

Final

CITY OF SANTA BARBARA SEA-LEVEL RISE ADAPTATION PLAN FOR THE LOCAL COASTAL PROGRAM UPDATE

Vulnerability Assessment Update

Prepared for
City of Santa Barbara

February 2020



Funded by:



Final

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Funded by
California Coastal Commission
California State Coastal Conservancy
City of Santa Barbara

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CITY OF SANTA BARBARA SEA-LEVEL RISE ADAPTATION PLAN FOR THE LOCAL COASTAL PROGRAM UPDATE:

Vulnerability Assessment Update

Executive Summary

Introduction

The City of Santa Barbara includes approximately six miles of shoreline. Although Santa Barbara has experienced a relatively small amount of sea-level rise to date from climate change, the rate of sea-level rise in the region is expected to significantly accelerate in coming years. Rising sea-levels will present increased physical risks to the City of Santa Barbara, including shoreline erosion and degradation, decreased beach widths, amplified storm surges, and inundation of coastal flood waters. There is a need for the City and the community to better understand these vulnerabilities, to analyze the physical and economic risks, and consider possible actions to prepare and adapt to the impacts of sea-level rise.

The purpose of the *City of Santa Barbara Sea-Level Rise Vulnerability Assessment Update* (Vulnerability Assessment Update) is to enhance the understanding of the City of Santa Barbara's coastal resources and assess existing and future vulnerabilities to projected sea-level rise, coastal flooding, and erosion. The Vulnerability Assessment Update is intended to build on previous work, including previous vulnerability work, completed at a local and regional level and to serve as a first step in the adaptation planning process.

The Vulnerability Assessment Update assesses what will happen if no action is taken to mitigate the increased hazard risks associated with sea-level rise. This will inform the development of an Adaptation Plan that will analyze the feasibility, effectiveness, economic and fiscal impacts, environmental consequences, recreation impacts, and other costs and benefits of various adaptation strategies to avoid and/or mitigate coastal hazards over time. The Adaptation Plan will include a detailed Economic and Fiscal Impacts Analysis that is currently underway. The information in the Adaptation Plan will be used to amend policies and development standards in the City's Local Coastal Program (LCP) to implement adaptation strategies.

Study Area

The study area includes all portions of the City projected to be impacted by sea-level rise to the year 2100 (6.6 feet of sea-level rise). This includes approximately 6.5 linear miles of coastline from Arroyo Burro to the Andree Clark Bird Refuge. It also includes Santa Barbara Harbor and

extends inland far enough to capture the extent of projected flooding of the downtown Santa Barbara area. The study area does not include the Santa Barbara Airport and Goleta Slough, which has been the subject of separate studies.

The study area was divided into 11 Shoreline Hazard Planning Subareas as depicted below in **Figure ES-1**.

Coastal Hazards and Vulnerabilities

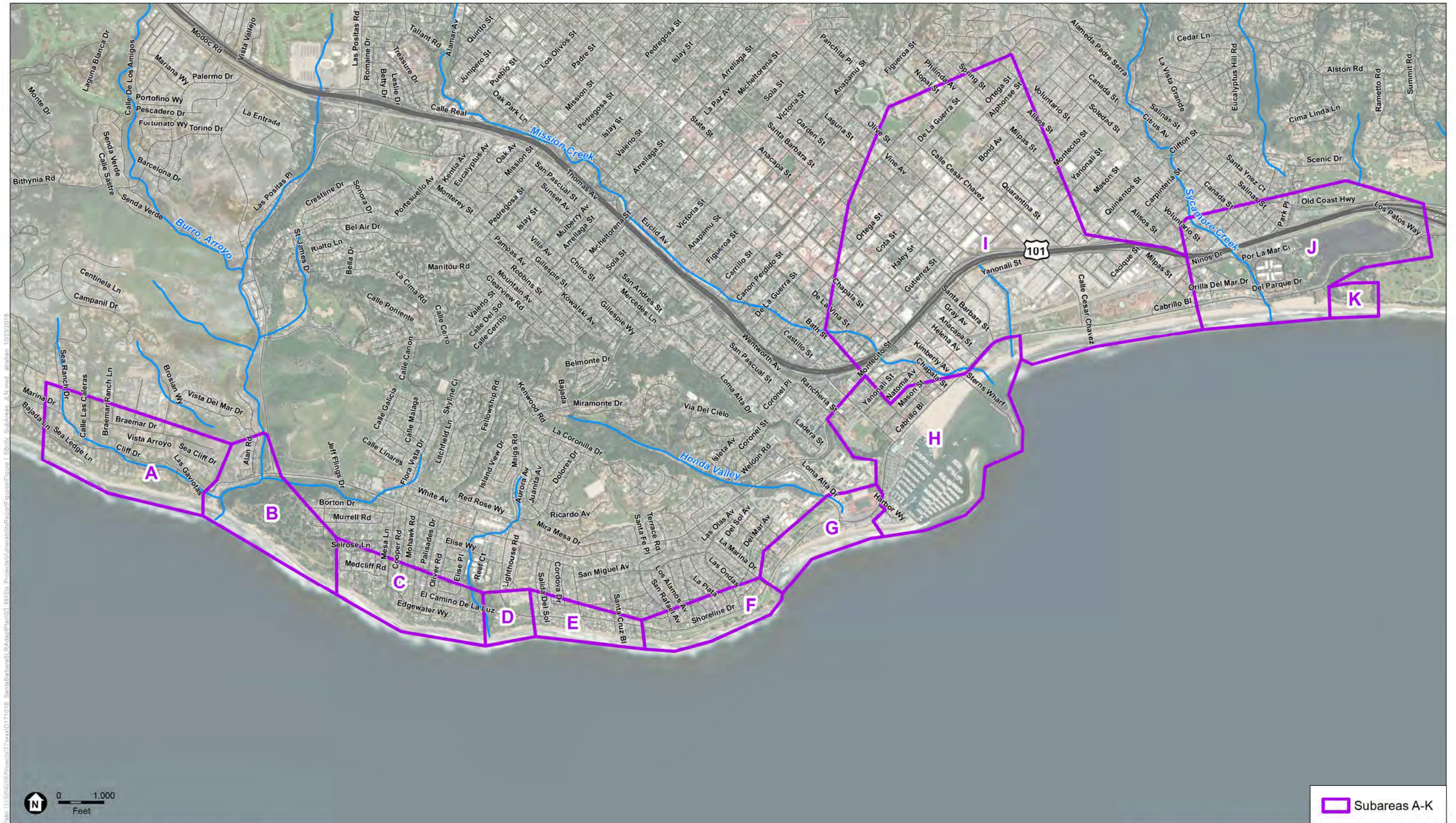
The Vulnerability Assessment Update evaluated hazards for three sea-level rise scenarios: 0.8 feet by 2030,¹ 2.5 feet by 2060, and 6.6 feet by 2100.

The State of California, in the 2018 *State of California Sea-Level Rise Guidance* (OPC 2018) recommends using these precautionary and more risk adverse scenarios when planning for structures, infrastructure, and other development that is not easily moved. The state guidance estimates that these sea-level rise values have a 0.5% chance of being met or exceeded by the year 2100. The state guidance identifies these as the “medium-high risk aversion scenarios” which are based on the assumption that existing levels of greenhouse gas emissions continue and are not significantly reduced (“high emission scenarios”).

The 2018 *State of California Sea-Level Rise Guidance* also includes much more likely scenarios that present sea-level rise values that have a 17% chance of being met or exceeded in the future (“low risk aversion scenarios”) that can be used for planning for adaptable development with few consequences of being impacted (e.g., dirt trails). The state guidance also presents an “extreme risk aversion” scenario called the H++ scenario that is based on recent scientific studies that indicate that there is a possibility that sea levels could rise faster than originally anticipated due to the potential loss of large portions of the West Antarctic Ice Sheet. While the probability of this extreme scenario is not known at this time, the state guidance recommends considering the H++ scenario in the planning of very critical infrastructure (e.g., coastal power plant). For very critical infrastructure, therefore, this Vulnerability Assessment Update considers the possibility that 6.6 feet (2100) of sea-level rise may occur sooner, at 2080 rather than 2100, under the extreme H++ sea-level rise scenario. **Table ES-1** and **Figure ES-2** below present the low-rise, medium-risk, and extreme risk aversion scenarios. All of these aversion scenarios correspond to the high greenhouse gas emissions scenario.

The State of California has updated the sea-level rise projections for the Santa Barbara area contained in the State of California Sea-Level Rise Guidance approximately every five years, based on best available information. While there is uncertainty in the timing of sea-level rise in any particular area, the amounts of sea-level rise considered in this Vulnerability Assessment Update are expected to occur at some time. Because of the timing uncertainty, this Vulnerability Assessment Update provides a framework of planning based on amounts of sea-level rise, rather than when those amounts of sea-level rise will occur.

¹ The 2018 *State of California Sea-Level Rise Guidance* recommends 0.7 feet at 2030. The closest Coastal Storm Modeling System (CoSMoS) Scenario, which has been used to generate maps and conduct vulnerability analyses is 25 cm, which is 0.8 feet. This difference is negligible at the scale of this study, and 0.8 feet at 2030 is used throughout.



SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

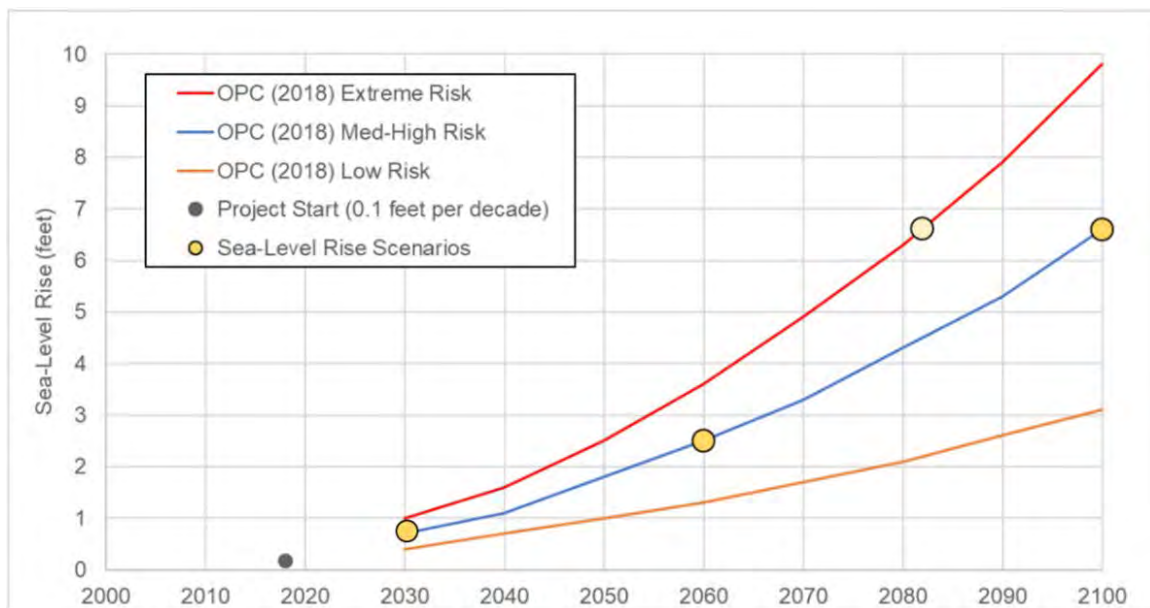
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TABLE ES-1
SEA-LEVEL RISE SCENARIOS FOR CITY OF SANTA BARBARA

| Scenario | Low Risk Aversion ^a (17% chance of being met or exceeded) | Med-High Risk Aversion (0.5% chance of being met or exceeded) | Extreme Risk Aversion (Unknown probability) |
|----------------------------|---|--|--|
| 0.8 feet of sea-level rise | Occurs by ~2040 | Occurs by ~2030 | Occurs before 2030 |
| 2.5 feet of sea-level rise | Occurs by ~2090 | Occurs by 2060 | Occurs by 2050 |
| 6.6 feet of sea-level rise | Occurs after 2150 | Occurs by 2100 | Occurs by ~2080 |

NOTES:

- ^a Low Risk Aversion values were not used for this analysis
- ~ Approximately



SOURCE: OPC 2018

Figure ES-2
OPC (2018) Sea-Level Rise Guidance Curves, with Selected Scenarios

This Vulnerability Assessment Update considers potential impacts to public and private assets (e.g., buildings, roads, utilities, parks) from the following hazards:

- Coastal Erosion – permanent loss of sandy beaches, dunes, and the low-lying backshore that occurs with changing sea-level or sand supply.
- Coastal Bluff Erosion – permanent loss of coastal bluffs as material falls or collapses onto the beach or into the ocean below.
- Tidal Inundation – coastal flooding during regular high tides under non-storm conditions.
- Storm Waves – exposure of the coast to large waves generated by local and distant storms.
- Coastal Storm Flooding – high water levels that occur during coastal storm events. The Vulnerability Assessment Update analyzed the “100-year storm” event, which has a 1% chance of occurring each year.

Low-lying areas that may potentially be subject to tidal and storm flooding but are not directly connected to flooding sources were also identified.

The assessment used the United States Geologic Society (USGS) coastal hazard model released in 2017 (CoSMoS v3.0) augmented by wave hazard zones from Coastal Resilience Santa Barbara, a study of sea-level rise impacts conducted by ESA for the County of Santa Barbara in 2015, and a 2009 geology and geohazards study of the City by URS. **Figures ES-3 through ES-10** illustrate the hazard areas under existing and future sea-level rise scenarios.

The City of Santa Barbara's public and private assets were organized into 8 sectors for the purpose of the analysis, including:

- Transportation Infrastructure
- Public Safety
- Stormwater Infrastructure
- Recreational Areas
- Harbor and Stearns Wharf
- Public and Private Properties
- Communication Infrastructure
- Water Supply and Wastewater Infrastructure

Summary of Physical Vulnerabilities

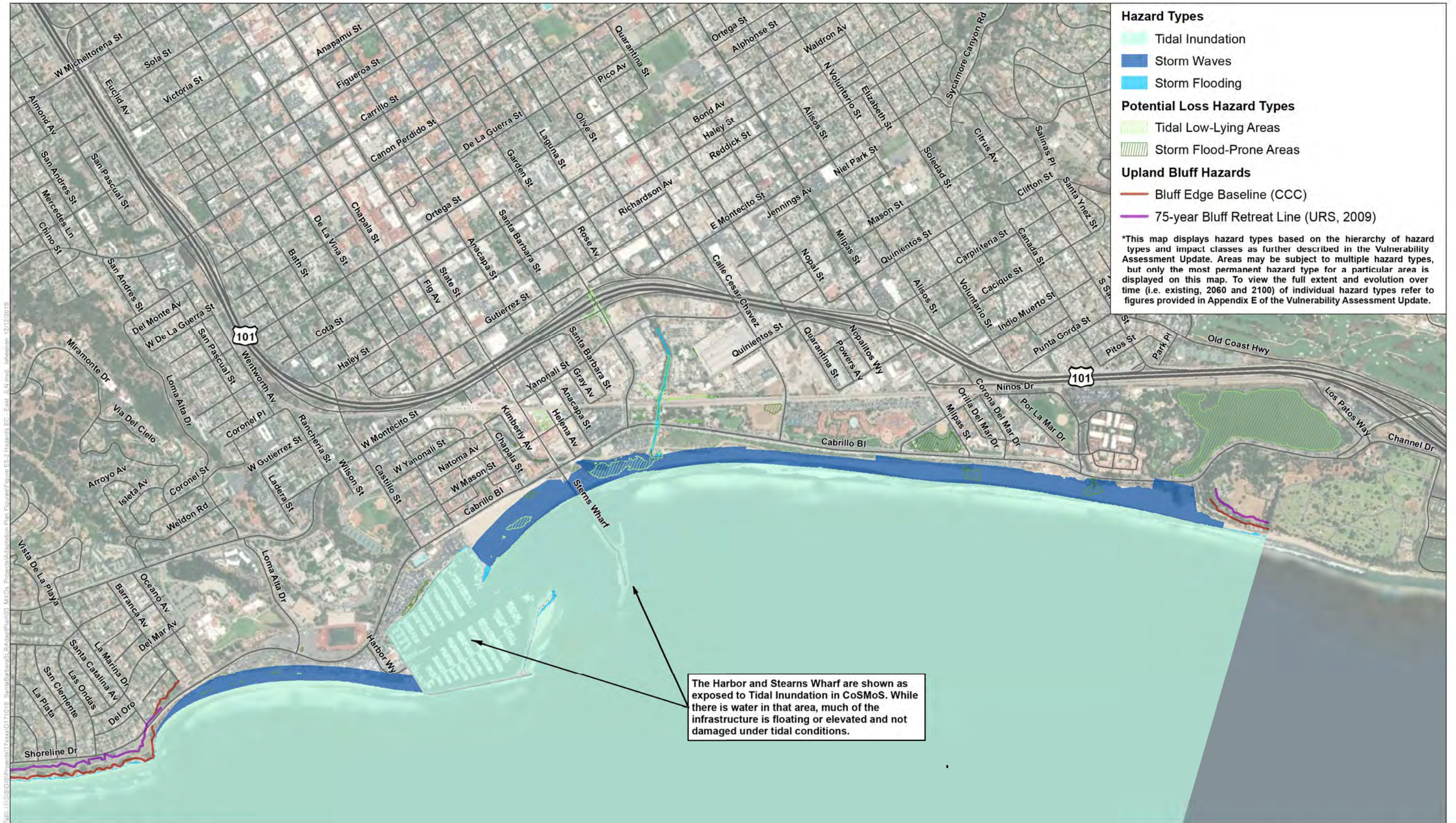
Bluff Areas

Much of the westerly portion of the City's coastal zone is situated on bluffs overlooking the beach. Bluff areas in the City include subareas A –F, from approximately Sea Edge Lane at the west end of the City of Santa Barbara to approximately Santa Barbara Point, as well as subarea K at the far easterly portion of the City by the Bellosguardo Estate. Only a few small portions of the bluff area along the City's shoreline are currently protected by shoreline protection devices. Shoreline protection devices, such as seawalls and rock revetments, are structures along the coast that can provide flood and erosion protection for properties, but which can result in accelerated erosion of sandy beach areas in front of (seaward) and adjacent to the devices.

These bluffs are currently eroding with exposure to waves and as a result of upland erosion and geologic hazards such as landslides. As sea level rises, they will be exposed to more extreme waves more often. Bluff erosion rates are expected to increase by 40% at 2.5 feet of sea-level rise and by 140% at 6.6 feet of sea-level rise.

At 2.5 feet of sea-level rise the City could lose 78% of its bluff-backed beaches to erosion, and at 6.6 feet of sea-level rise, the City could lose 98% of its bluff-backed beaches. In locations where these beaches are lost, the bluffs behind them will be more exposed to waves and are expected to erode more quickly.

The extent of the hazards in the coastal bluff areas are expected to reach bluff-top infrastructure and public and private properties at 6.6 feet of sea-level rise. At 6.6 feet of sea-level rise, erosion could extend to Shoreline Drive, Cliff Drive, and other bluff-top streets at several locations.



Hazard Types

- Tidal Inundation
- Storm Waves
- Storm Flooding

Potential Loss Hazard Types

- Tidal Low-Lying Areas
- Storm Flood-Prone Areas

Upland Bluff Hazards

- Bluff Edge Baseline (CCC)
- 75-year Bluff Retreat Line (URS, 2009)

*This map displays hazard types based on the hierarchy of hazard types and impact classes as further described in the Vulnerability Assessment Update. Areas may be subject to multiple hazard types, but only the most permanent hazard type for a particular area is displayed on this map. To view the full extent and evolution over time (i.e. existing, 2060 and 2100) of individual hazard types refer to figures provided in Appendix E of the Vulnerability Assessment Update.

The Harbor and Stearns Wharf are shown as exposed to Tidal Inundation in CoSMoS. While there is water in that area, much of the infrastructure is floating or elevated and not damaged under tidal conditions.

SOURCE: ESRI, 2018; USGS, 2018; ESA, 2018.

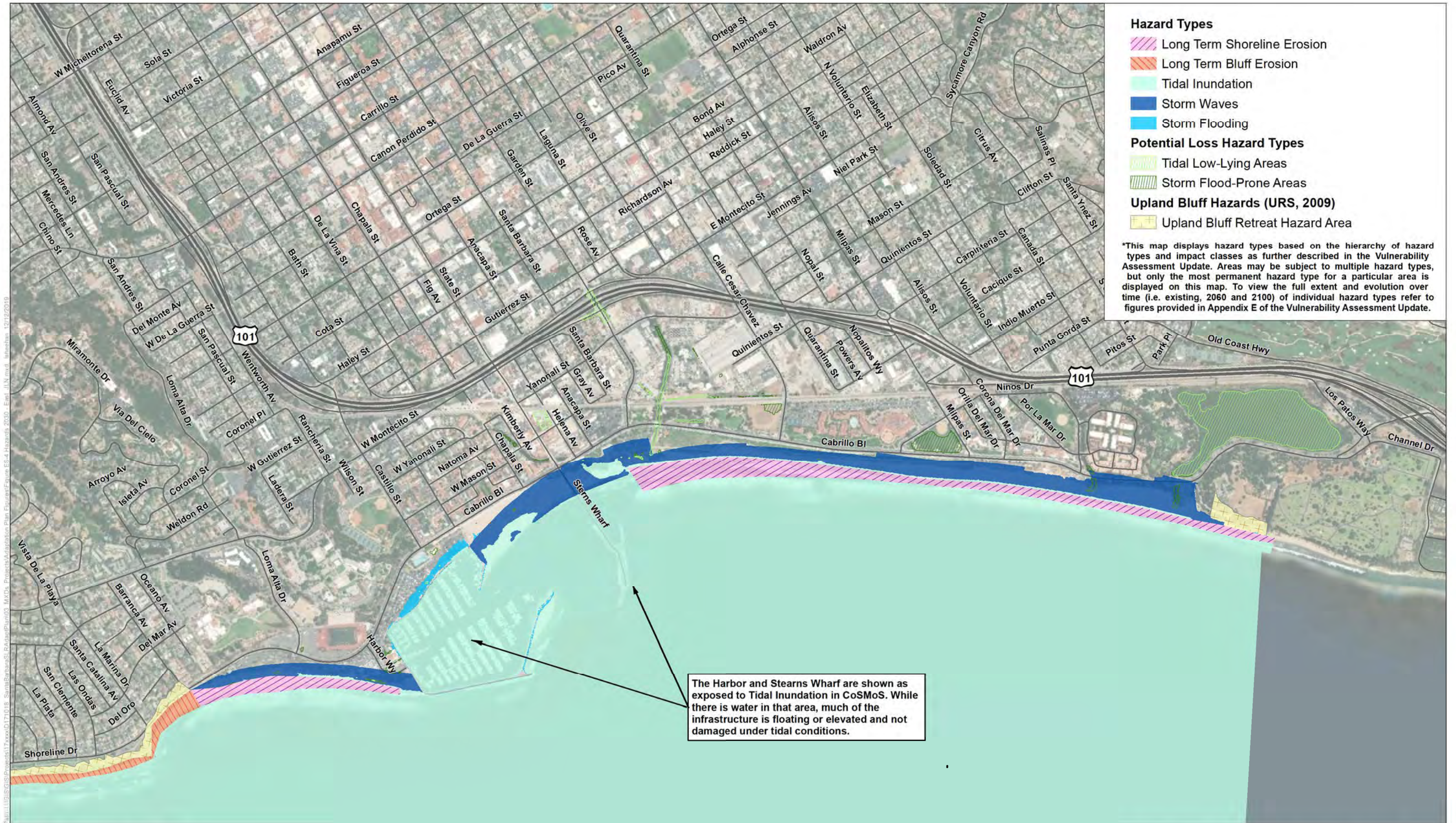
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Figure ES-3
Existing Conditions Hazards (East)



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SOURCE: ESRI, 2018; USGS, ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-5
Hazards with 0.8 Feet of Sea-Level Rise (±2030) (East)

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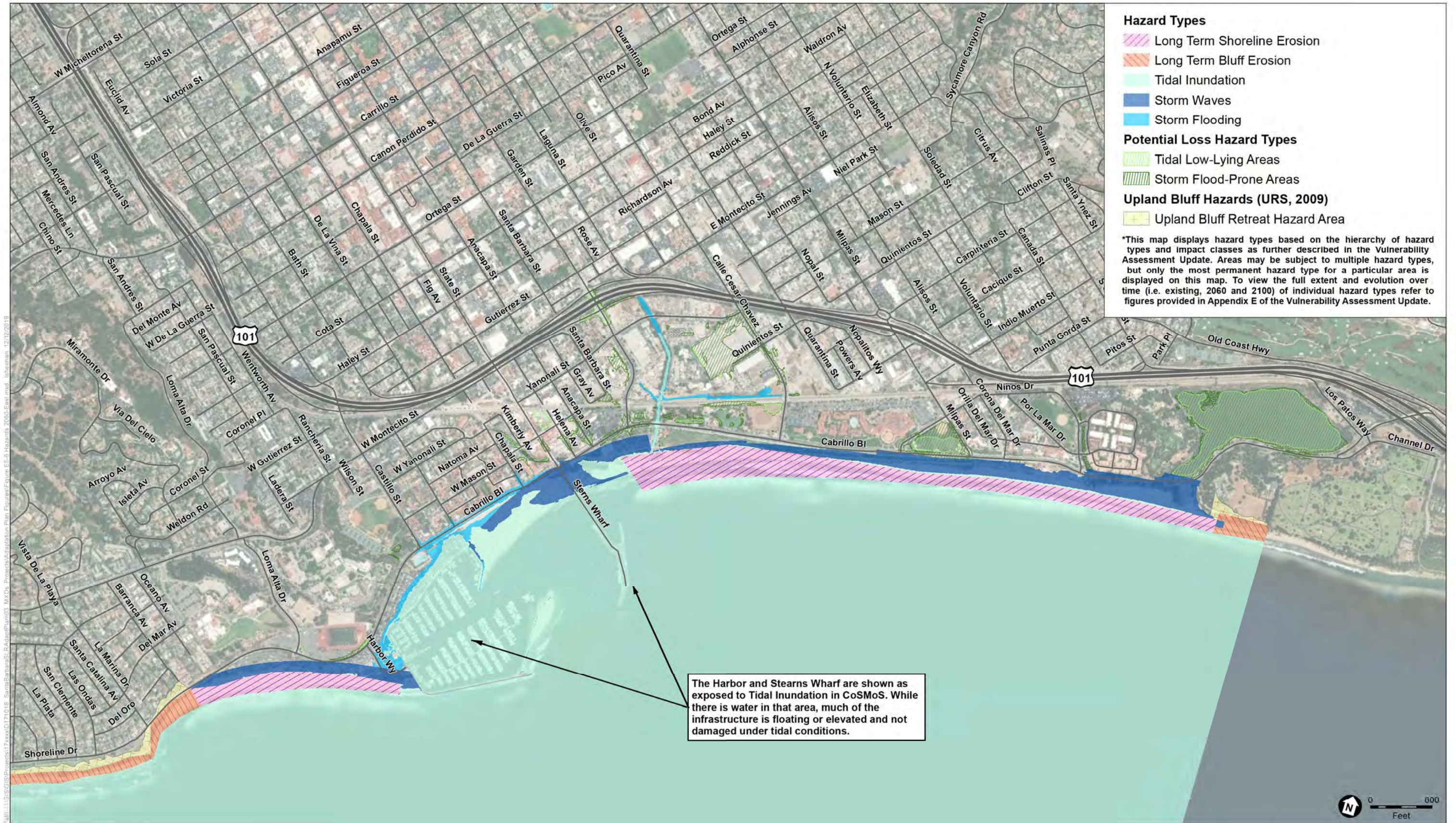
SOURCE: ESRI, 2018; USGS, 2018; ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-6
Hazards with 0.8 Feet of Sea-Level Rise (±2030) (West)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-7
Hazards with 2.5 Feet of Sea-Level Rise (±2060) (East)



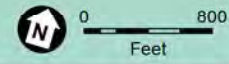
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Palmdale, CA: USGS/ES&S/Products/17/Products/01/171016_SantaBarbara/SB_RiskMap/Plum03_Maps/Products/Adaptation/Plan_Evaluation/Feature_E52_Hazards/2060_Visual.mxd - lshelham - 12/2/2018

- Hazard Types**
- Long Term Shoreline Erosion
 - Long Term Bluff Erosion
 - Tidal Inundation
 - Storm Waves
 - Storm Flooding
- Potential Loss Hazard Types**
- Tidal Low-Lying Areas
 - Storm Flood-Prone Areas
- Upland Bluff Hazards (URS, 2009)**
- Upland Bluff Retreat Hazard Area

*This map displays hazard types based on the hierarchy of hazard types and impact classes as further described in the Vulnerability Assessment Update. Areas may be subject to multiple hazard types, but only the most permanent hazard type for a particular area is displayed on this map. To view the full extent and evolution over time (i.e. existing, 2060 and 2100) of individual hazard types refer to figures provided in Appendix E of the Vulnerability Assessment Update.



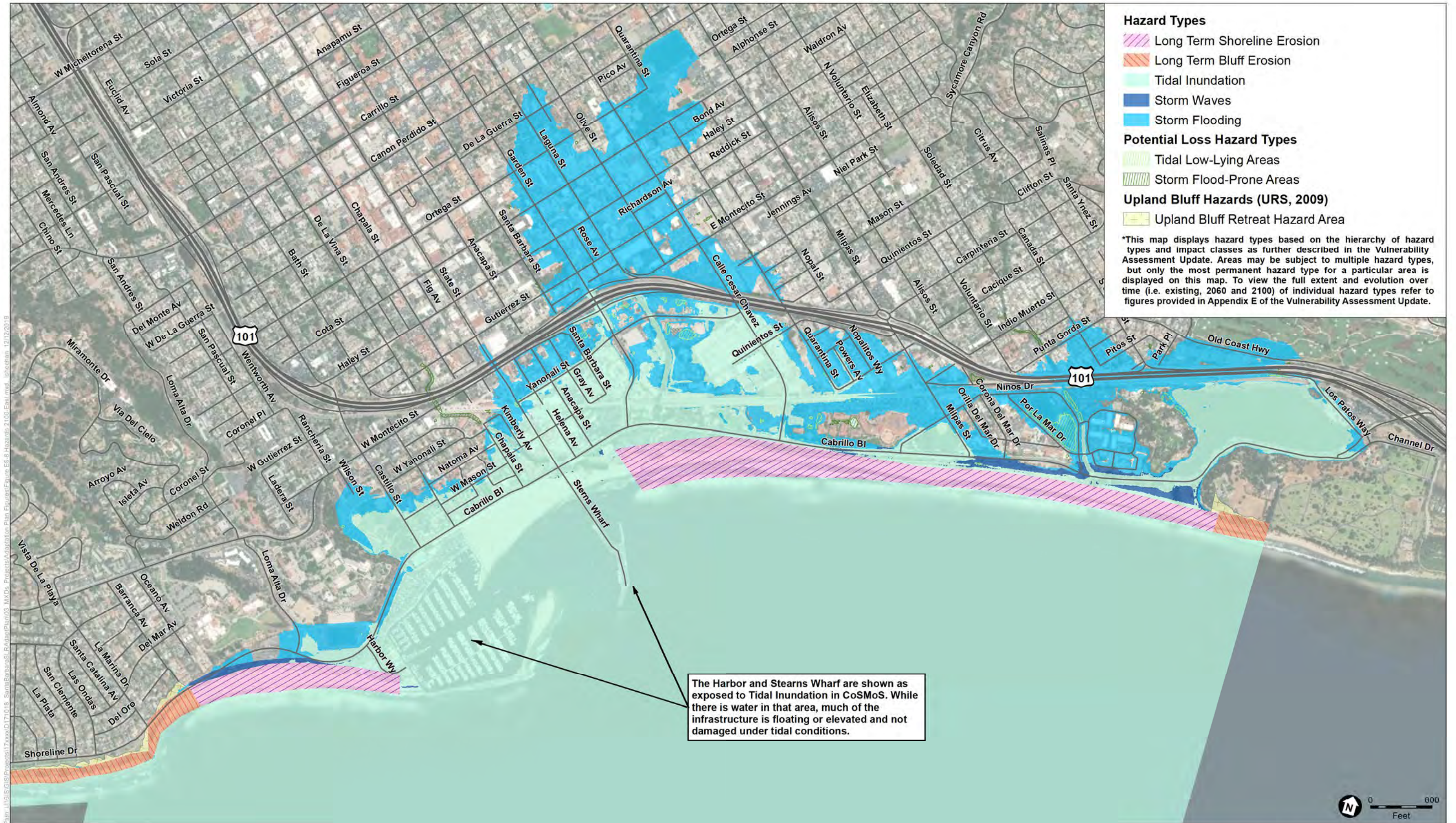
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-8
Hazards with 2.5 Feet of Sea-Level Rise (±2060) (West)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-9
Hazards with 6.6 Feet of Sea-Level Rise (±2100) (East)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure ES-10
Hazards with 6.6 Feet of Sea-Level Rise (±2100) (West)



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Low-Lying and Waterfront Areas

The low-lying areas of the City include the City's waterfront, lower downtown area, and Arroyo Burro County Beach Park. In these areas, sandy beaches and low-lying areas in the City are also expected to see a change in exposure with sea-level rise, predominantly due to increased tidal inundation during non-storm time periods and storm flooding. Under current conditions and at 2.5 feet of sea-level rise, impacts from erosion, tidal inundation, and storm waves are generally limited to the area south of Cabrillo Boulevard. However, at 6.6 feet of sea-level rise flooding from regular high tides and coastal storms is expected to extend north of Cabrillo Blvd toward Highway 101. Low lying areas north of Highway 101 that currently flood during extreme storms will see a higher frequency of flooding during storms.

Furthermore, at 2.5 feet of sea-level rise the City could lose 32% of its sandy beaches in these low lying areas to erosion, and at 6.6 feet of sea-level rise, the City could lose 60% of its sandy beaches in low lying areas. Erosion and tidal inundation are expected to lead to loss of 28% of recreational areas, open space areas, and parks in coastal parts of the City at 2.5 feet of sea-level rise, and 67% at 6.6 feet of sea-level rise. Many of these are located in low-lying waterfront areas, though some are in bluff-backed stretches of the coast.

The results also show that Cabrillo Pavilion would be at risk for flooding from storm waves under 6.6 feet of sea-level rise. Chase Palm Park would be threatened with erosion by 2.5 feet of sea-level rise and regularly inundated by the tides by 6.6 feet of sea-level rise. By 6.6 feet of sea-level rise, Chase Palm Park Center and the Carousel House would be regularly inundated by the tides. With 2.5 feet of sea-level rise, Los Banos del Mar Pool would begin to experience flooding during storms, and by 6.6 feet of sea-level rise, the flooding would occur more regularly as tidal inundation.

Harbor and Stearns Wharf

Under existing conditions, Stearns Wharf is exposed to wave damage during large storms and a 100-year coastal event is expected to require temporary closure and significant structural repairs. As sea level rises to 2.5 feet and 6.6 feet of sea-level rise, events large enough to damage Stearns Wharf are expected to become more common, though tidal conditions are not likely to pose a risk of damage for the wharf deck.

The harbor includes the marina, commercial uses, parking, industrial areas, and the City Pier (sometimes called the "harbor pier"), which supports the Coast Guard and houses a fuel dock. Under existing conditions, storm events and the highest high tides (e.g., "King Tides") can dislocate pile caps at the floating docks, and waves can overtop the harbor breakwater and reduce public access. More than 2 feet of sea-level rise (for example, the 2.5 feet of sea-level rise case) is expected to regularly impede normal harbor functions, and the harbor in its current configuration would be unusable at 6.6 feet of sea-level rise.

Storm Flooding Areas

Flooding from high waves and ocean water levels during coastal storms is expected to significantly increase in extent and frequency, particularly by 2100. FEMA flood insurance rate maps (FIRMs) are another hazard map generally used to assess exposure and vulnerability, so there is interest in how these relate to the results of this study. The City of Santa Barbara Flood Plain Management Ordinance (Municipal Code Section 22.24) also requires certain building standards based upon the location of the flood hazard zones and base flood elevations contained on FEMA FIRMs. FIRMs do not include future conditions or erosion hazards, so they indicate less severe coastal hazards from high waves and ocean levels than the hazard zones in this assessment in coastal areas. The FIRMs do, however, include extreme fluvial (river) events that occur during times of high precipitation. Coastal flooding from high waves and ocean levels during storms and river flooding from high precipitation during storms are mapped together on the FIRM, though extreme rainfall and extreme wave events are not expected to occur simultaneously.

Flood hazard areas currently mapped in the FIRMs are expected to experience more frequent flooding with sea-level rise, and the water levels are expected to change. The future coastal hazard zones in areas dominated by coastal or ocean flooding that are near the waterfront and downtown south of Highway 101 are expected to experience higher water levels and more severe flooding than currently shown on FEMA FIRMS (water levels up to 2 to 3 feet higher). Some areas south of Highway 101 that are not currently mapped in any flood hazard zone on the FEMA FIRMS right now are projected to experience flooding by 2100.

However, further inland (for example, downtown north of Highway 101), fluvial or river flooding is expected to be more extreme than coastal ocean flooding, so the FEMA FIRM (existing conditions) represent more extreme conditions than the hazard zones from this assessment (future conditions). These areas would likely experience more frequent flooding events by 2100 due to sea-level rise, but the flood depths from sea-level rise alone would likely not be more than the base flood elevations currently shown on the FEMA FIRMs.

Other changing climatic factors, such as increasing precipitation intensity, could increase the fluvial hazard and flood extents and depths. However, this would require further study and analysis outside the scope of this vulnerability assessment to fully understand.

Major Infrastructure Facilities

Major infrastructure facilities, including the El Estero Wastewater Treatment Plant, the Charles E. Meyer Desalination Plant, and several major roads, including Highway 101, are expected to experience increased flood risk by 2100. While they are expected to be exposed, facility-specific vulnerability assessments are recommended to better understand the adaptive capacity to flood proof these facilities and to more precisely assess the risk to these facilities.

The Vulnerability Assessment shows the El Estero Wastewater Treatment Plant partially in the tidal inundation and storm flooding hazard zones at 6.6 feet of sea-level rise and the Charles E. Meyer Desalination Plant, at least partially exposed to the tidal inundation and storm flooding

hazard zones at 6.6 feet of sea-level rise. However due to tidal inundation of the infrastructure associated with these plants, as well as portions of the plants themselves, both the El Estero Wastewater Treatment Plant and Desalination Plant will be permanently inoperable as currently designed at 6.6 feet of sea-level rise if no action is taken. Tidal inundation of some of the wastewater piping system flowing into the plant will occur at 2.5 feet of sea-level rise if no action is taken. Additional analysis is needed to determine how much this will affect operations of the plant. In addition, at 6.6 feet of sea-level rise, much of Cabrillo Boulevard is exposed to erosion or tidal inundation, Highway 101 may experience storm flooding near Andrée Clark Bird Refuge, and Shoreline and Cliff Drive could be threatened by shoreline and bluff erosion.

Next Steps

The City will use the findings of the vulnerability assessment to identify adaptation strategies that will address the impacts of coastal hazards and reduce the city's vulnerabilities. The City will prepare an Adaptation Plan that will provide a more detailed economic and physical analysis of adaptation scenarios, including a baseline scenario. A baseline scenario generally assumes the City will continue to manage their coastal resources as they have historically and provides an important point of comparison, in particular for the economic analysis, to consider and weigh the costs and benefits of other adaptation scenarios. The adaptation planning process will include working with the City and the community to discuss their priorities and to develop guiding principles that will help guide future adaptation choices and development of the Adaptation Plan.

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CITY OF SANTA BARBARA SEA-LEVEL RISE ADAPTATION PLAN FOR THE LOCAL COASTAL PROGRAM UPDATE:

Vulnerability Assessment Update

1. Introduction

This report addresses existing conditions and future vulnerability of the City of Santa Barbara (City) and its coastal resources to projected sea-level rise, coastal flooding and erosion if no action is taken to address these hazards. The report is an update to the Vulnerability Assessment previously completed for the County of Santa Barbara (County) (ESA 2015; 2016b), and builds on the refined hazard mapping prepared for the City (ESA, 2016a) and its assets (ESA, 2015). This update incorporates the most recent hazard mapping associated with the Coastal Storm Modeling System (CoSMoS) applied to southern California (version 3.0; Erikson et al., 2017). The updated Vulnerability Assessment will serve as a planning-level assessment meant to inform the development of a Sea-Level Rise Adaptation Plan that will analyze the feasibility, effectiveness, economic and fiscal impacts, environmental consequences, recreation impacts, and other costs and benefits of various adaptation strategies to avoid and/or mitigate coastal hazards over time. The Adaptation Plan will include a detailed Economic and Fiscal Impacts Analysis that is currently underway. The information in the Adaptation Plan will be used to amend policies and development standards in the City Local Coastal Program (LCP) to implement adaptation strategies. The City has been in the process of updating the LCP since 2014 and recently adopted an update to the LCP Land Use Plan.²

The City and County of Santa Barbara have performed several sea-level rise (sea-level rise) vulnerability studies, described in further detail in Appendix A. This study does not, and is not intended, to recreate the work performed in these previous studies. Instead, the Vulnerability Assessment Update augments those studies using the latest available data about coastal assets and infrastructure in the City. It also provides updated hazard information provided by the US Geological Survey (USGS), a focused study of local geology, and an investigation of the ecological effects of beach loss with sea-level rise. These elements fill gaps in the existing studies and provide the City with a more complete picture of its vulnerability to sea-level rise. The findings of this assessment will enable ESA to assist the City with development of adaptation strategies to prepare for future impacts and policy language for incorporation into the City's LCP Update.

² An LCP amendment to update the LCP Land Use Plan was approved by the City Council on August 7, 2018. As of the date of this study, the LCP Amendment had been submitted to the CCC for certification, but had not yet been scheduled for hearing.

The Vulnerability Assessment Update has been prepared consistent with the recommendations of the State’s most recent update to the California Coastal Commission Sea-Level Rise Policy Guidance document (OPC, 2018). The guidance document provides a synthesis of the best available science on sea-level rise in California, a step-by-step approach for state agencies and local governments to evaluate sea-level rise projections, and preferred coastal adaptation strategies. As State grant funded work, the project is also guided by the Safeguarding California Plan for Reducing Climate Risk (Safeguarding Plan) and supports the principles of the Safeguarding Plan.³

To support the adaptation planning process, vulnerability to erosion, tidal inundation, storm waves, and storm flooding hazards were analyzed under existing conditions and three future sea-level rise scenarios: 0.8 feet at 2030,⁴ 2.5 feet at 2060, and 6.6 feet at 2100. These scenarios were selected based on the latest State of California Sea-Level Rise Guidance (OPC 2018), which gives a range of sea-level rise projections for a region based on assumptions of risk aversion and low- versus high-emissions scenarios (the low being if emissions are greatly reduced in coming years and the high being if emissions continue as they have since the early 21st century). This document utilizes the high emissions scenario as recommended by California Coastal Commission (CCC) and others since 2013. A discussion of the selected sea-level rise scenarios and the State and Federal guidance that informed the selection of these scenarios and the approach to this Vulnerability Assessment Update is summarized in Section 3 and detailed in Appendix B.

Vulnerability was assessed by identifying potential hazard areas using available regional tools. Existing and potential future coastal tidal inundation, coastal storm flooding and coastal waves and erosion were mapped based on the results from the USGS’s the Coastal Storm Modeling System (CoSMoS) version 3.0 (Erickson et al., 2017) with some refinements provided by the Coastal Resilience Santa Barbara study (ESA, 2016) for wave hazard zones. The next steps were to identify assets located within the study area, assess the potential exposure of these assets to the different hazard areas, and evaluate the consequences. As sea levels rise, the extents of mapped hazards are expected to increase and a greater amount of assets will become exposed and vulnerable. Using available coastal hazard mapping products as further discussed in Sections 3

³ Safeguarding Plan principles:

- Use the best available science to identify risks and adaptation strategies;
- Understand that an effective strategy for preparing climate risks should evolve as new information is available;
- Involve all relevant stakeholders;
- Establish and maintain strong partnerships across all levels of government, tribes, businesses, landowners, and non-governmental organizations;
- Give priority to strategies that also achieve benefits other than climate risk reduction benefits, including additional benefits to public health, the economy, environmental justice, and conservation of natural resources; and
- Ensure that strategies to reduce climate risk are coordinated, to the extent possible, with the state’s efforts to reduce GHG emissions and other local, national and international efforts.

⁴ The OPC 2018 Guidance recommends 0.7 feet at 2030 (see Section 3.1). The closest CoSMoS Scenario is 25 cm, which is 0.8 feet. This difference is negligible at the scale of this study, and 0.8 feet is used throughout this report.

and 4, this assessment relies on reasonable assumptions and engineering judgement to simplify the analysis where needed.

The Vulnerability Report is organized as follows:

- Section 1 – Introduction
- Section 2 – Project Setting
- Section 3 – Existing and Future Coastal Hazard Zones
- Section 4 – Asset Exposure Analysis
- Section 5 – Ecological Vulnerability of Shoreline Habitats to Sea-Level Rise
- Section 6 – Conclusions
- Section 7 – References

1.1 Key Terms and Definitions

The following terms are used throughout the document based on the definitions included in this section:

- **Riverine flooding** refers to flooding originating from rainfall and high creek water levels.
- **Coastal flooding** refers to flooding due to waves and high water levels originating from the ocean.
- **Coastal storms** impact the shoreline through higher water levels and waves from the ocean and are commonly associated with low-pressure weather systems. Planning and analysis often occurs for the “100-year storm,” which is the storm estimated to have a 1% chance of occurring each year.
- **Coastal storm flooding** refers to coastal flooding that occurs during coastal storm events.
- **Hold the line** refers to a future scenario that assumes that management actions are taken to repair and replace damaged structures, and development will be maintained in its current position indefinitely.
- **Let it go** refers to a future scenario that assumes that no management actions are taken and erosion can continue unabated. Structures would not be removed, but would be destroyed over time as sea-level rise combined with storms impact them.
- **Tidal inundation** refers to coastal flooding during regular high tides under non-storm conditions.
- **Coastal erosion** refers to loss of sandy beaches, dunes, and the low-lying backshore along the shoreline through natural processes such as waves, wind, or tides.
- **Coastal bluff erosion** refers to loss of coastal bluffs as material falls or collapses onto the beach or into the ocean below.

1.2 Disclaimer and Use Restrictions

1.2.1 Funding Agencies

These data and this report were prepared for the City of Santa Barbara and is partially funded by California Coastal Commission (CCC) and the State Coastal Conservancy through the Local Coastal Program Local Assistance Grant Program. The data and report do 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.

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1.2.3 Data Usage

These data are freely redistributable with proper metadata and source attribution. Please reference ESA as the originator of the datasets in any future products or research derived from these data.

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 City of Santa Barbara, ESA, and all of the funders shall not be responsible or liable for any loss or damage of any sort incurred in connection with the use of the report or data.

2. Project Setting

This section presents information relevant to the physical context of the study area for the purposes of analyzing sea-level rise vulnerability. This includes a description of the study area in the City of Santa Barbara, a summary of a geologic review of seacliff areas in the City, a summary of the existing Federal Emergency Management Agency (FEMA) flood hazards, and a brief description of documented historic storm impacts to the City. Additional project setting information, including that related to coastal hydrology is included in Appendix C.

2.1 Study Area

The study area⁵ includes the coastal portion of the City, about 6.5 linear miles of coastline from Arroyo Burro in the west to the Andrée Clark Bird Refuge in the east. It also includes Santa Barbara Harbor and extends inland far enough to capture the inland extent of projected flooding of the downtown Santa Barbara area. The study area does not include the Santa Barbara Airport and Goleta Slough, which have been studied in a separate sea-level rise report as further described in Appendix A. The study area was divided into 11 planning subareas based on land use composition and shore type morphology (e.g., bluff versus low-lying beach and backshore) for discussion purposes and to investigate the spatial variability of sea-level rise vulnerability in these areas. These subareas are shown in **Figure 1** and their primary coastal characteristics, key features, and land uses are summarized in **Table 1**, below.

2.2 Geology

The geography within the study area is a mix of coastal bluffs and low-lying sandy beaches and backshores.⁶ The bluffs are composed of Monterey formation silt-mudstone, Casitas formations (which are moderately consolidated and mostly coarse sediment matrix formations), and unconsolidated sand and silt marine terrace deposits. The typical layering entails Monterey or Casitas formations overlain by marine terrace deposits. The layering geometry is not uniform owing to land movements as well as landslides. There is evidence of past landslides along the coastal bluffs, and landslides are expected to occur in the future. Beach sands and fill overlay the geology. Additional information on the geology of the study area is provided in a report prepared by Campbell Geo Inc. included in Appendix D. Additional information about geology and bluff erosion is provided in the existing studies described in Appendix A and include work by ESA (ESA, 2015; 2016, 2016b) and Erikson et al. (2017).

⁵ The study area was defined by the extent of the projected future coastal hazards occurring at 2100 under the medium high risk aversion scenario, or 6.6 feet of sea -level rise. This covers areas within the City's jurisdiction that could be exposed to any of the hazards used in this study.

⁶ Backshores are areas of a beach that extend inland from the limit of high water foam lines to the extreme inland limits of the beach, including bluffs and dunes that are in the coastal flood plain now or may be in the coastal flood plain in the future based on erosion and sea level rise. Backshore areas are typically only affected by waves during exceptional high tides or severe storms.

2.3 Existing FEMA Flood Zones

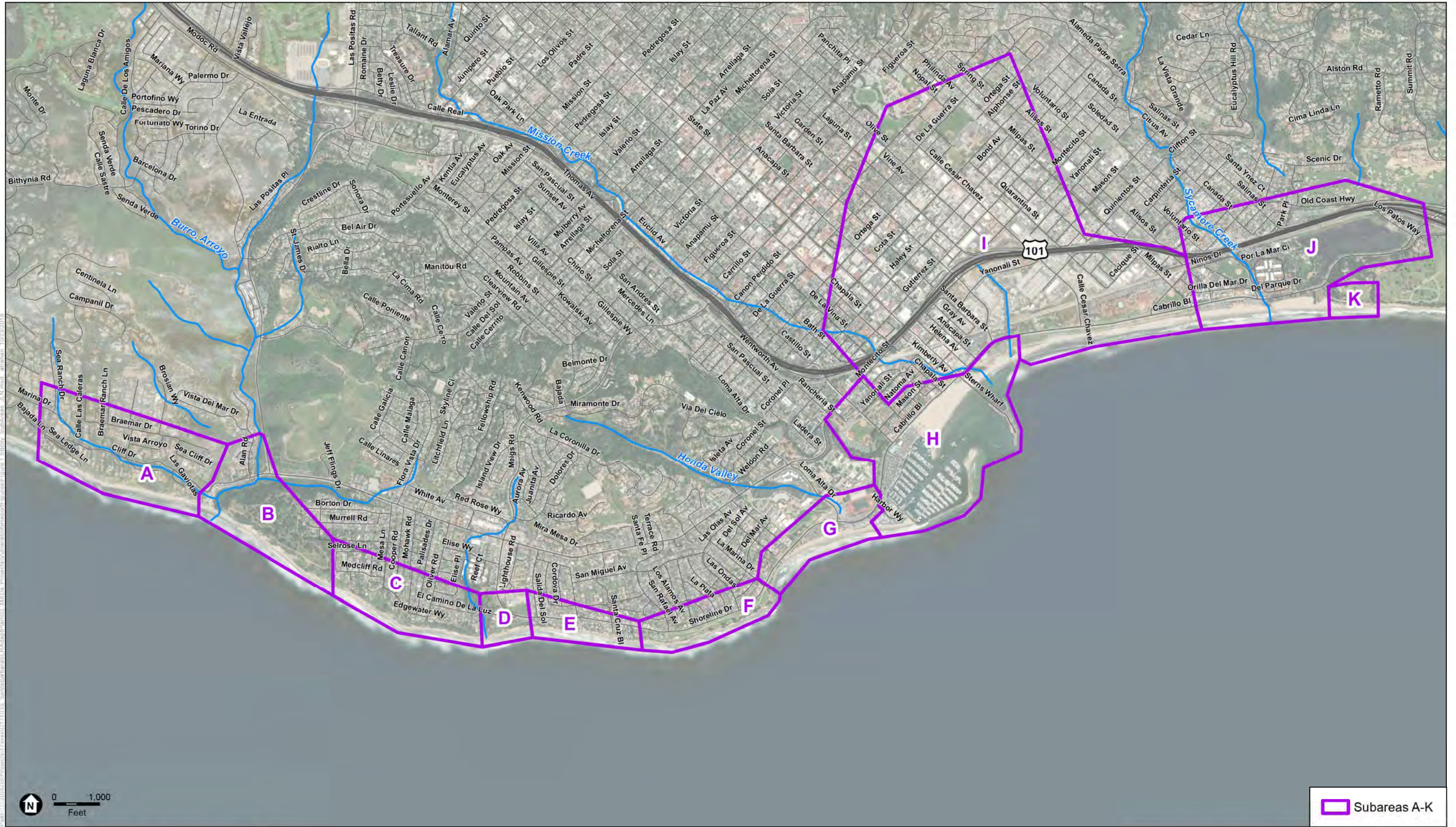
FEMA provides flood insurance rate maps (FIRMs) showing flood hazard information in support of the National Flood Insurance Program (NFIP). FEMA maps include Base Flood Elevations (BFEs) for flooding with a 1% chance of occurrence in a given year (otherwise known as a “100-year event”) from coastal and rainfall sources. FEMA maps show flood risk for current conditions. FEMA maps do not include coastal erosion or consider future coastal flooding or hazards resulting from sea-level rise. The City of Santa Barbara Flood Plain Management Ordinance (Municipal Code Section 22.24) requires certain building standards based upon the location of the flood hazard zones and BFEs contained on FEMA FIRMs.

This Vulnerability Assessment addresses future coastal hazards with projected sea-level rise for the purpose of informing adaptation planning and policy development. This Vulnerability Assessment is based on the U.S. Geological Survey’s Coastal Storm Modeling System (CoSMoS) results, which are described further in Section 3. CoSMoS provides coastal flood hazard results for a coastal storm with an approximate 1% annual chance or 100-year event, including flood hazards due to creek/river flows estimated to occur during such a coastal storm.^{7,8} In contrast to FEMA maps, CoSMoS results do not include flood hazards due to the 1% annual chance or 100-year river flow. Nuance of these differences is discussed in Appendix C.

Figure 2 presents the FEMA special flood hazard areas for the City of Santa Barbara. A significant portion of Santa Barbara is mapped in the FEMA 100-year floodplain, due primarily to fluvial (river and creek) sources, including Mission Creek, Laguna Channel, Sycamore Creek, and Arroyo Burro Creek. The downtown Santa Barbara area north of Highway 101 is a low-lying area with restricted drainage, and has flooded during historical precipitation storm events. Along the coast, areas denoted Zone VE indicate that waves are a main contributor to the BFEs. Coastal areas denoted Zone AE, for example at the outlet of Sycamore Creek in the east of the City, indicate that while waves are present, they are significantly lower in elevation than the fluvial flood hazards. Section 3.10 includes further comparison and discussion of FEMA flood mapping and the coastal hazard mapping used for this Vulnerability Assessment. Appendix E includes FEMA FIRM panels for the study area.

⁷ Note that CoSMoS flood hazard results for the 100-year coastal event and fluvial (river and creek) flooding during the coastal storm event are less extensive than FEMA’s mapping of the 100-year fluvial flood extents because CoSMoS’ estimates of the fluvial flows in Arroyo Burro, Mission creek, and Sycamore creek during the 100-year coastal storm are less than FEMA’s estimates of the 100-year fluvial flows due to extreme inland precipitation events.

⁸ FEMA also determines the flood extent and BFEs using statistics to estimate the 1% annual chance conditions based on many possible storms and runoff events, while CoSMoS uses a single storm with a 1% annual chance. CoSMoS’ selection of a single storm may capture most flooding at the 1% chance level, but may not fully capture the extent of 1% chance flooding.



SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 1
Shoreline Hazard Planning Subareas

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SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018; FEMA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 2
FEMA Special Flood Hazard Zones in Santa Barbara

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TABLE 1
DESCRIPTIONS OF SUBAREAS IN STUDY AREA

| Subarea | Location | Shore Development Type | Shoreline and Backshore Types | Other Key Facilities/Landmarks |
|----------------|--|--------------------------------|--|---|
| Subarea A | Sea Ledge Lane to west side of Arroyo Burro Beach County Park | urban bluff-top – residential | <ul style="list-style-type: none"> bluff-backed beach ancient landslide at Sea Ledge Lane | <ul style="list-style-type: none"> residential development |
| Subarea B | Arroyo Burro Beach County Park to east edge of Douglas Family Preserve | natural bluff-top – open space | <ul style="list-style-type: none"> bluff-backed beach low-lying drainage and coastal lagoon Arroyo Burro Lagoon | <ul style="list-style-type: none"> Arroyo Beach County Park (natural preserve) and parking Douglas Family Preserve (natural preserve) |
| Subarea C | west end of Medcliff Road to East End of El Camino de la Luz | urban bluff-top – residential | <ul style="list-style-type: none"> bluff-backed beach modern landslide at El Camino de la Luz | <ul style="list-style-type: none"> Mesa Lane beach access residential development |
| Subarea D | Lighthouse | natural bluff-top – open space | <ul style="list-style-type: none"> bluff-backed beach | <ul style="list-style-type: none"> Lighthouse La Mesa Park Washington Elementary |
| Subarea E | Meigs Road to Shoreline Park | urban bluff-top – residential | <ul style="list-style-type: none"> bluff-backed beach | <ul style="list-style-type: none"> 1,000 Steps beach access residential development |
| Subarea F | Shoreline Park to Santa Barbara Point | natural bluff-top – open space | <ul style="list-style-type: none"> bluff-backed beach | <ul style="list-style-type: none"> Shoreline Park and parking Shoreline Park beach access residential development |
| Subarea G | Leadbetter Beach | urban beachfront | <ul style="list-style-type: none"> low-lying beach and backshore | <ul style="list-style-type: none"> public parking Santa Barbara Community College park and open space commercial establishments residential development |
| Subarea H | Harbor to Laguna Tide Gates | harbor | <ul style="list-style-type: none"> protected harbor low-lying beach and backshore Mission Creek Lagoon | <ul style="list-style-type: none"> harbor marinas Harbor Pier (City Pier) yacht club and boat yard US Coast Guard office Waterfront Department offices park areas Waterfront Coastal Trail West Beach Sandspit (surf spot) recreation facilities (Los Baños del Mar Pool) Stearns Wharf Laguna Tide Gates and Pump Station commercial establishments residential development public parking lots |

| Subarea | Location | Shore Development Type | Shoreline and Backshore Types | Other Key Facilities/Landmarks |
|-----------|---|---------------------------------------|---|---|
| Subarea I | Chase Palm Park & Downtown | sandy beach | <ul style="list-style-type: none"> • low-lying backshore • inland areas | <ul style="list-style-type: none"> • Chase Palm Park and other parks • Waterfront Coastal Trail • El Estero Wastewater Treatment Plant • Charles E. Meyer Desalination Plan • railroad and train station • recreation and public facilities • Downtown area (north of Highway 101) with commercial establishments • East Beach • Highway 101 • Santa Barbara High School • Santa Barbara Junior High School • residential development |
| Subarea J | South Milpas Street to Andree Bird Clark Refuge | sandy beach – low lying and backshore | <ul style="list-style-type: none"> • low-lying backshore • inland areas | <ul style="list-style-type: none"> • East Beach • Sycamore Creek Lagoon • Waterfront Coastal Trail • Andrée Clark Bird Refuge • Santa Barbara Zoo • recreational and public facilities • commercial establishments • Cabrillo Pavilion Bathhouse • residential development |
| Subarea K | Bellosguardo Estate | urban bluff-top – recreational | <ul style="list-style-type: none"> • bluff backed beach | <ul style="list-style-type: none"> • Bellosguardo Estate |

2.4 Historical Damages from Storms

The City of Santa Barbara has been exposed to several severe floods in the last three decades, with particularly large events associated with El Nino events in 1983 and 1998. These events resulted in several forms of damage, including significant wave overtopping at the breakwater, damage to slips and vessels in the Harbor, flooding of coastal parking lots, localized erosion along the sandy shoreline, and flooding in the downtown area from Laguna Channel. Some examples of historical flooding are shown in **Figure 3** and **Figure 4**.

Historical flooding offers tangible examples of the damage caused by flooding, erosion, and waves in the City. Leadbetter Beach was eroded over 100 feet horizontally and over 10 feet vertically in 1978 and 1980 (NRC, 1982) In 1983 the shore retreated about 200 feet (NRC, 1984). The 1983 events also eroded West Beach and East Beach. The eroded beaches allowed breaking waves to propagate farther landward than normal, exposing inland facilities including Shoreline Drive and boat berths to waves. The beach erosion also allowed wave runup to flood inland areas. Coastal structures were constructed to mitigate future damage risk, including the breakwater extension built in 1986 and the beaches have recovered through both natural sand deposition and augmentation with dredged sand.



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00

SOURCE: City of Santa Barbara

Figure 3
Overtopping at the Southwest Corner of the Harbor Breakwater in March 2014



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00

SOURCE: City of Santa Barbara

Figure 4
Flooding at the Harbor West Parking Lot in January 2014

Future flooding is likely to follow similar patterns, leading to similar damage unless measures are taken to protect infrastructure along the coast. Furthermore, rare events like the 1983 and 1998 storms and sustained damage from rising water, waves, and coastal erosion are likely to become more common as sea level rises. While the extent of exposure and vulnerability outlined in the following chapter may seem extreme in some cases, it is worth remembering that similar damage has already occurred (if rarely) in the past, and is apt to become more common with sea-level rise.

3. Existing and Future Coastal Hazard Zones

This section describes coastal hazard zones under current conditions and future conditions. The sea-level rise scenarios that were used as a basis for the vulnerability analysis are discussed, with further information available in Appendix B. Coastal hazard zone mapping for this vulnerability assessment is addressed, both in general and with a more detailed description of each hazard that was mapped.

3.1 Sea-Level Rise

As discussed in the Introduction of this report, vulnerability to erosion, tidal inundation, storm waves, and storm flooding hazards were analyzed under existing conditions and three future sea-level rise scenarios: 0.8 feet at 2030, 2.5 feet at 2060, and 6.6 feet at 2100. These scenarios were selected based on the latest State of California Sea-Level Rise Guidance (OPC 2018), which gives a range of sea-level rise projections for a region based on assumptions of risk aversion and low- versus high-emissions scenarios (the low being if emissions are greatly reduced in coming years and the high being if emissions continue as they have since the early 21st century). This document utilizes the high emissions scenario as recommended by CCC and others since 2013.

The guidance document also recommends ranges in sea-level rise values for a region based upon likelihood of occurrence. Scenarios that are very likely to occur are to be utilized for low risk aversion planning, such as planning for trails or other assets that are easily moved. Scenarios that are less likely to occur are to be utilized for moderate/high risk aversion decisions, such as buildings and infrastructure that are harder to move. This Vulnerability Assessment Update utilizes the medium/high risk-aversion scenarios. The State of California Sea-Level Rise Guidance (OPC, 2018) also recommends considering an extreme risk aversion scenario, termed “H++” for the planning and design of “highly vulnerable or critical assets”. This report is a planning-level document that will inform adaptation planning and policy development; this report does not provide an engineering-level analysis. Therefore, this report generally uses the medium-high risk aversion scenario to indicate whether an asset is located in a hazard zone and to identify critical assets that will require subsequent, more detailed analyses in order to inform further planning and design. This report does not provide a detailed analysis of vulnerability under the H++ scenario, but it does use the H++ scenario to understand how much earlier the projected sea-level rise amounts could occur. Based on current research, the probability of the H++ scenario is unknown, so the City does not plan to design to this scenario.

Table 2 summarizes these sea-level rise scenarios, including the amount and associated time horizon, used for the technical analysis in this vulnerability assessment. OPC (2018) provides guidance for communities based on their risk aversion and based on different greenhouse gas emissions scenarios. A community with relatively little coastal exposure or easily replaceable assets may opt to prepare for the low risk aversion sea-level rise values, while a community with extensive coastal exposure or assets that are difficult or impossible to replace may opt to prepare for extreme risk aversion. Within the risk aversion categories, communities can make different assumptions about future greenhouse gas emissions. OPC (2018) provides low and high emissions scenarios. The three rows of Table 2 represent the risk aversion thresholds defined by OPC (2018), and the range in values at future time horizons represent the low and high greenhouse gas emissions scenarios.

TABLE 2
SEA-LEVEL RISE SCENARIOS FOR PROJECT (UNDERLINED, BOLD) ARE BASED ON OPC 2018 GUIDANCE

| Scenario | 2030 | 2060 | 2080 | 2100 |
|-------------------------------------|-----------------------------|------------------------|------------------------|------------------------|
| Low Risk Aversion ^a | 0.4 feet | 1.0 to 1.3 feet | — | 2.0 to 3.1 feet |
| Med-High Risk Aversion ^b | <u>0.7 feet^c</u> | 2.2 to <u>2.5 feet</u> | — | 5.3 to <u>6.6 feet</u> |
| Extreme Risk Aversion | — | — | 5.3 to <u>6.6 feet</u> | — |

NOTES:

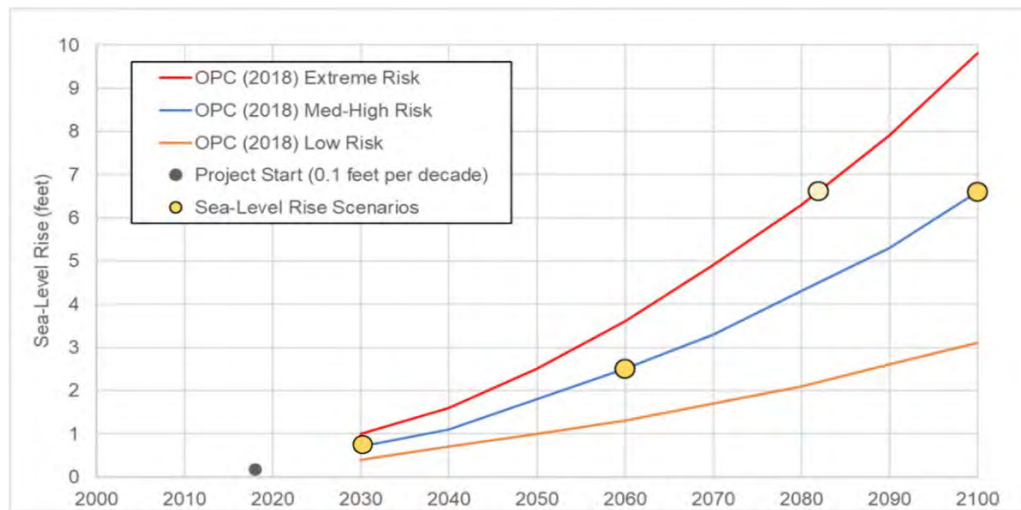
^a Low Risk Aversion values not used for this analysis.

^b Bold and underlined values in the Med-High Risk Aversion are used in this analysis.

^c The OPC 2018 Guidance recommends 0.7 feet at 2030. The closest CoSMoS Scenario is 25 cm, which is 0.8 feet. This difference is negligible at the scale of this study, and 0.8 feet is used throughout.

This study applied a range of sea-level rise amounts and time horizons consistent with the State’s guidance (CCC 2015, OPC 2018) which calls for consideration of a range of scenarios in order to bracket the range of likely impacts. Mid- and late-century timeframes of 2060 and 2100 (2.5 feet of sea-level rise and 6.6 feet of sea-level rise), respectively, were selected and are consistent with the timeframes selected in earlier vulnerability studies prepared for the City and County of Santa Barbara (ESA 2015; 2016). A near-term scenario at 2030 (0.8 feet of sea-level rise) was reviewed and was deemed similar enough to existing conditions, therefore it was not analyzed in detail.

Figure 5 depicts the selected sea-level rise scenarios used in this study.



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00

SOURCE: OPC 2018

Figure 5
Updated OPC (2018) Sea-Level Rise Guidance Curves, with Selected Scenarios

As stated previously, the extreme risk aversion scenario (H++) is used to understand how much earlier the selected sea-level rise amounts would occur if catastrophic melting of ice sheets was to occur. In this case, sea-level rise could reach 6.6 feet as early as 2080, not 2100. This serves to warn the City that the analysis and results described for 2100 (6.6 feet of sea-level rise) could occur almost 20 years earlier.

Further information on sea-level rise guidance and scenario selection is provided in Appendix B.

3.2 Hazard Zones

The Coastal Storm Modeling System (CoSMoS) implemented for Southern California (Version 3.0, Erikson et al. 2017, O’Neal et al 2018, Erikson et al, 2018) provides projections of erosion, permanent inundation, and temporary (storm event) inundation under future conditions. These projections were used to establish the hazard zones in this analysis. Based on our review and comparison with hazard data from previous studies, and further direction from the City of Santa Barbara, ESA augmented the CoSMoS wave runup estimates with additional wave hazard data represented in the Santa Barbara County *Coastal Resilience* maps (ESA 2016).

The hazard zones used in this analysis are described as follows:

- **Shoreline Erosion** – Over time, sandy beaches and dunes experience temporary erosion, with sand moving seasonally to and away from the beach, and permanent erosion, with sand moving away from the beach without returning. In this study, “shoreline erosion” refers to the permanent loss of sandy beaches, dunes, and the low-lying backshore that occurs with changing sea level or sand supply.
- **Bluff Erosion** – Over time, erosion causes the edge of coastal bluffs to move inland as material falls or collapses onto the beach (or into the ocean) below.
- **Tidal Inundation** – Tidal inundation refers to areas that are below the typical high tide elevation under non-storm conditions.
- **Storm Waves** – Storm waves refer to the exposure of the Santa Barbara shore to large waves generated by local and distant storms. These waves arrive at the Santa Barbara coast from a range of directions, and influence the coastal water levels and also directly induce flooding, erosion, and wave damage hazards, described generally as a wave hazard zone landward of the high tide line.
- **Storm Flooding** – When storms strike the Santa Barbara coast, they generally bring high water levels and waves. In this study, “storm flooding” refers to the combination of the high water levels that come with a storm, including some of the effects of waves. The coastal storm used to define the hazard zone is estimated to have a 1% chance of occurring each year (i.e., a “100-year storm”).

Some portions of the City are below the tidal inundation and storm flooding elevations, but are not directly connected to the ocean. These disconnected low-lying areas are subject to flooding and are further described in Section 3.8.

Table 3 presents a summary of the hazard types, their impact class and the data sources used to prepare hazard maps (Appendix F). This approach assumes that permanent impacts occur when assets are exposed to long-term erosion of sandy beach and dunes, long term erosion of bluffs, and tidal inundation, while temporary impacts occur when assets are exposed to storm flooding and storm wave impacts.⁹

⁹ Because large waves on the west coast are often generated at storms in the open ocean, while storm flooding occurs during local storms, storm flooding and storm waves may not occur at the same time and may affect different areas. The storm waves hazard zones represent the areas temporarily affected by waves when waves from these distant storms arrive at the coast.

**TABLE 3
SUMMARY OF HAZARD MAPPING DATA ORGANIZED BY HAZARD TYPE AND IMPACT CLASS**

| Hazard Type | Impact Class | Mapping Data Source |
|--|---------------------|---|
| Long-Term Erosion – Sandy Beach and Dune | Permanent | CoSMoS 3.0 ^a |
| Long-Term Erosion – Bluff | Permanent | CoSMoS 3.0 |
| Tidal Inundation | Permanent | CoSMoS 3.0 |
| Storm Waves | Temporary | Coastal Resilience – Santa Barbara ^b |
| Storm Flooding | Temporary | CoSMoS 3.0 |

NOTES:

^a CoSMoS 3.0: Erikson et al. 2017

^b Coastal Resilience – Santa Barbara: ESA (2015; 2016)

It should be noted that the previous vulnerability assessment (which this updates) used the Coastal Resilience projections (ESA 2016), and these could be used instead of CoSMoS. However, based on discussions with City staff and our understanding that the State of California intends to continue to use CoSMoS as the State standard and that use of CoSMoS as the standard is further supported by the USGS, the CoSMoS projections were selected going forward.

A hierarchy of the coastal hazard zones was used to identify the primary impact to an asset so that impacts are not double-counted. That is, if an asset is shown as being exposed to bluff erosion, it is not also presented as exposed to tidal flooding. This is because assets in eroded areas are considered permanently lost, so adding a flooding impact would be redundant. Using mutually exclusive hazard zones prevents over-estimating exposure to less severe hazards (i.e., storm flooding) which may cover large areas that have already been addressed with other hazards (i.e., tidal inundation). Hazard zones are evaluated in the order listed in Table 3, with erosion taking highest precedence and storm flooding taking lowest. Note that the figures below include disconnected low-lying areas in addition to the hazards in Table 3, which are used to indicate potential flood-prone areas and locations where future groundwater elevations could become a nuisance. The following figures present existing and future sea-level rise hazard zones:

- Existing Conditions:

- Figure 6 (east) and **Figure 7** (west)
- 0.8 feet of sea-level rise: **Figure 8** (east) and **Figure 9** (west)
- 2.5 feet of sea-level rise: **Figure 10** (east) and **Figure 11** (west)
- 6.6 feet of sea-level rise: **Figure 12** (east) and **Figure 13** (west)

Upon reviewing the hazard zones for 0.8 feet of sea-level rise, it was determined that this scenario is similar to existing conditions, showing no significant changes from the present. Some of the beach areas along the coast are exposed to erosion hazards at 0.8 feet of sea-level rise, rather than tidal flooding in existing conditions; however, these are both permanent loss hazards and therefore existing and 0.8 feet of sea-level rise hazards are similar in terms of asset impacts. This allowed the study to focus on assets that are exposed and vulnerable to coastal hazards at 2.5 feet of sea-level rise and 6.6 feet of sea-level rise.

3.3 Long-Term Shoreline Erosion

CoSMoS incorporates historical trends in shoreline position, longshore transport, and cross shore transport to provide a line indicating the inland extent of shoreline.¹⁰ This inland extent is defined as the mean high water mark and is averaged over all seasons to avoid capturing seasonal variation in the shoreline position. The shoreline erosion hazard zone is the area between the existing shoreline and estimated inland extent of the shoreline, and assets in this zone were deemed exposed to shoreline erosion. In this study, shoreline erosion is considered a **permanent loss hazard**, since assets in eroded areas will be completely lost.

3.4 Long-Term Bluff Erosion

CoSMoS incorporates cliff materials, changing water levels, and wave conditions to provide a line indicating the inland extent of bluff erosion.¹¹ This line represents the potential bluff edge at each time horizon. The assets between this line and the tidal inundation hazard zone were deemed exposed to bluff erosion, since they would be affected as the bluff edge moves inland over time. In this study, bluff erosion is considered a **permanent loss hazard**, since assets in eroded areas will be completely lost.

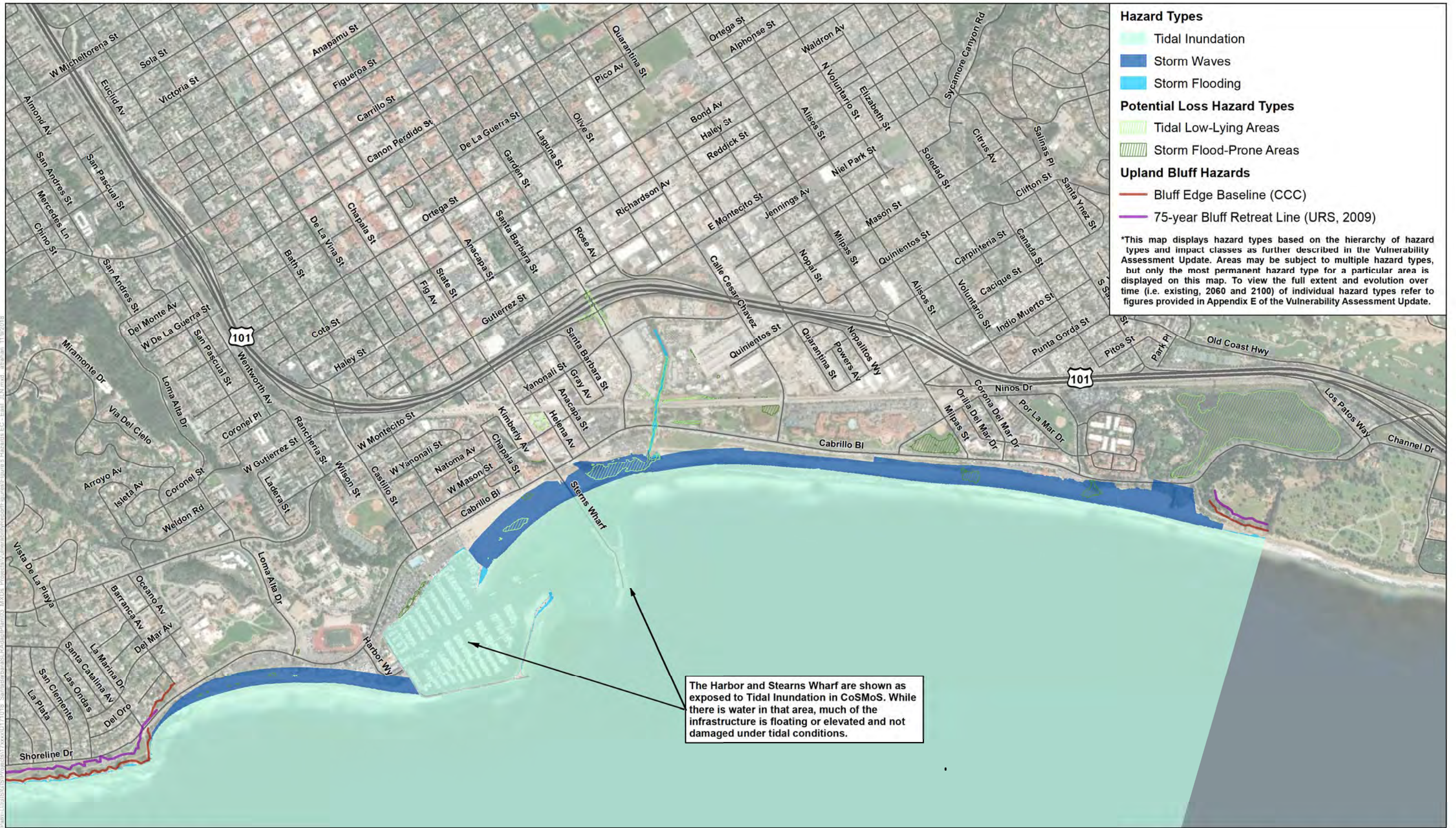
A review of the CoSMoS and Coastal Resilience erosion projections for the Santa Barbara shore is provided by Campbell Geo (Appendix D). The comparison concludes that the two methods provide similar results in general, but differ at specific locations due to differences in the methods used. The Coastal Resilience results are sensitive to the increase in wave runup (e.g., total water level) reaching the bluff face with future sea levels. The CoSMoS results are sensitive to the historic erosion rate used, which may lead to overestimating rates in areas with historically more erosion and underestimating rates in areas with less erosion. Based on a review of the average erosion projections over the century, bluffs will erode about 1.5 times as fast at 2.5 feet of sea-

¹⁰ CoSMoS includes a transect based shoreline change model, which was used to estimate the regions along the Santa Barbara coast that may erode by the study's two time horizons. The model assumes a Bruun type geomorphic response to sea-level rise.

¹¹ CoSMoS includes a transect based cliff recession model, which was used to estimate the regions along the Santa Barbara coast that may erode by the study's two time horizons.

level rise (a 40% increase over the historic rate), and more than twice as fast at 6.6 feet of sea-level rise (a 140% increase over the historic rate). Therefore, bluff top areas are expected to be increasingly exposed to hazards with sea-level rise.

The Coastal Resilience erosion projections are higher than the CoSMoS projections in some locations. The bluff erosion projections from the Coastal Resilience study identified existing cliff failure hazards (since cliff or bluff erosion is often episodic) and included a “factor of safety” based on the statistical uncertainty in bluff erosion rates. While the Coastal Resilience bluff erosion projections are higher than the CoSMoS projections, the Coastal Resilience erosion projections were not used in this vulnerability assessment. ESA notes that future bluff erosion may be higher than projected by CoSMoS, and thus may require a more precautionary approach to adaptation planning in these areas. Because the methods have similar results, as discussed previously, the CoSMoS results were selected for consistency with applying the CoSMoS inundation and flooding hazard zones.



Hazard Types

- Tidal Inundation
- Storm Waves
- Storm Flooding

Potential Loss Hazard Types

- Tidal Low-Lying Areas
- Storm Flood-Prone Areas

Upland Bluff Hazards

- Bluff Edge Baseline (CCC)
- 75-year Bluff Retreat Line (URS, 2009)

*This map displays hazard types based on the hierarchy of hazard types and impact classes as further described in the Vulnerability Assessment Update. Areas may be subject to multiple hazard types, but only the most permanent hazard type for a particular area is displayed on this map. To view the full extent and evolution over time (i.e. existing, 2060 and 2100) of individual hazard types refer to figures provided in Appendix E of the Vulnerability Assessment Update.

The Harbor and Stearns Wharf are shown as exposed to Tidal Inundation in CoSMoS. While there is water in that area, much of the infrastructure is floating or elevated and not damaged under tidal conditions.

SOURCE: ESRI, 2018; USGS, 2018; ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 6
Existing Conditions Hazards (East)



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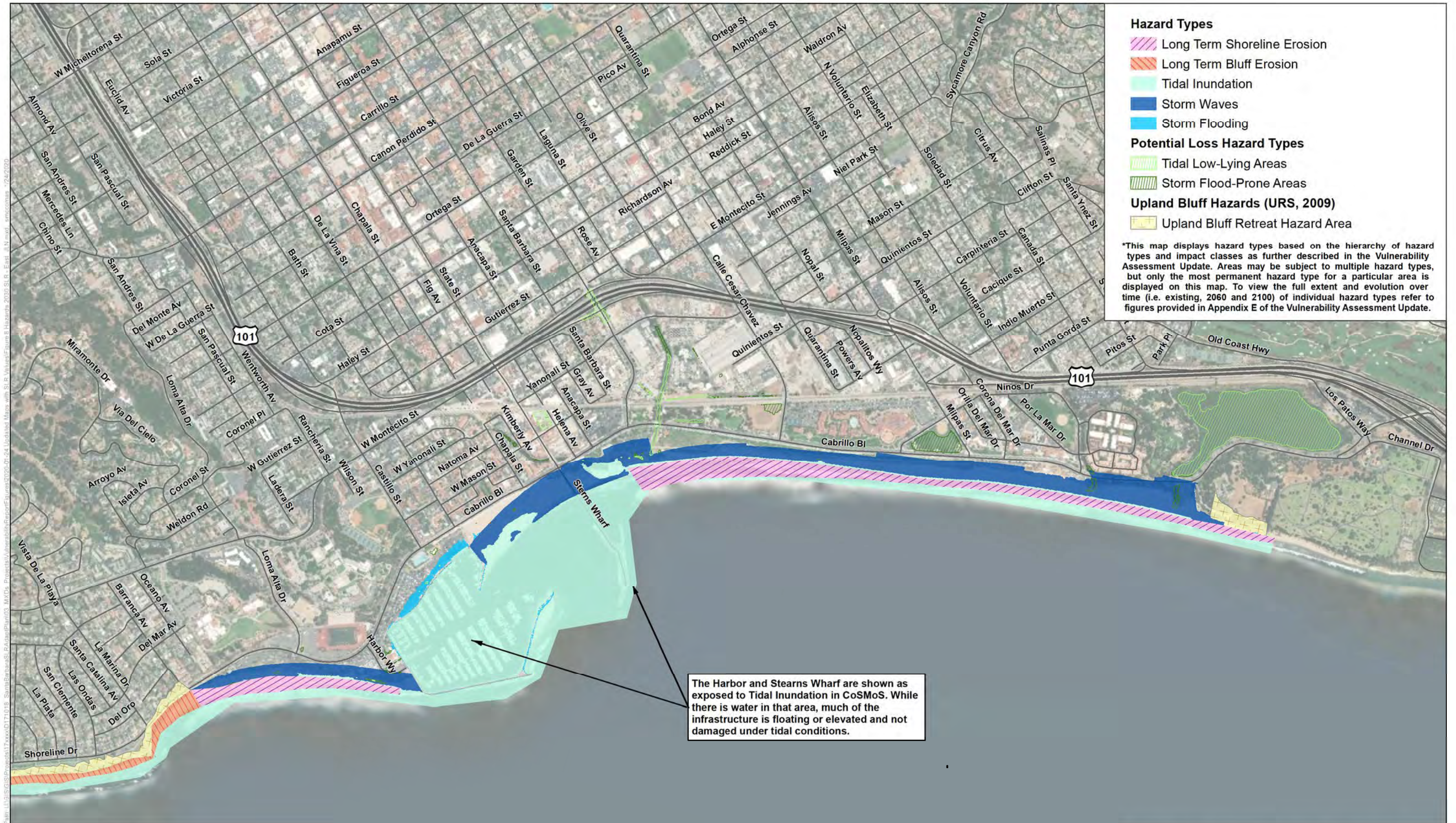
SOURCE: ESRI, 2018; USGS, 2018; ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 7
Existing Conditions Hazards (West)



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SOURCE: ESRI, 2018; USGS, ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 8
Hazards with 0.8 Feet of Sea-Level Rise (±2030) (East)



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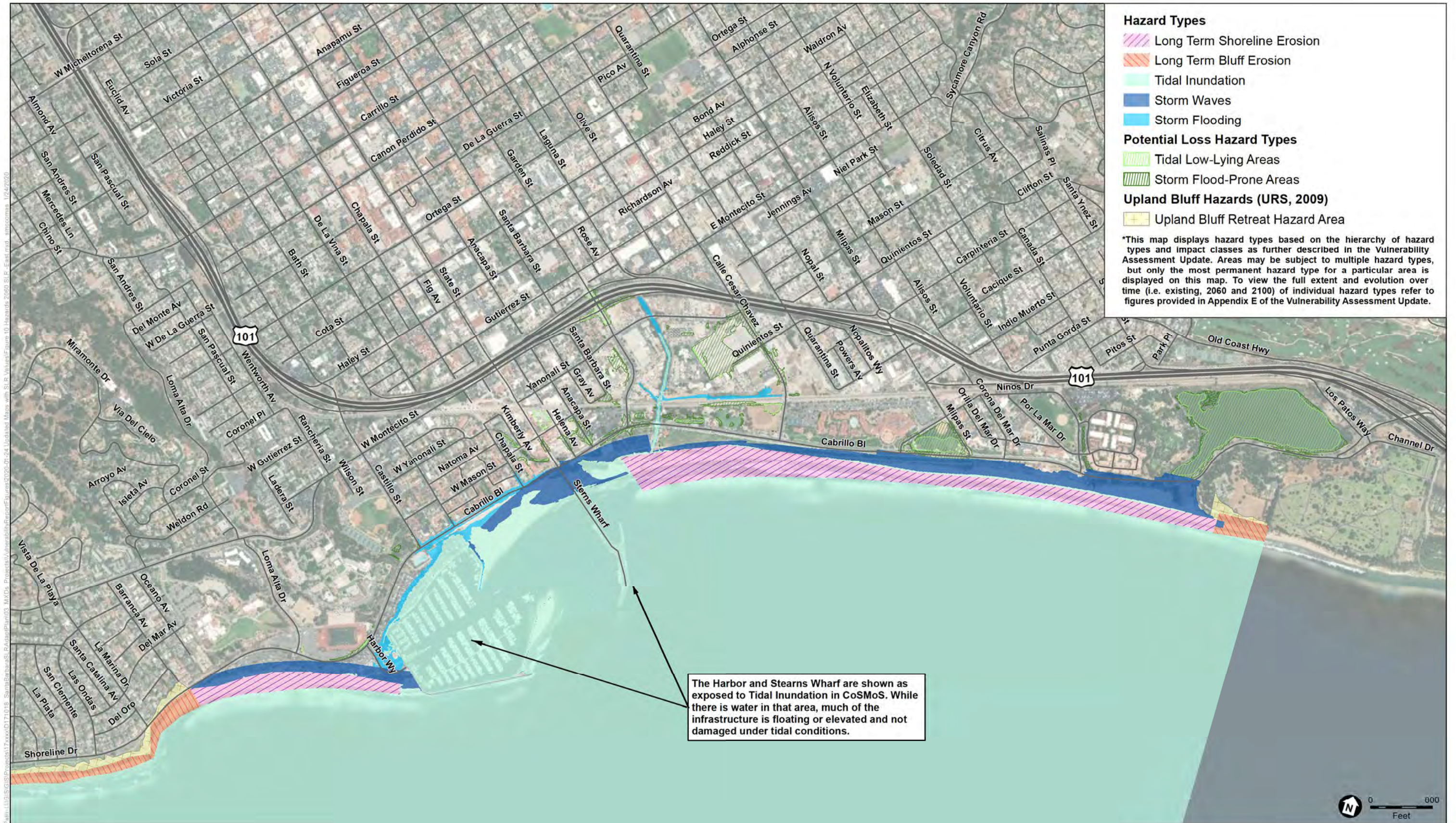


SOURCE: ESRI, 2018; USGS, 2018; ESA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 9
Hazards with 0.8 Feet of Sea-Level Rise (±2030) (West)

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Hazard Types

- Long Term Shoreline Erosion
- Long Term Bluff Erosion
- Tidal Inundation
- Storm Waves
- Storm Flooding

Potential Loss Hazard Types

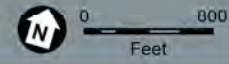
- Tidal Low-Lying Areas
- Storm Flood-Prone Areas

Upland Bluff Hazards (URS, 2009)

- Upland Bluff Retreat Hazard Area

*This map displays hazard types based on the hierarchy of hazard types and impact classes as further described in the Vulnerability Assessment Update. Areas may be subject to multiple hazard types, but only the most permanent hazard type for a particular area is displayed on this map. To view the full extent and evolution over time (i.e. existing, 2060 and 2100) of individual hazard types refer to figures provided in Appendix E of the Vulnerability Assessment Update.

The Harbor and Stearns Wharf are shown as exposed to Tidal Inundation in CoSMoS. While there is water in that area, much of the infrastructure is floating or elevated and not damaged under tidal conditions.



SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 10
Hazards with 2.5 Feet of Sea-Level Rise (±2060) (East)



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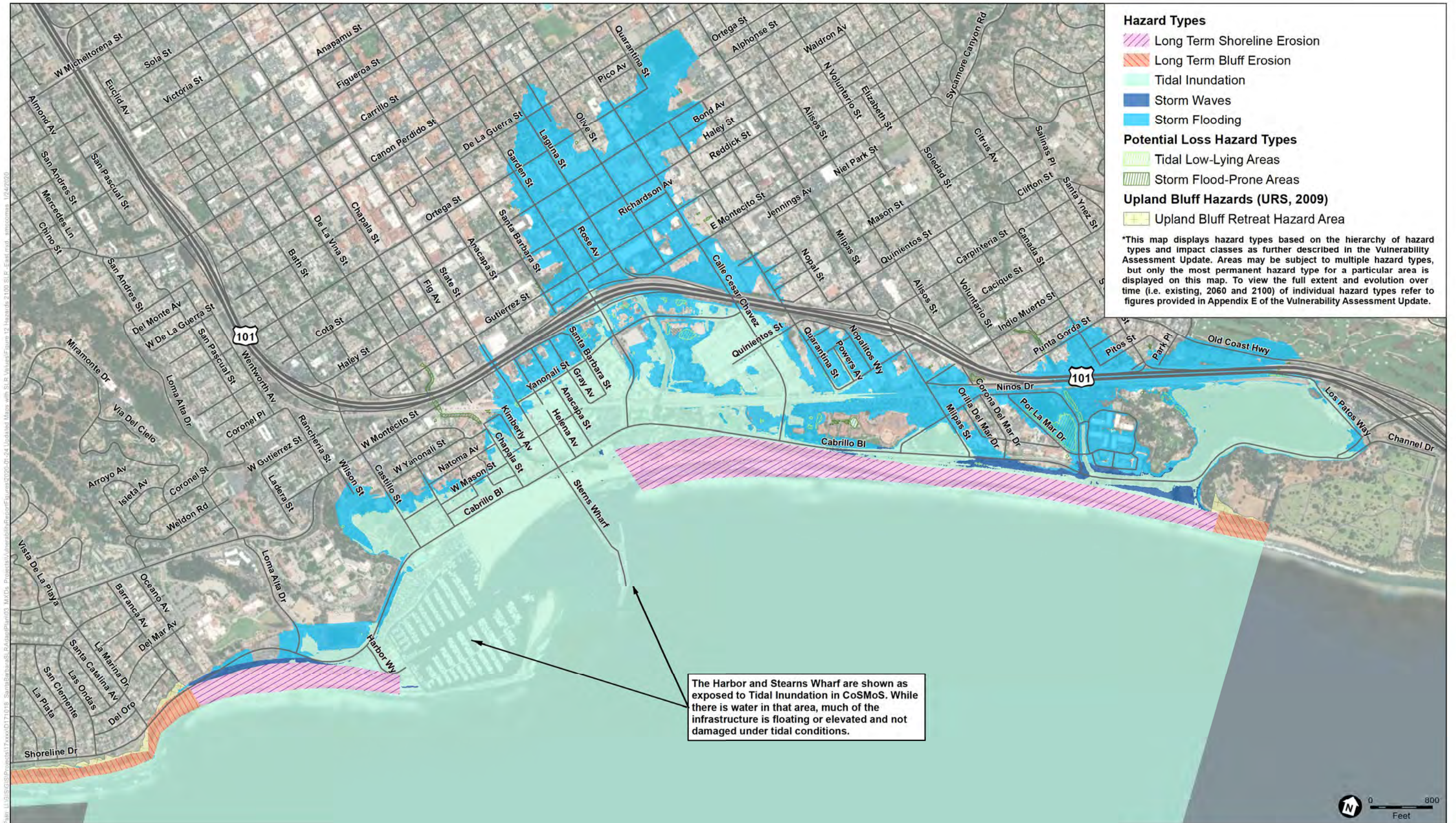
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 11
Hazards with 2.5 Feet of Sea-Level Rise (±2060) (West)



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Hazard Types

- Long Term Shoreline Erosion
- Long Term Bluff Erosion
- Tidal Inundation
- Storm Waves
- Storm Flooding

Potential Loss Hazard Types

- Tidal Low-Lying Areas
- Storm Flood-Prone Areas

Upland Bluff Hazards (URS, 2009)

- Upland Bluff Retreat Hazard Area

*This map displays hazard types based on the hierarchy of hazard types and impact classes as further described in the Vulnerability Assessment Update. Areas may be subject to multiple hazard types, but only the most permanent hazard type for a particular area is displayed on this map. To view the full extent and evolution over time (i.e. existing, 2060 and 2100) of individual hazard types refer to figures provided in Appendix E of the Vulnerability Assessment Update.

The Harbor and Stearns Wharf are shown as exposed to Tidal Inundation in CoSMoS. While there is water in that area, much of the infrastructure is floating or elevated and not damaged under tidal conditions.

SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 12
Hazards with 6.6 Feet of Sea-Level Rise (±2100) (East)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 13
Hazards with 6.6 Feet of Sea-Level Rise (±2100) (West)



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Coastal bluff erosion is expected to accelerate with sea level rise, but evidence of historical landslides in the City indicate that geologic factors may lead to further loss of bluff areas. These upland bluff retreat hazard areas were investigated by URS (2009) and are described in more detail in Appendix G. The upland bluff hazard areas identified by URS are presented in the hazard figures below, but the exposure tables in Appendix H include only long-term bluff erosion from CoSMoS, not the regions identified by URS (2009).

3.5 Tidal Inundation

CoSMoS uses a series of models¹² to determine tidal flooding extents under current and future conditions. Flood extents and depths for non-storm conditions correspond to tidal conditions that occur during a spring tide, which is a semi-monthly occurrence as a result of the moon being new or full. CoSMoS selected a spring tide elevation representative of this condition with high tides representing a near-worst case scenario (Erikson et al. 2017). This hazard would affect assets on the surface by inundation, and buried assets (like sewer lines) could be exposed to saltwater intrusion and corrosion as higher sea levels change groundwater depth and salinity. This hazard does not include changes to stormwater drainage and specific culverts and resulting changes to flooding. In this study, tidal flooding is considered a **permanent loss hazard**, since assets regularly beneath high tide will likely be effectively unusable.

3.6 Storm Waves

CoSMoS provides some wave conditions and runup elevations that are associated with the storm flooding extents. However, the wave runup outputs do not represent the potential for increased damages along the shoreline and backshore resulting from the force of waves during a large coastal storm event (similar to the VE zone hazard mapped in FEMA flood insurance maps).

For this study, ESA utilized wave runup hazard zones that were previously developed for the City and County of Santa Barbara for the Coastal Resilience project (ESA,2016b).^{13,14} Storm flooding mapped by CoSMoS does not extend to the landward limit of wave runup; rather, the CoSMoS storm flooding zone only includes areas that are inundated for more than one minute during the modeled storm event.¹⁵ Careful inspection of the CoSMoS maps will show colored “dots” that denote the modeled landward limit of wave runup, which is a CoSMoS output that is separate from the CoSMoS storm flooding zone. These CoSMoS wave runup limit point data are based on modeling of transects and do not accurately provide a wave runup zone beyond the CoSMoS

¹² CoSMoS uses a regional Delft3D model to drive a local SWAN model, which provides boundary conditions for XBeach models at the shore. This provides relatively fine-scale hydrodynamics, including wave setup.

¹³ Coastal Resilience storm wave hazard zones are based on real buoy data for existing conditions and utilized synthetic buoy and water level data developed by the USGS, which is consistent with the CoSMoS methodology. Descriptions of the input data and methodology used to develop these wave hazard zones can be found in ESA 2015 and 2016.

¹⁴ The Coastal Resilience wave hazard zones represent an extreme coastal flood based on analysis of time series of modeled wave runup data for several transects along the shore of the City.

¹⁵ Excerpt from O’Neill et al, 2018, page 16: “The frequency-filtered sustained water levels (constant water levels of durations longer than 1 min) are intended to capture the wave setup at the shore, which is the increase in mean water level above the still water line due to the transfer of momentum by breaking waves. Maximum runup, computed with the Tier III XBeach model, are also output as part of the CoSMoS results, but are mapped as single points and are not included in the flood footprint.”

storm flooding zone. For this reason, the Coastal Resilience wave runup limits were used instead as a more accurate representation of wave runup. Wave runup is considered in this vulnerability assessment because wave runup can cause significant damage when it collides with structures (FEMA, 2005). Impacts from storm waves are more severe than storm flooding hazards from standing water because wave momentum can cause structural damage, move vehicles, knock people over, etc. Finally, ESA notes that the CoSMoS runup limit point data were frequently farther landward than the Coastal Resilience wave runup hazard zone area/extents used in this study, and hence this Vulnerability Assessment may under-estimate the future extent of wave runup. However, the existing wave runup (from Coastal Resilience) compares favorably to the FEMA map. Similar to storm flooding (described below), storm waves are considered a **temporary loss hazard**.

The Coastal Resilience storm wave hazard zones used for this study represent an extreme flood based on analysis of time series of modeled wave runup data for several transects along the shore of the City. The 100-year wave runup elevation (known as the total water level and used to represent the 100-year flood) was selected based on statistical analysis of the time series, and represents an extreme wave condition at the shore. Although this type of analysis indicates the statistical extremes, the Santa Barbara shore has been vulnerable to rare but extreme wave conditions due to storms approaching from the southeast. The southeast storm conditions have been historically destructive to the Santa Barbara harbor and other waterfront assets. Both the CoSMoS and Coastal Resilience studies may under-represent the exposure of the City to this type of wave hazard. Adaptation planning should incorporate measures to improve resiliency to these wave directions which may become more frequent in the future.

3.7 Storm Flooding

CoSMoS uses the same set of models to determine storm flooding as tidal flooding (see above), but the analysis is performed for storms of different frequencies. A regional storm¹⁶ with a 1% chance of happening in any year (the “1% annual exceedance probability” or “100-year storm”) was selected and used to represent potential storm event flooding. The approach used to select a 100-year event in CoSMoS is not the same as how it is determined for FEMA and other standard flood analyses, where time series of the parameter is statistically analyzed in an extreme value analysis to identify the most extreme conditions based on a variety of storms. Therefore, the selection of the 100-year event resulting from a specific storm event may be different than would be determined using other methods. In this study, storm flooding is considered a **temporary loss hazard**, since assets in the storm hazard zone will be flooded only during extreme events, and service may be restored after the event.

¹⁶ The regional 1% annual exceedance probability storm event is reasonable for a large-scale study, but the selected storm may create flooding that is more or less likely (than 1%) at different locations in the City due to local conditions. While this level of detail is sufficient for the vulnerability assessment update, local analysis would be required for engineering decisions.

3.8 Disconnected Low-Lying Areas

Some portions of the City are below the coastal flooding elevations identified for tidal or storm conditions but are not directly connected to the ocean. While they may be protected from direct exposure by high ground or structures, they may still be susceptible to flooding. Areas below the tidal flooding elevation (called “tidal low-lying areas”) may experience flooding from a rising groundwater table with sea level rise. Areas below the storm flooding elevation (called storm flood-prone areas”) may experience flooding from precipitation or wave over wash that is unable to drain to the ocean because water levels are too high. In either case, indirect connectivity is unknown, so they are identified as potentially hazardous. In this study, flooding of these low-lying and flood prone areas is considered a **potential loss hazard**, since more analysis would be required to identify and describe the flood source.

3.9 Management Scenarios

CoSMoS provides future hazard zones for two management scenarios, referred to as “hold the line” (HTL) and “let it go” (LIG), for future time horizons. This study presents all hazards using the LIG management scenario. The LIG scenario assumes that no management actions are taken and erosion can continue unabated. While the LIG scenario assumes that no management actions are taken, there are several management actions that are implicit in the CoSMoS mapping. It is assumed that the harbor will remain, though the breakwater could be overtopped with sufficient sea-level rise. In addition, the erosion response of the shore is based on historical rates, so past actions taken by the City to manage sediment by dredging and placement are implicitly included in the results. Adaptation planning will address the effects of nourishment in a more direct manner to measure its effectiveness for mitigating erosion and flooding impacts.

The HTL scenario would assume that management actions are taken to repair and replace damaged structures, and development will be maintained in its current position. In the view of the consultant, the HTL scenario is very conceptual and not appropriate for planning purposes. This is because the “line” is drawn arbitrarily, and the effectiveness of the existing features to prevent overtopping and erosion, and to withstand future sea levels is not addressed from an engineering perspective. Additional information regarding shore armoring can be found in the report ESA prepared for the City of Santa Barbara on this topic (ESA, 2016b).

3.10 Comparison to FEMA Base Flood Elevations

As discussed in Section 2.3 there are significant differences in the methods and intent of the FEMA flood maps and the coastal hazard mapping in this report.

However, this study recognizes that a significant portion of the study area is located within FEMA special flood hazard zones which are subject to the City of Santa Barbara’s Floodplain Management Regulations. The Vulnerability Assessment Update does not include an extensive comparative analysis of the FEMA base flood elevations and the projected depths of water levels included in the coastal hazard zones. As a planning-level assessment and initial step in the adaptation planning process, the Vulnerability Assessment does not include an extensive review

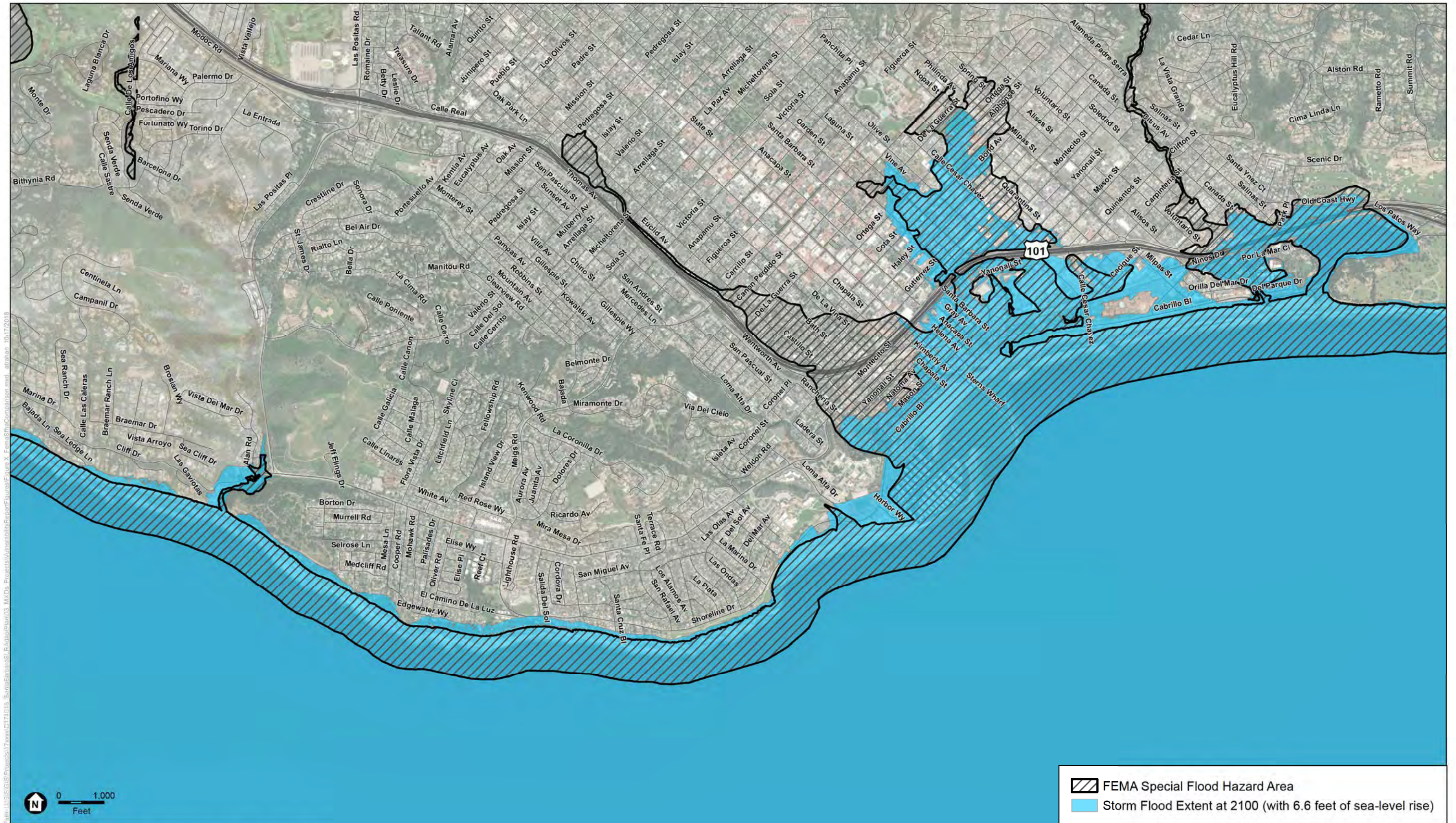
of the City's existing regulatory and policy environment including the city's Floodplain Management Ordinance (Municipal Code Section 22.24).

However, it is important to understand if the coastal hazard results generally align with the FEMA flood hazard results. **Figure 14** provides a comparison of the extent of the FEMA special flood hazard zones and the extent of coastal hazard zones at 6.6 feet of sea-level rise. This report also tested discrete locations to compare the FEMA base flood elevations with the CoSMoS 100-year storm flooding at 6.6 feet of sea-level rise. The result of this discrete analysis¹⁷ is summarized as follows:

1. North of Hwy 101: CoSMoS 100-year storm flooding at 6.6 feet of sea-level rise is 1 to 2 feet lower than the FEMA existing Base Flood Elevation.
2. South of Hwy 101: CoSMoS 100-year storm flooding at 6.6 feet of sea-level rise is 2 to 3 feet higher than the FEMA existing Base Flood Elevation. It should be noted that this point was selected in a location that is sheltered from wave action just west of Laguna Channel.

The above comparison is provided to assist the City in assessing whether the use of the FEMA map and current flood plain regulations, which are based on the FEMA hazard zones and identified base flood elevations, is adequate to address future conditions. Obviously use of the FEMA flood map is not sufficient where future water levels due to coastal flooding from sea-level rise exceed the FEMA flood map. Further, it is expected that precipitation intensity will increase due to climate changes and hence the future 100-year flood limits for the creeks in Santa Barbara are expected to be greater than shown on the FEMA map. While the climate-influenced flood hydraulics analysis for the streams in Santa Barbara was not performed for this study, a previous analysis of Carpinteria Creek indicated that the 100-year flow rate would increase 15% to 100% by 2100 (ESA, 2015). An increase in flowrate by 15% to 100% and the elevated ocean water level at the creek mouth would likely increase the depth and extent of creek flooding in Santa Barbara.

¹⁷ This was based on an evaluation of two discrete point locations north and south of Highway 101. This comparison of discrete point locations does not apply to other locations because ground elevations and slopes vary spatially and the discrete point comparison are therefore not accurate for other locations.



SOURCE: ESRI, 2018; ESA, 2018; City of Santa Barbara, 2018; FEMA, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 14
 Comparison between FEMA Special Flood Hazard Area and Storm Flooding Extent at 2100 (with 6.6 feet of sea-level rise)



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4. Asset Exposure Analysis

The vulnerability assessment is based on the exposure of identified assets to projected future coastal flood and erosion hazards. To assess asset exposure to hazards, the assets in different categories were intersected in Geographical Information System (GIS) software with each potential future hazard zone. Where an asset intersects a hazard zone, it is identified as at risk. Economic or other valuations will be applied to quantify the vulnerability (in a subsequent phase of the adaptation planning process. This type of analysis does not precisely assess the cause of failure or an established threshold for each asset type, and therefore is considered a planning-level vulnerability analysis. A planning-level vulnerability analysis is meant to inform the development of an Adaptation Plan and related LCP policies and it should not be used for asset-specific programming or engineering without additional scrutiny and possible refinements. Assessing the sea-level rise vulnerability of assets in the City requires an understanding of which assets are exposed to different hazards at different time horizons. To determine this, assets provided by the City were intersected with each hazard layer, leading to the exposure results summarized in Section 4.3 and provided in Appendices H and I.

4.1 Asset Datasets

Asset datasets were divided into categories to better understand the exposure of certain infrastructure systems. In addition to infrastructure assets, the asset datasets include recreational assets (e.g., parks, beaches), critical facilities, and building/parcel information. The datasets were primarily provided by the City with exception of the recreational areas data which was provided in a report prepared by the Bren School of Environmental Science & Management (Denka et al., 2015). There are three different geometries of data: points, lines, and polygons.¹⁸

It should be noted that some asset data was not available at the time this report was prepared; in particular power and gas data is not provided by utility corporations for public uses. Water and wastewater infrastructure assets are included in the analysis, but their locations are not included in maps in the report due to security concerns.

4.2 Analysis of Hazard Exposure

The assets described in Section 4.1 were intersected with seven hazard layers: shoreline erosion, bluff erosion, tidal flooding, storm waves, and storm flooding, low-lying areas, and flood-prone areas. The first three hazards (bluff erosion, shoreline erosion, and tidal flooding) are considered permanent loss hazards, as they result in loss of land or frequent flooding, which are likely to render assets unusable. The next two hazards (storm waves and storm flooding) are considered temporary loss hazards, since they result in occasional, temporary loss of service during storm events, which may lead to damage, but is not likely to destroy assets entirely. The last two hazards (low-lying and flood-prone) are considered potential loss hazards, since they are not directly connected to the ocean so the cause and likelihood of flooding are less clear.

¹⁸ These assets were not field verified by ESA.

As described in Section 3.2, a hierarchy of the coastal hazard zones was used to identify hazard exposure. The hierarchy from most severe hazard to least severe hazard is as follows: erosion, tidal inundation, storm waves, storm flooding, tidal low-lying areas, and finally storm flood-prone areas. The identified hazards are mutually exclusive to prevent over estimating exposure. For example, assets exposed to erosion are not marked as exposed to tidal flooding, since they are considered lost already.

Each hazard was assessed at three timelines: existing conditions, at 2.5 feet of sea-level rise, and at 6.6 feet of sea-level rise. However, erosion is a future hazard and so was not considered for existing conditions. Future hazard zones were also considered under the “let it go” management scenario, under which the shore progresses inland without the assumption that armoring will withstand sea-level rise. Because the hazard layers are mutually exclusive, some assets are less exposed to temporary loss hazards (like storm flooding) in the future, as permanent loss hazards (like tidal flooding) cover more area.

In addition to the extent of the hazard, inundation depth for storm flooding is presented in Figure 18 through Figure 25, below, as estimated by CoSMoS. The depth of flooding is related to the level of damage for a given asset. These are shown for only storm flooding because depth is especially important for temporary loss hazards, because assets may be abandoned or decommissioned if permanently inundated, even if the damage at that depth is relatively low.

4.3 Exposure Analysis Results by Category

The results of the exposure analysis are summarized in this section. The complete exposure tables and charts including exposure results for existing conditions, 2.5 feet of sea-level rise and 6.6 feet of sea-level rise, for each subarea, are provided in Appendix H. The exposed assets were tabulated based on the geometry of the feature: point assets are counted, line assets are measured in linear feet, and polygon assets are measured in square feet. Figure 26 through Figure 32, below, display exposure to hazard zones at 6.6 feet of sea-level rise by each asset category, while Appendix I provides exposure to hazard zones at 0.8 feet of sea-level rise and 2.5 feet of sea-level rise. The 6.6 feet of sea-level rise results convey the greatest extent of exposure to hazards that were analyzed in this study. Many of the assets see a mild increase in hazard at 2.5 feet of sea-level rise, followed by a sharp increase at 6.6 feet of sea-level rise. As discussed in Section 3.1, these increases in hazards could occur as soon as 2050 and 2080 under the H++ scenario. A summary of these results is provided below by asset category.

4.3.1 Critical Facilities

The City’s critical facilities are defined in the City’s 2013 Safety Element. Of the 43 critical facilities identified, 11 are within the future coastal hazard zones with 6.6 feet of sea-level rise. **Table 4** provides an overview of when these facilities are expected to be exposed to the different hazards. Further discussion on each facility is provided in the sections that follow.

TABLE 4
CRITICAL FACILITIES HAZARD EXPOSURE

| Critical Facility | Address | Hazard Exposure | Section for further discussion |
|--------------------------------------|-----------------------------------|--|---------------------------------------|
| Public Works/City Offices | 630 and 635 Laguna Street | Storm flooding with 6.6 feet of sea-level rise. | Section 4.3.8 |
| Charles E. Meyer Desalination Plant | 525 E. Yanonali Street | Storm flooding and tidal inundation with 6.6 feet of sea-level rise. | Section 4.3.10 |
| El Estero Wastewater Treatment Plant | 520 E. Yanonali Street | Storm flooding and tidal inundation of piping system with 2.5 feet of sea-level rise. Tidal inundation of plant with 6.6 feet of sea-level rise. | Section 4.3.10 |
| Stearns Wharf | 219 Stearns Wharf | Storm flooding and wave impacts under existing conditions, increasing in intensity with sea-level rise. | Section 4.3.6 |
| Santa Barbara Airport | 500 Fowler Road | Not evaluated | Not included in this study |
| Harbor | Various | Storm flooding and wave impacts under existing conditions. Damage and disruption of services expect to be more frequent at 2.5 feet of sea-level rise and commonplace at 6.6 feet of sea-level rise. | Section 4.3.7 |
| Corporate Yard Well | 402 E. Ortega Street | Storm flooding with 6.6 feet of sea-level rise. | Section 4.3.10 |
| Carrillo Recreation Center | 100 E. Carrillo Street | Storm flooding with 6.6 feet of sea-level rise. | Section 4.3.5 |
| City Pier | Harbor | Storm flooding and wave impacts under existing conditions. Damage and disruption of services expect to be more frequent at 2.5 feet of sea-level rise and commonplace at 6.6 feet of sea-level rise. | Section 4.3.7 |
| Marinas 1-4 | Harbor | Storm flooding and wave impacts under existing conditions. Damage and disruption of services expect to be more frequent at 2.5 feet of sea-level rise and commonplace at 6.6 feet of sea-level rise. | Section 4.3.7 |
| Ortega Well | Ortega Street /Salsipuedes Street | Storm flooding with 6.6 feet of sea-level rise. | Section 4.3.10 |

4.3.2 Transportation

Figure 26, below, presents transportation assets exposed to hazards at 6.6 feet of sea-level rise. Under existing conditions (e.g., with no sea-level rise), coastal parking lots have already experienced flooding during large storms associated with El Nino events (Section 2.4). Most of the roads and the railroad in the City show little exposure at 2.5 feet of sea-level rise, but public parking is exposed to increased tidal flooding and wave damage, and Shoreline Drive and Cabrillo Boulevard show minor exposure to erosion. At 6.6 feet of sea-level rise, much of the public parking and roads around the harbor are inundated regularly, and the railroad through the city is exposed to tidal and storm damage. Most of Cabrillo Boulevard is exposed to erosion or tidal inundation, and the junction of Megis Road and Shoreline Drive is exposed to erosion. The pedestrian bridge at El Camino De La Luz over Lighthouse Creek could be destabilized from bluff erosion near Lighthouse Place. Roads in the downtown area, like Gutierrez Street, Haley Street, and Milpas Street are exposed to storm flooding. This is likely to disrupt harbor and beach access. Furthermore, Highway

101 is exposed to storm flooding west of Andrée Clark Bird Refuge, potentially disrupting traffic at a regional scale.

4.3.3 Public Safety

Figure 27, below, presents fire stations (one of which is exposed), police stations (none of which are exposed) and wildland fire evacuation routes exposed to hazards at 6.6 feet of sea-level rise. The City sees very little exposure at 2.5 feet of sea-level rise. At 6.6 feet of sea-level rise, however, Santa Barbara Fire Station 2 (south of Highway 101) could be inundated during a storm event, potentially stranding emergency response personnel or equipment. While many coastal evacuation routes are spurs, the route through Arroyo Burro connects coastal communities west of the city to inland areas and could be flooded during a storm event.

4.3.4 Stormwater Infrastructure

Figure 28, below, presents stormwater infrastructure exposed to hazards at 6.6 feet of sea-level rise. At 2.5 feet of sea-level rise, drainage channels are likely to see more tidal flooding and storm flooding. While this may not damage the channels, it could cause more flooding during rain events. Starting at 2.5 feet of sea-level rise and worsening at 6.6 feet of sea-level rise, the City's water control structures are expected to be exposed to more frequent flooding. Water flowing into the stormwater drainage pipes could also cause stormwater backup and local ponding further inland than just tidal and storm inundation. This study did not assess whether future conditions would accelerate corrosion of stormwater infrastructure.

Laguna Channel and Tide Gate/Pump System

The Laguna Channel Tide Gate structure plays an important flood management role in the City. Located at the southern terminus of the low-lying Laguna Channel drainage, the tide gates prevent the waters from the Mission Creek Lagoon from extending landward. **Figure 15** presents a photo of the Laguna Channel Tide Gate structure during a period of high lagoon water levels, when the lagoon mouth is closed.¹⁹ The Mission Creek Lagoon is managed such that it forms a joint lagoon with the Laguna Channel discharge. During precipitation events, a significant portion of the City's downtown area drains to the Laguna Channel, which can only drain through the tide gates during periods when the Mission Creek Lagoon is open.²⁰

¹⁹ Mission Creek Lagoon closes when waves build the beach to an elevation that separates the Laguna Channel from the ocean, allowing water to build up behind the beach. Mission Creek Lagoon opens when water levels are high enough to breach the high beach, generally during a storm when runoff in Laguna Channel rapidly increases the water level in the Mission Creek Lagoon. (ESA, 2013)

²⁰ If the Mission Creek Lagoon is closed during a large rain event, the closed tide gates cause water to gather upstream of the Laguna Channel Tide Gate structure. When the water ponded upstream of the gates (on the north side) is higher than the Mission Creek Lagoon water level, the tide gates are opened and the ponded water flows into the Mission Creek Lagoon, causing the lagoon to open. (ESA, 2013)



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00

SOURCE: ESA

Figure 15
Laguna Channel Tide Gate Looking North (Upstream) during Period of Closed Lagoon with High Water

The Laguna pump station is located immediately north (upstream) of the Laguna Channel Tide Gate structure. When there are low flows in the Laguna Channel, the pump station uses low-flow pumps to move nuisance flows from the Laguna Channel into the Mission Creek Lagoon. When the Laguna Channel fills with stormwater runoff during large rain events, high-flow pumps are activated and pump water from Laguna Channel into the Mission Creek Lagoon. **Figure 16** shows a photo of the Laguna pump station on the right side of the Laguna Channel.

Prior studies indicate that the Laguna Channel flood control system can convey up to approximately the 10-year recurrence flowrate without flooding (ESA, 2013). At higher flowrates, flooding occurs in the low area downstream of Highway 101. Also, the culvert under Highway 101 impedes drainage and increases flooding upstream of Highway 101. With sea-level rise, it is expected that the flood performance for Laguna Channel will decrease because the higher ocean water levels will prevent the gates from discharging water from Laguna Channel more often than under existing conditions (ESA, 2013; 2014). This means that the flood flow capacity will become progressively less than the 10-year event, and flooding will become frequent and more extreme. The seaward location of the tide gates also exposes them to the forces of wave impacts, which will become greater in the future with sea-level rise.



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SOURCE: ESA

Figure 16
Laguna Pump Station and Laguna Channel Looking North (Upstream)

The hazards in this vulnerability study are based on coastal water levels migrating up Laguna Channel, and do not include rainfall runoff. The hazard zones indicated that this facility will be exposed to tidal inundation or erosion between 2.5 feet of sea-level rise and 6.6 feet of sea-level rise.

Mission Creek

Mission Creek is a major regional drainage that runs through Santa Barbara. The flood conveyance was recently improved by adding a bypass culvert, and the expected conveyance capacity without flooding is approximately the 20-year recurrence flowrate (ESA, 2013). The water level in the creek during low flows is elevated due to backwater from the elevated beach berm. Mission Creek flowrates are high enough to rapidly fill the lagoon and breach the beach berm, and hence the beach berm is not considered a significant flood-control impediment for existing sea levels (ESA, 2014). The hazards in this vulnerability study are based on coastal water levels migrating up Mission Creek, and include representative creek discharge and precipitation during a coastal storm but not severe rainfall runoff events that are likely to impact the creek.

4.3.5 Recreational Areas

Figure 29, below, presents recreational areas exposed to hazards at 6.6 feet of sea-level rise. Under existing conditions (e.g., with no sea-level rise), the beaches already experience localized erosion during large storm events, such as those during El Nino events (Section 2.4). Additionally, Chase Palm Park, and Shoreline Park are already at risk for flooding from storm waves during major storm events. Results indicate that many of the beaches and the parks on the bluffs – iconic features and major tourist attractions in Santa Barbara – would be at least temporarily affected at 2.5 feet of sea-level rise and potentially lost by 6.6 feet of sea-level rise. In many places, beach access along the bluff-backed beach in the west half of the City is provided by stairways down the bluff to the beach, and these would be exposed to erosion at 2.5 feet of sea-level rise (e.g., Mesa Lane Stairs and One Thousand Steps). Other recreational opportunities could be disrupted temporarily by flooding at 2.5 feet of sea-level rise and then permanently impacted by tidal inundation, such as portions of the California Coastal Trail.

The results also show that Cabrillo Pavilion would be at risk for flooding from storm waves under 6.6 feet of sea-level rise. Chase Palm Park would be threatened with erosion by 2.5 feet of sea-level rise and regularly inundated by the tides by 6.6 feet of sea-level rise. By 6.6 feet of sea-level rise, Chase Palm Park Center and the Carousel House would be regularly inundated by the tides. With 2.5 feet of sea-level rise, Los Banos del Mar Pool would begin to experience flooding during storms, and by 6.6 feet of sea-level rise, the flooding would occur more regularly as tidal inundation. With 6.6 feet of sea-level rise, the Carrillo Recreation Center would experience flooding during storms.

4.3.6 Stearns Wharf

Stearns Wharf is located on the Santa Barbara waterfront immediately east of the Santa Barbara harbor. Stearns Wharf is an important asset to the City and community, drawing large numbers of visitors and serving important services to the local tourism industry: approximately 1 million pedestrians and 250,000 cars use Stearns Wharf every year.²¹ Although the location of Stearns Wharf is generally sheltered from the large north Pacific swells, it is still exposed to storm waves.

Under existing conditions, Stearns Wharf is vulnerable to extreme storms with high water levels and large waves. Damage to a structure located on Stearns Wharf occurred in March 2014 during storm conditions with a particularly large wave event from the west. This suggests that a moderately extreme event is likely to cause minor damages and disrupt operations of businesses and public use of the Wharf. Under an extreme 100-year coastal event with existing sea levels, damages to the Wharf are expected to be much greater, potentially requiring temporary closure and significant structural repairs.

In the future with sea-level rise, events that trigger minor damage and operational impacts will become more frequent due to the increased proximity of the wave crest to the deck of the Wharf (approximately elevation 19.5 feet NAVD). The wave crest elevation (not including wave runup on a structure) for the 100-year event was estimated using the water level and wave output from

²¹ Personal communication, August 17, 2018, Karl Treiberg, Waterfront Facility Manager, City of Santa Barbara.

CoSMoS in the vicinity of the seaward end of Stearns Wharf: 18.5 feet NAVD, 21 feet NAVD, and 25 feet NAVD at existing, 2.5 feet of sea-level rise, and 6.6 feet of sea-level rise, respectively. Therefore, although typical tidal conditions are not likely to pose risk of damage to Stearns Wharf, damaging events will become much more frequent. Stearns Wharf appears in Figure 30, below, with other facilities in and around the harbor.

4.3.7 Facilities at the Harbor

The Santa Barbara harbor area includes the marina (about 1200 slips), commercial uses, parking, industrial areas, and the City Pier, also known as the “harbor pier,” which supports the Coast Guard, an ice house, a NOAA tide station, and the fuel dock. There is also a commercial area located west of the City Pier that includes restaurants and several marine-related businesses. The commercial area on the west side of the harbor is located at about the same elevation as the north side of the harbor (located farthest from the open ocean). However, much of the south and west sides of the harbor are built up since they are potentially more exposed to waves. This includes the breakwater sidewalk, which is about 2 feet higher than the sidewalk on the north side of the harbor.

Under existing conditions, portions of the harbor are vulnerable to high water levels and to large wave events. Damage to harbor assets, including dislocation of pile caps due to the upward movement of floating docks, has occurred due to high water levels resulting from storm surge or even from astronomically high tides (e.g., perigean spring tides or “King” tide). Large wave events overtop the harbor breakwater forcing closure of the public path on an approximately annual basis. Through current management practice, the harbor accommodates these relatively minor impacts. Under an extreme 100-year coastal event with existing sea levels, damages to the harbor would likely be severe. Several different damaging storm combinations are possible, but the worst may be a storm approaching from the southeast, from which direction the harbor entrance is most exposed to waves. Moderately sized wind waves entering the harbor combined with high water levels have caused damage to the floating infrastructure of the harbor in the past.

In the future, these impacts are expected to occur more frequently with sea-level rise. With one foot of sea-level rise, harbor functions could likely be managed, but more than 2 feet would likely induce impacts to several major assets that allow the harbor to function. With over 6 feet of sea-level rise at 6.6 feet of sea-level rise, the harbor would not be usable in its existing configurations without major modifications through adaptation. Figure 30, below, presents harbor assets exposed to hazards at 6.6 feet of sea-level rise. Some of these assets, such as the breakwater, protect inland assets and their damage would have significant secondary effects, such as damage to the marina docks and closure of harbor businesses while the docks were repaired. The breakwater and groins around Santa Barbara Harbor protect the marina and private, commercial, and recreational facilities. Damage and disruption of service happens occasionally under existing conditions and can be expected to be more frequent at 2.5 feet of sea-level rise and commonplace at 6.6 feet of sea-level rise.

The fuel dock at the City Pier is of particular concern due to the potential for spill and fire hazards. The dock is connected to underground supply tanks on the shore by double-walled pipelines running beneath the dock. These lines have shutoff valves, but the valves are located

under the dock, at the base of the pier and are only accessible by boat. This means that even small amounts of sea-level rise could make these valves inaccessible during a storm, when water levels could be too high to allow a boat under the pier. Increased sea-level rise would expose the pipelines and valves directly to waves or even periods of inundation, both of which could result in pipe damage and leakage.

4.3.8 Public and Private Properties

Figure 31, below, presents public and private properties (assessor parcels) exposed to hazards at 6.6 feet of sea-level rise. Under existing conditions (e.g., with no sea-level rise), the downtown area already experiences flooding from Laguna Channel during large storms, such as those associated with El Nino events (Section 2.4). Exposure to permanent hazards grows at 2.5 feet of sea-level rise as areas that were previously only exposed to storms are more regularly inundated by tides. This trend continues at 6.6 feet of sea-level rise when a large number of properties are expected to be exposed to temporary flooding or permanent inundation, including Public Works, Parks and Recreation, and other City offices. 5 presents a count of vulnerable parcels by parcel type over time, which shows an exponential increase in the number of parcels at risk from sea-level rise over time: the number of parcels impacted at 2.5 feet of sea-level rise is 1.7 times greater than existing conditions, and at 6.6 feet of sea-level rise is 12.5 times greater than existing conditions.

**TABLE 5
PARCEL COUNT BY TYPE INTERSECTING WITH HAZARD ZONES**

| | Existing Conditions | | 2.5 Feet of sea-level rise Conditions | | 6.6 Feet of sea-level rise Conditions | |
|---|---------------------|-----------|---------------------------------------|-----------------|---------------------------------------|-----------------|
| | Storm | Tidal | Storm | Tidal + Erosion | Storm | Tidal + Erosion |
| Vulnerable Parcels (Count)^a | | | | | | |
| Commercial | 2 | 2 | 2 | 3 | 124 | 46 |
| Hotels, Motels, B&Bs ^b | 0 | 0 | 4 | 0 | 13 | 26 |
| Industrial | 3 | 0 | 4 | 3 | 151 | 61 |
| Institutional ^c | 6 | 3 | 0 | 10 | 24 | 16 |
| Miscellaneous | 2 | 0 | 4 | 2 | 5 | 18 |
| Residential | 22 | 48 | 9 | 115 | 495 | 221 |
| Vacant | 6 | 5 | 1 | 16 | 17 | 24 |
| TOTAL | 41 | 58 | 24 | 149 | 829 | 412 |

NOTES:

^a Counts do not exclude based on if the parcel is impacted in previous conditions; rather, the parcels impacted by tide and/or erosion under 2.5 feet of sea-level rise conditions, for example, includes parcels that might be impacted by tide and/or erosion under existing conditions.

^b B&Bs = bed and breakfast establishments

^c "Institutional" assets include recreation, education, and government. Recreational here includes: golf courses, auditoriums, stadiums, and other recreational land uses.

4.3.9 Communication Infrastructure

Figure 32, below, presents communication infrastructure exposed to hazards at 6.6 feet of sea-level rise. The major fiber optic lines and associated cabinets running along the waterfront could experience temporary inundation at 2.5 feet of sea-level rise and could be inundated during tidal conditions at 6.6 feet of sea-level rise. While these assets are underground and not likely to be destroyed during temporary inundation, permanent flooding will preclude access and maintenance, making them unusable in the long run.

4.3.10 Water Supply and Wastewater Infrastructure

Water supply and wastewater infrastructure exposed to coastal hazards were also considered, but they are not shown on maps included in this study for security reasons. The water and wastewater assets considered include the recycled water distribution system. In general, most water supply assets are not significantly exposed to hazards at 2.5 feet of sea-level rise, but many are expected to see significant temporary and permanent flooding impacts at 6.6 feet of sea-level rise, including the Corporate Yard Well, a potable water drinking well. An exception is the recycled water system, which is used for irrigation at many of the coastal parks and public areas and may see permanent erosion and tidal inundation beginning at 2.5 feet of sea-level rise and increasing through 6.6 feet of sea-level rise. While temporary inundation is generally acceptable, erosion hazards may expose and damage pipelines. The loss of water supply pipelines can lead to major inconvenience.

This study does not assess the potential impacts of saltwater intrusion on the water supply, which is a possible impact of sea-level rise on the local coastal aquifers.

Portions of the wastewater piping system (gravity mains, etc.) that are south of Cabrillo Boulevard are expected to be exposed to tidal inundation and erosion at 2.5 feet of sea-level rise. At 6.6 feet of sea-level rise, tidal inundation would permanently impact several portions of the wastewater piping system, including the sewer trunk main. Damage to wastewater pipelines can lead to spills and significant public health concerns.

This analysis does not consider impacts that may occur from increased rates of corrosion of water and wastewater facilities from increased salinities in groundwater.

El Estero Wastewater Treatment Plant

The El Estero Wastewater Treatment Plant is an important asset located immediately east of the Laguna Channel. According to this analysis, the plant itself would not be exposed to storm flooding or tidal inundation at 2.5 feet of sea-level rise. However, portions of the wastewater piping system located south of Cabrillo Boulevard would be impacted by storm flooding and tidal inundation. Potential inundation of the sewer trunk main that runs along the beach south of Cabrillo Boulevard could require extended shutdowns of the plant. Additional analysis is needed to determine if the anticipated level of inundation of the wastewater system piping would significantly impact the operations of the plant at 2.5 feet of sea-level rise.

At 6.6 feet of sea-level rise, portions of the plant itself, as well as significant portions of the wastewater piping system south of highway 101 connected to the plant are located in the tidal inundation zone. Regular tidal inundation into manholes, pipelines, the sewer trunk main, and the plant area itself will make the plant and associated affected wastewater systems as they are currently designed permanently inoperable. This is partially due to the level of salinity of the water reaching the plant, the hydraulics associated with the gravity flow wastewater system, and water regularly inundating the plant facilities themselves. Additionally, access to the plant facilities will be limited. Future storm flood depths in the vicinity of the wastewater treatment plant at 6.6 feet of sea-level rise are expected to be approximately 1 to 4 feet depending on the ground elevation. CoSMoS output for the extreme storm indicates a future flood elevation of 14.2 feet NAVD at 6.6 feet of sea-level rise. The facility's outfall is located offshore. An additional, more detailed study would need to consider whether erosion of the coastal profile would expose portions of the outfall pipeline and supports, and how sea level rise may impact sediment deposition and seafloor configurations that could affect the outfall. In addition, saltwater intrusion and salinity- corrosion to underground utilities has not been studied.

The potential exposure of the facility indicates a need for subsequent detailed study of the vulnerability of the wastewater treatment plant and its assets to climate change and sea-level rise.

Charles E. Meyer Desalination Plant

The Charles E. Meyer Desalination Plant is a valuable and important asset north of El Estero Wastewater Treatment Plant along the east side of Laguna Channel, directly south of Highway 101. According to this analysis, the plant site is not likely to be exposed to coastal hazards under existing conditions or at 2.5 feet of sea-level rise, but is likely to be exposed at 6.6 feet of sea-level rise. Some of the site is exposed to tidal inundation at 6.6 feet of sea-level rise and some is exposed to storm flooding, but operations would likely be impacted, since some facilities or activities would need to be moved away from the permanent loss hazard (tidal inundation). Future storm flood depths in the vicinity of the desalination plant at 6.6 feet of sea-level rise are expected to increase be approximately 1 foot or more, depending on the ground elevation. CoSMoS output for the extreme storm indicates a future flood elevation of 14.1 feet NAVD at 6.6 feet of sea-level rise. The facility's intake and outfall are both located offshore. An additional, more detailed study would need to consider whether erosion of the coastal profile would expose portions of the intake and outfall pipelines and supports, and how sea level rise may impact sediment deposition and seafloor configurations that could affect the intake and outfall.

The potential exposure of the facility indicates a need for subsequent detailed study of the vulnerability of the desalination plant and its assets to climate change and sea-level rise.

Ortega Groundwater Treatment Plant

The Ortega Groundwater Treatment Plant is located north of Highway 101, and was designed to treat high levels of naturally occurring iron and manganese in the groundwater pumped from nearby wells. The treated groundwater is used to augment the City's drinking water supply. The treatment plant is located just outside the projected future flood hazard zone at 6.6 feet of sea-level rise. CoSMoS output for the extreme storm indicates a future flood elevation of 17.4 feet NAVD at 6.6 feet of sea-level rise near the plant. While the plant itself may not be impacted,

portions of the groundwater system, including two groundwater wells, that feed water into the plant may be affected by storm flooding and additional study in the future is needed to assess how this might impact the operations of the plant. A subsequent study is also needed to investigate the potential for sea-level rise-driven saltwater intrusion of the coastal aquifer that could affect the salinity levels of groundwater.

4.3.11 Public Works Replacement Costs in Place as Currently Designed

6 presents approximate replacement costs for various public works assets in the City. These costs assume replacement-in-place (no relocation) and as currently designed and represent a rough order of magnitude cost in 2018 dollars for planning purposes only. The values were developed with input from the City of Santa Barbara Public Works Department. It should be noted that actual replacement costs for these facilities in the future would likely be much higher due to inflation and the high likelihood that either the facility would need to be relocated, redesigned, or the site altered as part of replacement. The wastewater lift station near Arroyo Burro is known as the Braemar Lift Station. The Laguna Pump Station is for stormwater. Costs of these assets and the others are in the table below.

TABLE 6
APPROXIMATE 2018 REPLACEMENT COSTS FOR PUBLIC
WORKS ASSETS IN PLACE AS CURRENTLY DESIGNED

| Asset | 2018 Replacement Cost in Place as Currently Designed |
|--------------------------------------|---|
| Water Main | \$250/LF |
| Communications | \$100/LF |
| Wastewater – Gravity | \$200/LF |
| Wastewater – Force Main | \$300/LF |
| City Street Reconstruct | \$365/LF |
| Braemar Lift Station | \$3-5M |
| Laguna Tide Gates | \$3M |
| Laguna Stormwater Pump Station | \$10M |
| Harbor | \$50-60M |
| Stearns Wharf | \$59M ^a |
| El Estero Wastewater Treatment Plant | \$200-250M ^a |
| Charles E. Meyer Desalination Plant | \$72M |

NOTES:

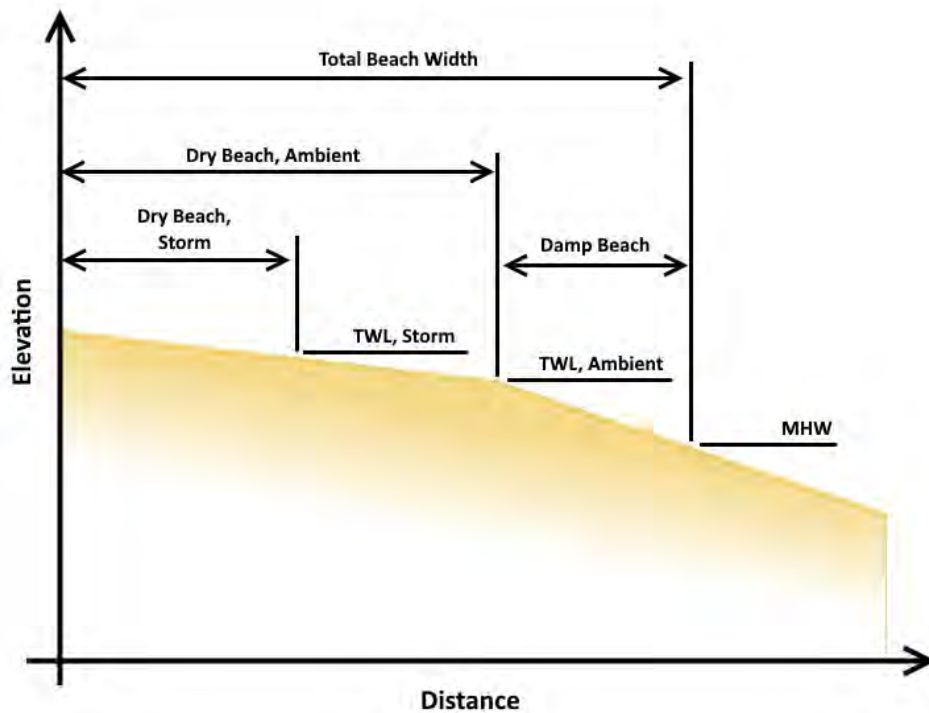
^a Costs estimated using assessed values per 2015 Property Schedule provided by the City

Cost of complete replacement of the Santa Barbara Harbor was estimated to be on the order of \$50-60 million dollars, based on review of damages documented at Crescent City and Santa Cruz harbors during earthquakes in 2006 and 2011.²² However, it is possible that only portions of the Harbor could be affected.

²² Damages at Crescent City and Santa Cruz were converted to 2018 dollars and scaled based on the larger size of Santa Barbara Harbor.

4.4 Beach Widths

Beach access is one of the defining characteristics of the City, both culturally and economically. Without action, sea-level rise is expected to drive beaches to shrink, squeezing them against existing bluffs or infrastructure on the backshore. Since beaches are a major recreational asset for the City, they were analyzed in additional detail. The beach width analysis employed a 2-line shoreline evolution model developed by ESA that tracks the shoreline and backshore erosion and thus beach width through time. Details on the shoreline evolution modeling are discussed in Appendix J. The beach widths from the shoreline evolution model were divided into zones based on the mean high water elevation,²³ ambient or daily typical wave runup elevation,²⁴ and the annual storm wave runup elevation.²⁵ **Figure 17** presents a schematic of the beach width zones.



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00
 SOURCE: ESA

Figure 17
 Definition of Beach Zones Used in the Ecological and Economical Vulnerability Analysis

²³ Mean high water is the high point on the beach that is completely underwater at each high tide during a normal, non-storm day. (MHW in Figure 17)

²⁴ Ambient wave runup elevation is the point on the beach reached by waves on a normal day. The water level including waves is called the “Total Water Level.” (TWL, Ambient in Figure 17)

²⁵ Storm wave runup elevation is the point on the beach reached by waves under storm conditions. The water level including waves is called the “Total Water Level.” (TWL, Storm in Figure 17)

The existing beach widths were determined manually in GIS by measuring the representative distance between the mean high water (MHW) shoreline (extracted from the CoSMoS DEM) and the backshore location (either development line or the toe of dune/bluff). The Santa Barbara Area Coastal Ecosystem Vulnerability Assessment (CEVA) (Myers et al. 2017) provides a description of the sandy beach ecosystems in Santa Barbara County and divides beach width into the areas that are generally damp (“damp beach”), those that are dry during normal conditions (“dry beach, ambient”), and those that are dry even during storm conditions (“dry beach, storm”).

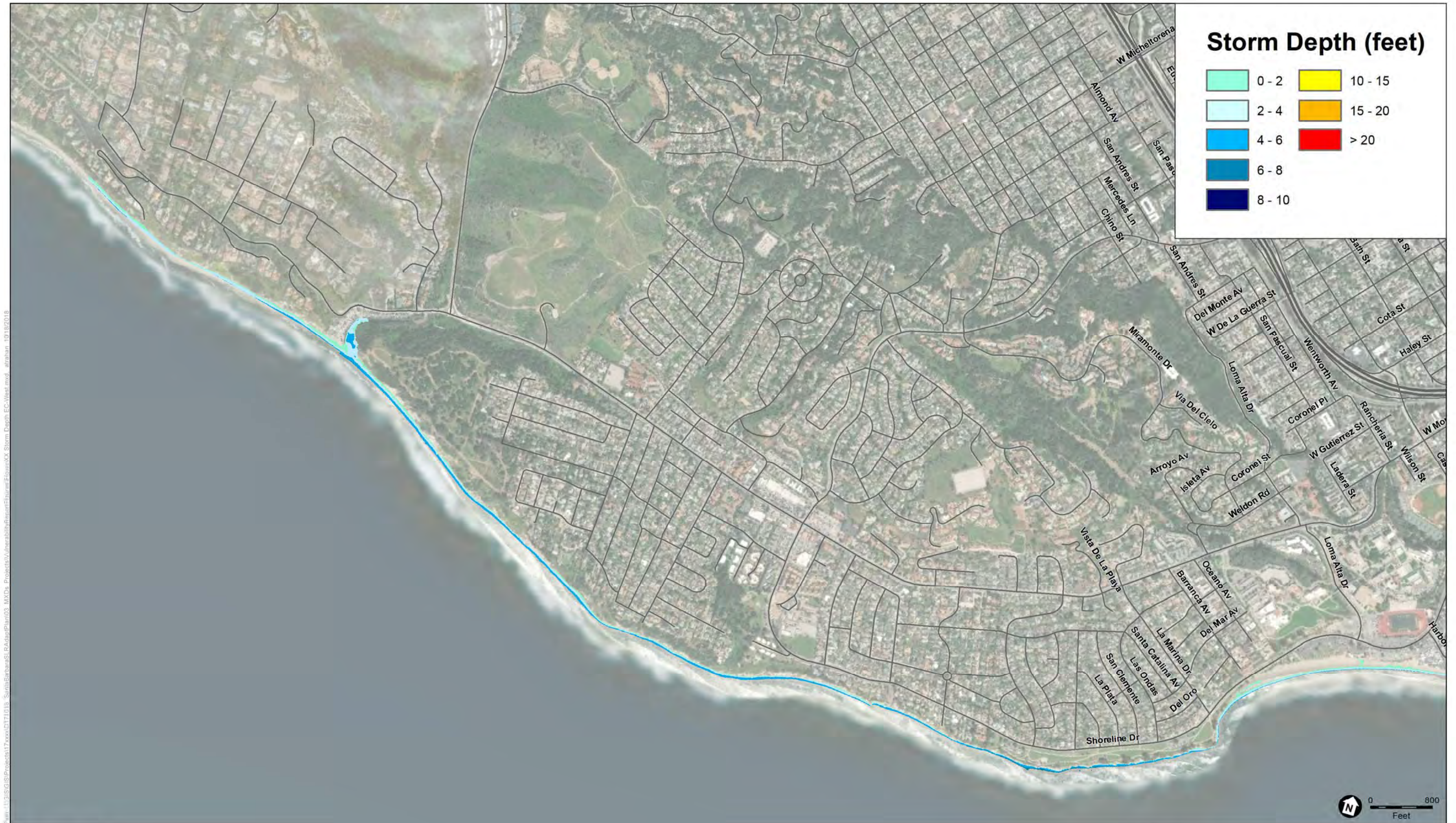
The beach width projections from Arroyo Burro (bluffs) and East Beach (sandy beach) were used to estimate the percent of the total existing beach width made up by the dry beach and the damp beach for each type of shoreline. The dry and damp widths at each of the other beaches in the City were determined based on the type of beach; bluffs were assumed to be similar to Arroyo Burro and sandy beaches were assumed to be similar to East Beach. As the shoreline evolution model proceeds and beaches narrow, the portion of dry beach (storm and ambient) are lost first, then the damp beach narrows when the dry beach is completely eroded. The results for dry beach (ambient daily), dry beach (annual storm), damp, and total beach width in each subarea are presented in **Table 7**. Total beach width is equal to the dry ambient plus damp beach widths.

**TABLE 7
BEACH WIDTHS WITH SEA-LEVEL RISE IN THE CITY OF SANTA BARBARA**

| Subarea | Description | Length of Shore (ft.) | Beach Width (ft.) | | |
|----------|---|-----------------------|---------------------|----------------------------|----------------------------|
| | | | Existing Conditions | 2.5 Feet of sea-level rise | 6.6 Feet of sea-level rise |
| A | Arroyo Burro (Bluffs) Total | 3781 | 94 | 33 | 0 |
| | <i>Damp Beach</i> | | 60 | 33 | 0 |
| | <i>Dry Beach, Ambient</i> | | 34 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 8 | 0 | 0 |
| B | Douglas Family Preserve (Bluffs) Total | 3427 | 65 | 7 | 0 |
| | <i>Damp Beach</i> | | 41 | 7 | 0 |
| | <i>Dry Beach, Ambient</i> | | 24 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 6 | 0 | 0 |
| C | Residential (Bluffs) Total | 3537 | 50 | 10 | 0 |
| | <i>Damp Beach</i> | | 32 | 10 | 0 |
| | <i>Dry Beach, Ambient</i> | | 18 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 4 | 0 | 0 |
| D | Lighthouse & Open Space (Bluffs) Total | 1116 | 40 | 18 | 22 |
| | <i>Damp Beach</i> | | 25 | 18 | 22 |
| | <i>Dry Beach, Ambient</i> | | 15 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 4 | 0 | 4 |
| E | Residential (Bluffs) Total | 2442 | 35 | 0 | 0 |
| | <i>Damp Beach</i> | | 22 | 0 | 0 |
| | <i>Dry Beach, Ambient</i> | | 13 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 3 | 0 | 0 |

| Subarea | Description | Length of Shore (ft.) | Beach Width (ft.) | | |
|----------|---------------------------------------|-----------------------|---------------------|----------------------------|----------------------------|
| | | | Existing Conditions | 2.5 Feet of sea-level rise | 6.6 Feet of sea-level rise |
| F | Shoreline Park (Bluffs) Total | 3415 | 30 | 0 | 0 |
| | <i>Damp Beach</i> | | 19 | 0 | 0 |
| | <i>Dry Beach, Ambient</i> | | 11 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 3 | 0 | 0 |
| G | Leadbetter Beach (Sandy) Total | 2734 | 120 | 95 | 69 |
| | <i>Damp Beach</i> | | 76 | 76 | 69 |
| | <i>Dry Beach, Ambient</i> | | 44 | 19 | 0 |
| | <i>Dry Beach, Storm</i> | | 11 | 0 | 0 |
| H | West Beach (Sandy) Total | 2646 | 430 | 396 | 344 |
| | <i>Damp Beach</i> | | 273 | 273 | 273 |
| | <i>Dry Beach, Ambient</i> | | 157 | 157 | 105 |
| | <i>Dry Beach, Storm</i> | | 38 | 4 | 0 |
| I | Chase Palm Park (Sandy) Total | 4001 | 170 | 44 | 0 |
| | <i>Damp Beach</i> | | 108 | 44 | 0 |
| | <i>Dry Beach, Ambient</i> | | 62 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 15 | 0 | 0 |
| J | East Beach (Sandy) Total | 2847 | 280 | 183 | 32 |
| | <i>Damp Beach</i> | | 178 | 178 | 32 |
| | <i>Dry Beach, Ambient</i> | | 102 | 5 | 0 |
| | <i>Dry Beach, Storm</i> | | 25 | 0 | 0 |
| K | Residential (Bluffs) Total | 1075 | 95 | 32 | 0 |
| | <i>Damp Beach</i> | | 60 | 32 | 0 |
| | <i>Dry Beach, Ambient</i> | | 35 | 0 | 0 |
| | <i>Dry Beach, Storm</i> | | 8 | 0 | 0 |

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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 18
Existing Conditions Storm Inundation Depth (West)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 19
Existing Conditions Storm Inundation Depth (East)

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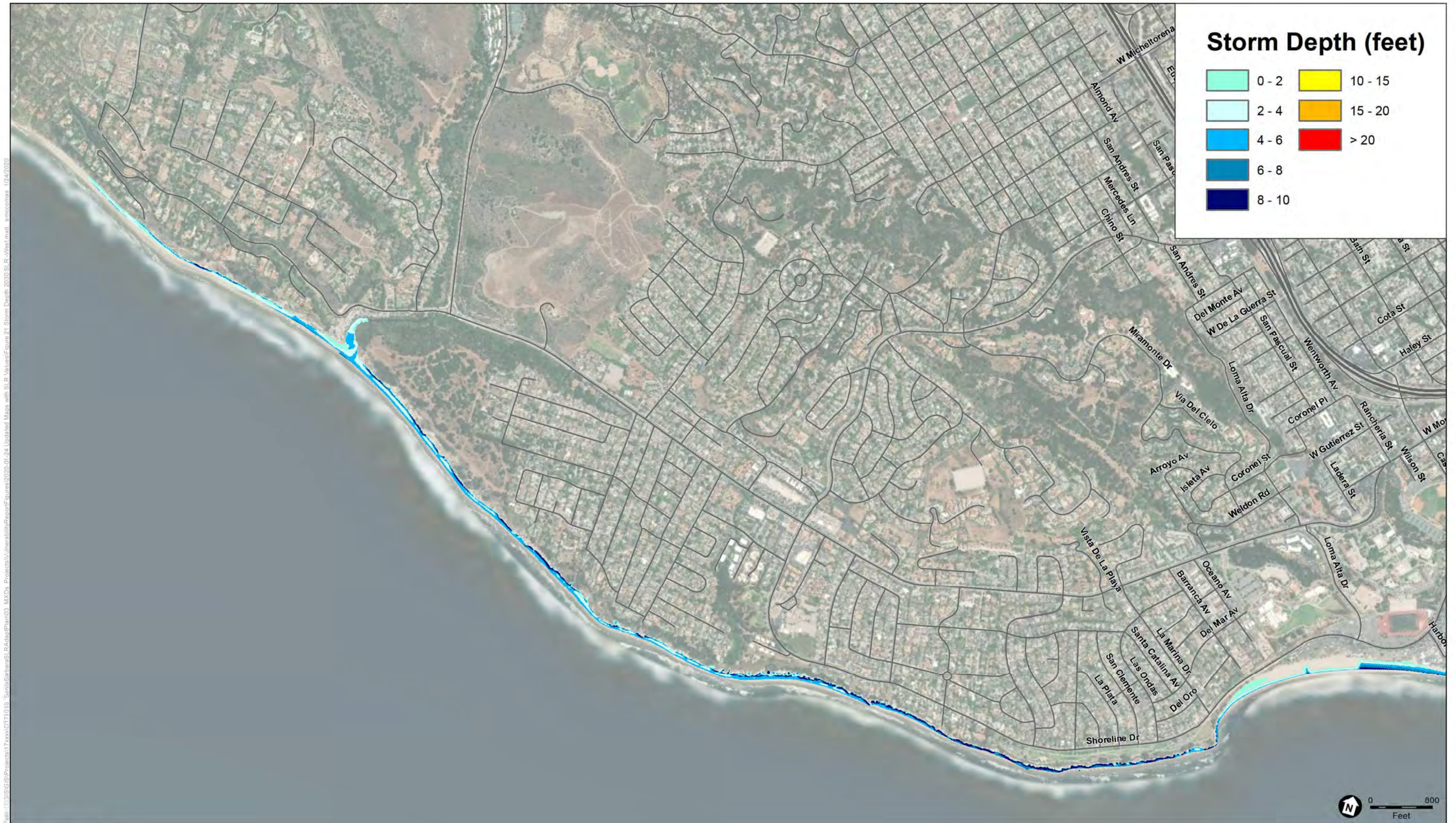
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 20
Storm Inundation Depth with 0.8 Feet of Sea-Level Rise (±2030) (East)



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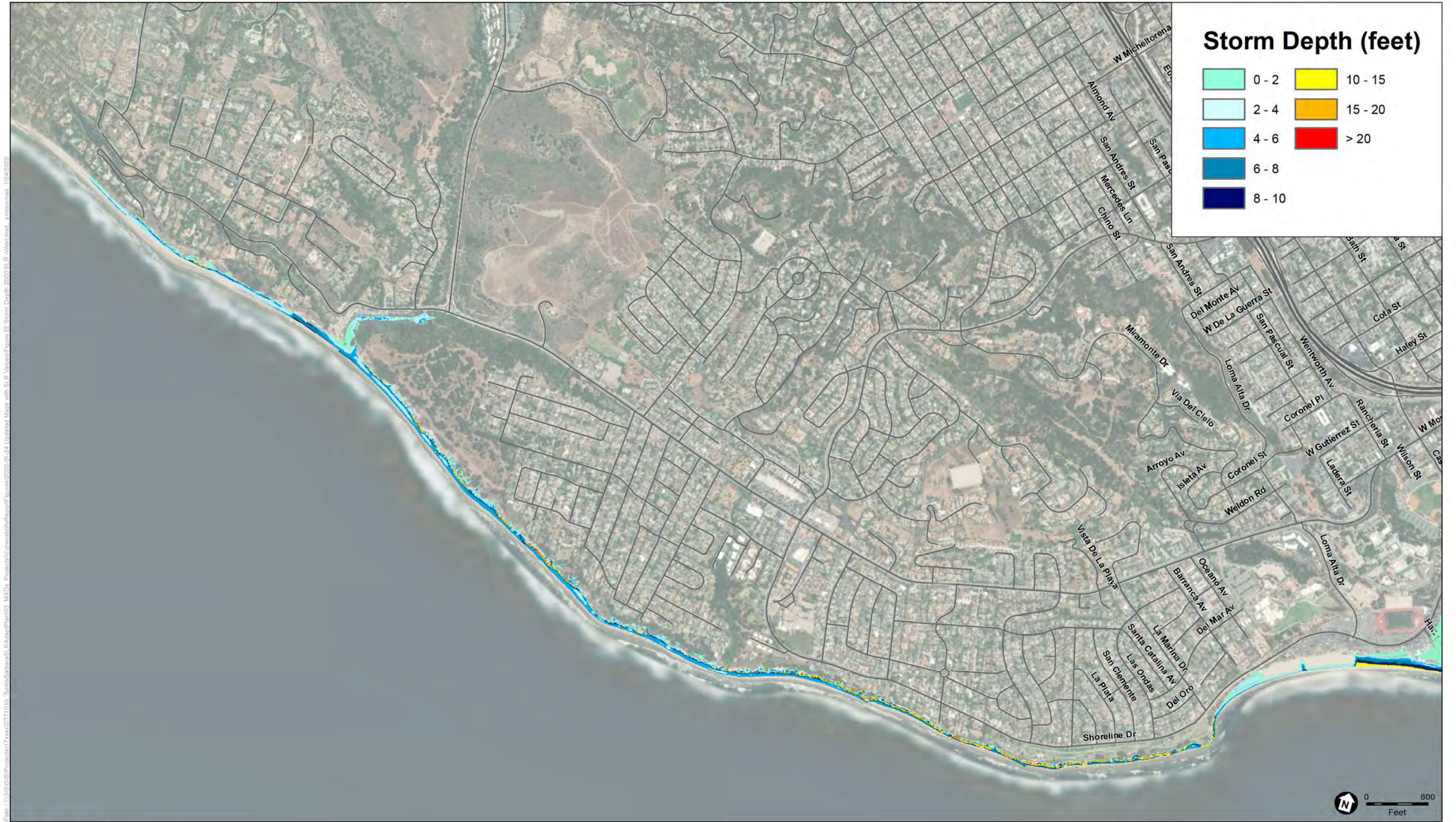
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 21
Storm Inundation Depth with 0.8 Feet of Sea-Level Rise (±2030) (West)



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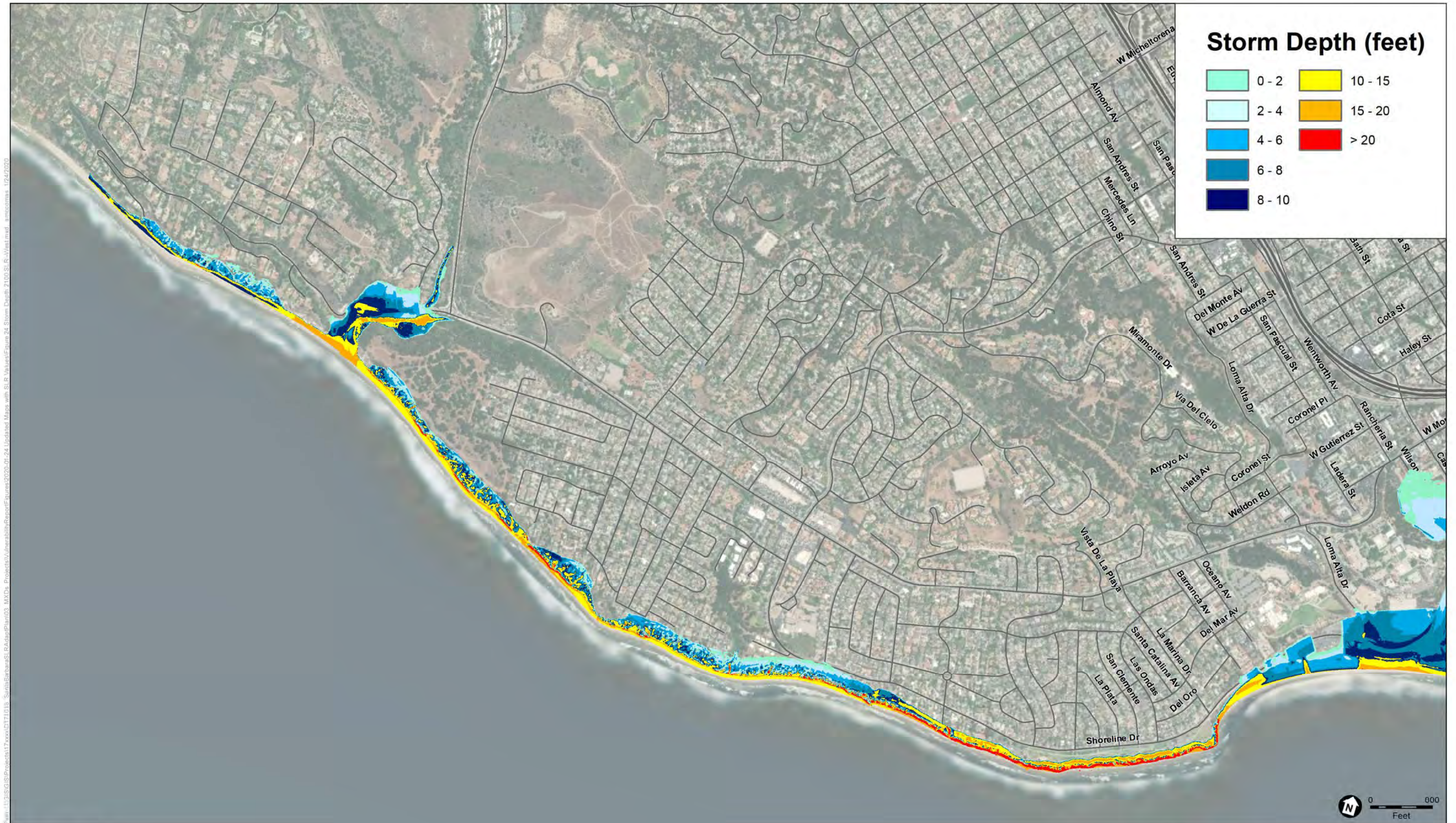
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 22
Storm Inundation Depth with 2.5 Feet of Sea-Level Rise (± 2060) (West)



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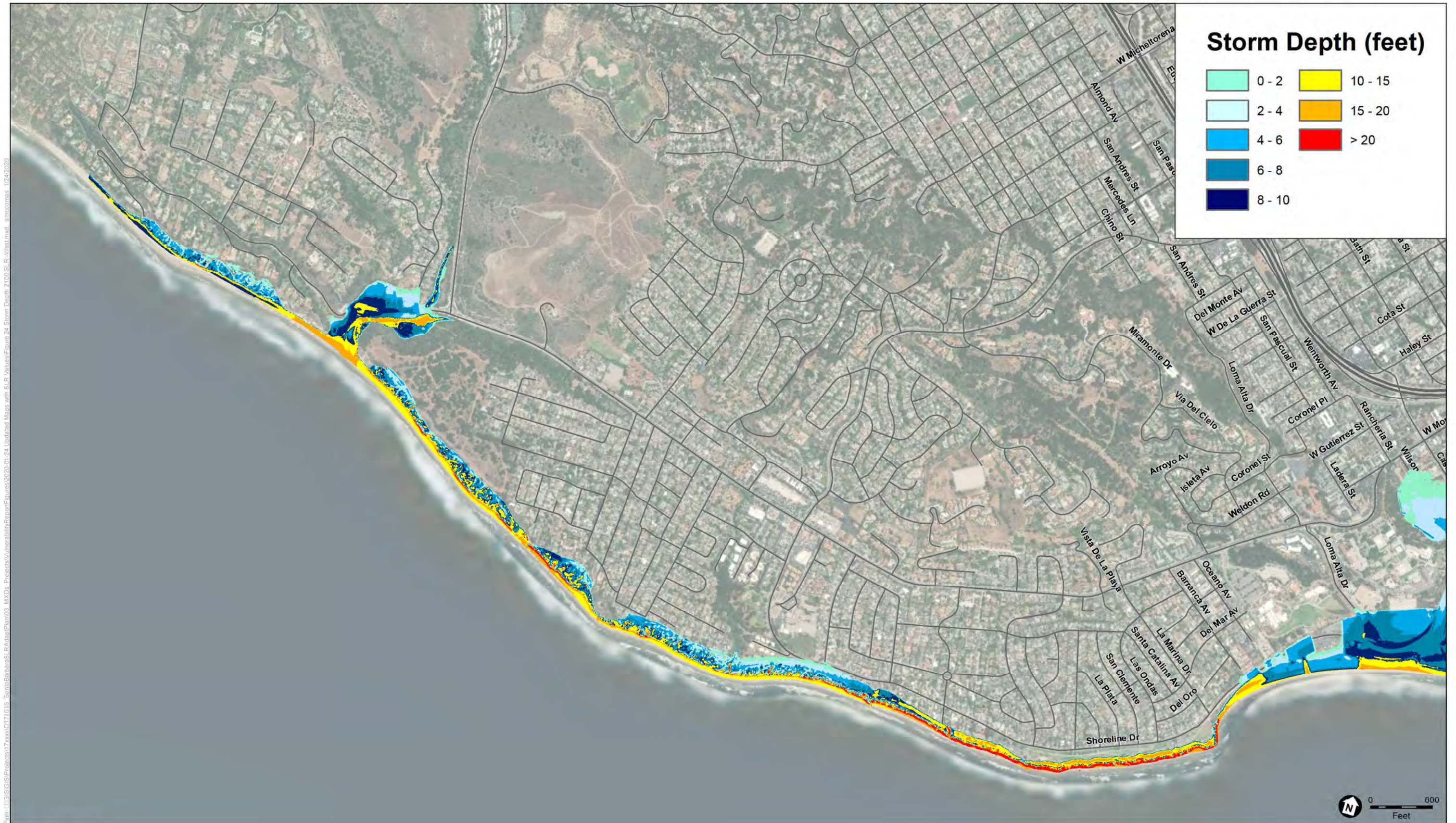
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 24
Storm Inundation Depth with 6.6 Feet of Sea-Level Rise (± 2100) (West)



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SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 24
Storm Inundation Depth with 6.6 Feet of Sea-Level Rise (± 2100) (West)



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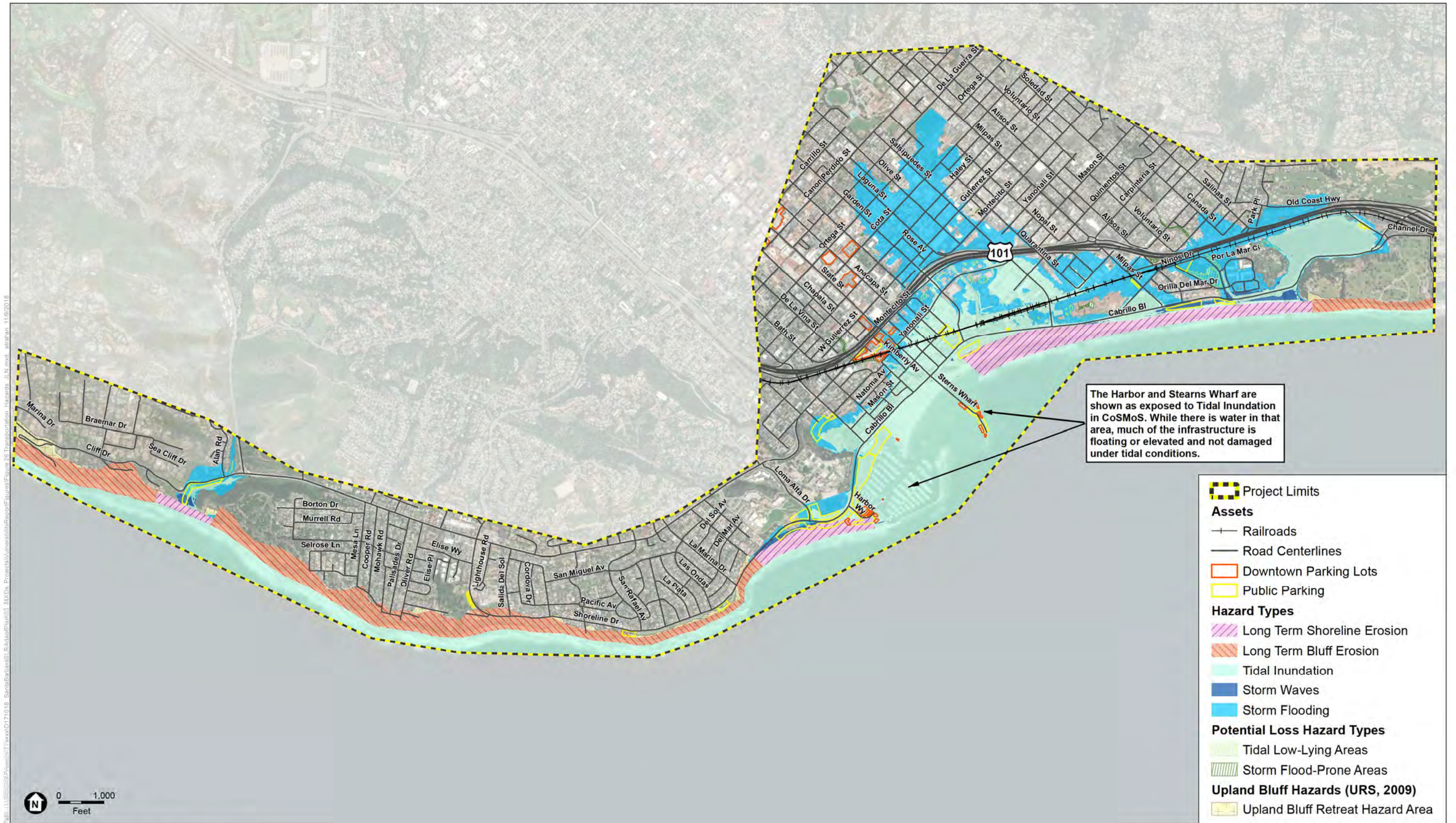
SOURCE: USGS, ESA

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 25
Storm Inundation Depth with 6.6 Feet of Sea-Level Rise (± 2100) (East)



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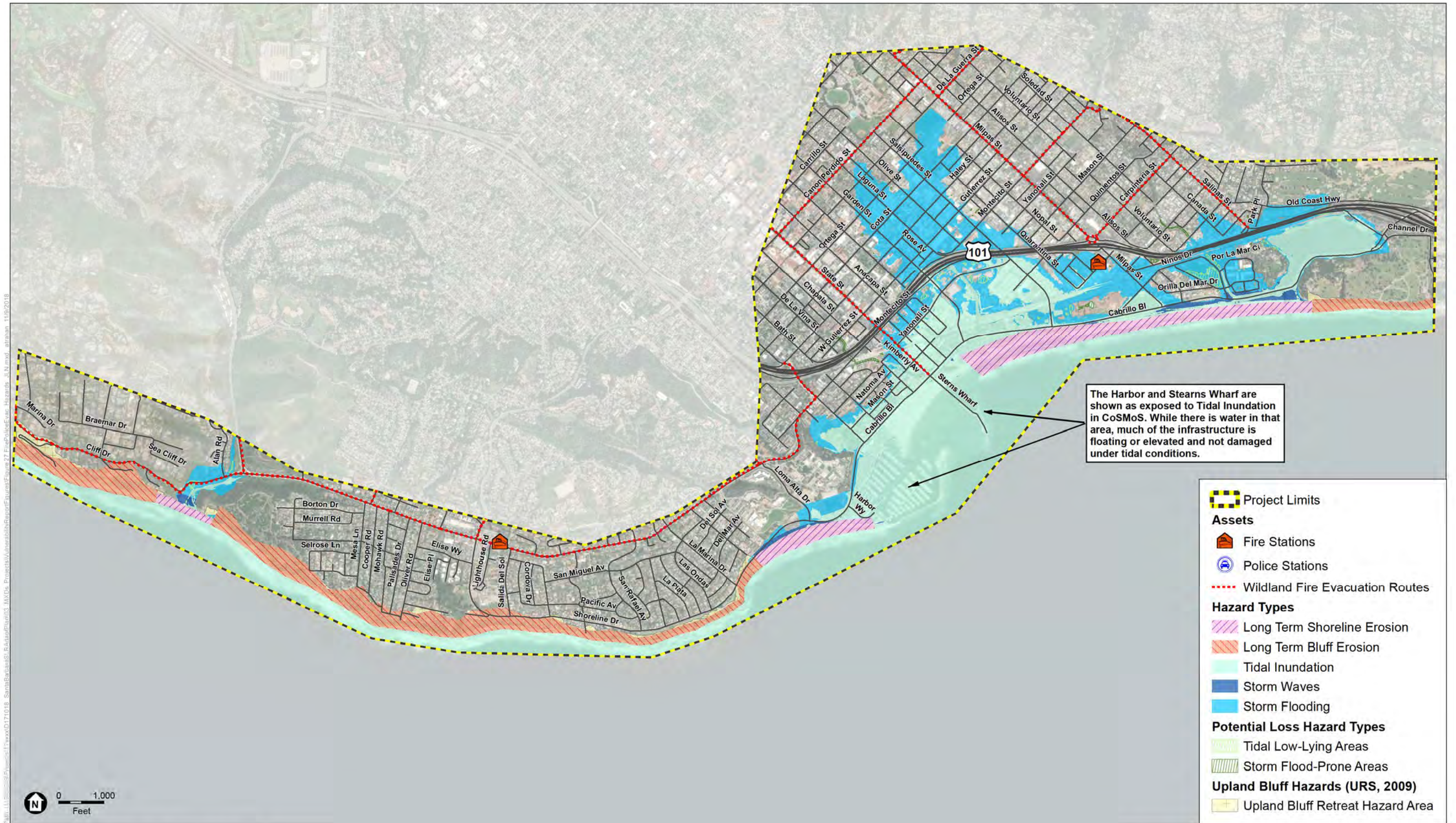
SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 26
Asset Hazard Map:
Transportation Hazards with 6.6 Feet of Sea-Level Rise



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SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

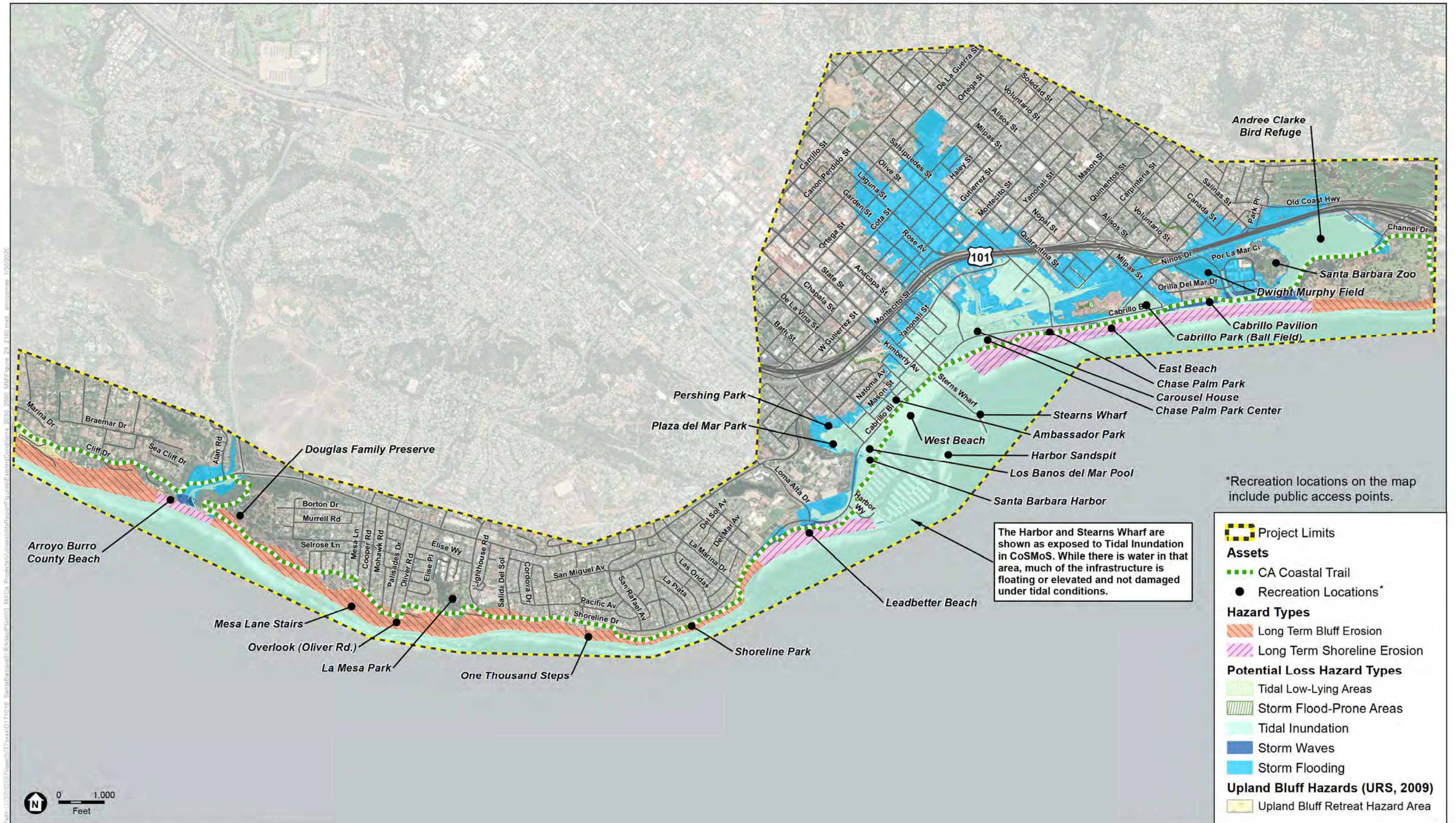
City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 27
Asset Hazard Map:
Public Safety Hazards with 6.6 Feet of Sea-Level Rise



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SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbra, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 29
 Asset Hazard Map:
 Recreation Areas Hazards with 6.6 ft SLR



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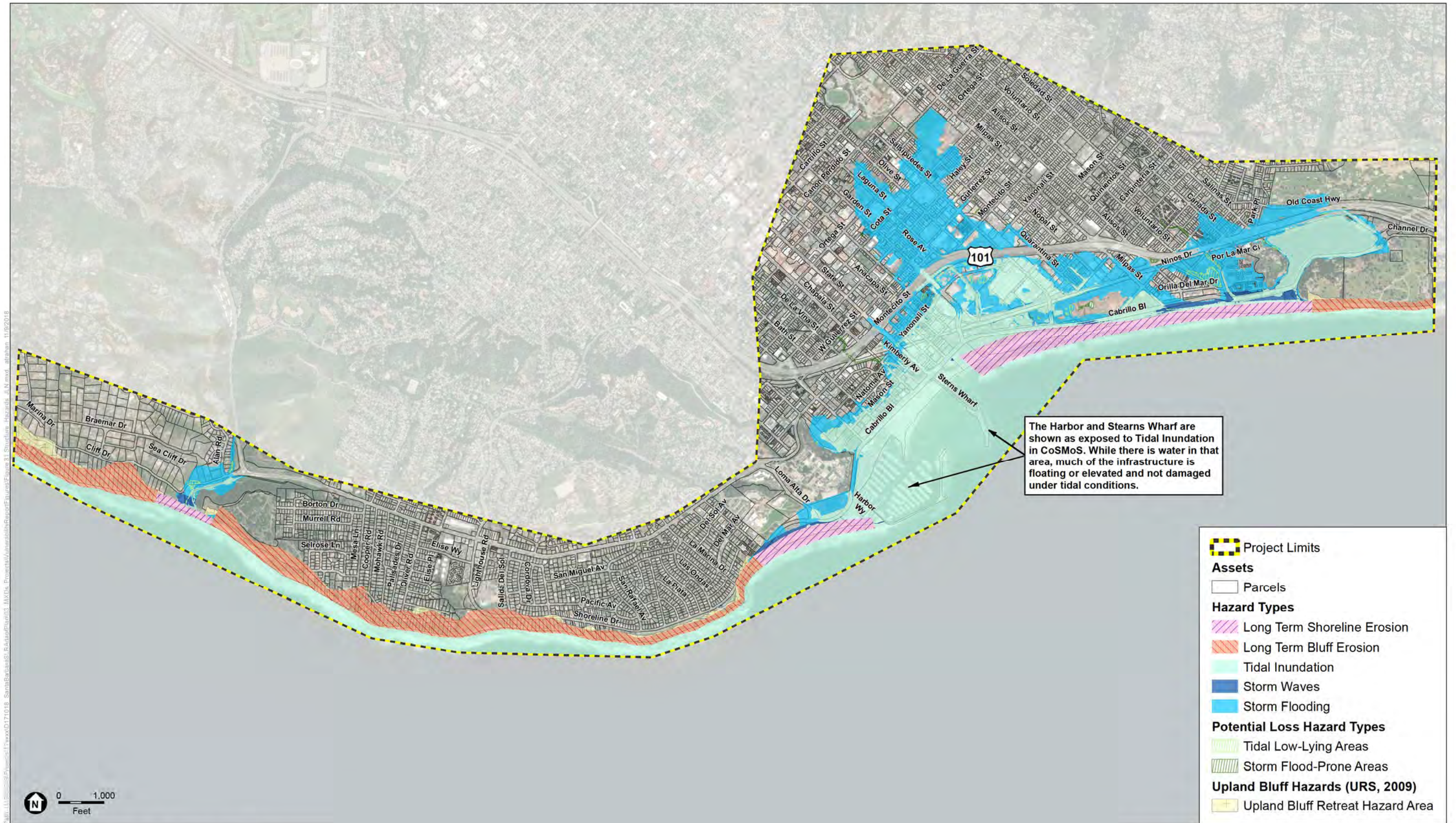


SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 30
 Asset Hazard Map:
 Harbor Assets Hazards with 6.6 Feet of Sea-Level Rise

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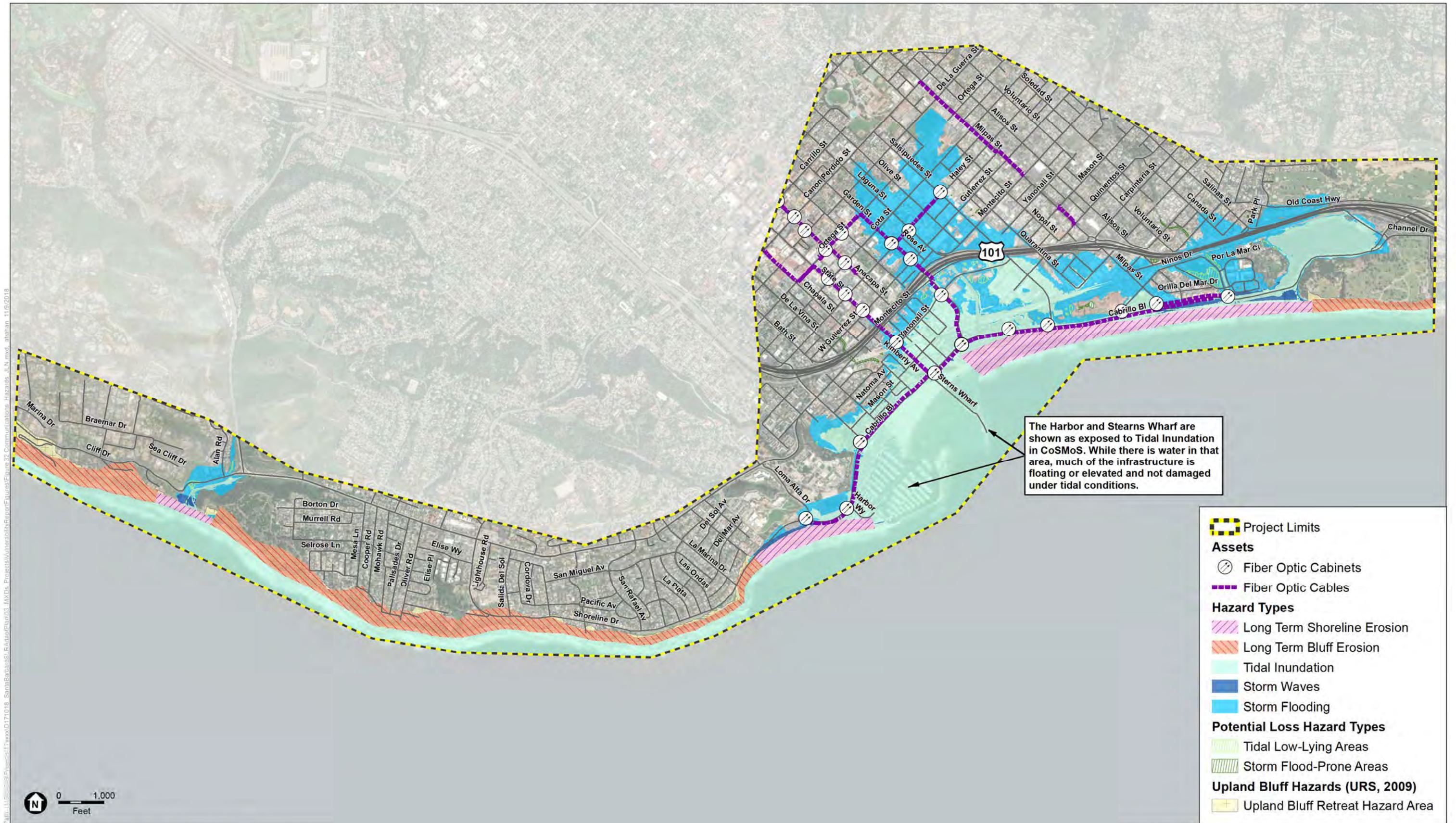
SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 31
 Asset Hazard Map:
 Public and Private Properties Hazards with 6.6 Feet of Sea-Level Rise



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SOURCE: ESRI, 2018, ESA, 2018, City of Santa Barbara, 2018.

City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update

Figure 32
Asset Hazard Map:
Communications Hazards with 6.6 Feet of Sea-Level Rise



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5. Ecological Vulnerability of Shoreline Habitats to Sea-Level Rise

Dave Hubbard of Coastal Restoration Consultants prepared the following section, which summarizes the ecological vulnerability of natural habitats to sea-level rise within the study area in the City of Santa Barbara.

5.1 Background

The ecological vulnerability of the study area was assessed by analyzing sea-level rise impacts to shoreline features and bluff erosion impacts to other habitats. The vulnerability of habitats to these mechanisms is linked as increasing sea levels will intensify bluff and shoreline erosion rates. The largest losses are projected to occur along the immediate coast with sea-level rise.

Beaches are dynamic edge habitats that lie on the interface between land and ocean. They are on the front line of climate change because they are sensitive to changes in sea level. In many places, beaches will be caught in a coastal squeeze as rising water on the ocean side pushes them toward fixed property lines, bluffs, and seawalls on the inland side.

Beaches provide a broad range of ecosystem services including water filtration and nutrient processing, habitat for diverse and abundant invertebrate species, food and habitat for shorebirds and other bird species, feeding resources for fish including species important for sport fishers, habitat for egg laying by grunion (**Figure 33**), and roosting areas for seabirds (Dugan and Hubbard 2016). The ecological resources of sandy shorelines depend on the ability of plants and animals to move with changing conditions as sand erodes and accretes²⁶ (Dugan et al 2013). The ecological zones of sandy shores can be broken roughly into zones by moisture content and effective tide level (although these change on daily and longer time scales):

1. Dune, above the reach of extreme tides, supports vegetation and wind-driven sand transport processes
2. Dry sand zone, between elevations of total water levels experienced spring tides and extreme water levels, can support coastal strand vegetation, also good for towel space and recreation
3. Damp sand zone, high intertidal high value for beach invertebrates
4. Saturated sand, low intertidal, high value for beach invertebrates, shorebird and fish foraging.

Beaches that have a full suite of zones will provide more ecosystem services than those that have fewer. The simplest way to assess the status and trends of ecosystem values of beaches is to understand the extent of the resource. This requires a description of the distribution of beach widths or acreage along the shore and an understanding that the shore is constantly changing. A greater understanding can be developed with a description of the distribution of functional zones along the coast. The locations and extents of the zones are determined by the interaction of waves and tides with sand on the shoreline. Generally, this requires more sophisticated modeling to

²⁶ Accretion is the opposite process of erosion, through which sand is naturally added to a beach rather than being removed.

generate a three dimensional representation of the habitat and an overlay describing typical wave and tide runup patterns.



City of Santa Barbara Sea-Level Rise Adaptation Plan for the LCP Update / D171018.00

Figure 33

Grunion Nests near the High-Tide Line in the Morning after a Spawning Event at Arroyo Burro Beach, Santa Barbara, July 1, 2017 (these fish lay their eggs in wet sand at night during extreme tides during spring and summer full and new moons)

5.2 Analysis

The analysis of beach ecosystem vulnerability presented here is based on the status and predicted trends in the area of the shoreline including damp, dry and high beach habitat in several shoreline segments for current conditions and two sea-level rise scenarios: 2.5 feet by 2060 and 6.6 feet by 2100 (see Table 7). We have summarized the results by shoreline type (bluff-backed beaches primarily in the western part of the study area and beaches backed by low lying topography in the eastern area). Bluff-backed beaches in the study area are narrow with an average total width of 63 feet (range from 30 to 95 feet) with little upper shore (see Table 7). The other segments in the eastern area, including Leadbetter Beach, West Beach, Chase Palm Park, and East Beach, have broader beaches with an average width of 250 feet (range 120 to 430 feet), and have more extensive dry sand zones backed by low topography. Average beach widths for current and future conditions (with 2.5 and 6.6 feet of sea-level rise) in the City of Santa Barbara were estimated for

upper total width, damp beach, dry beach (ambient), and dry beach during storm conditions. Habitat data for Arroyo Burro and East Beach are from the Santa Barbara Area Coastal Ecosystem Vulnerability Analysis (Myers et al. 2017, Barnard et al. 2017, Dugan et al. 2017).

5.3 Beach Habitats and Sea-Level Rise

In current conditions, the broad beach segments in the eastern area account for 39% of the shoreline length and 87% of the area in this analysis. There are 62 acres, and 2.3 miles in the eastern segments out of a total of 94 acres, and six miles of beach in the study area.

5.3.1 Upper Beach

The eastern segments contain 66% of the upper beach habitat in the study area. This upper shore is important for ecosystem services because it generally supports about 40% of the biodiversity on southern California's sandy beaches. The highest levels, above the reach of typical storms, and shown in Table 7 as widths above "Dry beach, storm" can support coastal strand vegetation and dunes. High beach habitat supports plants, rare species, grunion nesting during extreme tides (see Figure 33), and all species during storm conditions (as a refuge). Upper beach habitat width and acreage is also a good indicator of towel space (dry sand), lateral access along the beach during any tide, and easy and predictably accessible areas for general recreational use.

5.3.2 Damp Beach

The non-bluff-backed segments currently have about 66% of the damp beach habitat in the study area. The damp shore currently accounts for 63% of the total beach area. The lower zone of the beach supports very large numbers and a high diversity of invertebrates. These are important food sources for both shorebirds and near shore fish. Some beaches in the region still support harvestable populations of Pismo clams in this zone.

5.3.3 Sea-Level Rise Projections

In the analysis, beaches in the study area are projected to shrink substantially under all combinations of sea-level rise scenario, habitat zone and shoreline segment. We calculated the changes in area for damp, dry beach and high dry beach (above typical storm levels) habitats compared to current conditions using two sea-level rise projections for 2.5 feet and 6.6 feet for the shoreline segments in the study area (Table 7) and summarized them by shoreline type.

5.3.4 Conditions at 2060: 2.5 Feet of Sea-Level Rise

A rise of 2.5 feet in sea level is projected to eliminate 42 acres of beach for the study area (44% of the current beach area). The projections suggest that the losses would be proportionately greater for the upper shore (59%) than the lower shore (41%), and more rapid along bluff-backed beaches (76%) than beaches backed by low topography (25%). Losses are projected to be greatest for the highest zone, the dry beach during storm conditions. Projected average upper beach widths for the western segments in this scenario are zero, indicating loss of the upper beach. These zone

widths will not support upper beach ecological communities and functions and would be vulnerable to storm events and larger disturbances.

The impacts of a 44% loss in beach area would be substantial, but the system will probably lose more than that amount of ecological capacity. As the narrow, bluff-backed beaches erode toward widths of averages of 0 to 35 feet from current conditions with averages of 30 to 95 feet, they will be less able to recover from disturbances and deliver ecosystem services.

5.3.5 Conditions at 2100: 6.6 Feet of Sea-Level Rise

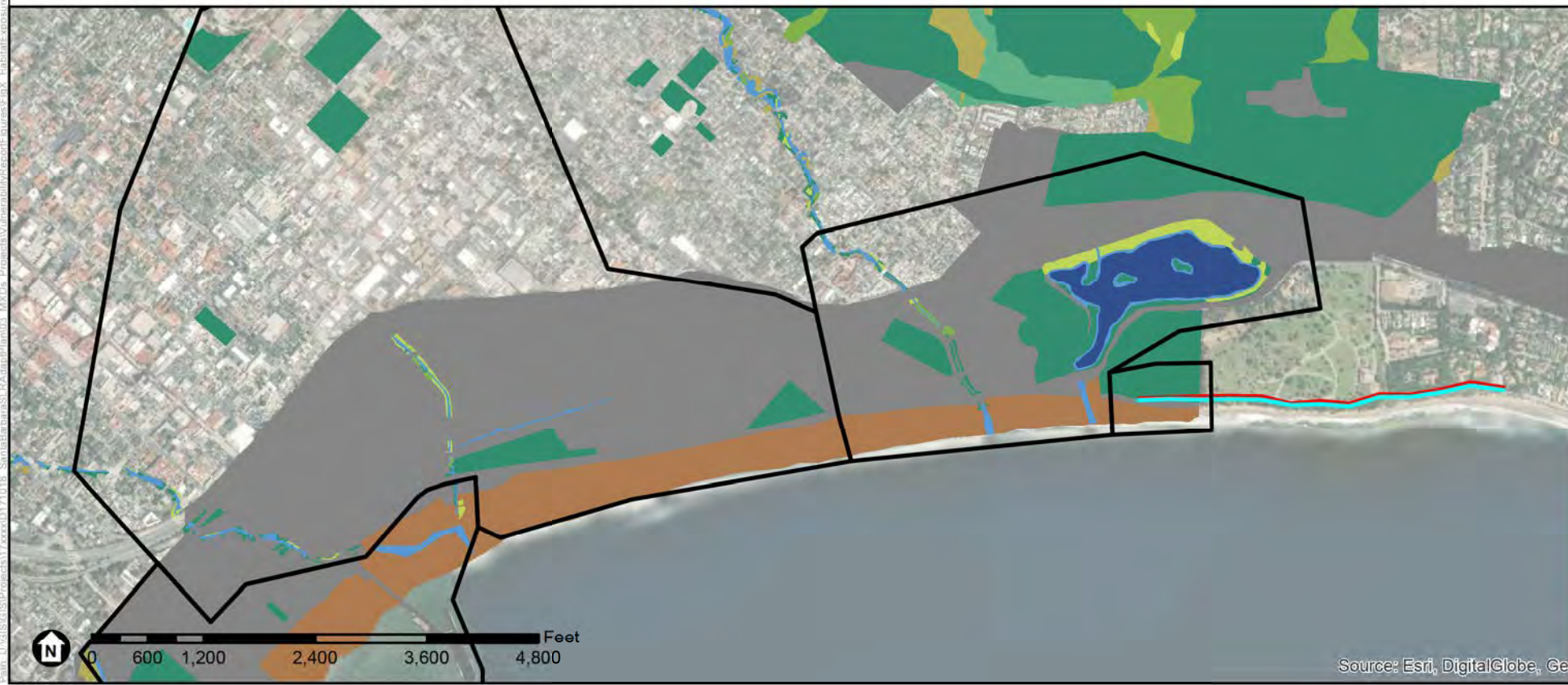
A rise of 6.6 feet in sea level is projected to reduce the beach habitat zones under consideration in this study by 70%. The projections indicate that about 66 acres of beach will be lost at 6.6 feet of sea-level rise in the study area. Bluff-backed beaches are likely to convert to other habitat types (bedrock, cobble or inundated) for substantial periods as they transition toward this loss because conversion will typically be driven by episodic events that punctuate climate change trends. The beaches backed by low topography are projected to lose 56% of their area. Beach ecosystem services will be greatly reduced in this scenario, as would beach recreation.

5.4 Other Habitats and Bluff Erosion

The analysis of the vulnerability of habitats further inland to climate change used existing habitat mapping (**Figure 34**) along with bluff erosion modeling (this report) to estimate changes in the extent of major habitat types in the study area (**Table 8**). As the bluffs erode inland, current bluffs will be destroyed and new bluff faces will be created from current bluff top habitats. The sandy shorelines assessed in this study either did not fully erode at 6.6 feet of sea-level rise or are backed by managed park area, thus having little effect on upland habitats, so this analysis focused on bluff areas.

Three habitat types (Coastal Sage Scrub, Eucalyptus Grove and Annual Non-native Grassland) are projected to lose at least one acre of area each for a total of 36.5 acres at 2.5 feet of sea-level rise, and 42.8 acres at 6.6 feet of sea-level rise. These losses range from 2 to 7% of the current acreage. Three other habitat types are projected to lose smaller areas: Ruderal (1 acre at 6.6 feet of sea-level rise, 0.9%), Riparian and Wetland (0.9 acre at 6.6 feet of sea-level rise, 0.3%), and Coast Live Oak Woodland, Savanna, or Forest (0.1 acre at 6.6 feet of sea-level rise, 0.0%).

Two other cover classes (Urban, and Ornamental Trees- Landscape) are projected to lose substantial area to bluff erosion, but are not analyzed as habitat.



Legend

| | |
|---|---------------------------------|
| Subareas | Coastal Sage Scrub/Oak Woodland |
| Bluff Erosion Boundary, 2060 | Coastal Strand/Beach |
| Bluff Erosion Boundary, 2100 | Eucalyptus Grove |
| DEFINITION | |
| Annual Non-native Grassland | Open Water |
| Chaparral | Orchard |
| Chaparral/Coastal Sage Scrub | Ornamental Trees - Landscape |
| Chaparral/Oak Woodland | Riparian and Wetland |
| Coast Live Oak Woodland, Savanna, or Forest | Ruderal |
| Coastal Bluff | Undetermined Grassland |
| Coastal Sage Scrub | Urban |
| Coastal Sage Scrub/ Grassland | |

SOURCE:
 Erosion: USGS CoSMoS, 2017
 Habitats: City of Santa Barbara, 2018

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Figure 34
 Habitat Areas Exposed to Bluff Erosion



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TABLE 8
PROJECTED AREAS AND PERCENTAGE OF COASTAL AND UPLAND HABITATS LOST TO BLUFF EROSION

| Habitat Type | Full City (Acres) | Area Lost to Bluff Erosion (Acres) | | Percent of Habitat Lost to Bluff Erosion | |
|---|-------------------|------------------------------------|----------------------------|--|----------------------------|
| | | 2.5 Feet of sea-level rise | 6.6 Feet of sea-level rise | 2.5 Feet of sea-level rise | 6.6 Feet of sea-level rise |
| Annual Non-native Grassland | 202.9 | 3.8 | 4.8 | 1.9% | 2.4% |
| Chaparral | 97.0 | 0.0 | 0.0 | 0.0% | 0.0% |
| Chaparral/Coastal Sage Scrub | 77.9 | 0.0 | 0.0 | 0.0% | 0.0% |
| Chaparral/Oak Woodland | 130.4 | 0.0 | 0.0 | 0.0% | 0.0% |
| Coast Live Oak Woodland, Savanna, or Forest | 820.5 | 0.0 | 0.1 | 0.0% | 0.0% |
| Coastal Sage Scrub | 468.9 | 27.9 | 32.6 | 6.0% | 6.9% |
| Coastal Sage Scrub/Grassland | 16.8 | 0.0 | 0.0 | 0.0% | 0.0% |
| Coastal Sage Scrub/Oak Woodland | 20.4 | 0.0 | 0.0 | 0.0% | 0.0% |
| Eucalyptus Grove | 112.0 | 4.8 | 5.4 | 4.3% | 4.8% |
| Native Perennial Grassland | 5.5 | 0.0 | 0.0 | 0.0% | 0.0% |
| Open Water | 27.5 | 0.0 | 0.0 | 0.0% | 0.0% |
| Orchard | 227.7 | 0.0 | 0.0 | 0.0% | 0.0% |
| Ornamental Trees – Landscape | 2,423.9 | 7.4 | 16.3 | 0.3% | 0.7% |
| Riparian and Wetland | 283.8 | 0.7 | 0.9 | 0.2% | 0.3% |
| Ruderal | 119.5 | 0.5 | 1.0 | 0.4% | 0.9% |
| Undetermined Grassland | 12.3 | 0.0 | 0.0 | 0.0% | 0.0% |
| Urban | 2,419.5 | 36.0 | 51.9 | 1.5% | 2.1% |

5.5 Summary

This analysis predicts significant losses in several habitat types in the study area. Due to the urban environment of the city and the juxtaposition of habitats next to development, there is no opportunity for habitats to migrate inland with sea-level rise. Coastal Sage Scrub habitat is projected to have the greatest loss of native habitats due to bluff erosion. The largest habitat losses in terms of acreage and proportion of current resources will be for beaches. The highest sensitivity for losses is for bluff-backed shores and upper beach habitats. The results of this analysis are consistent with other recent studies of sandy beaches in the study area: (two sections from Myers *et al.* 2017- Barnard *et al.*, 2017 and Dugan *et al.* 2017). This is not surprising because the analytical methods were quite similar. In addition, Vitousek *et al.* 2017 used the same model to analyze future trends for beaches throughout southern California. Their results predict major losses in beach widths, but also the total losses of beaches across a considerable proportion of the coast. Projections of major losses of beach habitat in southern California with sea-level rise in each of these studies indicate that the areal extent of sandy beach ecosystems and the ecosystem services they provide will decline precipitously in the coming decades.

6. Conclusions

The purpose of the City of Santa Barbara Vulnerability Assessment Update was to identify and quantify the vulnerability of coastal assets in the City to sea-level rise. As an update, this assessment aimed to fill gaps in previous studies for the City and County of Santa Barbara by:

- Using updated data about the City’s assets
- Using the most recent hazard zones from USGS (CoSMoS v3.0), augmented by wave hazard zones from Coastal Resilience Santa Barbara
- Performing a focused study of local geology and erosion risk
- Investigating the ecological impacts of beach loss in the City

The study evaluated the vulnerability of assets in nine categories (Critical Facilities, Transportation, Public Safety, Stormwater, Recreational, Harbor, Public and Private Property (Parcels), Communications, Water Supply, and Wastewater). These assets were analyzed for vulnerability to six hazards (bluff erosion, shoreline erosion, tidal inundation, storm waves, storm flooding, and low-lying areas). These hazards and the City’s vulnerability to them were evaluated under existing conditions and under two sea-level rise scenarios (2.5 feet and 6.6 feet). These scenarios represent the high greenhouse gas emissions scenario from the OPC (2018) guidance with Medium/High risk aversion in 2060 and 2100, respectively. A near-term 2030 condition (0.8 feet of sea-level rise) was reviewed, but was similar enough to existing conditions that a detailed analysis was not performed. The higher value, 6.6 feet of sea-level rise, also represents the extreme risk aversion case from OPC (2018) in the year 2080.

The conclusions of this assessment are summarized as general conclusions and sea-level rise vulnerability by subarea.

6.1 General Conclusions

6.1.1 Bluff Areas

Rising sea levels are expected to increase the coastal hazards that are currently impacting the City of Santa Barbara. Much of the westerly portion of the City’s coastal zone is situated on bluffs overlooking the beach. Bluff areas in the City include subareas A–F, from approximately Sea Edge Lane at the west end of the City of Santa Barbara to approximately Santa Barbara Point, as well as subarea K at the far easterly portion of the City by the Bellosguardo Estate.

These bluffs are currently eroding with exposure to waves, and as sea level rises, they will be exposed to more extreme waves more often. This is expected to increase bluff erosion rates to about 1.5 times current rates at 2.5 feet of sea-level rise (40% increase) and to more than twice current rates at 6.6 feet of sea-level rise (140% increase). At 2.5 feet of sea-level rise the City could lose 78% of its bluff-backed beaches to erosion, and at 6.6 feet of sea-level rise, the City could lose 98% of its bluff-backed beaches. In locations where these beaches are lost, the bluffs behind them will be more exposed to waves and are expected to erode more quickly. The extent

of the hazards in these areas are expected to reach bluff-top infrastructure, including roads and utility infrastructure and public and private properties at 6.6 feet of sea-level rise.

6.1.2 Low-Lying and Waterfront Areas

The low-lying areas of the City include the City's Waterfront, lower downtown area, and Arroyo Burro County Beach Park. In these areas, sandy beaches and low-lying areas in the City are also expected to see a change in exposure with sea-level rise, predominantly due to increased tidal inundation and storm flooding. Under current conditions and through 2.5 feet of sea-level rise, impacts from erosion, tidal inundation, and storm waves are generally limited to the area south of Cabrillo Boulevard. However, at 6.6 feet of sea-level rise these hazard zones are expected to reach north of Cabrillo Boulevard, exposing more assets in the City. Furthermore, at 2.5 feet of sea-level rise the City could lose 32% of its sandy beaches in these low-lying areas to erosion, and at 6.6 feet of sea-level rise, the City could lose 60% of its sandy beaches in low-lying areas.

There may also be changes in the direction from which waves come during different seasons, which may affect sand movement and erosion patterns at sandy beaches and in the harbor. In addition to rising sea level, a changing climate may also alter storm frequencies and patterns, bringing more severe storms more often or at different times.

6.1.3 Harbor and Stearns Wharf

The Santa Barbara Harbor and Stearns Wharf are valuable and important assets in the City. Under existing conditions, Stearns Wharf is exposed to wave damage during large storms and a 100-year coastal event is expected to require temporary closure and significant structural repairs. As sea level rises through 2.5 feet of sea-level rise and into 6.6 feet of sea-level rise, events large enough to damage Stearns Wharf are expected to become more common, though non-storm tidal conditions are not likely to pose a risk of damage for the wharf deck.

The harbor includes the marina, commercial uses, parking, industrial areas, and the City Pier (sometimes called the "harbor pier"), which supports the Coast Guard and houses a fuel dock. Under existing conditions, storm events and especially high tides (e.g., "King Tides") can dislocate pile caps at the floating docks, and waves can overtop the harbor breakwater and reduce public access. More than 2 feet of sea-level rise (for example, the 2.5 feet of sea-level rise case) is expected to regularly impede normal harbor functions, and the harbor in its current configuration would be unusable at 6.6 feet of sea-level rise, with over 6 feet of sea-level rise.

6.1.4 Storm Flooding Area

Flooding from coastal storms is expected to significantly increase in extent and frequency, particularly at 6.6 feet of sea-level rise. FEMA flood insurance rate maps (FIRMs) are another hazard map generally used to assess exposure and vulnerability, so there is interest in how these relate to the results of this study. FEMA FIRMs are used to assess flood insurance rates and for regulatory purposes. For instance, the City's current Flood Plain Management Ordinance (Municipal Code Section 22.24) requires certain development standards, including floodproofing and raised foundations, based on the extent of flood hazard areas and the base flood elevations

shown on the FEMA FIRMs. FEMA FIRMs do not include future conditions, future sea-level rise, or erosion hazards, so they indicate less severe coastal hazards than the hazard zones in this assessment in coastal areas. The FIRMs do, however, include extreme fluvial (river) events. The coastal and river flood events are mapped together on the FIRM, though they are not expected to occur simultaneously. Note that the FIRM flood hazard extent includes areas that are subject to river flooding that are not including in the Vulnerability Assessment's coastal flood hazard extent since the Vulnerability Assessment does not include extreme river flood hazards. The Vulnerability Assessment does, however, consider the degree of river flow that has historically occurred concurrent with extreme coastal storm events.

Some of the flood hazard areas currently mapped in the FIRMs are expected to experience more frequent flooding with sea-level rise, and in some areas the water levels are expected to change. The future hazard zones in areas dominated by coastal flooding that are near the waterfront and downtown south of Highway 101 are expected to experience higher water levels and more severe flooding than FEMA (water levels up to 2 to 3 feet higher than current base flood elevations). Some areas south of Highway 101 that are not currently mapped in any flood hazard zone on the FEMA FIRMS right now are projected to experience flooding at 6.6 feet of sea-level rise. However, further inland (for example, downtown north of Highway 101), fluvial flooding is expected to be more extreme than coastal flooding, so the FEMA FIRM (existing conditions) represent more extreme conditions than the hazard zones from this assessment (future conditions). These areas would likely experience more frequent flooding events at 6.6 feet of sea-level rise due to sea-level rise, but the flood depths from sea-level rise alone would likely not be more than the base flood elevations currently shown on the FEMA FIRMs.

Other changing climatic factors, such as increasing precipitation intensity, could increase the fluvial hazard and flood extents and depths, but would require further study and analysis outside the scope of this vulnerability study to fully understand.

6.1.5 Major Infrastructure Facilities

Major infrastructure facilities, including the El Estero Wastewater Treatment Plant, the Charles E. Meyer Desalination Plant, and several major roads including Highway 101 are expected to experience increased flood risk at 6.6 feet of sea-level rise. While they are expected to be exposed, facility-specific vulnerability assessments are recommended to better understand the adaptive capacity to flood proof these facilities and the actual risk to these facilities.

The vulnerability assessment identifies shows the El Estero Wastewater Treatment Plant partially in the tidal inundation and storm flooding hazard zones at 6.6 feet of sea-level rise and the Charles E. Meyer Desalination Plant, at least partially exposed to the tidal inundation and storm flooding hazard zones at 6.6 feet of sea-level rise. However due to tidal inundation of the infrastructure associated with these plants, as well as portions of the plants themselves, both the El Estero Wastewater Treatment Plant and Desalination Plant will be permanently inoperable at 6.6 feet of sea-level rise if no action is taken. Tidal inundation of some of the wastewater piping system flowing into the plant will occur by at 2.5 feet of sea-level rise if no action is taken. Additional analysis is needed to determine how much this will interrupt operations of the plant.,

In addition, at 6.6 feet of sea-level rise much of Cabrillo Boulevard is exposed to erosion or tidal inundation, and Highway 101 may experience storm flooding near Andrée Clarke Bird Refuge, and Shoreline and Cliff Drive could be threatened by shoreline and bluff erosion.

6.2 Conclusions by Subarea

Each of the subareas in Figure 1 contains different assets (see Table 1), exposed to different coastal hazards at different time horizons. The following sections describe the subareas and how exposure is expected to change with sea-level rise.

6.2.1 Subarea A

Subarea A covers the area from Sea Ledge Lane at the west end of the City of Santa Barbara to the west side of Arroyo Burro Beach County Park. It consists of a bluff-backed beach, with an ancient landslide at the west end and residential neighborhoods running along the bluff for much of its length. Under existing conditions, Subarea A has extensive recreational area (the bluff-backed beach) exposed to tidal flooding hazards and storm wave hazards. Projected bluff erosion in this area is being investigated further due to geologic complexities, so results at 2.5 feet of sea-level rise and 6.6 feet of sea-level rise are not yet available.

6.2.2 Subarea B

Subarea B stretches from the west end of Arroyo Burro Beach County Park to the east edge of the Douglas Family Preserve. It consists of a bluff-backed beach with bluff-top open space (Douglas Family Preserve) and a coastal lagoon with extensive low-lying drainage (Arroyo Burro and Arroyo Burro Creek) and beach area (Arroyo Burro Beach County Park and associated parking area). Under existing conditions, Subarea B has large recreational and natural areas and some stormwater drainage channels exposed to tidal flooding, storm waves, and storm flooding, particularly surrounding the coastal lagoon (Arroyo Burro). At 2.5 feet of sea-level rise, the erosion hazard zone begins to affect the bluff-top open space (including access roads) and the bluff-backed beach. Some areas exposed to storm flooding under current conditions become exposed to tidal flooding, and some areas exposed to tidal flooding become exposed to erosion. At 6.6 feet of sea-level rise storm flooding becomes a significant concern, causing temporary loss of service for sewer infrastructure, water supply infrastructure, roads, and evacuation routes. In addition, more of the bluff-backed beach area is exposed to tidal inundation, and large areas of both bluff-backed beach and bluff-top open space are exposed to erosion.

6.2.3 Subarea C

Subarea C covers the area from the west end of Medcliff Road to the east end of El Camino de la Luz. It consists of a bluff-backed beach with bluff-top residential neighborhoods. There is a modern landslide at El Camino de la Luz and beach access at Mesa Lane. Under existing conditions this subarea only has minor exposure to coastal hazard zones; however, at 2.5 feet of sea-level rise, erosion is likely to damage sewer lines, stormwater drainage pipes, roads, and properties in the bluff-top residential neighborhoods. This trend continues into the future, with

more roads, properties, and infrastructure in the bluff-top residential neighborhoods exposed to erosion at 6.6 feet of sea-level rise.

6.2.4 Subarea D

Subarea D covers the area surrounding the Santa Barbara Lighthouse. It consists of a bluff-backed beach with bluff-top open space surrounding the lighthouse itself. Under existing conditions this subarea only has minor exposure to coastal hazard zones, which increases up to 2.5 feet of sea-level rise, at which point some of the roads, trails, sewer lines, and water supply lines supporting the lighthouse and associated open space are exposed to erosion. This trend continues into the future, with more roads and infrastructure around the lighthouse exposed to erosion at 6.6 feet of sea-level rise. Shoreline drive will be impacted by erosion at 2.5 feet and 6.6 feet of sea-level rise.

6.2.5 Subarea E

Subarea E spans from the edge of the lighthouse open space area where Meigs road becomes Shoreline Drive to the west edge of Shoreline Park. It consists of bluff-backed beach with bluff-top residential neighborhoods and includes beach access for 1,000 Steps Beach. Under existing conditions, several properties in the subarea are exposed to tidal flooding and storm flooding, but at 2.5 feet of sea-level rise these properties, along with roads, beach access, open space areas, sewer lines, and water lines in the bluff-top neighborhoods are exposed to erosion. This trend continues into the future, with more roads, properties, and infrastructure in the bluff-top residential neighborhoods exposed to erosion at 6.6 feet of sea-level rise. Shoreline Drive will be impacted by erosion at 6.6 feet of sea-level rise.

6.2.6 Subarea F

Subarea F covers Shoreline Park and the area east of the park to Santa Barbara Point. It consists of bluff-backed beach with bluff-top open space, primarily Shoreline Park, with associated parking and beach access. Under existing conditions, the beach areas at Shoreline Park are exposed to tidal flooding and storm flooding. At 2.5 feet of sea-level rise, much of this area is exposed to tidal flooding, and bluff-top segments of Shoreline Park are exposed to erosion, along with associated trails and irrigation infrastructure. This grows more severe at 6.6 feet of sea-level rise, when the beach and more of the bluff-top park area are exposed to erosion or tidal flooding. Shoreline drive will be impacted by erosion at 2.5 feet and 6.6 feet of sea-level rise.

6.2.7 Subarea G

Subarea G encompasses Ledbetter Beach and properties behind it. It consists of Ledbetter Beach itself, with associated park area and parking lot, neighboring bluff recreation area to the west, Santa Barbara Community College, and several commercial establishments. Under existing conditions, some of the beach is exposed to tidal inundation, and much of the beach is exposed to storm waves, along with some sewer and stormwater lines. At 2.5 feet of sea-level rise, portions of the beach area and neighboring bluff-top recreation area are exposed to erosion, and sewer and irrigation systems in the bluffs are exposed to erosion. Portions of the beach and sewer and

stormwater lines continue to be exposed to storm waves. Erosion continues through 6.6 feet of sea-level rise, eventually affecting all of the bluff recreation area and most of the beach, along with roads, communication infrastructure, sewer lines, and irrigation water supply lines. Some of these systems are also exposed to tidal flooding inland of the erosion hazard, and they are all exposed to storm waves. Shoreline Drive will be impacted by tidal inundation at 6.6 feet of sea-level rise.

6.2.8 Subarea H

Subarea H covers the area in and around Santa Barbara Harbor, reaching as far east as the Laguna Tide Gates. The subarea consists of harbor and wharf region, with its breakwater, Waterfront Department offices, US Coast Guard facilities, marinas, and the harbor pier (City Pier). It also includes West Beach, the Sand Spit (a popular surf spot), a yacht club and boat yard, and Stearns Wharf. The low-lying areas around the harbor are home to parking lots, recreational facilities, park areas, commercial establishments, residential development, and a coastal trail. Subarea H also includes the Mission Creek Lagoon (which is also connected to Laguna Creek).

Under existing conditions, Subarea H has significant recreational areas (generally beaches), roads, and drainage infrastructure exposed to tidal flooding and storm flooding, with more exposure to storm waves. There are also launch ramps and harbor protection infrastructure (i.e., breakwater elements and rock groins) exposed to tidal and storm flooding. At 2.5 feet of sea-level rise, parts of the beach and some drainage infrastructure in the recreational areas are exposed to erosion. Many recreational areas, stormwater infrastructure, and harbor protection infrastructure that were exposed to storm waves and tidal flooding under existing conditions are exposed to tidal flooding at 2.5 feet of sea-level rise. Sewer infrastructure, particularly gravity mains, are also exposed to tidal and storm inundation at 2.5 feet of sea-level rise, along with some irrigation lines in the recreational areas. Between 2.5 feet and 6.6 feet of sea-level rise, most assets that were exposed to storm waves and storm flooding become exposed to tidal flooding. Some of the drainage and irrigation infrastructure associated with recreational areas, along with sections of West Beach, are exposed to erosion, though much more is exposed to tidal flooding. At 6.6 feet of sea-level rise, storm flooding and storm waves are lesser concerns in Subarea H because most of the low-lying assets are exposed to tidal flooding instead. Cabrillo Boulevard and State Street will be impacted by tidal inundation at 6.6 feet of sea-level rise.

6.2.9 Subarea I

Subarea I covers Chase Palm Park and Downtown Santa Barbara. Much of this area is beach (East Beach) and low-lying backshore (Chase Palm Park and Downtown Santa Barbara). The park and beach include recreational facilities, a waterfront coastal trail, and parking areas. Inland, this subarea includes Downtown Santa Barbara with commercial and residential areas. The subarea also contains a segment of Highway 101, a railroad station (and the railroad), segments of Laguna Channel and Mission Creek, and El Estero Wastewater Treatment Plant.

Under existing conditions, the recreational areas in Subarea I (East Beach and Chase Palm Park) are primarily exposed to storm waves, with some of the beach exposed to tidal flooding. There

are also some sewer lines exposed to tidal flooding and several sewer, drainage, and irrigation lines exposed to storm waves. At 2.5 feet of sea-level rise, recreational areas (the beach and park) along with segments of the coastal trail and some drainage and irrigation infrastructure are exposed to erosion. As the erosion hazard zone increases, less recreational area is exposed to flooding and waves, but more properties are exposed to both tidal flooding and storm flooding. Tidal flooding also begins to impact drainage and irrigation infrastructure at 2.5 feet of sea-level rise. At 6.6 feet of sea-level rise, much of the beach area and some of the park area are exposed to erosion (including the coastal trail, drainage, and irrigation), and most of what remains is exposed to tidal or storm flooding. Storm waves play a lesser role in Subarea I at 6.6 feet of sea-level rise because many assets are exposed to erosion or flooding by that point, including many of the properties and facilities south of Highway 101, including El Estero Wastewater Treatment Plant, which is within the storm flooding hazard zone and which will not be operable due to tidal inundation into key components of the wastewater system. North of Highway 101, many private and public parcels in the Downtown Santa Barbara area are exposed to storm flooding, with many more considered flood-prone (i.e., below the storm flooding elevation but not directly connected to the ocean). Along with private and public parcels, this means that extensive sewer and water supply infrastructure in Downtown Santa Barbara is exposed to storm flooding, and infrastructure south of Highway 101 is exposed to tidal or storm flooding. Cabrillo Boulevard will be exposed to tidal inundation at 6.6 feet of sea-level rise.

6.2.10 Subarea J

Subarea J covers the region from South Milpas Street to Andree Clark Bird Refuge. It consists of a beach (East Beach) with waterfront coastal trail and low-lying backshore with some residential and commercial development. The Santa Barbara Zoo, Cabrillo Pavilion, Sycamore Creek, and Sycamore Creek Lagoon, and Andree Clark Bird Refuge are all located within Subarea J. Under existing conditions, much of the beach recreational area, a portion of the coastal trail, and some of the surrounding roads are exposed to storm waves. At 2.5 feet of sea-level rise, some segments of the beach recreation area are exposed to erosion, others to tidal flooding. Storm waves continue to be a concern, with roads, communications infrastructure, stormwater lines, and some properties and sewer lines exposed. Between 2.5 feet and 6.6 feet of sea-level rise, storm flooding becomes severe enough to overrun the beach, exposing much of the infrastructure behind the beach. This includes roads, railroads, many properties, and the sewer, stormwater, and water supply systems. There is significantly less exposure to storm waves, but only because much of what was previously exposed to storm waves is exposed to erosion or tidal flooding at 6.6 feet of sea-level rise. Cabrillo Boulevard will be impacted by tidal inundation at 6.6 feet of sea-level rise, and Highway 101 will be impacted by storm flooding at 6.6 feet of sea-level rise.

6.2.11 Subarea K

Subarea K covers the Bellosguardo Estate at the east end of the City. It consists of a bluff-backed beach with bluff-top development. Under existing conditions, the beach portion of this subarea is exposed to tidal flooding, storm flooding, and storm waves. At 2.5 feet of sea-level rise, these beach areas are exposed to erosion, and beach and bluff areas further inland are exposed to storm

waves. This progresses through 6.6 feet of sea-level rise, at which point all of the beach and portions of the estate on the bluffs are exposed to erosion.

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