



Memorandum

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To: Jennifer Haddow, Ph.D. (Rincon Consultants)
From: David Cannon, P.E., M.C.E. (Everest)
Copy to:
Date: January 26, 2016
Project Number: P2208
Re: Oxnard LCP Update – Sea Level Rise Vulnerability Assessment
Tsunami Analysis

BACKGROUND

As part of the effort for the Local Coastal Program (LCP) Update, the City of Oxnard (City) retained Rincon and Everest International Consultants (Everest) to conduct the analysis summarized in this memorandum to evaluate potential tsunami inundation under existing and future sea levels (*i.e.*, with sea level rise) for the four Planning Areas in the City of Oxnard and Port Hueneme. This tsunami analysis is supplemental to the work previously conducted by RINCON and Revell Coastal on the impacts of sea level rise within the City's coastal zone. The results of the tsunami analysis will be incorporated into the ongoing comprehensive LCP Update.

PURPOSE AND OBJECTIVES

The purpose of this analysis is to determine the degree of potential inundation associated with tsunamis without and with sea level rise. The following objectives were established to fulfill this purpose:

- Select tide condition(s)
- Select future sea level rise condition(s)
- Select tsunami event(s)
- Determine the extent of potential tsunami inundation

APPROACH

Potential tsunami inundation elevations were determined from the selected tide condition and tsunami wave heights. These potential tsunami inundation elevations were then mapped for the City LCP Planning Areas using GIS and topographic/bathymetric data to evaluate areas with the potential to be inundated by a tsunami occurring in Year 2015 without sea level rise as well as a tsunami occurring in Years 2030, 2060, and 2100 with sea level rise.

INUNDATION ELEVATIONS

Tides

Tide elevations are monitored by the National Oceanic and Atmospheric Administration (NOAA) along the California coastline at designated tide stations. The Santa Barbara station (Station 9411340) and Santa Monica station (Station 9410840) are the two NOAA stations closest to the City of Oxnard. Tidal datums obtained from NOAA for these two stations are shown in Table 1 with elevations in feet relative to the North American Vertical Datum of 1988 (NAVD88). These tidal datums represent long term average water levels for the latest National Tidal Datum Epoch from Years 1983 to 2001. Since the City is approximately equal distance from the two NOAA stations, the average tide elevation at the two tide stations was used for this analysis. For the potential tsunami inundation analysis, Mean Higher High Water (MHHW) was selected as a representative tide condition for the historical tsunami (2011 Japanese Tsunami). For the locally generated tsunami developed by the State of California (California Geological Survey, 2014), mean sea level (MSL) tide was selected for the work presented in that report so that tide was selected for the analysis presented in this technical memo.

Table 1. NOAA Tidal Datums for Santa Barbara and Santa Monica

TIDE	ELEVATION (FEET, NAVD88)	
	SANTA BARBARA (STATION 9411340)	SANTA MONICA (STATION 9410840)
Highest Observed Water Level	7.26	8.31
Mean Higher High Water (MHHW)	5.27	5.24
Mean High Water (MHW)	4.51	4.50
Mean Sea Level (MSL)	2.66	2.60
Mean Low Water (MLW)	0.85	0.74
North American Vertical Datum – 1988 (NAVD88)	0.00	0.00
Mean Lower Low Water (MLLW)	-0.13	-0.19
Lowest Observed Water Level	-3.02	-3.03

Sea Level Rise

The sea level rise scenarios were consistent with the coastal hazards mapping prepared by ESA PWA (2013) for the County of Ventura. The ESA PWA study followed the intent of the California Coastal Commission Draft Sea Level Rise Policy Guidance (CCC 2013), National Research Council (NRC 2012), and U.S. Army Corps of Engineers guidance (USACE 2011). It also included an adjustment for local vertical land motion using the Santa Monica tide station (NOAA #9410840) for the medium and high SLR projections. The sea level rise projections relative to 2010 extracted from the ESA PWA 2013 are shown in Table 2. The same sea level rise projections for Years 2030, 2060, and 2100 from the ESA PWA study (2013) High Scenario were used for this analysis to define future mean sea level conditions.

TABLE 2. SEA LEVEL RISE PROJECTIONS, RELATIVE 2010 (ESA PWA 2013)

YEAR	SEA LEVEL RISE PROJECTIONS (INCHES)		
	LOW SLR	MEDIUM SLR	HIGH SLR
2030	2.3	5.2	8.0
2060	7.4	16.1	25.3
2100	17.1	36.5	58.1

Tsunamis

The tsunami data for the historical tsunami and local tsunami used in this analysis are presented below and summarized in Tables 3 and 4.

Historical Tsunami

The 2010 Chilean and 2011 Japanese tsunamis were the most significant tsunamis to hit California since the 1964 Alaska tsunami. The 2010 Chilean tsunami was generated by a magnitude 8.8 earthquake on February 26, 2010 at the Maule region near central Chile, and the tsunami subsequently reached the Los Angeles region around noon on February 27, 2010. On March 11, 2011, a magnitude 9.0 earthquake struck the east coast of the Tohoku region in Japan, and it generated a large tsunami that reached the Los Angeles region at around 8:40 am on March 11, 2011.

The NOAA ocean water level data collected at the Santa Barbara and Santa Monica gages for these two tsunamis were downloaded and analyzed for this analysis. Figure 1 shows a graphic record of the water levels at Santa Monica and Santa Barbara gages for the 2010 Chilean event. In the figure, the blue line shows the observed (measured) ocean water level and the green line shows the predicted ocean water level. The difference between the

measured and predicted ocean water level (shown as the red line in the figure) primarily represents the tsunami wave. Based on the data, the maximum measured tsunami amplitude (wave amplitude equals half the wave height) was approximately 1.61 ft at Santa Monica and 1.91 ft at Santa Barbara. Similar plots for the 2011 Japanese tsunami are shown in Figure 2. For this tsunami, the maximum tsunami amplitude at Santa Monica was about 2.43 ft and 2.39 ft at Santa Barbara. The tsunami wave amplitude off the shoreline of Oxnard is likely between those measured at Santa Monica and Santa Barbara so an average value was calculated for these two locations (1.75 ft for the 2010 Chilean event and 2.41 ft for the 2011 Japanese event) to represent the tsunami amplitude. For this analysis, the 2011 Japanese tsunami amplitude was used since it represented the higher tsunami wave condition.

Local Tsunami

Given the lack of measured information for historical tsunamis and the potential for extreme tsunamis that have not been captured in the historical measurements, consideration was given to potential tsunamis that could be generated by distant sources and local sources. The State of California conducted an analysis of tsunamis that could be generated by numerous distant sources (e.g., Cascadian Subduction Zone earthquake) and local sources (e.g., Goleta 2 Landslide). A numerical model was used in the analysis conducted by the State of California to determine the maximum potential tsunami elevation for each individual source and then the maximum tsunami elevation was identified for each source type (distant and local). The results were provided for different locations along the California coast, including the Oxnard and Ventura area. For the Oxnard area, the maximum tsunami elevation of +12 ft, MSL resulting from the Goleta 2 Landslide source was reported (California Geological Survey, 2014). This tsunami was selected for inclusion in the analysis presented herein to allow consideration of a potentially large tsunami not captured in the historical measured record that could strike the Oxnard coast in the future. This tsunami is also being considered by the City of Oxnard for emergency evacuation planning.

Potential Tsunami Inundation Elevations

The potential tsunami inundation elevations for the 2011 Japanese tsunami and Goleta 2 Landslide tsunami are summarized in Tables 3 and 4, respectively. The values in Table 3 are based on the tsunami occurring during a high tide condition of MHHW in Year 2015 (no sea level rise) as well as Years 2030, 2060, and 2100 (with sea level rise). The values in Table 4 are based on the tsunami occurring during a tide condition of MSL in Year 2015 (no sea level rise) as well as Years 2030, 2060, and 2100 (with sea level rise).

Table 3. 2011 Japanese Tsunami Potential Inundation Elevations

YEAR	MHHW (FT, NAVD88)	TSUNAMI AMPLITUDE (FT)	SEA LEVEL RISE (FT)	INUNDATION ELEVATION (FT, NAVD88)
2015	5.26	2.4	0.00	7.7
2030	5.26	2.4	0.67	8.3
2060	5.26	2.4	2.11	9.8
2100	5.26	2.4	4.84	12.5

Table 4. Goleta 2 Landslide Tsunami Potential Inundation Elevations

YEAR	MSL (FT, NAVD88)	TSUNAMI NEARSHORE HEIGHT (FT)	SEA LEVEL RISE (FT)	INUNDATION ELEVATION (FT, NAVD88)
2015	2.63	12.0	0.00	14.6
2030	2.63	12.0	0.67	15.3
2060	2.63	12.0	2.11	16.7
2100	2.63	12.0	4.84	19.5

DATA USED IN GIS-AIDED INUNDATION ANALYSIS

Imagery: World Imagery

The imagery “World Imagery” is available as a basemap in ESRI ArcGIS (ESRI, 2015). World Imagery provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide. The map features 0.3 m resolution imagery in the continental United States.

Topographic/Bathymetric Data: 2013 NOAA Coastal California TopoBathy Merged Project

The raster data set was downloaded from the NOAA Digital Coast Data Access Viewer (NOAA, 2015). Data providers include the California State Coastal Conservancy, California Ocean Protection Council, and California Department of Water Resources. The data was extracted from a larger classified data set and only includes points classified as Ground, Model Key-point (mass point), Bathymetric Lidar Points, and Acoustic Bathymetry (bare

earth) within the requested geographic bounds. This project merged recently collected topographic, bathymetric, and acoustic elevation data along the entire California coastline from approximately the 10 m elevation contour out to the three-mile State water's boundary.

The topographic Lidar data used in this merged project was the 2009-2011 California State Coastal Conservancy Lidar Project. The bathymetric Lidar data used in this merged project was 2009-2010 U.S. Army Corps of Engineers (USACE) Joint Airborne Lidar Bathymetry Center of Expertise (JALBTCX) Lidar, provided by JALBTCX. The data were collected for the California Coastal Mapping Project (CCMP). The multibeam acoustic data used in this merged project were provided by the California Seafloor Mapping Program (CSMP) Ocean Protection Council and NOAA's National Geophysical Data Center (NGDC). Vertical accuracy of the topographic data is reported at 4.8 centimeters (cm) root mean square error (RMSE). JALBTCX bathymetric data is reported at 15 cm RMSE. As multiple multibeam acoustic datasets from multiple sources were used, the vertical accuracy varies. Horizontal accuracy is 100 cm.

Storm Drain Data

GIS storm drain data were obtained from the City of Oxnard. The types of data include locations of storm drains, open channels, manholes, inlets and outfalls. Among the information provided in the attribute tables are elevations of pipe inverts, manhole covers and inlets.

LCP Planning Areas

The four LCP Planning Areas in the City of Oxnard and adjacent Port Hueneme Planning Area are the focus of the analysis. The five areas are listed in Table 5. The boundaries of these Planning Areas were provided by the City in GIS format.

Table 5. Oxnard LCP Planning Areas and Port Hueneme

ID	DESCRIPTION
PA1	McGrath / Mandalay Beach
PA2	Oxnard Shores
PA3	Channel Islands
PA4	Ormond Beach
PA5	Port Hueneme (Not in LCP)

POTENTIAL TSUNAMI INUNDATION AREA MAPPING

Potential tsunami inundation elevations accounting for tide, tsunami, and sea level rise for Years 2015, 2030, 2060, and 2100 discussed in the previous section are summarized in Table 6. Areas below these potential tsunami inundation elevations (*i.e.*, at lower elevations) were identified and delineated on topographic maps as areas that may be inundated if there are hydraulic connections between the tsunami waves and low lying areas. An example of a hydraulic connection would be breaches in the beach dune system that lies between the ocean and infrastructure along the shore. Such breaches could occur in the future due to gradual erosion of the beach/dune system associated with decreases in sand supply or such breaches could occur during a tsunami with the initial tsunami waves eroding the beach and breaching the dune system. Another example of a hydraulic connection is a storm drain, which may consist of a series of inlets and pipes through which water is conveyed from one area to another, and ultimately to a river channel, or an ocean outfall.

Table 6. Summary of Potential Tsunami Inundation Elevations

YEAR	INUNDATION ELEVATION (FT, NAVD88)	
	2011 JAPANESE TSUNAMI	GOLETA 2 LANDSLIDE TSUNAMI
2015	7.7	14.6
2030	8.3	15.3
2060	9.8	16.7
2100	12.5	19.5

Potential tsunami inundation maps for Planning Areas 1, 2, 3, 4 and 5 are shown in Figures 3, 4, 5, 6, and 7, respectively. In each figure, the inundation areas for Years 2015, 2030, 2060, and 2100 are shown from left to right. The yellow lines in the figures designate the boundaries of the Planning Areas and the colored (light and dark blue) areas depict the potential tsunami inundation areas.

As can be seen in Table 6, the Goleta 2 Landslide Tsunami inundation elevations are higher than those of the 2011 Japanese Tsunami, implying that the potential tsunami inundation impact areas of the Goleta 2 Landslide would be more extensive than those of the 2011 Japanese tsunami. In the figures, the areas potentially inundated by the 2011 Japanese Tsunami are the areas in light blue, while the areas potentially inundated by the Goleta 2 Landslide Tsunami include both the light and dark blue areas. The areas below the inundation elevations would experience potential inundation impacts if hydraulic connections

are present. The storm drain data are plotted in Figures 3 to 7 to provide information regarding potential hydraulic connections.

SEA LEVEL RISE VULNERABILITY ASSESSMENT TSUNAMI ANALYSIS SUMMARY

The results of the potential tsunami inundation analysis show that the LCP Planning Areas could experience inundation impacts if a tsunami occurs in the future with higher sea levels. Between Year 2015 and Year 2060, LCP Planning Areas 1 to 3 are not likely to experience substantial inundation from a tsunami similar to the 2011 Japanese Tsunami if it occurred, while Planning Area 4 would potentially be inundated due to lower ground elevations. For a tsunami similar to the Goleta 2 Landslide Tsunami, most of the Planning Areas could experience inundation, whether it occurred in recent years or future years with sea level rise.

REFERENCES

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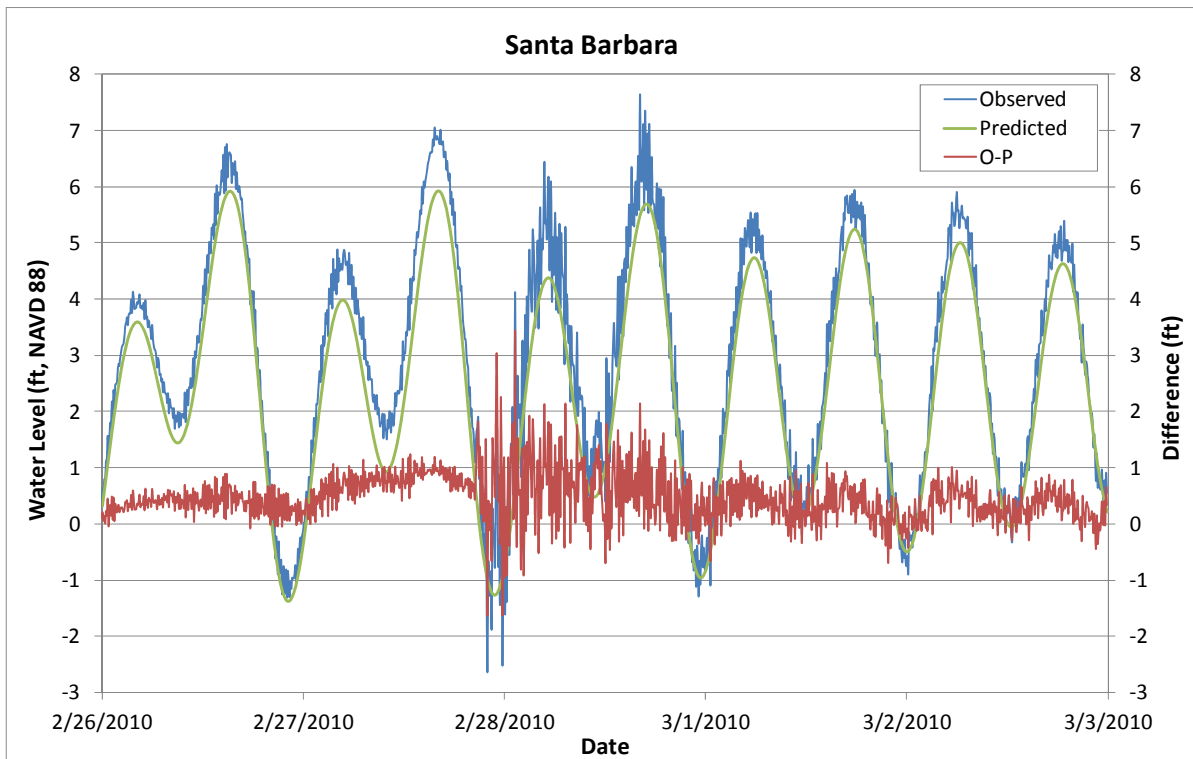
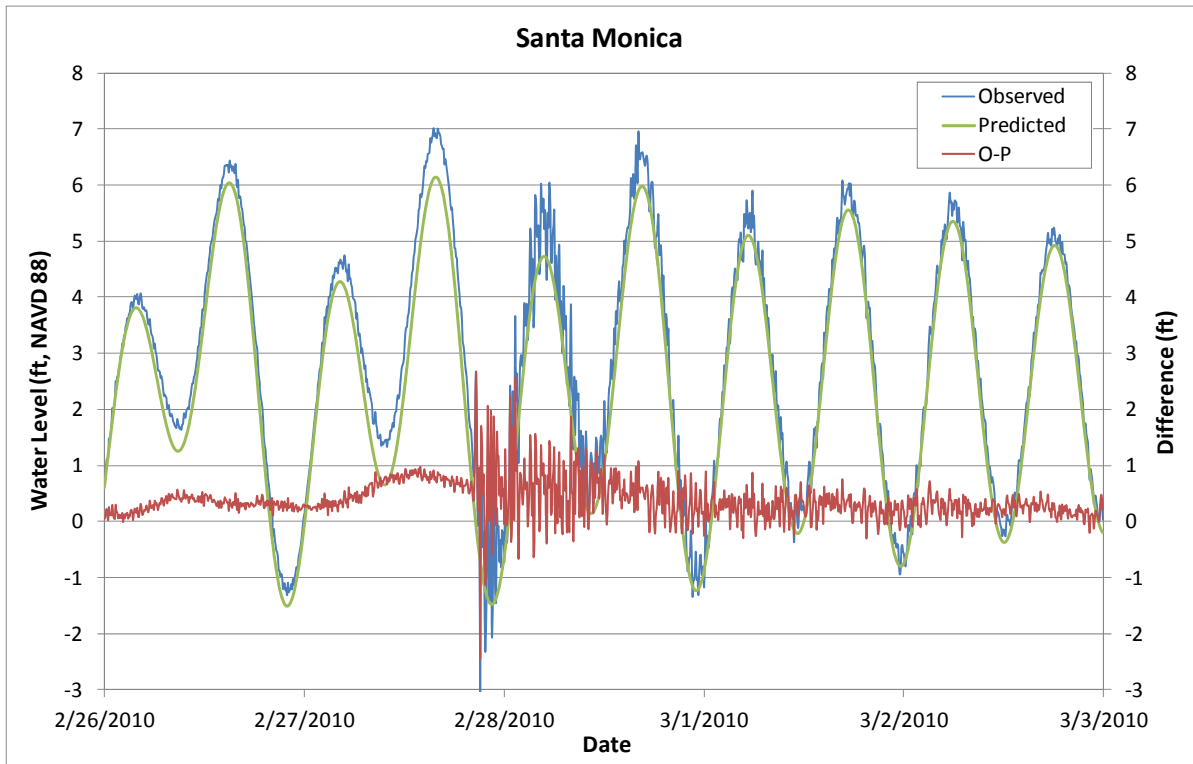


Figure 1. Marigrams for Santa Monica and Santa Barbara during the February 27, 2010 Chilean Tsunami

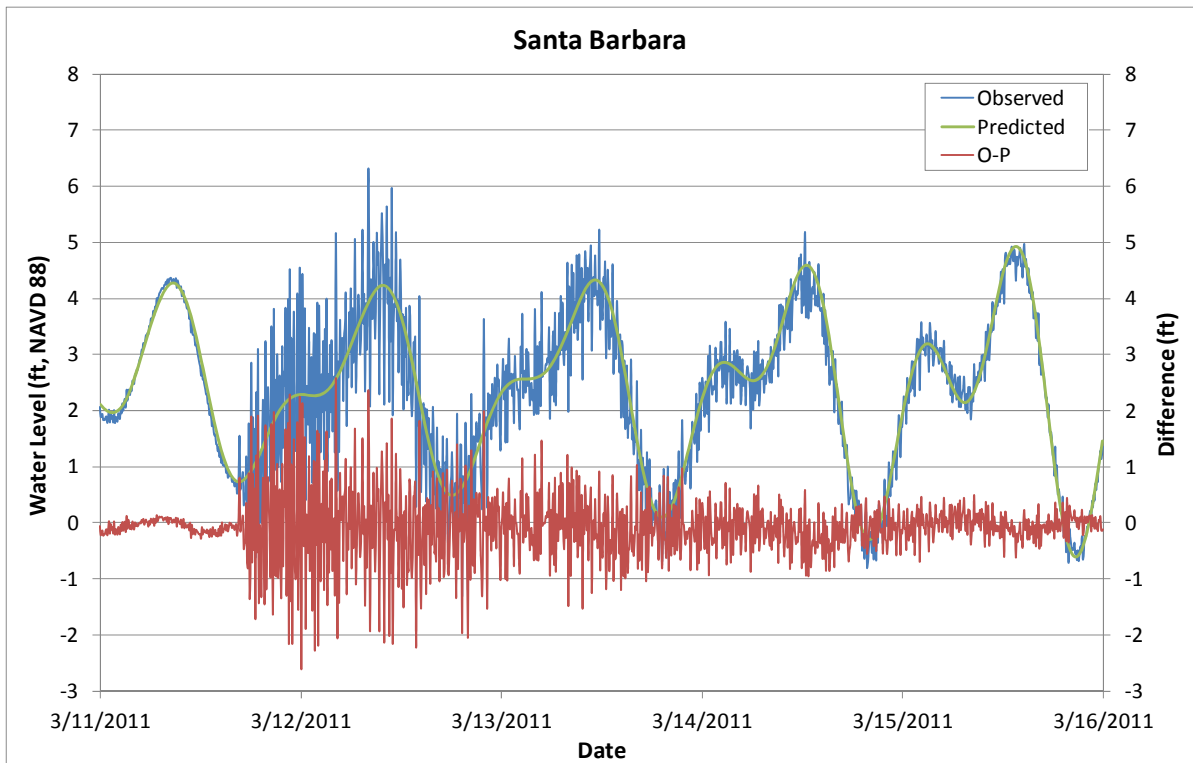
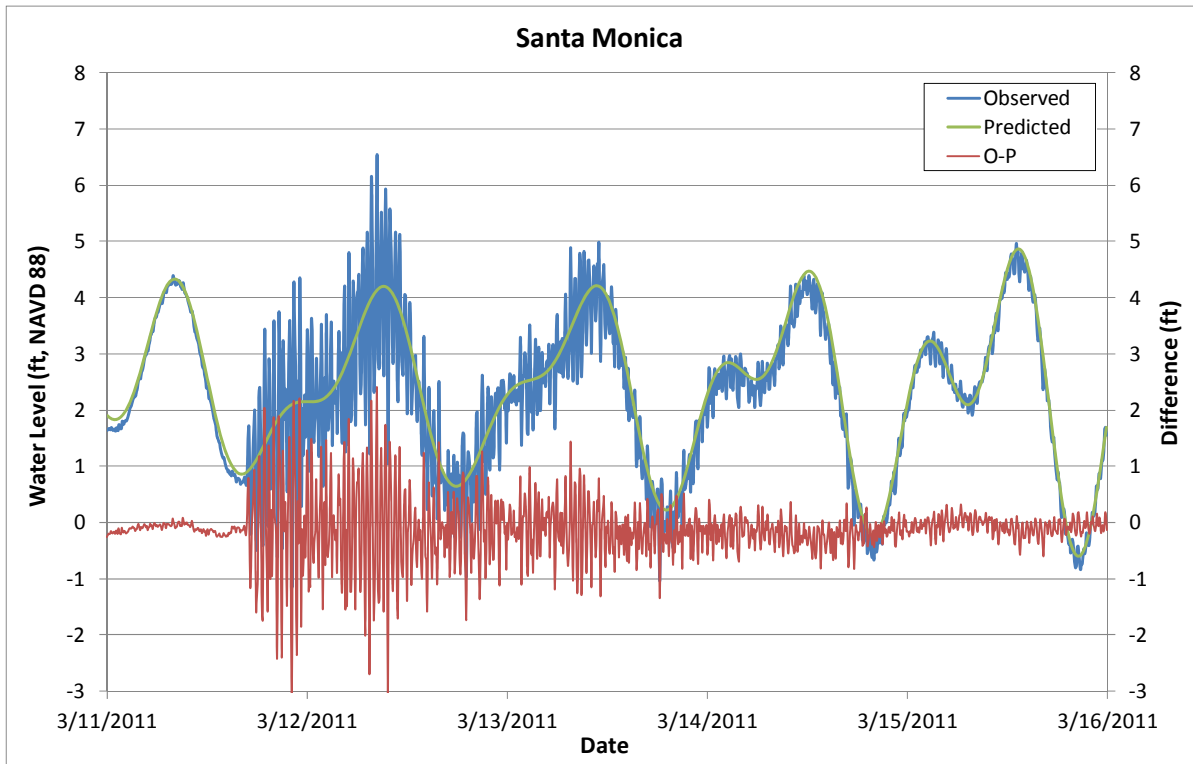
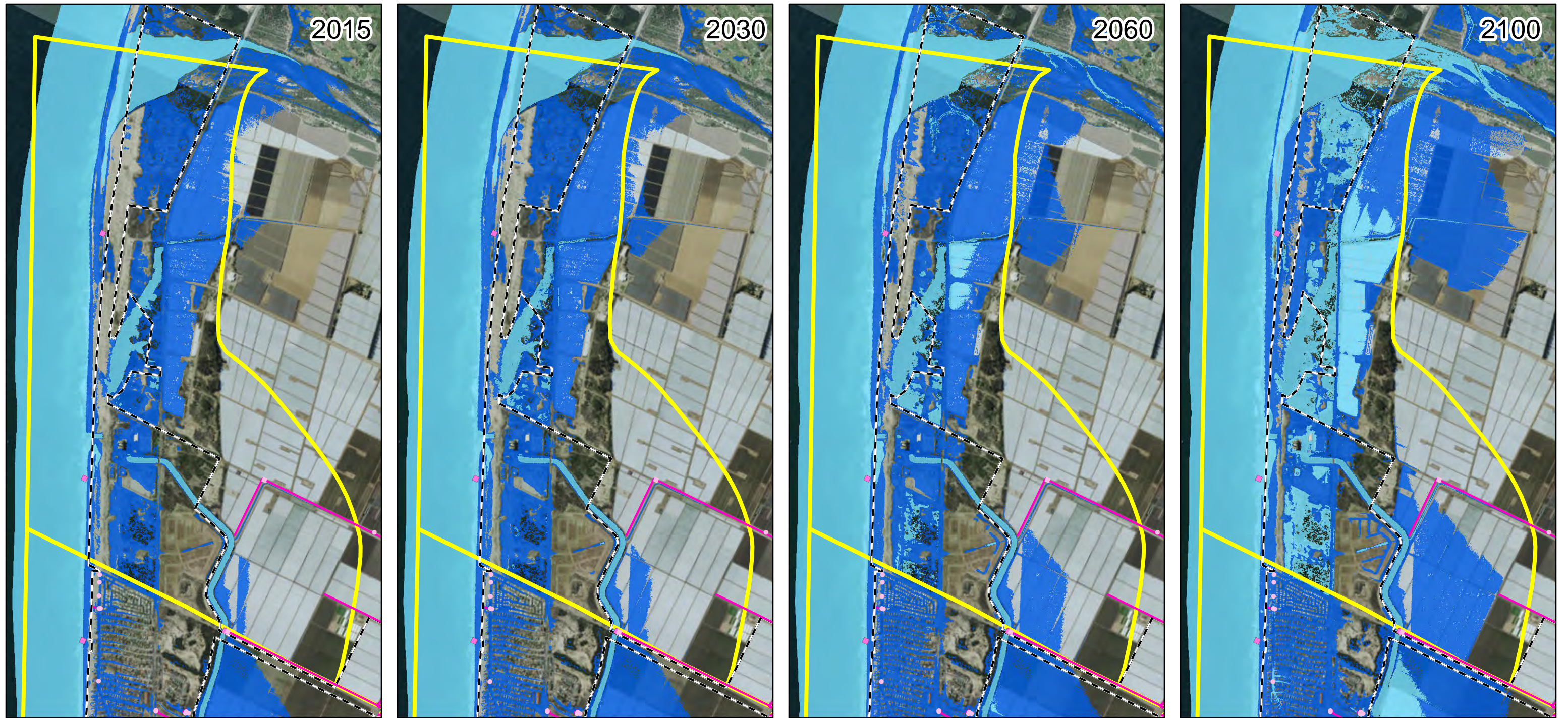


Figure 2. Marigrams for Santa Monica and Santa Barbara during the March 11, 2011 Japanese Tsunami

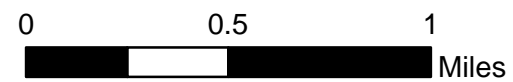


Tsunami Scenario 2015

- Potential inundation area below 7.7' NAVD (J or G Tsunami + 2015 Sea Level)
- Potential inundation area below 14.6' NAVD (G Tsunami + 2015 Sea Level)
- City Boundary
- City of Oxnard LCP Planning Area
- Adjacent Jurisdictions
- Storm Drain Inlet/Catch Basin
- Storm Drain Pipe/Open Channel

Tsunami Scenario 2030

- Potential inundation area below 8.3' NAVD (J or G Tsunami + 2030 Sea Level)
- Potential inundation area below 15.3' NAVD (G Tsunami + 2030 Sea Level)



Abbreviations: J = 2011 Japanese Tsunami; G = Goleta 2 Landslide Tsunami

Tsunami Scenario 2060

- Potential inundation area below 9.8' NAVD (J or G Tsunami + 2060 Sea Level)
- Potential inundation area below 16.7' NAVD (G Tsunami + 2060 Sea Level)

Tsunami Scenario 2100

- Potential inundation area below 12.5' NAVD, (J or G Tsunami + 2100 Sea Level)
- Potential inundation area below 19.5' NAVD (G Tsunami + 2100 Sea Level)

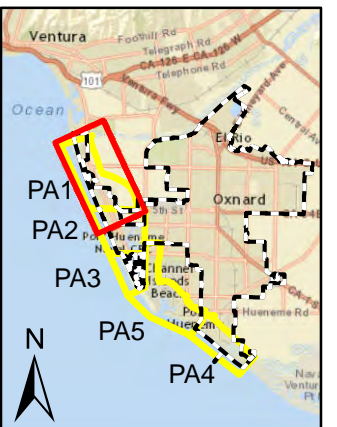
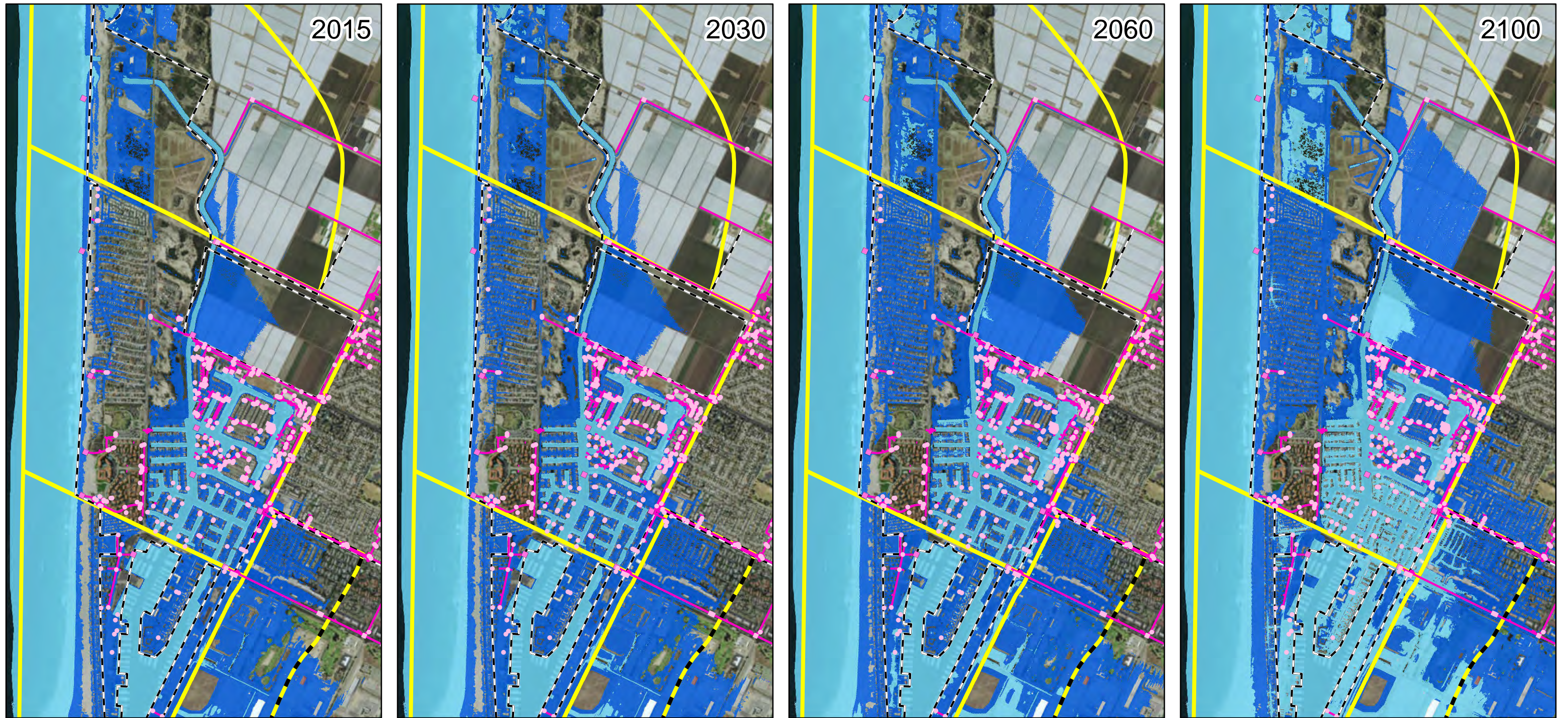


Figure 3. Storm Drain Sea Level Rise Vulnerability Mapping for Planning Area 1: McGrath / Mandalay Beach

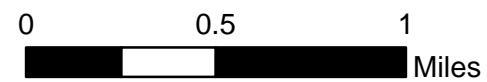


Tsunami Scenario 2015

- Potential inundation area below 7.7' NAVD (J or G Tsunami + 2015 Sea Level)
- Potential inundation area below 14.6' NAVD (G Tsunami + 2015 Sea Level)
- City Boundary
- City of Oxnard LCP Planning Area
- Adjacent Jurisdictions
- Storm Drain Inlet/Catch Basin
- Storm Drain Pipe/Open Channel

Tsunami Scenario 2030

- Potential inundation area below 8.3' NAVD (J or G Tsunami + 2030 Sea Level)
- Potential inundation area below 15.3' NAVD (G Tsunami + 2030 Sea Level)



Abbreviations: J = 2011 Japanese Tsunami; G = Goleta 2 Landslide Tsunami

Tsunami Scenario 2060

- Potential inundation area below 9.8' NAVD (J or G Tsunami + 2060 Sea Level)
- Potential inundation area below 16.7' NAVD (G Tsunami + 2060 Sea Level)

Tsunami Scenario 2100

- Potential inundation area below 12.5' NAVD, (J or G Tsunami + 2100 Sea Level)
- Potential inundation area below 19.5' NAVD (G Tsunami + 2100 Sea Level)

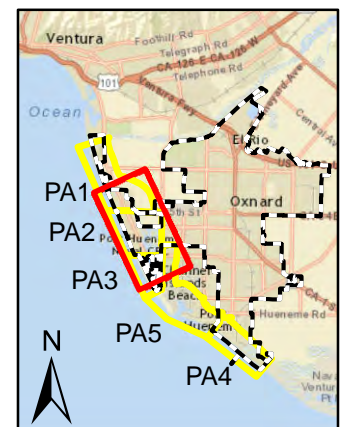


Figure 4. Storm Drain Sea Level Rise Vulnerability Mapping for Planning Area 2: Oxnard Shores

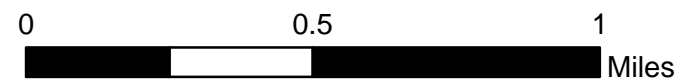


Tsunami Scenario 2015

- Potential inundation area below 7.7' NAVD (J or G Tsunami + 2015 Sea Level)
- Potential inundation area below 14.6' NAVD (G Tsunami + 2015 Sea Level)
- City Boundary
- City of Oxnard LCP Planning Area
- Adjacent Jurisdictions
- Storm Drain Inlet/Catch Basin
- Storm Drain Pipe/Open Channel

Tsunami Scenario 2030

- Potential inundation area below 8.3' NAVD (J or G Tsunami + 2030 Sea Level)
- Potential inundation area below 15.3' NAVD (G Tsunami + 2030 Sea Level)



Abbreviations: J = 2011 Japanese Tsunami; G = Goleta 2 Landslide Tsunami

Tsunami Scenario 2060

- Potential inundation area below 9.8' NAVD (J or G Tsunami + 2060 Sea Level)
- Potential inundation area below 16.7' NAVD (G Tsunami + 2060 Sea Level)

Tsunami Scenario 2100

- Potential inundation area below 12.5' NAVD, (J or G Tsunami + 2100 Sea Level)
- Potential inundation area below 19.5' NAVD (G Tsunami + 2100 Sea Level)

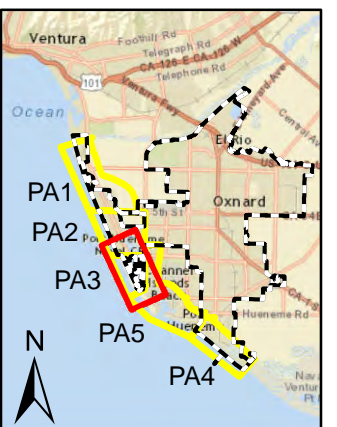
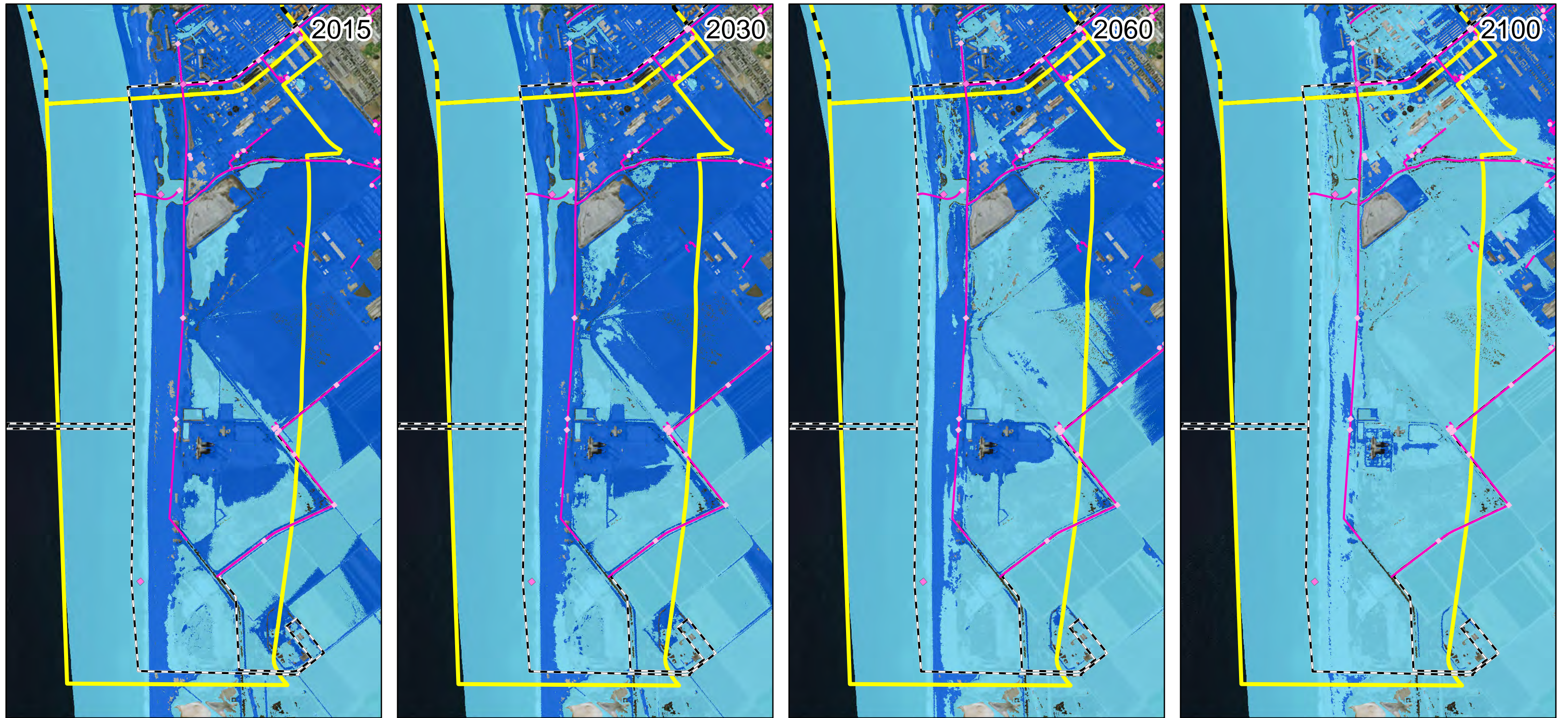


Figure 5. Storm Drain Sea Level Rise Vulnerability Mapping for Planning Area 3: Channel Islands



Tsunami Scenario 2015

- Potential inundation area below 7.7' NAVD (J or G Tsunami + 2015 Sea Level)
- Potential inundation area below 14.6' NAVD (G Tsunami + 2015 Sea Level)
- City Boundary
- City of Oxnard LCP Planning Area
- Adjacent Jurisdictions
- Storm Drain Inlet/Catch Basin
- Storm Drain Pipe/Open Channel

Tsunami Scenario 2030

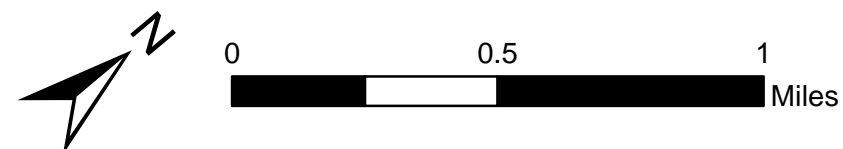
- Potential inundation area below 8.3' NAVD (J or G Tsunami + 2030 Sea Level)
- Potential inundation area below 15.3' NAVD (G Tsunami + 2030 Sea Level)

Tsunami Scenario 2060

- Potential inundation area below 9.8' NAVD (J or G Tsunami + 2060 Sea Level)
- Potential inundation area below 16.7' NAVD (G Tsunami + 2060 Sea Level)

Tsunami Scenario 2100

- Potential inundation area below 12.5' NAVD, (J or G Tsunami + 2100 Sea Level)
- Potential inundation area below 19.5' NAVD (G Tsunami + 2100 Sea Level)



Abbreviations: J = 2011 Japanese Tsunami; G = Goleta 2 Landslide Tsunami

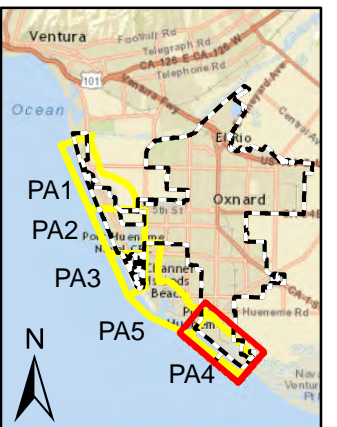
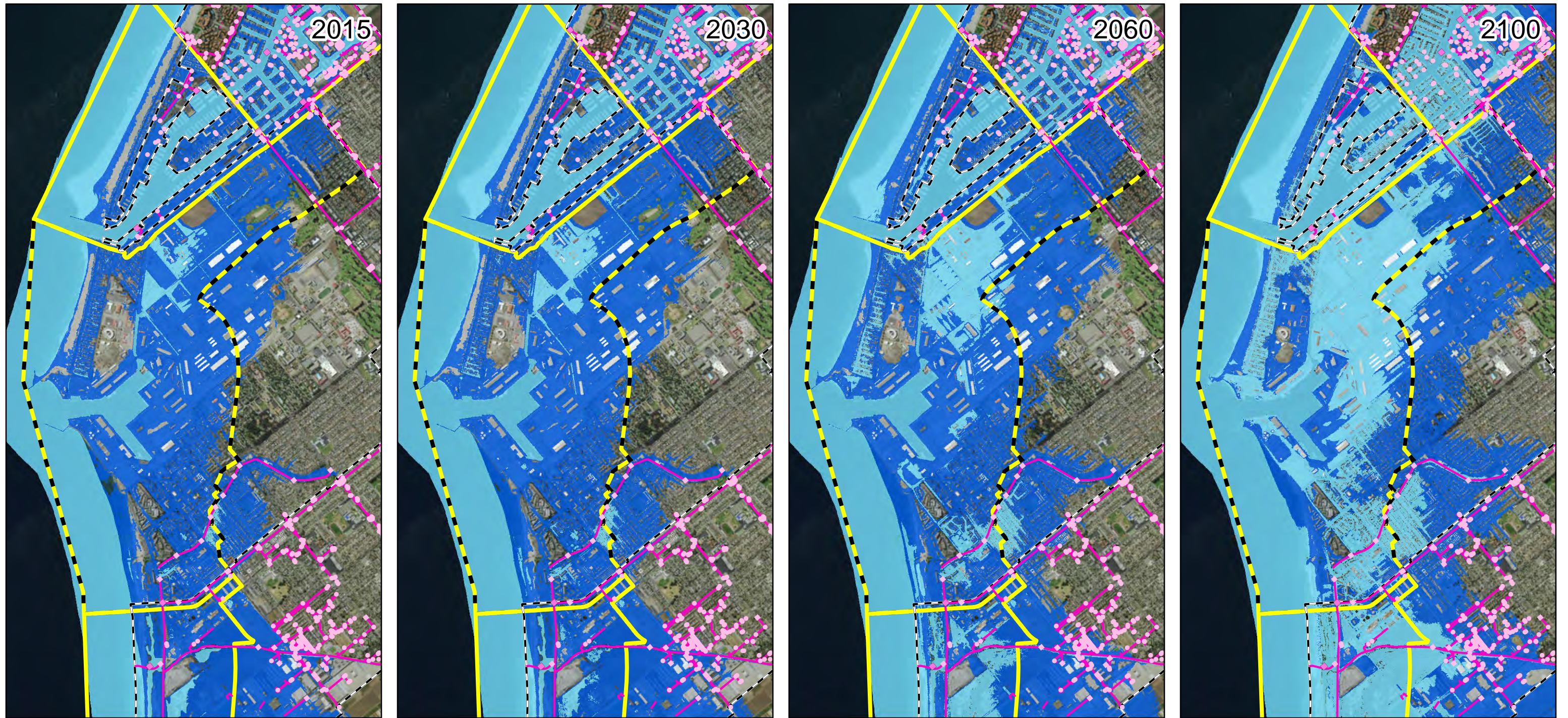


Figure 6. Storm Drain Sea Level Rise Vulnerability Mapping for Planning Area 4: Ormond Beach

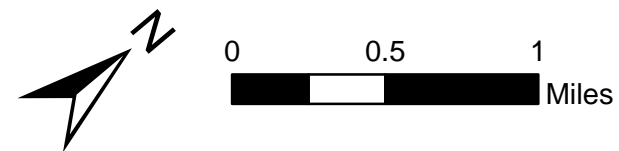


Tsunami Scenario 2015

- Potential inundation area below 7.7' NAVD (J or G Tsunami + 2015 Sea Level)
- Potential inundation area below 14.6' NAVD (G Tsunami + 2015 Sea Level)
- City Boundary
- City of Oxnard LCP Planning Area
- Adjacent Jurisdictions
- Storm Drain Inlet/Catch Basin
- Storm Drain Pipe/Open Channel

Tsunami Scenario 2030

- Potential inundation area below 8.3' NAVD (J or G Tsunami + 2030 Sea Level)
- Potential inundation area below 15.3' NAVD (G Tsunami + 2030 Sea Level)



Abbreviations: J = 2011 Japanese Tsunami; G = Goleta 2 Landslide Tsunami

Tsunami Scenario 2060

- Potential inundation area below 9.8' NAVD (J or G Tsunami + 2060 Sea Level)
- Potential inundation area below 16.7' NAVD (G Tsunami + 2060 Sea Level)

Tsunami Scenario 2100

- Potential inundation area below 12.5' NAVD, (J or G Tsunami + 2100 Sea Level)
- Potential inundation area below 19.5' NAVD (G Tsunami + 2100 Sea Level)

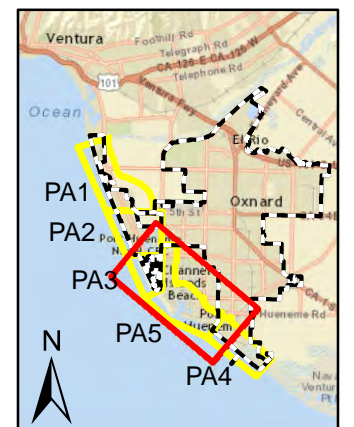


Figure 7. Storm Drain Sea Level Rise Vulnerability Mapping for Planning Area 5: Port Hueneme (Not in LCP)