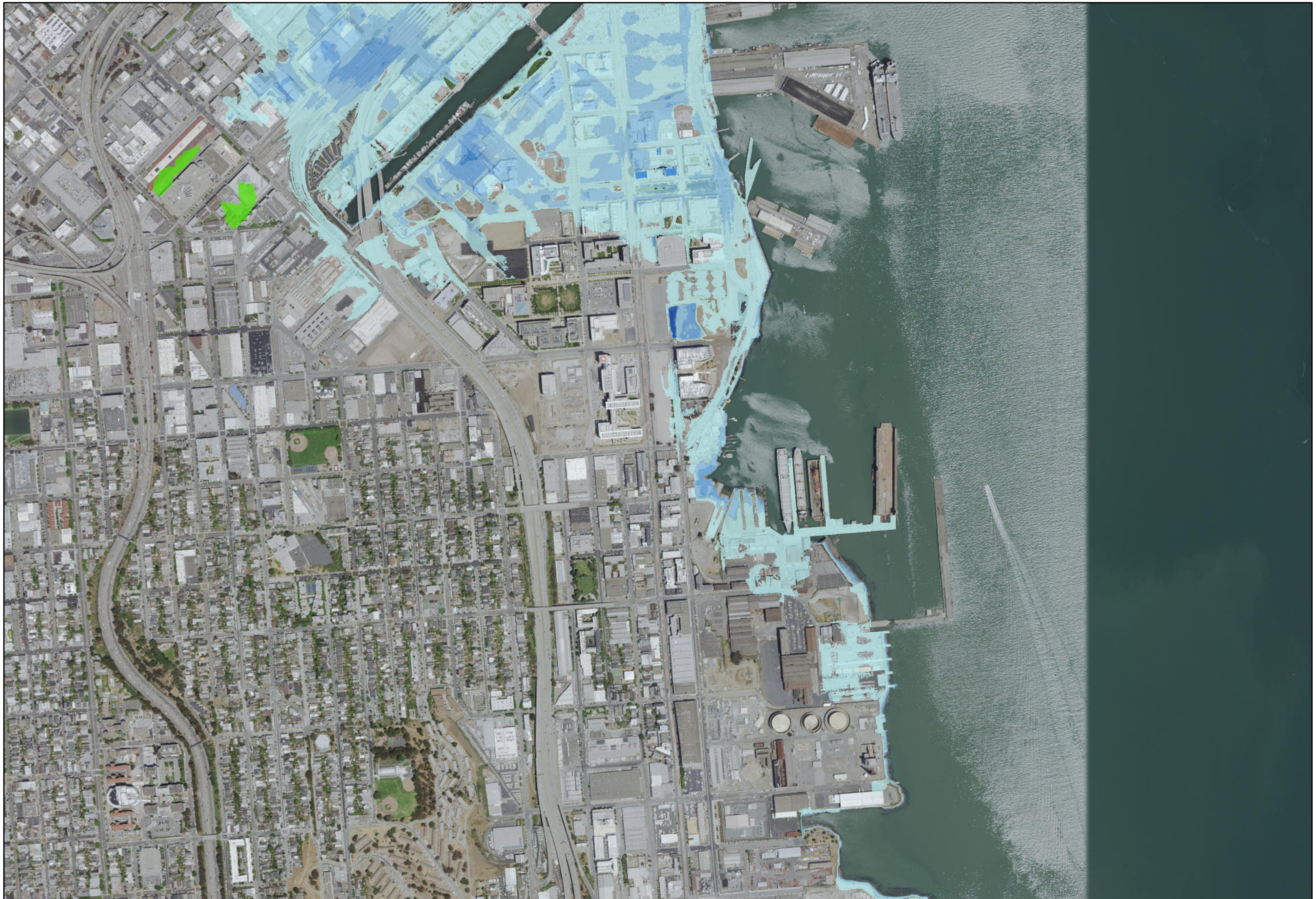

PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 66" SEA LEVEL RISE

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54" SLR + 1-YEAR STORM SURGE
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PORT OF SAN FRANCISCO

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 77" WATER LEVEL

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

Depth in Feet

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

Disconnected Areas > 1 Acre

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

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66” SLR + 1-YEAR STORM SURGE
60” SLR + 2-YEAR STORM SURGE
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36”SLR + 100-YEAR STORM SURGE

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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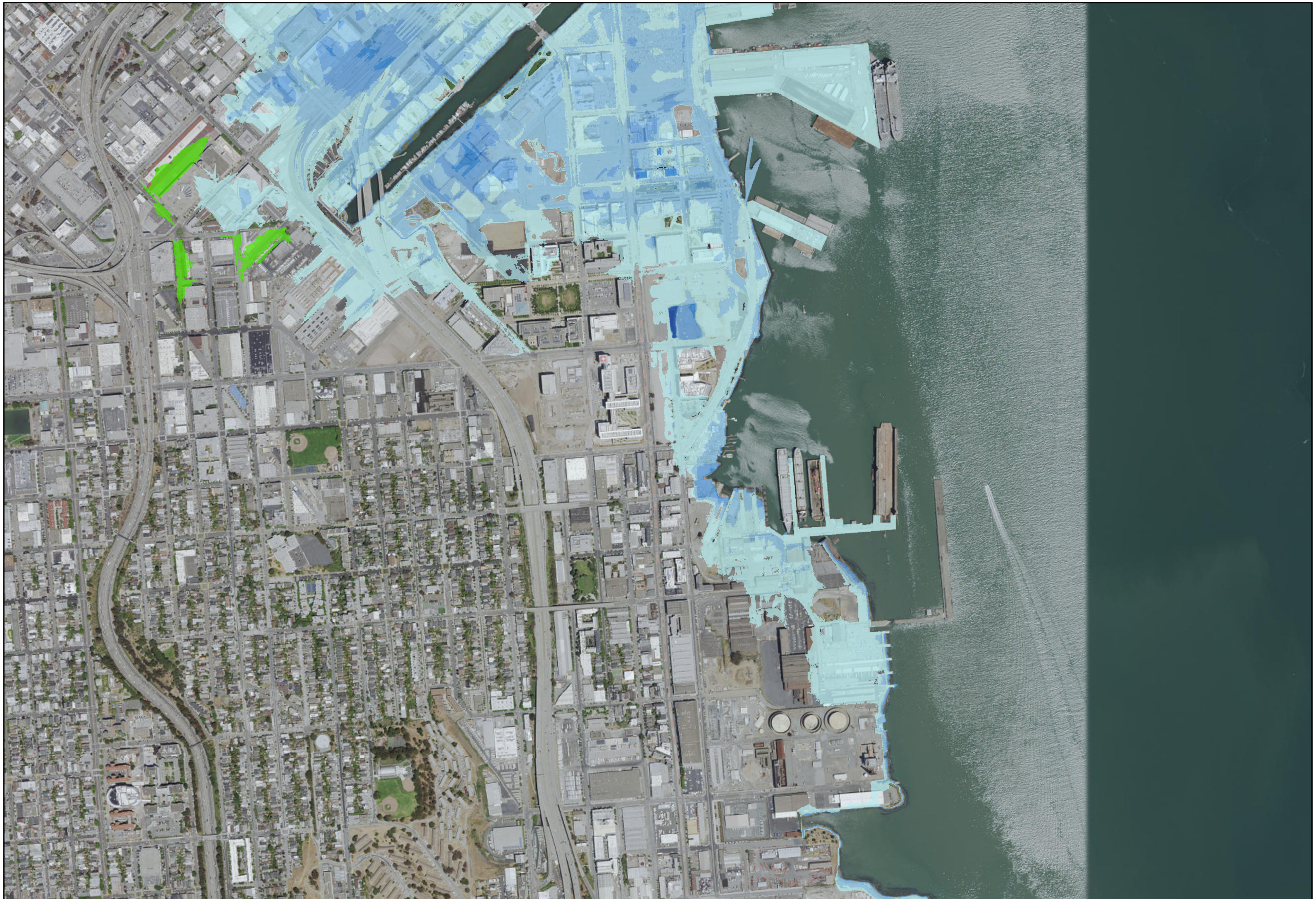

PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 77" WATER LEVEL

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66" SLR + 1-YEAR STORM SURGE
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PORT OF SAN FRANCISCO
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MHHW + 77" WATER LEVEL

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66" SLR + 1-YEAR STORM SURGE
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36"SLR + 100-YEAR STORM SURGE

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Disconnected Areas > 1 Acre

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UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 84" WATER LEVEL

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

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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MHHW + 84" WATER LEVEL

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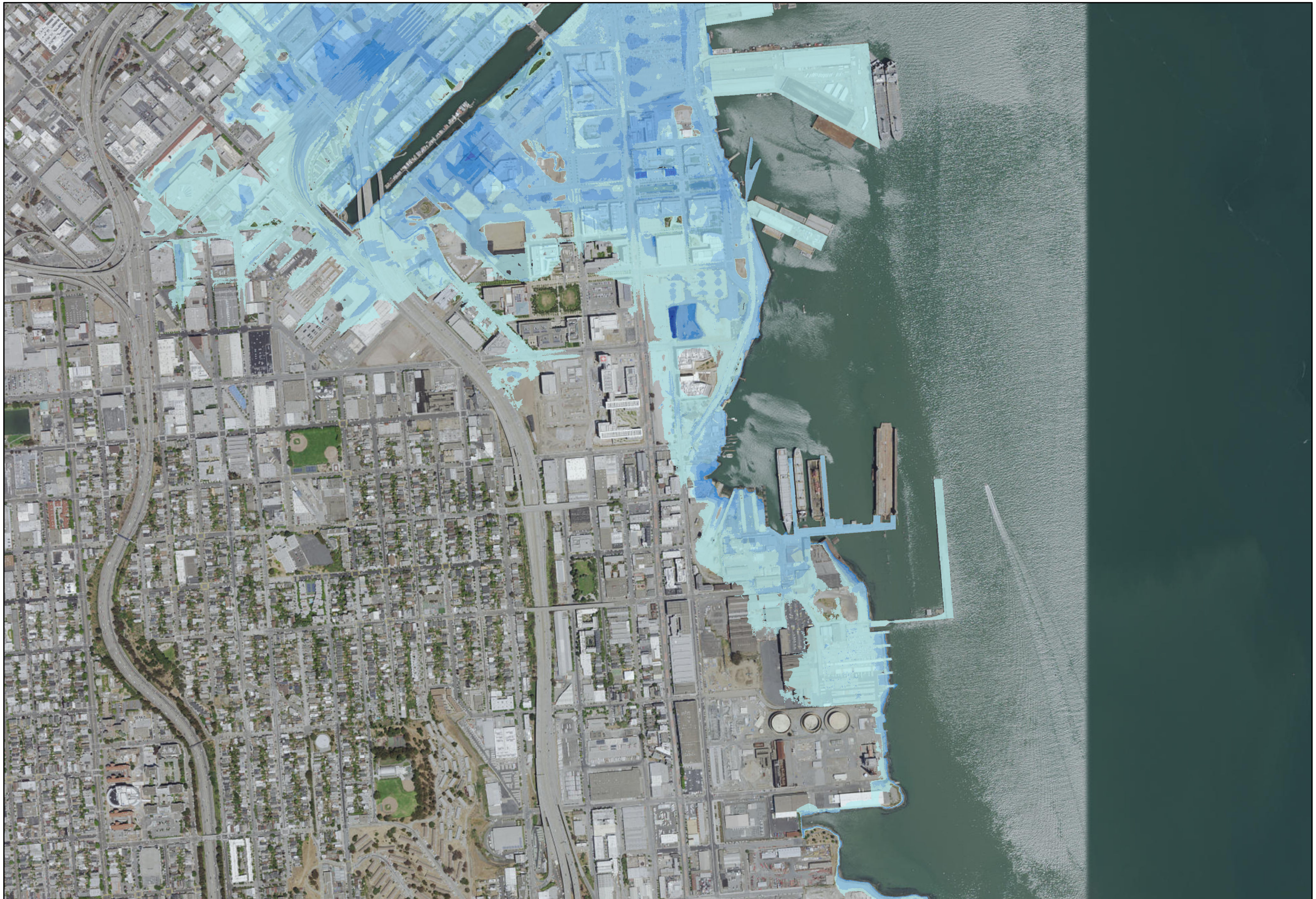

PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 84" WATER LEVEL

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12+
Disconnected Areas > 1 Acre

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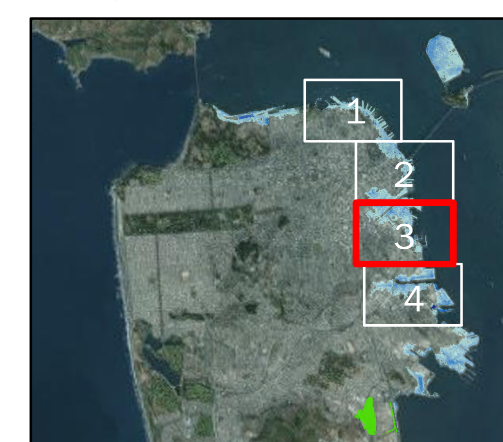
0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016



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12+
Disconnected Areas > 1 Acre

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0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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UTM Zone 10N; North American Datum 1983

Date: 3/9/2016

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 96" WATER LEVEL

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

Depth in Feet

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

N

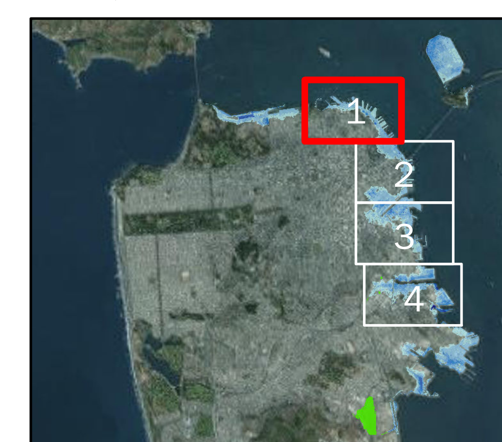
0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

Date: 3/9/2016



PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 96" WATER LEVEL

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

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

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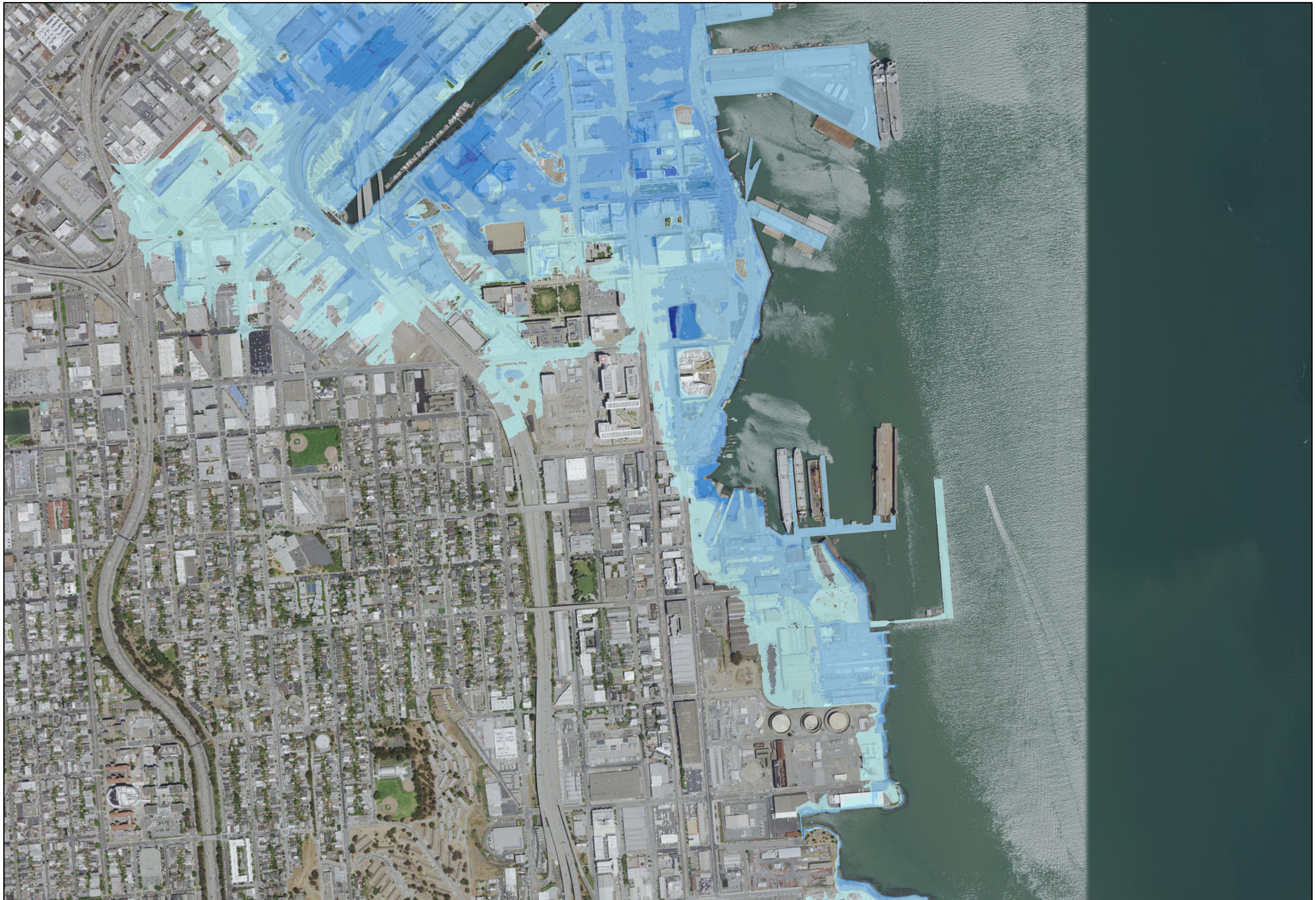

PORT OF SAN FRANCISCO
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MHHW + 96" WATER LEVEL

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PORT OF SAN FRANCISCO

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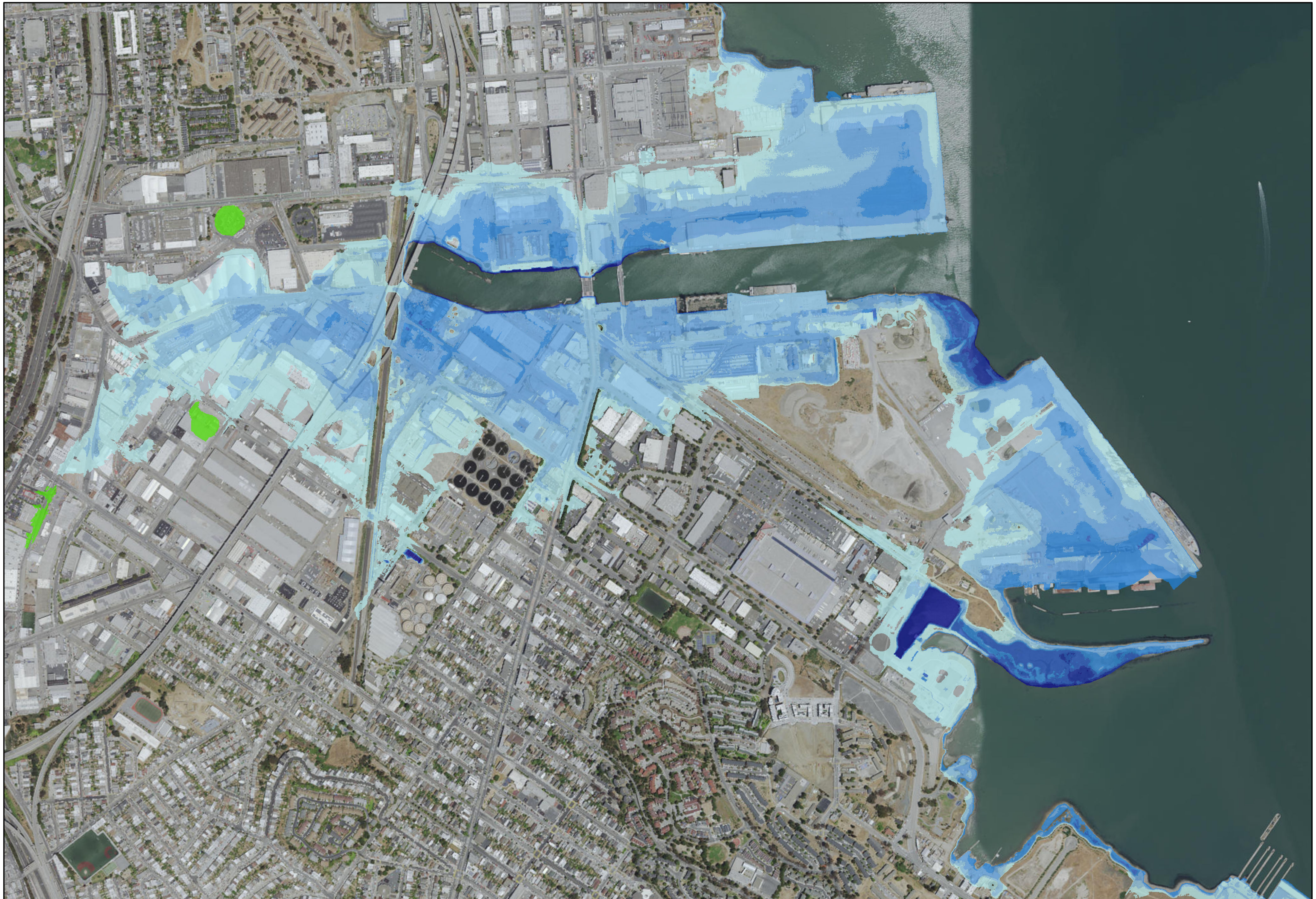

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60” SLR + 50-YEAR STORM SURGE
54” SLR + 100-YEAR STORM SURGE

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

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PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 108" WATER LEVEL

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66" SLR + 100-YEAR STORM SURGE

Depth in Feet

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

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

Projection:
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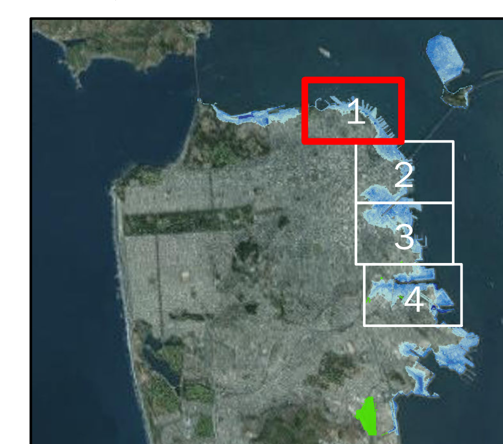

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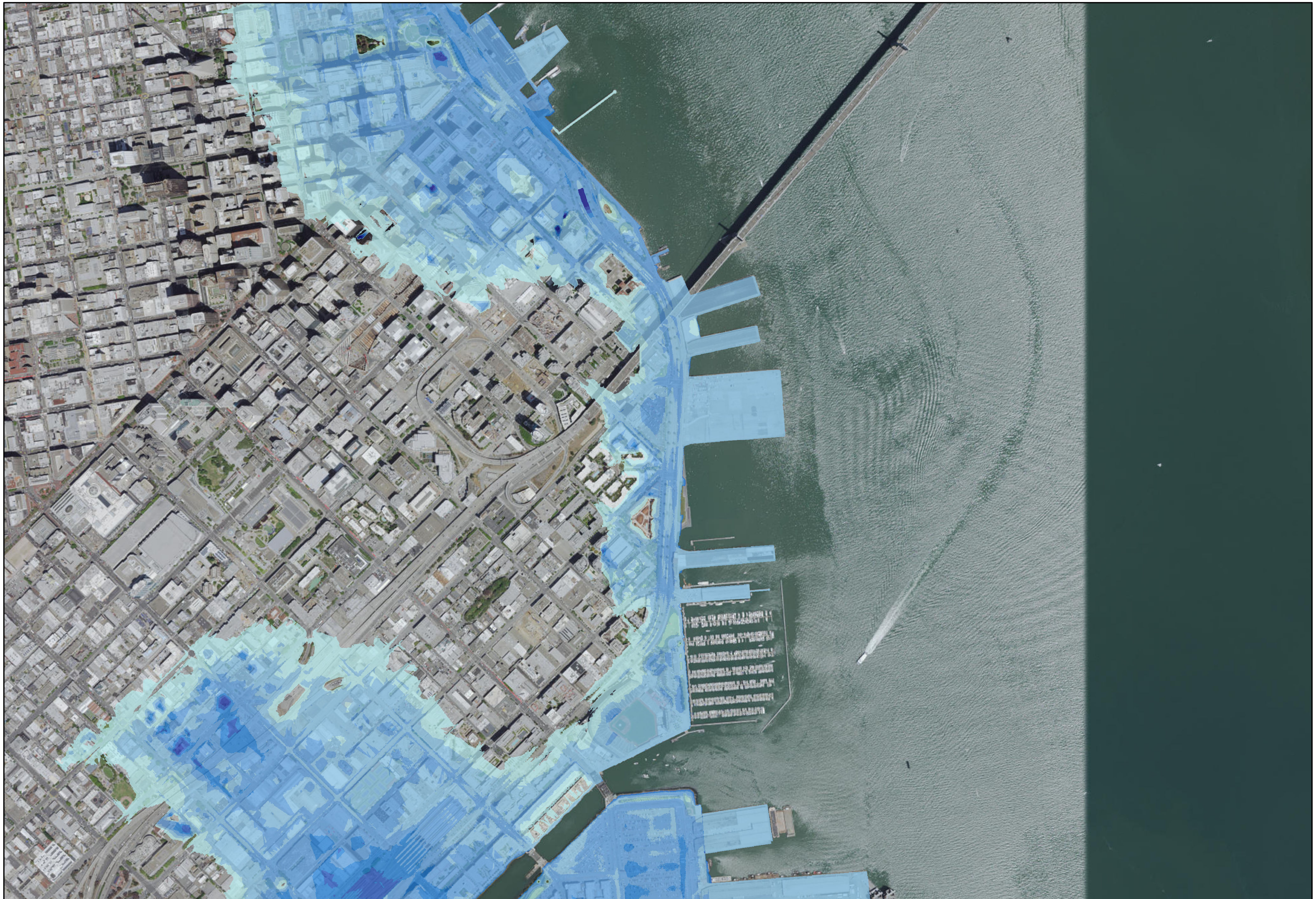

PORT OF SAN FRANCISCO
Inundation Mapping

MHHW + 108" WATER LEVEL

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66" SLR + 100-YEAR STORM SURGE

Depth in Feet

0 - 2

2 - 4

4 - 6

6 - 8

8 - 10

10 - 12

12+

Disconnected Areas > 1 Acre

N

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

PORT OF SAN FRANCISCO

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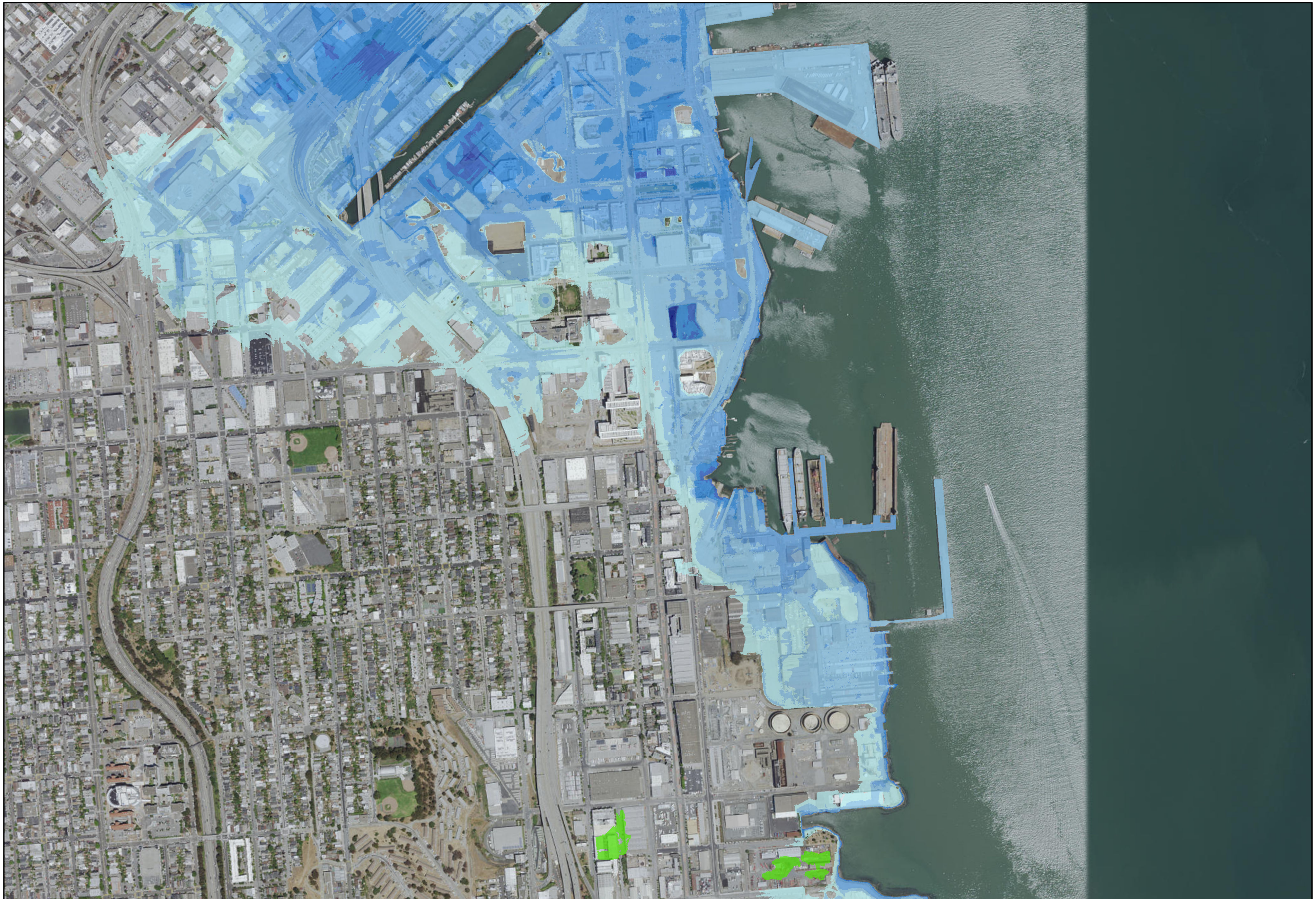

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66" SLR + 100-YEAR STORM SURGE

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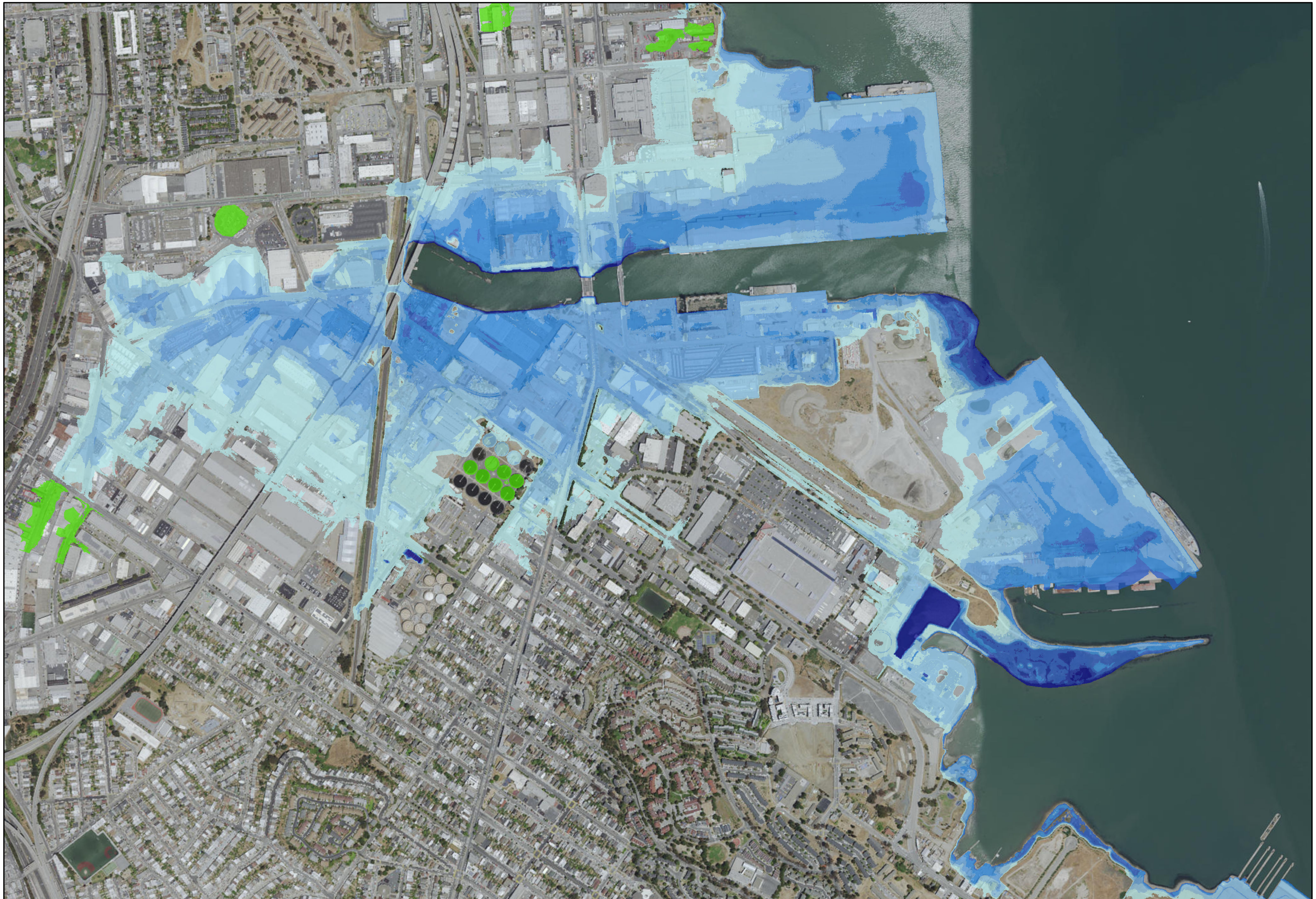

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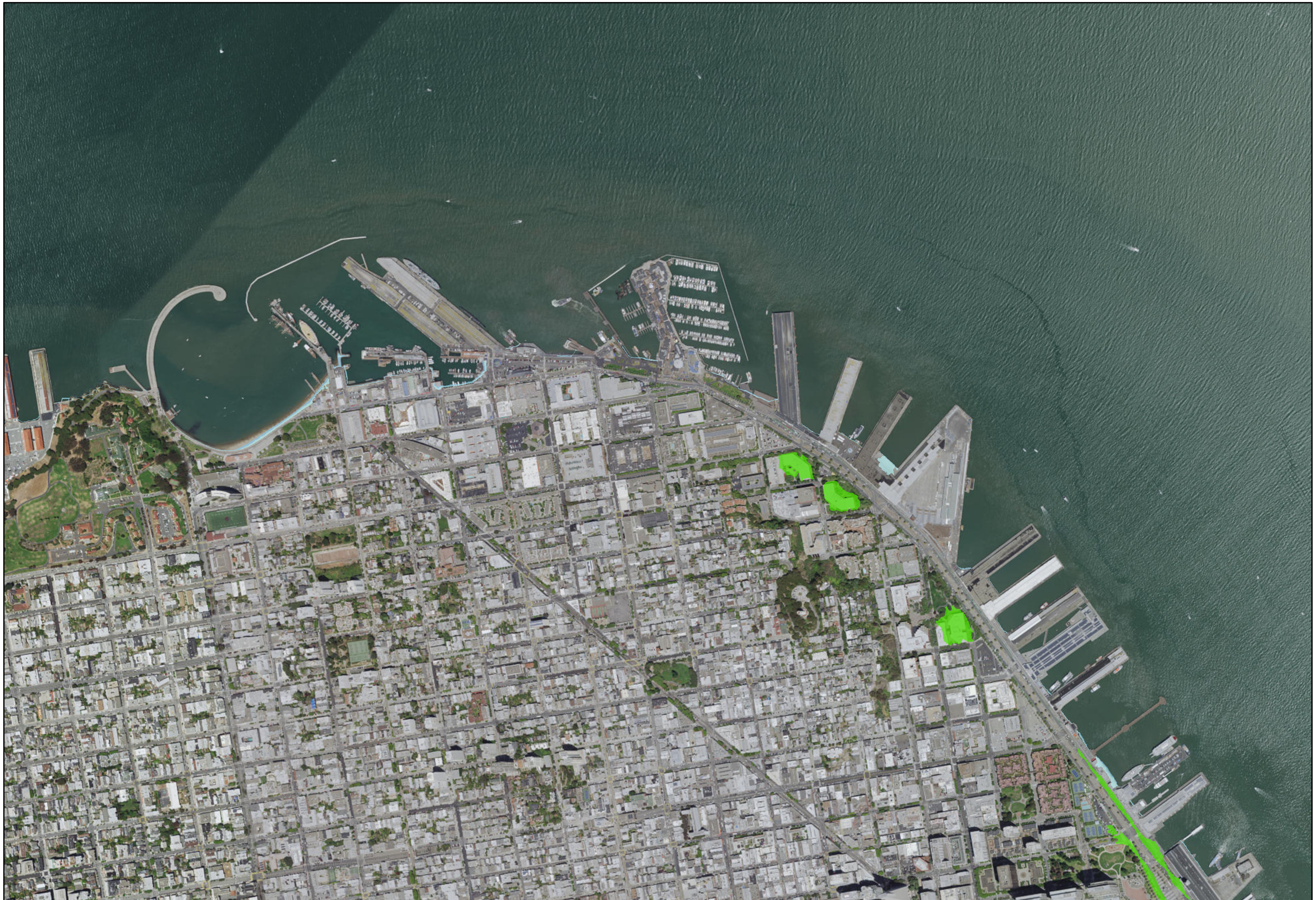
PORT OF SAN FRANCISCO
Inundation Mapping

100-YEAR STORM SURGE



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

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

N

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

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PORT OF SAN FRANCISCO
Inundation Mapping
100-YEAR STORM SURGE

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

0 0.1 0.2 0.3 Miles
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UTM Zone 10N; North American Datum 1983

Date: 3/8/2016

* Disclaimer: The inundation maps and the associated analyses are intended as planning level tools to illustrate the potential for inundation and coastal flooding under a variety of future sea level rise and storm surge scenarios. The maps depict possible future inundation that could occur if nothing is done to adapt or prepare for sea level rise over the next century. The maps do not represent the exact location or depth of flooding. The maps relied on a 1-m digital elevation model created from LiDAR data collected in 2010 and 2011. Although care was taken to capture all relevant topographic features and coastal structures that may impact coastal inundation, it is possible that structures narrower than the 1-m horizontal map scale may not be fully represented. The maps are based on model outputs and do not account for all of the complex and dynamic San Francisco Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to sea level rise. For more context about the maps and analyses, including a description of the data and methods used, please see the Climate Stressors and Impacts Report: Bayside Sea Level Rise Inundation Mapping Technical Memorandum, June 2014.

PORT OF SAN FRANCISCO
Inundation Mapping
100-YEAR STORM SURGE

Depth in Feet

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

0 0.1 0.2 0.3 Miles

0 250 500 1,000 1,500 Feet

N

PORT OF SAN FRANCISCO

Projection:
UTM Zone 10N; North American Datum 1983

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