Final

COASTAL RESILIENCE VENTURA

Technical Report for Coastal Hazards Mapping

Prepared for
The Nature Conservancy

July 31, 2013

Looking south from the Ventura Pier. Photo by E. Vandebroek, August 2012.

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1. INTRODUCTION

1.1 Purpose

This memorandum presents technical documentation of the methods used to map erosion and flood hazards under various future climate scenarios for the Ventura County, California coastline. The data that result from this work will be part of The Nature Conservancy's Coastal Resilience Ventura project. This report is intended to supplement the metadata associated with each dataset.

This report was prepared by Elena Vandebroek, P.E., David Revell, Ph.D. (Project Manager), James Gregory, P.E., and To Dang, Ph.D., with technical oversight by Bob Battalio, P.E. (Project Director).

1.2 Background

The Nature Conservancy is leading Coastal Resilience Ventura – a partnership to provide science and decision-support tools to aid conservation and planning projects and policymaking to address conditions brought about by climate change. The primary goals of Coastal Resilience Ventura are assessing the vulnerabilities of human and natural resources, and identifying solutions that help nature help people.

Steering Committee

The Coastal Resilience Ventura project has been guided directly by stakeholders and local decision-makers to develop tools and information to answer questions related to local climate change impacts. The steering committee consists of city, regional, state, and national government agencies and public and private organizations[1]. The committee provided input to the methods and results described in this report as well as provided data and input on deliverables throughout the project including four in-person meetings in Ventura.

1.3 Ventura Study Area

The study area is located within the southern California Bight, where the north-south trending U.S. West Coast takes an abrupt turn to a west-east trending shoreline. Point Conception in the northwest and the Channel Islands to the south, create a narrow swell window that shelters much of the Ventura coast from extreme wave events. The Mediterranean climate of southern California results in mild annual temperatures and low precipitation punctuated by episodic and often extreme events frequently associated with El Niños. The sand found on these beaches moves eastward along the coast of southern Santa Barbara and Ventura Counties to the Point

[1] A complete list of the agencies and organizations represented on the steering committee can be found on the Coastal Resilience Ventura website at http://coastalresilience.org/geographies/ventura-county/partners (Accessed 3 April 2013).

Mugu submarine canyon in the south. Winds and wave heights vary seasonally but focusing of waves into the Santa Barbara Channel drive an almost unidirectional longshore sediment transport from west to east in which beaches narrow during the winter and spring (November to April), and widen during the summer and fall (May to October). Tidal fluctuations in this area range from ~3 feet during a neap cycle and up to ~7.5 feet on a spring tide cycle. Longshore transport rates for the study area are approximated by the 49-yr Ventura Harbor dredge record which shows a mean annual rate of ~720,000 yd^3 of sand removed per year (Patsch and Griggs 2007) Variability in the dredge volumes stem from sediment supply, navigational depth requirements and funding.

There are several major faults that segment Ventura County into three typical coastal reaches and are directly related to the coastal backshore type. The Red Mountain fault running along the west side of the Ventura River shows strong uplift. To the west, the coastline is backed by steep bluffs while to the east, the coast is primarily sandy with large sediment accumulation on the Oxnard plain, largely caused by deposition of sediments from the Santa Clara River along the Simi Santa Rosa and Ventura Faults. Finally near Point Mugu, the Bailey, Sycamore Canyon and Malibu Coast faults separate the Santa Monica Mountains from the Oxnard plain and the coast is once again backed by bluffs. Much of the bluff backed stretches of coastline are armored as a result of the construction of major transportation infrastructure, including Highway 101 and Highway 1.

The study area differed slightly based on the analysis. The study area limits are summarized in Table 1 and shown in Figure 1.

Table 1. Study Area Limits by Analysis

Analysis	Study Area(s)	Rationale
Coastal Erosion	North of the Ventura River mouth to south of Mugu Lagoon	Areas to the north and south area bluff-backed and heavily armored. Highway 1 runs along these bluffs and any projected shoreline erosion will depend on how the road is managed and maintained.
Coastal Flooding	All of Ventura County	
Fluvial Flooding	Ventura River from the mouth to 2.5 miles upstream and Santa Clara River from the mouth to 11 miles upstream	Two major rivers in Ventura County.

1.4 Previous Coastal Hazards Analysis

In 2009, Philip William and Associates (now ESA PWA) was funded by the Ocean Protection Council to provide the technical hazards analysis in support of the Pacific Institute report on the “Impacts of Sea Level Rise to the California Coast” (“The Pacific Institute study,” Pacific Institute 2009). In the course of this work, ESA PWA projected future coastal flooding hazards for the entire state based on a review of existing FEMA hazard maps. In addition, ESA PWA projected future coastal erosion hazard areas for the northern and central California coastline, but did not include Ventura County. These hazard areas were used in the Pacific Institute study, which evaluated potential socio-economic impacts of sea level rise. These maps completed as part of the Pacific Institute study specifically disclaimed that the results were not to be used for local planning purposes given the use of “best statewide available data sets”; however, the modeling methods (Revell et al 2011) were developed to be readily re-applied as improved data became available.

The present study has improved and added to the methods from the Pacific Institute Study and applied them to the Ventura Study area with higher resolution local data to analyze the coastal hazards associated with sea level rise. The net result of these improved methods has been to produce projections of future coastal hazards that are suitable to supporting local planning processes.

2. SUMMARY OF GIS DELIVERABLES

This section summarizes the GIS deliverables developed as a result of this work and points to the sections in this document that describe how they were developed in more detail. An example map is included for each type of data. Hazard zones were developed at three planning horizons (2030, 2060, and 2100) based on guidance from the Coastal Resilience Ventura steering committee. All GIS deliverables are provided in the NAD 1983 datum and UTM Zone 11N projection. Horizontal units are in meters.

Coastal Erosion Hazard Zones (Section 8 & Figure 2):

These zones represent future coastal erosion hazard zones, incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and the potential erosion impact of a large storm wave event. At each planning horizon, the hazard zones for all scenarios are overlaid into a single “spatially aggregated” layer that counts the number of scenarios that are projected to be hazardous at a particular location. This is intended to be a planning tool that helps identify which areas will be hazardous for all sea level rise and wave scenarios and, for a given planning horizon, which areas may only be hazardous for the worst case scenarios.

- Erosion hazard zones
  27 polygon shapefiles: 3 planning horizons x 3 wave climates x 3 SLR scenarios

- Spatially aggregated erosion hazard zones
  3 polygon shapefiles: 3 planning horizons

Fluvial 100-year Storm Floodplains (Section 9 & Figure 3):

These floodplains show the projected future 100-year floodplains for the Santa Clara River and Ventura River, based on hydraulic modeling driven by future run-off projections and increasing ocean water levels. The future run-off projections were derived using downscaled climate models.

- 100-year floodplain inundation areas
  7 polygon shapefiles: existing conditions, 3 planning horizons x 2 SLR scenarios

Rising Tide Inundation Zones (Section 10 & Figure 4a and Figure 4b):

These zones show the area and depth of inundation caused simply by rising tide levels (not considering storms, erosion, or river discharge). The water level mapped in these inundation areas is the Extreme Monthly High Water (EMHW) level[2], which is a high water level that is reached approximately once a month.

- Potential inundation area of Extreme Monthly High Water
  10 polygon shapefiles: existing conditions and 3 planning horizons, 3 SLR scenarios

- Depth of water within the rising tide inundation zone (in meters)
  10 rasters (5 meter cell size): existing conditions and 3 planning horizons x 3 SLR scenarios

Coastal Storm Wave Impact Area (Section 11.1 & Figure 5):

The coastal storm wave impact area is one component of the coastal storm flood hazard zone (described below). This hazard area is somewhat analogous to the FEMA V-zone, where the dominant hazard is wave momentum. This is the zone where water could potentially rush inland due to waves breaking at the coast and damage structures, move cars, and knock people off their feet.

- Flooded areas within the wave impact zone
  10 polygon shapefiles: existing conditions and 3 planning horizons x 3 SLR scenarios

Coastal Storm Flood Hazard Zones (Section 11.2 & Figure 5)

This hazard zone maps two types of flooding caused by coastal processes: flooding caused by storm waves rushing inland (see description above) and flooding due to ocean storm characteristics such as storm surge (a rise in the ocean water level caused by waves and pressure changes during a storm). The zones were developed using representative wave conditions based on observed historical events, with added sea level rise. This hazard zone also takes into account areas that are projected to erode in the future, sometimes leading to additional flooding through new hydraulic connections between the ocean and low-lying areas.

- Storm flood hazard zones
  10 polygon shapefiles: existing conditions and 3 planning horizons x 3 SLR scenarios

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[2] Extreme Monthly High Water is approximately 36 cm (14 inches) above Mean Higher High Water at the Rincon Island tide gage or 2.0 meters (6.6 feet) NAVD88.

Combined Storm Flood Hazard Zones (Section 11.3 & Figure 6)

This hazard zone combines the coastal erosion, fluvial storm flooding, wave impact area, and coastal storm flood hazard zones into a single, comprehensive, combined storm flood hazard area. The previous hazards zones are delivered independently so the map user can see the cause(s) of flooding at a particular location. At each planning horizon, the flood hazard zones for all scenarios are overlaid into a single "spatially aggregated" layer that counts the number of scenarios that are projected to cause flooding at a particular location. This is intended to be a planning tool that helps identify which areas will be hazardous for all sea level rise scenarios and which areas may only be hazardous for the worst case scenarios, for a given planning horizon.

- Storm flood hazard zones
  10 polygon shapefiles: existing conditions and 3 planning horizons x 3 SLR scenarios

- Spatially aggregated storm flood hazard zones
  3 polygon shapefiles: 3 planning horizons

2.1 File Naming Convention

The naming conventions for the GIS deliverables are based on hazard zone type, sea level rise scenario, wave scenario (if applicable), and planning horizon, as follows:

Hazard zone type + _ + *Sea level rise scenario* + *Wave scenario* + *planning horizon*

Hazard zone types:

erosionHZ –	Coastal erosion hazard zone
erosionHZ_aggr –	Spatially aggregated coastal erosion hazard zones
river100-yr_floodplain –	Fluvial 100-year storm floodplains
tide_emhw –	Rising tide (Extreme Monthly High Water) inundation area
depth –	Rising tide inundation zone depth
coastal_storm_waveHZ –	Coastal storm wave impact area
coastal_storm_floodHZ -	Coastal storm flood hazard zone
combine_storm_floodHZ -	Combined storm flood hazard zone
combine_storm_floodHZ_aggr -	Spatially aggregated combined storm flood hazard zones

Sea level rise scenarios:
ec – Existing conditions (2010 water level)
s1 – Low sea level rise
s2 – Medium sea level rise
s3 – High sea level rise

Wave scenarios: (only applies to erosion hazard zones)
w0 – Existing waves

w2 – Doubling of El Niño Frequency
w3 – Doubling of El Niño Frequency and Arkstorm in the year 2060

Emissions scenarios: (only applies to fluvial 100-year storm floodplains)
A2 – A2 future emissions scenario
B1 – B1 future emissions scenario

Planning horizons:
2010 (Existing conditions)
2030
2060
2100

Example: The coastal erosion hazard zone at *2100* with medium *sea level rise* (s2) and *existing waves* (w0) is named "erosionHZ_s2w02100.shp"

A complete list of GIS deliverables is provided in Appendix A.

3. DISCLAIMER AND USE RESTRICTIONS

Funding Agencies

These data and this report were prepared as the result of work initially funded by The Nature Conservancy, with supporting funds from the County of Ventura, and the California Coastal Conservancy (collectively "the funding agencies"). It does not necessarily represent the views of the funding agencies, their respective officers, agents and employees, subcontractors, or the State of California. The funding agencies, the State of California, and their respective officers, employees, agents, contractors, and subcontractors make no warranty, express or implied, and assume no responsibility or liability, for the results of any actions taken or other information developed based on this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. These study results are being made available for informational purposes only and have not been approved or disapproved by the funding agencies, nor have the funding agencies passed upon the accuracy, currency, completeness, or adequacy of the information in this report. Users of this information agree by their use to hold blameless each of the funding agencies, study participants and authors for any liability associated with its use in any form.

ESA PWA

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The data are provided "as is" without any representations or warranties as to their accuracy, completeness, performance, merchantability, or fitness for a particular purpose. Data are based on model simulations, which are subject to revisions and updates and do not take into account many variables that could have substantial effects on erosion, flood extent and depth. Real world results will differ from results shown in the data. Site-specific evaluations may be needed to confirm/verify information presented in this dataset. This work shall not be used to assess actual coastal hazards, insurance requirements or property values, and specifically shall not be used in lieu of Flood insurance Studies and Flood Insurance Rate Maps issued by FEMA.

The entire risk associated with use of the study results is assumed by the user. The Nature Conservancy, ESA, County of Ventura, and the State of California, aka “the Coastal Resilience partners” shall not be responsible or liable to you for any loss or damage of any sort incurred in connection with your use of the report or data.

4. DATA SETS

4.1 Planning Horizons and Sea Level Rise Projections

The planning horizons (2030, 2060, and 2100) were selected based on input from the steering committee. Many general plans are currently planning for 2030. The intermediate planning horizon, 2060, was selected because it aligns with the lifespan of a typical building constructed as part of the 2030 plan. Finally, 2100 is the longest planning horizon since this is the last year that most sea level rise projections and guidance consider. This horizon is roughly a typical structural life expectancy for large infrastructure projects, such as bridges, which often prove to be significant constraints to large scale adaptation planning and nature based adaptation solutions. These planning horizons do not address any specific timeline for plans/policies such as General Plans or Local Coastal Plans that use the current year as a baseline and plan for 25, 50, 75, or 100 years into the future.

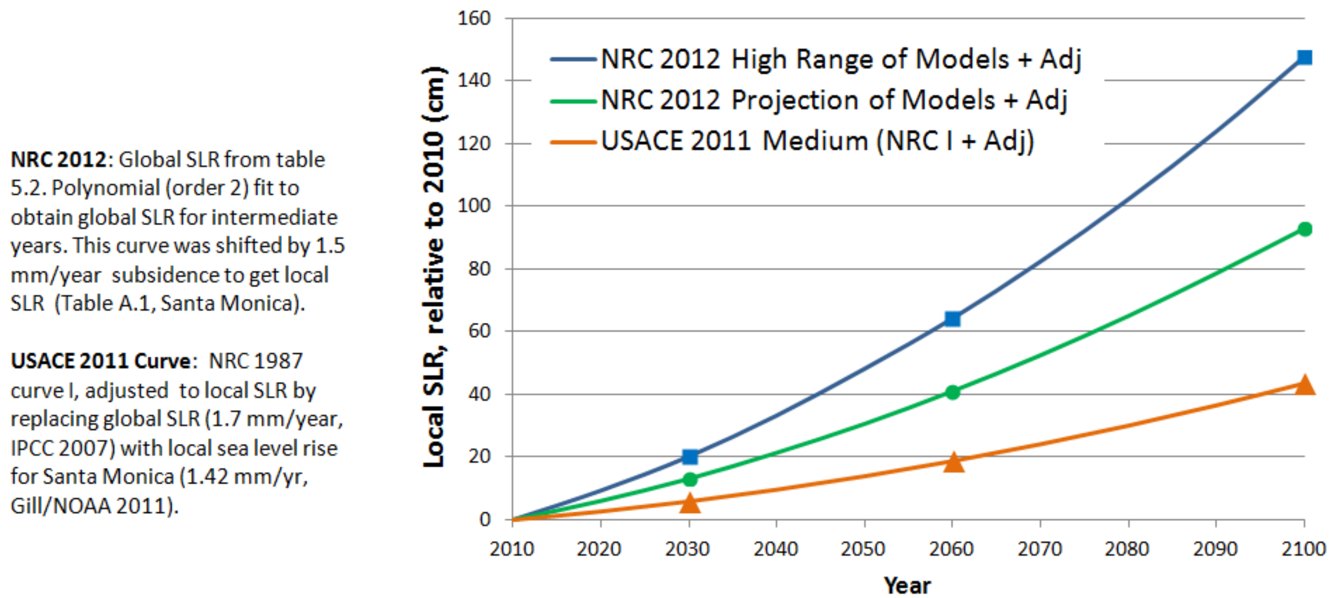
The sea level rise scenarios used in this project are based on recent National Research Council (NRC, 2012) and U.S. Army Corps of Engineers (USACE, 2011) guidance[3]. The USACE medium curve was selected as the low curve in this study because it is the lowest of all the USACE and NRC projections that incorporates future increases in the rate of sea level rise. The high and medium curves are based on the high and middle range of models discussed in the NRC 2012 report. All curves include an adjustment for local vertical land motion using the Santa Monica tide station (NOAA #9410840). The sea level rise at each planning horizon is shown in Table 2 and marked in Figure 7.

Table 2. Sea Level Rise Projections, relative to 2010

Year	*Low SLR*	*Medium SLR*	*High SLR*
2030	6 cm (2.3 inches)	13 cm (5.2 inches)	20 cm (8.0 inches)
2060	19 cm (7.4 inches)	41 cm (16.1 inches)	64 cm (25.3 inches)
2100	44 cm (17.1 inches)	93 cm (36.5 inches)	148 cm (58.1 inches)

[3] While the state of California guidance on sea level rise prescribed the use of 55 inches of rise by 2100, this present study attempted to combine federal and scientific guidance in anticipation of revised guidance expected to be issued by the state shortly after the completion of this study.

Figure 7 - Sea Level Rise Scenarios (Local SLR, relative to 2010)



4.2 Aerial Imagery

Digital Orthophotography

ESA PWA downloaded the aerial mosaics from the NOAA Digital Coast Data Access Viewer (NOAA, 2012b). This imagery is the California Coastal ADS40 4-Band 8 bit collected from August to November 2010 as part of the 2009 – 2011 Coastal LiDAR project. This imagery is reported to have 30 cm resolution with a horizontal accuracy of 2 meters or better at the 95% confidence level. This imagery was downloaded from the USDA GeoSpatial Data Gateway and reportedly has 1 meter resolution and ± 6 meter horizontal accuracy.

Oblique Aerial Imagery

ESA PWA used the California Coastal Records Project website to identify coastal armoring and other relevant structures along the coast in Santa Barbara. These photos were accessed through the project website (Adelman and Adelman, 2010).

4.3 Digital Elevation Models

2009 – 2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth DEM

Downloaded from the NOAA Digital Coast Data Access Viewer (NOAA, 2012a). LiDAR data was collected in November 2009 for the Ventura study area. The LiDAR data has 1 meter resolution with a horizontal accuracy of ± 50 cm and a vertical accuracy of ± 9 cm. The LiDAR data was reclassified, filtered, edited, and hydro-flattened by the DEM creators using 3D hydro breaklines to develop the final DEM[4]. This was the primary DEM used for conducting topographic analysis and mapping coastal erosion and flood hazard zones.

Seamless, High-Resolution, Coastal DEM for Southern California

Downloaded from the USGS website (Barnard and Hoover, 2010). This DEM combines a variety of datasets, including offshore multibeam bathymetry, airborne LiDAR, IfSAR, tsunami DEM, and data interpolation where data was not available (especially between coastal LiDAR and offshore multibeam bathymetry). The coastal LiDAR used in the Ventura study area was collected by the University of Texas on October 15, 2005 as part of the Santa Barbara and Ventura Coastal Processes Study for BEACON. This dataset was used to generate a 2005 shoreline.

USGS Southern California Post Storm LiDAR DEM

LiDAR data and DEM for a 500 meter wide zone along the southern California coast was provided on a hard drive by the USGS. All LiDAR was collected in October 2010 and has a vertical accuracy of ± 9.25 cm (USGS 2011). The DEM was created by Dewberry for USGS to the USGS National Geospatial Program Base LiDAR Specifications, version 12, with a 1 meter cell size and from the class 2, ground, LiDAR points. The ocean surface was flattened from a 3D breakline, but no other hydro-enforcing was done. Detailed information about DEM development is available in the project report (USGS, 2011). This dataset was used as a reference during the topographic analysis (see Section 5).

Airborne 1 LiDAR Flight for Ventura County

LiDAR data collected by Airborne1 in March, 2005 was provided by the Ventura County Watershed Protection District (VCWPD). The data was originally collected for floodplain and sediment transport analyses on the Ventura River, the Santa Clara River, and Calleguas Creek. A subset of points titled “model key points” which were filtered from the raw LiDAR data by Airborne 1 were used for upstream topography on the Ventura River.

4.4 Geology

California geologic map data

Downloaded from the USGS website (Ludington et al. 2005). This GIS database is a compilation of previously published hardcopy maps that have been digitized and combined into a standard format. The California dataset is based on the Geologic map of California by Jennings et al, 1977. Table 3 lists the geologic units observed along the coastline in Ventura County. This dataset was used in development of the backshore classification and division of the coast into analysis blocks.

[4] Detailed metadata describing DEM development is available on the NOAA Digital Coast Data Access Viewer at this link: http://csc.noaa.gov/dataviewer/webfiles/metadata/ca2010_coastal_dem.html (Accessed April 2, 2013).

Table 3. Coastal Geologic Units in Coastal Ventura County

Geologic Unit	Description	General Location
M	Miocene marine rocks (sandstone, shale, siltstone)	Rincon Point, Point Mugu State Park, Solromar
P	Pliocene marine rocks	Faria County Park, Park Number Three, Dulah
Q	Quaternary alluvium and marine deposits	Oxnard Plain
QPc	Plio-Pleistocene and Pliocene loosely consolidated deposits	Emma Wood State Park
Ti	Tertiary intrusive rocks (hypabyssal)	Point Mugu State Park

4.5 Tides

The NOAA Rincon Island tide gage tidal datum was selected because it is the tide gage nearest to (just north of) the Ventura study area (Figure 1). The main use of this datum was for shoreline analysis: mean high water (MHW) was used as the representative elevation for shoreline change analysis (see Section 5.2).

Table 4. Rincon Island Tidal Water Levels

Tide	meters, NAVD88	feet, NAVD88
Extreme Monthly High Water*	2.00	6.55
Mean Higher High Water	1.638	5.37
Mean High Water	1.408	4.62
Mean Tide Level	0.842	2.76
Mean Sea Level	0.835	2.74
Mean Low Water	0.275	0.90
NAVD88	0	0
Mean Lower Low Water	-0.026	-0.09

Notes: The tidal datum analysis period was 1973 - 1990 at National Oceanic and Atmospheric Administration station #9411270; NAVD88 = North American Vertical Datum of 1988. Sources: Tidal Datums (NOAA, 2005b)
* Extreme Monthly High Water was calculated by averaging the maximum monthly high water for all monthly data available at the Rincon Island tide gage (217 months).

Since the Rincon Island tide gage was decommissioned in 1990, the Santa Barbara tide gage (NOAA #9411340, the next closest gage) was used for analyses that required a time series of water levels, such as the wave runup analysis (discussed in Section 7.2).

4.6 Waves

Offshore Waves

A 20-year offshore wave time series (1992 – 2012) of wave height, period, and direction was developed by combining data from multiple offshore buoys:

- Harvest Platform Wave Offshore Buoy (CDIP 063): 1992 - 1998

- Harvest Point Conception Offshore Wave Buoy (CDIP 071): 1998 - 2012
- Diablo Canyon Offshore Wave Buoy (CDIP 076)

All wave data were downloaded from the Coastal Data Information Program (CDIP) website. The Harvest Platform buoy time series was combined with the Harvest Point Conception buoy. The small data gaps that remained were filled with data from the Diablo Canyon buoy. This time series was used to develop nearshore wave data for input to the coastal erosion model (Section 7).

Nearshore Waves

Nearshore wave height, period, and direction from the following buoys were used to calibrate the wave model: Ventura Nearshore wave buoy (CDIP 169), Anacapa Passage (NDBC 46217), Pitas Point Nearshore (CDIP 130), Rincon Nearshore (CDIP 131) Port Hueneme Nearshore (CDIP 141) (Section 7.1). Data were available for the period from March 2010 to February 2011.

4.7 Historic Shoreline Positions

USGS National Assessment of Shoreline Change for Sandy Shorelines

Downloaded from the USGS website (Hapke et al 2006). This assessment calculated short (1970s to 1998)- and long-term (1870s to 1998) shoreline change rates for sandy shorelines along the California Coast. The report includes a GIS database containing four historic shorelines and other GIS files used to calculate the rates of change. The shoreline position error for each time period ranged from 1.5 to 17.8 meters. The most recent shoreline used in this study was extracted from April 1998 LiDAR, which was immediately after the 1997-1998 El Nino. Inclusion of this shoreline likely resulted in over-estimation of long- and short-term erosion rates. Section 5.2 discusses how these erosion rates were updated with three additional recent non-post storm LiDAR datasets.

4.8 Coastal Armoring Database

In 2005, NOAA Coastal Service Center Fellow Jennifer Dare developed a statewide coastal armoring GIS database for the CCC by using a combination of oblique aerial images from the California Coastal Records Photo website (www.californiacoastline.org) and georeferenced orthoimages to identify and locate shoreline protective structures (seawalls, revetments, etc.) along the entire California coast. This database represents structure extents along a single California shoreline. This dataset was used to identify study blocks backed by at least 50% shoreline armoring.

4.9 Culvert Inventory

To improve the mapped projections of future flood hazards it was important to represent the hydraulic connectivity not apparent from the digital elevation model (e.g. through culverts or under bridges). Within the Ventura County study area, this is most relevant for the Mugu Lagoon area, which is characterized by a series of low-lying ponds, interconnected by underground culverts. Martin Ruane at Naval Base Ventura County (NBVC) provided culvert data as a GIS polyline shapefile. This dataset covered the extent of the NBVC Point Mugu property, which includes Mugu Lagoon.

4.10 Downscaled Climate Data: Daily Runoff and Baseflow

Extensive work has been done by several international groups to model the changing trends in global climate caused by anthropogenic and natural sources. International modeling groups have developed coarse scale Global Circulation Models (GCMs) for assessing various climate stressors and responses under a range of emissions scenarios. Emissions scenarios used to drive the GCMs are based on future conditions of population composition and technology advancement as outlined in the International Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios (SRES). Two emissions scenarios covering a range of plausible emissions trajectories have been extensively applied for research and planning purposes in California. The two scenarios—A2 and B1—represent, respectively, medium-high and low projected emissions pathways. Work has been done through the California Climate Change Center (CCCC) to regionalize the broad scale GCM data and to identify the models that most reliably capture the climate phenomena in the state of California (Cayan *et al* 2012). These data have been collected under the IPCC's phase 3 Coupled Model Intercomparison Project (CMIP3) and are available to the public through an online database (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/). For evaluating streamflow projections in Ventura County, data were collected from the hydrology projections available on the CMIP3 database for daily runoff and baseflow. The data sets are available as 1/8° (~14km x 14km) grids covering the western continental United States.

5. TOPOGRAPHIC ANALYSIS

5.1 Beach Profiles

Beach profiles were analyzed to identify topographic feature pertinent to the coastal erosion analysis. Profiles were extracted at 100 meter along-shore spacing from the three digital elevation models described in Section 4.3 at 1 meter point spacing. These profiles were then analyzed in elevation view using an interactive, custom-built MATLAB tool to identify various geomorphic features including the foreshore beach slope (approximately between mean low water and mean high water) and back beach (dune, seawall) toe and crest elevations. All geomorphic feature locations were then mapped in plan-view over high resolution aerial imagery to verify the profile-based interpretation. The 2010 and 2009 LiDAR DEMs were prioritized for use in this analysis; the 2005 LiDAR was consulted when discrepancies arose. In some areas, especially where development encroaches on the beach and the profile shows a consistently flat beach surface, a "dune crest elevation" was estimated by choosing a point directly shoreward of development. The LiDAR elevations were replaced with beach profile survey interpretations in areas where survey data were collected and readily available (e.g. Surfer's Point).

5.2 Shoreline Change Rates – Update to USGS

The USGS sandy shoreline erosion rates (Hapke et al 2006) were updated with three additional shorelines by extracting the mean high water (MHW) contour from the previously discussed digital elevation models. These shorelines as well as the USGS shorelines are summarized in Table 5.

Table 5. Shorelines Included in Shoreline Change Analysis

Year (Month)	Source	Method
1855/1857/1870 (Unknown)	USGS 2006 Study, NOAA NOS T-Sheets	Digitize shoreline
1932/1933/1934 (Dec-Feb)	USGS 2006 Study, NOAA NOS T-Sheets	Digitize shoreline
1974/1975 (Mar/Oct)	USGS 2006 Study, NOAA NOS T-Sheets	Digitize shoreline
1998 (Apr)	USGS 2006 Study, Airborne LiDAR	Extract MHW contour
2005 (Oct)	This study, Composite DEM (Barnard and Hoover 2010)	Extract MHW contour
2009 (Nov)	This study, Airborne LiDAR DEM (NOAA 2012a)	Extract MHW contour
2010 (Oct)	This study, Airborne LiDAR DEM (USGS 2011)	Extract MHW contour

The USGS Digital Shoreline Analysis System (DSAS, Thieler et al 2009) was used to calculate long-term and short-term rate-of-change statistics for an array of transects at 50 meter spacing along the entire study area. Short-term rates were calculated excluding the 1800's and 1930's shorelines. A linear regression was used to calculate the shoreline change rates.

6. BACKSHORE CHARACTERIZATION

ESA PWA developed a backshore classification segmented at 500 meter (~1500 feet) spacing ("Blocks") to conduct the coastal modeling at a scale appropriate to decision making. A baseline approximately 250 meters offshore was divided into blocks based on backshore type (dune, inlet, cliff, armor) and geology. The datasets described in Section 4 and the results from the topographic analysis were summarized into each of these alongshore blocks (78 in total). Each block was assigned a set of parameters including median elevations and slopes, short-term erosion rates, coastal armor types, and geology. A similar backshore characterization was developed for the North-Central California coast in the Pacific Institute study and this study served to extend that baseline to the Los Angeles County line.

Following the initial summary of existing data sets into the blocks, the backshore characterization was adjusted in a number of specific regions:

- Blocks at the mouths of harbor were excluded from erosion analysis because the rate of erosion in these areas is dependent on how the jetties are maintained.

- Blocks that showed accretion but are backed by at least 50% coastal armoring were assigned a shoreline erosion rate of 0 because the accretion processes that occurred prior to construction are expected to differ from the processes after construction. In these cases (5 blocks), we assume that this site had previously experienced episodic erosion that is not represented in average annual regression rates. It is also anticipated that over time as the structure begins to interact with waves more frequently that there will be an acceleration of erosion. Also, armored shorelines can appear to "accrete" due to placement of additional structure such as additional rocks, or by the exposure of the lower foundation which often slopes seaward. The short-term erosion rate from the Ventura Pier through Pierpont Bay to Ventura Harbor was replaced with the long-term rate because the short-term rate showed relatively high accretion due to the construction of the groins in the 1950s. This area is now relatively stable over the long term due to the effectiveness of the groins at trapping and retaining sediment.

- The short-term erosion rates just upstream and downstream of the Santa Clara River were replaced with long-term rates after discussion with BEACON technical advisor Jim Bailard because the short-term rates were dominated by a very strong recent accretion signal caused by the large flood year of 2004-2005 (Barnard and Warrick 2010)

- The shoreline change rates for the blocks on either side of the Mugu wetland outlet were replaced with the averages of the rates further upstream and downstream because the short-term erosion rate reflected the artificial "accretion" caused by the placement of the coastal armoring constructed on the beach.

7. WAVE MODELING AND RUNUP CALCULATIONS

7.1 Nearshore Wave Transformation Modeling

Offshore waves were transformed to nearshore waves using a Simulating Waves Nearshore (SWAN) model. SWAN is an industry-standard numerical model which is incorporated inside the Delft3D package. The SWAN wave model was used to model wave refraction, discretized into bands, for a range of offshore wave directions and periods.

Two model grids obtained from the USGS were combined to model nearshore waves (Barnard and Li 2012, pers. comm.). The coarse grid covers Southern California and the fine grid covers the Santa Barbara Channel (Figure 8 a). Figure 8 b shows the bathymetry of the model grid. The coarse grid was run for offshore wave directions to represent the typical south swell direction of 155 to 245 degrees, in 15 degree increments. The fine grid was run for offshore wave directions to represent the prevailing northwest swell that reaches the study area through the Santa Barbara Channel of 230 to 330 degrees. Each wave direction was run with varying wave periods from 3 to 22 seconds, at 2 second increments. The grids were run separately to obtain higher resolution wave transformation data in the Santa Barbara Channel, where wave conditions are complex and difficult to model at coarser resolutions, while minimizing computational costs.

In SWAN, it is possible to change the power coefficient (*ms*) in the directional spectrum $D(\theta, ms)$ to for the model inputs to calibrate the model for swells or wind waves. The power coefficient (*ms*) for directional spectral distribution is defined as $D(\theta, ms) = A\cos(\theta)^{ms}$.

The one-sided directional width of the spectrum (*DSPR*) which is related to $D(\theta, ms)$, namely, directional spreading or directional standard deviation (in degrees), is defined as

$$DSPR^2 = \left(\frac{180}{\pi}\right)^2 \int_0^{2\pi} \left(2sin\left(\frac{\theta - \bar{\theta}}{2}\right)\right)^2 D(\theta, ms)d\,\theta$$

In this memo, the power coefficients (*ms*) and directional-spreading (DSPR) were chosen based on model calibration and fall within the accepted ranges of these parameters as published in the coastal engineering literature. As the exponent increases, the distribution becomes narrower, and the waves are more “focused” close to the principal direction. The selected coefficient varied with the wave periods (*T*) because the shorter period waves were assumed to be seas and hence have a broader directional distribution, and conversely long periods were associated with swell and a narrow directional distribution:

Table 6. Power Coefficients and Directional Spectrum Width

Period (T) *sec*	**Power Coefficient (ms)** *unitless*	**Directional Spreading (DSPR)** *degrees*
3	2	31.5
5	4	24.9
7	6	21.2
9	8	18.8
11	10	17.1
13	20	12.4
15	30	10.2
17	40	8.9
20	60	7.3
22	60	7.3

Results from separate model runs were used to develop wave transformation matrices for each of 13 shallow (10 m water depth) nearshore locations along the study area (Figure 9). The runs consisted of selected combinations of wave direction (155 to 330 degrees) and wave period (3 to 22 second periods) using a unit wave height of 1.0 meter. A wave transformation matrix is used to convert offshore wave conditions at Harvest Platform to nearshore wave height and period for any time series of offshore data, as long as the data fall within the ranges provided in the matrix (155 to 330 degrees and 3 to 22 second periods). The matrices from the two model grids were combined to produce a single matrix for each of the nearshore points.

The nearshore transformation matrices were used to transform the 20-year time series of offshore waves (Section 4.6) to nearshore wave height and period. These nearshore time series were then used to calculate a time series of runup for each along-shore analysis block (next section).

This approach provides a reasonable approximation of wave propagation from the open ocean to the Ventura County coast by accurately transforming the powerful swells that are primarily important in shaping the California coast. However, seas generated landward of the open ocean were not included. These “local seas” can be significant contributors to erosion and flooding, and their omission may result in under-estimation of hazards in some areas. Several other physical processes were also not included owing to the additional computational effort and generally lesser importance: wave reflection, diffraction and current-induced refraction.

7.2 Wave Runup Calculations and Total Water Level Curves

The total water level is a water elevation determined by the sum of tides, waves and wave runup, and other components including nearshore currents, storm surge, and atmospheric forcing such as El Niño. As sea level rises, the relative amount of time that the water contacts the toe of the dune will increase. This relative increase is the key driving factor in this dune erosion model.

For each along-shore study block the wave runup was calculated using the Stockdon equation (Stockdon et al 2006) with the median beach slope for the block and the time series of wave height and period developed at the nearest of the 13 nearshore wave transformation points. Runup was added to the historic tide water levels from the Santa Barbara tide gage (NOAA #9411340) from 1992 to 2012 to produce a total water level time series for each block.

Future sea level rise was added to the total water level incrementally at each 10-year time step, with the magnitude depending on which of the three sea level rise scenarios was being modeled. For the “doubling of El Niño frequency” scenario, two regular years in the existing wave time series were replaced with an additional 1982-1983 and 1997-1998 El Niño years.

The time series of total water levels for each block and scenario was converted to a total water level exceedance curve, which shows the relative amount of time that wave runup reaches a certain elevation (example in Figure 10). These curves are the key input to the dune erosion model discussed in the following section .

8. SHORELINE EROSION HAZARD ZONES

Shoreline erosion hazard zones were developed using methods described in the Pacific Institute study, with the backshore characterization as the main input. The most important variables in this model are the backshore toe elevation and the total water level. This section gives a brief description of the erosion hazard zone methods. For more details about the methods please see the complete Pacific Institute study (PWA 2009 and Revell et al 2011).

The coastal hazard zones are developed from three components: historic erosion, additional erosion due to sea level rise, and the potential erosion impact caused by a large storm wave event (e.g. 100-year or 500-year). The historic erosion rate is applied by the planning horizon to get the baseline erosion, which is an indirect means to account for the sediment budget. It is important to note that this potential erosion model ignores the effect of coastal armoring at mitigating erosion. However, if shoreline armoring has been present and maintained over a number of years its presence will be reflected in the calculated historic erosion rates. Additionally, the model does not account for other shore management actions such as sand placement to mitigate future shore recession. In this region, where beaches are controlled in part by dredge placements, we assumed that there were no changes to existing dredge management practices.

The potential inland shoreline retreat caused by sea level rise and the impact from a large storm event (either 100-year or 500-year, depending on the scenario) was estimated using the geometric model of dune erosion originally proposed by Komar et al (1999) and applied with different slopes to make the model more applicable to sea level rise (Revell et al 2011). This method is consistent with the FEMA Pacific Coast Flood Guidelines (FEMA 2005).The ARkstorm[5] was applied by including a one-time 500-year erosion event using the same process as the 100-year storm event. All potential erosion distances were calculated relative to 2010. Potential erosion accounts for uncertainty in the duration of a future storm. Instead of predicting storm specific characteristics and response, this potential erosion projection assumes that the coast would erode or retreat to a maximum storm wave event with unlimited duration.

Table 7 shows an example of how the erosion rates increase over time as a function of sea level rise at one particular location. It also includes an estimate of potential erosion caused by two large storm events at this location. The projected continuous erosion is added to the potential erosion caused by a large storm to delineate the coastal erosion hazard zone.

[5] A hypothetical but scientifically realistic “superstorm” scenario published by the USGS. More information is available here: http://pubs.usgs.gov/of/2010/1312/ (Accessed 2 April 2013).

Table 7. Projected Erosion Rates for Block 73, at Mandalay Beach Road (meters/year)

Date Range	**Low Sea Level Rise** *Existing Waves*	**Medium Sea Level Rise** *Existing Waves*	**Medium Sea Level Rise** *Existing Waves*
2010 to 2020	0.30	0.47	0.64
2020 to 2030	0.33	0.52	0.71
2030 to 2040	0.36	0.58	0.82
2040 to 2050	0.38	0.63	0.91
2050 to 2060	0.41	0.69	0.97
2060 to 2070	0.44	0.74	1.07
2070 to 2080	0.47	0.79	1.16
2080 to 2090	0.49	0.85	1.25
2090 to 2100	0.52	0.88	1.36

Potential erosion caused by a 100-year storm wave event = 38 meters
Potential erosion caused by a 100-year storm wave event = 46 meters

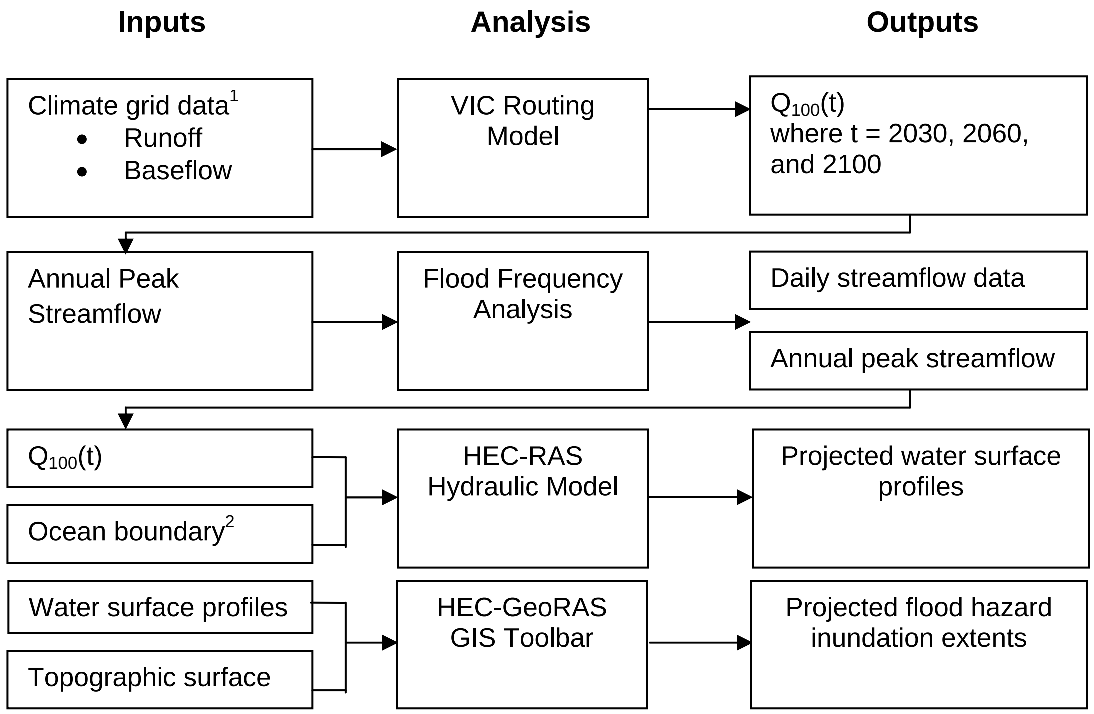
8.1 Erosion Hazard Mapping

The erosion hazard zones were mapped for each sea level rise scenario, wave scenario, and planning horizon using a one-sided buffer in ESRI's ArcGIS software with an ArcINFO® license. The reference line for the erosion hazard zone is the location of the toe of the dune. The hazard zone also includes the area from the offshore baseline to the reference line, as this area is already in the active coastal zone.

9. FLUVIAL 100-YEAR FLOOD HAZARD ZONES

The fluvial flood hazard analysis was carried out using a combination of downscaled climate projections, hydraulic modeling, and floodplain inundation mapping to evaluate the impact of climate change on fluvial flooding on the Santa Clara River (SCR) and Ventura River (VR) for a suite of climate scenarios. The fluvial model was initially developed to support FEMA's flood mapping along these rivers and has been adapted and re-run to incorporate climate change influences on precipitation and sea level rise. The general stepwise procedure conducted to characterize project flood frequency and flood hazard conditions is summarized in Figure 11.

Figure 11 – Fluvial flood hazard analysis workflow



[1]Data produced by CCCC and hosted on CMIP3 data archive
[2]Dynamic water level

This approach was carried out for both A2 and B1 emissions scenarios for both the Santa Clara and Ventura rivers using averaged output from a set of 6 GCMs. The GCMs selected match the list evaluated by Cayan *et al* (2012) for the 2012 California Vulnerability and Adaptation Assessment. The six models selected for the assessment were:

- The National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM);
- The National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluids Dynamics Laboratory (GFDL) model, version 2.1;
- The NCAR Community Climate System Model (CCSM);
- The Max Plank Institute 5th generation ECHAM model (ECHAM5/MPI-OM);
- The medium-resolution model from the Center for Climate System Research of the University of Tokyo and collaborators (MIROC 3.2); and
- The French Centre National de Recherches Météorologiques (CNRM) models.

Downscaled model data from the CMIP3 archive was downloaded for these models and averaged to estimate future conditions hydrology on the SCR and VR. The tidal boundary condition was set based on the sea level rise and dynamic water level analysis conducted for this study. The full list of scenarios analyzed for the fluvial hazard analysis is presented in Table 8.

Table 8. List of Scenarios and Parameters for Fluvial Flood Hazard Analysis

River	Time horizon	Emissions scenario	GCM	Fluvial condition	Tidal condition	Tidal Boundary (ft NAVD)
Santa Clara River	2030	A2	Average	Q100 (See Table 10)	High SLR + DWL + 1'	12.7
	2060					14.21
	2100					16.73
	2030	B1			Medium SLR + DWL + 1'	12.7
	2060					13.39
	2100					15.09
Ventura River	2030	A2	Average	Q100 (See Table 10)	High SLR + DWL + 1'	17.91
	2060					19.69
	2100					22.7
	2030	B1			Medium SLR + DWL + 1'	17.81
	2060					19.29
	2100					21.19

As shown in the table, a total of six future scenarios were modeled for each of the rivers analyzed. The process for deriving projected flood frequency, conducting the hydraulic modeling, and developing flood hazard inundation maps is described in the following sections.

9.1 Flood Frequency

Projections for a number of hydrologic variables including surface runoff and baseflow (i.e. subsurface flow), have been derived using downscaled temperature and precipitation grids as input to the University of Washington's Variable Infiltration Capacity (VIC) model. The VIC model is a large scale physically based model which applies information on land use, vegetation coverage, elevation, and soil moisture capacity, to estimate energy and water fluxes at each grid cell (Gao *et al* 2009). The VIC model also employs a large-scale routing scheme developed by Dag Lohmann et al (Lohmann *et al* 1996, 1998a, 1998b).

Using the VIC routing model with daily runoff and baseflow data downloaded from the CMIP3 archive, we developed a daily discharge time series for the two analyzed rivers from which peak annual flows were extracted for each year. The peak annual streamflow values were used to estimate the change in flood frequency for each river as described below.

Santa Clara River

The Ventura County Department of Public Works (VCDPW) has developed flood magnitudes for the 10-, 50-, 100-, and 500-year flows (n-year flows) for the Santa Clara River at multiple points in the watershed (VCDPW, 2006) using the guidelines in Bulletin 17B (USGS, 1982). Measured data for the lower SCR was collected from the USGS Santa Clara River at Montalvo gauge near Highway 101 (USGS gauge number 1114000) for water years 1932-2005. The peak flows from years 1932-1993 were adjusted in a prior study by the Ventura County Public

Works Agency (VCPWA) to account for missing data years and the influence of reservoirs in the watershed (VCWPA 1994). The existing conditions flood frequency for the SCR at Montalvo is summarized in Table 9.

Table 9. Santa Clara River Existing Conditions Flood Frequency

Source	Recurrence Interval (n-year)			
	10-year	50-year	100-year	500-year
VCWPD 2006	72,800	172,000	**226,000**	373,000

A time series of peak annual streamflow values from 1950-2100 was extracted from the daily time series of runoff and baseflow data routed to the lower SCR using the VIC routing model. Using this data, a moving flood frequency curve was derived for future conditions relative to model output from the historic model period from 1950-2010 using the Bulletin 17B statistical approach. The trend in the 100-year floods for three future time horizons, 2030, 2060, and 2100, is summarized in Table 10.

Table 10. Santa Clara River Projected Flood Frequency (100-year Recurrence Interval)

	Time-horizon	**A2 Scenario**	**B1 Scenario**
% Change relative to historic period (1950 – 2010: 226,000 cfs)	2030	23%	-4%
	2060	15%	-9%
	2100	11%	-14%
Projected Flow (cfs)	2030	278,000	216,000
	2060	260,000	205,000
	2100	252,000	195,000

Ventura River

Several studies have been undertaken to estimate flood frequency at various points on the Ventura River. The effective Flood Insurance Study for Ventura County (FEMA 2010), contains discharge values for the 10-, 50-, 100-, and 500-year event which were derived in a 1970 USACE hydrology study conducted for FEMA (FEMA 2010). The US Bureau of Reclamation (USBR) developed peak flow estimates for floods with 2-, 5-, 10-, 20-, 50-, 100-, and 500-year return periods (USBR 2006). This study suggested that, due to weather pattern variability within the Ventura River watershed, the historic distribution of flood peaks does not adhere to the standard log-Pearson III (LPIII) probabilistic distribution. As an alternative, the USBR applied a "top-fitting" approach wherein a regression relationship was developed for the seven largest flows on record and used to estimate peak flows for events with recurrence intervals greater than 10 years. The 2-, and 5-year recurrence floods were estimated in a previous study (Bullard 2002b).

Ventura County developed a hydrologic model using the Hydrologic Simulation Program-Fortran (HSPF) for the Ventura River watershed (VCWPD 2010). Flood frequency for this analysis was derived using the LPIII method to estimate the 100-year peak discharge which was used to calibrate the hydrologic model. Peak discharges for the 10-, 50-, and 500-year floods were estimated using multipliers (relative to Q_{100}) derived from the LPIII flow-frequency results for several gauges in the watershed.

A 2010 hydrologic study was conducted by HDR to update the effective discharges in the FEMA FIS. This study compared the log-Pearson III and top-fitting results from the USBR report, Ventura County HSPF and LPIII analyses, new estimates derived using USGS regional regression relationships for California (USGS 1982), and the effective FEMA data. In general, the 2010 HDR study results agreed with the USBR results, the USGS regression results, and the FEMA published values. A comparison of the n-year flood peaks from the USBR, HDR, and FEMA is shown in Table 11.

Table 11. Ventura River Existing Flood Frequency

		Recurrence Interval (n-year flood)			
Location	**Source**	**10-year**	**50-year**	**100-year**	**500-year**
Ventura River, at Shell chemical plant	FEMA	34,000	66,000	77,000	102,000
	USBR	41,300	67,900	78,900	105,500
	HDR[1]	41,300	67,900	78,900	105,500
Ventura River, at Pacific Ocean	FEMA	34,000	67,000	78,000	103,000
	USBR[2]	-	-	-	-
	HDR	41,438	68,126	**79,166**	105,500

[1]Adopted from USBR report
[2]None presented

For this analysis, the results from the HDR hydrologic review were used as the basis for the existing conditions hydrology on the Ventura River.

As for the Ventura River analysis, the VIC routing model was employed to route downscaled daily data of baseflow and runoff to the outlet of the Ventura River to construct a daily time series of streamflow from 1950-2100. This dataset was used to obtain modeled peak annual flow estimates out to year 2100. Using these data, a moving flood frequency curve was derived for future conditions relative to model output from the historic model period from 1950-2010. The trend in the 100-year flood for three future time horizons, 2030, 2060, and 2100, is summarized in Table 12.

Table 12. Ventura River Projected Flood Frequency (100-year Recurrence Interval)

	Time-horizon	A2 Scenario	B1 Scenario
% Change relative to historic period (1950 – 2010: 79,166 cfs)	2030	49%	-8%
	2060	42%	-14%
	2100	35%	-18%
Projected Flow (cfs)	2030	118,000	73,000
	2060	112,000	68,000
	2100	107,000	65,000

9.2 Hydraulic Modeling

Santa Clara River

For modeling future conditions flood hazards on the SCR we used an existing FEMA hydraulic model which was developed using the 1D HEC-RAS modeling platform. The model was developed by FEMA for a 2008 restudy of the SCR and 9 of its tributaries (FEMA 2008). The model was obtained for our study from a preliminary release of the Technical Support Data Network (TSDN) released by FEMA in 2008. The FEMA model extends from the mouth of the river at the Pacific Ocean to the Los Angeles County Line. For the flood hazard analysis we trimmed the model extent to go between the Pacific Ocean at the downstream west end and Todd Road at the upstream eastern boundary.

For evaluating out of bank flows on the lower portion of the SCR, FEMA divided the model into individual geometries and applied an iterative flow balancing scheme to match water levels between the main channel and the individual overbank flowpaths. FEMA modeled the overbank flows leaving the main channel of the SCR using a series of four independent model runs separately representing:

1. The main SCR channel with lateral structures capturing levee overtopping (main SCR)
2. The left overbank of the river downstream of highway 101 and north of Gonzales road (LOB)
3. Flows overtopping Gonzales road that do not rejoin the main channel flow (East-Gonzales)
4. Flows overtopping Gonzales road that eventually rejoin the main channel (West-Gonzales)

The cross-sections covering these four plans downstream of Highway 101 are shown in Figure 12. The modeling consisted of iteratively running these plans and balancing flows in the main channel and overbank areas until water surfaces matched within a tolerance of 0.5 feet at conjoining cross-sections between the independent flowpaths. The sequence of modeling steps, depicted in Figure 12, is as follows:

1. Flows overtop the main SCR into the LOB downstream of Highway 101 (Figure 12, 1a-1d)
2. The LOB flows rejoin the main SCR at XS 11169 (LOB XS 3658) and the water surface at this location is used as the downstream boundary of the LOB run
3. At XS 4972 in the LOB, flows overtop Gonzales Rd entering the East-Gonzales flowpath at XS 9194. Flow at this location was balanced between the LOB and East-Gonzales until water surfaces matched.
4. At XS 3658 in the LOB, flows overtop Gonzales Rd entering the West-Gonzales flowpath at XS 5115. Flow at this location was balanced between the LOB and West-Gonzales until water surfaces matched.
5. Some flow from West-Gonzales at XS 5155 flows into the East-Gonzales path at XS 6675. Flows were balanced at this location until water surfaces matched between the to Gonzales overflow flowpaths.
6. The total discharge estimated in the overbank flowpaths was removed from the main SCR at XS 11169 and the water surface was compared to the matching cross-sections in West-Gonzales (5115) and East-Gonzales (6675)
7. Flow from West-Gonzales sections 2999, 1233, and 273, re-enter the main SCR at sections 8849, 5860, and 4659 respectively (Figure 12 , 7a-7c). The amount of flow that re-enters the

main channel was determined by balancing water surfaces between the main SCR and West-Gonzales flowpaths at these sections.

These steps were repeated until water surfaces matched within the 0.5-foot tolerance

A more integrated approach was adopted for our analysis whereby all the flowpaths were combined into a single geometry connected via lateral weir structures which can be set to automatically balance the water levels between independent flowpaths. While this simplified model operation it retained all of the original specificity in the channel geometry and model components. The benefit of unifying model geometries under a singular run is that the iterative water level and flow balancing procedures, manually done by FEMA in their 2009 model, can be automated within HEC-RAS. Automating this procedure allowed for improved convergence between water levels at the overtopping locations and potentially more accurate flow balancing between the main SCR channel and the overbank flowpaths.

Under future scenarios higher mean sea level conditions are likely to lead to increased depositional patterns along the lower reaches of the SCR. Additionally changes in the hydrology and land use in the upper watershed are likely to lead to changes in erosion and sediment delivery through the length of the river. To account for the long term bed aggradation that may be a consequence of sea level rise and watershed sediment inputs, future conditions model scenarios were configured assuming that bed aggradation was equal to the magnitude of the change in mean sea level. This was represented in the model by raising the bed elevation of downstream cross-sections and linearly projecting the bed to a point where the aggradational effects of sea level rise will likely attenuate.

Modeled 100-year water surface profile results of projected changes in hydrology, sea level rise, and channel profile are shown in Figure 13. The projected range of bed profiles is also contained in this figure.

Ventura River

Hydraulic modeling for the Ventura River was conducted using the HEC-RAS model developed by the US Bureau of Reclamation for the Matilija Dam Ecosystem Restoration Project (USBR, 2006). The model was constructed in support of hydrologic, hydraulic, and sedimentation analyses conducted by the USBR. The model extends from the river mouth at the Pacific Ocean to the Matilija Dam. Cross-sections were extracted from the 2005 LiDAR survey conducted by Airborne 1 described above. The six future conditions flood scenarios were modeled on the Ventura River assuming the same bed aggradation pattern that was applied for the SCR analysis. The resultant water surface profiles and range in projected channel bed profiles are shown in Figure 14.

9.3 Fluvial Sediment Yield

Using the rating curves developed by Warrick and Mertes (2009) for the Santa Clara River and Ventura River, in conjunction with the projected daily flow record derived for the flood frequency analysis, the relative change in future conditions sediment yield was evaluated for both A2 and B1 emissions scenarios. The rating curves were developed for a number of rivers in the western transverse ranges of California using gauge records of suspended sediment concentrations and discharge. For the sediment yield analysis, the rating curve for the USGS gauge at Montalvo (USGS 11114000) was used for the Santa Clara River, and the rating curve for the USGS gauge at Ventura (USGS 111185000) was used for the Ventura River. The two rating curves are shown in Figure 15.

Given the limitations of this study, projected sediment yield conditions were analyzed assuming the sediment rating curve was stationary through time. There are a number of factors that lead to significant uncertainty with this assumption including future conditions including: land use changes, the impact of climate change on fire risk which influences watershed sediment yield, and errors associated with data limitations for the current conditions sediment rating curve. Refinements to the sediment yield analysis would include accounting for these future watershed conditions which will have a significant impact on overall sediment delivery through time.

To provide a general measure of the trend in sediment delivery over time as a function of changes to precipitation and streamflow only, the flow record derived from the downscaled baseflow and runoff data was used to compute daily sediment load from the sediment rating curves for the SCR and VR. This was converted into an annual loading rate and used to compute the change in annual sediment delivery for future years relative to a 30-year historic average selected to capture the period from 1980-2010. A 10-year moving average of sediment delivery relative to this historic average is shown for both rivers under A2 and B1 emissions scenarios in Figure 16. A summary table of selected output years is included below in Table 13.

Table 13. Relative Change in Annual Watershed Sediment Yield over Time

		Santa Clara River		Ventura River	
	Time Horizon[1]	A2	B1	A2	B1
% Change relative to 1980-2010 average	2030	69.5%	11.4%	77.6%	37.3%
	2050	0.5%	-20.0%	-12.8%	30.8%
	2100	-17.7%	-31.9%	1.2%	-3.0%

[1] 10-year moving average is centered on the identified year

The trend in rainfall and streamflow, and thus in estimated sediment yield, reflects a general decreasing trend in sediment delivery through the end of the century for both rivers and emissions scenarios. This agrees with the recently released third assessment report on climate change in California from the California Climate Change Center (CCCC) which found that a plurality of GCMs now show drier end-of-century conditions than the present day (CCCC 2012). The data shown in Figure 16 show a slight rise in sediment production in 2030 however the range of inter-annual variability for the short-term is similar to historic conditions. Though the general trend is towards drier end-of-century conditions, the downward trend is less pronounced on the Ventura River.

For the Santa Clara River, Stillwater (2007) found that the dominant discharge, or the discharge for which the majority of sediment transport occurs, corresponds to the largest flow on record. Traditionally, dominant discharge falls somewhere in the more frequently occurring flow range, often in the range of the 2-, to 5-year flood. This finding indicates that sediment delivery on the SCR is governed by the next largest flood event which may still be larger than the flood of record even under future conditions that are drier on average than existing conditions. Additionally, higher projected temperatures will lead to increased fire risk in this region which will increase watershed sediment production from burned land. Future conditions land development also has the potential to disrupt runoff and sediment transport regimes which will influence future sediment conditions. With the range of uncertainty in sediment conditions, it was determined reasonable to assume that sediment conditions were sufficient to increase the thalweg in the lower reach of the SCR at the same rate as sea-level rise.

For the Ventura River, the Casitas and Matilija dams have historically impounded a significant portion of the upper watershed sediment delivery. Fluctuations in watershed runoff upstream of the dams will not likely impact the sediment delivery to the lower watershed in the future with these dams operating under current conditions. The same assumption was adopted for modeling the downstream thalweg on the VR as for the SCR due to the range of additional factors influencing watershed sediment yield, however this trend in downstream bed levels may be less likely in the case of the Ventura River. Improving the assumption for downstream bed levels on both rivers would necessitate a more detailed analysis of changes in other significant factors driving watershed sediment yield, including analysis of future management strategies such as removal of Matilija Dam.

9.4 Fluvial 100-year Floodplain Hazard Mapping

Floodplain hazard inundation mapping was conducted using the HEC-GeoRAS tool in ArcGIS. HEC-GeoRAS enables data transfer between HEC-RAS and GIS. The tool was used to export modeled water surface results from HEC-RAS to GIS which are then projected against a topographic surface to create quasi-two-dimensional output from one-dimensional cross section results.

For the Santa Clara River, water surface profile results were projected against a composite topographic surface based on the 2009 – 2011 Coastal Conservancy LiDAR dataset which covers coastal areas and the 2005 Airborne 1 LiDAR flight which was used to cover upstream areas. The inundation extents for overbank areas are approximate as one-dimensional modeling is not well suited for separated flowpaths with complex flow directions.

A composite surface of the 2009 – 2011 Coastal Conservancy LiDAR and the Airborne 1 LiDAR datasets was also developed for mapping inundation extents on the Ventura River. Water surface results were imported into GIS using HEC-GeoRAS and projected against the composite surface for the six future climate scenarios.

Some subtle differences between the existing FEMA DFIRM and the project future flood levels which are largely related to re-running the existing conditions flood model and mapping the impact on the new higher resolution statewide LIDAR topography. These differences constitute an improvement to the previous FEMA flood mapping efforts.

10. RISING TIDES HAZARD ZONES

The “rising tides” hazard zone was developed separately from the other hazard zones to show which areas will be regularly flooded by high tides under future sea level rise (not considering storm events). Two types of rising tide dataset were developed: a general inundation area and a depth raster.

10.1 Mapping monthly inundation areas

The monthly Extreme Monthly High Water (EMHW) was estimated by averaging the maximum monthly water level for every month recorded at the Rincon Island tide gage (EHW = 2.0 meters NAVD88[6]). Sea level rise projections were added to the EHW for each sea level rise and planning horizon (Section **Error! Reference source not found.**) and mapped over the 2009 – 2011 CA Coastal Conservancy DEM (Section 4.3). Areas in the DEM below the flood elevation were marked as “flooded.” Then, flooded areas that were connected to the ocean through overland flow or through culverts were selected, as well as any pools within 3 meters of areas connected to the ocean to conservatively account for seepage and potential errors in the DEM. For comparison, the Pacific Institute included areas within 50 meters of a flooded area to account for the coarser DEM used in that analysis. The NOAA SLR Viewer does not utilize this method and instead shows areas as “low lying” but not flooded. Gaps smaller than 1 acre were assumed flooded, and isolated pools less than 3 m^2 were omitted. This analysis is intended to represent areas that may be inundated at least on a monthly recurrence. The hydraulic conveyance (flow rate and volume) through the connections (e.g. culvert) were not modeled, and hence these are potential flood limits.

10.2 Mapping depth within monthly inundation areas

A depth map was developed by overlaying the monthly inundation area over the topography and using the difference between the flood elevation and the topography to calculate depth. The 2009-2011 CA Coastal Conservancy DEM is hydroflattened, which means that the reported elevations in wet areas correspond to an approximate water surface elevation rather than the actual bathymetry. These areas (as identified by the 3D breaklines provided with the DEM) were assigned a value of 999.

[6] Extreme High Water is approximately 36 cm (14 inches) above Mean Higher High Water (the daily average of the highest tides) at the Rincon Island tide gage.

11. COASTAL STORM FLOOD HAZARD ZONES

11.1 Coastal Storm Wave Impact Area

The coastal wave hazard zones were developed using representative wave conditions based on observed historical events. This developed from steering committee discussions requesting information on the inland extent of wave run up or a “knock you off your feet hazard zone”. The nature of the Ventura coastline lends itself to two types of destructive wave overtopping events. Storms originating in the Pacific Northwest tend to cause the most coastal flooding in the northern half of the study area (north of Port Hueneme) while strong swells from the south cause the most coastal flooding in the southwest-facing southern part of the study area (south of Port Hueneme). The two coastal flood events selected for this analysis are summarized in Table 14. The still water level was increased by sea level rise for each of the future sea level rise scenarios and planning horizons (see Section **Error! Reference source not found.**). Wave height, period, and direction were assumed to stay constant for all future scenarios.

Table 14: Representative Wave Conditions for Flood Event

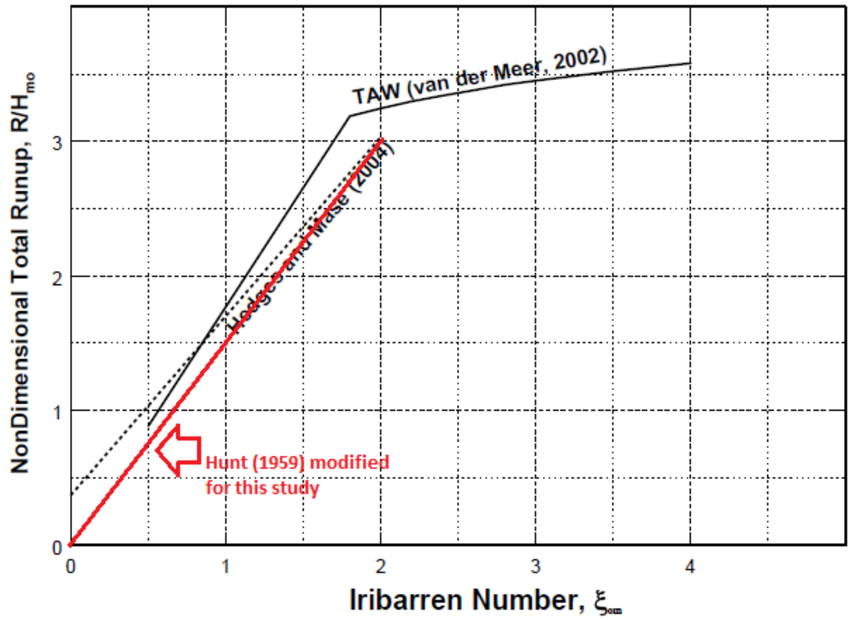
Area	Still Water Level	Significant Wave Height	Significant Wave Period	Dominant Wave Direction
North of Port Hueneme	2.35 m NAVD	7.3 meters	22 seconds	279 degrees
South of Port Hueneme	2.35 m NAVD	3 meters	25 seconds	180 degrees

Sources: Extreme still water level is the highest observed water level at the Rincon Island tide gage, on January 27th, 1983. Significant wave height, period, and direction for north area from Seymour, 1996 as recorded on the Harvest Platform buoy (CDIP 071) Wave heights and periods for south area are design conditions used in the Naval Base Ventura Erosion Control Study Report (BradyG2 and Moffatt & Nichol, 2012). The wave direction and still water level was assumed for the south area.

Wave impact hazard zones were assessed using a wave run-up analysis on fourteen representative profiles along the entire Ventura County study area (Figure 9). The profiles are based on the USGS High Resolution DEM (Barnard and Hoover, 2010) and the USGS Southern California post-storm DEM (USGS, 2011). They reflect the wide range in topography and bathymetry across the Ventura study area.

A run-up program developed by ESA PWA and consistent with FEMA guidelines was used to iteratively calculate the dynamic water surface profile along each representative profile, the nearshore depth-limited wave, and the run-up elevation at the end of the profile. Wave run-up is computed using the method of Hunt (1959) which is based on the Irribarren number (also called the Surf Similarity Parameter), a non-dimensional ratio of shore steepness relative to wave steepness. The run-up is limited to a maximum of about three times the incident wave height, which is generally consistent with other methods that rely on the relative steepness parameter, as depicted in Figure 17. While there are a variety of run-up equations, they provide a range of results and hence the most simple and direct was chosen (Hunt, 1959).

Figure 17 - Non-dimensional Total Runup vs. Iribarren Number



Wave runup relative to wave height is modeled as being proportional to the Iribarren Number, also known as the Surf Similarity Parameter, which is the ratio of the beach slope to the square root of wave steepness (relative slope steepness). Note that the wave runup is limited above a value of three times the incident wave height. (Source: FEMA 2005).

The program also uses the Direct Integration Method (DIM) to estimate the static and dynamic wave setup and resulting water surface profile (FEMA 2005; Dean and Bender 2006; Stockdon 2006). The methodology is consistent with the FEMA Guidelines for Pacific Coastal Flood Studies for barrier shores, where wave setup from larger waves breaking farther offshore, and wave runup directly on barriers combine to form the highest total water level and define the flood risk (FEMA 2005). This program also incorporates surface roughness of the structure and overland which acts as friction on the uprush of the waves and uses a composite slope technique as outlined in the Shore Protection Manual (USACE 1984) and Coastal Engineering Manual (USACE 2002).

The runup equation uses an average slope. For very steep and very flat slopes, the numerical routine can over-predict the vertical and horizontal extent of runup, respectively. Hence, for very steep profiles the wave runup height is limited to a maximum value based on the slope of the cliff (or armor), extended upward. Similarly for very flat profiles, the maximum inland extent is limited to a maximum value based on a slope of 1:100. The wave impact area was determined using the maximum inland extent generated from the runup program (above). For very flat backshores and depressions, where the maximum inland extent was limited to a 1:100 slope, the computed wave runup elevation was sometimes above the land surface. The excess height of runup (computed elevation minus ground elevation) was converted to an additional inland propagation distance calculated as 30 feet times the excess height.

Within the wave impact area, the runup elevation at the inland extent was mapped over the CA Coastal Conservancy LiDAR DEM to generate an approximate extent of inundation. This final step ensures that features at very high elevations close to the coast (i.e. a landfill) are not mapped as inundated.

11.2 Coastal Storm Flood Hazard Zones

The coastal storm flood hazard zone combines the various hazards related to coastal storms using hydraulic connectivity:

- Shoreline erosion hazard zones (Section 8), areas that are eroded are assumed to be flooded during a large storm).
- Wave impact zone flooding (Section 11)
- Rising tides water level, calculated using the highest observed water level (HOWL) at Rincon Island tide gage, with added sea level rise depending on the scenario. This component was mapped using the same methods described in Section 10.1.

Flooded areas with connectivity to the ocean (either overland or through culverts) were mapped, as well as any pools (greater than 3 m^2) within 3 meters of areas connected to the ocean to conservatively account for seepage and potential errors in the DEM. For the same reason, donut holes smaller than 1 acre (208 ft x 208 ft) were assumed flooded.

11.3 Combined Storm Flood Hazard Zones

The combined storm flood hazard zones were developed by merging and dissolving the fluvial 100-year storm hazard zones (Section 9) with the coastal storm flood hazard zones (Section 11.2). An example of the combined storm flood hazard zones is shown in Figure 6.

Since the river floodplain scenarios consider two global climate change scenarios (A2 and B1), rather than simply sea level rise curves, the river floodplain projections were paired with the coastal flood hazard zones as follows:

Coastal sea level rise scenario	Future climate scenario used in river modeling
Existing conditions & low sea level rise →	Existing 100-year river floodplains
Medium sea level rise →	Projected 100-year river floodplains for B1 scenario
High sea level rise →	Projected 100-year river floodplains for A2 scenario

This pairing scheme ensured that the widest possible range of flood hazards would be represented in the result combined storm flood hazard zones.

12. ASSESSING RANGE OF HAZARD ZONES

At each planning horizon, the combined storm flood hazard zones (Section 11.3) for each SLR scenario were combined using a process called “spatial aggregation” to show the number of scenarios that are projected to cause flooding for a given location. The concept of spatial aggregation is shown in Figure 18 and an example output is shown in Figure 6 for the 2100 planning horizon. Spatial aggregation was also conducted for the coastal erosion hazard zones, but with only the nine scenarios (3 wave climate and 3 sea level rise). An example output for the erosion hazard zone aggregation is shown in Figure 2.

13. LIST OF FIGURES

14. LIST OF TABLES

15. REFERENCES

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4/2/2013

N

0 2.5 5 Miles

Legend

- Ventura County Shoreline (Coastal Flood Study Area)
- Ventura County Shoreline (Flood & Erosion Study Area)
- Major Rivers (Fluvial Study Area)

figure 1

Ventura County Climate Change Vulnerability Study

Coastal Hazards Mapping Study Area

ESA PWA Ref# - D211452

ESA PWA

Service Layer Credits: Image courtesy of USGS © 2013
Microsoft Corporation © 2010 NAVTEQ © AND

4/3/2013

N

0 1,000 2,000
Feet

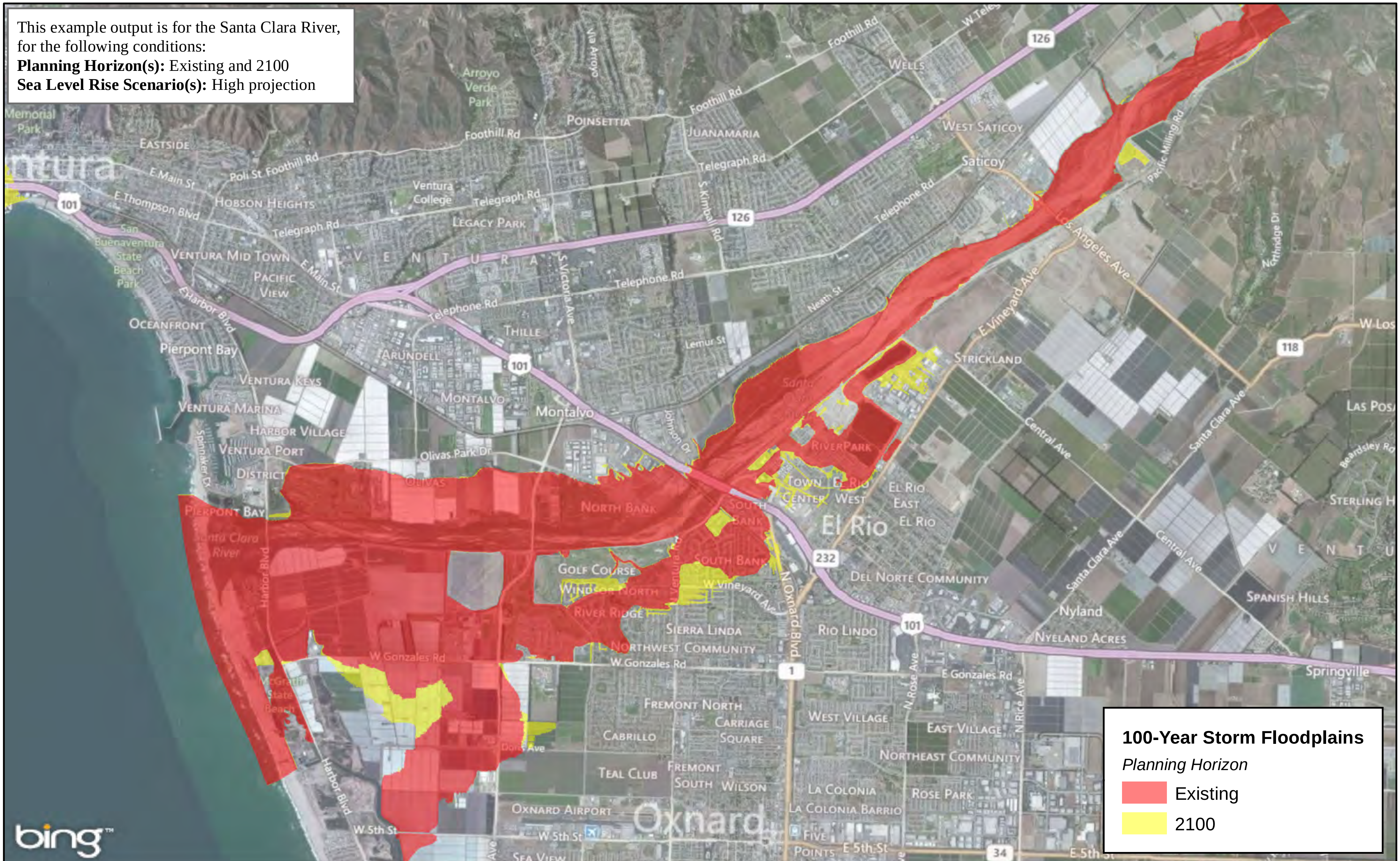
*figure **2***

Ventura County Climate Change Vulnerability Study

Example of Coastal Erosion Hazard Zones

ESA PWA Ref# D211452.00

ESA PWA



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N

0 0.5 1 Miles

figure **3**

Ventura County Climate Change Vulnerability Study

Example of Fluvial 100-Year Storm Floodplains

ESA PWA Ref# D211452.00

ESA PWA

This example output is for the Mugu Lagooon area, for the following conditions:
Planning Horizon(s): All
Sea Level Rise Scenario(s): Medium projection

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N

0 0.5 1 Miles

* EMHW is Extreme Monthly High Water, the average of the highest monthly tides.

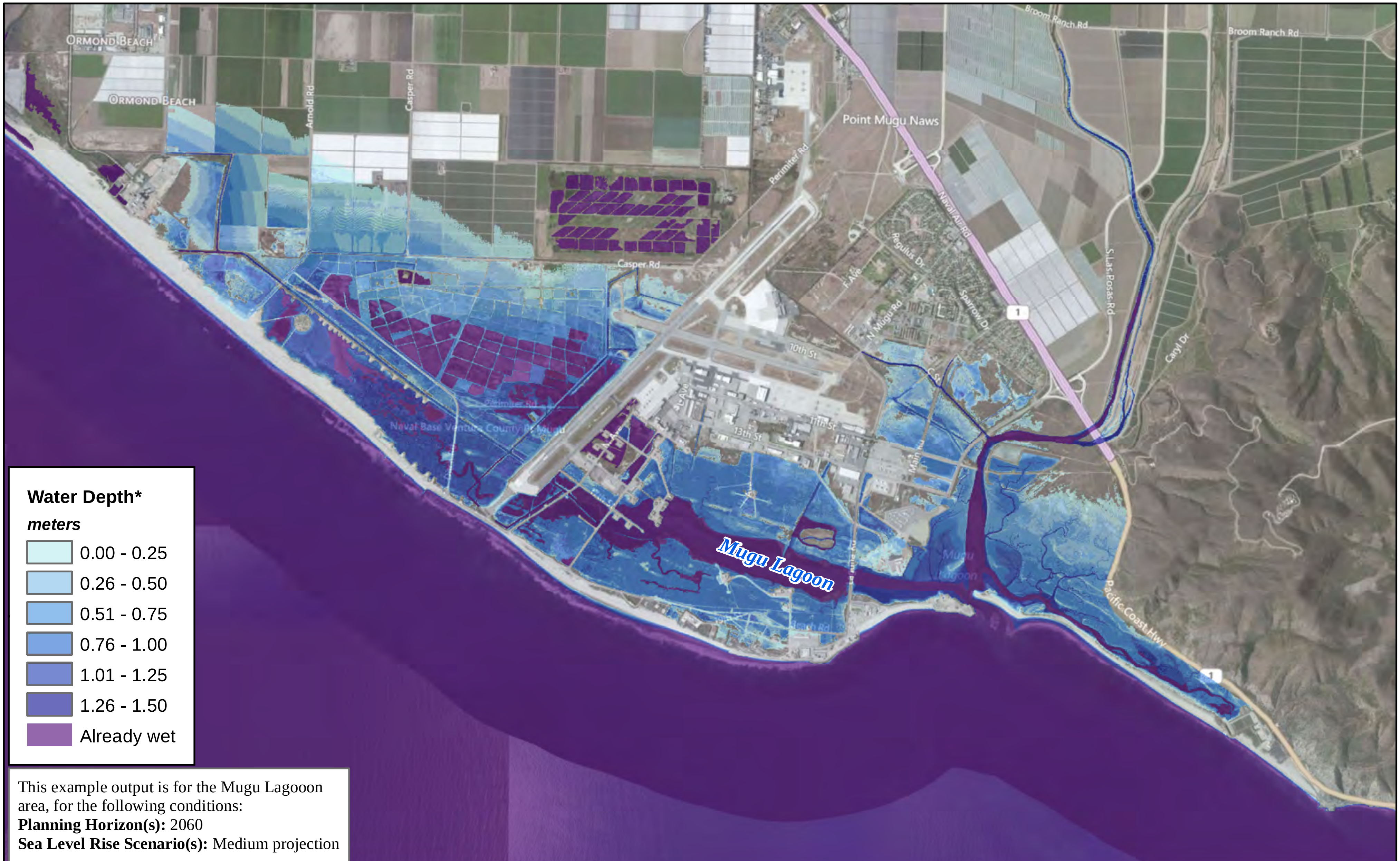
*figure **4a***

Ventura County Climate Change Vulnerability Study

Example of Rising Tides Inundation: Area

ESA PWA Ref# D211452.00

ESA PWA



This example output is for the Mugu Lagooon area, for the following conditions:
Planning Horizon(s): 2060
Sea Level Rise Scenario(s): Medium projection

Aerial Image by Bing Basemap
3/13/2013

*Depth is calculated as the difference between the ground surface elevation and the water surface elevation of "Extreme High Water." Extreme High Water is an average of the highest observed tides, on a monthly basis.

N
0 0.5 1 Miles

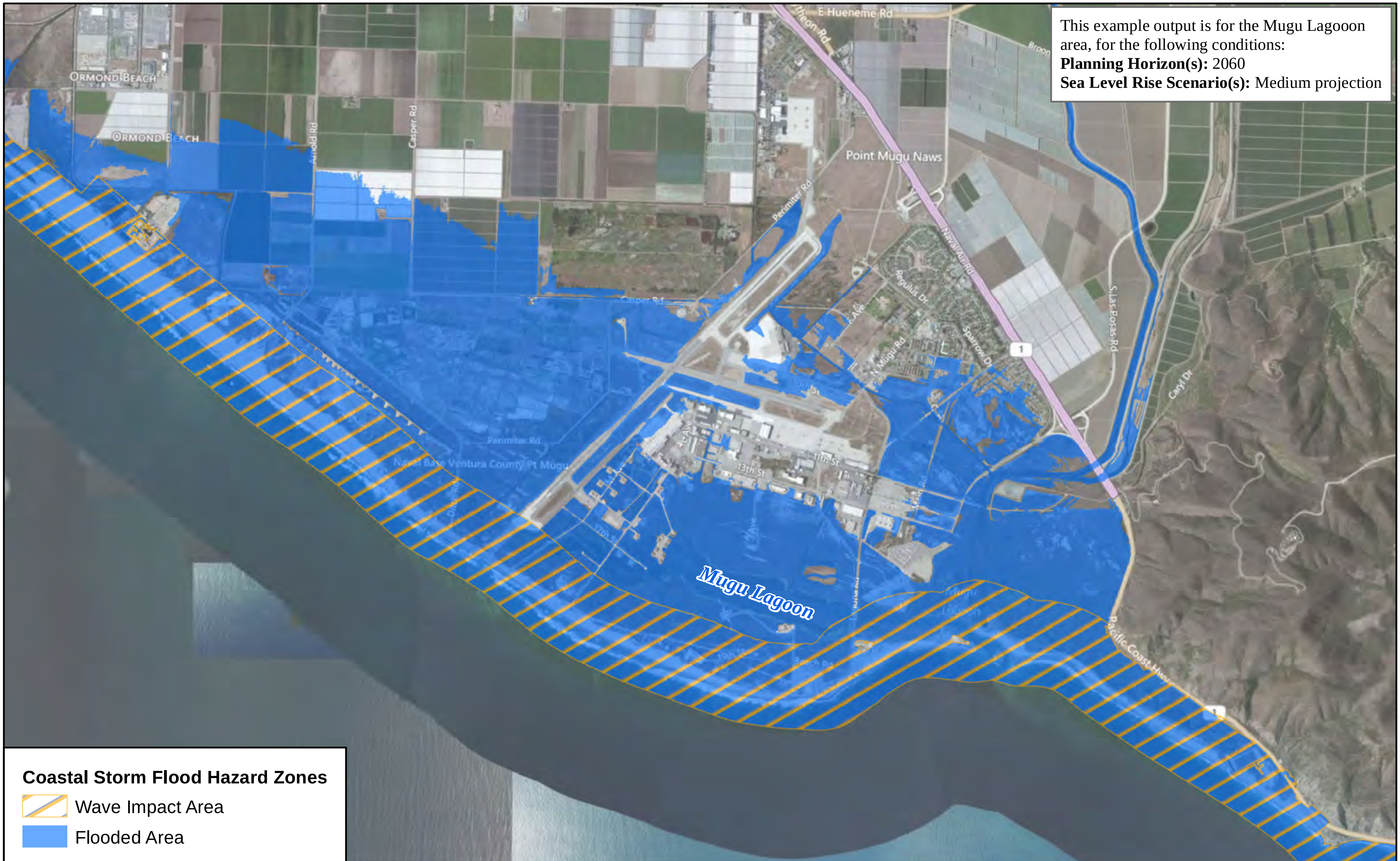
figure 4b

Ventura County Climate Change Vulnerability Study

Example Model Output: Depth Raster

ESA PWA Ref# - D211452

ESA PWA



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4/3/2013

N

0 0.5 1 Miles

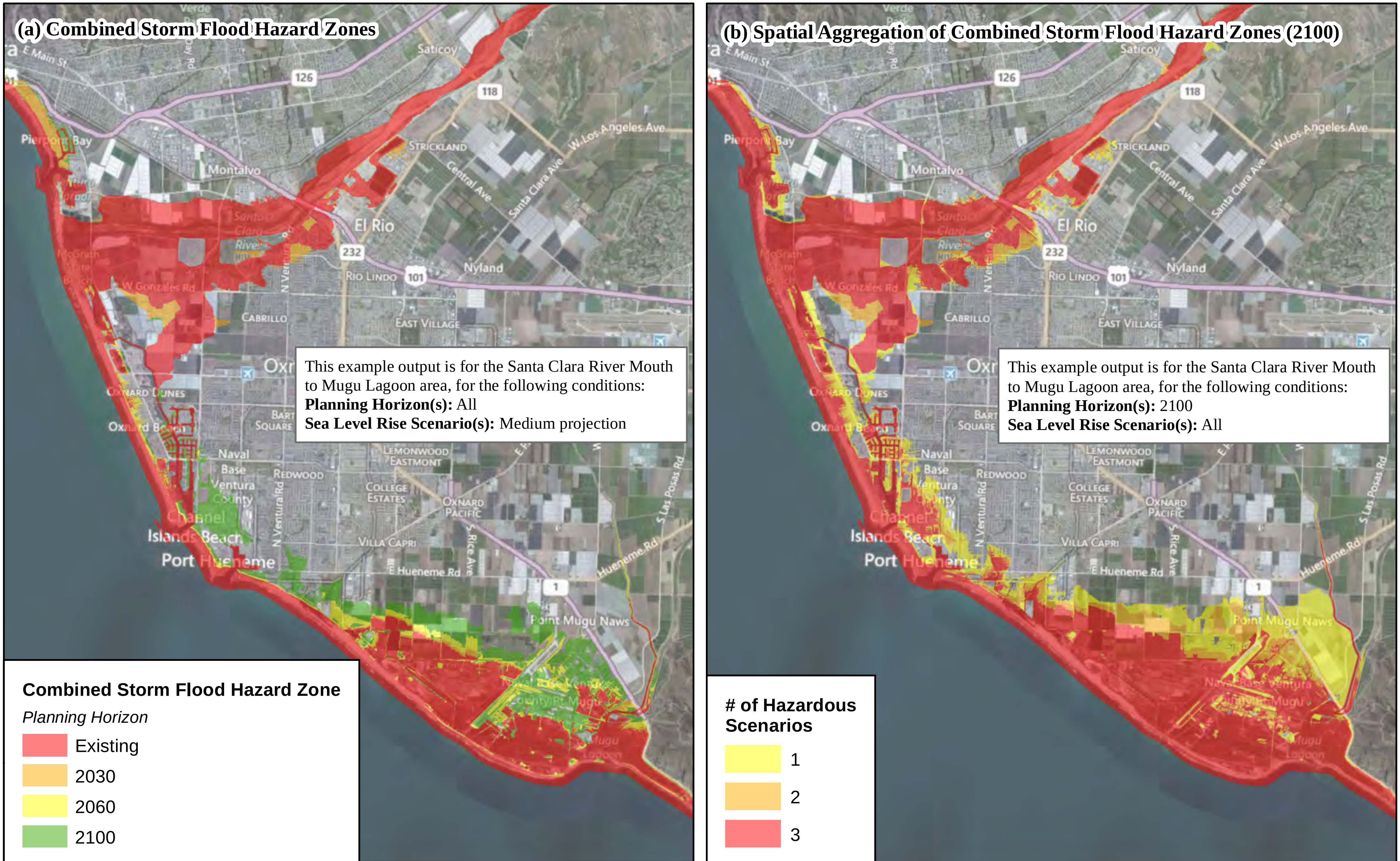
figure ***5***

Ventura County Climate Change Vulnerability Study

Example of Coastal Storm Wave Impact Area and Flood Hazard Zone

ESA PWA Ref# D211452.00

ESA PWA



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N

0 1 2 Miles

*figure **6***

Ventura County Climate Change Vulnerability Study

Example of Combined Storm Flood Hazard Zones

ESA PWA Ref# D211452.00

ESA PWA

(a) Nested Model Grids **(b) Bathymetry**

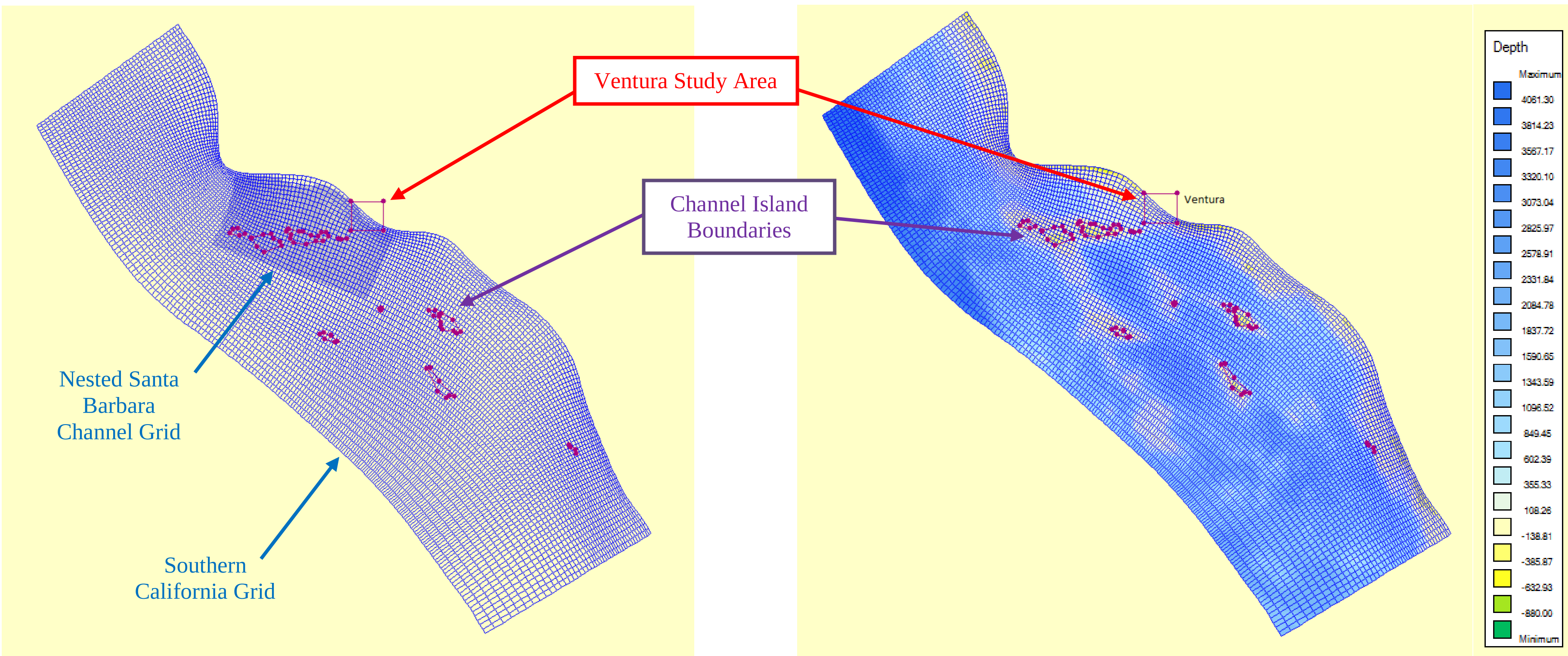


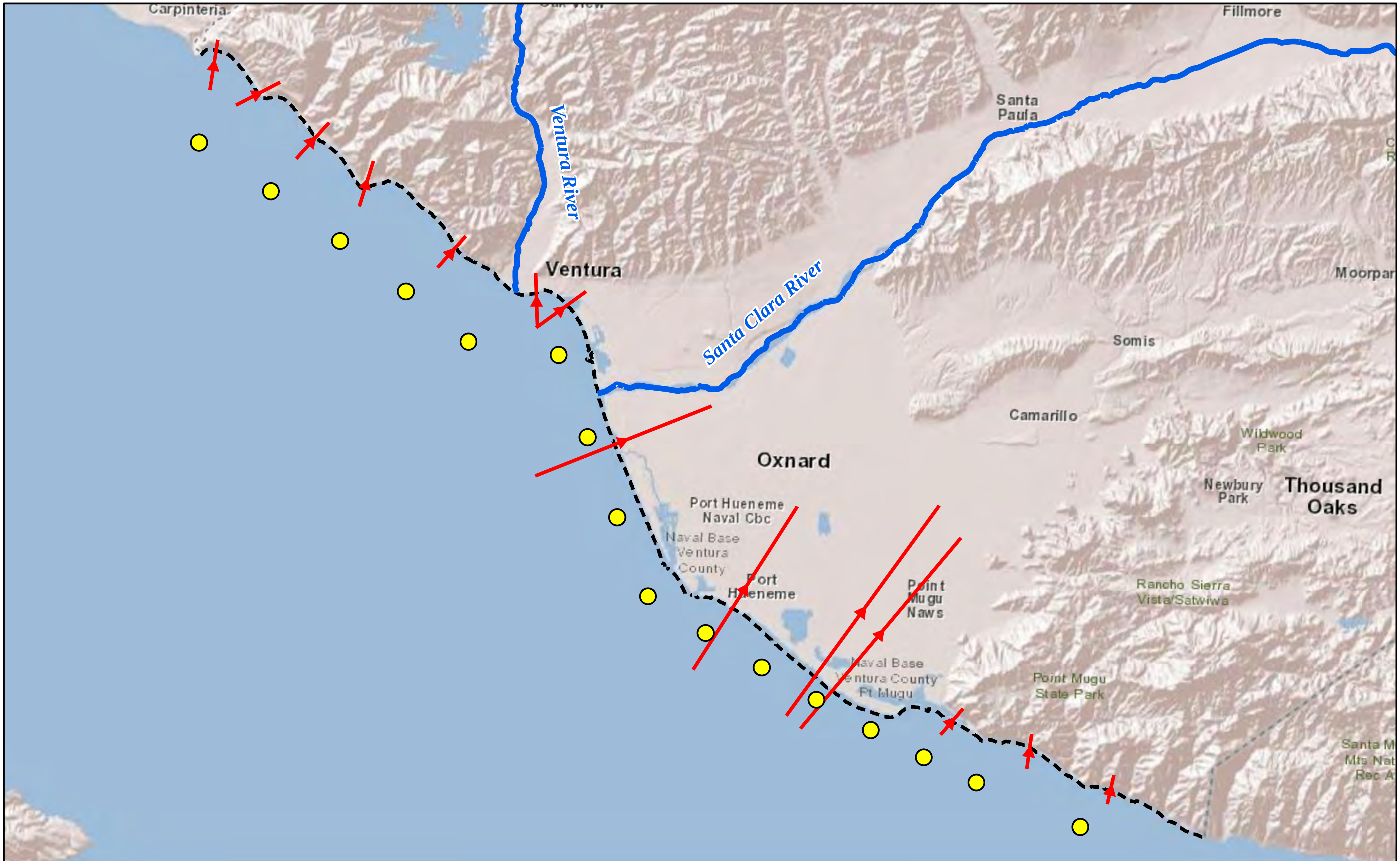
figure **8**

Ventura County Climate Change Vulnerability Assessment

Nearshore Wave Transformation Model Grids

ESA PWA Ref# D211452.00

ESA PWA



Legend

- Wave Transformation Points
- Flood Analysis Profiles
- Ventura County Shoreline

N

0 2.5 5 Miles

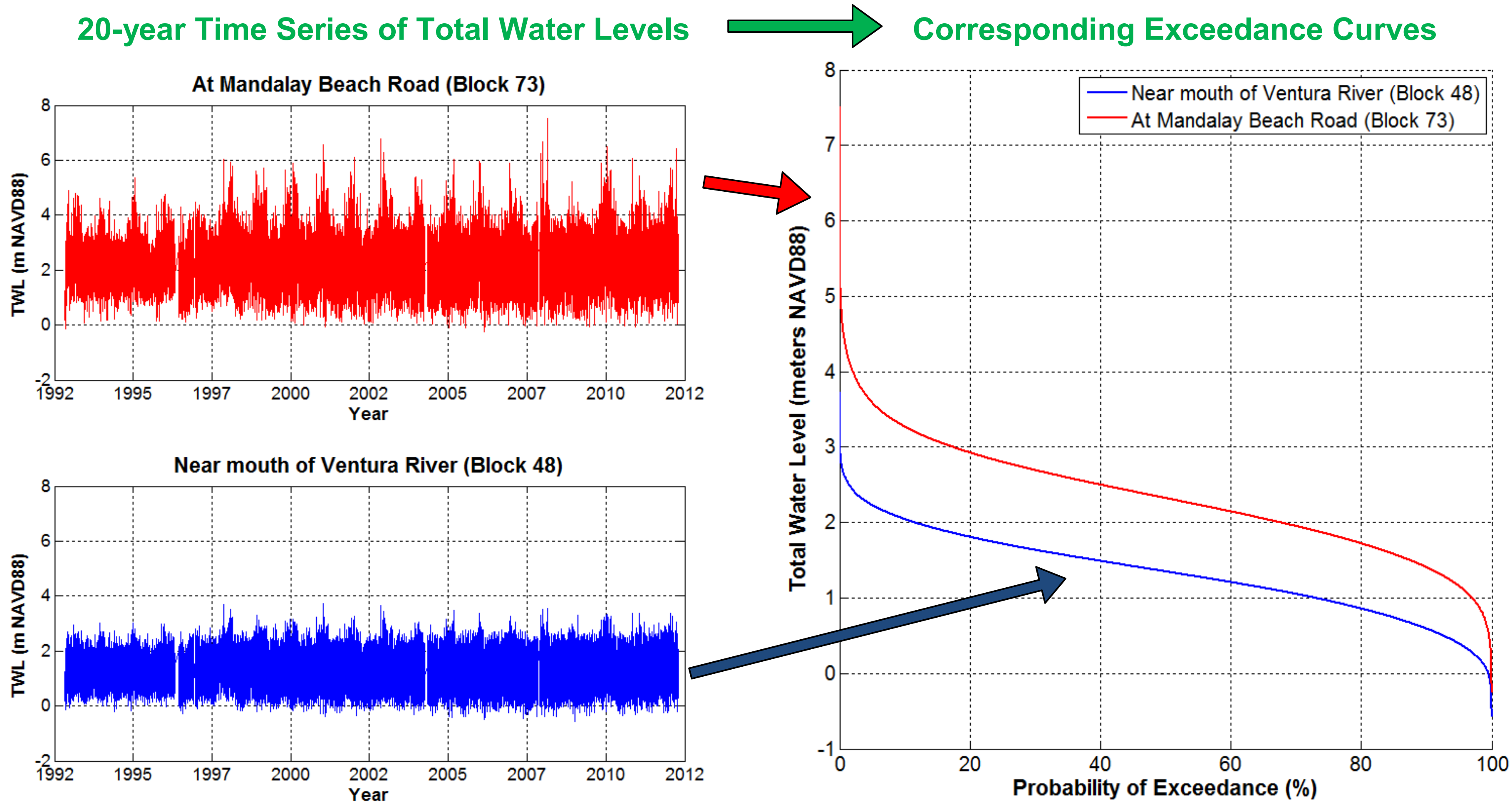
figure 9

Ventura County Climate Change Vulnerability Study

Nearshore Wave Transformation Points and Representative Profiles

ESA PWA Ref# D211452.00

ESA PWA



This example shows the existing total water level exceedance curves for a region with a relatively flat beach (at the mouth of the Ventura River) and a region with a relatively steep beach (near Mandalay Beach Road).

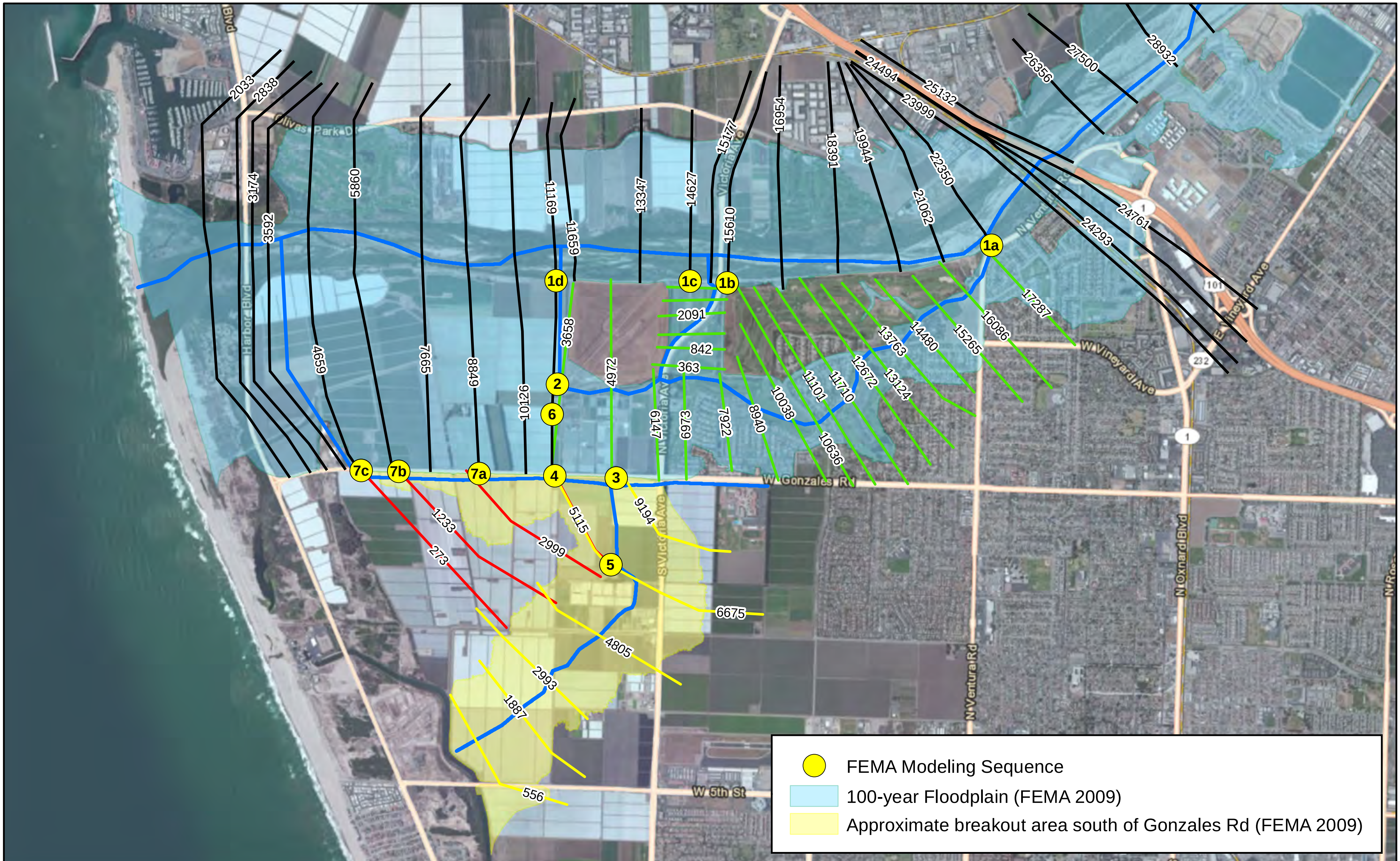
figure **10**

Ventura County Climate Change Vulnerability Assessment

Example of Total Water Level Exceedance Curves

ESA PWA Ref# D211452.00

ESA PWA



Basemap Credits: Copyright:© 2013 Esri, DeLorme, NAVTEQ, TomTom
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

N

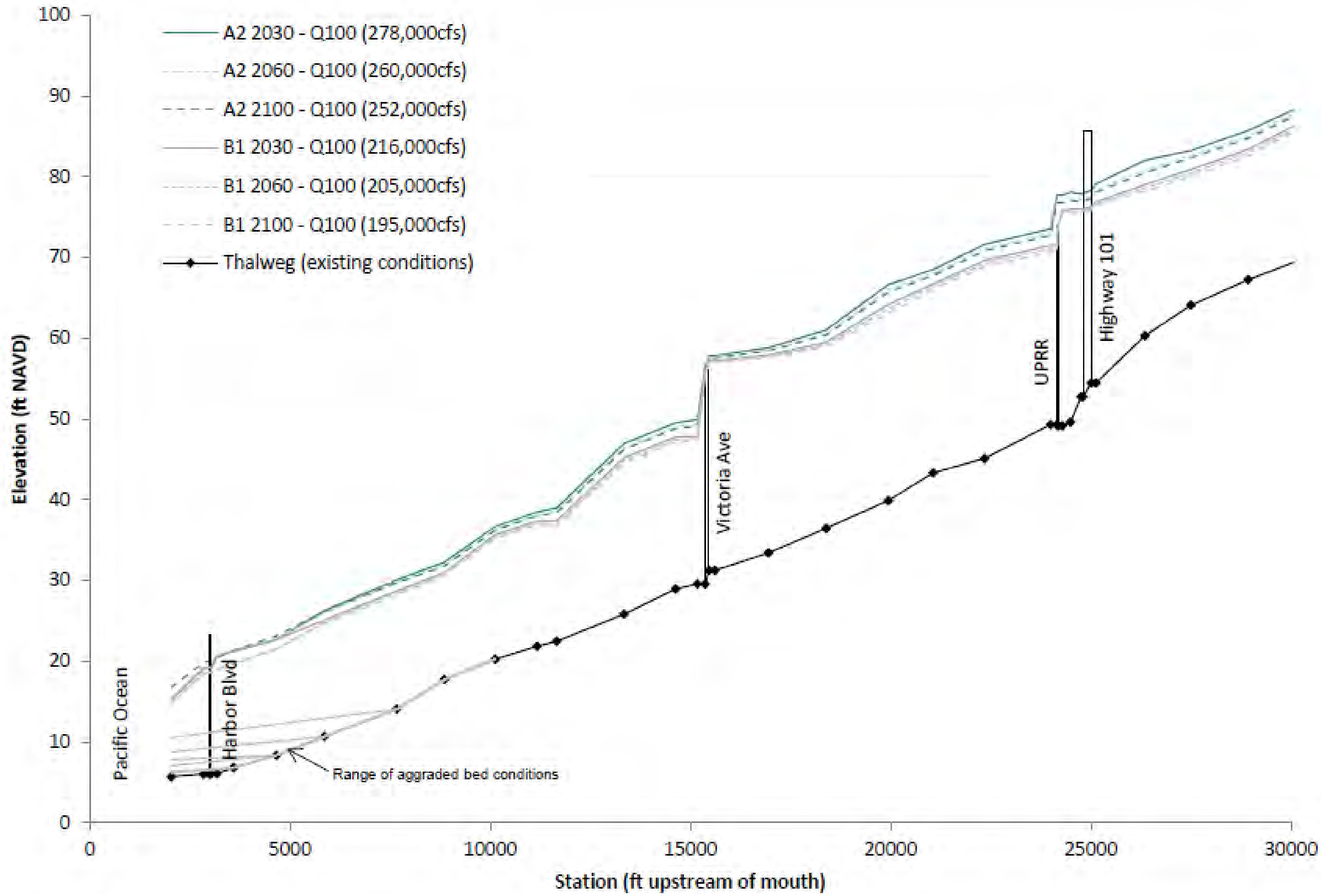
0 0.5 1 Miles

Cross Sections
Location
Main Santa Clara River
Left of Bank
East-Gonzales
West-Gonzales

figure 12
Ventura County Climate Change Vulnerability Study

FEMA Flood Modeling Sequence for the Santa Clara River

ESA PWA Ref# D211452.00

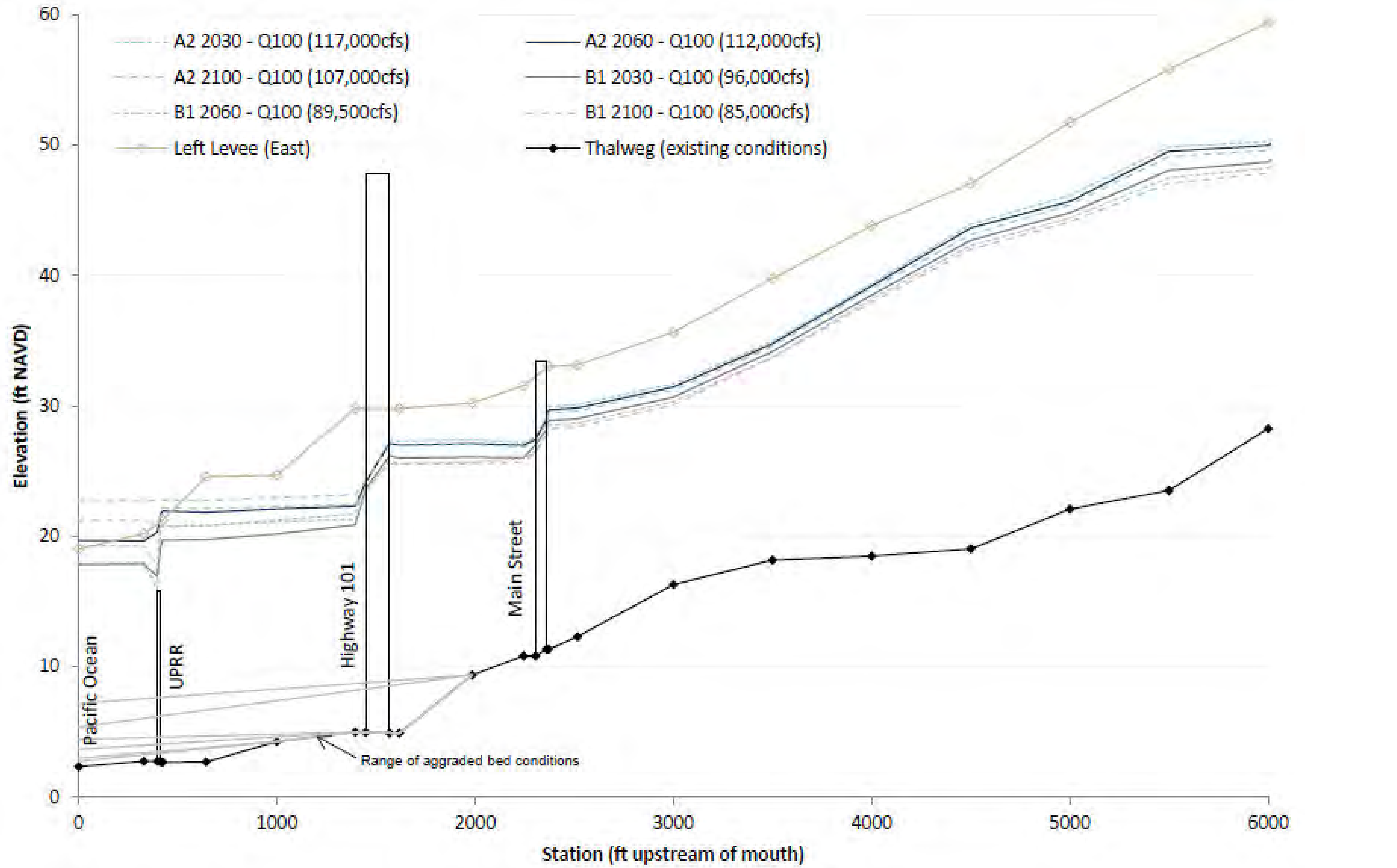


Source: FEMA 2008 hydraulic model
Note: Present conditions Q100 = 226,000 cfs

figure **13**
Ventura County Climate Change Vulnerability Assessment

Projected 100-year Water Surface Profiles for the Santa Clara River

ESA PWA Ref# D211452.00



Source: USBR 2006 HEC-RAS model provided by VCWPD
Note: Present conditions Q100 = 79,000 cfs

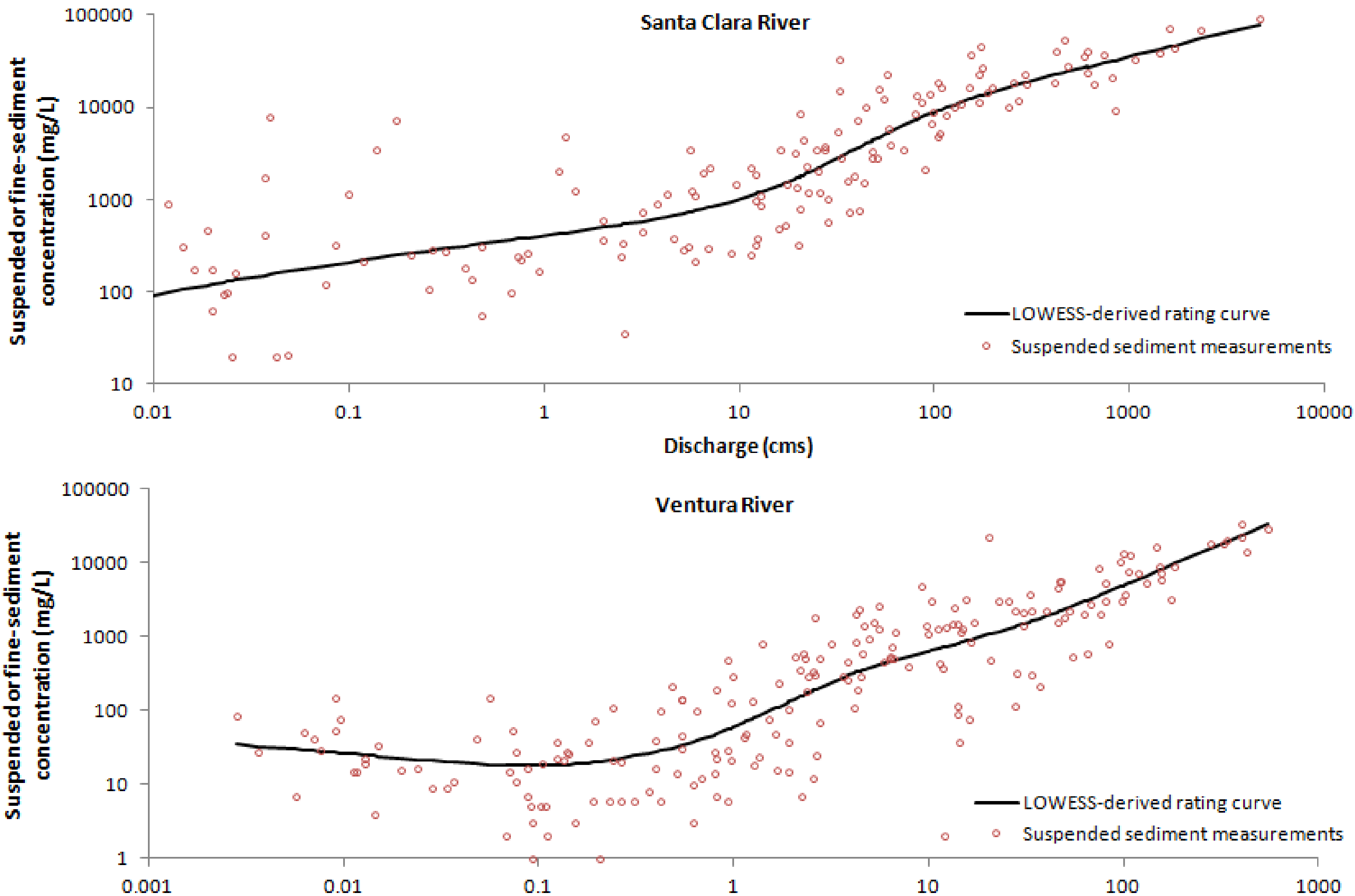
figure ***14***

Ventura County Climate Change Vulnerability Assessment

Projected 100-year Water Surface Profiles for the Ventura River

ESA PWA Ref# D211452.00

ESA PWA



Source: Warrick (2009)
Note: Santa Clara River data from USGS 11114000
Ventura River data from USGS 111185000

figure ***15***
Ventura County Climate Change Vulnerability Assessment

Suspended Sediment Rating Curves

ESA PWA Ref# D211452.00

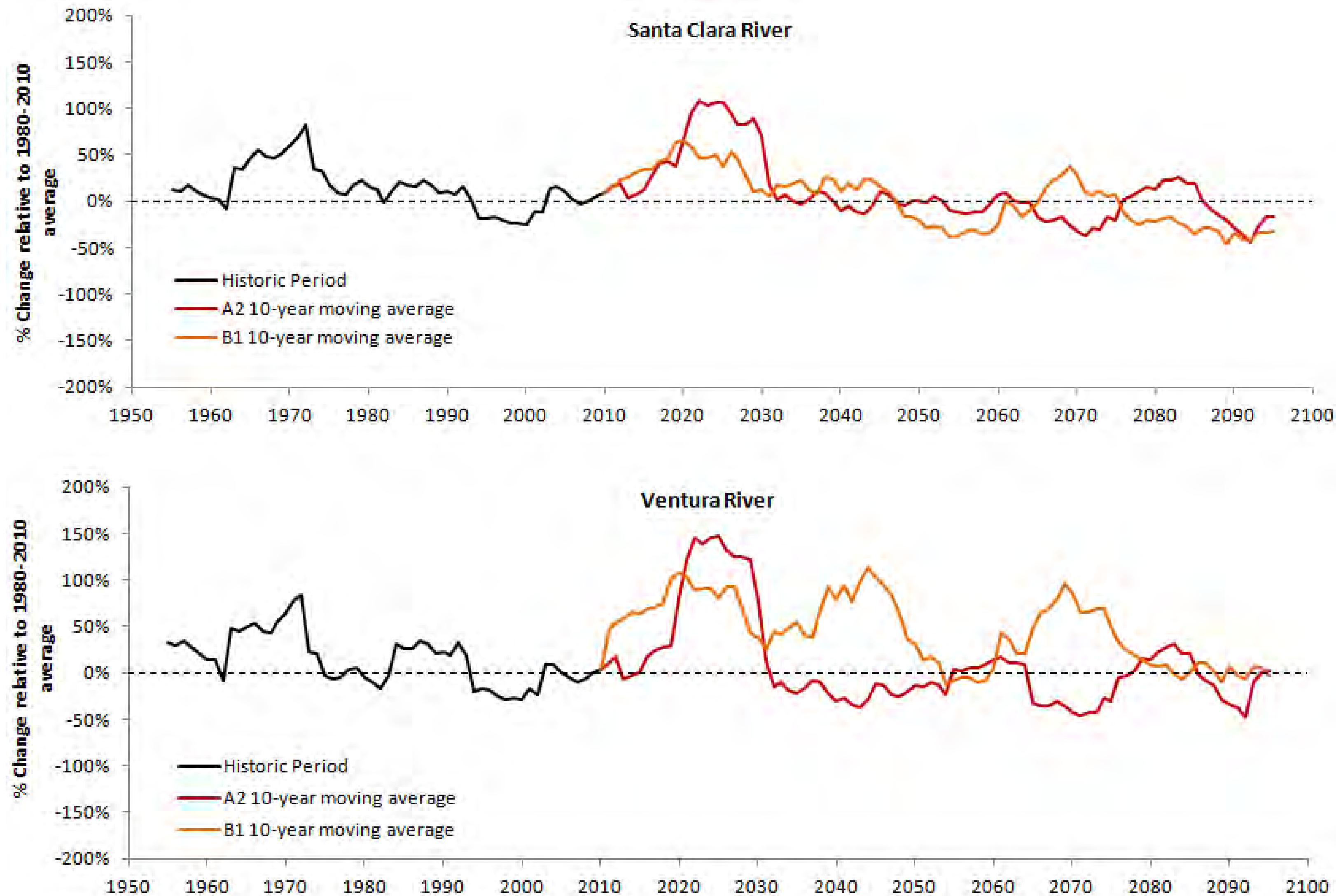


figure ***16***

Ventura County Climate Change Vulnerability Assessment

Relative Change in Sediment Yield

ESA PWA Ref# D211452.00

ESA PWA

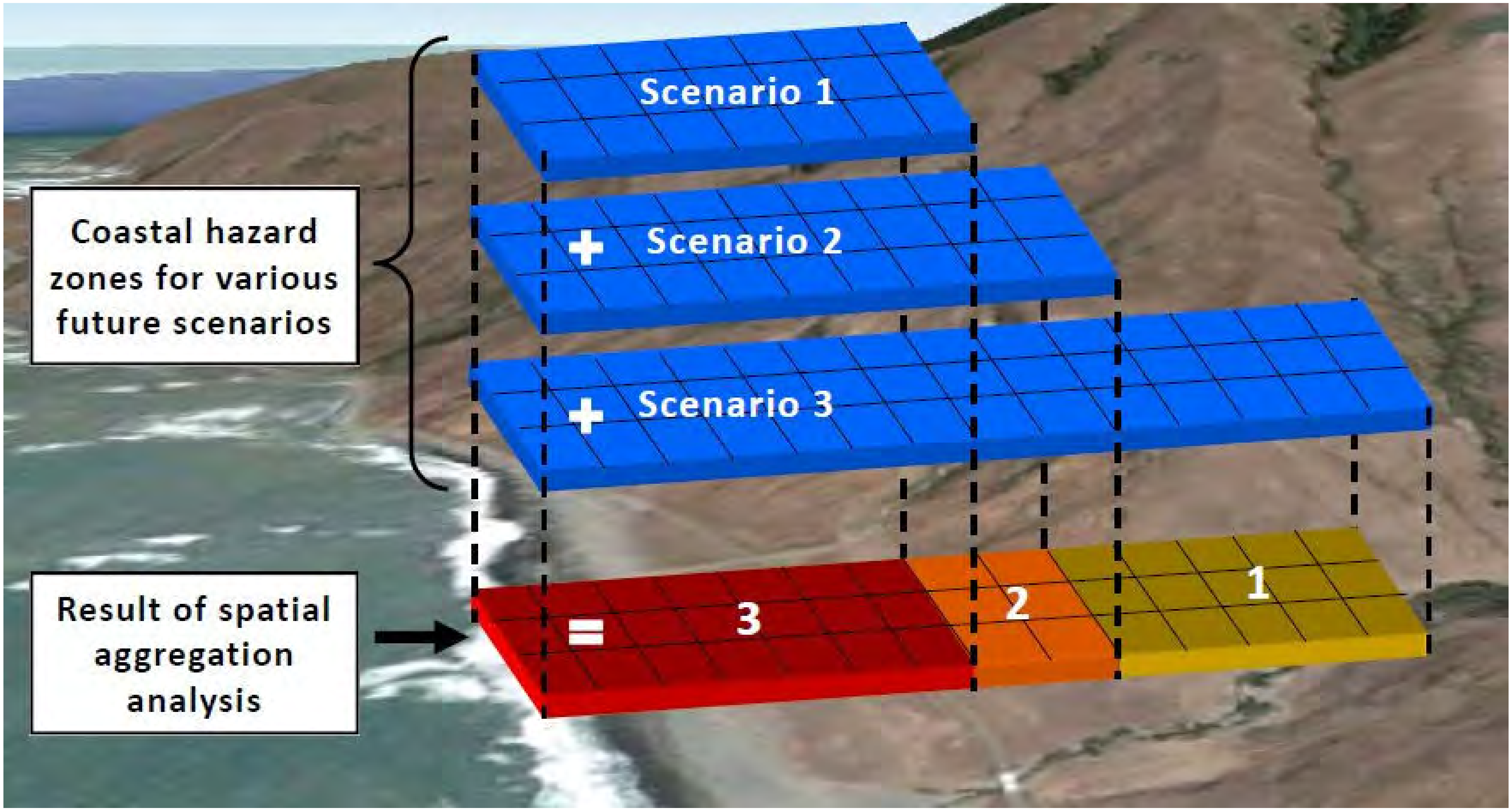


figure ***18***

Ventura County Climate Change Vulnerability Assessment

Spatial Aggregation Schematic

ESA PWA Ref# D211452.00

ESA PWA

Appendix A. Table of GIS Deliverables

File Name	Folder	Type	Hazard Zone Type	Prefix	Spatial Aggr?	Sea Level Rise	Wave Climate	Climate Scenario	Planning Horizon
erosionHZ_s1w02030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w0	N/A	2030
erosionHZ_s1w02060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w0	N/A	2060
erosionHZ_s1w02100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w0	N/A	2100
erosionHZ_s1w22030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w2	N/A	2030
erosionHZ_s1w22060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w2	N/A	2060
erosionHZ_s1w22100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w2	N/A	2100
erosionHZ_s1w32030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w3	N/A	2030
erosionHZ_s1w32060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w3	N/A	2060
erosionHZ_s1w32100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s1	w3	N/A	2100
erosionHZ_s2w02030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w0	N/A	2030
erosionHZ_s2w02060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w0	N/A	2060
erosionHZ_s2w02100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w0	N/A	2100
erosionHZ_s2w22030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w2	N/A	2030
erosionHZ_s2w22060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w2	N/A	2060
erosionHZ_s2w22100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w2	N/A	2100
erosionHZ_s2w32030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w3	N/A	2030
erosionHZ_s2w32060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w3	N/A	2060
erosionHZ_s2w32100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s2	w3	N/A	2100
erosionHZ_s3w02030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w0	N/A	2030
erosionHZ_s3w02060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w0	N/A	2060
erosionHZ_s3w02100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w0	N/A	2100
erosionHZ_s3w22030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w2	N/A	2030
erosionHZ_s3w22060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w2	N/A	2060
erosionHZ_s3w22100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w2	N/A	2100
erosionHZ_s3w32030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w3	N/A	2030
erosionHZ_s3w32060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w3	N/A	2060
erosionHZ_s3w32100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	No	s3	w3	N/A	2100
erosionHZ_aggr_2030	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	Yes	N/A	N/A	N/A	2030
erosionHZ_aggr_2060	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	Yes	N/A	N/A	N/A	2060
erosionHZ_aggr_2100	Coastal_Erosion_HZs\v09	polygon shapefile	Coastal Erosion Hazard Zone	erosionHZ	Yes	N/A	N/A	N/A	2100
coastal_storm_floodHZ_ec2010	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	ec	N/A	N/A	2010
coastal_storm_floodHZ_s12030	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s1	N/A	N/A	2030
coastal_storm_floodHZ_s12060	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s1	N/A	N/A	2060
coastal_storm_floodHZ_s12100	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s1	N/A	N/A	2100
coastal_storm_floodHZ_s22030	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s2	N/A	N/A	2030
coastal_storm_floodHZ_s22060	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s2	N/A	N/A	2060
coastal_storm_floodHZ_s22100	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s2	N/A	N/A	2100
coastal_storm_floodHZ_s32030	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s3	N/A	N/A	2030
coastal_storm_floodHZ_s32060	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s3	N/A	N/A	2060
coastal_storm_floodHZ_s32100	Coastal_Storm_Flood_HZs\v5_no_fluvial_clean_UTM	polygon shapefile	Coastal Storm Flood Hazard Zones	coastal_storm_floodHZ	No	s3	N/A	N/A	2100
coastal_storm_waveHZ_ec2010	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	ec	N/A	N/A	2010
coastal_storm_waveHZ_s12030	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s1	N/A	N/A	2030
coastal_storm_waveHZ_s12060	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s1	N/A	N/A	2060
coastal_storm_waveHZ_s12100	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s1	N/A	N/A	2100
coastal_storm_waveHZ_s22030	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s2	N/A	N/A	2030
coastal_storm_waveHZ_s22060	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s2	N/A	N/A	2060
coastal_storm_waveHZ_s22100	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s2	N/A	N/A	2100
coastal_storm_waveHZ_s32030	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s3	N/A	N/A	2030
coastal_storm_waveHZ_s32060	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s3	N/A	N/A	2060
coastal_storm_waveHZ_s32100	Coastal_Storm_Wave_Impact_Area\v5_clean_clipped_UTM	polygon shapefile	Coastal Storm Wave Impact Area	coastal_storm_waveHZ	No	s3	N/A	N/A	2100

Appendix A. Table of GIS Deliverables

File Name	Folder	Type	Hazard Zone Type	Prefix	Spatial Aggr?	Sea Level Rise	Wave Climate	Climate Scenario	Planning Horizon
combine_storm_floodHZ_ec2010	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	ec	N/A	N/A	2010
combine_storm_floodHZ_s12030	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s1	N/A	N/A	2030
combine_storm_floodHZ_s12060	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s1	N/A	N/A	2060
combine_storm_floodHZ_s12100	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s1	N/A	N/A	2100
combine_storm_floodHZ_s22030	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s2	N/A	N/A	2030
combine_storm_floodHZ_s22060	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s2	N/A	N/A	2060
combine_storm_floodHZ_s22100	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s2	N/A	N/A	2100
combine_storm_floodHZ_s32030	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s3	N/A	N/A	2030
combine_storm_floodHZ_s32060	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s3	N/A	N/A	2060
combine_storm_floodHZ_s32100	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	No	s3	N/A	N/A	2100
combine_storm_floodHZ_aggr_2030	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	Yes	N/A	N/A	N/A	2030
combine_storm_floodHZ_aggr_2060	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	Yes	N/A	N/A	N/A	2060
combine_storm_floodHZ_aggr_2100	Combined_Storm_Flood_HZs\v5_clean_UTM	polygon shapefile	Combined Storm Flood Hazard Zones	combine_storm_floodHZ	Yes	N/A	N/A	N/A	2100
river100-yr_floodplain_ec2010	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	ec	N/A	N/A	2010
river100-yr_floodplain_s2B12030	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s2	N/A	B1	2030
river100-yr_floodplain_s2B12060	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s2	N/A	B1	2060
river100-yr_floodplain_s2B12100	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s2	N/A	B1	2100
river100-yr_floodplain_s3A22030	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s3	N/A	A2	2030
river100-yr_floodplain_s3A22060	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s3	N/A	A2	2060
river100-yr_floodplain_s3A22100	Fluvial_Storm_100-yr_Floodplains\UTM	polygon shapefile	Fluvial 100-year Storm Floodplains	river100-yr_floodplain	No	s3	N/A	A2	2100
tide_emhw_ec2010	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	ec	N/A	N/A	2010
tide_emhw_s12030	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s1	N/A	N/A	2030
tide_emhw_s12060	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s1	N/A	N/A	2060
tide_emhw_s12100	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s1	N/A	N/A	2100
tide_emhw_s22030	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s2	N/A	N/A	2030
tide_emhw_s22060	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s2	N/A	N/A	2060
tide_emhw_s22100	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s2	N/A	N/A	2100
tide_emhw_s32030	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s3	N/A	N/A	2030
tide_emhw_s32060	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s3	N/A	N/A	2060
tide_emhw_s32100	Rising_Tides_Zones\Area\clean	polygon shapefile	Rising Tide (EMHW Inundation Area)	tide_emhw	No	s3	N/A	N/A	2100
depth_ec2010	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	ec	N/A	N/A	2010
depth_s12030	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s1	N/A	N/A	2030
depth_s12060	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s1	N/A	N/A	2060
depth_s12100	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s1	N/A	N/A	2100
depth_s22030	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s2	N/A	N/A	2030
depth_s22060	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s2	N/A	N/A	2060
depth_s22100	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s2	N/A	N/A	2100
depth_s32030	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s3	N/A	N/A	2030
depth_s32060	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s3	N/A	N/A	2060
depth_s32100	Rising_Tides_Zones\Depth\v5	raster (5m)	Rising Tide (EMHW Inundation Depth)	depth	No	s3	N/A	N/A	2100