DRAFT

Coastal Hazard Vulnerability Assessment, City of Malibu

Prepared for
City of Malibu

August 2023

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EXECUTIVE SUMMARY

INTRODUCTION

Climate change and sea-level rise are projected to impact communities across the globe. Many communities are working to understand and prepare for potential impacts to their homes, businesses, built infrastructure and the natural environment. In California to date, nearly four dozen coastal jurisdictions from Del Norte County to San Diego County have completed vulnerability assessments to understand the potential effects of sea-level rise and related hazards.

This Coastal Vulnerability Assessment was undertaken to begin to plan for measures to reduce the potential future vulnerability of the City's built and natural coastal resources to projected sea-level rise. The assessment analyzes coastal hazards including tidal inundation, shoreline and bluff erosion, and extreme coastal storm flooding. The assessment projects the potential impacts and vulnerabilities of sea-level rise (SLR) by mid century (2050-2060) and late century (2080-2100) in the City of Malibu. This Coastal Vulnerability Assessment is intended to inform public and private stakeholders and decision-makers of the potential impacts and the development of SLR adaptation strategies to avoid or reduce the impacts.

STUDY AREA

The study area includes Malibu's shoreline that stretches approximately 22.6-miles from Nicholas Canyon County Beach to Topanga Beach and includes the lower Trancas and Zuma canyons and low-lying areas around Malibu Lagoon. The Malibu coastline consists of a series of bluffs backed by the Santa Monica Mountains that are interspersed with stream and river canyons that transition to coastal floodplain areas and sandy beaches, including the lower Trancas and Zuma canyons and low-lying areas around Malibu Lagoon.

Beaches in Malibu are mostly narrow and exist around the mouths of streams and local bluff alcoves except for the widest stretch of beach along Zuma Beach. Malibu's coastline was filled with approximately 1.3 million cubic yards of soil for the construction of Highway 1 in the 1920s (Noble 2010), which covered much of the narrow beaches and dunes that existed along the coast. Today, Malibu's coastline is largely developed by residential and commercial properties that occupy much of the historic beach and dune areas and extend up the bluff face and top in many areas.

Several LA County beaches are located within Malibu and include Nicholas Canyon, El Sol, Zuma, Latigo Shores, Dan Blocker, Las Tunas, and Topanga Beaches. State beaches within Malibu include the Robert H. Meyer State Beaches (El Pescador, La Piedra, El Matador Beaches), Point Dume, Malibu Lagoon, Malibu Surfrider (a World Surfing Reserve) and Las Tunas Beaches. These beaches are supported by infrastructure including parking, restrooms and other amenities, lifeguard towers, and maintenance yards.

Historic Flooding Events and Existing Conditions in Malibu

Malibu has experienced impacts from numerous coastal storm events over the past few decades that included flooding and erosion damages. The Malibu coastline is most vulnerable to swells coming from southern hemisphere storms that typically arrive outside of the winter storm season. These swells can be very damaging because they typically are long crested and powerful, and the south facing coastline has direct exposure. Typical winter storm swells that come from the northwest are blocked by the Channel Islands. Past years of the biggest swells (southern swells in bold) include: **August 19, 1969**, December 1969, **May 1975**, January 1993, April 2004, March 2005, **July 2009**, **September 2011, September 2014, August 2020, August 2021, July 2022**, January 2023 (L. Doyel, pers. com. February 2023). In the late fall and winter of 1982/83, California experienced an El Niño that produced significant precipitation, strong winds, and high surf along the southern California coast. The storms damaged a Paradise Cove Pier, eroded beaches and coastal cliffs, destroyed homes above the beach, and caused flooding in creek and river systems. Other notable El Niño seasons occurred in 1988, 1998, and 2010. Most recently, the Adamson House property was damaged in 2019. Malibu oceanfront properties are also subject to tidal inundation during high tides that occur monthly (spring tides) to yearly (king tides).

Due to the coastal flooding and erosion impacts that have occurred in Malibu, numerous adaptation strategies have already been implemented to reduce vulnerabilities to coastal hazards along the City's shoreline. Numerous beach nourishment projects have been completed in Malibu including Las Tunas Beach (1960-1974) and Zuma Beach (1979). Coastal armoring structures such as seawalls and rock revetments cover approximately 31% of the coastline in Malibu. Los Angeles County Department of Beaches and Harbors regularly constructs temporary beach sand berms to reduce winter flooding of the lifeguard facilities, restrooms, and maintenance yard in the Zuma Beach parking lots.

Data Collection

Sea-level rise scenarios for the vulnerability assessment were based on California State guidance from 2018. The sea-level rise scenarios are based on high greenhouse gas emissions scenarios and are listed in Table ES-1 below. Coastal vulnerabilities in the City were analyzed for existing sea level, 2.5 feet (0.75 m) of sea-level rise, and 6.6 feet (2 m) of sea-level rise. The timing of potential impacts for these scenarios was determined from the medium-high risk and extreme risk aversion projections for sea-level rise. The first date in the date range assumes rapid ice sheet loss on Antarctica (per the H++ scenario), while the later date assumes emissions continue as usual, with no ice sheet loss, thereby delaying the extent of potential sea-level rise. The first date is generally consistent with the extreme risk aversion scenario, while the later date is consistent with the medium-high risk aversion scenario.

Table ES-1. Malibu Sea-Level Rise Scenarios

Scenario	Date Range[1]	Potential Amount of Sea-Level Rise	
		(feet)	(meters)
Existing conditions	Now	0	0
Mid Century	2050 - 2060	2.5	0.75
Late Century	2080 - 2100	6.6	2

[1] Date range presents timing of sea-level rise based on the projections for extreme risk aversion (sooner date) and medium-high risk aversion (later date) from OPC (2018), see Table 2-1.

Available spatial data were collected for the built and natural assets in the City of Malibu. Many of these assets are currently or may potentially become exposed to tidal inundation, storm flooding and wave run-up, and erosion due to sea-level rise. Spatial data for assets in Malibu were processed and overlaid in GIS with sea-level rise hazard layers to assess vulnerability. The data sources for each asset class are listed in **Appendix A.** Maps showing built and natural assets in Malibu are provided in **Appendix B**. Spatial datasets were obtained for the following asset categories:

Communication - Communication Towers

Critical Facilities and Services - Fire, Public Offices, Lifeguards

Development: Buildings, armoring structures

Ecology - Environmentally Sensitive Habitat Areas (ESHA), Wetlands, Beaches

Energy - Electrical Meters

Recreation and Visitor-Serving - Parks and Open Space, Piers, Hiking Trails, Beaches, Coastal Access Points

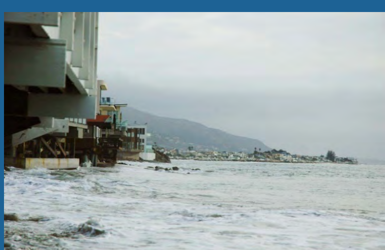
Transportation – Bridges, Fueling Stations, Roads and Highways, Parking Lots

Water – Sewers/Sewer Treatment, Stormwater

Not all assets within Malibu are represented by existing spatial datasets. Data gaps include natural gas and communications infrastructure (internet, phone utilities) as well as drinking water and local wastewater infrastructure. Septic systems are used for all beachfront properties and a large percentage of development in Malibu in general, but information on septic systems was not readily available for this study.

Coastal Hazards and Vulnerability Methods

Tidal Inundation



Source: LA Waterkeeper

Storm Wave Runup/Flooding

Source: Pepperdine University

Erosion

Source: KBUU News

The following coastal hazard zones were mapped for the vulnerability assessment:

- **Tidal inundation (non-storm) and groundwater levels**
  - Extent of monthly spring high tides with existing topography in Malibu. Low lying areas that are adjacent to but disconnected from tidal areas by high ground are considered in this study as surrogates for areas that may experience potential groundwater issues due to high tides. Some portions of the City around Malibu Lagoon are below the tidal inundation and storm flooding elevations, but are not directly connected to the ocean or areas inundated by high tides. These disconnected low-lying areas may be subject to groundwater issues or storm flooding
- **Storm flooding from a 100-year coastal storm event**
  - The storm flooding hazard zone represents areas flooded during a 100-year coastal storm event. This zone includes low areas flooded by wave overtopping and Trancas, Zuma and Malibu Creek flows (i.e., modest creek flooding occurring during a 100-year coastal storm event). USGS CoSMoS mapped 100-year coastal storm flooding in Malibu considering a large southern swell (deepwater wave height of 20 to 22 feet).
  - The storm waves hazard zone represents the landward limit of wave run-up during the 100-year coastal storm.

> **Coastal erosion**
  - Shoreline and beach erosion due to ongoing coastal processes and future sea-level rise. These projections of shoreline erosion are also used to compute beach width changes due to sea-level rise.
  - Bluff erosion from sea-level rise and terrestrial processes

Available data from the U.S. Geological Survey's (USGS) Coastal Storm Modeling System (CoSMoS) show that Malibu's beaches and many oceanfront properties behind them are exposed to extreme coastal storm flooding and wave run-up at today's current sea level. CoSMoS results show that various facilities and structures along Zuma Beach (e.g. Lifeguard station, helipad, other buildings and parking lots) are exposed to extreme coastal wave run-up. Around Malibu Creek and Lagoon, most of the Malibu Colony properties, the golf course, and a section of Highway 1 are also shown to be exposed to coastal storm wave run-up hazards, while properties adjacent to Malibu Creek are exposed to storm flooding. Several areas west of Malibu Creek are also shown to be low lying and potentially flooded (areas are at elevations below the adjacent projected storm flooding water levels in the creek, while some smaller areas are identified as below tidal elevations).

The sea-level rise **vulnerability** of each asset category to a given hazard was analyzed based on the asset **exposure** (i.e. whether and when it is impacted by coastal hazards), the asset **sensitivity** (i.e. whether hazard damages the asset or caused other consequences), and **adaptive capacity** (i.e. can the asset be easily modified to reduce hazard impacts).

Sea-level rise Vulnerability Summaries

With projected sea-level rise, Malibu's vulnerabilities to coastal flooding and erosion are projected to increase. There are many assets shown as currently exposed to flooding and erosion hazards in the coastal zone that are protected to experience greater hazard impacts without action. There are also many assets that are shown as not being currently subject to coastal hazards, but may become exposed under projected future conditions. The sections that follow summarize key vulnerabilities in Malibu.

Critical Facilities and Infrastructure

Critical infrastructure in Malibu includes Lifeguard Towers and the Station at Zuma Beach, which may need modification/relocation to avoid erosion and flooding impacts with sea-level rise. Several stretches of Highway 1 are vulnerable to late century hazards including bluff erosion or coastal storm flooding and wave run-up (along Zuma Beach, Dan Blocker County Beach, Puerco Beach and Carbon Beach). Several fire hydrants may be exposed to coastal flooding and erosion with sea-level rise. Other important infrastructure includes a sewer pump station at the east end of Subarea A that may be exposed to coastal erosion with sea-level rise. In addition, beachfront parcels may also experience issues with onsite septic systems due to rising groundwater levels with sea-level rise. Failure of septic systems may result in discharge of untreated wastewater, poor local water quality and adverse impacts to human health and the environment.

Development

Vulnerable development in Malibu includes beachfront and blufftop homes and businesses, much of which are currently armored and/or elevated. With sea-level rise, development on the beaches or lower bluffs may be subjected to coastal erosion and flooding more frequently, leading to property damages and degradation of existing coastal armoring structures. Some oceanfront property and buildings may become impacted by tidal inundation depending on floor elevation and configuration of utilities beneath structures. Shore and bluff erosion may impact upland property and structures. By late century, much of the commercial area west of Malibu Creek and lagoon is vulnerable to coastal storm flooding and regular inundation by spring tides.

Access roads to beachfront development may become exposed to erosion with sea-level rise, while Malibu Colony Road may also be subject to tidal inundation and coastal storm flooding.

Beaches

Many of the narrow beaches along the Malibu coast may disappear with sea-level rise, impacting shore ecology and recreation. Beaches in Malibu mostly exist as narrow stretches along beachfront homes, coastal bluffs and Hwy 1, with wider beaches exist at Zuma/Westward Beach, Point Dume State Beach, and Malibu Surfrider Beach. Today, approximately one quarter of beaches in Malibu may disappear annually from seasonal fluctuations alone; nearly two thirds may disappear annually by mid century. In addition, beaches may cease to recover along coastal armoring and other hardened shorelines without action. The disappearance of beaches in Malibu would adversely impact ecological functions along the coastline as well as recreation opportunities for Malibu residents and visitors.

Next Steps

Following this Coastal Vulnerability Assessment, ESA and the City will develop a range of potential adaptation measures that can be taken to reduce the sea-level rise vulnerabilities identified in this report. The City will hold public workshops to present this Assessment along with potential adaptation options for the various coastal areas in Malibu in order to gather community input and develop next steps in the planning process.

Section 1

INTRODUCTION

Future sea-level rise is expected to create a permanent rise in ocean water levels that would shift the water's edge landward. If no action is taken, higher water levels would increase erosion of the beach, cause a loss of sand, and result in a narrower beach. Additionally, the combination of higher ocean water levels and beach erosion would result in greater flooding and damage during coastal storms.

Climate change and sea-level rise are projected to impact communities across the globe. Many communities are working to understand and prepare for potential impacts to their homes, businesses, built infrastructure and the natural environment. In California to date, nearly four dozen coastal jurisdictions from Del Norte County to San Diego County have completed vulnerability assessments to understand the potential effects of sea-level rise and related hazards.

This Coastal Vulnerability Assessment was undertaken to begin to plan for measures to reduce the potential future vulnerability of the City's built and natural coastal resources to projected sea-level rise. The assessment analyzes coastal hazards including tidal inundation, shoreline and bluff erosion, and extreme coastal storm flooding. The assessment projects the potential impacts and vulnerabilities of sea-level rise (SLR) by mid century (2050-2060) and late century (2080-2100) in the City of Malibu. This Coastal Vulnerability Assessment is intended to inform public and private stakeholders and decision-makers of the potential impacts and the development of SLR adaptation strategies to avoid or reduce the impacts.

1.1 Study Area

The shoreline in the City of Malibu stretches approximately 22.6-miles from Nicholas Canyon County Beach at the west to Topanga Beach at the east. . The geography in Malibu consists of coastal bluffs backed by the Santa Monica Mountains that are interspersed with stream and river canyons with low-lying sandy beaches and backshores, including the lower Trancas and Zuma canyons and low-lying areas around Malibu Lagoon. Backshores are areas of a beach that extend inland from the limit of high water to the extreme inland limits of the beach, including bluffs and dunes that are in the coastal floodplain now or may be in the coastal floodplain in the future with projected erosion and sea-level rise. Backshore areas are typically only affected by waves during exceptional high tides or severe coastal storms and southern swell events.

Beaches in Malibu are mostly narrow and exist around the mouths of streams and local bluff alcoves except for the widest stretch of beach along Zuma Beach. Malibu's coastline was filled with approximately 1.3 million cubic yards of soil for the construction of Highway 1 in the 1920s (Noble 2010), which covered much of the narrow beaches and dunes that existed along the coast. Today, Malibu's coastline is largely developed by residential and commercial properties that occupy much of the historic beach and dune areas.

Several LA County beaches are located within Malibu and include Nicholas Canyon, El Sol, Zuma, Latigo Shores, Dan Blocker, Las Tunas, and Topanga Beaches. State beaches within Malibu include the Robert H. Meyer State Beaches (El Pescador, La Piedra, El Matador Beaches), Point Dume, Malibu Lagoon, Malibu Surfrider (a World Surfing Reserve) and Las Tunas Beaches. These beaches are supported by infrastructure including parking, restrooms and other amenities, lifeguard towers, and maintenance yards.

Sub-areas were defined for the Coastal Vulnerability Assessment (**Figure 1-1**). It is useful to define sub-areas in Malibu to properly characterize the range of shoreline typology (e.g. low beach, tall bluff, lagoon), wave exposure, geomorphic processes, and level/type of development. These factors together determine what sea-level rise adaptation measures are appropriate for a given area. Potential adaptation measures for these areas will be discussed in the next phase of this project. **Table 1-1** lists the five sub-areas that define Malibu's coastline including the extents of each, type(s) of development, shore morphology type, and existing assets.

Table 1-1. City of Malibu Sub-areas

Sub-area	Extents	Shore Development Types	Shore Morphology Types	Assets
A	Nicholas Canyon County Beach to Point Lechuza *3.9 mi shoreline, 0.4 mi armored*	Mixed developed and natural blufftop	• Bluff-backed beach	• Residential development • Nicholas Canyon County Beach, Robert H. Meyer State Beaches (El Pescador La Piedra, El Matador), Lechuza Beach
B	Point Lechuza to Point Dume *3.9 mi shoreline, 0.8 mi armored*	Developed beachfront and blufftop Recreational beach backshore	• Beaches and coastal lagoon • Bluff-backed beach • Bluff headland	• Residential development • Pacific Coast Highway, Zuma Parking (Emergency Shelter Location) • Broad Beach, Trancas Creek, Zuma Beach and Lagoon, Westward Beach/Point Dume State Beach
C	Point Dume to Escondido Beach *3.2 mi shoreline, 0.2 mi armored*	Natural and developed blufftop – Developed beachfront	• Bluff headland • Bluff-backed beach	• Residential development • Paradise Cove • Point Dume State Beach and Nature Preserve, Big Dume State Beach
D	Escondido Beach to Malibu Lagoon State Beach *6.1 mi shoreline, 2.8 mi armored*	Developed blufftop and beachfront Developed floodplain around Malibu Lagoon Public road	• Beach • Bluff-backed beach • Coastal lagoon, adjacent and upstream wetlands	• Residential development • Malibu Village Commercial Center • Pacific Coast Highway • Adamson House and Malibu Lagoon Museum, Malibu Pier • Malibu Lagoon State Beach, Malibu Point, Malibu Surfrider Beach, Dan Blocker Beach, Corral Canyon Beach
E	Malibu Surfrider Beach to Topanga Beach *5.4 mi shoreline, 2.9 mi armored*	Developed beachfront Public road	• Sandy beach • Rocky and armored shores • Developed backshore	• Commercial and residential development, • Pacific Coast Highway • Carbon, La Costa, Las Flores, Big Rock, and Las Tunas Beaches, Topanga State Beach

SOURCE: ESRI, ESA, NAIP, USGS, City of Malibu

Malibu Coastal Vulnerability Assessment . 190785.00

Figure 1
Malibu City
Sub-Areas

1.2 Historic Flooding Events and Existing Conditions

Malibu is currently vulnerable to tidal inundation, storm flooding, wave overtopping and direct wave impacts, and shoreline and bluff erosion. In the past, extreme coastal flood events have caused significant damage along the coastline. This section describes significant extreme coastal flood events that have occurred since the 1970s, as well as recent king tides and erosion events. Events are characterized based on news and technical reports. In the future, coastal impacts from these types of events will increase in intensity and frequency due to sea-level rise and climate change, as discussed in Section 3.

1.2.1 Coastal Storms

Malibu has experienced impacts from numerous coastal storm events over the past few decades that included flooding and erosion damages. The Malibu coastline is most vulnerable to swells coming from southern hemisphere storms that typically arrive outside of the winter storm season. These swells can be very damaging because they typically are long crested and powerful, and the south facing coastline has direct exposure to wave impacts and wave overtopping. Typical winter storm swells that come from the northwest are screened out by the Channel Islands. Past years of the biggest swells (southern swells in bold) include: **August 19, 1969**, December 1969, **May 1975**, January 1993, April 2004, March 2005, **July 2009**, **September 2011, September 2014, August 2020, August 2021, July 2022**, January 2023 (L. Doyel, pers. com. February 2023). The January 2023 swell did not cause very much damage because it came from the west northwest, even though it was notably one of the largest swells in the last 7 years. In the late fall and winter of 1982/83, California experienced an El Niño that produced significant precipitation, strong winds, and high surf along the southern California coast. The storms damaged coastal structures, eroded beaches and coastal cliffs, and caused flooding in creek and river systems. Waves damaged the Paradise Cove Pier and caused shoreline and cliff erosion that damaged buildings along the Malibu coastline (**Figure 1-2**). Some homes constructed on pier foundations above the beach were destroyed. Erosion from large surf stripped the sand away from beaches and exposed the underlying rock in many locations. Other notable El Niño seasons occurred in 1988, 1998, and 2010. Most recently, the Adamson House property was damaged in 2019 as high water levels and wave run-up caused erosion and loss of a 100-year old palm tree (**Figures 1-3** and **1-4**).

Source: Pepperdine University Digital Archives

Figure 1-2. Photos from the 1983 El Niño showing the damaged Paradise Cove Pier (left) and wave overtopping along the shore (right)

Source: KBUU News

Figure 1-3. Photos taken after Spring 2019 show a fallen 100-year old palm tree and property damage from erosion at the Adamson House (left) and beach erosion in front of the Lifeguard Station at Surfrider Beach (right)

Source: ESA

Figure 1-4. Photos taken in July 2019 show fallen palm tree (left) partially buried by the recovered beach and remaining erosion damage (right) at the Adamson House.

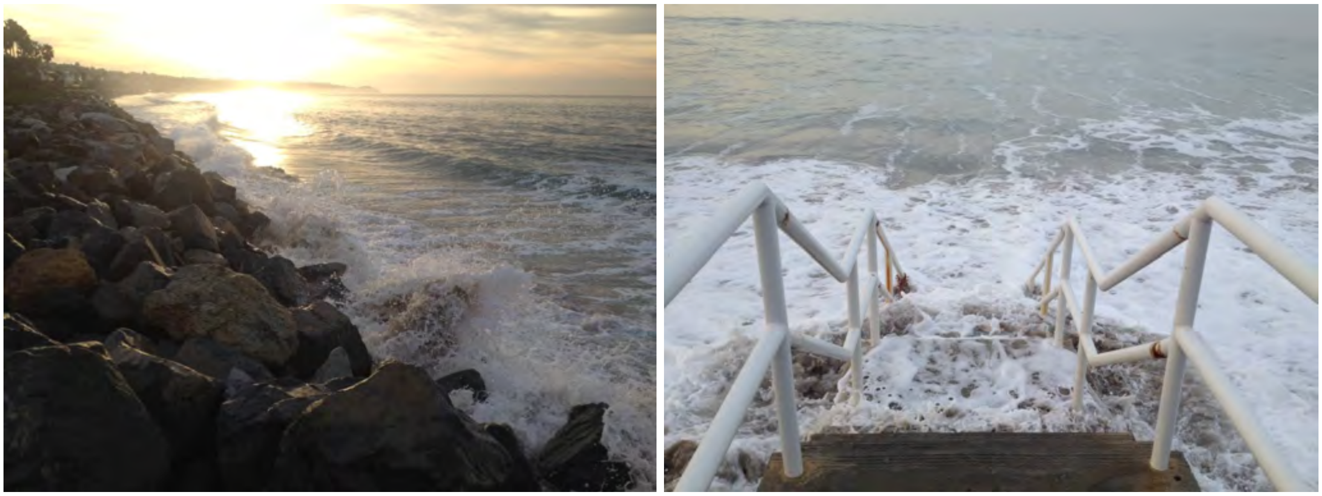
1.2.2 King Tides

King tides refer to the highest tides of the year, which occur naturally and predictably when the gravitational pull of the sun and moon align. King tides provide an example of future conditions with sea-level rise, since they are higher than typical tides. The California King Tides Project[1] is an initiative that has documented recent king tides around the country, including Malibu. **Figures 1-5** and **1-6** below show king tide conditions in 2012 and 2016, respectively, which appear on the King Tides Project website.

Source: LA Waterkeeper via https://www.coastal.ca.gov/kingtides/gallery.html

Figure 1-5. King tide inundation beneath homes along Malibu Road in 2012

[1] Learn about the CA King Tides Project at www.coastal.ca.gov/kingtides/learn



Source: LA Waterkeeper via https://www.coastal.ca.gov/kingtides/gallery.html

Figure 1-6. King tide conditions at Broad Beach along the revetment (left) and at a beach access point (right) on January 22, 2016

1.2.3 Existing Adaptation Strategies

Due to coastal flooding and erosion impacts that have occurred along the Malibu coastline, numerous adaptation strategies have already been implemented to reduce vulnerabilities to coastal hazards along the City's shoreline.

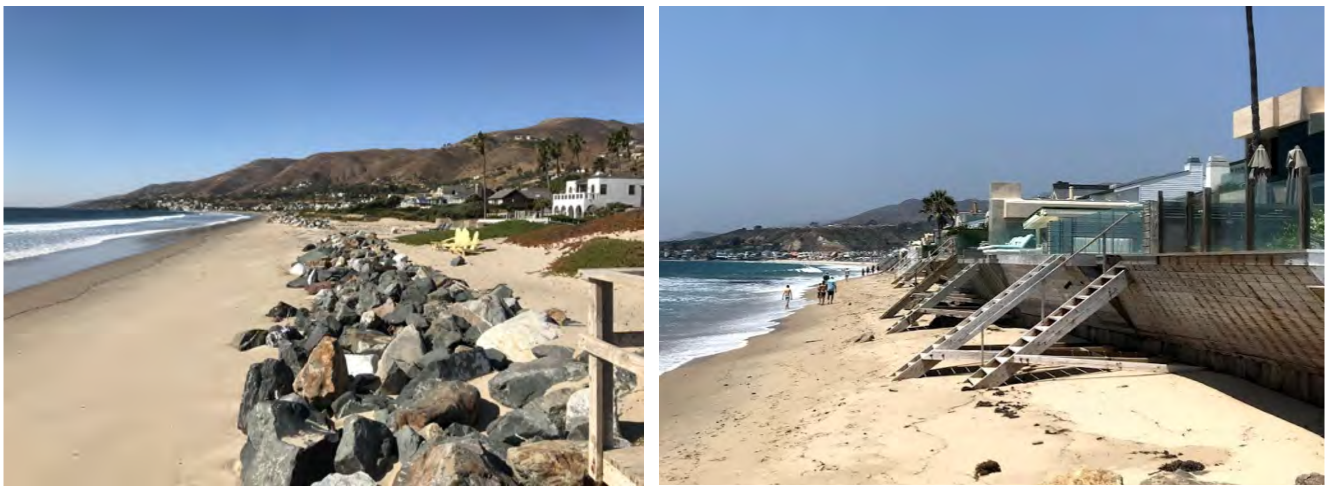
Beach Nourishment: Historically, sediments from various sources have been used to nourish beaches. Las Tunas Beach was nourished with 50,000 cubic yards of suitable fill from 1960-74 and Zuma Beach received 22,000 cubic yards in 1979. In 2010, an emergency permit was granted to build a rock revetment wall to protect homes along Broad Beach. The permit is no longer valid and the property owners have proposed the Broad Beach Restoration Project that proposes importing 300,000-600,000 cubic yards of sediment to widen the beach.

Coastal Armoring: Shoreline protection through seawalls or other armoring can reduce flooding and erosion impacts behind them. Today, approximately 31% of the Malibu coastline is protected by coastal armoring structures such as rock revetments and sea walls of various materials including concrete, timber, rock and combinations thereof. While sea walls and revetments provide protection to existing shoreline development, these structures can contribute to erosion and accelerate beach loss. An inventory of shoreline protective devices was developed in 2005 by NOAA for the entire California coastline, including a GIS database of structures. ESA updated the shoreline armoring extents along Malibu for this study by interpreting recent aerial imagery and oblique shoreline photography from the California Coastal Records project[2].

[2] Access the CA Coastal Records project at https://www.californiacoastline.org/

Existing shoreline protection devices in Malibu range from timber walls and old cemented rubble to engineered rock revetments and concrete seawalls, as shown in **Figure 1-7** below. **Figure 1-8** shows the extents of existing shoreline protective devices along the Malibu coastline.

Temporary Sand Berms: Los Angeles County Department of Beaches and Harbors regularly constructs temporary beach sand berms to reduce winter flooding of the lifeguard facilities, restrooms, and maintenance yard in the Zuma Beach parking lots, as shown in **Figure 1-9** below.



Source: ESA

Figure 1-7. Existing shoreline protection in Malibu: Rock revetment at Broad Beach (left) and timber seawalls at Malibu Colony (right)

Source: ESA, City of Malibu, NAIP, NOAA

Figure 1-8. Existing Coastal Armoring Structures in Malibu

Source: Noble 2016

Figure 1-9. Temporary Winter Sand Berm Locations at Zuma County Beach

Section 2

DATA COLLECTION AND PROCESSING

ESA collected publicly available data of Malibu coastal hazards and assets (i.e., built and natural resources). The data included in the following sections relate specifically to the vulnerability assessment. Additional details on input data and processing for this vulnerability assessment are included in **Appendix A**.

2.1 Sea-Level Rise Scenarios

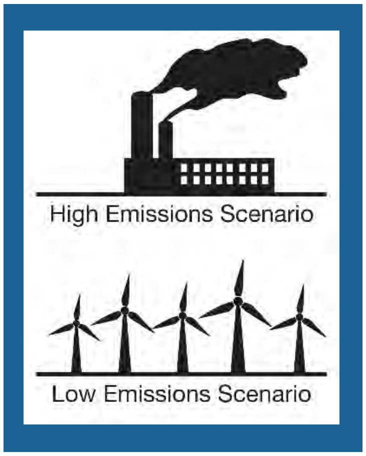
Sea-level rise scenarios[3] were determined for the vulnerability assessment based on California State guidance from 2018. Information on current science and state guidance on sea-level rise is discussed in the following sections. The planning horizons and sea-level rise scenarios selected for this study are discussed in Section 2.1.4.

2.1.1 Regional Sea-Level Rise Projections

In 2018, the California Ocean Protection Council (OPC) updated the *State of California Sea-Level Rise Guidance* (OPC 2018), which includes projections[4] for sea-level rise at various locations along the coast of California through 2150. The guidance is based on the science update prepared by the CA OPC and the California Natural Resources Agency, in collaboration with the Governor's Office of Planning and Research, the California Energy Commission, and the California Ocean Science Trust (Griggs et al. 2017). Documented in the report "Rising Seas in California: An Update on Sea-Level Rise," the update was prepared by the nation's foremost experts in climate change and sea-level rise, coastal processes, climate and coastal modeling science, probability of extreme events and uncertainty. The OPC Guidance presents different sea-level rise values based on two global greenhouse gas emissions scenarios:

[3] A sea-level rise scenario is a potential amount of sea-level rise occurring by a certain date. Typically, multiple scenarios are chosen to represent the range of possible outcomes, since the exact amount of sea-level rise is uncertain and depends on future greenhouse gas emissions.

[4] A sea-level rise projection is a scientific estimate of how much sea-level rise is expected to occur over time based on various assumptions.



High Emissions Scenario – This scenario assumes a future where there are no significant global efforts to limit or reduce emissions. This scenario assumes "high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long-term to high energy demand and GHG emissions" (Riahi et. al 2011).

Low Emissions Scenario – This scenario assumes more aggressive emissions reduction corresponding to the aspirational goals of the 2015 Paris Agreement, which calls for limiting mean global warming to 2 degrees Celsius and achieving net-zero greenhouse gas emissions in the second half of the century. This scenario is considered challenging to achieve and would include updated climate policies, concerted action by all countries, and a shift to a lower emissions service and information economy.

The 2018 OPC Guidance provides a range of probabilistic projections of sea-level rise, which was an update specifically designed to help inform decision-makers. However, per the OPC Guidance, these projections may underestimate the likelihood of extreme sea-level rise, particularly under high-emissions scenarios. To address this, an extreme scenario, called the H++ scenario[5], was also included in the OPC Guidance. The H++ scenario assumes rapid ice sheet loss on Antarctica, which could drive rates of sea-level rise 30-40 times faster than the sea-level rise experienced over the last century. The guidance also identified different risk aversion projections that correspond to different levels of risk tolerance. These levels are represented as low, medium-high, and extreme risk aversion:

- The low risk aversion projection is appropriate for adaptive, lower consequence projects (e.g., unpaved coastal trail).
- The medium-high risk aversion projection is appropriate as a precautionary projection that can be used for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea-level rise (e.g., coastal housing development).
- The extreme risk aversion projection is appropriate for high consequence projects with little to no adaptive capacity and which could have considerable public health, public safety, or environmental impacts (e.g., coastal power plant, wastewater treatment plant, etc.).

Table 2-1 shows the OPC 2018 projections for Santa Monica with the risk aversion scenarios identified in the blue boxes. Santa Monica is the closest location to Malibu for which projections are available from the OPC Guidance.

[5] Note that NOAA's 2022 Sea-level rise Technical Report dropped the H++ scenario. See https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html

Table 2-1. Sea-Level Rise Projections for Santa Monica

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…		5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 -	0.5	0.6	0.8	1
	2040	0.6	0.4 -	0.8	0.9	1.2	1.7
	2050	0.8	0.6 -	1.1	1.3	1.9	2.6
Low emissions	2060	0.9	0.6 -	1.2	1.5	2.3	
High emissions	2060	1.1	0.8 -	1.4	1.8	2.6	3.8
Low emissions	2070	1.0	0.7 -	1.4	1.9	3.0	
High emissions	2070	1.3	1.0 -	1.8	2.3	3.4	5.1
Low emissions	2080	1.2	0.8 -	1.7	2.3	3.8	
High emissions	2080	1.7	1.1 -	2.3	2.9	4.4	6.5
Low emissions	2090	1.3	0.8 -	2.0	2.7	4.6	
High emissions	2090	2.0	1.3 -	2.8	3.5	5.5	8.1
Low emissions	2100	1.5	0.9 -	2.3	3.1	5.5	
High emissions	2100	2.3	1.5 -	3.3	4.3	6.8	10.0
Low emissions	2110*	1.6	1.0 -	2.4	3.3	6.1	
High emissions	2110*	2.5	1.8 -	3.5	4.5	7.2	11.7
Low emissions	2120	1.7	1.0 -	2.7	3.8	7.3	
High emissions	2120	2.9	2.0 -	4.0	5.2	8.5	14.0
Low emissions	2130	1.9	1.1 -	3.0	4.2	8.3	
High emissions	2130	3.2	2.2 -	4.5	5.9	9.8	16.3
Low emissions	2140	2.0	1.1 -	3.2	4.7	9.4	
High emissions	2140	3.5	2.4 -	5.1	6.7	11.3	18.9
Low emissions	2150	2.2	1.1 -	3.6	5.3	10.8	
High emissions	2150	3.9	2.6 -	5.7	7.6	12.9	21.7

SOURCE: OPC 2018

While the OPC Guidance provides projections through 2150, it is important to note that sea-level rise is expected to continue for centuries, because the earth's climate will require time to respond to the emissions that have already been released to the atmosphere. Although sea-level rise is typically presented as a range in the amount of sea-level rise that will occur by a certain date (e.g., 1-2 feet of sea-level rise by 2050), it can also be presented as a range of time during which a certain amount of sea-level rise is projected to occur (e.g., 1.5 feet of sea-level rise between 2040 and 2070). It is important to note that even if emissions are reduced to levels consistent with the low-emissions-based projections, sea levels will rise to higher levels, just at a later date. A sea-level rise science update is expected from the State of California in 2023 that may change the timing of sea-level rise for the probabilistic projections listed in Table 2.1. Once new sea-level rise projections are released to the public, this study may be updated, for example by revising the vulnerabilities identified in this study at the new time frames for each sea-level rise scenario used in this study (Section 2.1.4).

2.1.2 State Planning Guidance

The California Coastal Commission (CCC) updated their *Sea-Level Rise Policy Guidance* in 2018 (CCC 2018). The guidance recommends using the OPC sea-level rise projections at various planning horizons to assess vulnerability and conduct adaptation planning. The CCC guidance provides a step-by-step process for addressing sea-level rise and adaptation planning, specifically for updating LCPs (CCC 2018).

State planning guidance calls for considering a range of scenarios (OPC 2018; CCC 2018) in order to bracket the range of likely impacts. Scenario-based analysis promotes the understanding of impacts from a range of potential outcomes and identifies the amounts of sea-level rise that would cause these impacts. Section 2.1.4 presents the scenarios considered for this vulnerability assessment.

The CCC guidance recommends that long-term, community-wide planning efforts evaluate, at a minimum, the "medium-high risk aversion" projection. The extreme risk aversion projection is to be used to evaluate critical facilities.

2.1.3 CoSMoS Modeling Scenarios

The Coastal Storm Modeling System (CoSMoS)[6] was developed by the United States Geologic Survey (USGS) with state funding for use in sea-level rise planning (Barnard and others 2014). The modeling effort focused on evaluating flood hazards associated with sea-level rise, as well as shoreline and bluff erosion. Coastal hazards were last mapped for the Malibu coastline with CoSMoS 3.0 in 2016. A total of 40 scenarios were run combining sea-level rise and storm type: ten sea-level rise amounts (0 to 6.6 feet at 0.8 foot increments and 16.4 feet) were modeled with four coastal storm conditions (100-year, 20-year, and 1-year events and no storm). Hazard modeling outputs include the extent of inundation, wave run-up, and long-term erosion. GIS data for these outputs were downloaded[7] for Malibu and processed for use in the vulnerability assessment. Details on the CoSMoS hazard data and required processing for this assessment are provided in **Appendix A**.

2.1.4 Malibu Sea-Level Rise Scenarios

To assess vulnerabilities for the City of Malibu (City), two sea-level rise scenarios were selected in addition to existing sea level (noted as "zero sea-

[6] Details on the USGS CoSMoS model are accessible online at: https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos

[7] CoSMoS hazard maps are accessible online at: https://www.sciencebase.gov/catalog/item/5633fea2e4b048076347f1cf

level rise") to represent the range of potential impacts that the City may experience from coastal hazards. The scenarios selection was informed by the State guidance and considers the sea-level rise probabilistic projections of OPC (2018) as well as the sea-level rise modeling scenarios available from CoSMoS 3.0. **Table 2-2** presents the sea-level rise scenarios used for this vulnerability assessment. Coastal vulnerabilities in the City were analyzed for existing sea level, 2.5 feet (0.75 m) of sea-level rise, and 6.6 feet (2 m) of sea-level rise. The timing of impacts for these scenarios was determined from the medium-high risk and extreme risk aversion projections for sea-level rise. The first date in the date range assumes rapid ice sheet loss on Antarctica (per the H++ scenario), while the later date assumes emissions continue as usual, but no ice sheet loss, thereby delaying the extent of potential sea-level rise. The first date is generally consistent with the extreme risk aversion scenario, while the later date is consistent with the medium-high risk aversion scenario.

Table 2-2. Malibu Sea-Level Rise Scenarios

Scenario	Date Range[1]	Potential Amount of Sea-Level Rise	
		(feet)	(meters)
Existing conditions	Now	0	0
Mid Century	2050 - 2060	2.5	0.75
Late Century	2080 - 2100	6.6	2

[1] *Date range presents timing of sea-level rise based on the projections for extreme risk aversion (sooner date) and medium-high risk aversion (later date) from OPC (2018), see Table 2-1.*

2.2 Asset Inventory

Available spatial data were collected for the built and natural assets in the City of Malibu. Many of these assets are currently or may potentially become exposed to tidal inundation, storm flooding and wave run-up, and erosion due to sea-level rise. Spatial data for assets in Malibu were processed and overlaid in GIS with sea-level rise hazard layers to assess the exposure of each asset class listed below (hazard exposure results are presented in Section 4). The data sources for each asset class are listed in **Appendix A.** Maps showing built and natural assets in Malibu are provided in **Appendix B**.

Communication

Communication Towers

Critical Facilities

Fire Stations
Fire Hydrants
Lifeguard Towers
Public Defenders' Offices

Development

Coastal Armoring Structures
Commercial Buildings
Other Buildings
Recreational Buildings
Residential Buildings
Government Buildings
Institutional Buildings
Industrial Buildings

Ecology

Environmentally Sensitive Habitat Areas (ESHA)
Wetlands
Beaches

Energy

Electrical Meters

Recreation and Visitor-Serving

Parks and Open Space
Hiking Trails
Beaches
Paradise Cove and Malibu Piers
Coastal Access Points

Transportation

Bridges
Roads and Highways
Fueling Stations
Parking Lots

Water

Sewer Mains
Sewer Pump Stations
Storm Drain Inlets/Junctions
Sewer Pipes
Sewer Treatment
Storm Drain Lines

2.2.1 Asset Data Gaps

Not all assets within Malibu are represented by existing spatial datasets. Data gaps include natural gas and communications infrastructure (internet, phone utilities) as well as drinking water infrastructure. Septic systems are used for all beachfront properties and a large percentage of development in Malibu in general, but information on site-septic systems was not readily available for this study.

Section 3

FUTURE TIDAL INUNDATION, STORM FLOODING, WAVES, AND EROSION

A small storm today may cause limited damage, but the same storm event could have a much larger impact with higher sea levels in the future.

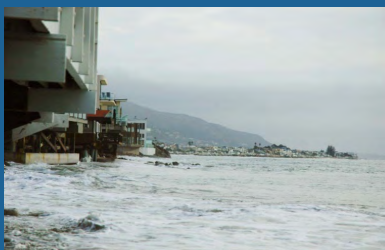
Future sea-level rise is expected to create a permanent rise in ocean water levels that would shift the water's edge landward. Higher water levels would increase erosion of beaches and cliffs, and result in a narrower beach, if no action is taken. Additionally, the combination of higher ocean water levels and beach erosion would mean that coastal storms will potentially cause greater flooding and damage alongshore, because reduced beach width is less effective at reducing wave energy, and waves that break in deeper water and/or closer to shore will result in greater wave run-up. For example, a small storm event under today's sea levels may not cause much damage, but with higher sea levels, the same event could potentially have a much larger impact. This section identifies future hazard zones including permanent tidal inundation, beach, and bluff erosion and temporary storm flooding and wave run-up, as well as low lying areas associated with the permanent and temporary coastal water levels. This section also discusses the underlying data sets and assumptions and methods used to map each hazard zone.

3.1 Potential Future Hazard Zones

The first step in understanding Malibu's vulnerabilities to sea-level rise is identifying potential hazard areas. Existing and potential future tidal inundation, storm flooding and wave run-up, and beach and bluff erosion were determined using publicly available hazard maps from the USGS CoSMoS model with some refinements made by ESA for use in geospatial analysis software (GIS).

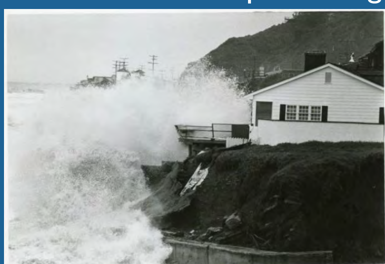
The following coastal hazard zones were mapped for the vulnerability assessment:

Inundation



Source: LA Waterkeeper

Storm Wave Runup/Flooding



Source: Pepperdine University

Erosion

Source: KBUU News

> **Tidal inundation (non-storm) and groundwater levels**

- Extent of regular high tides with existing topography in Malibu. Low lying areas that are adjacent to but disconnected from tidal areas by high ground are considered in this study as surrogates for areas that may experience potential groundwater issues due to high tides. Some portions of the City around Malibu Lagoon are below the tidal inundation and storm flooding elevations, but are not directly connected to the ocean or areas inundated by high tides. These disconnected low-lying areas may be subject to groundwater issues or storm flooding and are further described in Section 3.2.4.

> **Storm flooding from a 100-year coastal storm event**

- The storm flooding hazard zone represents areas flooded (for more than 2 minutes) during a coastal storm event. This zone includes low areas flooded by wave overtopping and Trancas, Zuma and Malibu Creek flows (i.e., creek flooding occurring during a 100-year coastal storm event). USGS CoSMoS mapped 100-year storm flooding in Malibu considering a large southern swell (deepwater wave height of 20 to 22 feet).
- The storm waves hazard zone represents the landward limit of wave run-up during a coastal storm.

> **Coastal erosion**

- Shoreline and beach erosion due to ongoing coastal processes and future sea-level rise. These projections of shoreline erosion are also used to compute beach width changes due to sea-level rise.
- Bluff erosion from sea-level rise and terrestrial processes

Table 3-1 presents a summary of the hazard types and their impact class (i.e., permanent or temporary impact). This study assumes that permanent impacts occur when assets are exposed to long-term erosion of beaches, long-term erosion of bluffs, and tidal inundation, while temporary impacts occur when assets are exposed to storm flooding and storm wave impacts.

Table 3-1 Summary of Hazard Type and Impact Class

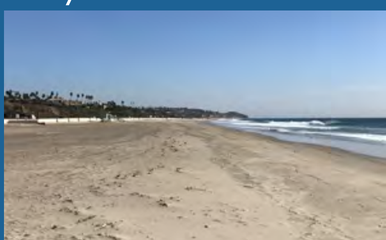
Hazard Type	Impact Class	Mapping Data Source
Tidal Inundation / Low Lying Areas	Permanent	CoSMoS 3.0[a]
Long-Term Erosion – Sandy Beach and Dune	Permanent	CoSMoS 3.0 [a]
Long-Term Erosion – Bluff	Permanent	CoSMoS 3.0 [a]
Storm Flooding	Temporary	CoSMoS 3.0 [a] /AdaptLA[b]
Storm Waves	Temporary	CoSMoS 3.0 [a]

NOTES:

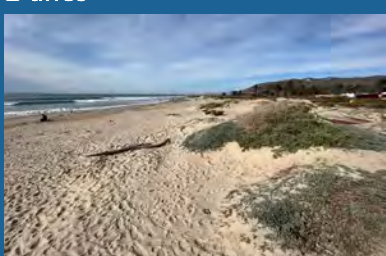
[a] *Coastal Hazards from CoSMoS 3.0: Erikson et al. 2017*

[b] *Lagoon berm flooding added per AdaptLA: ESA 2016*

Sandy Beach



Dunes



Bluff

Shoreline Armoring

Photos Source: ESA

A hierarchy of the coastal hazard zones was used to identify the primary impact to an asset location so that impacts are not double-counted. That is, if an asset is shown as being exposed to shoreline or bluff erosion, it is not also presented as exposed to storm flooding. This is because assets in eroded areas are considered permanently lost; adding a flooding impact to a permanently lost asset would cause the asset to be double-counted. 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 3-1, with tidal inundation taking highest precedence and storm flooding waves with least potential impact. Note that the figures below include disconnected low-lying areas in addition to the hazards in Table 3-1, which are used to indicate potential flood-prone areas and locations where future groundwater elevations could become a nuisance or impact buried utilities and/or septic systems. Figures presenting coastal hazard zones in Malibu for existing conditions and future sea-level rise are provided in **Appendix C**. See Section 5 for discussion of existing and future vulnerabilities with sea-level rise and Section 6 for focused discussions of each study sub-area.

3.2 Coastal Processes

The following sections describe the data used to understand different coastal processes in Malibu for the purpose of this vulnerability assessment.

3.2.1 Beach and Bluff Erosion with Sea-Level Rise

Beach and bluff erosion results from the USGS CoSMoS model were used to develop the potential future hazard zones for coastal erosion. The USGS modeled beach and bluff erosion for four management scenarios in CoSMoS:

- Hold the line, no beach nourishment
- Hold the line, beach nourishment

- Let it go, no beach nourishment
- Let it go, beach nourishment

The "hold the line" scenarios assume that management actions are taken to repair and replace damaged structures and construct new armoring to protect all existing development. The "let it go" scenarios assume that no management actions are taken, and erosion can continue unabated into coastal development. Neither scenario reflects any policy determination on the part of the City. Specific policies regarding how to address sea-level rise impacts will be developed in future phases of work.

The CoSMoS model does not directly account for beach nourishment. The model uses past shoreline position data to estimate the historic "background" rate of shoreline change (e.g., if a shoreline moves inland, the beach has eroded). This background (i.e. long term) erosion rate is then included in the projections of future erosion with sea-level rise (i.e., results include long term erosion rate plus increased rate of erosion due to sea-level rise). ; If the model results show a shoreline position farther seaward than past shoreline position data, then the model estimates the amount of beach nourishment needed to match this shoreline condition. For the beach nourishment model scenarios, the model includes these estimates of past beach nourishment as part of the shoreline erosion projections. For the "no beach nourishment" model scenarios, the model does not include this adjustment.

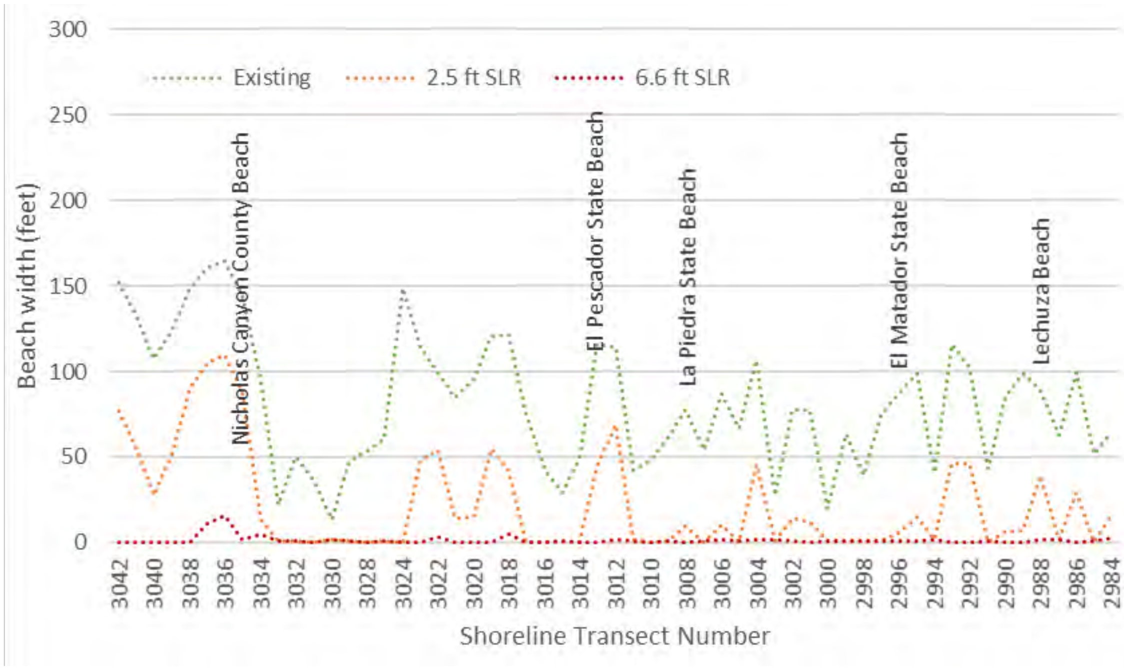
This Coastal Vulnerability Assessment applies erosion hazard zones from the "Let it go, no nourishment" management scenario in order to characterize the full extent of potential impacts to Malibu assets. It is important to understand the full scope of potential impacts and consequences of sea-level rise so that impacts can be evaluated and later compared to adaptation strategies and the benefits they provide.

Future Beach Widths with Sea-Level Rise

Beaches will shift upwards and landwards with sea-level rise depending on a number of factors that include wave climate, sediment supply, as well as what is behind the beach (e.g. natural dune/bluff or built assets/coastal armoring). Long term erosion of the shoreline and beach is commonly calculated from the combination of the historic change rate (erosion or accretion/growth) of the shoreline and the additional erosion of the shoreline profile resulting from sea-level rise. The shoreline retreat from sea-level rise is typically calculated by multiplying the increase in sea level by the overall profile slope (between the beach berm and the offshore limit of the active beach profile). Malibu beach profile slopes are approximately 0.03 on average, or 1 foot vertical for every 30 feet horizontal, meaning that the shoreline may erode by 30 feet for every foot of sea-level rise (ESA 2016).

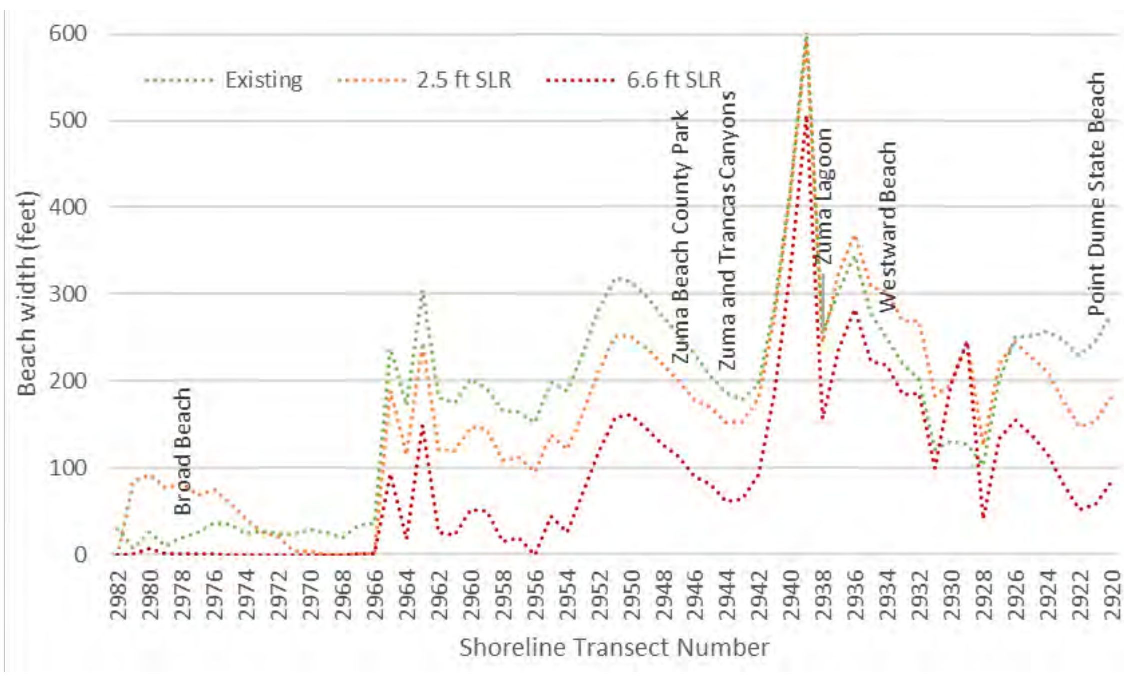
Existing beach widths in Malibu were defined as the distance of sandy beach from the mean high water shoreline to the back of beach (dune or bluff toe, or edge of development/armoring structure). To characterize the full potential vulnerability of Malibu beaches, future beach widths were determined from CoSMoS eroded shorelines for 2.5 and 6.6 feet sea-level rise and the backshore boundary line (backshore development or bluff toe). This essentially represents a "hold the line" scenario which has the greatest implications for beaches, indicating the maximum potential vulnerability of beaches to sea-level rise impacts (compared to a scenario in which bluffs or development retreat to allow increased beach width). As sea-level rises and/or as coastal erosion continues over time, holding the line (with armoring) behind the beach will result in the squeezing and ultimate disappearance of beaches seaward of the armoring. Beach widths for existing conditions at Malibu were determined from CoSMoS data using the 2010 fall mean high water shoreline extracted from the digital elevation model used for CoSMoS and the backshore boundary/development line from CoSMoS. ESA shifted the CoSMoS backshore boundary/development line seaward along Zuma Beach and Point Dume State Beach to account for existing parking lots and roads.

Beaches along the CA coast fluctuate seasonally due to changes in the wave climate (stormy seas in winter erode beaches, long period swell in summer rebuilds beaches); widest conditions typically occur in summer/fall and narrowest in winter/spring. Beach widths along the Malibu coastline fluctuate seasonally by about 30 feet on average from summer/fall to winter/spring (Noble/GEC 2016). In 2010 (recent fall shoreline), 23% of fall beach widths were below 31 feet, meaning they could disappear almost completely during an average winter. By mid-century, 62% of beach widths along Malibu are projected to be below the seasonal fluctuation width. By late century, 86% of beach widths are projected to be below this threshold. Coastal storm erosion causes many beaches to temporarily disappear under current conditions. Coastal storm erosion is projected to have greater potential impacts to beaches with future sea-level rise. Existing (fall 2010) and future beach widths with sea-level rise for Malibu sub-areas A through K are shown in Figures 3-1 to 3-5. The horizontal axes in the figures indicate the CoSMoS modeling transect numbers on which future shorelines were projected; these increase in value from east to west. Labels for landmarks are added to each plot for reference. Note that CoSMoS erosion projections show a wider beach with 2.5 feet sea-level rise compared to existing beach width in some locations; this is because the historic data used in CoSMoS analysis showed an accreting shoreline (widening beach) at such locations including the west end of Broad Beach and Westward Beach. Note that existing beach widths along the Malibu Lagoon mouth (Figure 3-4) are assumed to persist with future sea-level rise since there is room within the lower lagoon for the beach to shift inland. Beach vulnerability is further discussed in Section 4.



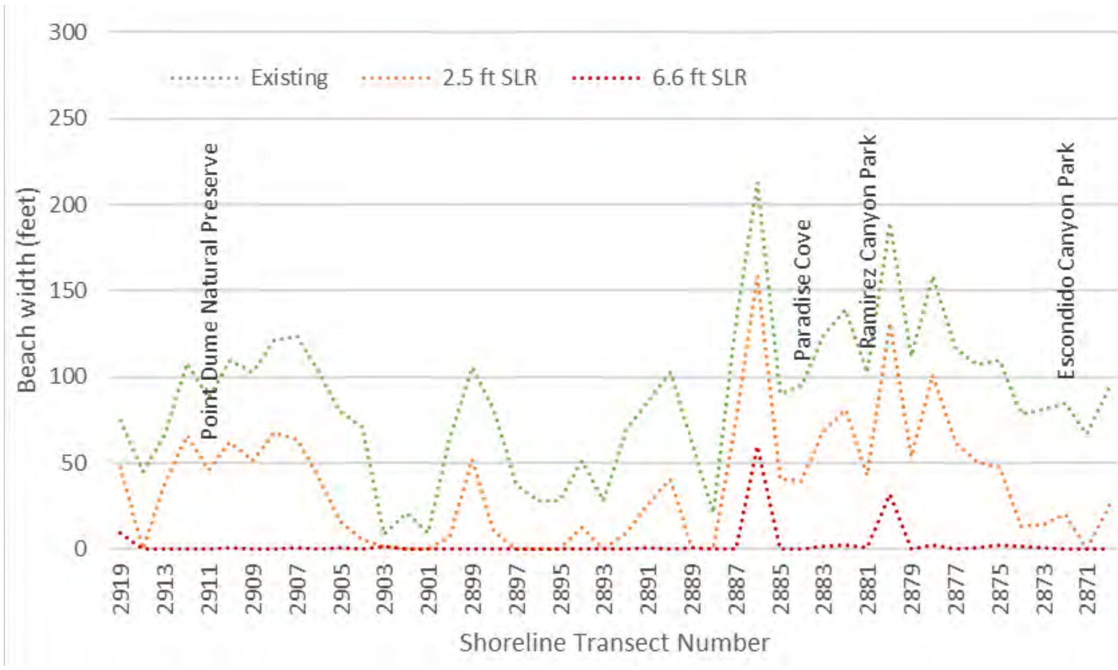
Source: ESA, USGS CoSMoS

Figure 3-1. Existing and Future Beach Widths in Sub-area A: Nicholas Canyon County Beach to Point Lechuza



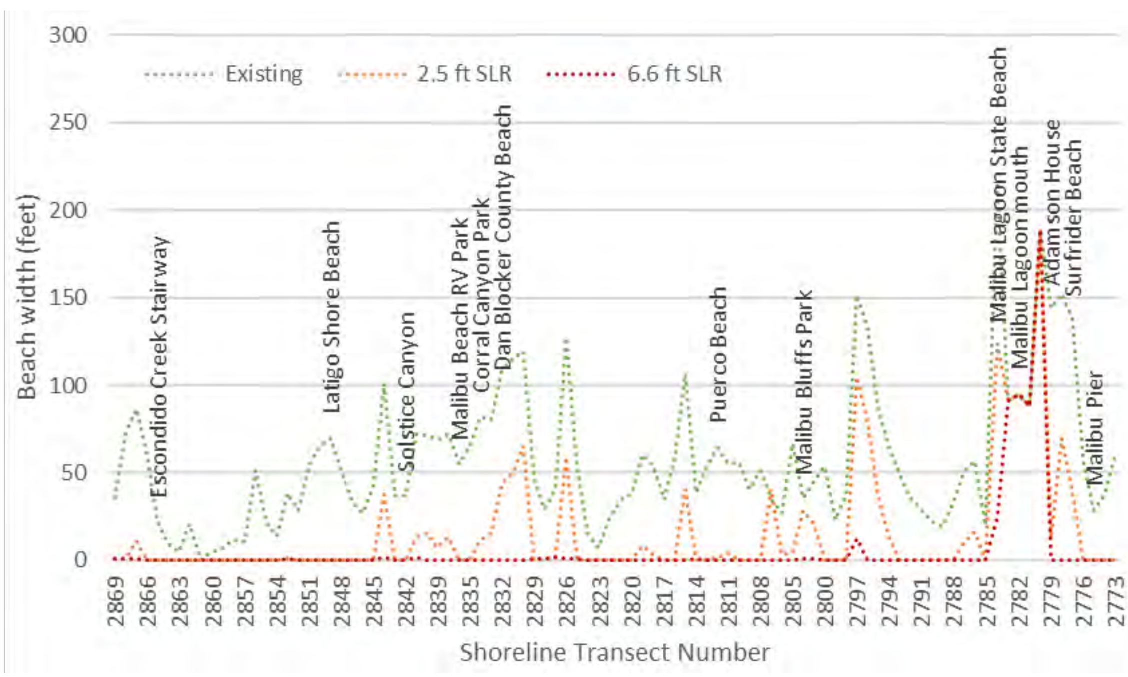
Source: ESA, USGS CoSMoS

Figure 3-2. Existing and Future Beach Widths in Sub-area B: Point Lechuza to Point Dume



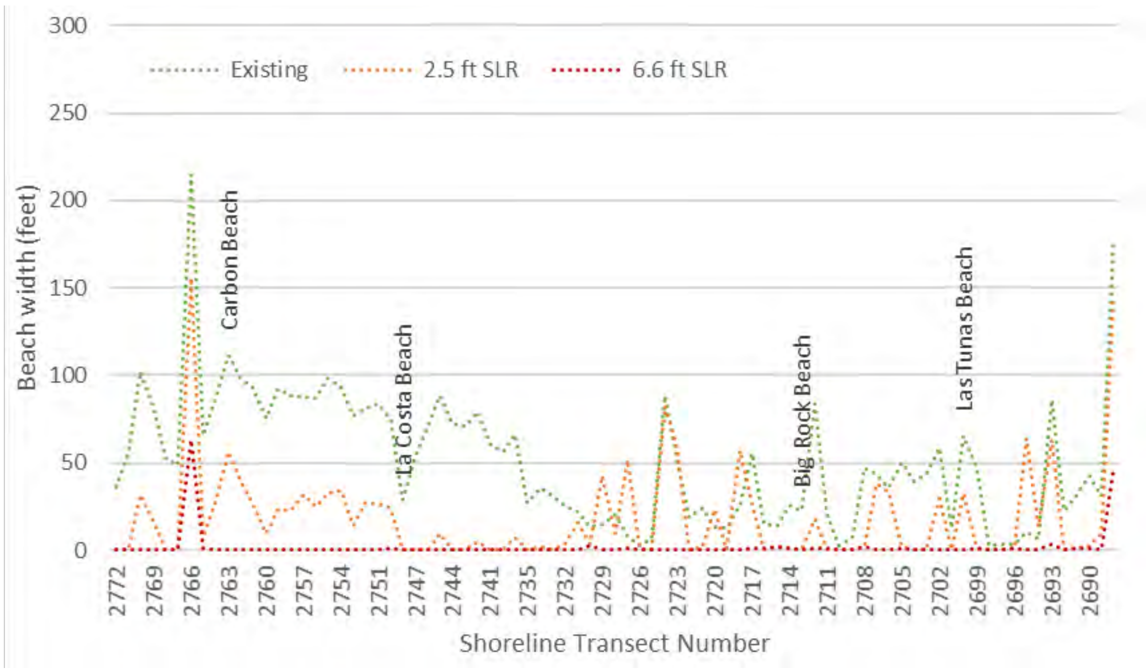
Source: ESA, USGS CoSMoS

Figure 3-3. Existing and Future Beach Widths in Sub-area C: Point Dume to Escondido Beach



Source: ESA, USGS CoSMoS

Figure 3-4. Existing and Future Beach Widths in Sub-area D: Escondido Beach to Malibu Lagoon State Beach



Source: ESA, USGS CoSMoS

Figure 3-5. Existing and Future Beach Widths in Sub-area E: Malibu Surfrider Beach to Topanga Beach

3.2.2 Tidal Inundation and Storm Flooding Levels with Sea-Level Rise

Storm flooding refers to potential impacts from a coastal storm that happens infrequently, whereas tidal inundation refers to the extents of regular tides that occur day-to-day. Storm flooding and tidal inundation results from the USGS CoSMoS model were used to determine potential impacts of sea-level rise in Malibu for average high tide conditions and extreme storm conditions. The USGS modeled and mapped storm flood and tidal inundation extents, flood depth, and wave run-up for four storm scenarios:

- No flood (regular tidal inundation from the average high tide)
- 1-year coastal storm flood event (100% chance of occurring each year)
- 20-year coastal storm flood event (5% chance of occurring each year)
- 100-year coastal storm flood event (1% chance of occurring each year)

These four storm scenarios were analyzed under ten sea-level rise scenarios:

- 0 feet (existing sea level)
- 0.8 feet
- 1.6 feet
- 2.5 feet
- 3.3 feet
- 4.1 feet
- 4.9 feet
- 5.7 feet
- 6.6 feet
- 16.4 feet

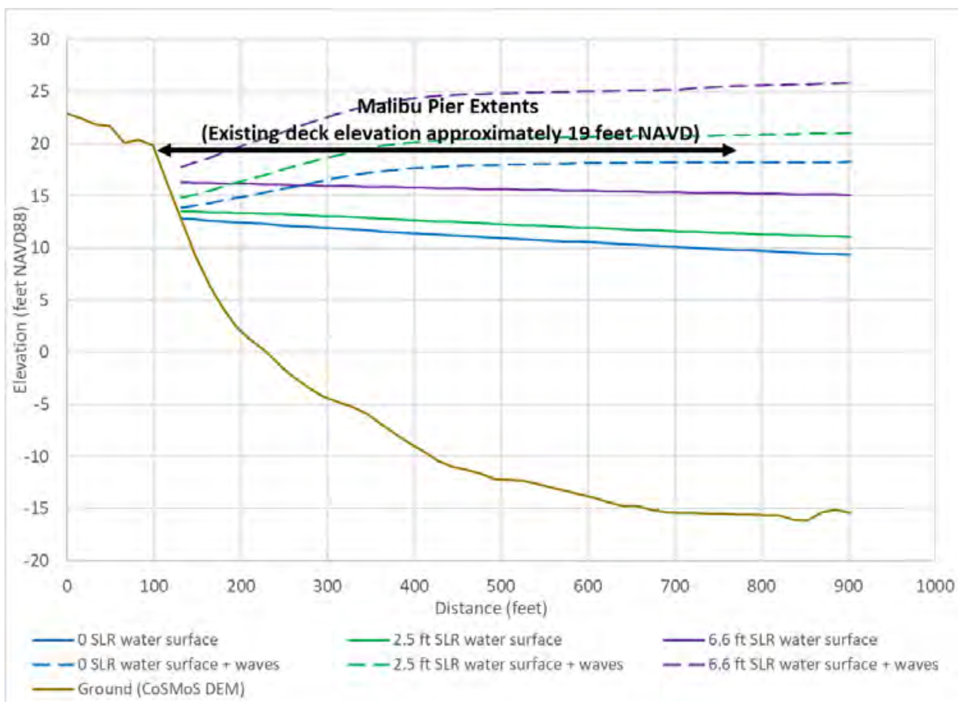
As discussed in Section 2.1.4, three sea-level scenarios were selected for this Coastal Vulnerability Assessment corresponding to zero feet (existing conditions), 2.5 feet , and 6.6 feet sea-level rise. These sea-level scenarios were evaluated considering two ocean conditions for this assessment: regular tidal inundation (no flood event, typical monthly spring high tide conditions) and 100-year coastal storm flooding. These two scenarios were chosen to efficiently bracket the potential impacts that Malibu could experience with sea-level rise; annual and 20-year storm impacts were not evaluated. The tidal inundation scenario depicts areas where inundation is a regular event, which shows how daily inundation could potentially change in the future with sea-level rise. The 100-year coastal storm flood event represents the potential temporary impacts that could occur during an extreme coastal storm event. For context, FEMA flood mapping through the National Flood Insurance Program also provides river and coastal storm flooding extent and floodwater elevations for a 100-year coastal storm event under current conditions. FEMA does not model or map coastal storm events with sea-level rise, so this planning-level Coastal Vulnerability Assessment does not use FEMA flood hazard data. See **Appendix A**for discussion on processing storm flooding hazard maps for this study is provided in.

In addition to the coastal flooding results from CoSMoS, ESA applied a simplified lagoon flooding analysis, which ESA previously developed and implemented for the AdaptLA project (ESA 2016). This approach accounts for lagoon flooding as an additional flooding mechanism that is not analyzed in CoSMoS. The method considers a potential condition in which (1) the beach berm at a lagoon mouth is built up to an exceptionally high elevation over an active summer of waves and (2) an early wet season storm fills the lagoon behind the elevated berm at the mouth and causes increased flood exposure to low areas surrounding the lagoon. Such analysis was performed for Trancas, Zuma and Malibu Creek Canyons. The lagoon flood potential hazard zones were combined with the CoSMoS coastal storm flooding hazard zones for vulnerability mapping and analysis in these three lagoons.

3.2.3 Maximum Wave Run-up with Sea-Level Rise

Coastal wave run-up results from the USGS CoSMoS model were used to develop the potential coastal storm flooding and waves hazard zone. The USGS modeled wave run-up at discrete transects along the coast, with a point output used to represent the inland extent of wave run-up along each transect. ESA connected these points using GIS to form a potential wave run-up exposure zone (a polygon showing spatial extent, instead of individual points). However, it is important to note that a linear interpolation between points is not accurate in many situations. The USGS did not model all of the sea-level rise scenarios discussed in Section 3.2.2 for wave run-up. The CoSMoS results only include wave run-up hazards at each 0.8-foot increment, so the more conservative 1-meter sea-level rise scenario was used for the mid-term (2.6 feet) wave hazard zone in this assessment. Further details on the processing and modifications made by ESA are described in **Appendix A**. Note that the wave run-up extents mapped by CoSMoS show the landward-most limit of wave action. CoSMoS does not distinguish the zone of high momentum wave action that may cause damage to life and property, such as the VE wave hazard zone shown on FEMA maps.

Coastal storm flooding model outputs from CoSMoS were used to evaluate the exposure of Malibu Pier to coastal storms with sea-level rise. The water surface elevation and wave height maps from CoSMoS were extracted along the length of Malibu Pier and combined to illustrate the storm swells that can impact the pier. **Figure 3-6** shows water surface plus wave height (dashed lines) at 0, 2.5 and 6.6 feet sea-level rise computed from the 100-year storm model outputs from CoSMoS (solid line shows water surface without waves added). The figure provides an indication of existing and future wave exposure to Malibu Pier for extreme storm conditions. Actual wave run-up height may be greater than shown in **Figure 3-6** due to interactions between the waves and pier structure.



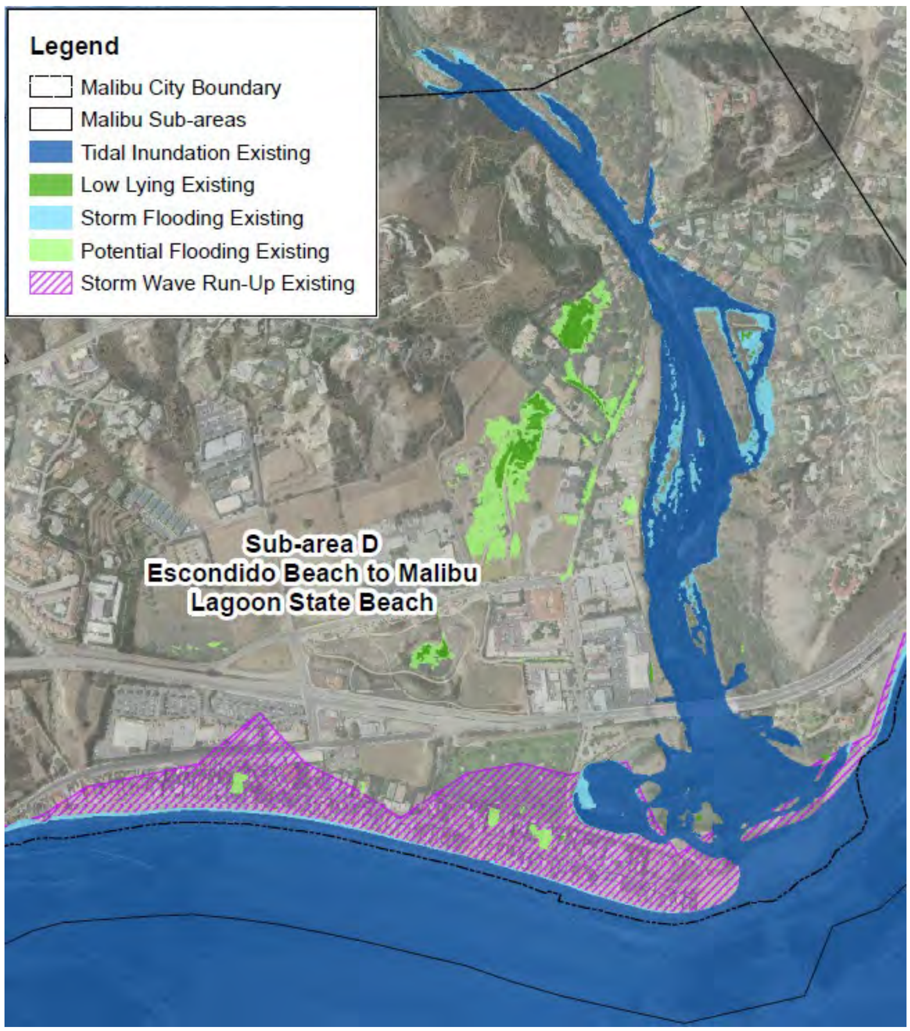
Source: ESA, USGS CoSMoS

Figure 3-6. Malibu Pier Coastal Storm Wave Exposure with Sea-Level Rise

3.2.4 Disconnected Low-Lying and Flood-Prone Areas

There are a few low-lying areas in Malibu that are below existing spring tide inundation elevation (called “low-lying areas”); see dark green areas in Figure 3-7 below, which is excerpted from Appendix C Figure C1-6. These low areas are mostly around Malibu Lagoon and may experience issues due to a rising groundwater table with sea-level rise even if they remain disconnected from the ocean tides. These areas are included as potential areas of permanent impact.

Additional portions of the City are below the water surface elevations identified for 100-year coastal storm conditions but are not directly connected to the ocean. These areas consist of lower stream canyons, Zuma Lagoon and areas around Malibu Lagoon (Figure 3-7). While these low areas may be protected from direct exposure by high ground or structures, they may still be susceptible to flooding. These areas are called "potential flooding areas" and may experience flooding from precipitation or wave over wash that is unable to drain to the ocean because water levels are too high during a storm. Flood-prone areas are considered to have potential temporary impacts for this study.



Source: ESA, City of Malibu, USGS CoSMoS

Figure 3-7. Malibu Creek and Lagoon Existing Coastal Storm Exposure

Higher sea levels will likely increase riverine flooding, because higher ocean water levels will limit river drainage to the ocean and water will back up into the river or creek. Additionally, the sand berm at the mouth of the river or creek will likely increase in height as waves push sand up, which will also limit drainage and increase flooding upstream.

3.2.5 Riverine Flooding

The effects of climate change and sea-level rise on extreme river and creek flooding is not explicitly examined in this Coastal Vulnerability Assessment because data on the increase in river and creek flooding with sea-level rise and climate change is not readily available. In general, climate change will lead to flashier (i.e. fast-peaking), more extreme floods and more intense droughts. Higher sea levels will also increase riverine flooding in downstream reaches closest to the coast. Higher ocean water levels cause water levels to back up in coastal rivers and can limit river drainage to the ocean. During flood events, this can cause flood waters to inundate greater areas in river and creek floodplains near the ocean. CoSMoS 3.0 coastal storm flooding extents used for this study do include flooding due to river and creek flows that occur coincident with extreme coastal storms, but these coincident river and creek flows are less severe than flooding due to extreme (i.e., 100-year) precipitation and extreme river and creek flows.

Section 4

VULNERABILITY ASSESSMENT

This section uses the coastal hazard zones described in Section 3 and mapped in **Appendix C** to identify the assets potentially at risk from sea-level rise (e.g. homes, roads, utilities). These assets (described in Section 2.2) are categorized into the following asset categories: communication, critical facilities, development, ecology, energy, recreation, transportation, and water.

Understanding the risk of not taking action is an important first step in planning for sea-level rise.

In order to develop an effective adaptation plan and policies to address sea-level rise vulnerability, the risk of not taking action must be understood first. For this reason, this Vulnerability Assessment considers a "no action" scenario in which the City or other asset managers do not respond to or prepare for sea-level rise. This scenario assumes the existing armoring would not be maintained, per the "let it go" scenario modeled with CoSMoS. By considering this scenario, decision makers are able to understand the full potential impacts of sea-level rise and identify areas with the greatest vulnerabilities (areas with high asset density that are subject to flooding and or erosion). In reality, the City, its residents, and businesses will likely take action (many already have, see Section 1.2.4). This assessment of vulnerability is the first step in taking a proactive approach to sea-level rise adaptation planning in Malibu.

4.1 Methodology

Each asset category was analyzed to determine the potential exposure to the different hazard areas and consequences, and the sensitivity of the assets to the potential hazard and adaptive capacity of the assets. The results of these analyses are summarized in tables provided in Section 5.2 for each asset category. Each table summarizes the types of assets in a particular category and provides details relevant to Malibu along with vulnerability assessment categories and overall vulnerability summary. The following sections describe in further detail the assessment categories within each of these tables.

4.1.1 Hazard Exposure

To assess exposure to hazards, the assets in different categories were intersected in GIS with each potential future hazard zone. In general, point

*The **hazard exposure** of an asset is based on the type of hazard an asset is subjected to under future conditions and the timing at which the hazard occurs.*

assets (like fire stations, lifeguard towers, pump stations) in each potential future hazard zone are counted, linear assets (like roads and pipelines) are measured by mile, and planar assets (like wetland areas) are measured by acre. The resulting **hazard exposure** for each asset class is summarized in the second row of each result table in the following sections. Hazard Exposure maps showing assets and hazards are provided in **Appendix D**. A full tabular summary of hazard exposure results for each asset class is provided in **Appendix E**.

To characterize an asset's exposure to hazards for this vulnerability assessment, a *hazard exposure* grade of low, medium, or high was assigned based on the potential consequences of exposure and the timeframe in which the asset is exposed. For example, if an asset is flooded in the near-term it has a higher hazard exposure grade than one that only floods in the long-term. The hazard zones described in Section 3 represent different levels of severity and consequences as further described below. The different mapped hazard zones correspond to either permanent or temporary impacts to built and natural assets. Thus, consequences of asset exposure can vary depending on what hazard zone(s) the assets are exposed to and when. Generally, permanent impacts (erosion and tidal inundation) have greater consequences than temporary impacts (storm flooding and wave run-up). Areas subject to the potential future beach and bluff erosion hazard zones could be lost entirely (permanent impacts, greatest consequences). Areas in the potential future tidal inundation flooding zone could also be lost entirely (permanent impacts, greatest consequences). Areas in the potential future coastal storm flooding hazard zone could likely be heavily damaged by ocean storm surge and waves (temporary impacts, significant consequences). Areas in the potential future coastal storm wave run-up hazard zone may be damaged or disrupted from flowing or ponded water, but assets are likely recoverable, and would return to service when waves and floodwaters recede (temporary impacts, low to moderate consequences). Note that the wave run-up hazard zone depicted by CoSMoS data represents the landward most limit of potential wave run-up, which extends beyond the high wave momentum zone depicted in FEMA maps as Zone VE.

The following list describes the exposure grades for different timing and types of coastal hazards considered in this study.

- Mid century erosion and tidal inundation (permanent impacts) equate to **high** exposure
- Mid century storm flooding (temporary impacts) equate to **medium** exposure
- Mid century wave run-up flooding equates to **low** exposure, given how this data is provided by CoSMoS relative to storm flooding
- Late century erosion and tidal inundation (permanent impacts) equate to **medium** exposure

- Late century storm and wave run-up flooding (temporary impacts) equate to **low** exposure

The hazard exposure grading scheme is summarized in **Table 4-1**.

Table 4-1. Hazard Exposure Grading Scheme

Timeframe	Beach and Bluff Erosion	Tidal Inundation	Coastal Storm Flooding	Wave Run-up Flooding
Mid-century	High	High	Medium	Low
Late-century	Medium	Medium	Low	Low

4.1.2 Sensitivity to Hazards

*An asset's **sensitivity** to a given hazard is defined as the asset's level of impairment if impacted (e.g. flooded temporarily, inundated permanently, or if impacted by erosion or waves).*

For an exposed asset, the overall vulnerability of the asset depends in part on the **sensitivity** of the asset to the hazard. In general, assets that are highly sensitive can lose their primary function if exposed to any flooding or erosion whatsoever. If assets can maintain their primary function(s) during hazard impacts, they have low sensitivity. For example, one of the sensitivities of impacts to wave run-up on transportation corridors is the disruption of vehicular access critical for the provision of emergency services (e.g. Highway 1), which would mean the asset has a high sensitivity. In contrast, a lifeguard tower that sits high above the beach has a lower sensitivity to wave run-up.

Similar to the hazard exposure grades, grades for an asset's *sensitivity to hazards* are based on the specific asset and exposure(s) considered. **Table 4-2** presents the grading scheme for hazard sensitivity ranging from low to high. Low sensitivity means an asset is lightly impacted and continues to function or can recover quickly after impacted by a hazard. High sensitivity means an asset would be damaged and disabled by the hazard and would not recover quickly. Another aspect of asset sensitivity is what impact an asset's failure has on the environment or public safety. For example, failure of septic systems along a stretch of oceanfront residential homes can result in untreated wastewater leaching through the beach, affecting water quality, the environment and public safety.

Table 4-2. Asset Sensitivity Grading Scheme

Considerations	Grade
The given hazard would have no or a low impact on the asset function. The asset would be able to rebound from the impact quickly.	Low
The given hazard would cause minor damage or temporary operational interruption.	Medium

Table 4-2. Asset Sensitivity Grading Scheme

Considerations	Grade
The given hazard would cause major damage or long-term operational interruption (direct or indirect) including impacts to public safety. The asset would require significant effort to rebound from the impact.	High

4.1.3 Adaptive Capacity

*The **adaptive capacity** of an asset is the ability of that asset to change over time and respond to a hazard.*

In the fourth row of each Asset Vulnerability table in Section 4.2, an asset's adaptive capacity is discussed. Adaptive capacity refers to the ability of an asset to change in response to hazard exposure with rising sea-levels. For example, a lifeguard tower may be exposed to flooding or erosion today (high exposure), but the tower can be moved easily (high adaptive capacity).

Grades for an asset's *adaptive capacity* is assigned based on the type of asset and its relative function in relation to development or infrastructure system. **Table 4-3** presents the grading scheme for adaptive capacity, which ranges from High to Low. High adaptive capacity means an asset can be easily adapted to accommodate higher sea levels, while low adaptive capacity means an asset requires a significant effort to adapt or adaptation has significant implications to surrounding assets or the infrastructure system that the asset is part of.

Table 4-3. Adaptive Capacity Grading Scheme

Considerations	Grade
The asset could easily adapt to higher sea-levels.	High
The asset requires moderate effort to adapt to higher sea levels.	Medium
The asset requires significant effort to adapt to higher sea levels or adaptation would cause ripple effects to the wider system (e.g. sewer system or other infrastructure)	Low

4.1.4 Vulnerability Summary

The overall **vulnerability** of the assets to potential future hazards is based on analysis of the above grading categories. The overall vulnerability score for each asset was determined based on the combination of an asset's vulnerability components (exposure to hazard(s), sensitivity to hazard(s), and adaptive capacity) by assigning point scores to each vulnerability component. Hazard exposure and sensitivity scores range from 1 point for low grade exposure/sensitivity to 3 points for high grade exposure/sensitivity (i.e. higher hazard exposure and higher asset sensitivity to lead to higher asset vulnerability). The adaptive capacity grade is inversely related to score; the point scale ranges from 1 point for high adaptive capacity to 3 points for low adaptive capacity (i.e. an asset with higher adaptive capacity has a lower potential vulnerability). All component scores are summed to calculate the total vulnerability score for each asset category. **Table 4-4** presents the vulnerability score calculation determined from each component. The vulnerability summaries are indications of the degree of potential vulnerability, not rankings or priorities.

*An asset's **vulnerability** depends on*

*the degree and type of **hazard** the asset is **exposed** to,*

*the **sensitivity** of the asset to the hazard, and*

*the **capacity** of the asset to **adapt** to mitigate the hazard exposure.*

Table 4-4. Vulnerability Summary Grading Scheme

Component	Grade	Score
Hazard Exposure	Low to High	1 to 3
Asset Sensitivity	Low to High	1 to 3
Adaptive Capacity	High to Low	1 to 3
Vulnerability	**Grade**	**Total**
Sum of component scores	**High**	**9**
	Medium-High	**7 to 8**
	Medium	**5 to 6**
	Medium-Low	**4**
	Low	**3**

4.2 Malibu Asset Vulnerabilities

Vulnerability of each asset type in Malibu is summarized in the following tables. Vulnerability of some Categories are presented as separate tables (e.g. Critical assets, Development, Water). A City-wide Malibu Vulnerability summary, **Table 4-5,** is provided in **Section 4.3** that presents average vulnerability grades for each asset class based on average hazard exposure across each class. Hazard exposure is summarized for permanent and temporary impacts for existing conditions and by mid century and late century sea-level rise. Vulnerability Maps shown in **Appendix D** overlay the assets and coastal hazards for each sea-level rise scenario. The asset and hazard mapping data used for the exposure analysis are also shown in the Malibu Sea-Level Rise WebMap that is linked on the City's Website.

4.2.1 Communication

Table 4-5. Communication Asset Vulnerability	
Assets	Communication assets within Malibu include cellular and other communication towers.
Hazard Exposure	The GIS analysis shows that 19 communication towers could be impacted by sea-level rise this century. Exposure of Communication Towers: ▪ Permanent: 1 mid century, 11 late century ▪ Temporary: 9 mid century, 8 late century
	Hazard Exposure grade: ▪ Communication Towers: 3 Low, 15 Medium, 1 High
Asset Sensitivity	▪ Increased frequency of flooding of towers leading to water damage and other flood related damages. ▪ Long-term operational interruption if mechanical/electrical systems are subject to damage. ▪ Increased risk of erosion or storm damage which could damage or down the tower and cause delays in communications.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Communications towers may require significant effort to modify or relocate given the size and implications to ongoing communications during modifications.
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Communication towers: 3 Med-Low, 16 Medium

4.2.2 Critical Facilities

Emergency Facilities, Fire Stations, Fire Hydrants

Table 4-6. Emergency Facilities Vulnerability	
Assets	Emergency facilities in Malibu include a designated emergency shelter location at Zuma Beach parking lot. Four LA County fire stations and numerous fire hydrants exist in Malibu. Pacific Coast Highway (a critical access route) is summarized in Transportation.
Hazard Exposure	Part of the Zuma Beach parking lot is a designated emergency shelter location with a helipad. The area is currently exposed to coastal storm flooding wave run-up; flooding exposure increases with sea-level rise. LA County Fire Station #88 on Malibu Road is at risk of storm flooding today and mid century. The other fire stations in Malibu are not at risk within the sea-level rise scenarios analyzed. The GIS analysis shows that 155 fire hydrants could be impacted by sea-level rise this century. Exposure of Fire Hydrants: ▪ Permanent: 18 mid century, 96 late century ▪ Temporary: 34 mid century, 59 late century
	Hazard exposure grade: ▪ Zuma Beach emergency shelter location: Medium ▪ LA County Fire Station #88: Medium ▪ Fire Hydrants: 42 Low, 95 Medium, 18 High
Asset Sensitivity	▪ Flooding of Fire Station 88 may impact fire response capabilities and response time. Erosion of many fire hydrants could impact response capabilities and disrupt the hydrant network. ▪ Increased frequency of flooding may lead to water damage and other flood related damages. ▪ Flooding of Zuma parking lots would impact emergency shelter operations.
	Sensitivity grade: High
Adaptive Capacity	▪ Adaptation modifications to Fire Station 88 may require a temporary station to be established to provide continued emergency response coverage. ▪ Fire Hydrants may be difficult to relocate because they are part of a greater pipe network. ▪ Emergency Shelter location parking lot could be elevated above flood elevations, protected by other means with sea-level rise or relocated to another area.
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Zuma Beach emergency shelter location: Medium ▪ Fire Station 88: Medium ▪ Fire Hydrants: 137 Med-High, 18 High

Lifeguard Facilities

Table 4-7. Lifeguard Facilities Vulnerability	
Asset	There are many LA County lifeguard towers along Malibu's beaches.
Hazard Exposure	Many of the lifeguard towers are already at risk of flooding during a 100-year storm or through wave run-up. Future sea-level rise will expose many lifeguard facilities to flooding and erosion this century. Exposure of Lifeguard Facilities: ▪ Permanent: 6 mid century, 24 late century ▪ Temporary: 24 mid century, 7 late century Lifeguard Towers #1, #2, and #3 at Dan Blocker/Corral State Beach are exposed to beach erosion by mid century, as are Surfrider Beach Lifeguard Tower #1 and the tower at Nicholas Canyon Beach. Zuma Beach Lifeguard Tower #13 is expected to be inundated daily by mid century. Most of the remaining lifeguard stations (19 stations) are expected to experience erosion or tidal inundation by late century, including the Zuma Beach Lifeguard Headquarters
	Hazard exposure grade: ▪ Lifeguard Towers and Stations: 1 Low, 21 Medium, 6 High ▪ Westward Beach Lifeguard Substation: Low ▪ Zuma Beach Lifeguard Headquarters: Medium
Asset Sensitivity	▪ Lifeguard Stations: Flooding and erosion of headquarters buildings may impact emergency response capabilities and response time. Increased frequency of flooding may lead to water damage and other flood related damages. ▪ Lifeguard towers on beaches have greater adaptive capacity; they can be moved landward from flooding and erosion hazards as needed
	Sensitivity grade: ▪ Lifeguard Towers: Low ▪ Lifeguard Headquarters and Sub Stations: High
Adaptive Capacity	▪ Extensive modifications to lifeguard headquarters and stations may require temporary stations to be established for continued first responder service. ▪ Lifeguard headquarters and stations could be reconfigured to improve flood resilience by locating important components and utilities higher in the building, elevate structures entirely, or move structures landward. ▪ Lifeguard towers in Malibu are mobile by design and can be relocated as needed to avoid/reduce erosion and flooding impacts as long as there is available space (on beach or bluff top).

Table 4-7. Lifeguard Facilities Vulnerability	
	Adaptive Capacity grade: ▪ Lifeguard Towers: High ▪ Lifeguard Headquarters and Substation: Medium
Vulnerability Summary	▪ Lifeguard Towers: 1 Low, 21 Medium-Low, 6 Medium ▪ Topanga Beach Lifeguard Station: Medium-High ▪ Westward Beach Lifeguard Sub Station: Medium ▪ Zuma Beach Lifeguard Headquarters: Medium-High

Other Public Safety Facilities

Table 4-8. Legal Facilities Vulnerability	
Assets	Public Defenders' offices are in the City of Malibu.
Hazard Exposure	The Los Angeles County Superior Courthouses, Public Defenders' offices, and District Attorney's offices are all at risk of daily tidal inundation by late century.
	Hazard exposure grade: ▪ Legal Facilities: 3 Medium
Asset Sensitivity	▪ Flooding disruptions may impact operations of the legal system. ▪ Increased frequency of flooding may lead to water damage and other flood related damages.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Large buildings may be difficult to elevate or relocate away from hazards without serious effort and disruptions to the legal system.
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Legal Facilities: 3 Medium-High

4.2.3 Development

Coastal Armoring

Table 4-9. Coastal Armoring Vulnerability	
Assets	Several coastal armoring structure types exist in Malibu, including: ▪ Timber walls ▪ Seawalls (concrete, sheet pile) ▪ Rock revetments ▪ Other rubble
Hazard Exposure	Coastal armoring is specifically designed and intentionally located to be in the hazard zones. However, over time, the exposure of the structures will likely increase, so that a revetment that experiences occasional flooding today could experience deeper floodwaters and stronger wave action in the future. Failure of a coastal armoring structure can have high consequences for landward development that it protects depending on the offset between armoring and development. The GIS analysis shows that 7 miles of coastal armor could be impacted this century Exposure of Coastal Armoring Structures: ▪ Permanent: 5.9 miles mid century,7.0 miles late century ▪ Temporary: 0.7 miles mid century, 0.0 miles late century
	Hazard exposure grade: ▪ Coastal Armoring Structures: 0.0 miles Low, 1.1 miles Medium, 5.9 miles High
Asset Sensitivity	Coastal structures are designed to be in hazard zones, however: ▪ Increased water levels and wave run-up during storms can cause damage to the armoring structures; and ▪ Increased erosion in front of and around the ends of armoring structures can lead to incremental reduction in the level of flood protection and/or increased maintenance costs.
	Sensitivity grade: Medium with adequate maintenance (note sensitivity would be high with little to no maintenance)
Adaptive Capacity	▪ Some armoring structures may be easily modifiable, while others may require full reconstruction in order to provide increased protective services.
	Adaptive Capacity grade: Medium
Vulnerability Summary	▪ Coastal Armoring Structures: 1.1 miles Medium, 5.9 miles High

Commercial

Table 4-10. Commercial Buildings Vulnerability	
Assets	A total of 248 commercial buildings exist within Malibu, including: ▪ Commercial retail stores; ▪ Office buildings; ▪ Service stations; ▪ General industrial; ▪ Restaurants and bars; and ▪ Hotels and motels.
Hazard Exposure	The GIS analysis shows that 126 commercial building assets could be potentially impacted this century. Exposure of Commercial Buildings: ▪ Permanent: 22 mid century, 75 late century ▪ Temporary: 41 mid century, 51 late century
	Hazard exposure grade: ▪ Commercial Buildings: 45 Low, 59 Medium, 22 High
Asset Sensitivity	▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages. ▪ Long-term operational interruption if flooding or mechanical and plumbing systems are present on the ground floor and are subject to damage. ▪ Disrupted access to and from buildings.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Large buildings may be difficult to elevate or relocate away from hazards.
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Commercial Buildings: 45 Medium-Low, 81 Medium

Government and Institutional

Table 4-11. Government and Institutional Buildings Vulnerability	
Assets	A total of 195 Government and Institutional buildings exist within the coastal zone in Malibu, including: ▪ State buildings ▪ County buildings ▪ Libraries ▪ Churches ▪ Colleges and schools
Hazard Exposure	The GIS analysis shows that 33 government buildings could be potentially impacted this century. Exposure of Government Buildings: ▪ Permanent 5 mid century, 14 late century ▪ Temporary 19 mid century, 19 late century No Institutional buildings are exposed for the sea-level rise scenarios considered in this study.
	Hazard exposure grade: ▪ Government Buildings: 6 Low, 22 Medium, 5 High
Asset Sensitivity	▪ Disrupted access to and from the buildings. ▪ Affected ability to provide emergency services. ▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Large buildings may be difficult to elevate or relocate away from hazards
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Government Buildings: 6 Medium, 27 Medium-High

Industrial

Table 4-12. Industrial Buildings Vulnerability	
Assets	A total of 68 Industrial buildings exist within Malibu, including: ▪ Manufacturing ▪ Warehousing/Storage ▪ Distribution ▪ Mineral Processing
Hazard Exposure	The GIS analysis shows that 6 industrial buildings could be potentially impacted this century. Exposure of Industrial Buildings: ▪ Permanent: 1 mid century, 5 late century ▪ Temporary: 0 mid century, 1 late century
	Hazard exposure grade: ▪ Industrial Buildings: 1 Low, 4 Medium, 1 High
Asset Sensitivity	▪ Disrupted access to and from the buildings. ▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Large buildings may be difficult to elevate or relocate away from hazards
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Industrial Buildings: 1 Medium, 5 Medium-High

Recreational

Table 4-13. Recreational Building Vulnerability	
Assets	A total of 35 Recreational buildings exist within Malibu, including: ▪ Athletic and Amusement ▪ Camps ▪ Clubs and Lodge Halls
Hazard Exposure	The GIS analysis shows that 4 recreational buildings could be potentially impacted this century. Exposure of Recreational Buildings: ▪ Permanent 2 mid century, 3 late century ▪ Temporary 2 mid century, 1 late century
	Hazard exposure grade: ▪ Recreational Buildings: 2 Medium, 2 High
Asset Sensitivity	▪ Disrupted access to and from the buildings. ▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Large buildings may be difficult to elevate or relocate away from hazards
	Adaptive Capacity grade: Low
Vulnerability Summary	▪ Recreational Buildings: 4 Medium-High

Residential

Table 4-14. Residential Building Vulnerability	
Assets	A total of 6966 residential buildings exist in Malibu, including: ▪ Single-family homes ▪ Single-family homes ▪ Mobile homes ▪ Mobile homes
Hazard Exposure	The GIS analysis shows that 1410 residential buildings could be potentially impacted this century. Exposure of Single Family Homes: ▪ Permanent: 613 mid century, 1146 late century ▪ Temporary: 446 mid century, 126 late century Exposure of Multi-Family Buildings: ▪ Permanent: 104 mid century, 129 late century ▪ Temporary: 18 mid century, 4 late century Exposure of Mobile Homes: ▪ Permanent: 1 mid century, 5 late century ▪ Temporary: 1 mid century, 0 late century
	Hazard exposure grade: ▪ Single Family Homes: 56 Low, 603 Medium, 613 High ▪ Multi-Family Buildings: 1 Low, 29 Medium, 103 High ▪ Mobile homes: 3 Medium, 2 High
Asset Sensitivity	▪ Disrupted access to and from the buildings. ▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages. ▪ Many building footprints are shown to be exposed to existing tidal inundation, though they may be elevated (e.g. on piles) above tidal elevations and potentially also above flooding elevations. Additional study would be needed to refine the sensitivity and vulnerability of oceanfront buildings based on finished floor elevations and their foundations.
	Sensitivity grade: ▪ Single Family Homes: 56 Low, 603 Medium, 613 High ▪ Multi-Family Buildings: 1 Low, 29 Medium, 103 High ▪ Mobile homes: 3 Medium, 2 High

Table 4-14. Residential Building Vulnerability	
Adaptive Capacity	▪ Some residential buildings could be further elevated or relocated to reduce inundation and/or flooding exposure. Relocation options are limited for buildings on smaller parcels. ▪ Larger residential buildings and homes may require significant effort to adapt to erosion and flooding hazards. ▪ Mobile homes may be relatively easier to relocate or elevate than other building types.
	Adaptive Capacity grade: ▪ Single family homes: Medium ▪ Multi-family buildings: Low ▪ Mobile homes: High
Vulnerability Summary	▪ Single Family Homes: 659 Medium, 613 Medium-High ▪ Multi-Family Buildings: 1 Medium, 132 Medium-High ▪ Mobile homes: 5 Medium

Other Development

Table 4-15. Other Building Vulnerability	
Assets	A total of 79 uncharacterized buildings exist within the coastal zone in Malibu that are included for completeness.
Hazard Exposure	The GIS analysis shows that 12 uncharacterized buildings could be potentially impacted (mid to late century): Exposure of Other Buildings: ▪ Permanent: 6 mid century, 12 late century ▪ Temporary: 3 mid century, 0 late century
	Hazard exposure grade: ▪ Other Buildings: 6 Medium, 6 High
Asset Sensitivity	▪ Disrupted access to and from the buildings. ▪ Increased frequency of flooding of buildings leading to water damage and other flood related damages.
	Sensitivity grade: ▪ Medium
Adaptive Capacity	▪ Some buildings could be elevated or relocated to reduce inundation and or flooding exposure. Relocation options are limited for buildings on smaller parcels. ▪ Larger buildings may require significant effort to adapt to erosion and flooding hazards.
	Adaptive Capacity grade: ▪ Medium
Vulnerability Summary	▪ Other Buildings: 6 Medium, 6 Medium-High

4.2.4 Ecology

Vulnerability for ecological resources in Malibu is based on exposure determined in GIS similar to other built assets as well as specific evaluations for Malibu Lagoon and beaches along the Malibu coastline.

<table>
<tr><th colspan="2">Table 4-16. Ecology Vulnerability</th></tr>
<tr><td>Assets</td><td>Natural assets within the coastal zone include beaches, wetlands and environmentally sensitive habitat areas (ESHA). Wetland types considered include estuarine, marine wetland (e.g. beaches), freshwater emergent wetland, freshwater forested wetland, freshwater pond, and riverine. ESHAs in Malibu include lagoons, rivers, creeks, canyons, bluff top and upland foothills of the Santa Monica Mountains. For context, the following ecological assets are exposed to tidal inundation under existing conditions:
Beaches: 54.3 acres
ESHAs: 67.9 acres
Wetlands: 243.8 acres</td></tr>
<tr><td rowspan="2">Hazard Exposure</td><td>Natural assets can be resilient to storm events (e.g., by only sustaining mild impacts and/or recovering) but can be impacted by erosion and increased inundation with sea-level rise. The GIS analysis shows that many ecological assets could be potentially impacted this century.
Exposure of Beaches:
Permanent: 152.3 acres mid century, 191.6 acres late century
Temporary: 71.9 acres mid century, 35.4 acres late century
Includes 100 to 176 acres of beach lost to shoreline erosion by mid to late century respectively, or 40 feet (mid century) to 68 feet (late century) reduction in average beach width.
Beaches along 43% to 78% of the shore may be lost by mid and late century, respectively
Exposure of ESHAs:
Permanent: 144.3 acres mid century, 169.9 acres late century
Temporary: 36.3 acres mid century, 37.0 acres late century
Includes 68 to 82 acres lost to erosion and 8 to 19 acres of increased tidal influence compared to existing conditions (by mid to late century, respectively).
Exposure of Wetlands:
Permanent: 324.8 acres mid century, 357.8 acres late century
Temporary: 76.2 acres mid century, 47.8 acres late century;
Includes 44 to 63 acres of wetlands lost to erosion (e.g. beaches, lagoons and freshwater streams) and 37 to 51 acres of increased tidal inundation compared to existing conditions (by mid to late century, respectively)</td></tr>
<tr><td>Hazard exposure grade:
Beaches: 1.0 acres Low, 73.6 acres Medium, 152.3 acres High
Wetlands: 3 acres Low, 90 acres Medium, 335 acres High
ESHAs: 11.3 acres Low, 51.8 acres Medium, 144.3 acres High</td></tr>
</table>

Table 4-16. Ecology Vulnerability	
Asset Sensitivity	Beaches: While some beaches in Malibu are wide and can accommodate erosion from year to year (seasonal fluctuations), many beaches in Malibu are already narrow, are lost to erosion in winter, and are thus sensitive to small amounts of sea-level rise and coastal storm erosion. ESHA: Environmentally sensitive habitat areas are sensitive to fragmentation and encroachment. Erosion will encroach on bluff top areas and riparian corridors that drain to the ocean, converting habitat in the process. Tidal inundation will encroach upon wetlands and may lead to expansion. Habitats subject to flooding near the coast are only temporarily affected. Wetlands: While wetland habitats by definition experience some amount of inundation or flooding, erosion and increased inundation may change habitats and the species that can establish in those areas (e.g., salt marsh vegetation species tend to establish at elevations dependent on inundation frequency. With sea-level rise, if certain plant species are inundated too frequently, they will drown out, and other plant species that are adapted to more frequent inundation can establish).
	Sensitivity grade: ▪ Beaches: High ▪ Wetlands: Medium ▪ ESHA: Medium
Adaptive Capacity	▪ Beaches have some adaptive capacity in the few areas that are currently wide (Zuma, Westward Beach) and/or have lowland transgression space at lagoon mouths (Zuma and Malibu). Beaches in front of unarmored bluffs may have some adaptive capacity for sea-level rise but may become unable to persist with higher rates of sea-level rise. Beaches have little to no adaptive capacity in front of armoring structures. ▪ ESHAs subject to permanent erosion impacts have limited ability to adapt other than wildlife to migrate upland/inland as certain ESHAs are eroded. On the other hand, wetland ESHAs have adaptive capacity depending on local topography and sediment supply (see wetlands description below). ▪ Adaptive capacity of wetland habitats depends in part on space for habitats to migrate (transgress) with sea-level rise. Wetlands in Malibu (lagoons) appear to have some adaptive capacity for habitat transgression with sea-level rise. As higher sea levels cause higher lagoons water levels, wetland vegetation will establish further upstream higher onto floodplains and upland slopes. Analysis of CoSMoS tidal inundation extents in Malibu Lagoon suggests that there is space to accommodate wetland transgression in lower Malibu Canyon; existing tidal inundation increases from 54.1 acres to 57.7 acres by mid century and up to 67.7 acres by late century. This suggests that the lagoon itself is not constrained topographically (i.e. there is some lateral space for habitats to migrate). However, these acreages include areas that become subtidal and are not able to sustain marsh habitats. Detailed habitat evolution modeling is needed to better

Table 4-16. Ecology Vulnerability	
	understand the vulnerability of Malibu Lagoon to sea-level rise. Other factors influencing wetland adaptive capacity includes changes in salinity, sedimentation and nutrient supply.
	Adaptive Capacity grade: ▪ Beaches: Low ▪ ESHA: Medium ▪ Wetlands: Medium
Vulnerability Summary	**Vulnerability grade:** ▪ Beaches: High ▪ ESHA: Medium-High ▪ Wetlands: Medium

4.2.5 Energy

Table 4-17. Energy Vulnerability	
Assets	Energy assets within Malibu include electrical meters that represent the power distribution infrastructure throughout Malibu.
Hazard Exposure	The GIS analysis shows that 130 electrical meters could be potentially impacted this century. Exposure of Electrical Meters: ▪ Permanent: 10 mid century, 60 late century ▪ Temporary: 10 mid century, 70 late century
	Hazard exposure grade: ▪ Electrical Meters: 70 Low, 50 Medium, 10 High
Asset Sensitivity	▪ Increased erosion or storm flooding damages could shut down the electric meters and cause service disruptions.
	Sensitivity grade: ▪ Electrical meters: Medium
Adaptive Capacity	▪ Electrical infrastructure could be difficult to reconfigure for increased inundation, flooding or erosion in some areas. Underground lines may already be waterproofed and overhead lines are already protected from flooding and inundation. Electrical meters and connection points could be relocated or elevated above flooding elevations where applicable.
	Adaptive Capacity grade: Electrical meters: Medium
Vulnerability Summary	▪ Electrical meters: 120 Medium, 10 Medium-High

4.2.6 Recreation

Table 4-18. Recreation Vulnerability	
Assets	Public recreation and visitor-serving assets in Malibu's coastal zone include: ▪ Beaches (see ecology) ▪ Parks and Open Space ▪ Hiking Trails ▪ Paradise Cove and Malibu Piers ▪ Coastal Access Points
Hazard Exposure	The GIS analysis shows that the following assets would potentially be impacted (mid to late century): Exposure of Parks and Open Space: ▪ Permanent: 141.4 acres mid century, 186.6 acres late century ▪ Temporary: 101.0 acres mid century, 81.0 acres late century ▪ Includes 50 to 80 acres lost to erosion; 16 to 32 acres more tidal inundation than under existing conditions Exposure of Hiking Trails: ▪ Permanent: 0.61 miles mid century, 0.74 miles late century ▪ Temporary: 0.24 miles mid century, 0.26 miles late century Exposure of Coastal Access Points: ▪ Permanent: 20 mid century, 32 late century ▪ Temporary: 9 mid century, 3 late century Exposure of Piers: ▪ Paradise Cove Pier is exposed to storm flooding under existing conditions (designated as high exposure) ▪ Malibu Pier is exposed to storm flooding impacts under existing conditions and erosion by mid century.
	Hazard exposure grade: ▪ Parks: 13.8 acres Low, 112.9 acres Medium, 141.4 acres High ▪ Hiking Trails: 0.2 miles Low, 0.3 miles Medium, 0.6 miles High ▪ Coastal Access Points: 0 Low, 15 Medium, 20 High ▪ Malibu Pier and Paradise Cove Pier: High
Asset Sensitivity	▪ Increased frequency of flooding and erosion leading to water damage and other flood related damages. ▪ Loss of coastal access due to inundation of and storm impacts to coastal access points. ▪ Loss of access to recreational amenities due to inundation of parks and other facilities. ▪ Loss of mobility for pedestrian and bicyclists within the coastal zone due to inundation of segments of existing trails. ▪ Access to the piers would be disrupted during flood events, which would halt operations of facilities on Malibu Pier.

Table 4-18. Recreation Vulnerability	
	Sensitivity grade: ▪ Parks: Low ▪ Hiking trails: Medium ▪ Coastal access points: Medium ▪ Malibu and Paradise Cove piers: Medium (assuming some level of maintenance)
Adaptive Capacity	▪ Parks and Open Space can accommodate more impacts due to limited built assets. ▪ Hiking trails are easily relocated to avoid inundation or erosion impacts in most cases. ▪ Coastal access points may need to be reconstructed or reconfigured to accommodate permanent and temporary impacts. ▪ Malibu and Paradise Cove Piers may be raised on existing piers or may potentially need new taller piers.
	Adaptive Capacity grade: ▪ Parks: High ▪ Hiking trails: High ▪ Coastal access points: Medium ▪ Malibu and Paradise Cove piers: Medium
Vulnerability Summary	▪ Parks: 13.8 acres Low, 112.9 acres Medium-Low, 141.4 acres Medium ▪ Hiking Trails: 0.2 miles Medium-Low, 0.9 miles Medium ▪ Coastal Access Points: 15 Medium, 20 Medium-High ▪ Malibu Pier and Paradise Cove Pier: Medium-High

The Malibu and Paradise Cove Piers are designed to avoid flooding and wave impacts. However, over time, the exposure of the structure to waves and large storm events will increase. Additionally, the assets on top of the Malibu pier (e.g., restaurant, restrooms) will experience more frequent flooding and wave exposure with sea-level rise. Given the damages sustained at each pier during previous El Niño events and hazard exposures above, both are categorized as high exposure.

4.2.7 Transportation

Pacific Coast Highway is a critical local and regional access corridor through Malibu. Some neighborhoods are at risk of isolation if major impacts to the highway or other local roads occur.

Table 4-19. Transportation Vulnerability	
Assets	The transportation assets in Malibu include: ▪ Pacific Coast Highway (PCH), a critical access route in the region ▪ Many local roads that provide access to businesses, residences, and the coast ▪ Fueling Stations (County fueling, propane, electricity) ▪ Bridges (Pacific Coast Highway) ▪ Parking Lots
Hazard Exposure	The GIS analysis shows that the following transportation assets may be impacted by sea-level rise this century: Exposure of Local Roads: ▪ Permanent: 1.16 miles mid century, 5.52 miles late century ▪ Temporary: 2.31 miles mid century, 2.18 miles late century Exposure of Pacific Coast Highway: ▪ Permanent: 0.55 miles mid century, 2.71 miles late century ▪ Temporary: 0.32 miles mid century, 1.91 miles late century Exposure of Fueling Stations: ▪ Permanent: 0 mid century, 1 late century ▪ Temporary: 0 mid century, 2 late century Exposure of Bridges: ▪ Permanent: 1 mid century, 3 late century ▪ Temporary: 2 mid century, 3 late century Exposure of Parking Lots: ▪ Permanent: 3 mid century, 27 late century ▪ Temporary: 31 mid century, 25 late century
	Hazard exposure grade: ▪ Local Roads: 1.2 miles Low, 5.4 miles Medium, 1.2 miles High ▪ PCH: 1.6 miles Low, 2.5 miles Medium, 0.5 miles High ▪ Fueling Stations: 2 Low, 1 Medium ▪ Bridges: 1 Low, 4 Medium, 1 High ▪ Parking Lots: 12 Low, 37 Medium, 3 High
Asset Sensitivity	▪ Disrupt access pathways critical for emergency services. ▪ Disrupt transportation links to local businesses, residences, and municipal infrastructure. ▪ Damage to existing roadways and related infrastructure due to scour and erosion of embankments, footings and other structural/ geotechnical elements. ▪ Fueling stations may be relied upon by emergency vehicles, and may be damaged by saltwater flooding. ▪ Bridges are designed for some level of creek flooding.

Table 4-19. Transportation Vulnerability

	Sensitivity grade: ▪ Local Roads: Medium ▪ Pacific Coast Highway: High ▪ Fueling Stations: High ▪ Bridges: Low ▪ Parking Lots: Medium
Adaptive Capacity	▪ Local Roads may be elevated in place, but may have implications to property access during construction and may require modifications to property access connections. ▪ Pacific Coast Highway is a critical transportation corridor that would require more significant efforts to elevate or realign. ▪ Bridges for PCH would require significant efforts to elevate or realign, however erosion protection measures could be implemented at exposed locations.
	Adaptive Capacity grade: ▪ Local roads: Medium ▪ Pacific Coast Highway: Low ▪ Fueling Stations: Low ▪ Bridges: Low ▪ Parking Lots: Medium
Vulnerability Summary	▪ Local roads: 6.6 miles Medium, 1.2 miles Medium-High ▪ Pacific Coast Highway: 4.1 miles Medium-High, 0.5 miles High ▪ Bridges: 5 Medium, 1 Medium-High ▪ Fueling Stations: 3 Medium-High ▪ Parking Lots: 49 Medium, 3 Medium-High

Pacific Coast Highway is exposed by mid century to erosion and coastal flooding near Corral Canyon and coastal flooding near Zuma Beach. In the long term it is exposed to erosion at Nicholas Canyon Beach. The following local roads may be permanently impacted by erosion or inundation resulting from sea-level rise:

- Bayshore Dr
- Big Rock Dr
- Birdview Av
- Budwood Mtwy
- Civic Center Wy
- Cross Creek Rd
- Escondido Beach Rd
- Fines Rd
- Fines Rd
- Guernsey Av
- La Paz Ln
- Latigo Shore Dr
- Latigo Shore Pl
- Malibu Colony Dr
- Malibu Colony Rd
- Malibu Cove Colony Dr
- Malibu Rd
- Mariposa De Oro
- Nicholas Beach Rd
- Point Lechuza Dr
- Puerco Canyon Rd
- Rambla Vista
- Sea Daisy Dr
- Sea Level Dr
- Seafield Dr
- Shearwater Ln
- Stuart Ranch Rd
- Topanga Beach Rd
- Tuna Canyon Rd
- Via Escondido
- Victoria Point Rd
- Webb Wy
- Zuma Bay Wy
- Zuma Beach Access Rd

4.2.8 Water Infrastructure

Stormwater

Table 4-20. Stormwater Infrastructure Vulnerability	
Assets	The municipal storm drain system serves coastal communities in Malibu. The asset data for the stormwater system includes: ▪ Storm Drain Lines (pipes and culverts) ▪ Storm Drain Blocks (inlets, junctions)
Hazard Exposure	The analysis shows that the following stormwater assets could potentially be impacted (mid to late century): ▪ Storm Drain Lines: 2.5 to 6.9 miles Permanent, 1.5 to 1.7 miles Temporary ▪ Storm Drain Blocks: 9 to 76 Permanent, 20 to 45 Temporary
	Hazard exposure grade: ▪ Storm Drain Lines: 1.6 miles Low, 5.4 miles Medium, 2.5 miles High ▪ Storm Drain Blocks: 36 Low, 76 Medium, 9 High
Asset Sensitivity	▪ Potential blockage of stormwater drains by beach sediment or damage of drains from waves. ▪ Backwater effects in drainage lines due to downstream flow blockage or constrictions. ▪ Insufficient capacity for conveying increased rainfall runoff. ▪ Failure of storm drainage systems may cause flooding in low areas away from the coast and associated property damage. ▪ Failure of storm drainage system may cause impacts to water quality.
	Sensitivity grade: Medium
Adaptive Capacity	▪ Storm drains typically extend beneath roads or other developed areas and may be difficult to reconfigure without impacting other assets.
	Adaptive Capacity grade: Medium
Vulnerability Summary	▪ Storm Drain Lines: 7.0 miles Medium, 2.5 miles High ▪ Storm Drain Blocks: 36 Low, 76 Medium, 9 High

Wastewater

Table 4-21. Wastewater Infrastructure Vulnerability	
Assets	Sanitary sewer pipes, pumping stations, and treatment plants are essential to the function of the sewer system for some areas. The wastewater infrastructure includes sewer lines and mains, pump stations and treatment facilities. Beachfront properties and most others in Malibu rely on septic systems that may be susceptible to impacts from rising groundwater levels.
Hazard Exposure	The GIS analysis shows that the following wastewater assets could potentially be impacted this century. Sewer mains, treatment plants and pump stations: none exposed by late century Exposure of Sewer Pipes: ▪ Permanent: 0.00 miles mid century, 0.09 miles late century ▪ Temporary: 0.00 miles mid century, 0.04 miles late century
	Hazard exposure grade: ▪ Sewer Pipes: 0.04 miles Low, 0.09 miles Medium
Asset Sensitivity	▪ Increased flooding exposure of critical infrastructure (pumps, utilities), may disrupt operations and potentially damage equipment. ▪ Rising surface waters may limit access to facilities and pipelines for maintenance and operations. ▪ Rising ground water levels may place unanticipated buoyancy forces on buried pipelines, potentially leading to leaks and/or other pipe-related issues. ▪ Erosion may damage the wastewater system and cause impacts to water quality
	Sensitivity grade: ▪ Sewer infrastructure: High
Adaptive Capacity	▪ Sewer pipes flow via gravity and typically extend beneath roads or other developed areas and may be difficult to reconfigure conveyance lines without impacting other assets. ▪ Sewer mains may have more flexibility in location and elevation because they are pressurized, although are more resource intensive and may require additional pump stations
	Adaptive Capacity grade: ▪ Sewer infrastructure: Low
Vulnerability Summary	▪ Sewer Pipes: 0.04 miles Medium, 0.09 miles Medium-High

NOTE: Most properties in Malibu are on septic wastewater systems. Septic systems are used at most beachfront parcels and most parcels near the coastline in Malibu. Septic systems typically rely on a buried tank and a groundwater infiltration system that slowly drains into the groundwater. Septic systems are most vulnerable to sea-level rise on parcels at beach elevations with a shallow groundwater table. Rising groundwater levels may intercept buried tanks and cause buoyancy issues (i.e. force tanks upwards) or limit the efficacy of infiltration systems. Because site-specific data on Malibu septic system configurations are not available, vulnerability could not be quantified. For the purpose of this study, septic system vulnerability to sea-level rise is rated Medium-High given the large number of beachfront properties. Further study is needed to determine septic system vulnerabilities on a parcel level.

GIS data for stormwater and sewer manholes were not available at the time of this study. Manholes for stormwater and sewer infrastructure may intercept saltwater when exposed to storm flooding and/or tidal inundation, which may impact transmission and/or treatment infrastructure.

4.3 Malibu Vulnerability Summary

With projected sea-level rise, Malibu's current vulnerabilities to coastal flooding and erosion are projected to increase. There are many assets currently exposed to flooding and erosion hazards in the coastal zone that will experience greater hazard impacts without action. There are also many assets that are not currently subject to coastal hazards but may become exposed under projected future conditions. **Table 4-22** summarizes the grades for each asset category's exposure to hazard, sensitivity to hazard, and overall vulnerability.

Table 4-22. Malibu Sea-Level Rise Vulnerability Summary

Asset Category	Asset	Hazard Exposure	Asset Sensitivity	Adaptive Capacity	Vulnerability
Communication	Communication Towers	Med	Med	Low	**Med-High**
Critical Facilities	Fire Stations	Med	High	Low	**High**
	Fire Hydrants	Med	High	Low	**High**
	Emergency Shelter	Med	High	Low	**High**
	Legal Facilities	Med	Med	Low	**Med-High**
	Lifeguard Towers	Med-High	Low	High	**Med**
	Lifeguard Stations and Headquarters	Med	High	Med	**Med-High**
Development	Coastal Armoring Structures	High	Med	Low	**Med-High**
	Commercial Buildings	Med	Med	Low	**Med-High**
	Government Buildings	Med	Med	Low	**Med-High**
	Industrial Buildings	Med	Med	Low	**Med-High**
	Recreational Buildings	Med-High	Med	Low	**Med-High**
	Single Family Homes	Med-High	Med	Med	**Med-High**
	Multi-Family Buildings	High	Med	Low	**Med-High**
	Mobile Homes	Med-High	Med	High	**Med**
	Parking Lots	Med	Med	Med	**Med**
	Other Buildings	Med-High	Med	Med	**Med-High**
	Malibu Parcels	Med-High	Med	Med	**Med-High**
Ecology	Wetlands	High	Med	Med	**Med-High**
	Beaches	Med-High	High	Low	**High**
	Environmentally Sensitive Habitat Areas (ESHA)	Med-High	Med	Med	**Med-High**
Energy	Electrical Meters	Med-Low	Med	Med	**Med**

Table 4-22. Malibu Sea-Level Rise Vulnerability Summary

Asset Category	Asset	Hazard Exposure	Asset Sensitivity	Adaptive Capacity	Vulnerability
Recreation	Parks and Open Space	Med-High	Low	High	**Med**
	Hiking Trails	Med-High	Med	High	**Med**
	Coastal Access Points	Med-High	Med	Med	**Med-High**
	Paradise Cove and Malibu Piers	Med	Med	Med	**Med**
Transportation	Bridges	Med	Low	Low	**Med**
	Local Roads	Med	Med	Med	**Med**
	Pacific Coast Highway	Med	High	Low	**Med**
	Fueling Stations	Med-Low	High	Low	**Med-High**
Water	Sewer Mains	n/a*	High	Med	**n/a***
	Sewer Pipes	Med-Low	High	Med	**Med**
	Sewer Treatment	n/a**	High	Low	**n/a***
	Sewer Pump Stations	n/a*	High	Low	**n/a***
	Storm Drain Lines	Med	Med	Med	**Med**
	Storm Drain Blocks	Med	Med	Med	**Med**

**n/a – vulnerability grading not applicable; assets are not exposed to hazards by late century*
*** septic systems are not evaluated in this study but have the potential for high vulnerability*

Section 5

DISCUSSION BY SUB-AREA

The following sections summarize vulnerabilities within each sub-area and how hazard exposure is expected to change with sea-level rise. The sub-area discussions are focused on critical infrastructure, development and ecology.

5.1 NICHOLAS CANYON COUNTY BEACH TO POINT LECHUZA (SUB-AREA A)

Source: ESA, ESRI/Maxar

Figure 5-1. Malibu Sub-Area A

Coastal erosion is the dominant hazard that can impact assets in Sub-area A. The vulnerabilities in Sub-area A include a mix of residential development and open space on top of the bluffs as well as bluff-backed beaches. Some residential development exists at the bottom of the bluffs in small pocket beaches that are vulnerable to erosion and flooding. The narrow beaches in Sub-area A and coastal access points are also vulnerable to sea-level rise.

Critical Infrastructure

Critical infrastructure in this reach includes the Nicholas Canyon Lifeguard Tower, which may experience erosion impacts late-century. A portion of Highway 1 along Nicholas Canyon Beach is vulnerable to bluff erosion. Several fire hydrants in the eastern subarea may be exposed to bluff erosion. Other important infrastructure includes a sewer pump station at the east end of Subarea A that may be exposed to erosion.

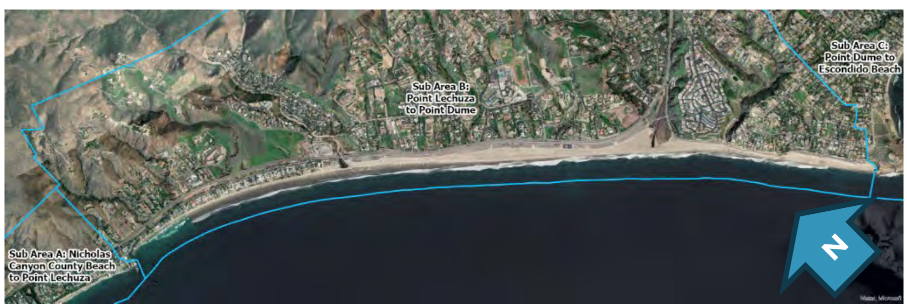
Development

Vulnerable assets in this reach include residences built on the bluff slope. With sea-level rise, development on the beaches or lower bluffs will flood more frequently, leading to property damages and degradation of coastal armoring structures. Some oceanfront homes may become exposed to tidal inundation with 6.6 feet of sea-level rise. Bluff erosion may impact upland property and expose other buildings on the bluff slope and top that are not subject to flooding. Supporting utilities and other infrastructure (e.g. sewer, electricity, roads) may also be jeopardized by flooding and erosion, such as Sea Level Drive at the east end of the sub-area. Coastal access points along the sub-area are vulnerable to flooding and erosion with sea-level rise.

Ecology

Ecological resources in the sub-area include ESHAs at Nicholas Canyon County Beach, several creek drainages, and El Matador State Beach. There are also sea lion haul outs in this area, as well as kelp beds along the length of Subarea A. Average beach widths in Sub-area A (82 feet existing) may erode by 60 to 81 feet with 2.5 to 6.6 feet SLR, respectively if the bluff and beachfront development are held in place. All of these resources are subject to increasing erosion with higher sea levels.

5.2 Point Lechuza to Point Dume (Sub-area B)



Source: ESA, ESRI/Maxar

Figure 5-2. Malibu Sub-Area B

Sub-area B vulnerabilities include erosion of blufftop development as well as flooding and erosion of low-lying beachfront development.

Critical Infrastructure

Critical infrastructure includes Highway 1 which may be exposed to wave run-up near Trancas Creek by late century. The emergency shelter location at Zuma Beach parking lot, lifeguard facilities and fire hydrants are also exposed.

Development

Vulnerable residential development includes the Broad Beach community and blufftop homes above Zuma Beach and Point Dume State Beach. The Broad Beach residential development is vulnerable to sea-level rise and increased erosion and flooding hazards. Some buildings may become exposed to tidal inundation by late century. Most of the shoreline is currently armored. This armoring will be overtopped with increasing frequency and experience more severe flooding with higher sea levels, leading to damage of property (e.g., storm wave run-up and flooding damages to buildings and property). Beachfront parcels may also experience issues with onsite septic systems due to rising groundwater levels with sea-level rise. The backshore parking lots along Zuma and Point Dume state Beach are exposed to storm flooding impacts today which will become more frequent and extensive with higher sea levels. Bluff erosion may impact residential structures from terrestrial erosion processes above Zuma Beach, if not a direct result of sea-level rise.

Ecology

The sub-area includes Broad Beach, Zuma Beach and Point Dume State Beach. Ecological resources in the sub-area include Pismo clam habitat offshore and some kelp beds at the western most end. ESHAs include Zuma creek and lagoon and adjacent creek canyon to the east. Erosion of ESHA upland areas is likely the greatest vulnerability to ecological resources. The Zuma lagoon has some inland migration space. Shoreline erosion will reduce beach widths along the sub-area. Broad Beach has already experienced beach loss, while Zuma and Point Dume State Beaches are wide enough that they are projected to persist beyond late century (6.6 feet of SLR). Average beach widths in Sub-area B (179 feet existing) may erode by 15 to 88 feet with 2.5 to 6.6 feet SLR, respectively, if the bluff and beachfront development are held in place.

5.3 POINT DUME TO ESCONDIDO BEACH (SUB-AREA C)

Source: ESA, ESRI/Maxar

Figure 5-3. Malibu Sub-Area C

Sub-area C vulnerabilities include erosion of residential development on the top of tall bluffs and some small pocket beaches. The west end of the sub-area includes blufftop open space Point Dume Natural Preserve which transitions to blufftop residential property, all of which is fronted by very narrow beaches.

Critical Infrastructure

Critical infrastructure in this sub-area includes fire hydrants, two of which are subject to bluff erosion with higher sea levels.

Development

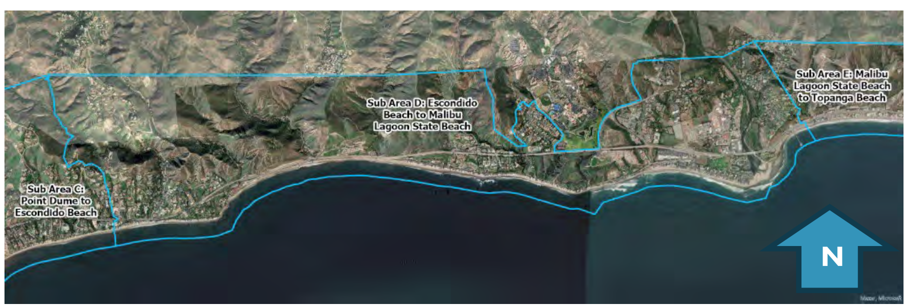
Blufftop residences are vulnerable to bluff erosion, while beachfront buildings along the eastern sub-area are also vulnerable to shoreline erosion and coastal storm flooding and wave run-up. The Paradise Cove Pier, which was damaged in the 1987-88 El Niño , will become more vulnerable to coastal storm damage with higher sea levels. Coastal armoring structures are vulnerable to increased wave action with higher sea levels. Bluff erosion with higher sea levels threatens the most seaward blufftop roads on either side of Paradise Cove. Coastal access stairways are vulnerable to flooding and erosion by mid century.

Ecology

Ecological resources in the sub-area include ESHA-designated Point Dume Natural Reserve and the sea lion haul outs and clam habitat at Point Dume. Kelp beds stretch along most of the shore in Sub-area C. Existing beaches are mostly limited to small pockets along the western sub-area; the beach widens slightly east of Paradise Cove.

Average beach widths in Sub-area C (91 feet existing) may erode by 51 to 86 feet with 2.5 to 6.6 feet SLR, respectively, if the bluff and beachfront development are held in place.

5.4 Escondido Beach to Malibu Surfrider Beach (Sub-Area D)



Source: ESA, ESRI/Maxar

Figure 5-4. Malibu Sub-Area D

Vulnerabilities along Sub-area D include the more extensive residential development at or near beach elevations and Highway 1, which are vulnerable to erosion, coastal storm flooding and wave run-up.

Critical Infrastructure

Critical assets in Sub-area D include fire, lifeguard, and other public safety facilities. Fire hydrants along the backshore development access roads are vulnerable to erosion. Fire Station #88 on Malibu Road is vulnerable to coastal storm wave run-up flooding today and more significant flooding with sea-level rise. Lifeguard towers are exposed to coastal erosion and flooding hazards but are more easily movable, whereas the permanent lifeguard structure at Malibu Surfrider Beach is vulnerable to erosion in the long term.

By mid century, segments of Highway 1 are vulnerable to erosion on both sides of Solstice Canyon. By late century, Highway 1 is vulnerable to erosion at Escondido Creek and Malibu Surfrider Beach as well as flooding east of the Malibu Creek bridge.

Development

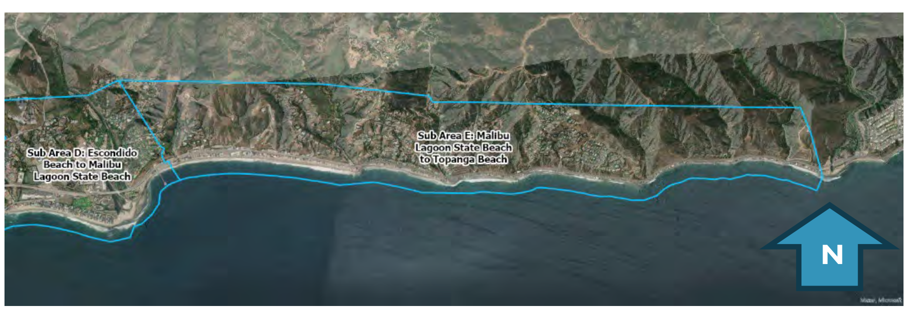
Much of the beachfront residential development is armored in Sub-area D, indicating existing exposure to erosion and flooding. Sea-level rise will lead to greater wave forces on the coastal armoring structures as well as increased wave run-up and overtopping into properties. Beachfront parcels may also experience issues with onsite septic systems due to rising groundwater levels with sea-level rise. Access roads to beach-level development include Escondido Beach Road, Malibu Colony Cove Drive, Latigo Shore Road, Malibu Road and Malibu Colony Road. Nearly all of these roads are vulnerable to erosion by late century (Malibu Colony Road is also vulnerable to tidal inundation late century), while some are vulnerable to erosion and or coastal storm flooding by mid century. Many coastal access points are vulnerable to erosion in the short term while others may be impacted by coastal storms; all access points are vulnerable to erosion by late century.

Malibu Pier is vulnerable to coastal storm impacts by mid century.

Ecology

Ecological resources in Sub-area D include beaches, ESHAs in most creek canyons and Malibu Lagoon. Average beach widths in Sub-area D (57 feet existing) may erode by 45 to 53 feet with 2.5 to 6.6 feet SLR, respectively, if the bluff and beachfront development are held in place.

5.5 Malibu Surfrider Beach to Topanga Beach (Sub-Area E)



Source: ESA, ESRI/Maxar

Figure 5-5. Malibu Sub-Area E

Sub-area E vulnerabilities include beachfront residential development seaward of Highway 1 with narrow fronting beaches.

Critical Infrastructure

By mid century, Highway 1 may be exposed to erosion in a few locations along Sub-area E and storm wave run-up at the western end of Subarea E (east of Malibu Pier). By late century, Highway 1 may be widely exposed to coastal erosion and storm wave run-up along Sub-area E. Several Lifeguard towers are also vulnerable to erosion and flooding. Some of the fire hydrants serving the beachfront properties are also vulnerable to erosion by mid century, threatening the fire main that serves much of the properties seaward of Highway 1.

Development

Vulnerable development in Sub-area E includes beach front residential and commercial properties/buildings built seaward of Highway 1. Much of these properties are already protected with some form of coastal armor that will require maintenance and upgrades with future sea-level rise.

Ecology

Ecological resources in the sub-area include narrow beaches, streams and some upland ESHAs landward of Highway 1. Average beach widths in Sub-area E (52 feet existing) may erode by 33 to 50 feet with 2.5 to 6.6 feet SLR, respectively, if the bluffs and beachfront development are held in place. Several coastal access points are vulnerable to erosion by mid century. Most access points are vulnerable to erosion and tidal inundation by late century.

Section 6

CONCLUSIONS AND NEXT STEPS

CONCLUSIONS

The City of Malibu has experienced impacts from coastal hazards such as erosion and flooding. Much of the oceanfront development is armored today. With sea-level rise, the City's residential and commercial properties and supporting infrastructure along the coast may be impacted more frequently and to a greater degree by coastal erosion and flooding while regular tidal inundation will progress further inland and expose more coastal property and structures to regular high tides. Highway 1 may be exposed to coastal storm flooding in several locations by mid century, while local roads may also be impacted by coastal storm flooding and wave run-up and even regular tidal inundation by late-century.

Many of the narrow beaches along the Malibu coast may disappear with sea-level rise, impacting shore ecology and recreation. Beaches in Malibu mostly exist as narrow stretches along beachfront homes, coastal bluffs and Hwy 1, with wider beaches exist at Zuma/Westward Beach and Point Dume State Beach and Malibu Surfrider Beach. Today, approximately one quarter of beaches in Malibu may disappear annually from seasonal fluctuations alone; nearly two thirds may disappear annually by mid century. In addition, beaches may cease to recover along coastal armoring and other hardened shorelines without action. The disappearance of beaches in Malibu would adversely impact ecological functions along the coastline as well as recreation opportunities for Malibu residents and visitors.

NEXT STEPS

Following this Coastal Vulnerability Assessment, ESA and the City will develop a range of potential adaptation measures that can be taken to reduce the sea-level rise vulnerabilities identified in this report. The City will hold public workshops to present this Assessment along with potential adaptation options for the various coastal areas in Malibu in order to gather community input and develop next steps in the planning process.

Section 7

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Section 8

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Appendix A

Data Sources and Processing

MALIBU COASTAL VULNERABILITY ASSESSMENT

APPENDIX A: DATA SOURCES AND PROCESSING

Section 1

ASSET DATA

This Coastal Vulnerability Assessment utilizes spatial data representing built and natural assets in Malibu. Data sources include the City of Malibu, County of Los Angeles, local utilities and other sources. This section describes the asset data that were used for the Assessment. Table A-1 lists the various GIS asset data that were used in the hazard exposure analysis. Some of the source data layers were processed in GIS to clip down county-wide assets to the vicinity of Malibu. All asset layers were compiled in a geodatabase of Malibu's built and natural assets used to conduct the exposure assessment and to produce the Malibu Coastal Vulnerability Assessment Webmap.

TABLE A-1. CITY OF MALIBU ASSET DATA SOURCES

ASSET CLASS	ASSET NAME	SOURCE
Communication	Communication Towers	LA County eGIS
Critical Facilities	Fire Stations	LA County eGIS
Critical Facilities	Fire Hydrants	LA County eGIS
Critical Facilities	Legal Facilities	LA County eGIS
Development	City Parcels	Malibu City
Development	Building Outlines	LA County eGIS
Development	Parking Lots	LA County eGIS
Development	Coastal Armoring Structures	CA Coastal Commission, ESA
Ecology	Streams	Malibu City
Ecology	Wetlands	CA Fish and Wildlife Service
Ecology	ESHA	Malibu City
Energy	Electrical Meters	Southern CA Edison
Recreation	Coastal Access	Malibu City
Recreation	Hiking Trails	Malibu City
Recreation	Parks	Malibu City
Transportation	Roads	LA County eGIS
Transportation	Bridges, Fueling Stations	LA County eGIS
Stormwater	Storm Line	Malibu City
Stormwater	Storm Junction	Malibu City
Wastewater	Sewer Main	LA Department of Public Works
Wastewater	Sewer Pipe	LA Department of Public Works
Wastewater	Sewer Pump Station	LA Department of Public Works
Wastewater	Sewer Treatment	LA Department of Public Works

Section 2

HAZARD DATA

The hazard mapping data used in this Coastal Vulnerability Assessment was primarily compiled from USGS CoSMoS model results. The CoSMoS model results data can be viewed on Point Blue's webmapper Our Coast Our Future (https://data.pointblue.org/apps/ocof/cms/index.php?page=flood-map) and downloaded directly from the USGS ScienceBase website (https://www.sciencebase.gov/catalog/item/5633fea2e4b048076347f1cf). Specific information on hazard modeling can be found on the USGS CoSMoS 3.0 webpage (https://www.usgs.gov/centers/pcmsc/science/cosmos-30-southern-california?qt-science_center_objects=0#qt-science_center_objects). The CoSMoS hazard data were processed in ArcGIS for the purposes of the Vulnerability Assessment. Additional flooding sources of Trancas, Zuma and Malibu Creek mouth closure were also considered, per AdaptLA County-wide hazard mapping previously conducted by ESA. The following subsections document specific data processing and edits that were made to produce the hazard maps used in this study.

2.1 CoSMoS Hazard Data Workup

CoSMoS projections for shoreline and cliff erosion as well as wave runup were processed by ESA using GIS to enable an exposure analysis for the Vulnerabilty Assessment. These hazard projections are provided by the USGS as lines and points, whereas polygons representing the hazard zones are needed to overlay and count the "exposed" assets for a given hazard type. There are a number of gaps in the erosion projections from CoSMoS that had to be addressed also. The following sections describe the general workup process for each hazard data category and the specific criteria used to address gaps in shoreline/cliff projections alongshore and transition areas in between shore and cliff erosion projections.

2.1.1 Shoreline Erosion Projections

Gaps in shoreline projections where cliff erosion is not projected – interpolate across transects using the relative distance from the development line and seaward-most shoreline. The example below shows that the shorelines on the left are further seaward, so the interpolated shoreline was placed relative to the distance between the developed line and the future shorelines at that transect, while the right end of the interpolated shoreline was edited to connect with the CoSMoS projections there. The light blue line is the developed line, the grey lines are the CoSMoS modeling transects, the thick lines are CoSMoS projections while the thin lines are the interpolated shoreline segments (yellow is 75 cm SLR, orange is 200 cm SLR).

2.1.2 Cliff Erosion Projections

Gaps spanning 1 transect between cliff projections – interpolate directly from cliff to cliff. Since there is no baseline cliff position to adjust relative positions by on the gap transect, cliffs are interpolated straight through these single transect gaps. Two examples are shown below. Grey lines are the CoSMoS modeling transects, white points are beginning cliff positions, black-color dashed lines are CoSMoS cliff projections while color-only dashed lines are cliff interpolations (yellow is 75 cm SLR, orange is 200 cm SLR), solid lines are CoSMoS shoreline projections, for reference.

Gaps spanning more than 1 transects between cliff projections and shoreline-cliff transitions – interpolate cliff to adjacent shoreline on transect. Grey lines are the CoSMoS modeling transects, white points are beginning cliff positions, black-color dashed lines are CoSMoS cliff projections while color-only dashed lines are cliff interpolations (yellow is 75 cm SLR, orange is 200 cm SLR), solid lines are CoSMoS shoreline projections, for reference.

Cliff erosion in areas with wide beaches/development between cliff and ocean – project cliff-top erosion only. Along Zuma beach, CoSMoS projects future cliff erosion landward of the beach and infrastructure, while shoreline erosion does not encroach on the infrastructure. An explanation is that terrestrial (rainfall-runoff and other land-based erosion) continues with SLR and may increase during storms as waves reach the cliff toe, while the parking and road may be flooded during such an event in the future, we chose not to classify the area between shoreline and cliff erosion projections as lost to erosion (this area would be evaluated as flooded where applicable). Grey lines are the CoSMoS modeling transects, white points are beginning cliff positions, black-color dashed lines are CoSMoS cliff projections while color-only dashed lines are cliff interpolations (white is beginning position, yellow is 75 cm SLR, orange is 200 cm SLR), solid lines are CoSMoS shoreline projections, for reference. Solid polygons represent the erosion area that will be considered in the Vulnerability Assessment for exposure to cliff erosion.

2.1.3 Wave Run-up Projections

Gaps in Run-up projections alongshore – Existing and future wave run-up projections from CoSMoS have some gaps alongshore that lead to overestimated runup extents when run-up points were interpolated across the gaps (see below for example of gap in run-up results and modifications to run-up "line" for use in exposure assessment).

Apparent GIS errors in run-up points – Some run-up results appear incorrectly mapped in the CoSMoS results. This interpretation was made based on observed run-up points that appear to be shifted away from the corresponding analysis transects upon which run-up was computed. See the two examples of shifted run-up points in the images below at Point Dume (with adjusted run-up lines) and the Las Flores Canyon mouth (no adjustment made). A straight line can be drawn between the adjacent points that map onto the transects, which is interpreted as a mapping error for the points that do not map directly onto transects.

Over-prediction at Malibu Lagoon - Generally speaking, the wave runup results from CoSMoS appear reasonable (along bluffs this is largely the case) though in low lying areas the modeling approach and results shown in CoSMoS over represents the potential wave damage zone, as CoSMoS shows runup extending farther inland than high-momentum forces from wave run-up would realistically propagate. The major areas where this issue is most notable is Malibu Spit and Lagoon.

2.1.4 Storm Flooding Extent and Depth Projections

CoSMoS 100-year storm flooding hazard mapping results were processed to include the potential impacts from lower storm scenarios to account for model sensitivities and to account for the full potential impacts with sea-level rise. For the 6.6 feet (2 meter) sea-level rise scenario, CoSMoS storm flooding extents along lower Malibu Creek interestingly do not increase with increasing storm severity (i.e. from 1- to 20- up to 100-year storms) for a given sea-level rise scenario. In other words, CoSMoS flooding around Malibu Lagoon and Creek (e.g. Malibu Village) is worse in the annual (1-year) storm than the 100-year storm. Reasons for this difference could be the modeling approach for coincident Malibu Creek flows that are included in the CoSMoS flood results or the coastal wave run-up, overtopping, and erosion modeled at the Malibu Lagoon mouth. See the snapshot below showing the no-storm inundation (left) and 100-year storm (right). Note the difference in flooding extents upstream of Highway 1. Increases in storm flooding are visible along the shoreline, while fluvial storm flooding appears less severe upstream.

To capture the most severe storm impacts (which 100-year storm was selected to represent), flooding extents for the three positive storm scenarios (not including the no-storm scenario) were merged to represent the 100-year storm so that potential damages are not underestimated for Malibu Creek and Lagoon in particular. Flood depths were similarly calculated for parcel damage analysis to be the maximum depth of the three storm scenarios.

2.2 Closed Lagoon Flood Hazards

In addition to the coastal flooding results from CoSMoS, ESA applied a simplified lagoon flooding analysis previously implemented for the AdaptLA project (ESA 2016) to consider this additional flooding mechanism that is not analyzed in CoSMoS. The method considers a potential condition in which (1) the beach berm at a lagoon mouth is built up to an exceptionally high elevation over an active summer of waves and (2) an early wet season storm precipitates in the canyon watershed, fills the lagoon behind the elevated berm at the mouth and causes increased flood exposure to low areas surrounding the lagoon. Such analysis was performed for Trancas, Zuma and Malibu Creek Canyons using the following potential beach berm elevations:

- **Trancas Canyon: 11.8 feet**
- **Zuma Canyon: 12.8 feet**
- **Malibu Canyon: 12.8 feet**

These beach berm elevations were used for existing conditions lagoon flooding potential; sea-level rise of 2.5 and 6.6 feet were respectively added to the beach berm elevations to produce future lagoon flooding zones for mid-century and late century sea-level rise. The resulting lagoon flood potential hazard zones were combined with the CoSMoS coastal storm flooding hazard zones for vulnerability mapping and analysis.

Appendix B

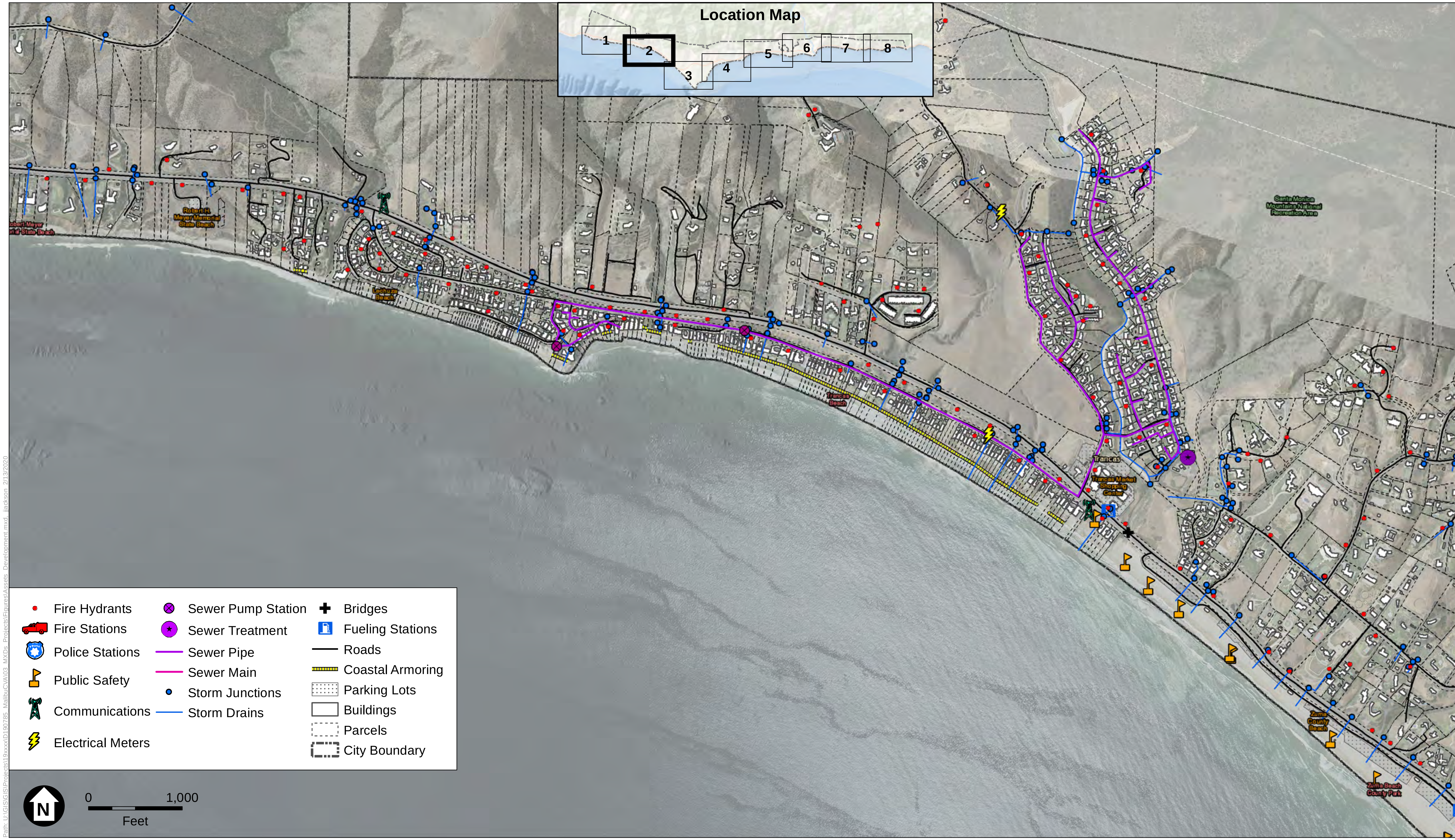
Malibu Asset Maps

Path: U:\GIS\GIS\Projects\19xxxx\D190785_MalibuCVA\03_MXDs_Projects\Figures\Assets_Development.mxd, jjackson 2/13/2020

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B1-1
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B1-2
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA

SOURCE: XXX

Malibu Coastal Vulnerability Assessment . 190785.00

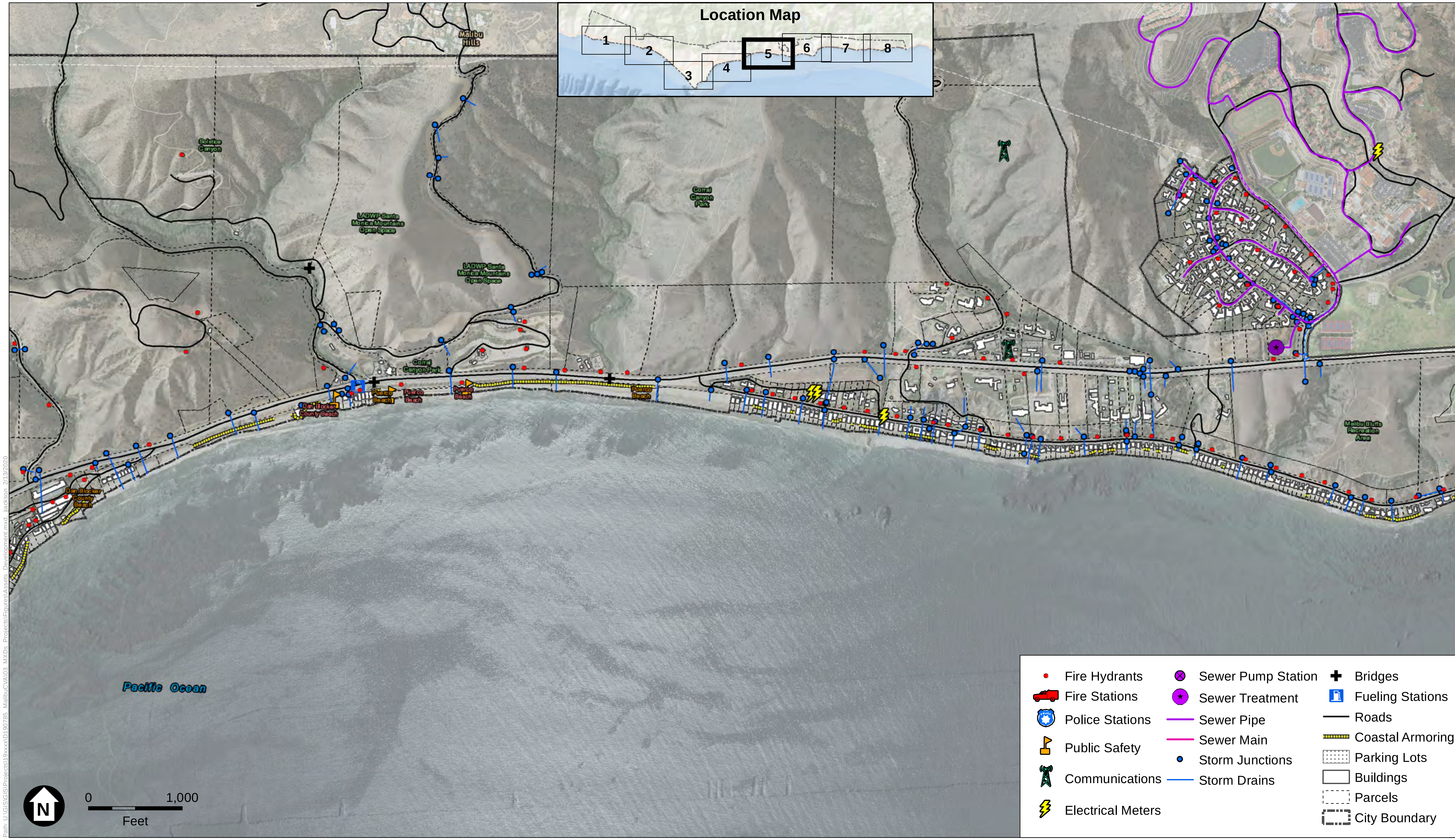
Figure B1-3
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA

SOURCE: XXX

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B1-4
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

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Figure B1-5
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

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Figure B1-6
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

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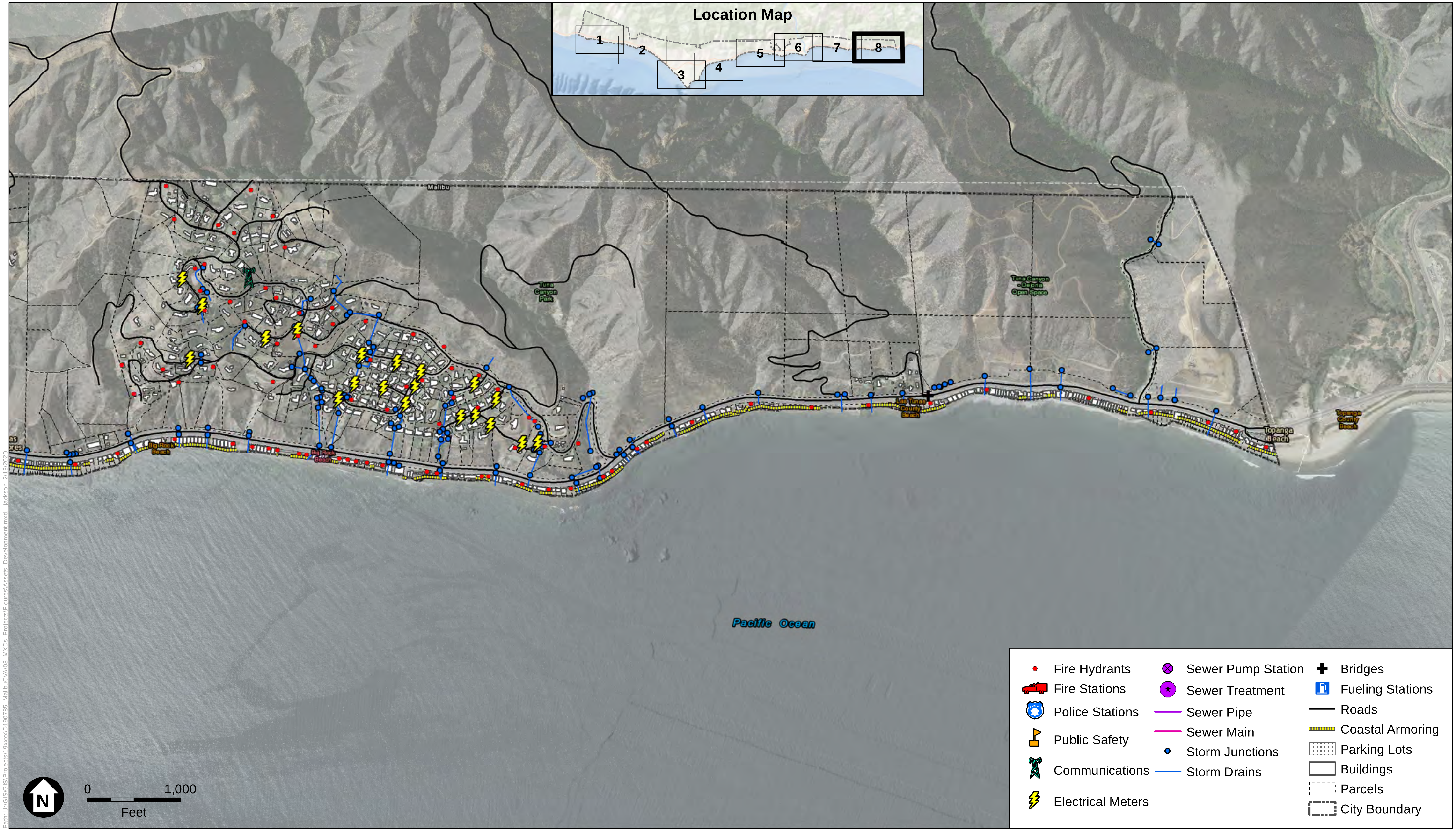
Figure B1-7
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B1-8
Malibu Asset Maps
Critical, Water, Transportation and Development Infrastructure

ESA

SOURCE: CCC, City of Malibu, USFWS, ESRI, LA County,

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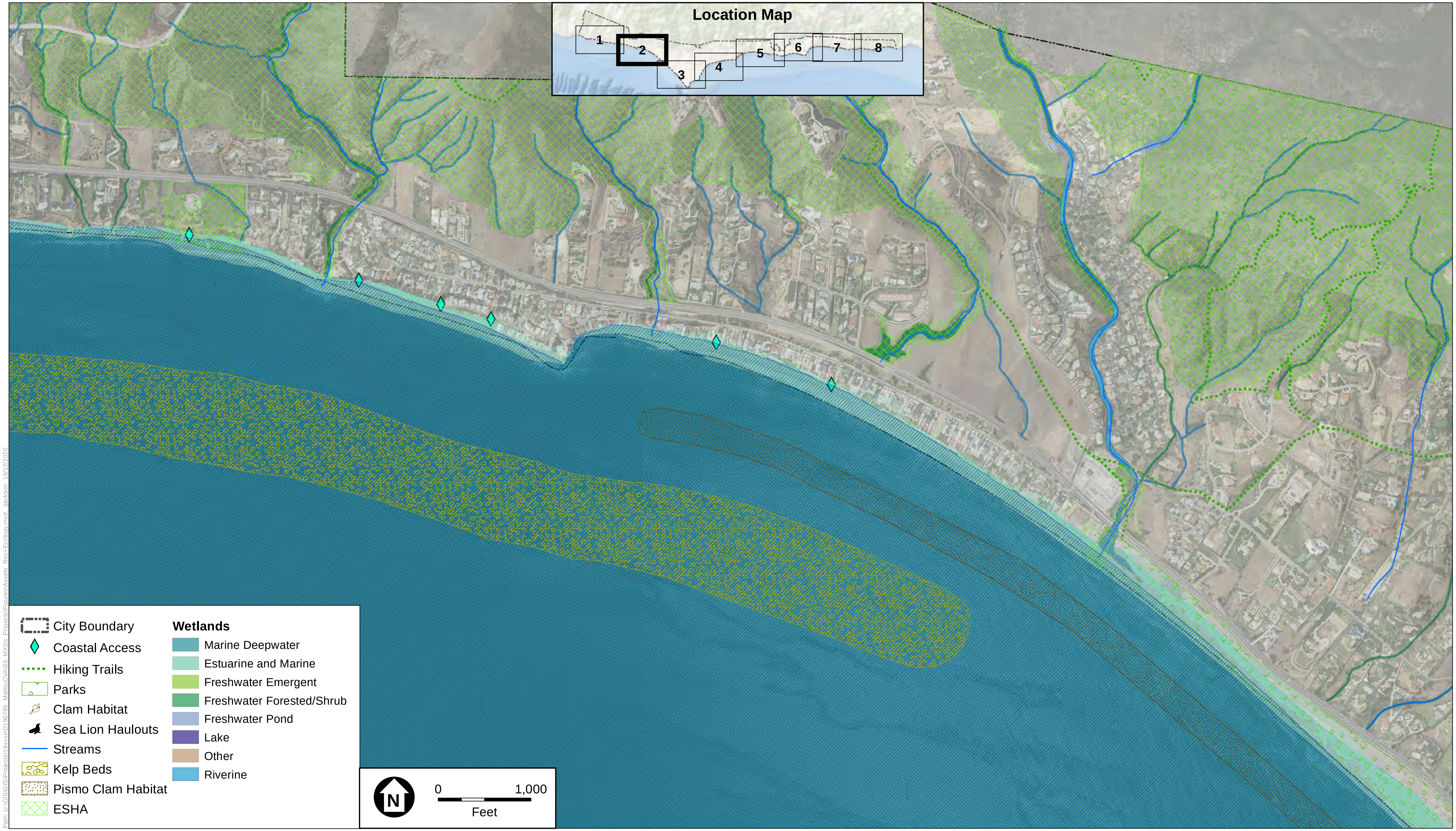
Figure B2-1
Malibu Asset Maps
Recreation and Ecology

ESA



SOURCE: CCC, City of Malibu, USFWS, ESRI, LA County,

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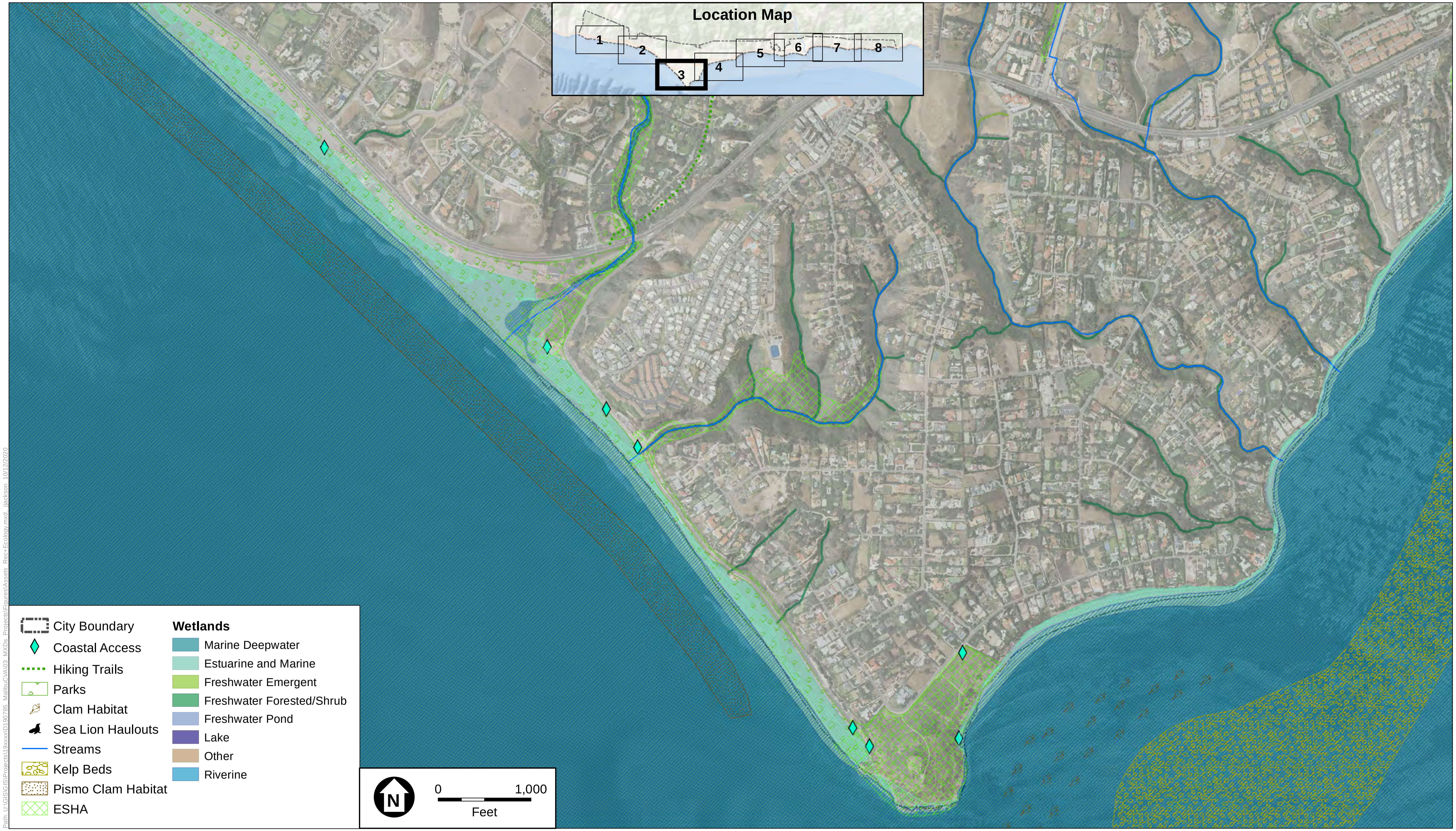
Figure B2-2
Malibu Asset Maps
Recreation and Ecology

ESA



SOURCE: CCC, City of Malibu, USFWS, ESRI, LA County,

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B2-3
Malibu Asset Maps
Recreation and Ecology

ESA

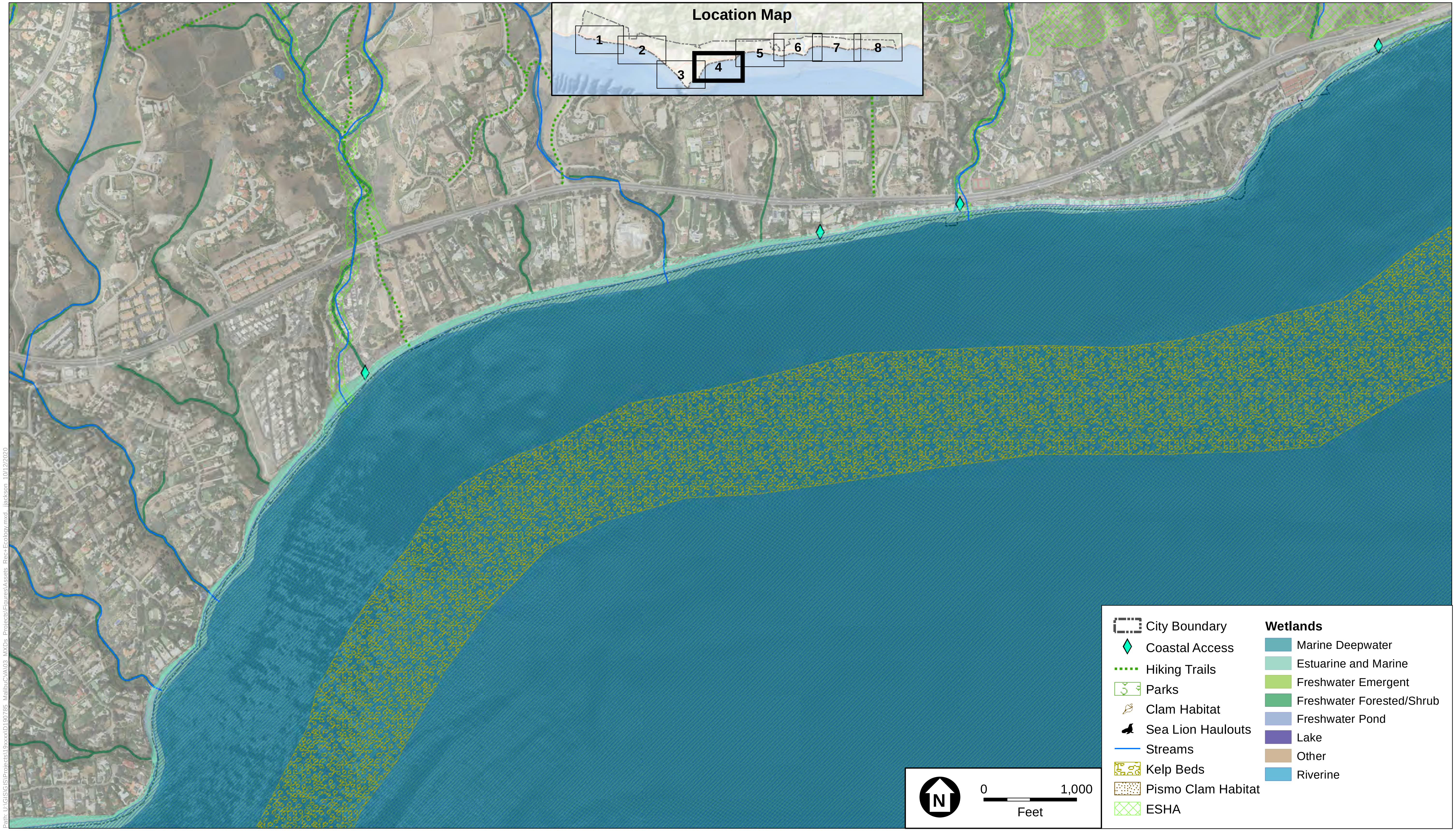


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Figure B2-4
Malibu Asset Maps
Recreation and Ecology

ESA

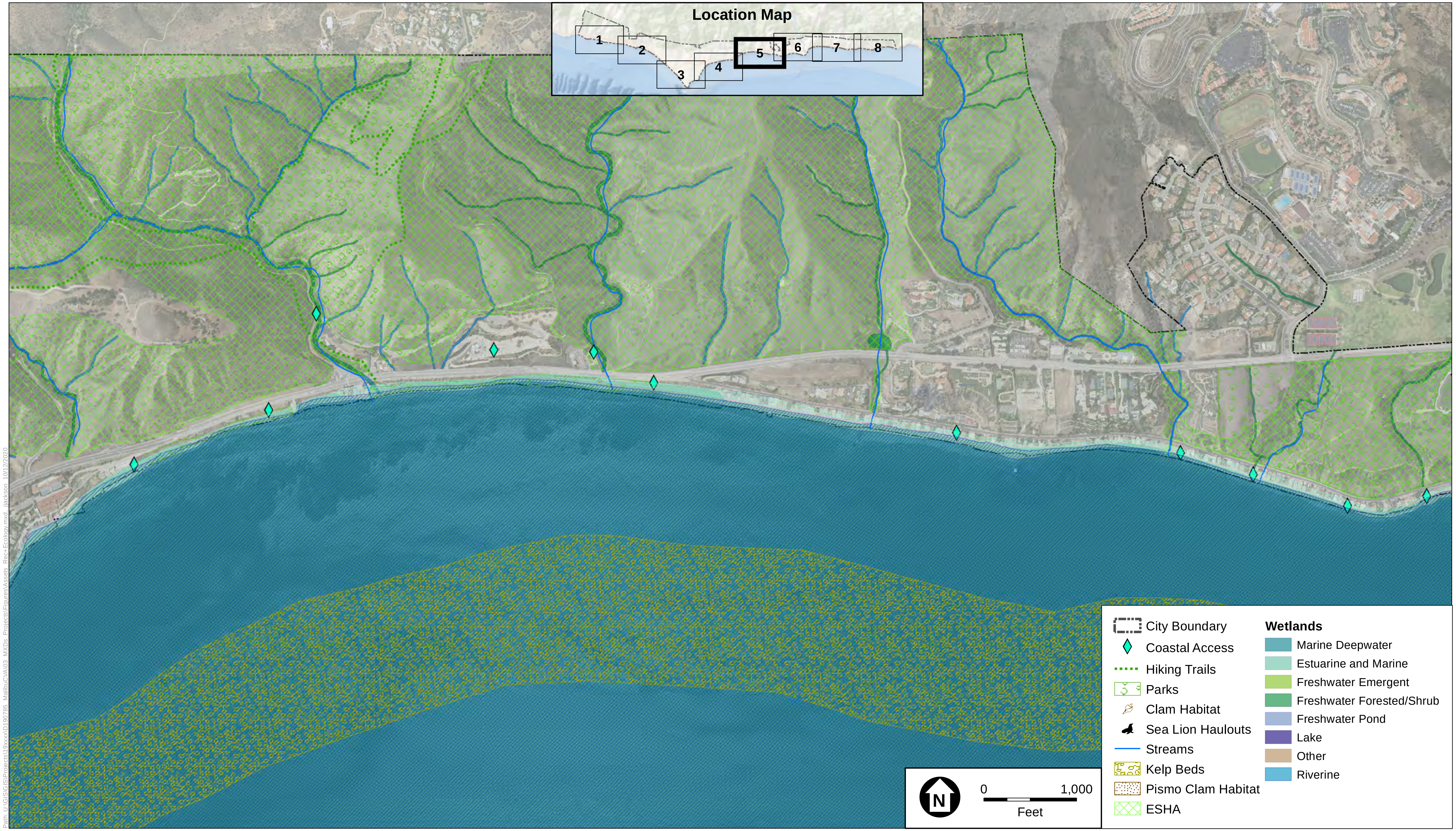

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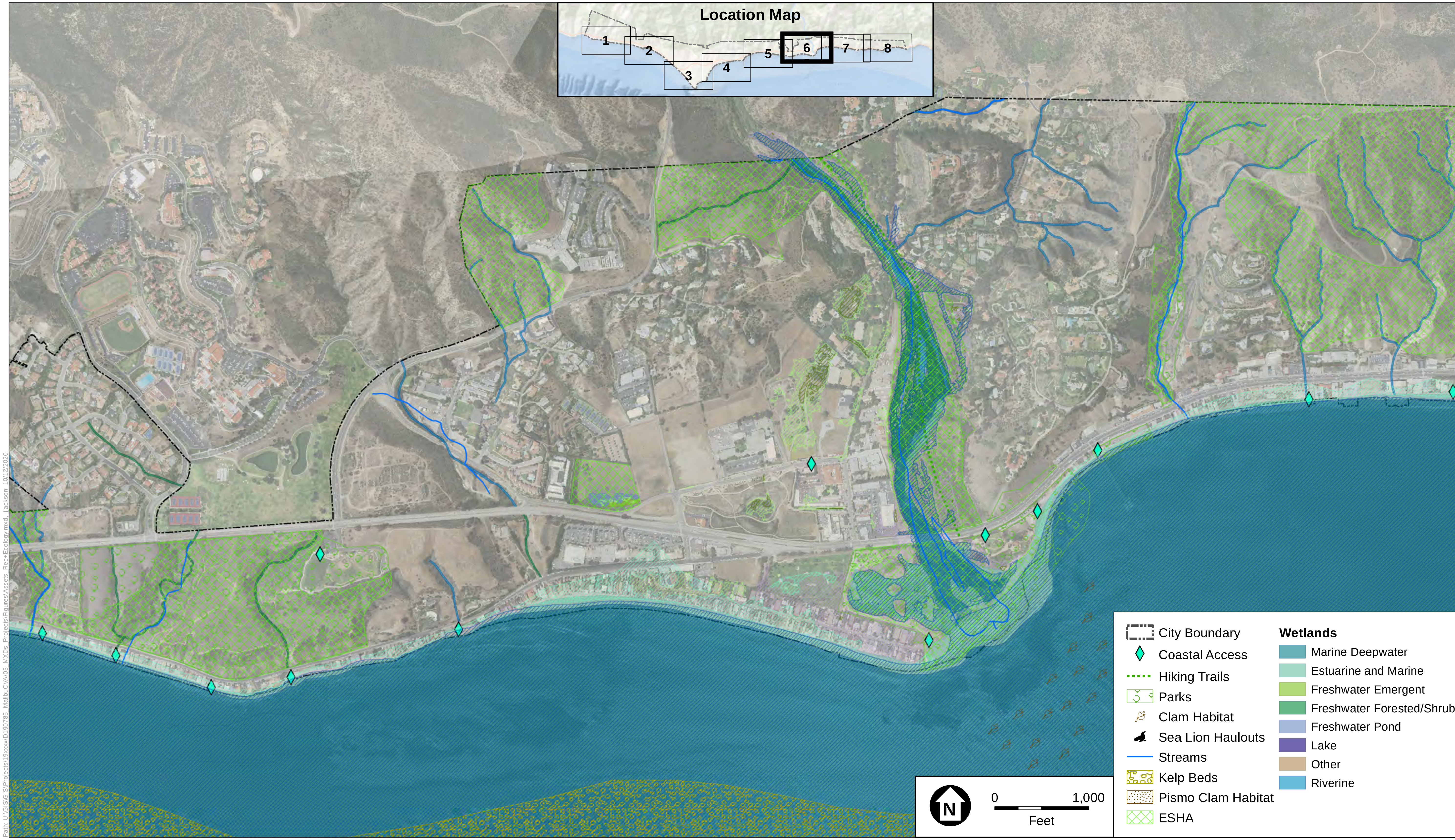
Figure B2-5
Malibu Asset Maps
Recreation and Ecology

ESA



SOURCE: XXX

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Figure B2-6
Malibu Asset Maps
Recreation and Ecology

ESA

SOURCE: XXX

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B2-7
Malibu Asset Maps
Recreation and Ecology

SOURCE: XXX

Malibu Coastal Vulnerability Assessment . 190785.00

Figure B2-8
Malibu Asset Maps
Recreation and Ecology

ESA

Appendix C

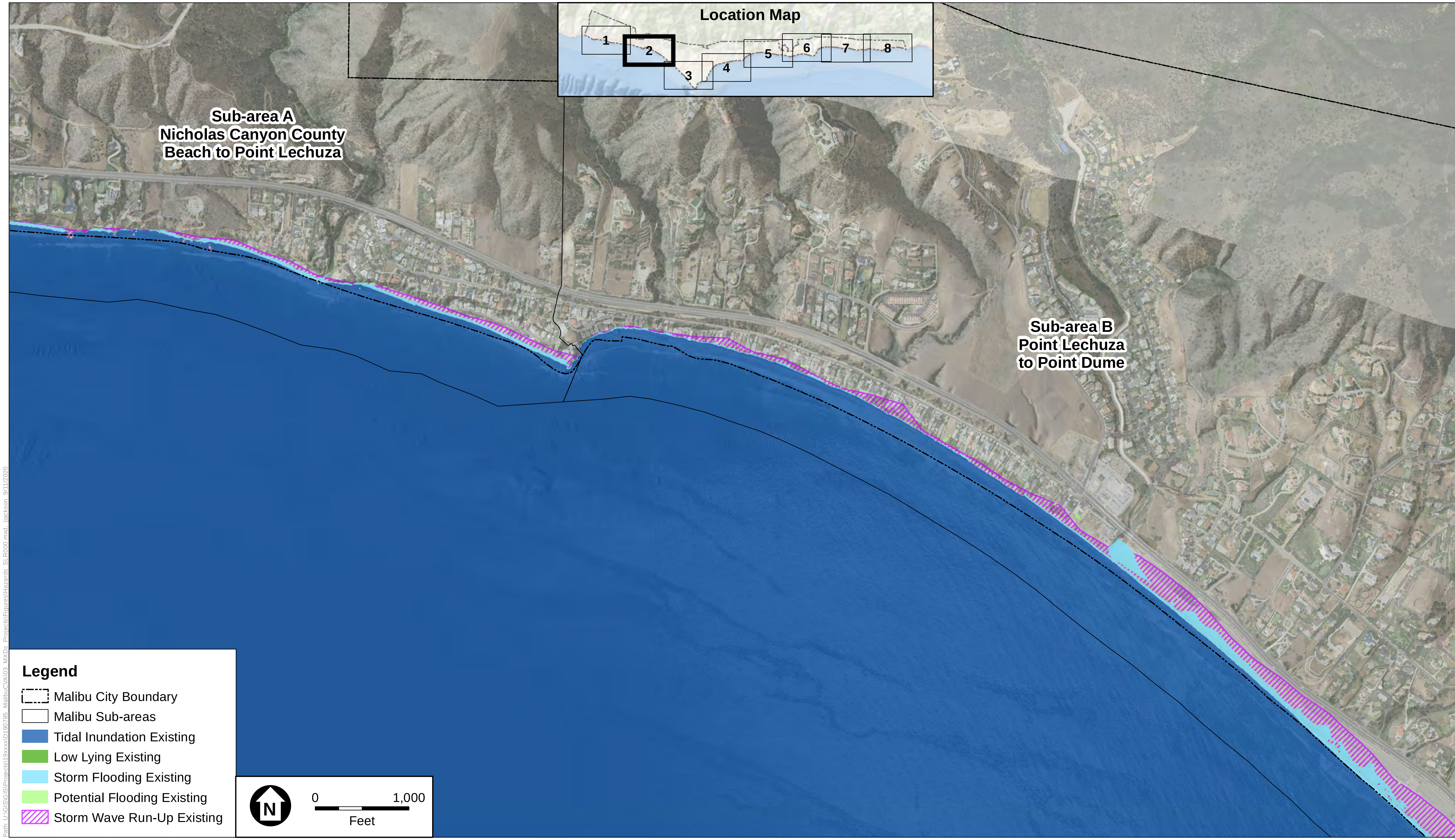
Coastal Hazard Exposure Maps

SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

Malibu Coastal Vulnerability Assessment . 190785.00

NOTE:

Figure C1-1
Coastal Hazard Exposure Map
Existing Sea Level



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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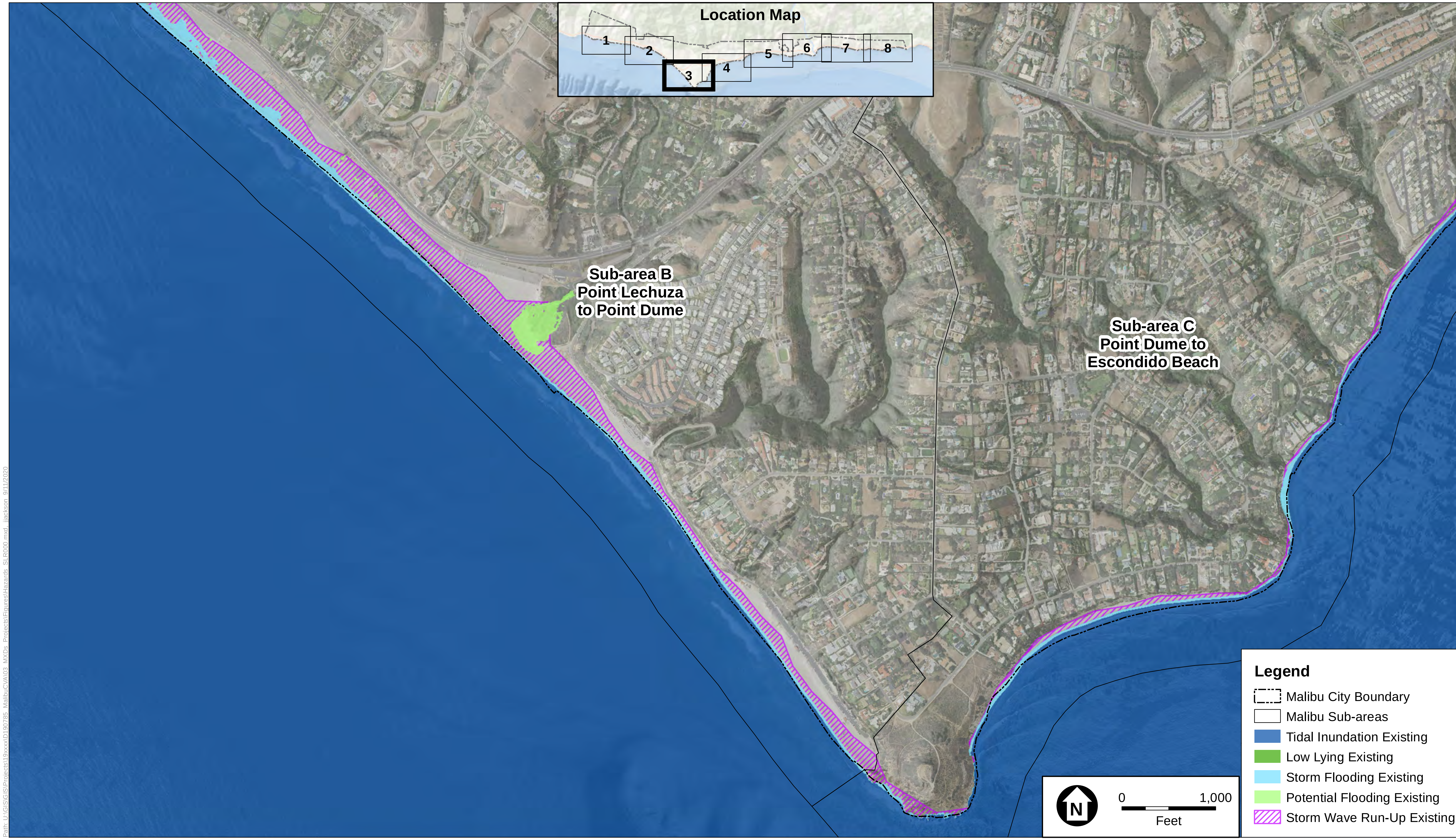
NOTE:

ESA

Figure C1-2
Coastal Hazard Exposure Map
Existing Sea Level



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

ESA

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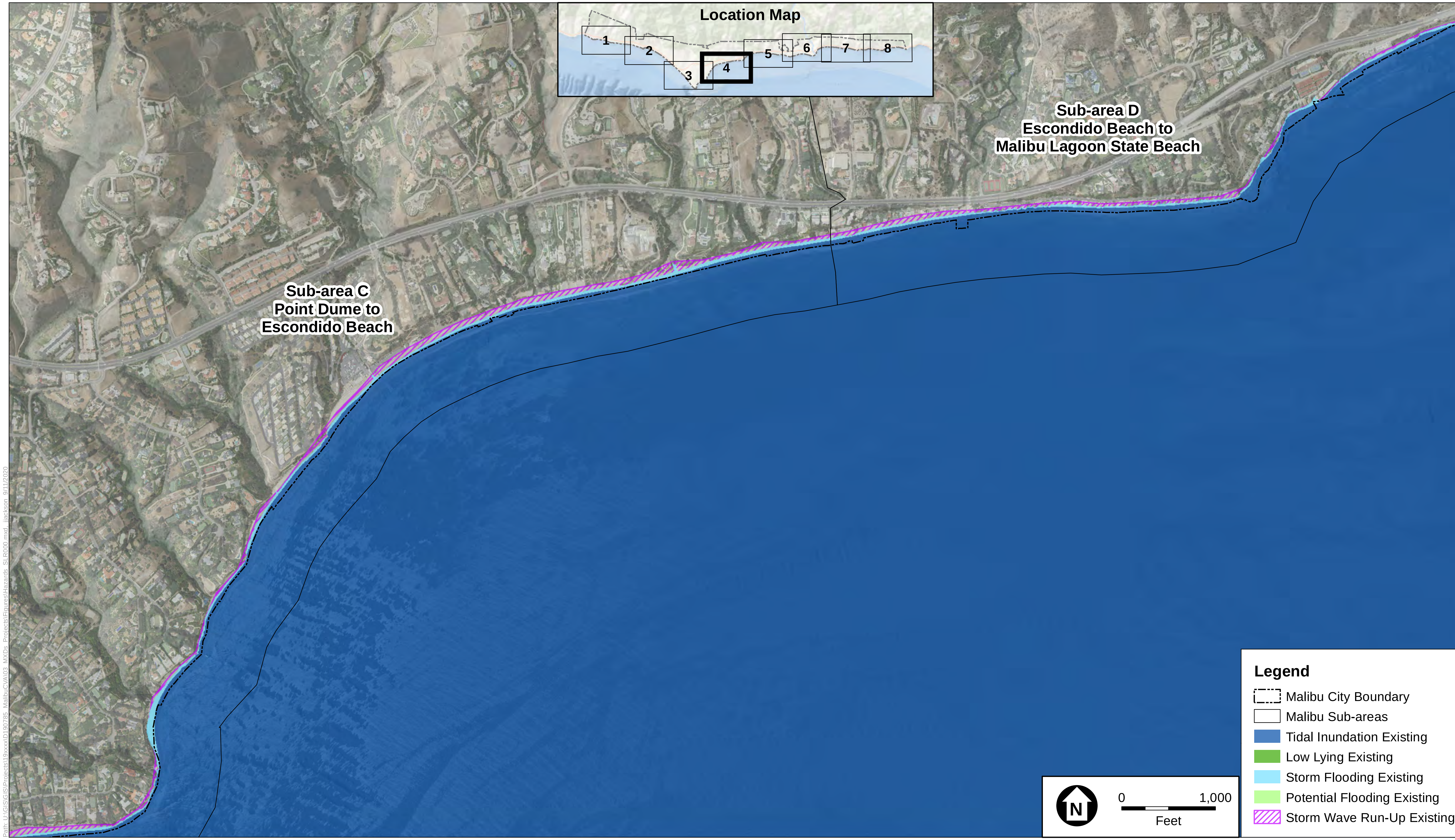
Figure C1-3
Coastal Hazard Exposure Map
Existing Sea Level



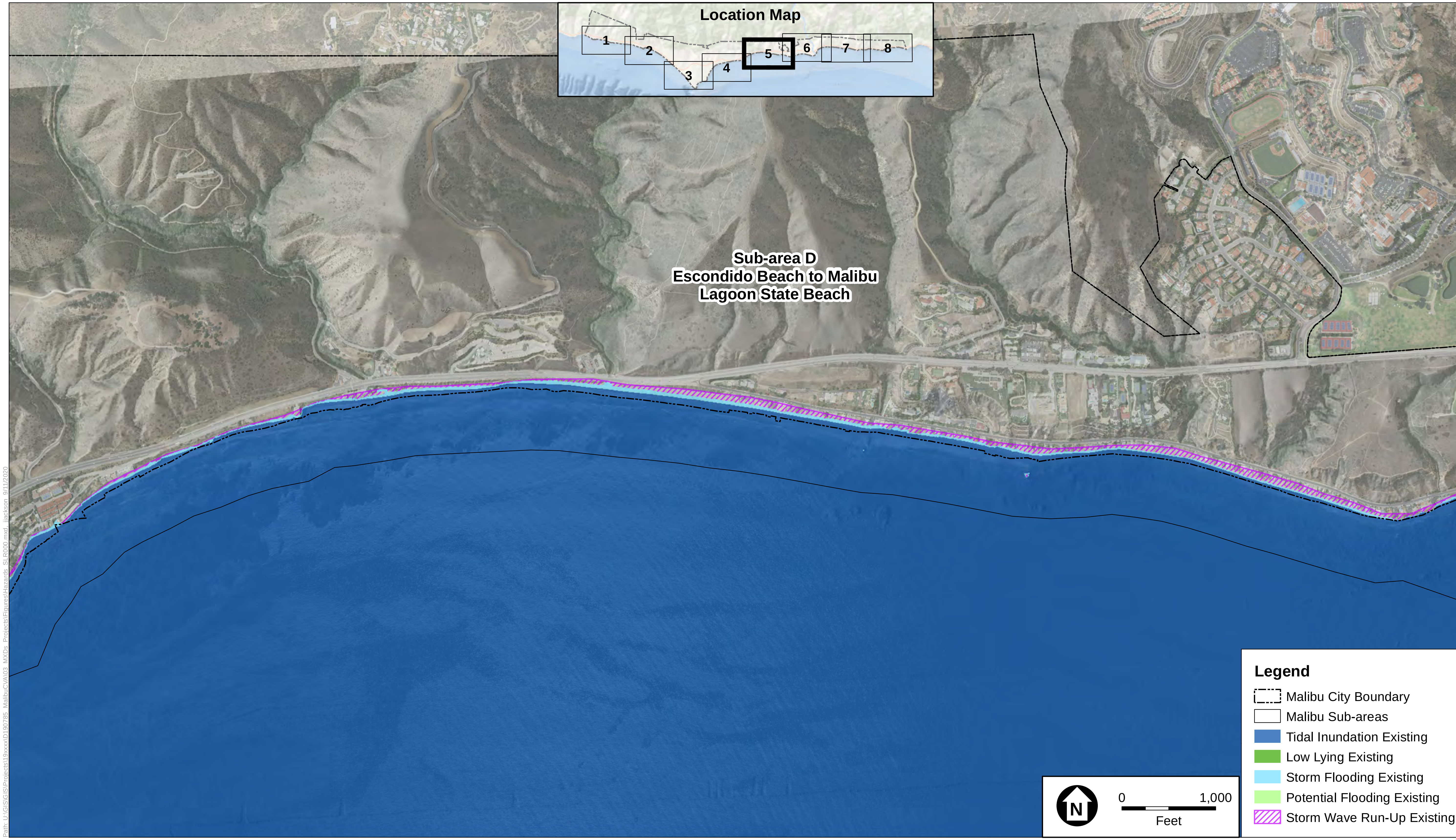
SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

ESA

Malibu Coastal Vulnerability Assessment . 190785.00

Figure C1-4
Coastal Hazard Exposure Map
Existing Sea Level



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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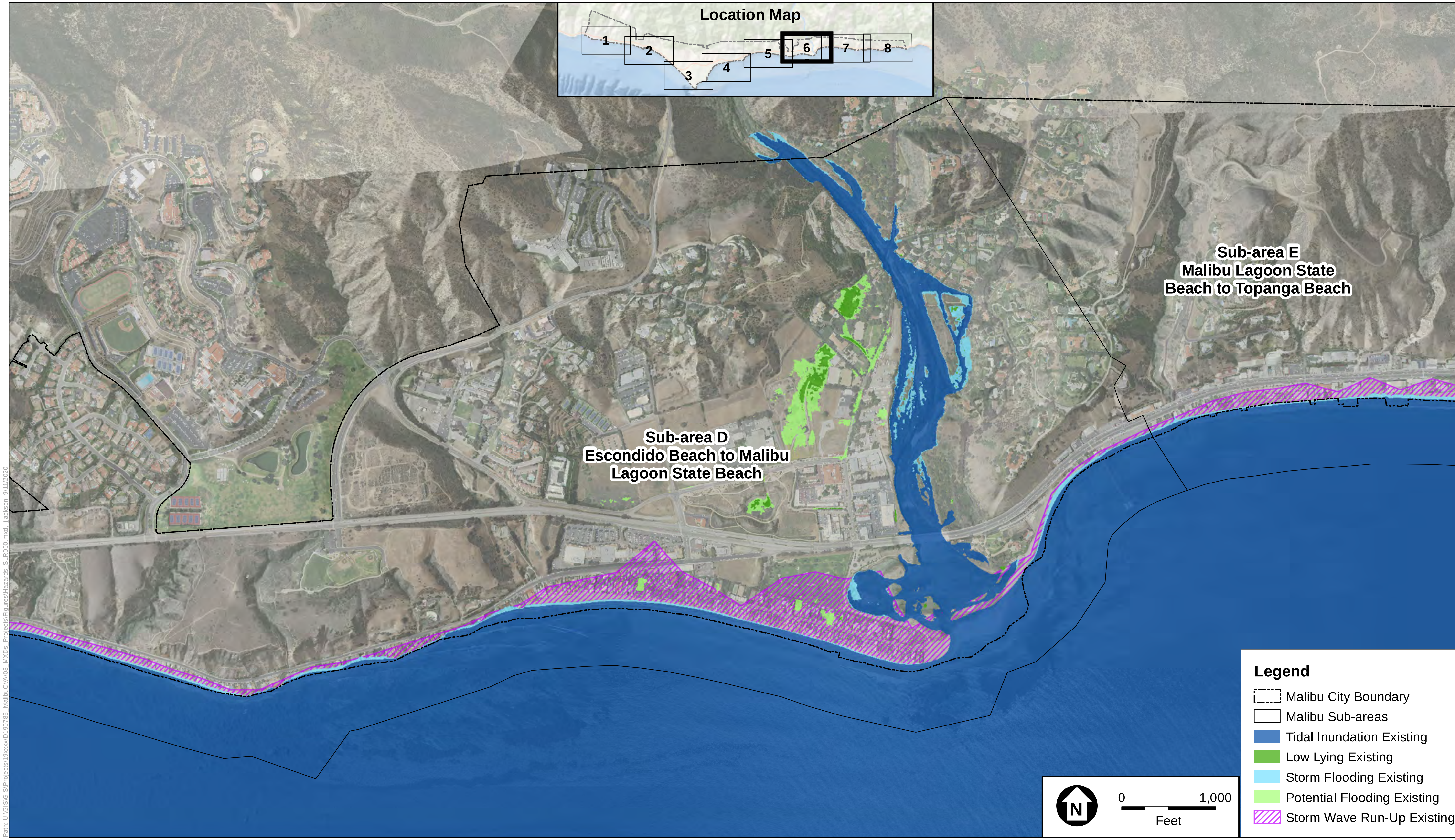
NOTE:

ESA

Figure C1-5
Coastal Hazard Exposure Map
Existing Sea Level



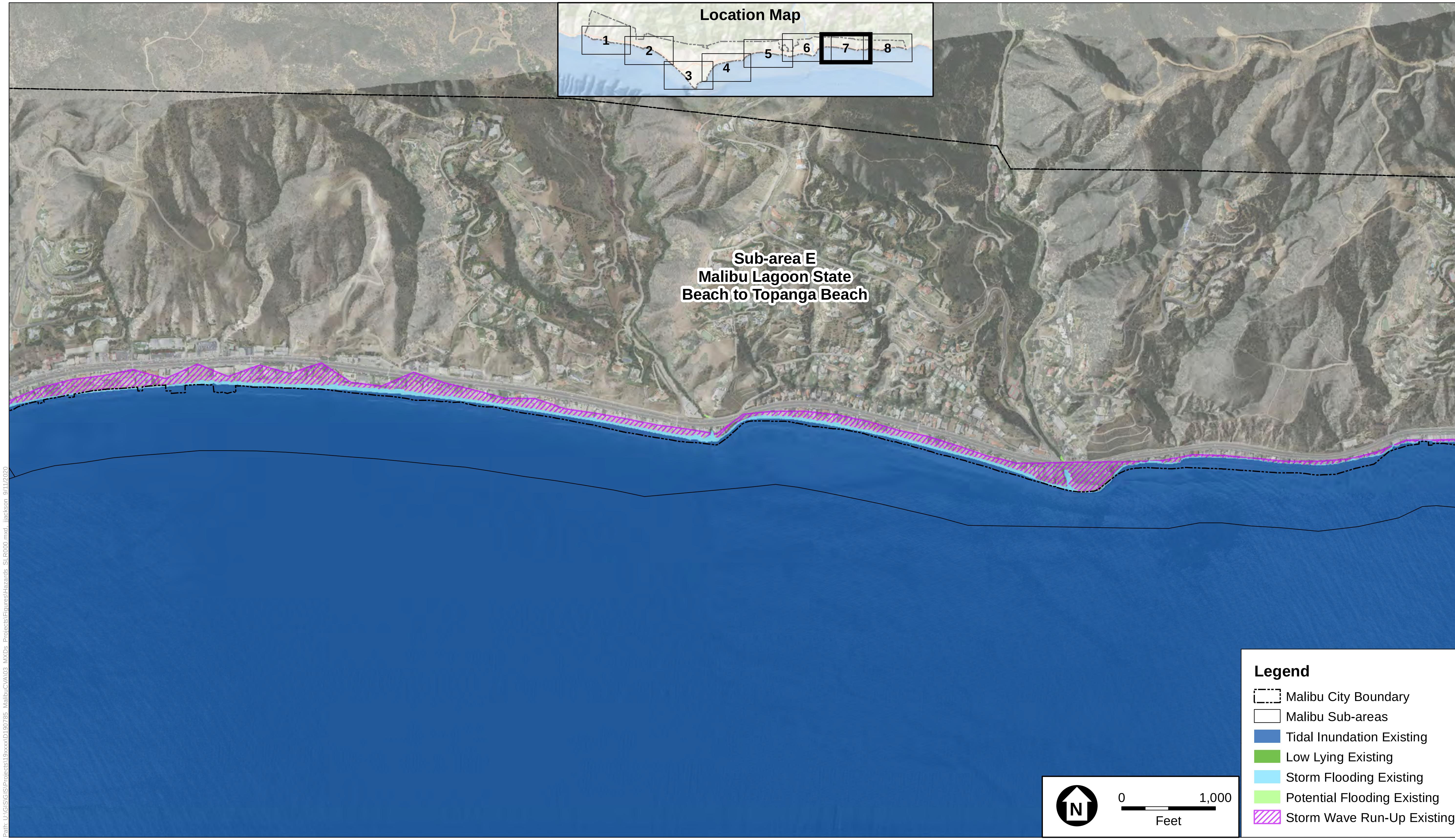
SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

ESA

Malibu Coastal Vulnerability Assessment . 190785.00

Figure C1-6
Coastal Hazard Exposure Map
Existing Sea Level



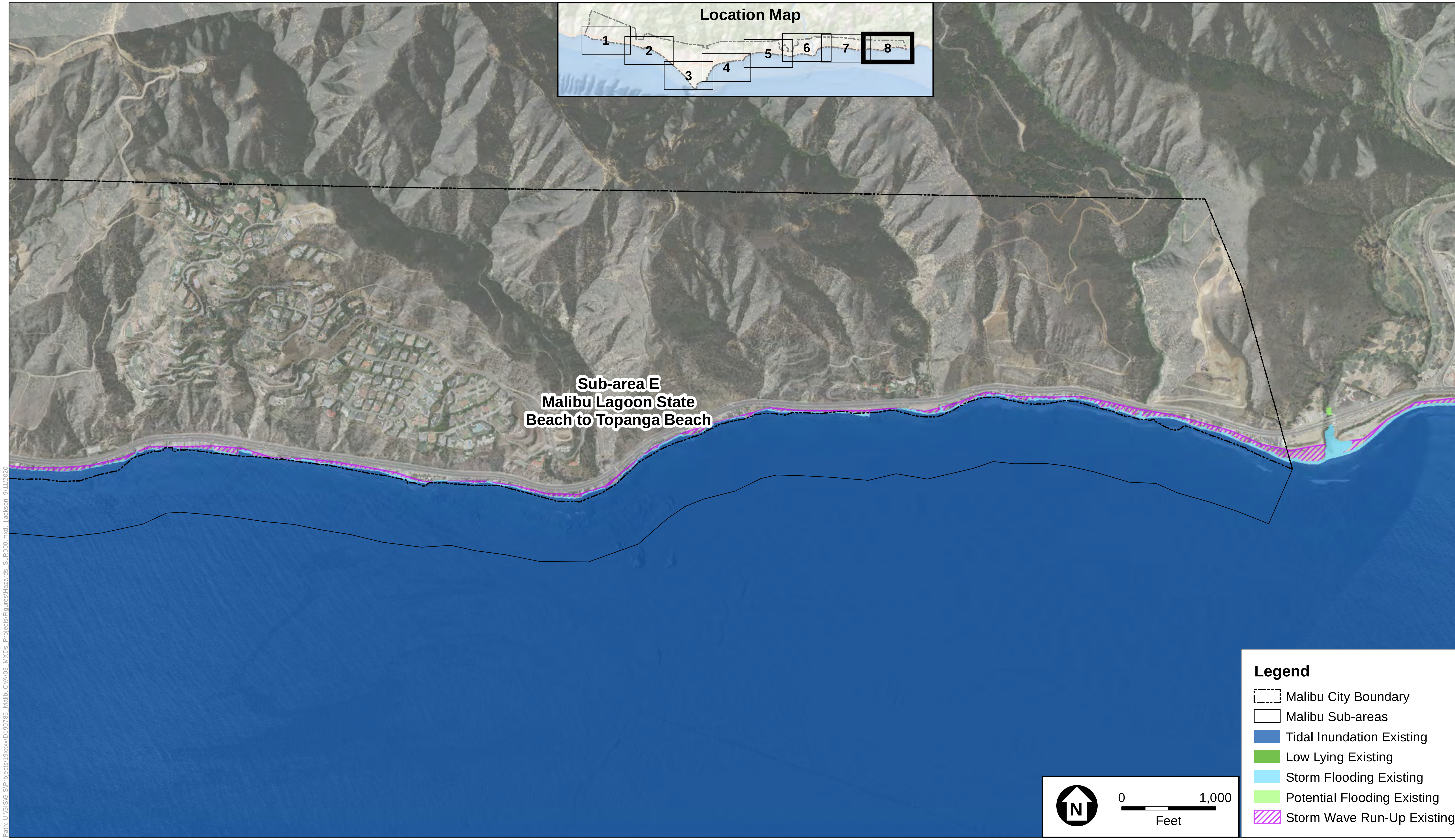
SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

Malibu Coastal Vulnerability Assessment . 190785.00

NOTE:

ESA

Figure C1-7
Coastal Hazard Exposure Map
Existing Sea Level



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

Malibu Coastal Vulnerability Assessment . 190785.00

NOTE:

ESA

Figure C1-8
Coastal Hazard Exposure Map
Existing Sea Level

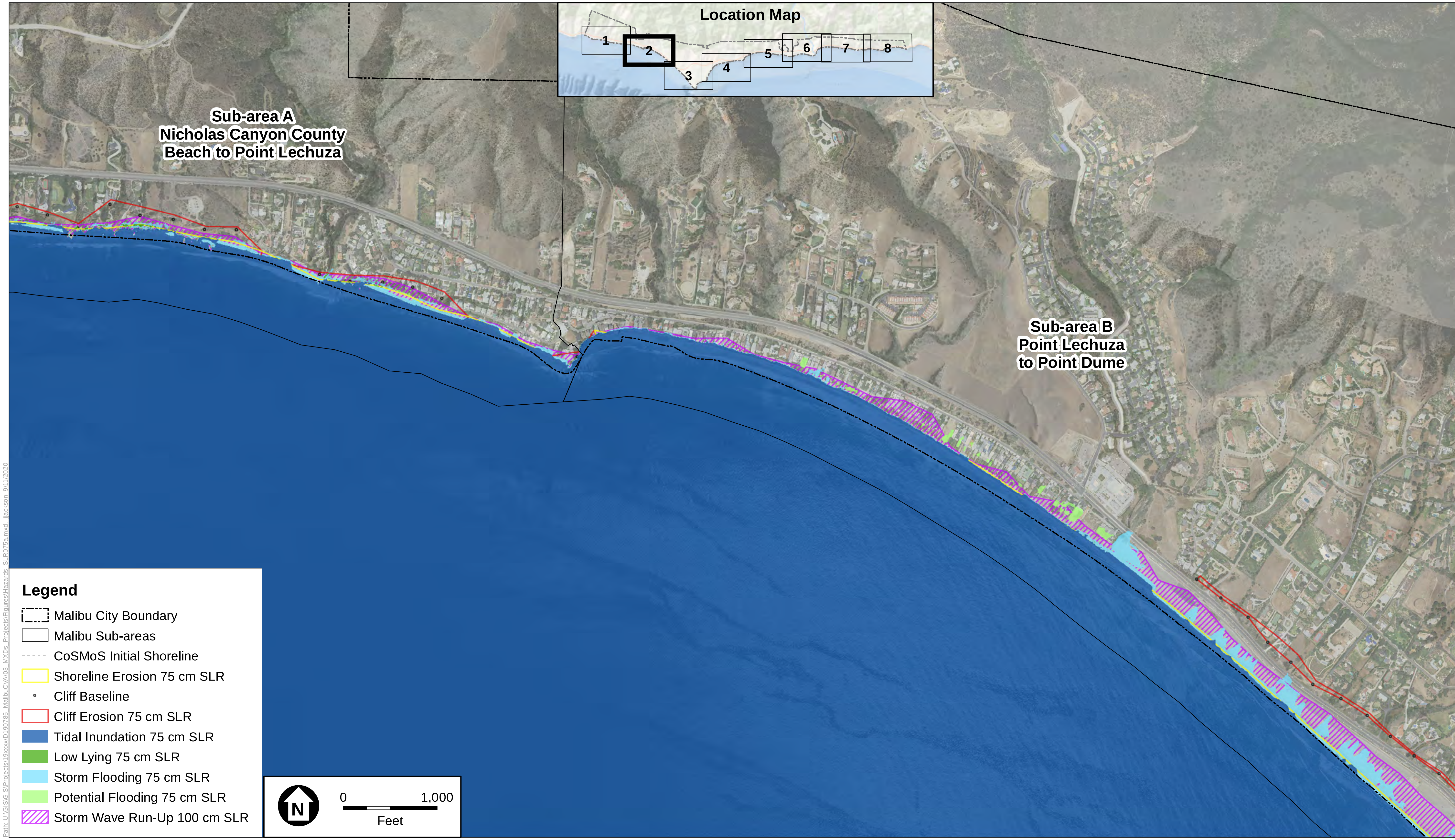
SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

Malibu Coastal Vulnerability Assessment . 190785.00

Figure C2-1
Potential Mid Century Coastal Hazard Exposure
Map 2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated
for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

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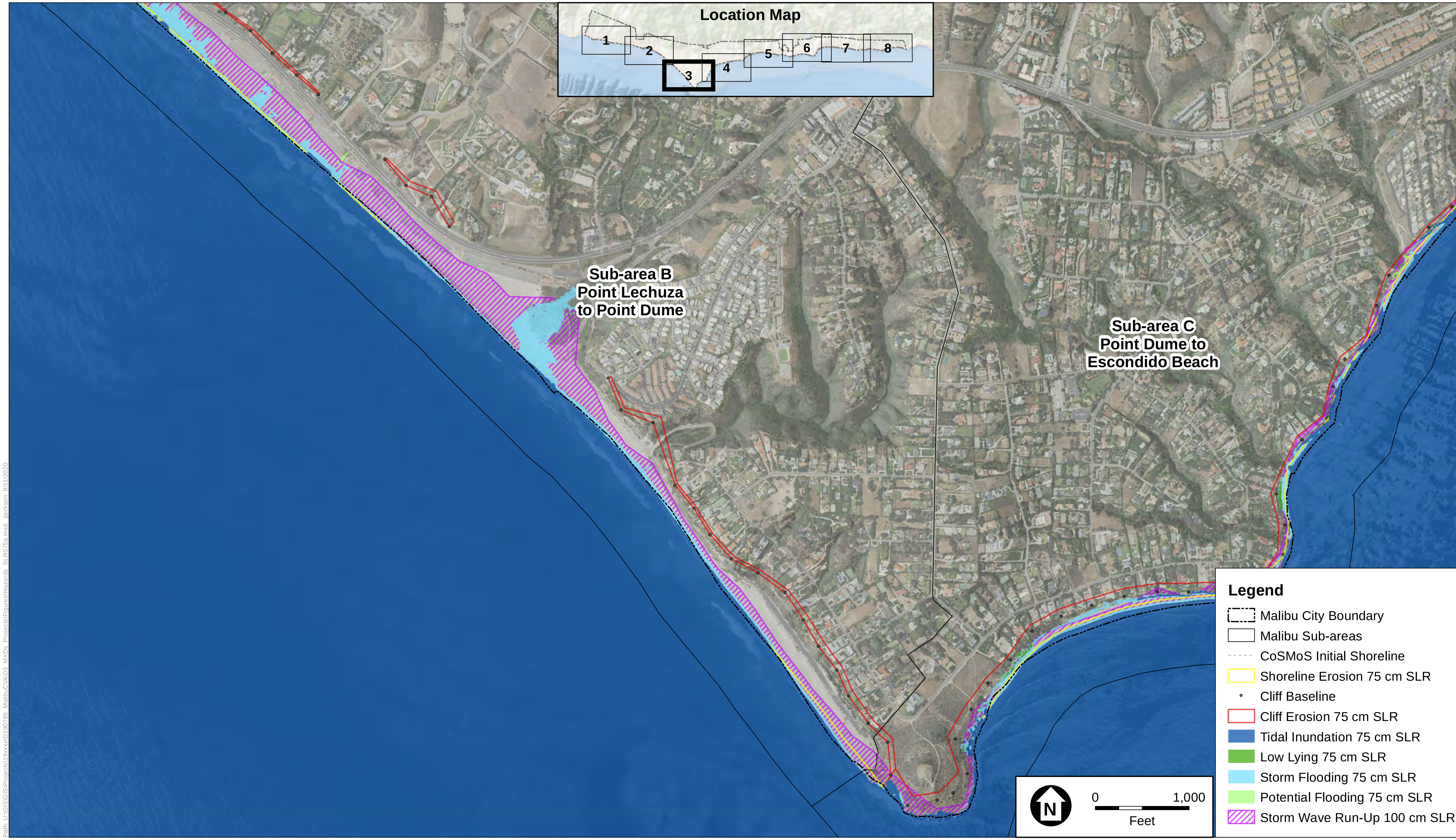
Figure C2-2
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

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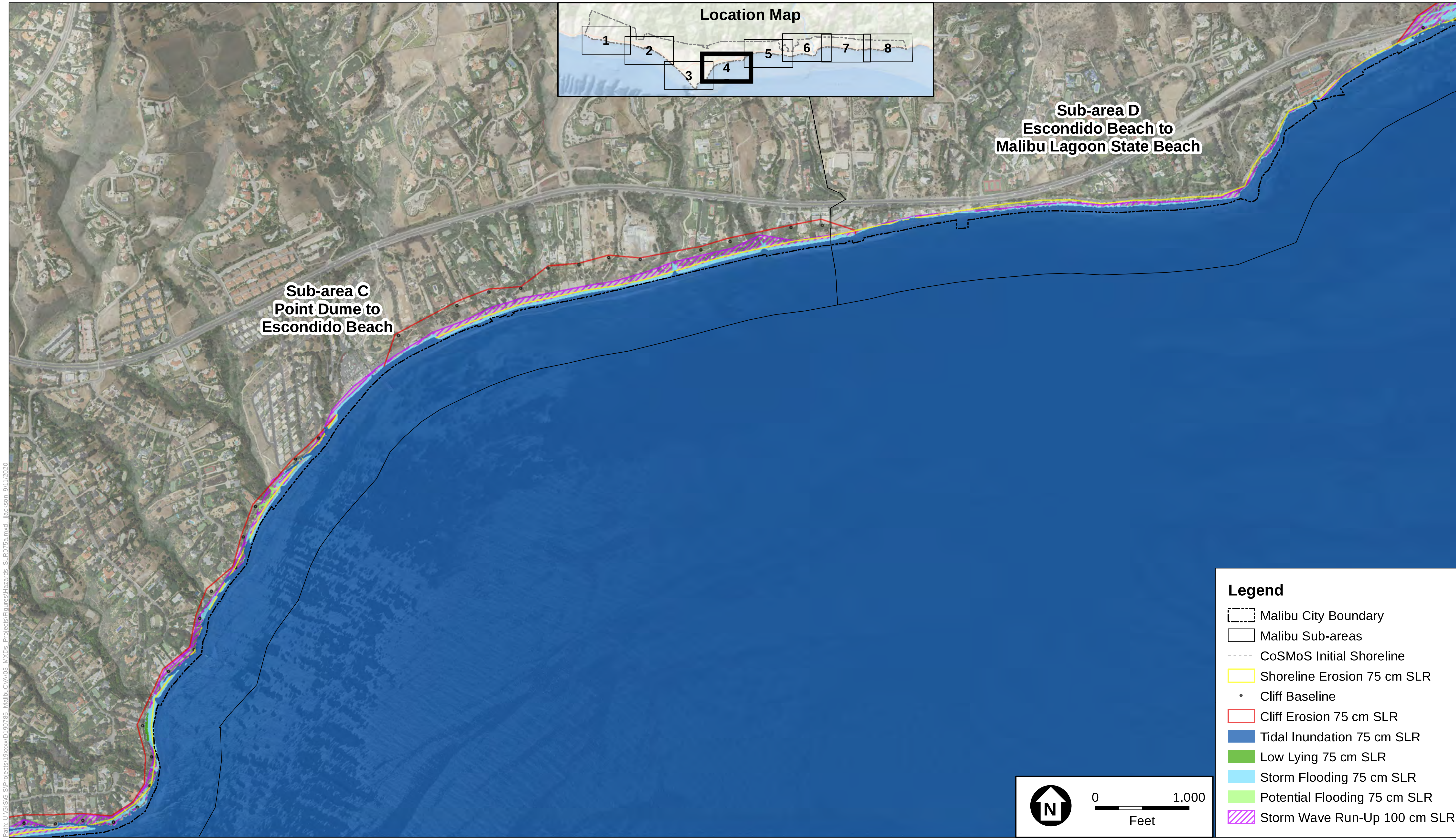
Figure C2-3
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise

ESA



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated
for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

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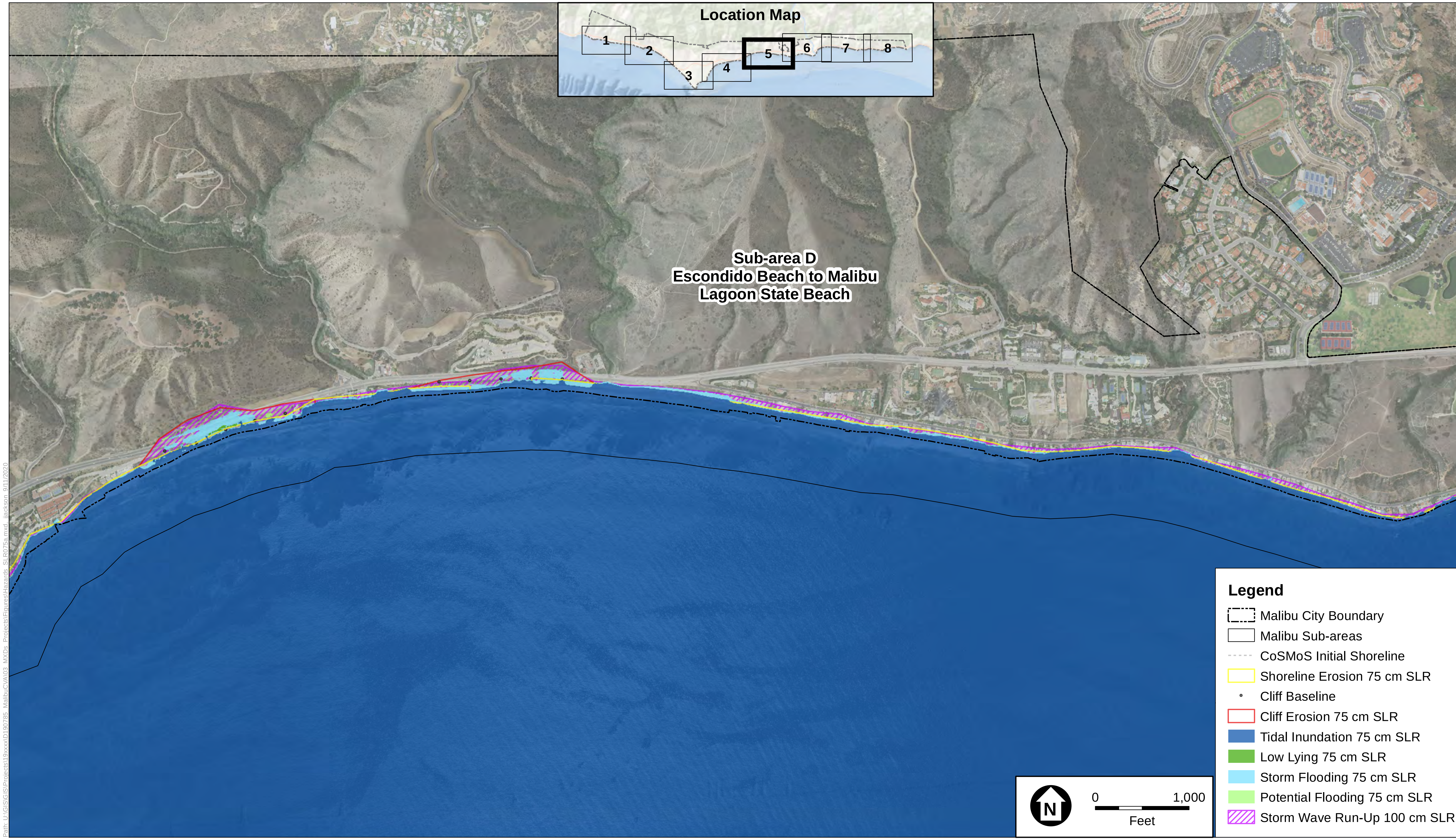
Figure C2-4
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated
for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

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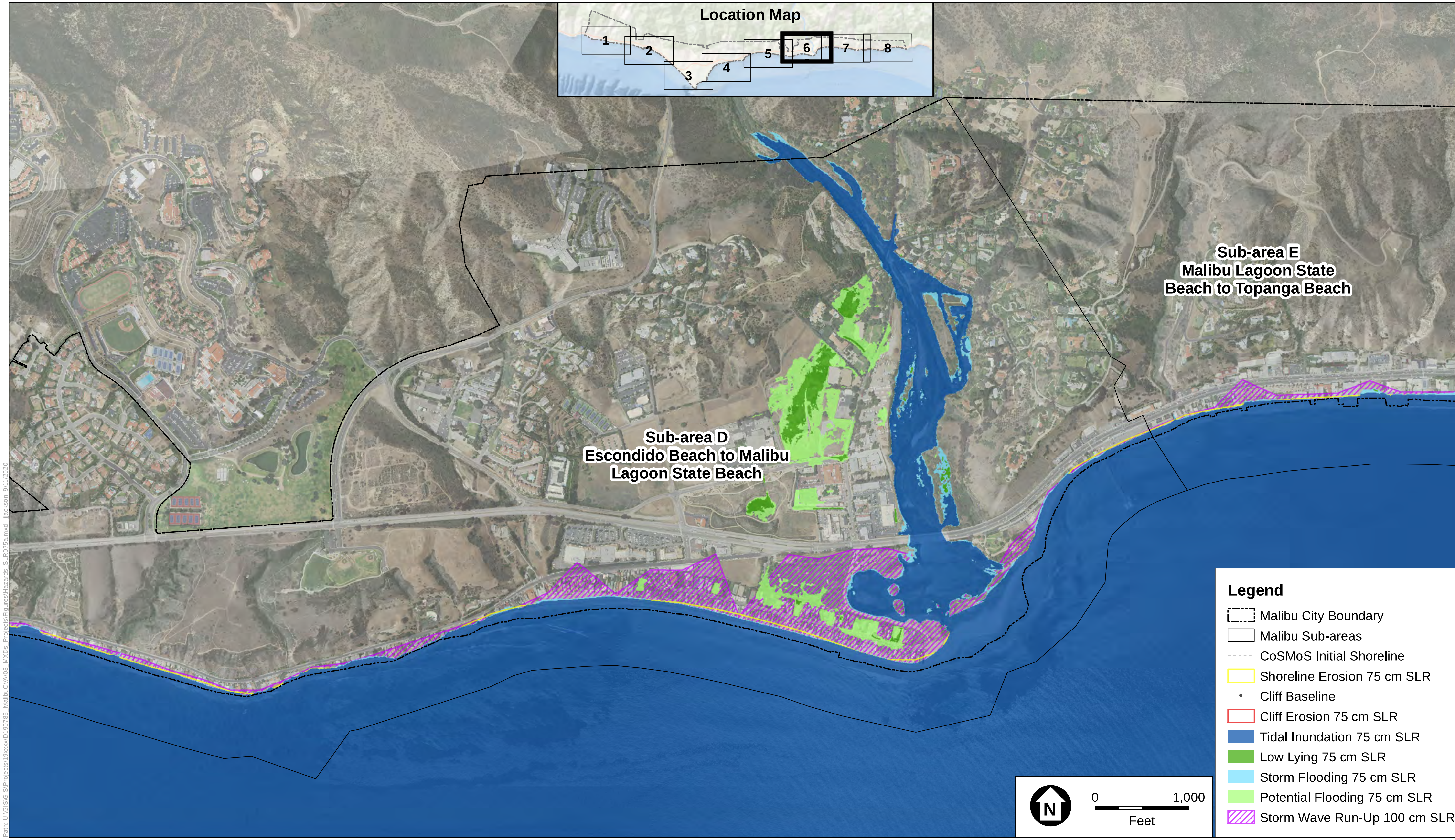
Figure C2-5
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

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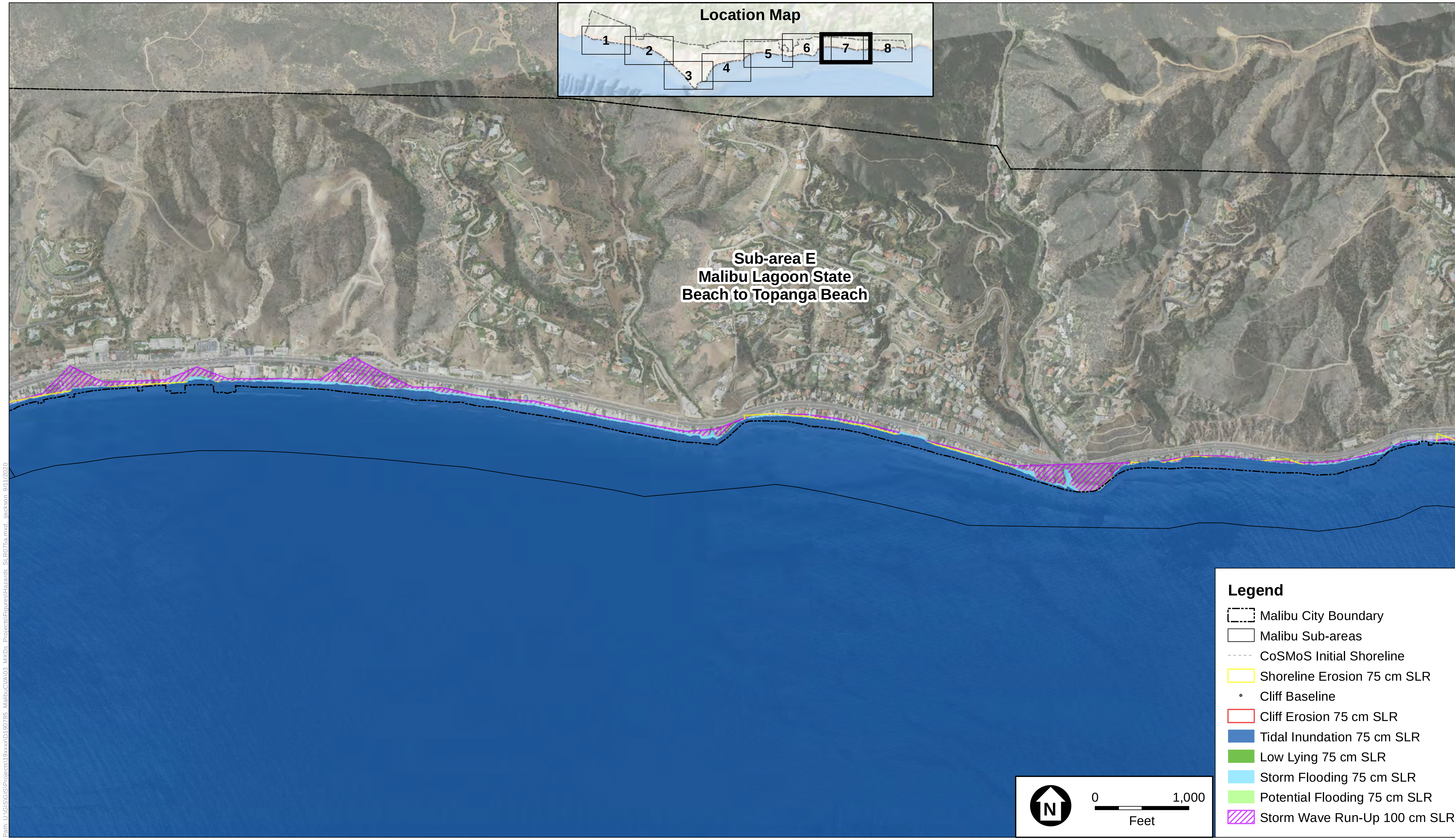
Figure C2-6
Potential Mid Century Coastal Hazard Exposure
Map 2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

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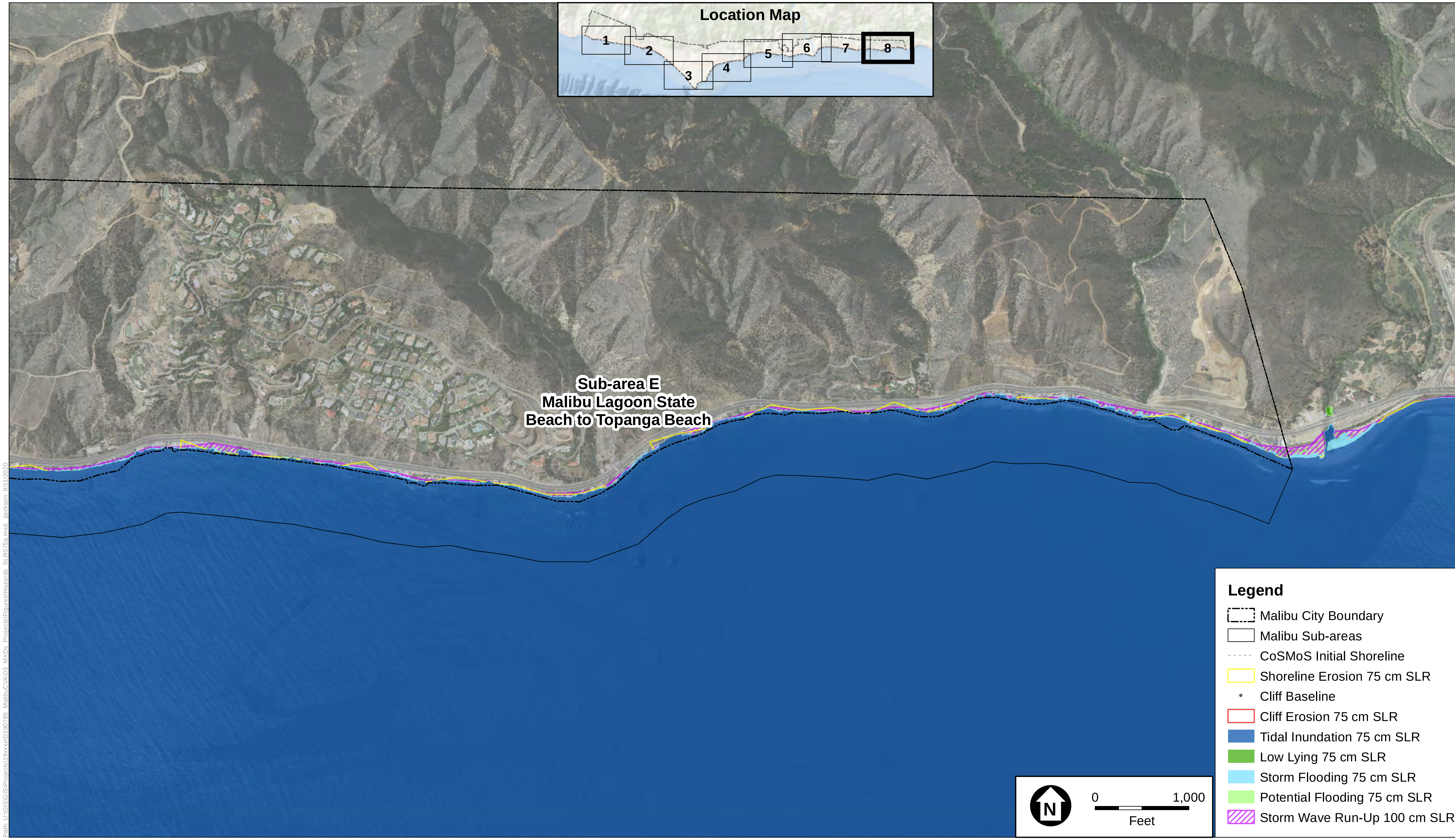
Figure C2-7
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE: CoSMoS wave run-up results were not generated for 0.75 m SLR, so wave run-up results for 1 m SLR are used.

ESA

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Figure C2-8
Potential Mid Century Coastal Hazard Exposure Map
2.5 ft (0.75 m) Sea-Level Rise

SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

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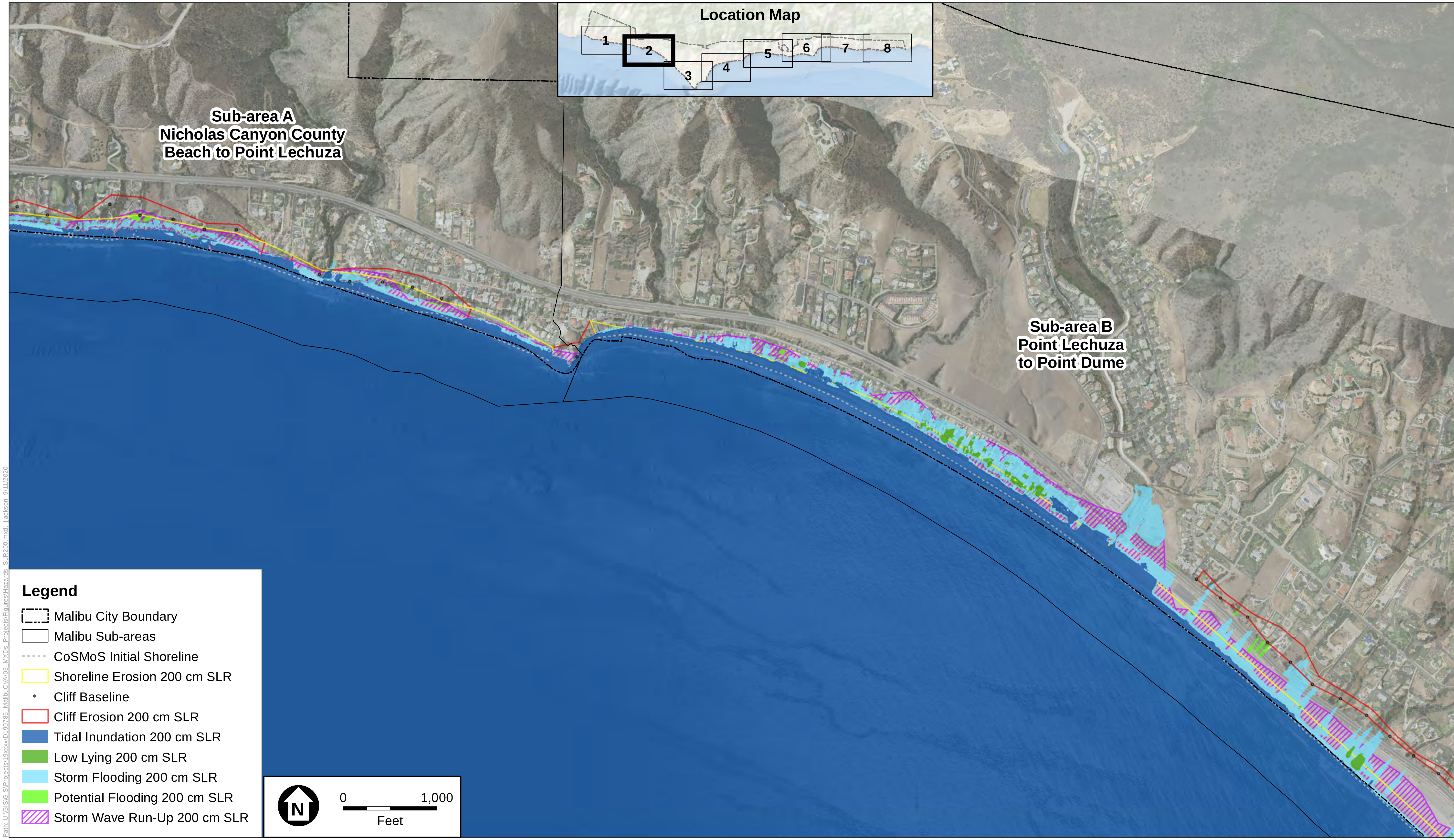
Figure C3-1
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

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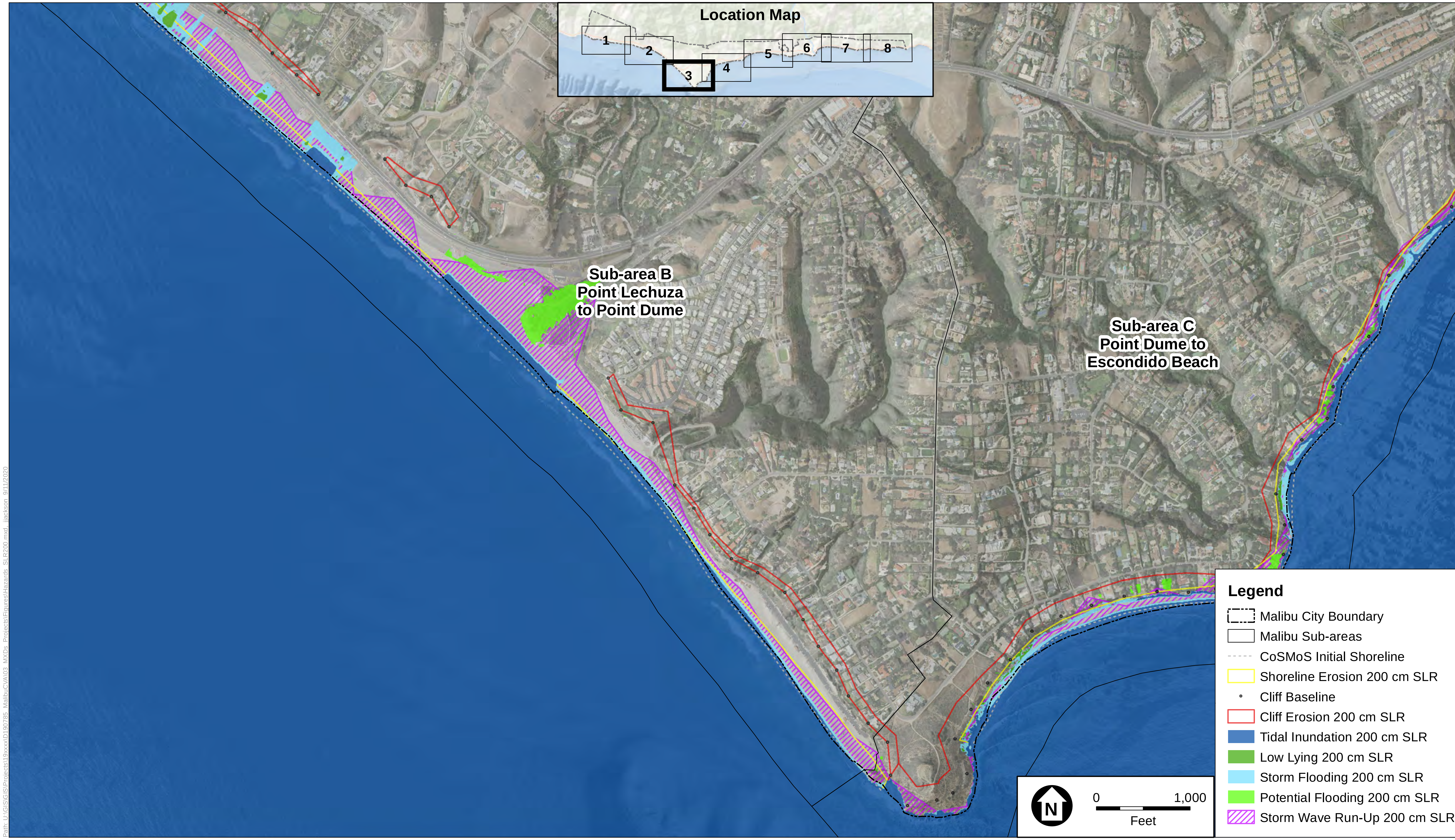
Figure C3-2
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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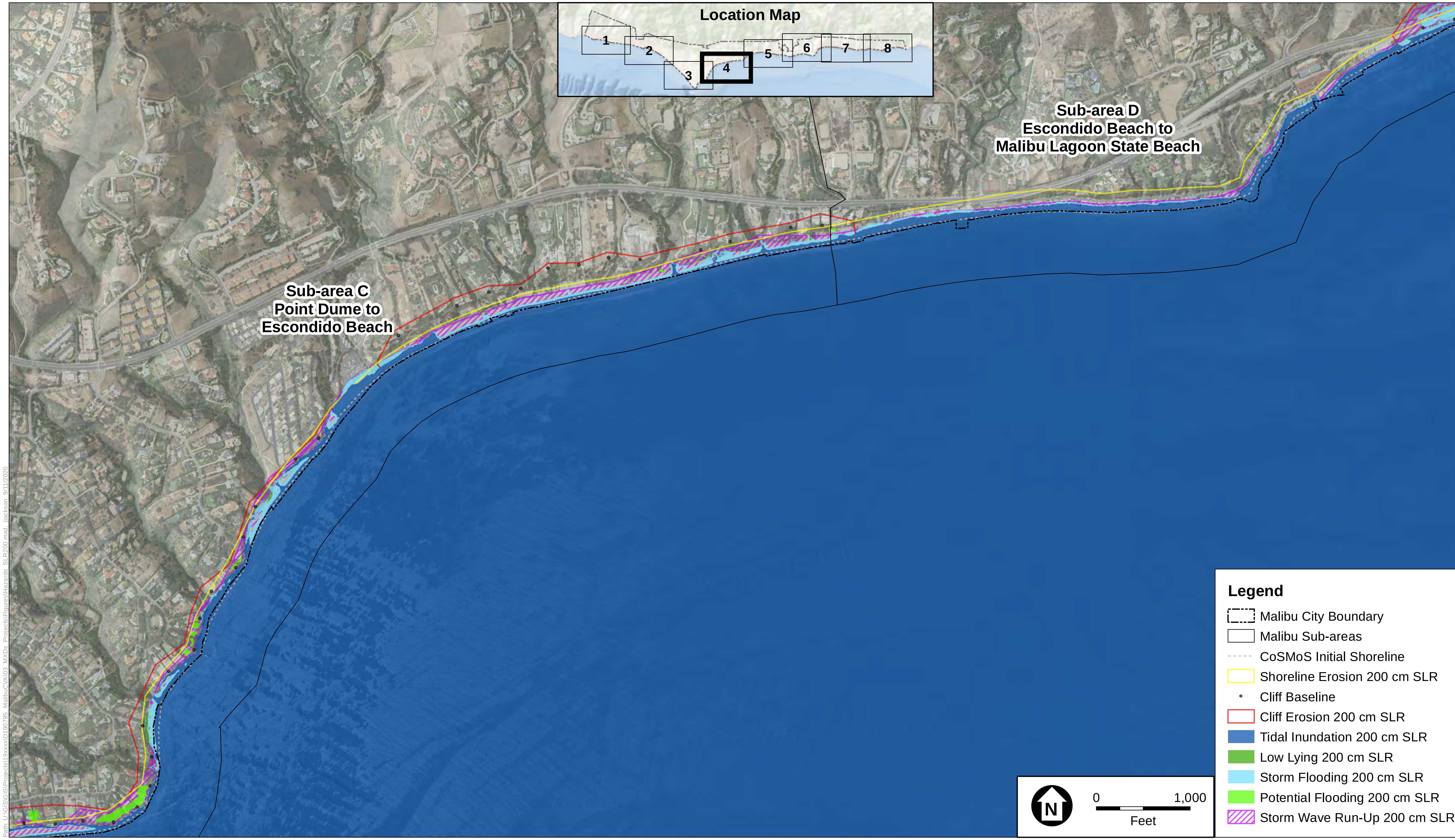
NOTE:

ESA

Figure C3-3
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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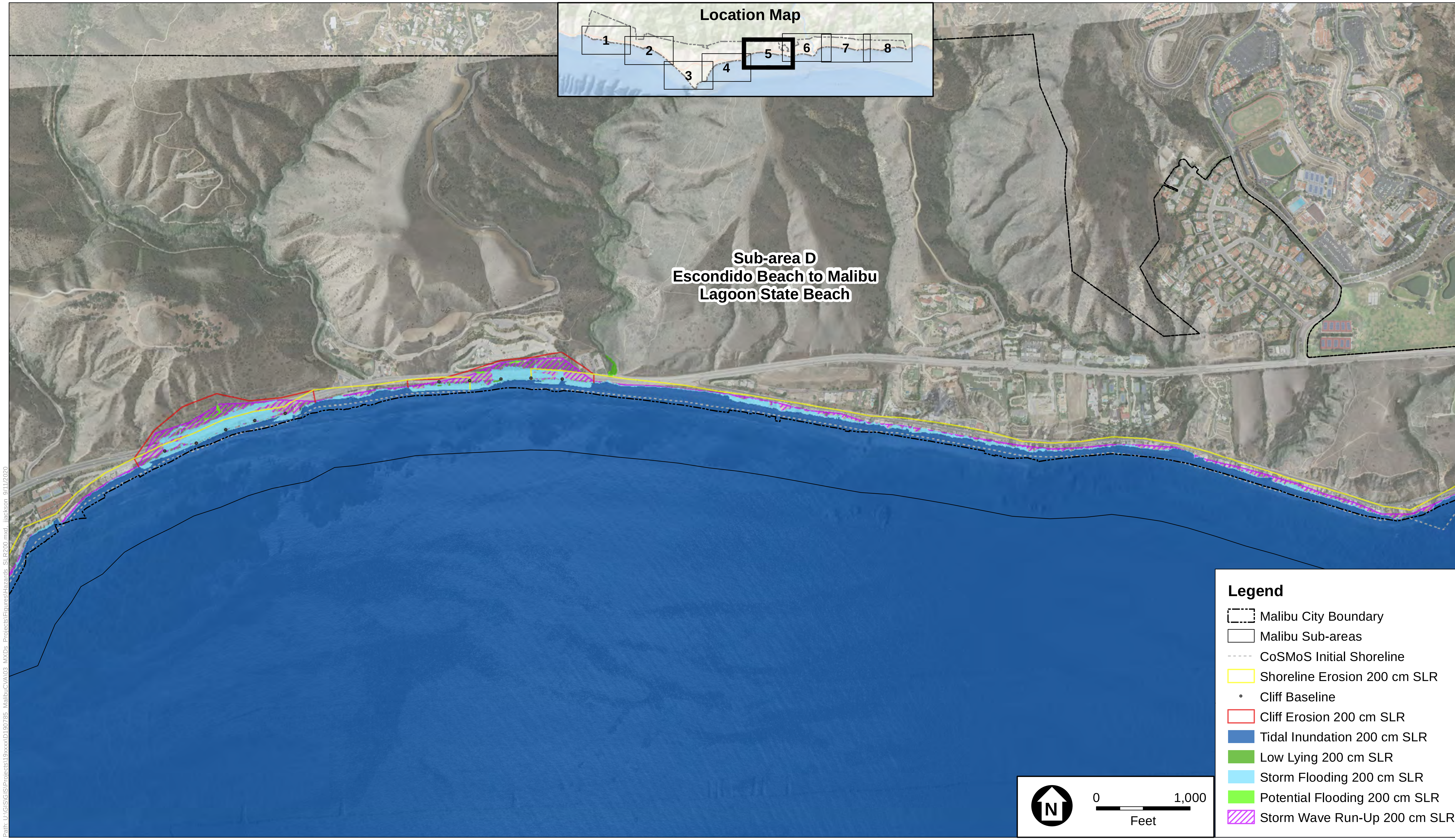
NOTE:

Figure C3-4
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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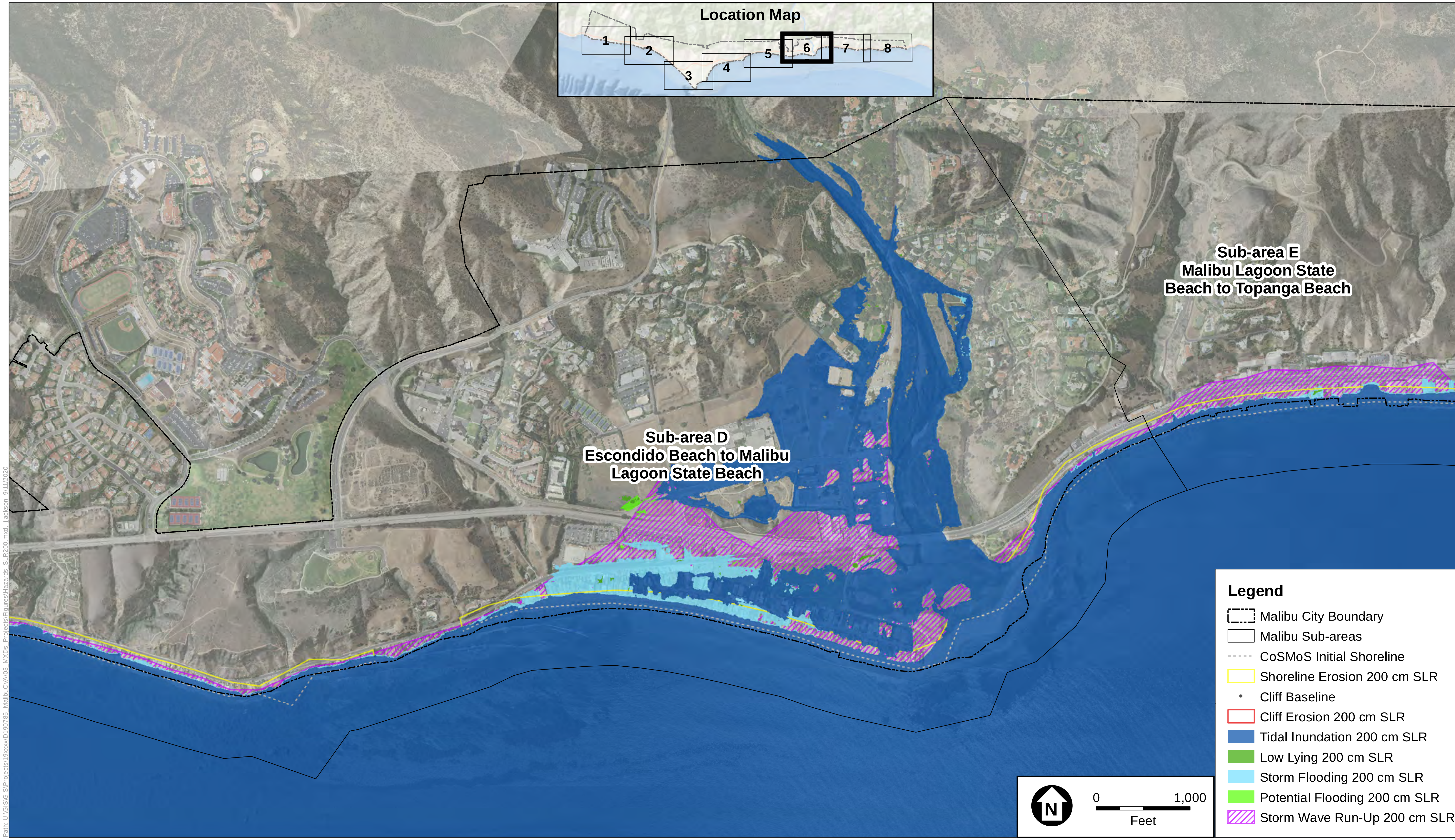
NOTE:

ESA

Figure C3-5
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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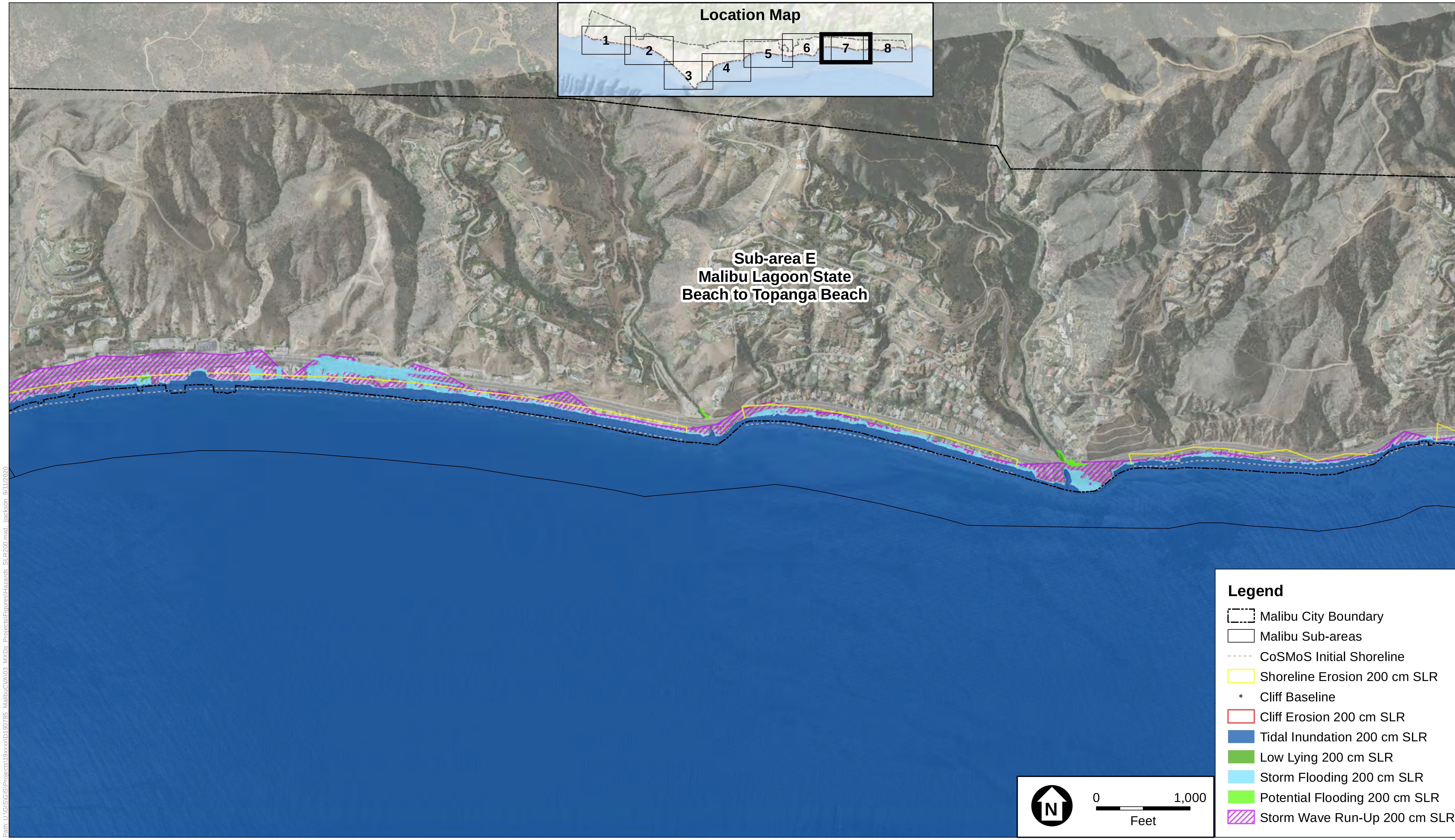
NOTE:

ESA

Figure C3-6
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

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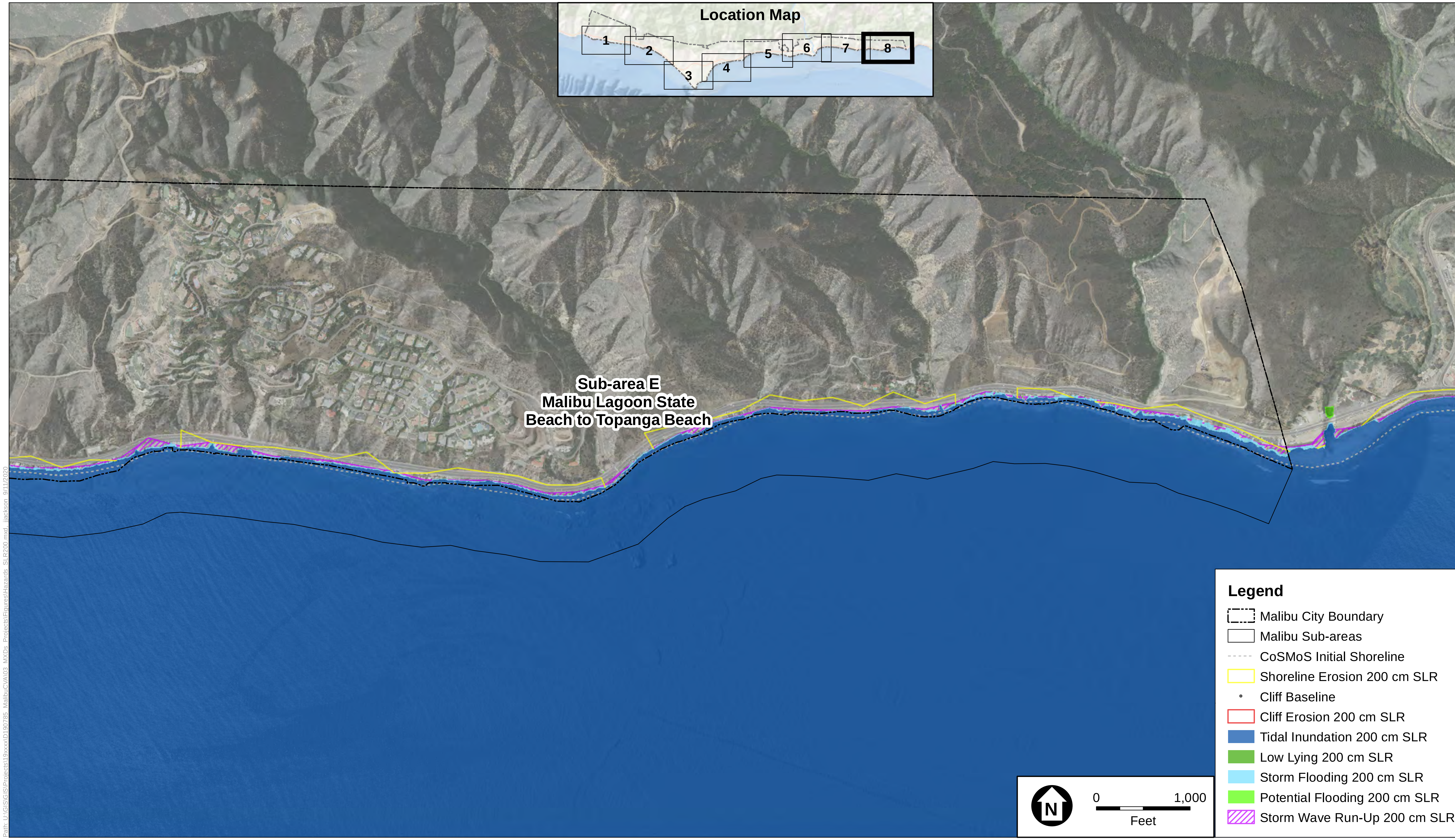
NOTE:

ESA

Figure C3-7
Potential Late Century Coastal Hazard Exposure Map
6.6 ft (2 m) Sea-Level Rise



SOURCE: USGS, NAIP, ESRI, ESA, City of Malibu

NOTE:

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Figure C3-8

Potential Late Century Coastal Hazard Exposure Map

6.6 ft (2 m) Sea-Level Rise

Appendix D

Malibu Asset Exposure Maps (Assets with overlaid Hazards)

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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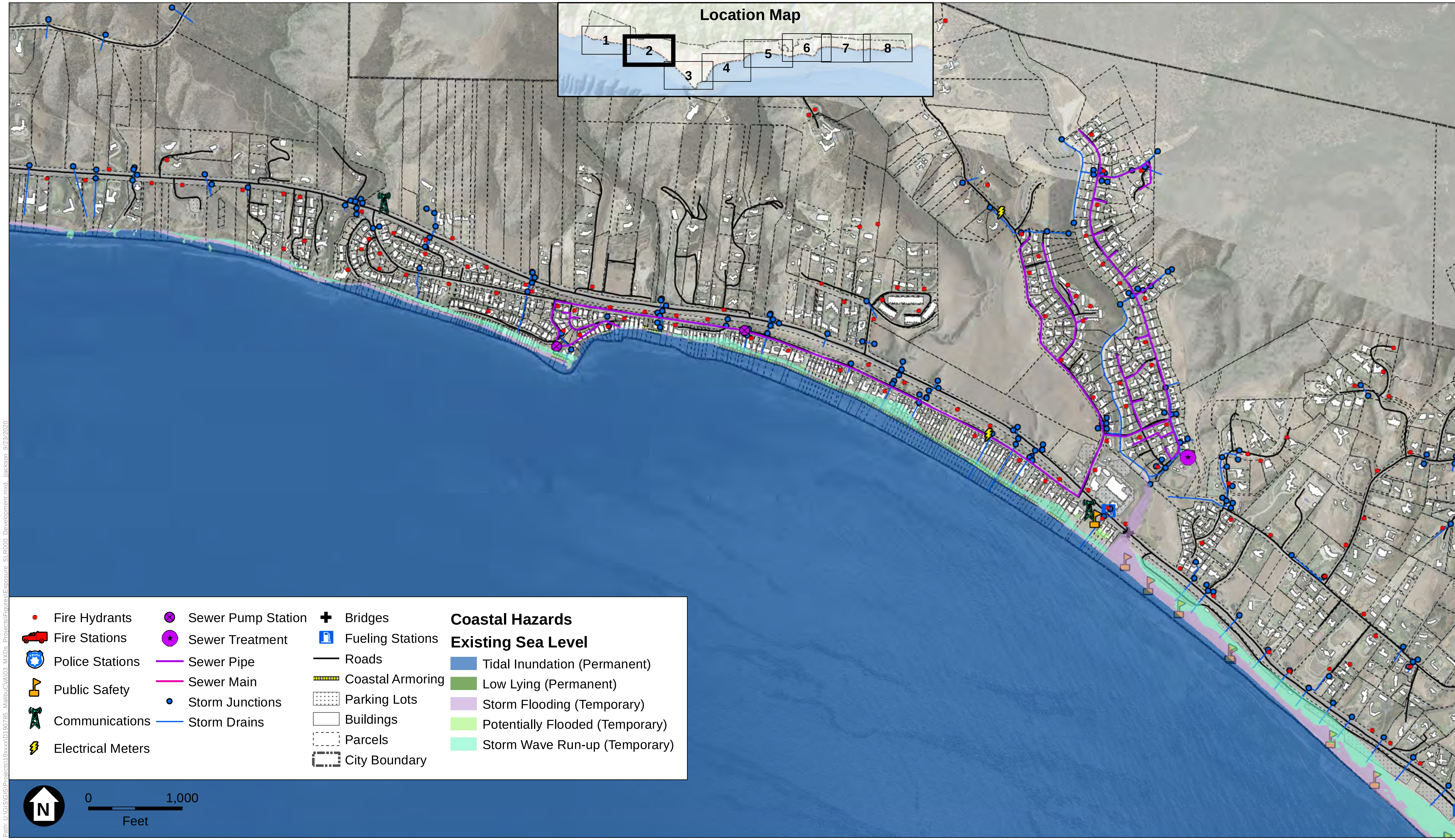
Figure D1-1
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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Figure D1-2
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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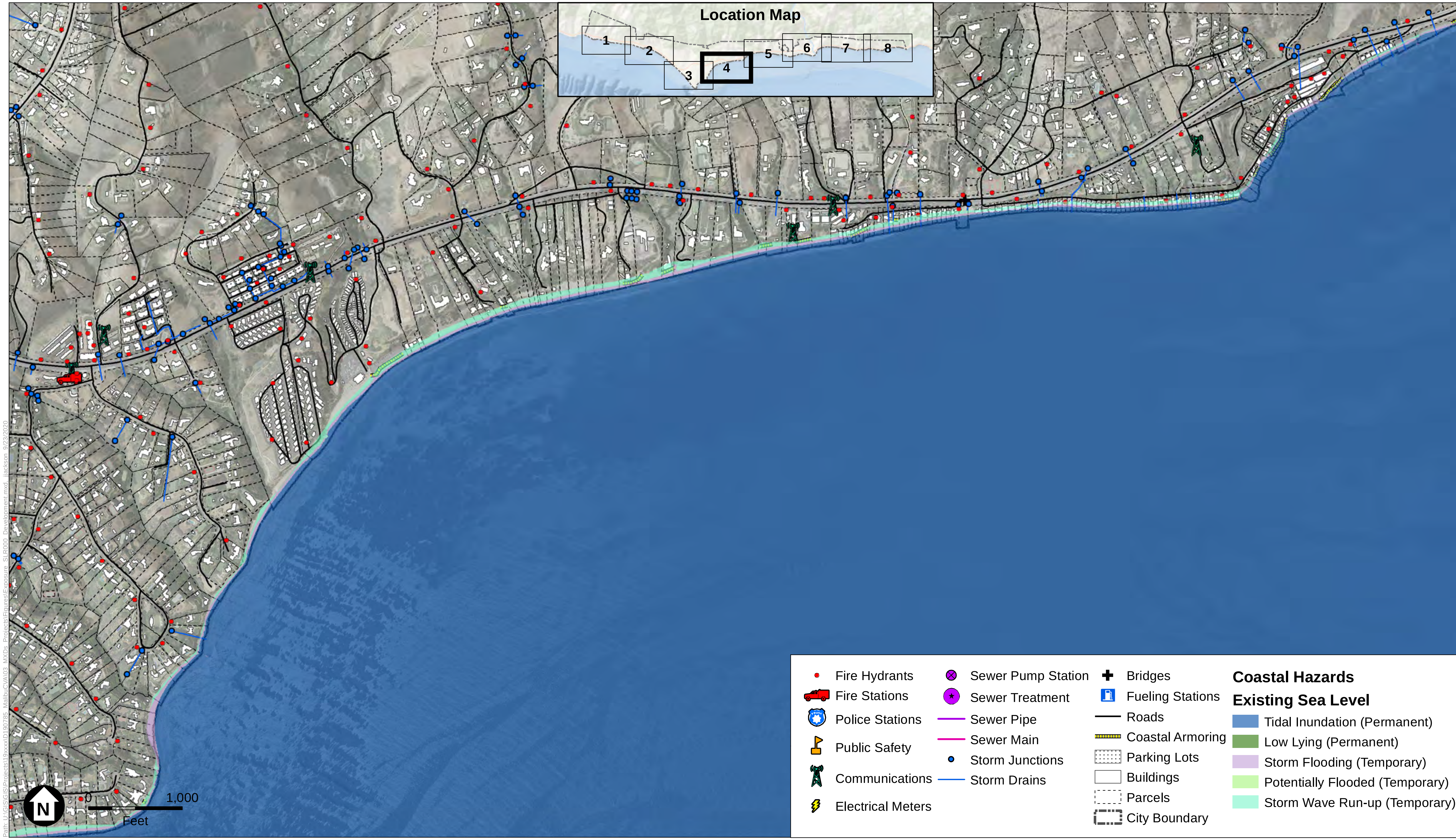
Figure D1-3
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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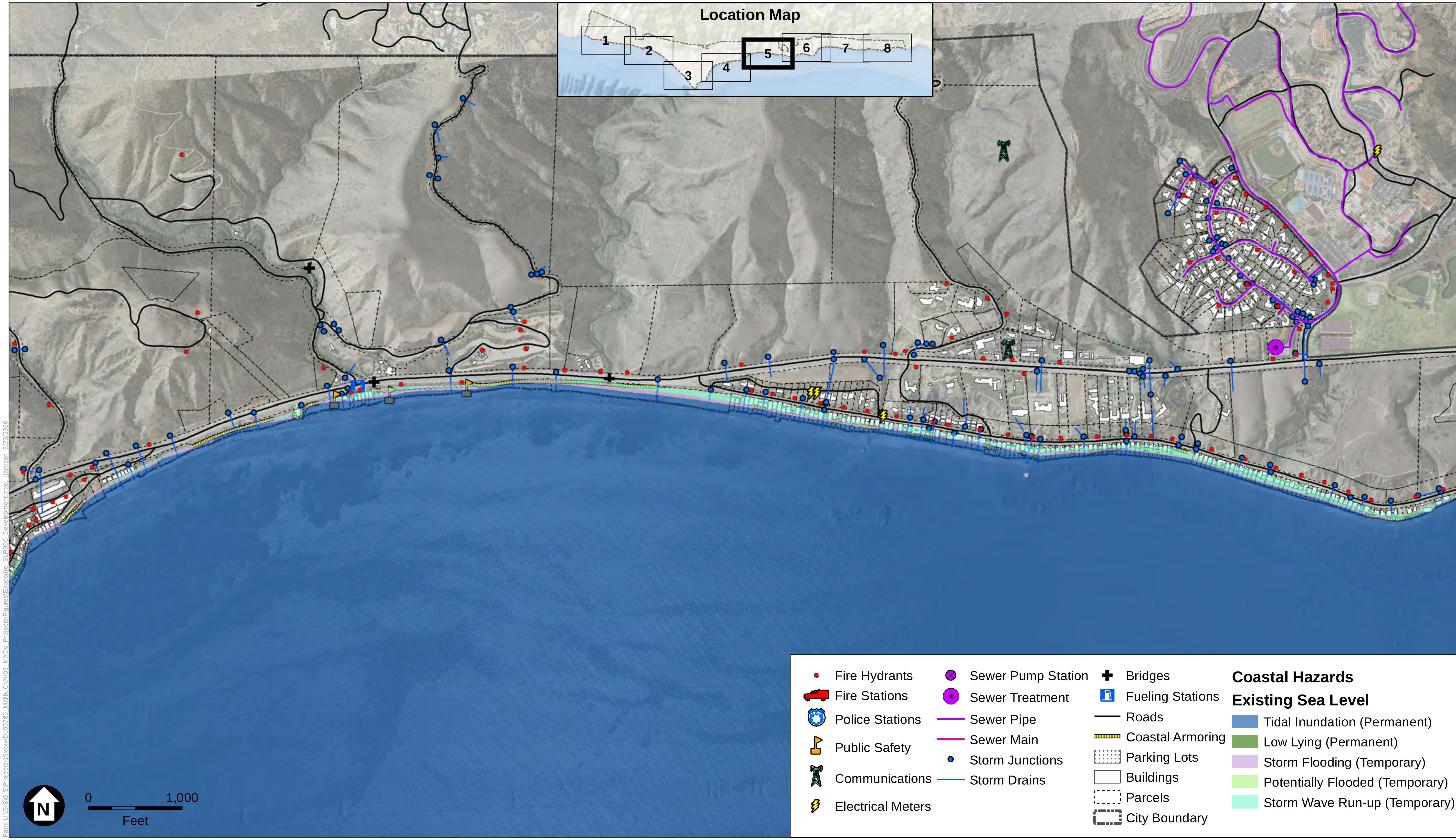
Figure D1-4
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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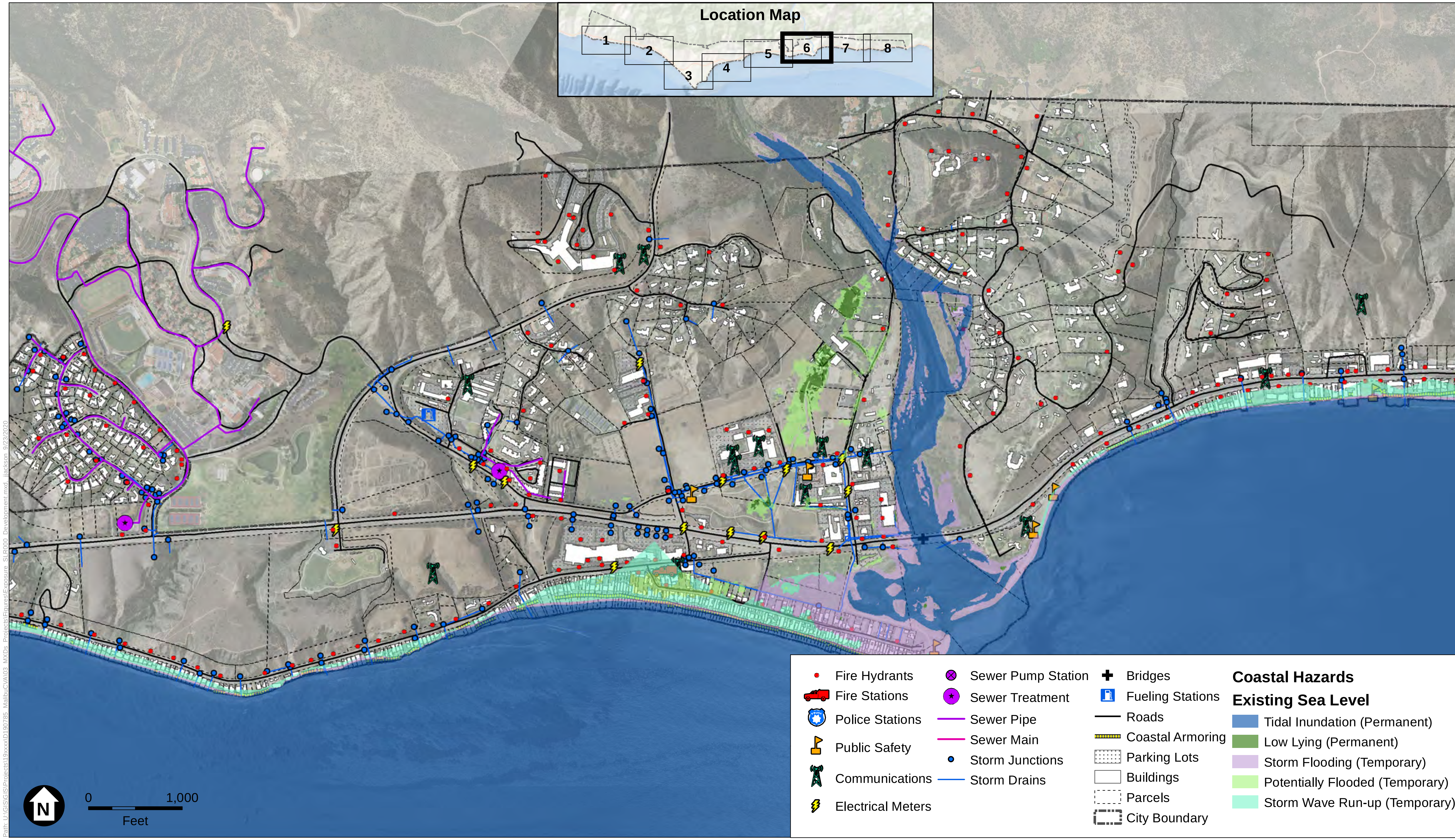
Figure D1-5
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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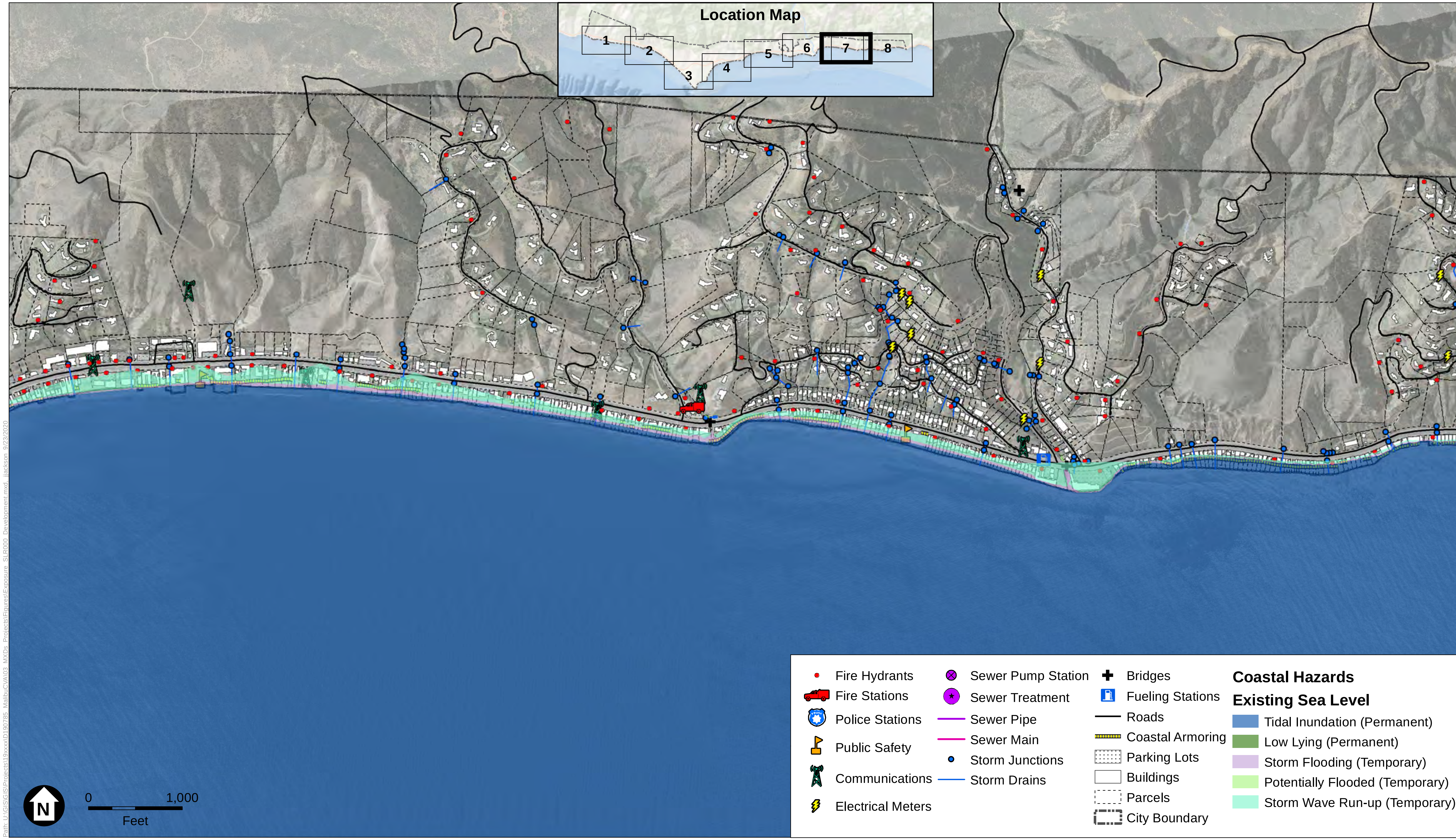
Figure D1-6
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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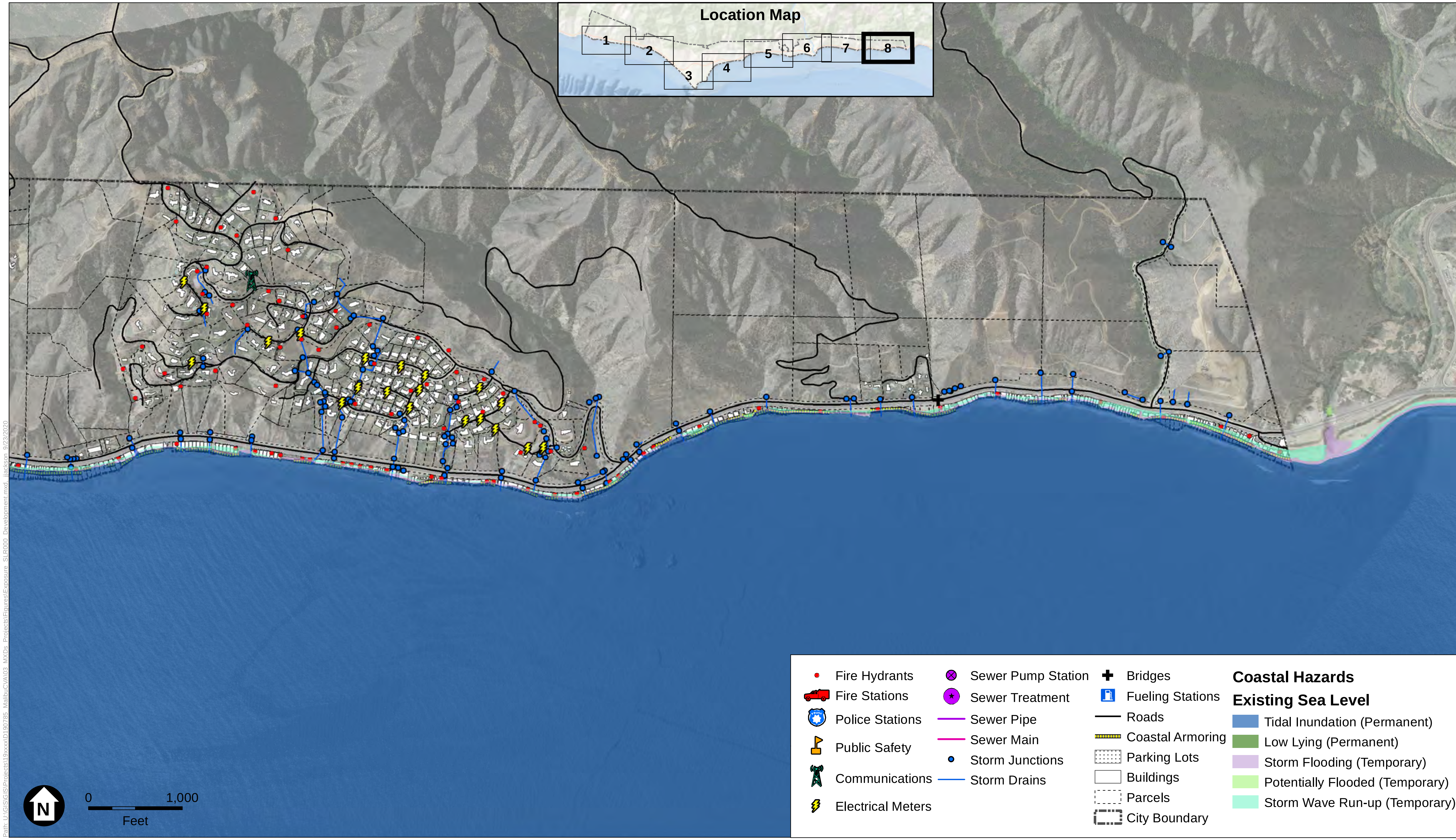
Figure D1-7
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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Figure D1-8
Malibu Exposure Map for Existing Sea Level
Development and Infrastructure

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

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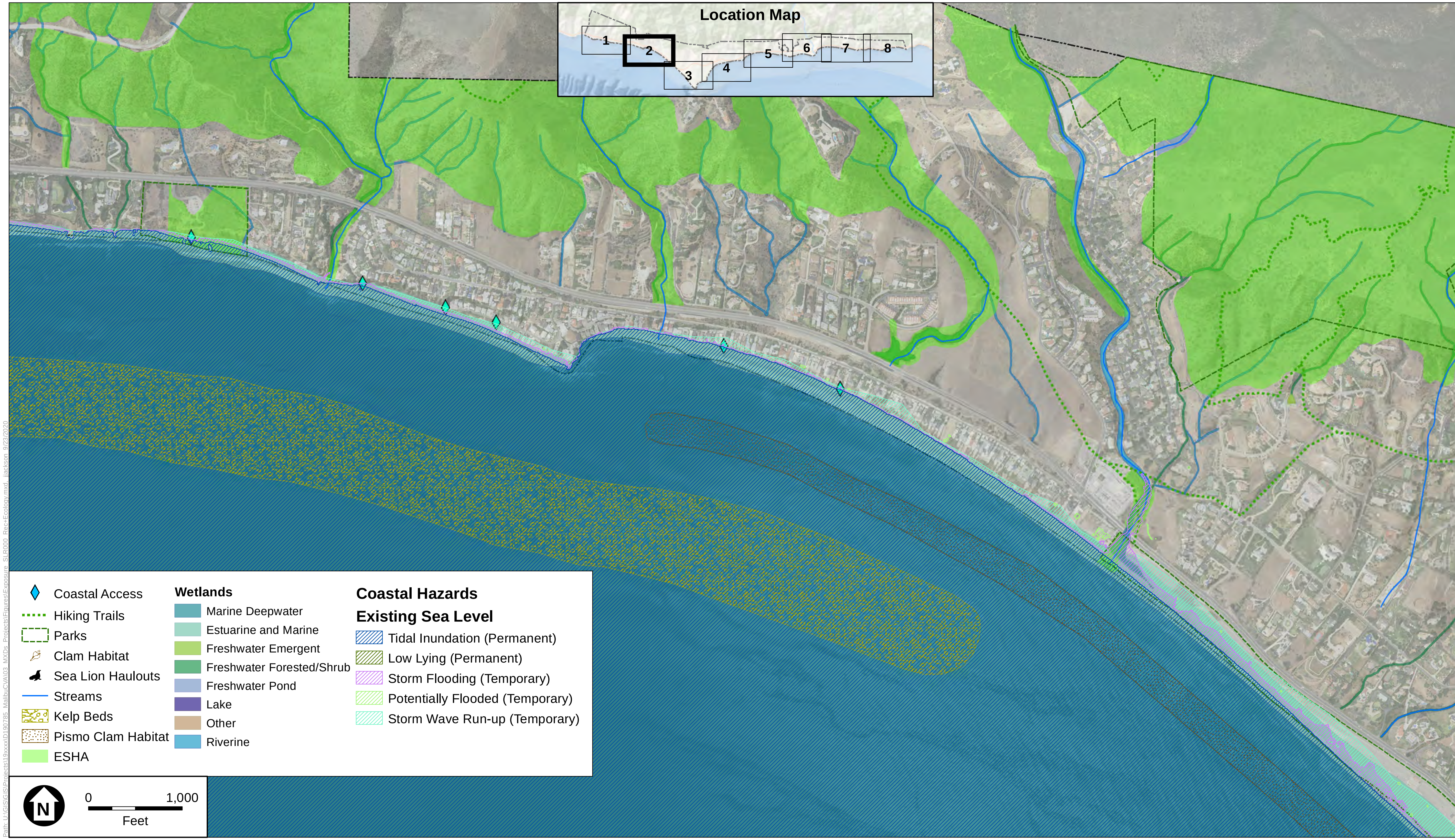
Figure D1-9
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D1-10
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

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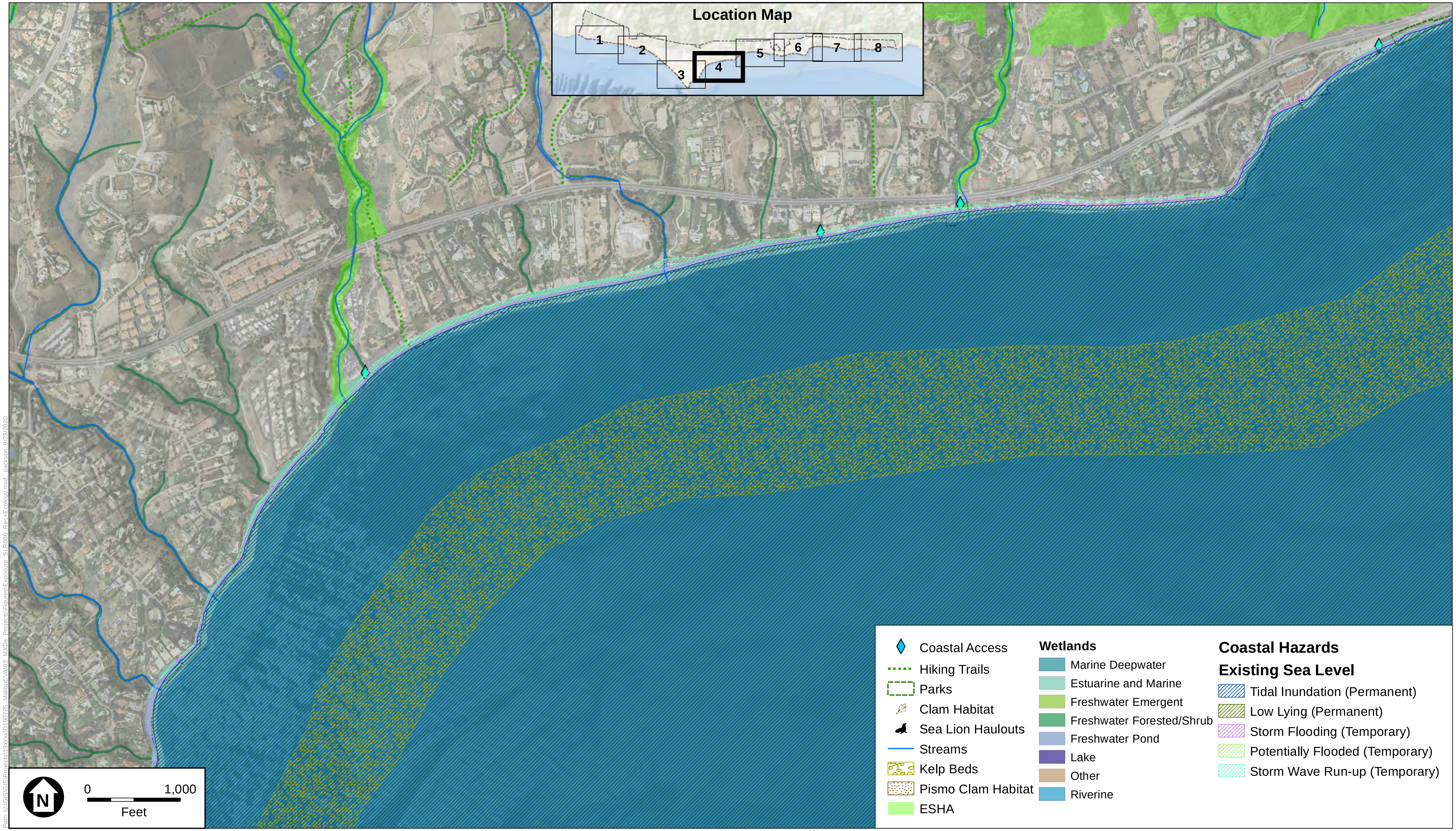
Figure D1-11
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology

ESA

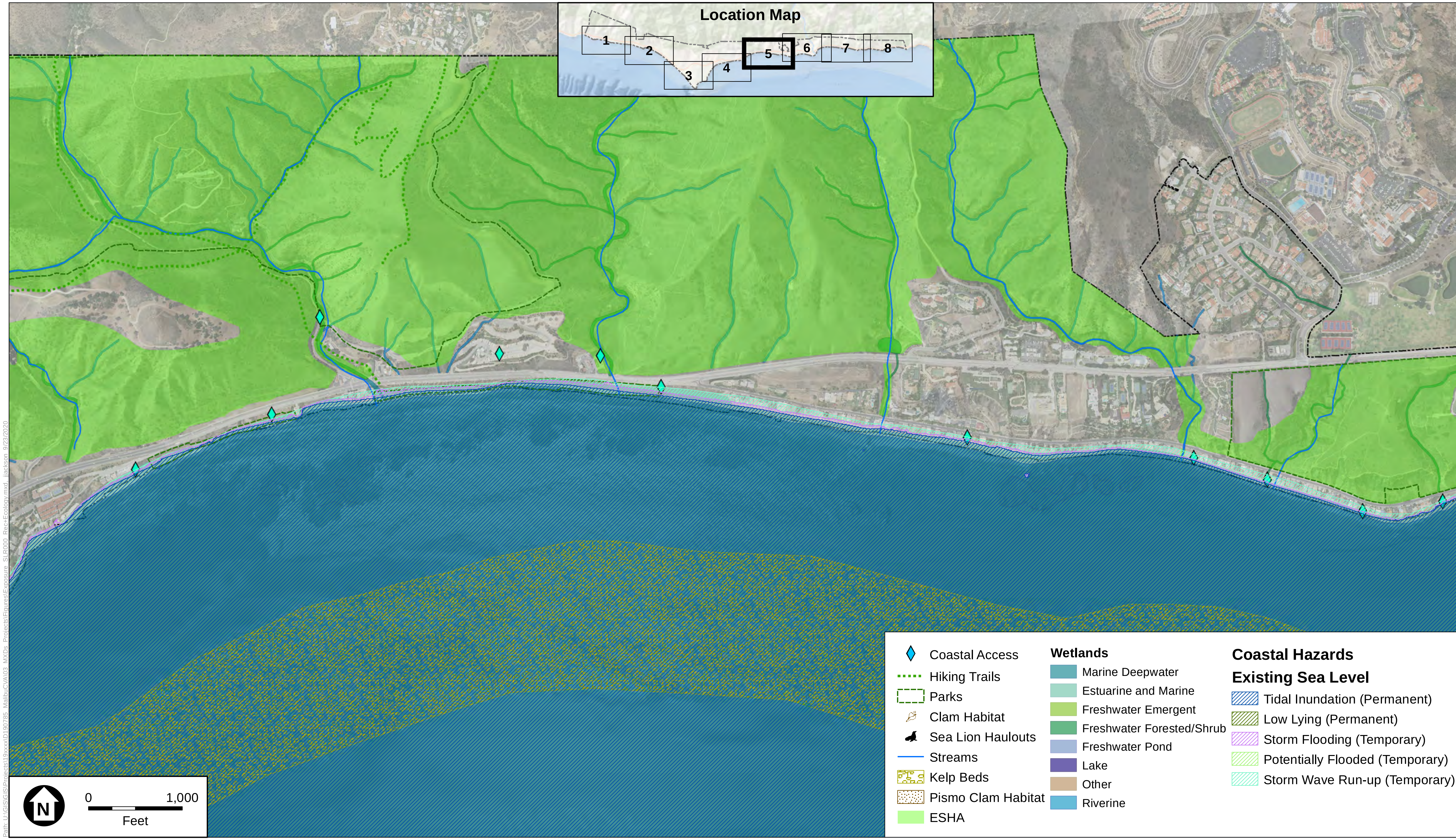


SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

ESA

Figure D1-12
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology Assets

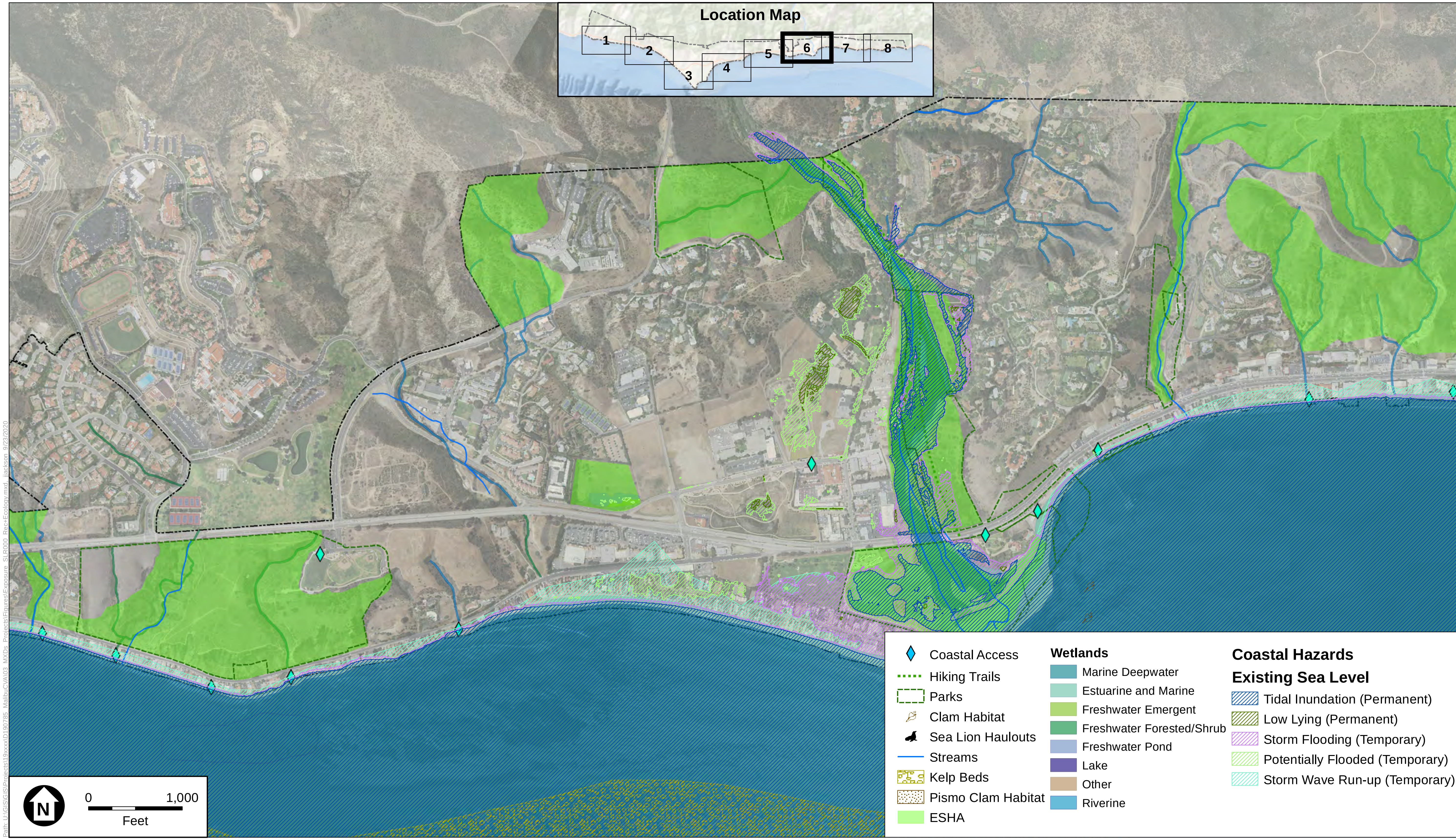


SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D1-13
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology Assets

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

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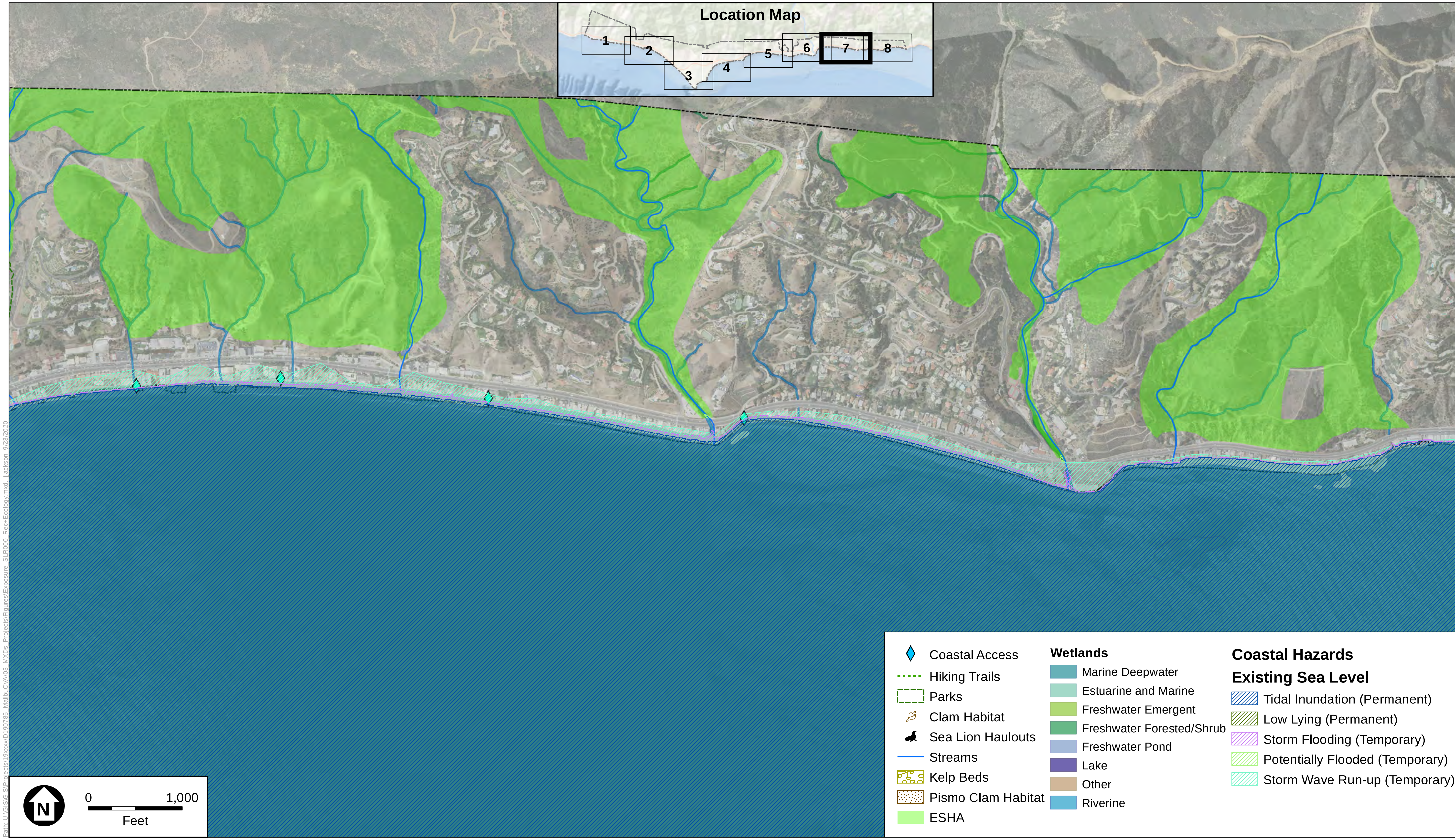
Figure D1-14
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology Assets

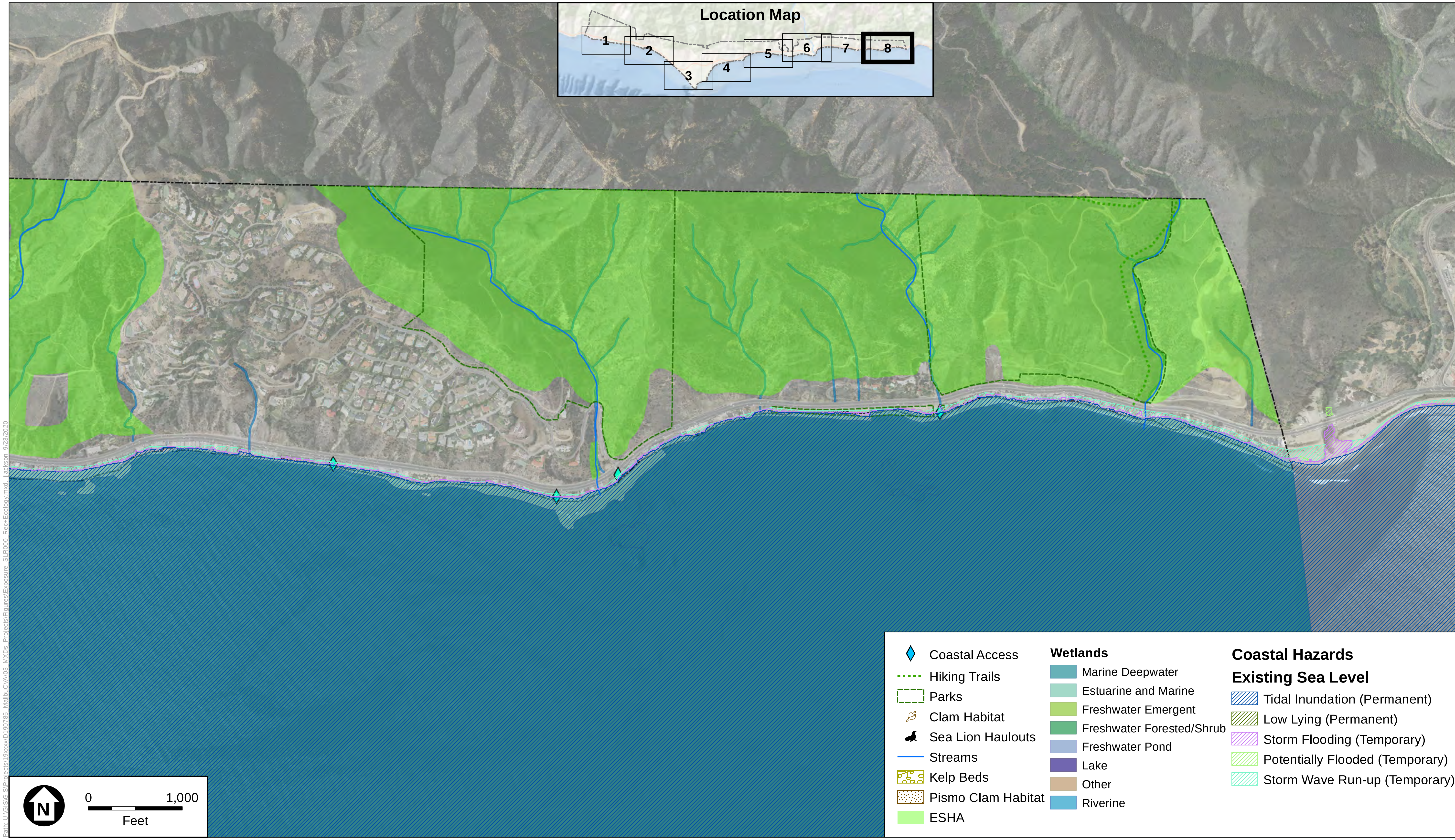
ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D1-15
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology Assets



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

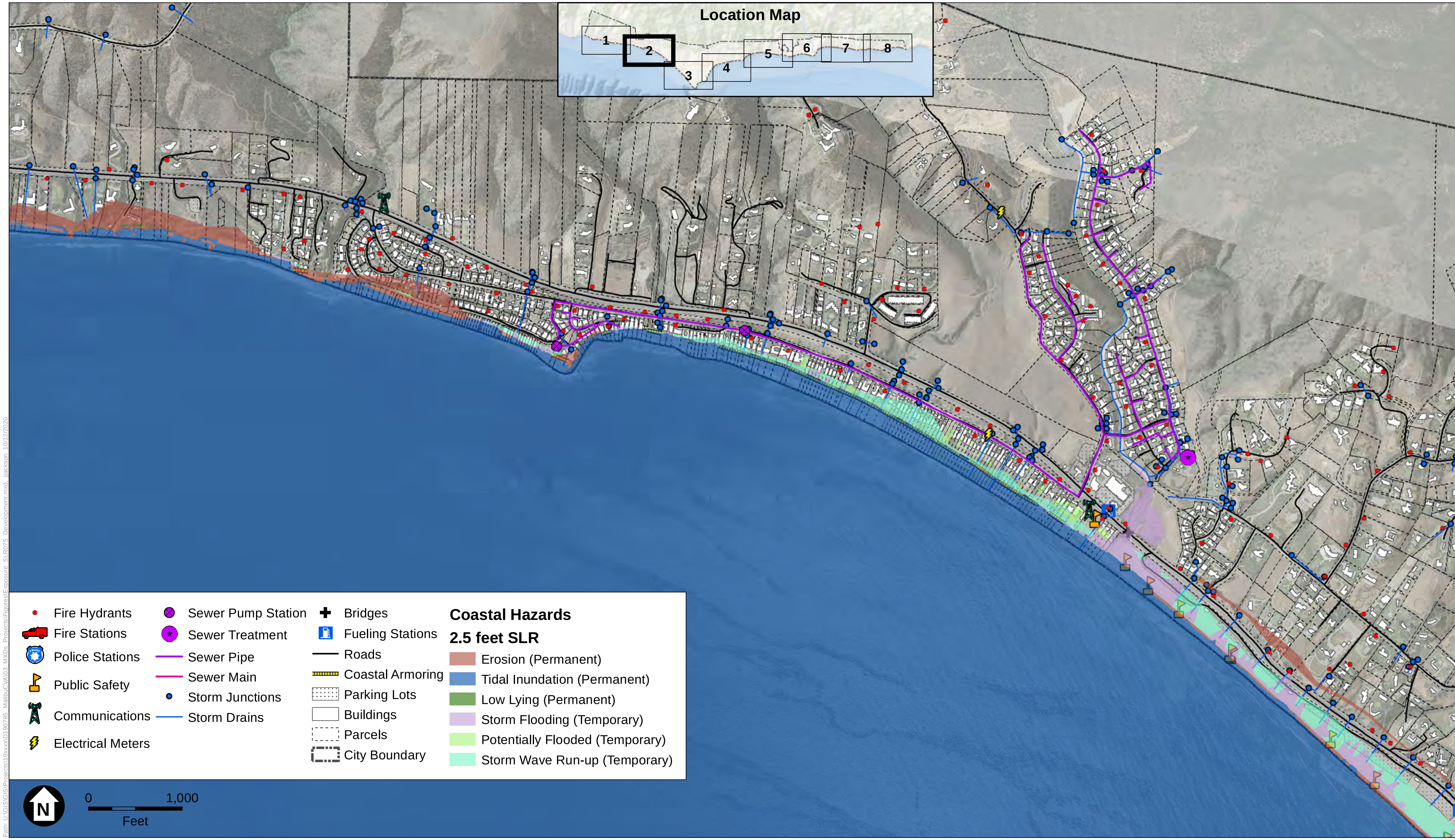
Figure D1-16
Malibu Exposure Map - Existing Sea Level
Recreation and Ecology Assets

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-1
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-2
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

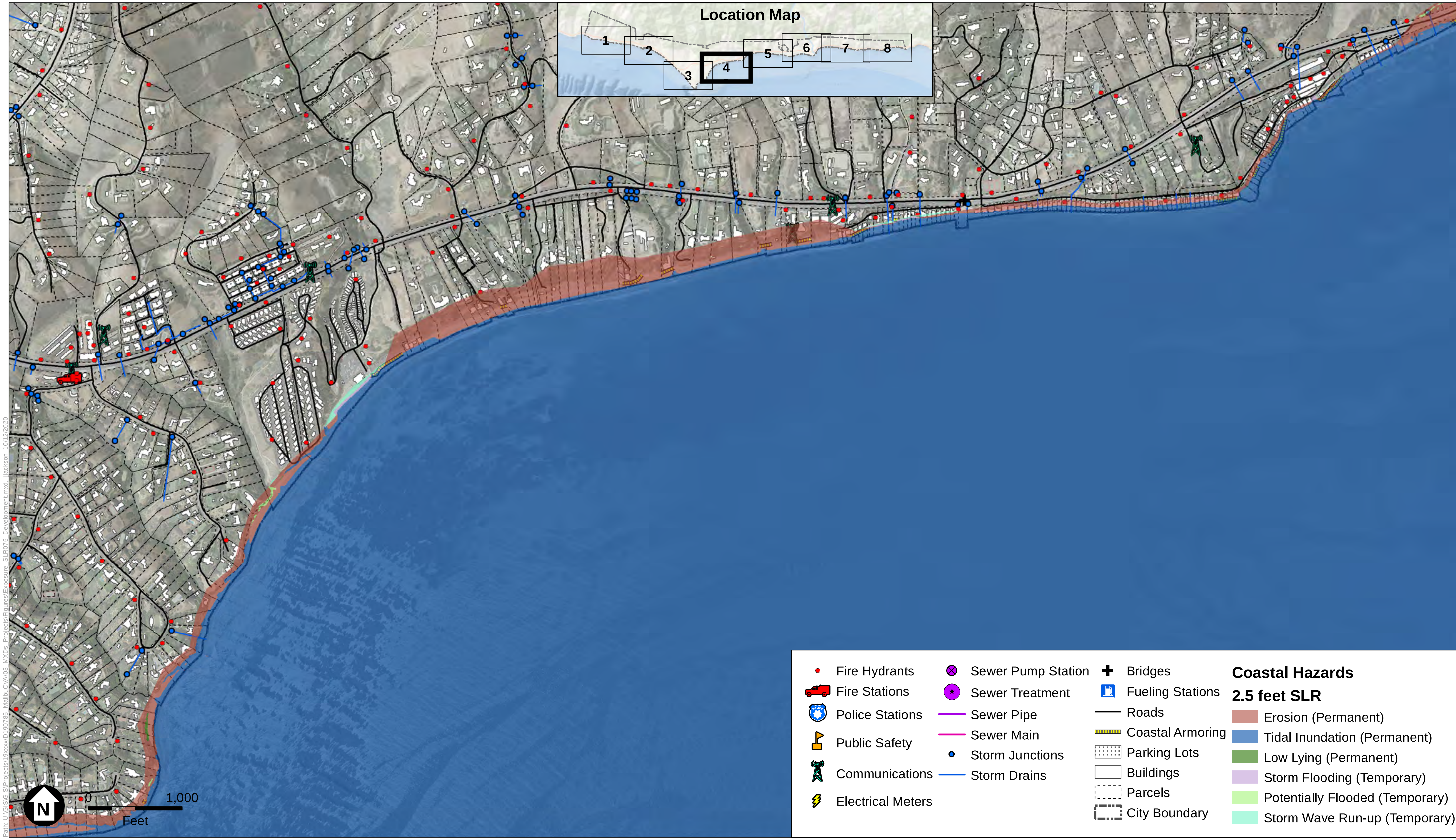
ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-3
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA

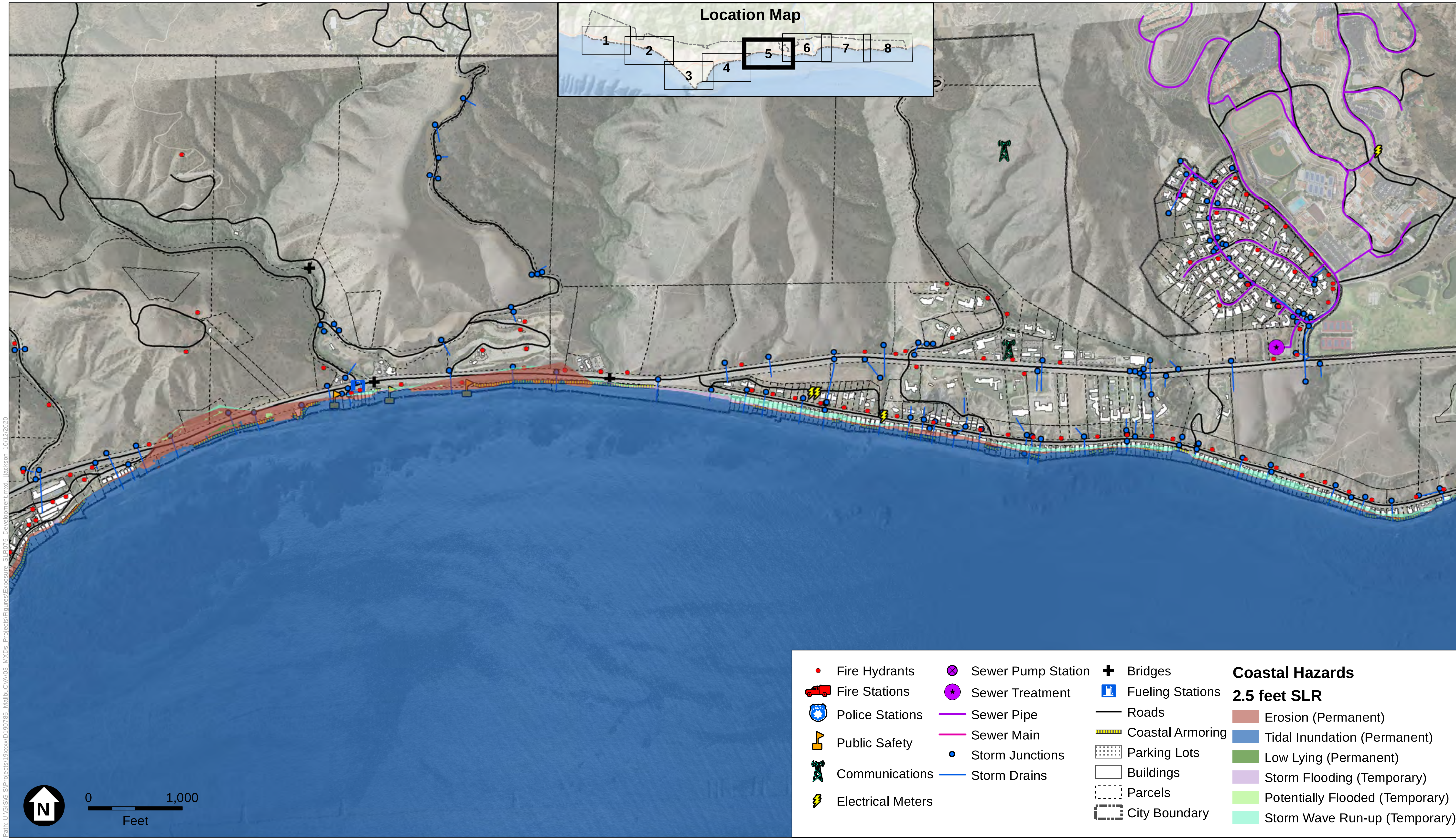


SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-4
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA

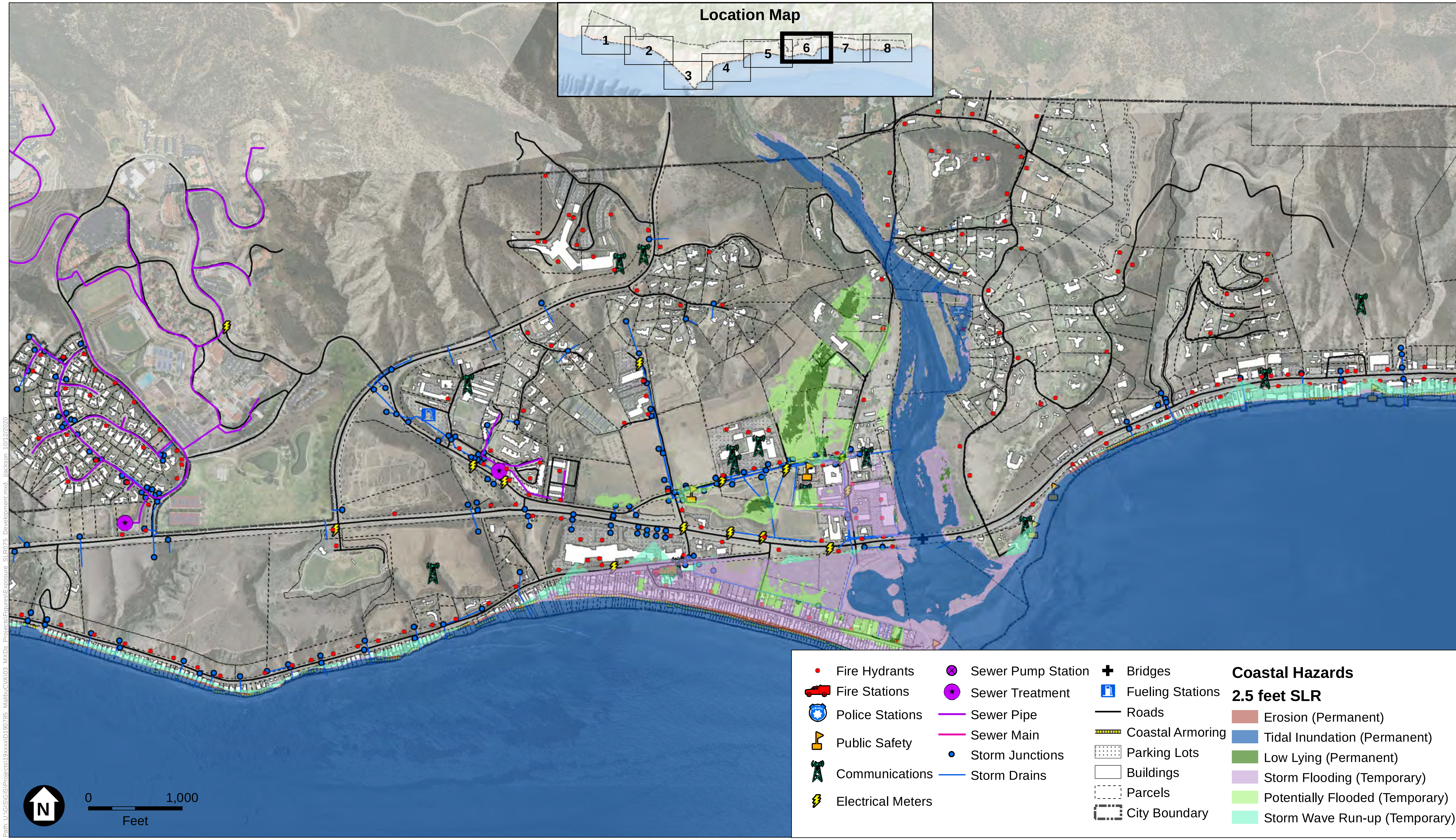


SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-5
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA

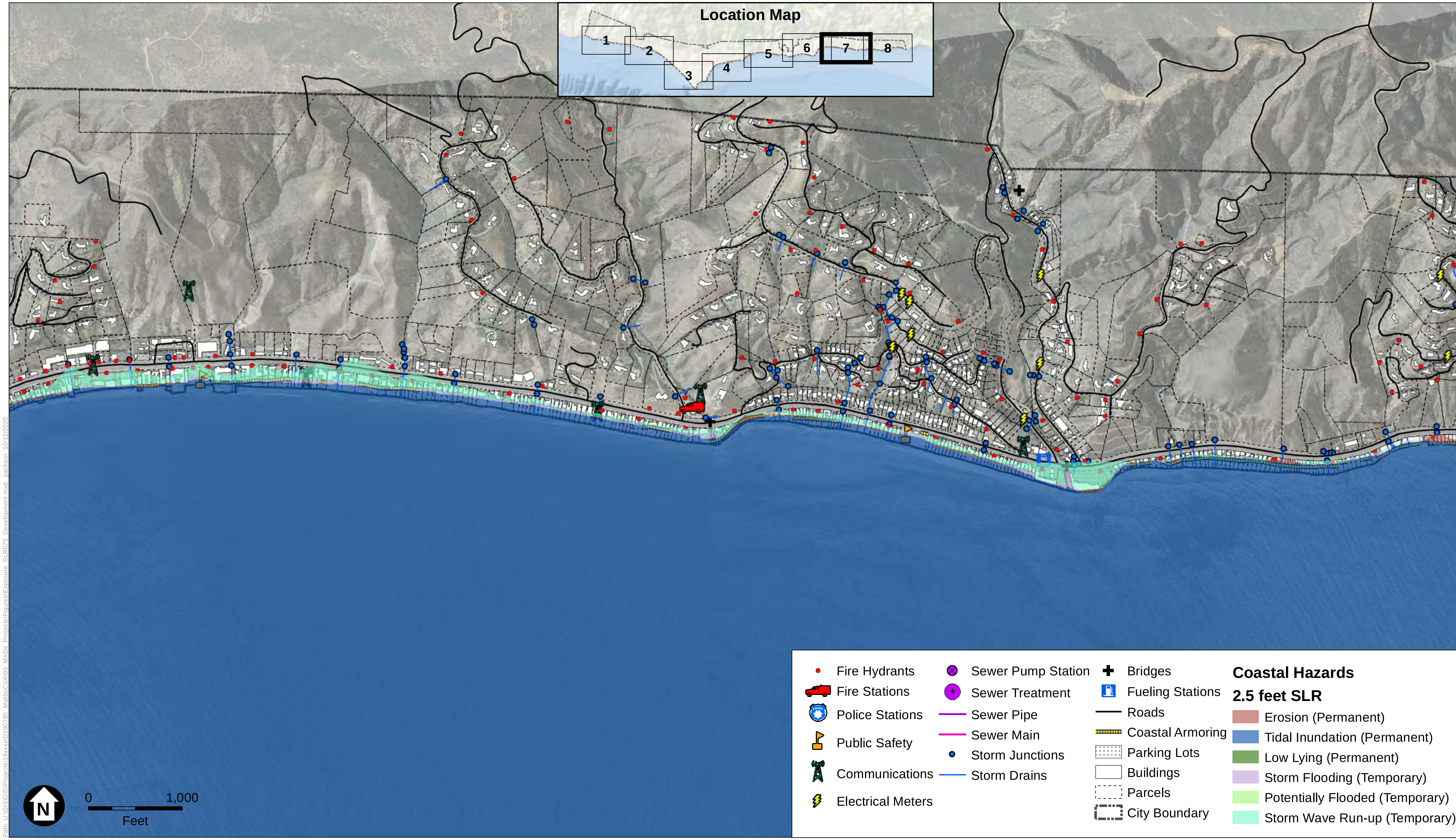


SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-6
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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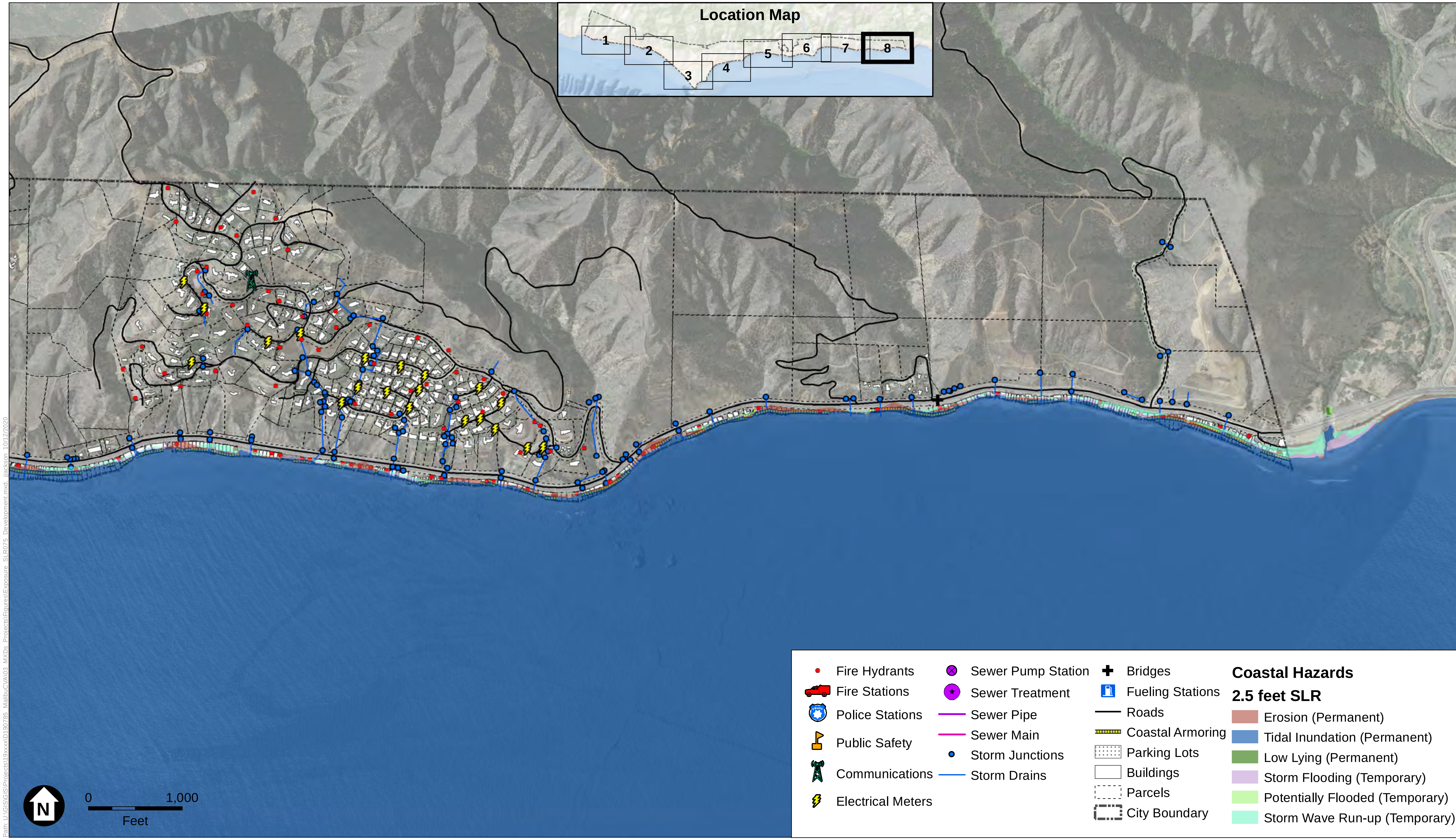
Figure D2-7
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA



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SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-8
Malibu Exposure Map for 2.5 feet Sea-Level Rise
Development and Infrastructure

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

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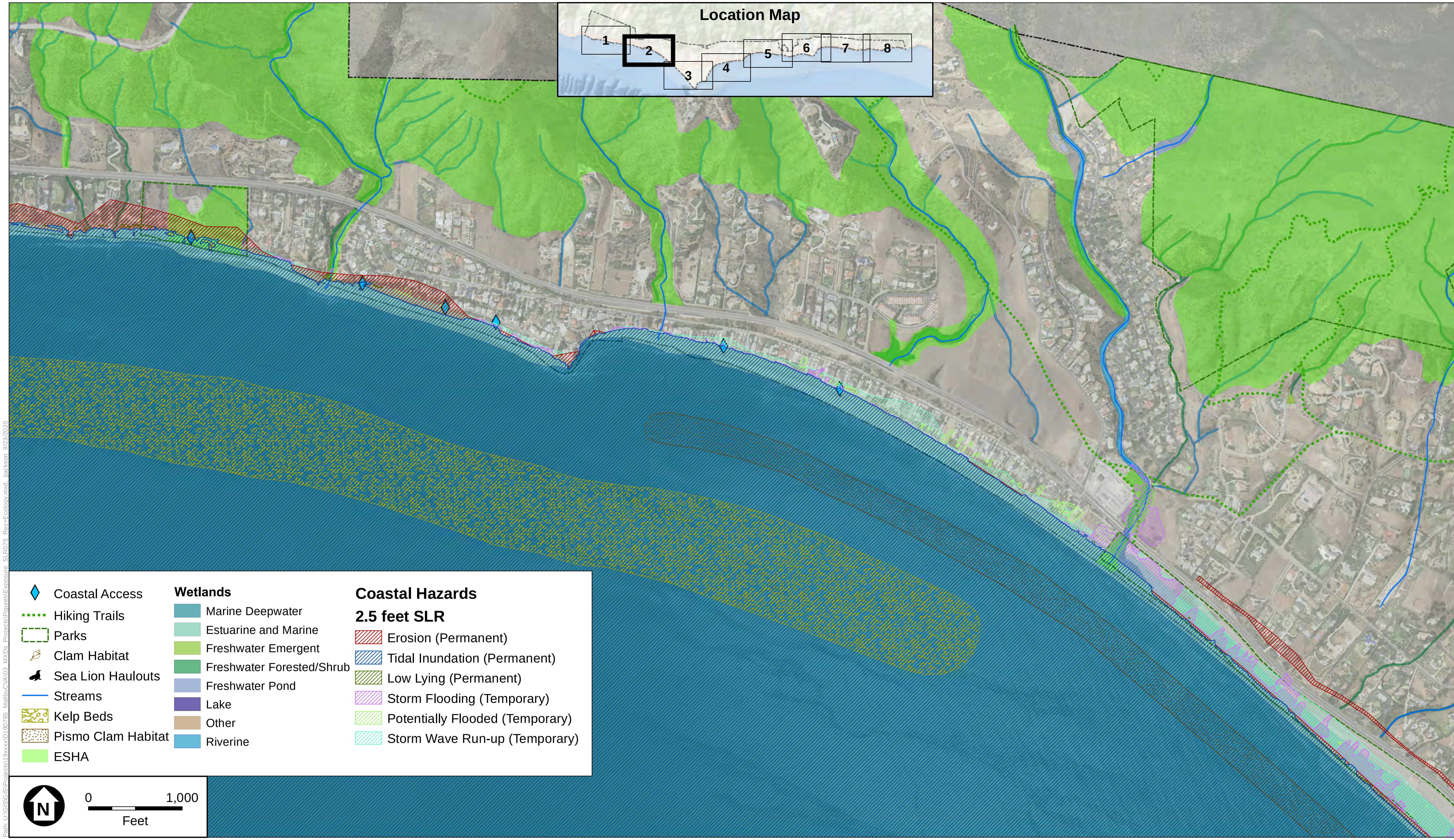
Figure D2-9
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-10
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology

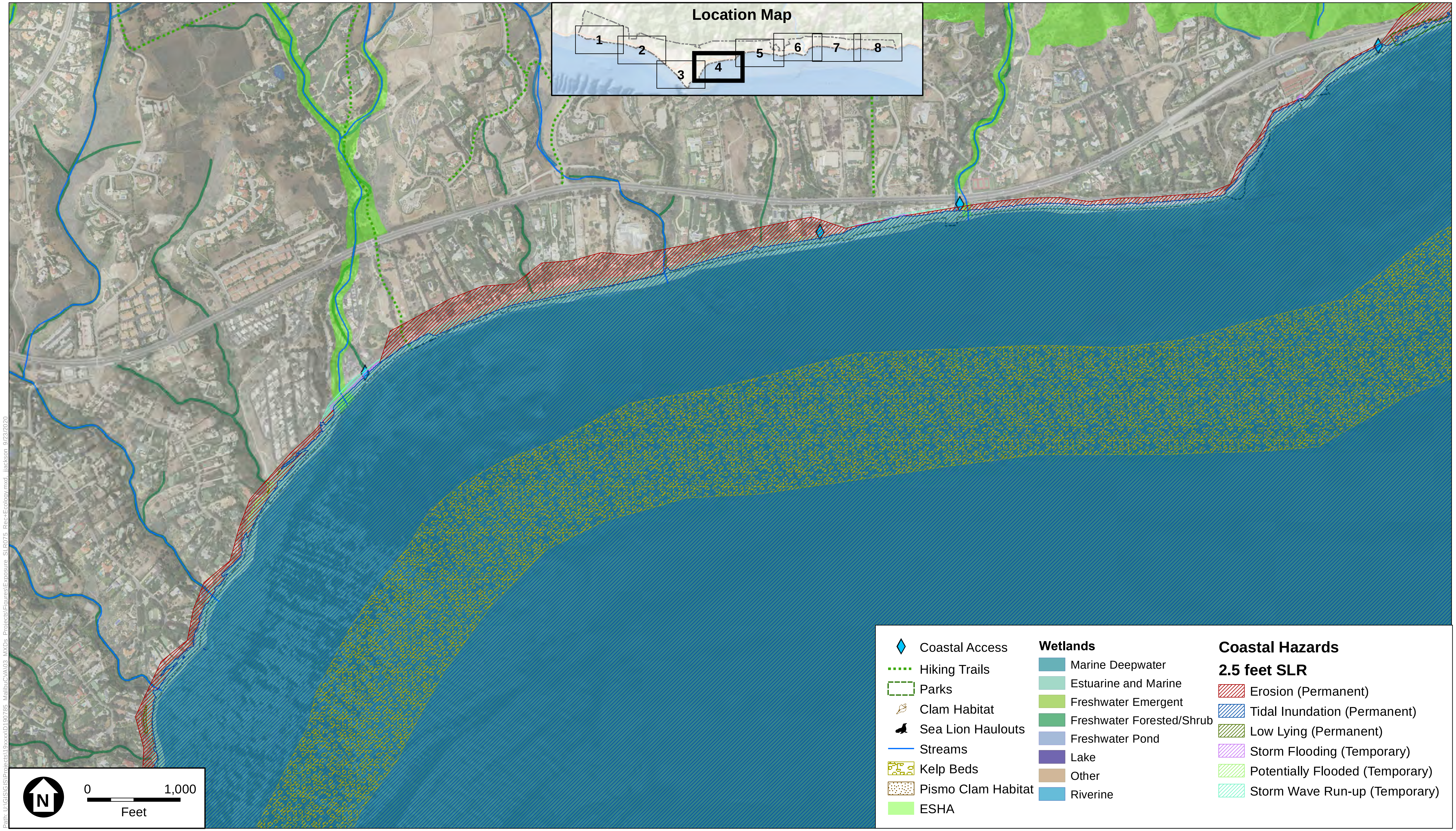
ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-11
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology

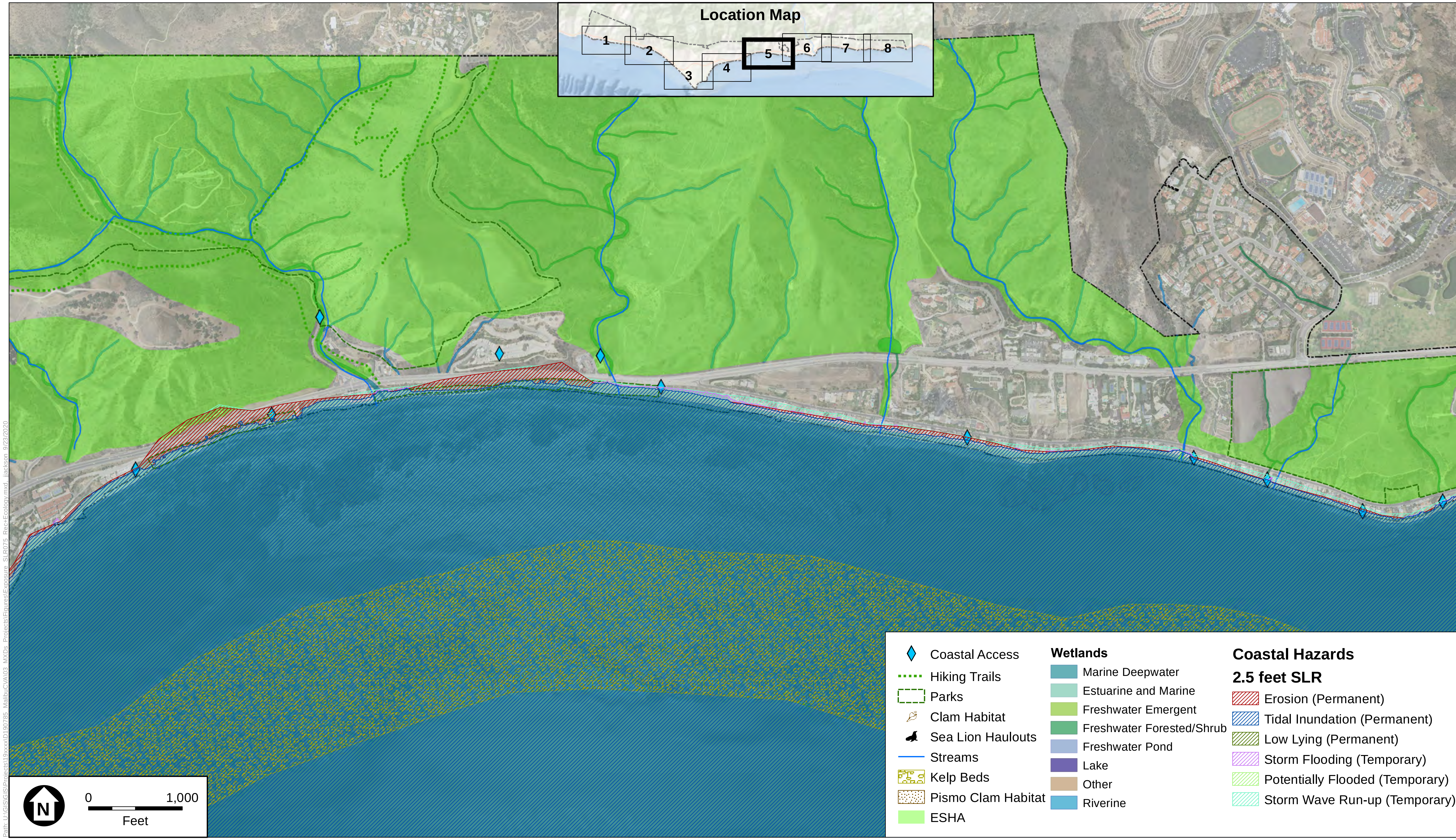
ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-12
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology Assets

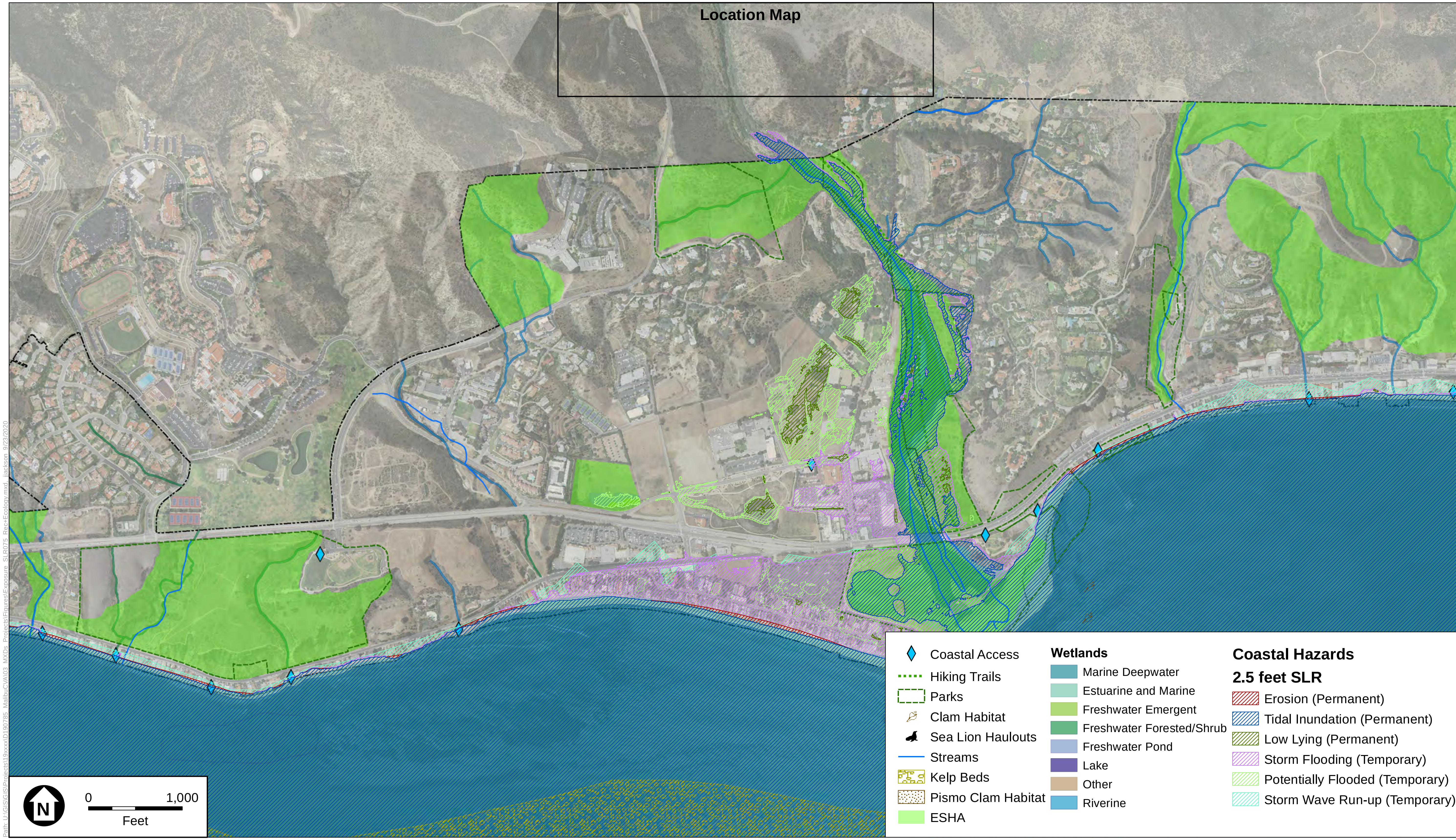


SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-13
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-14
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-15
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA, USGS

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D2-16
Malibu Exposure Map - 2.5 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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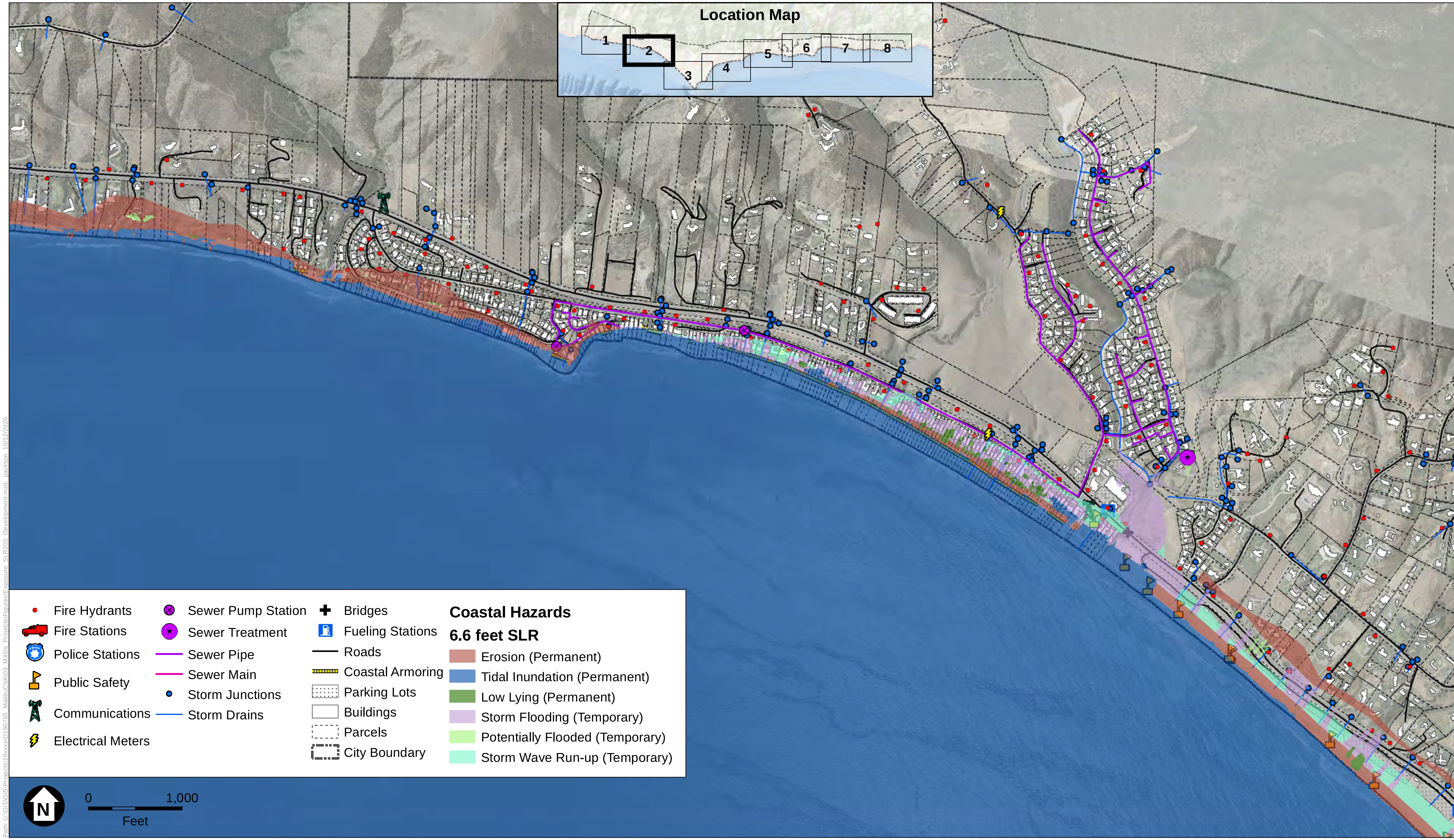
Figure D3-1
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

Malibu Coastal Vulnerability Assessment . 190785.00

Figure D3-2
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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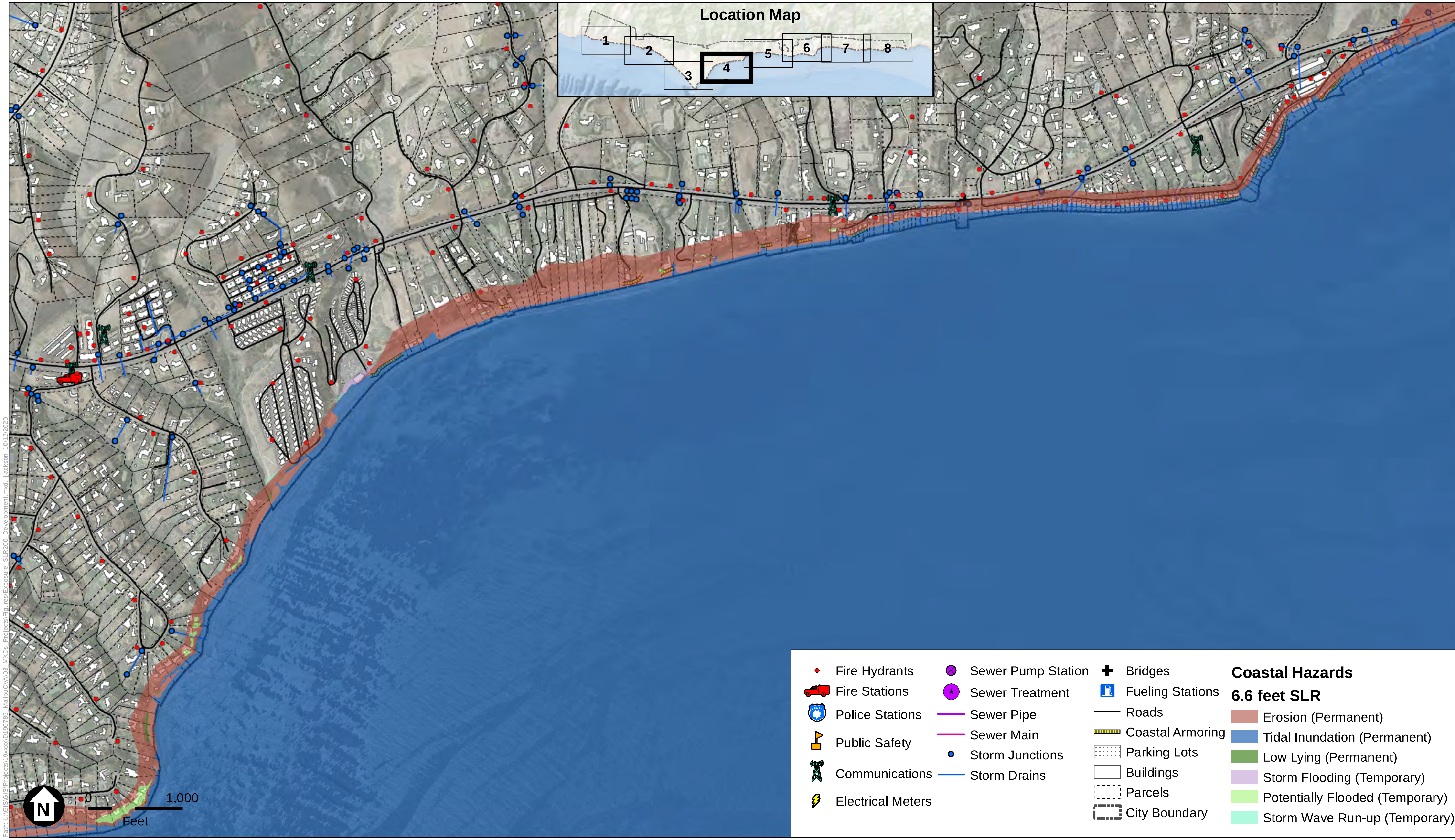
Figure D3-3
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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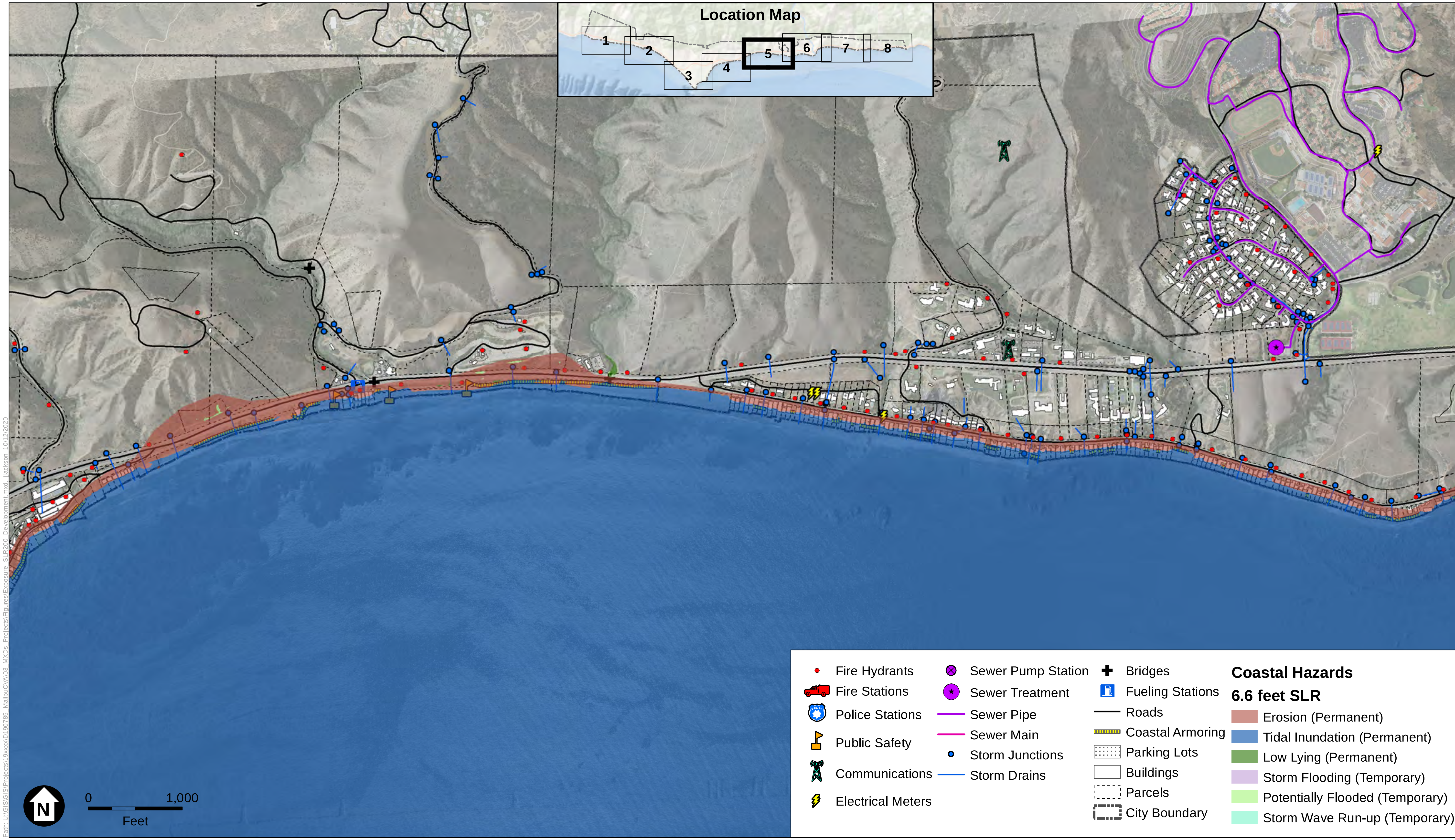
Figure D3-4
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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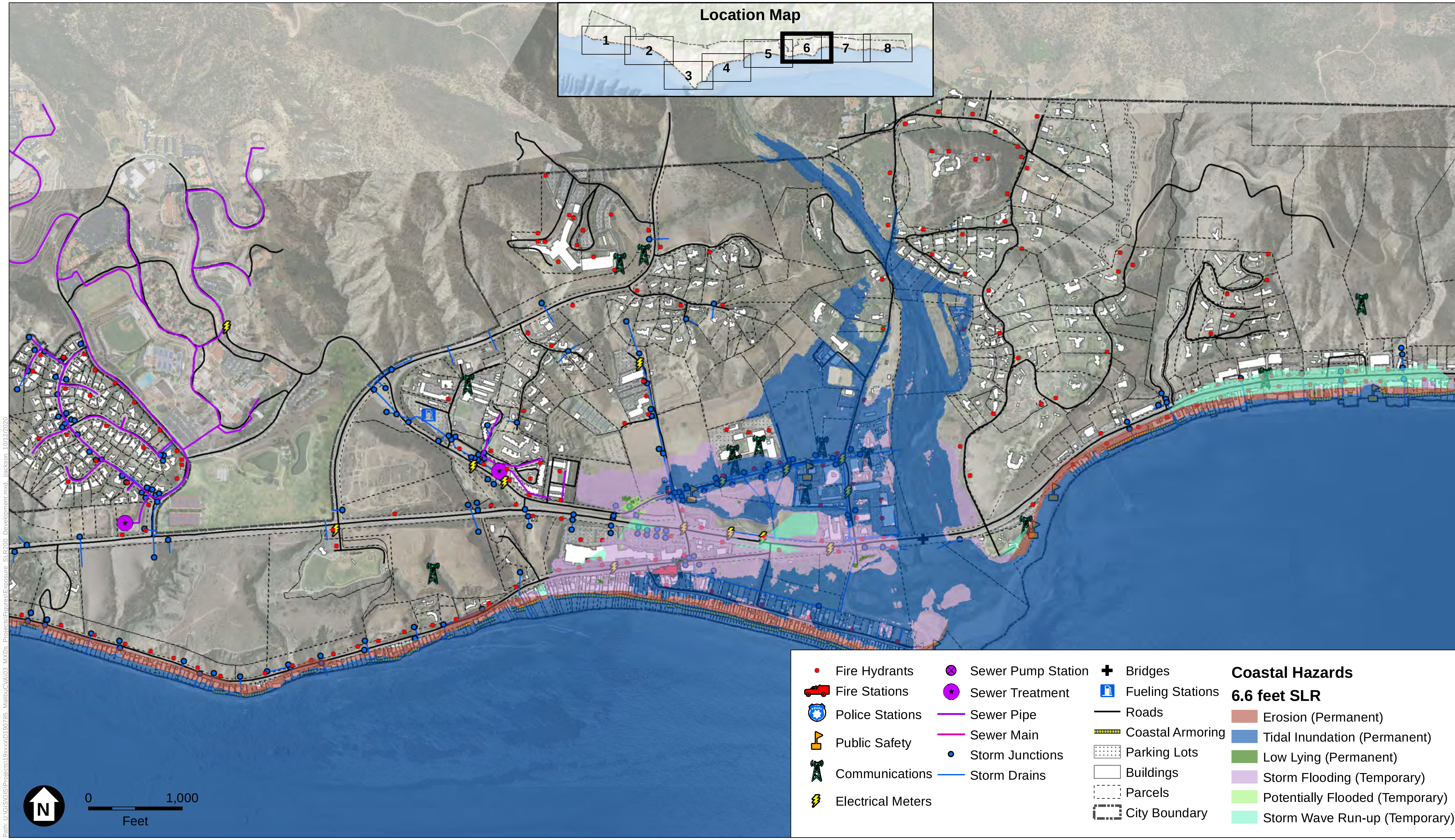
Figure D3-5
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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Figure D3-6
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA

SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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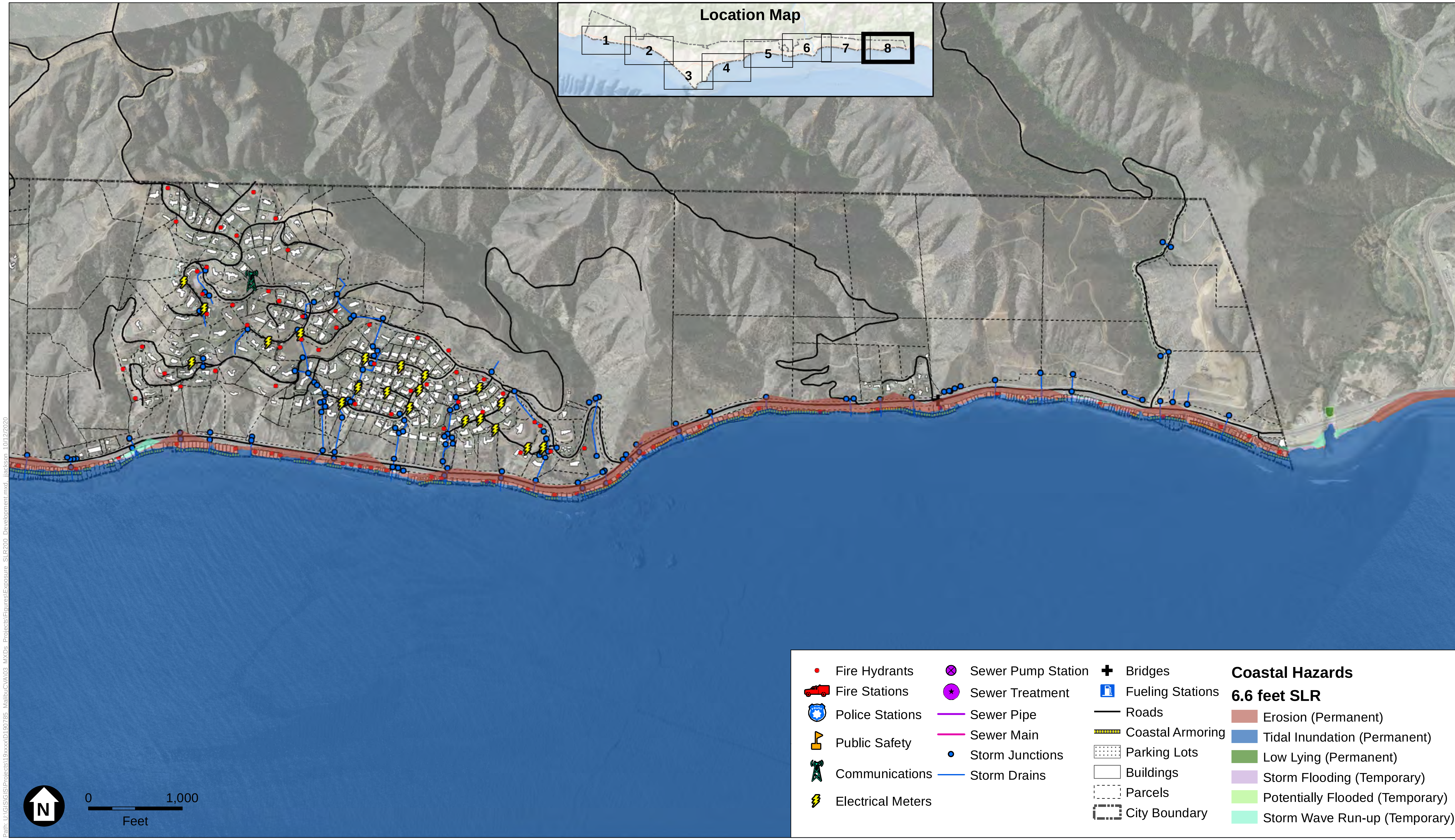
Figure D3-7
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA



SOURCE: City of Malibu, Los Angeles County, LAC DPW, LAC DBW, CCC, USFWS, ESA, USGS, SCE, ESRI

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Figure D3-8
Malibu Exposure Map for 6.6 feet Sea-Level Rise
Development and Infrastructure

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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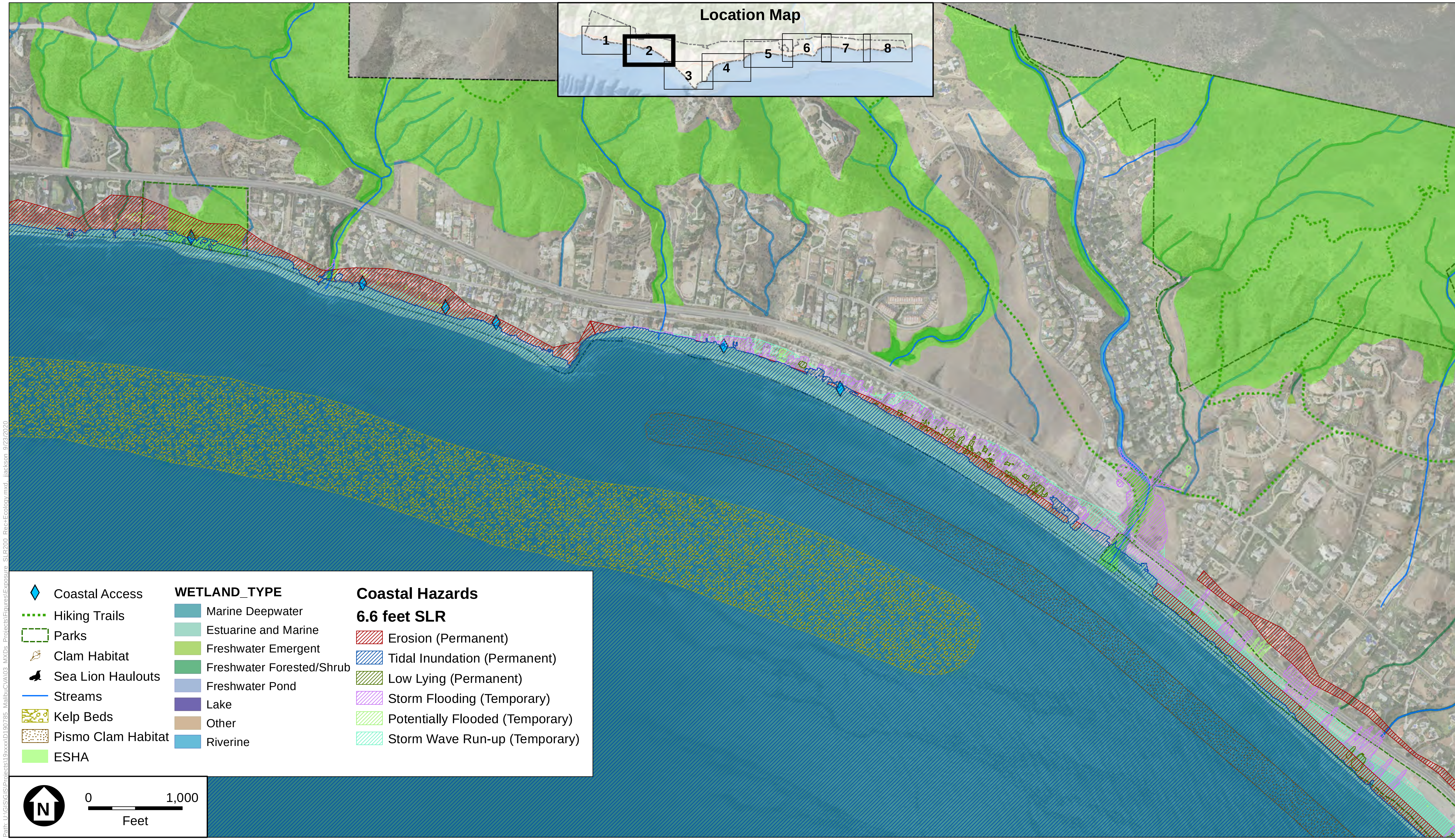
Figure D3-9
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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Figure D3-10
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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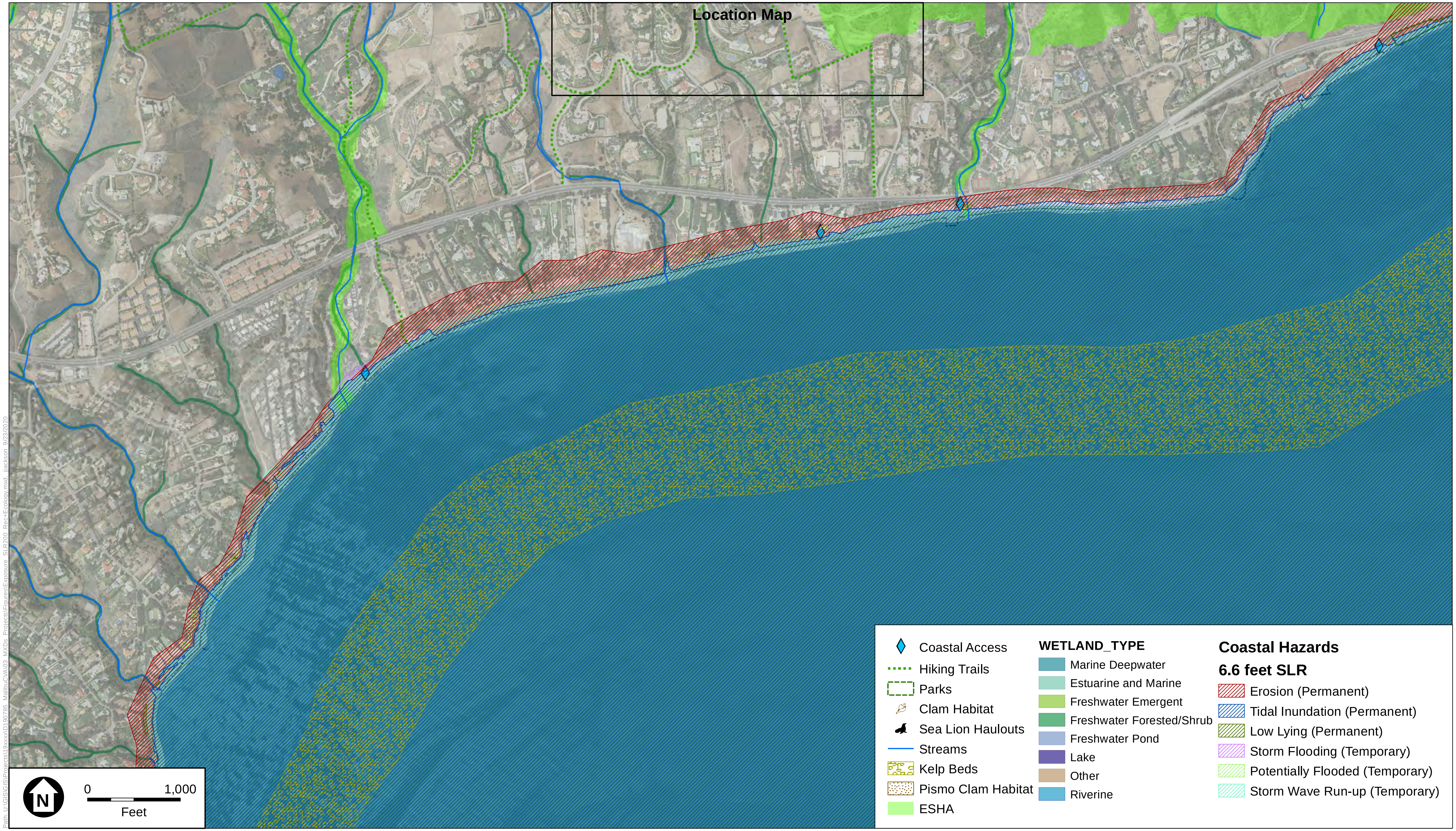
Figure D3-11
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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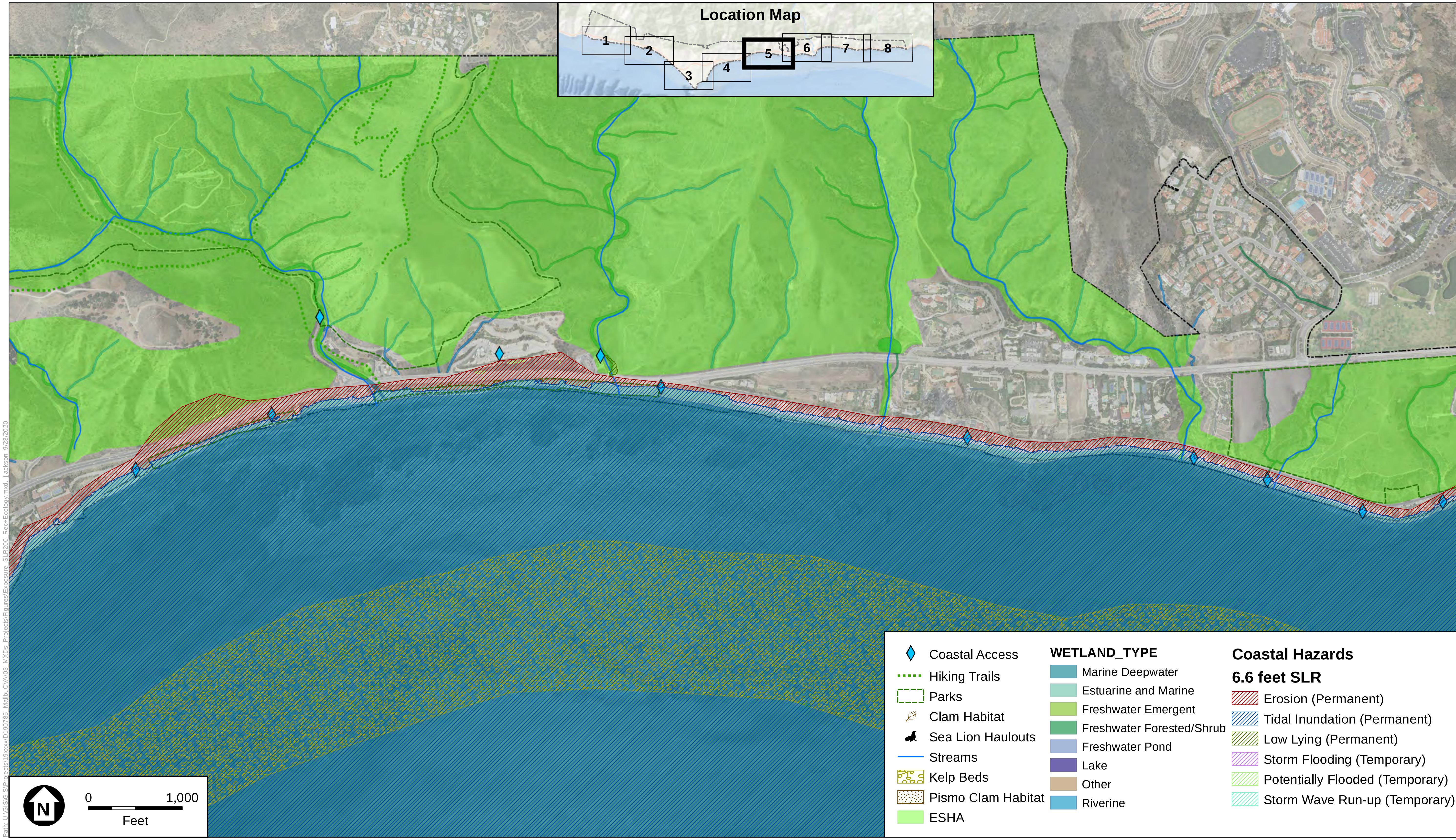
Figure D3-12
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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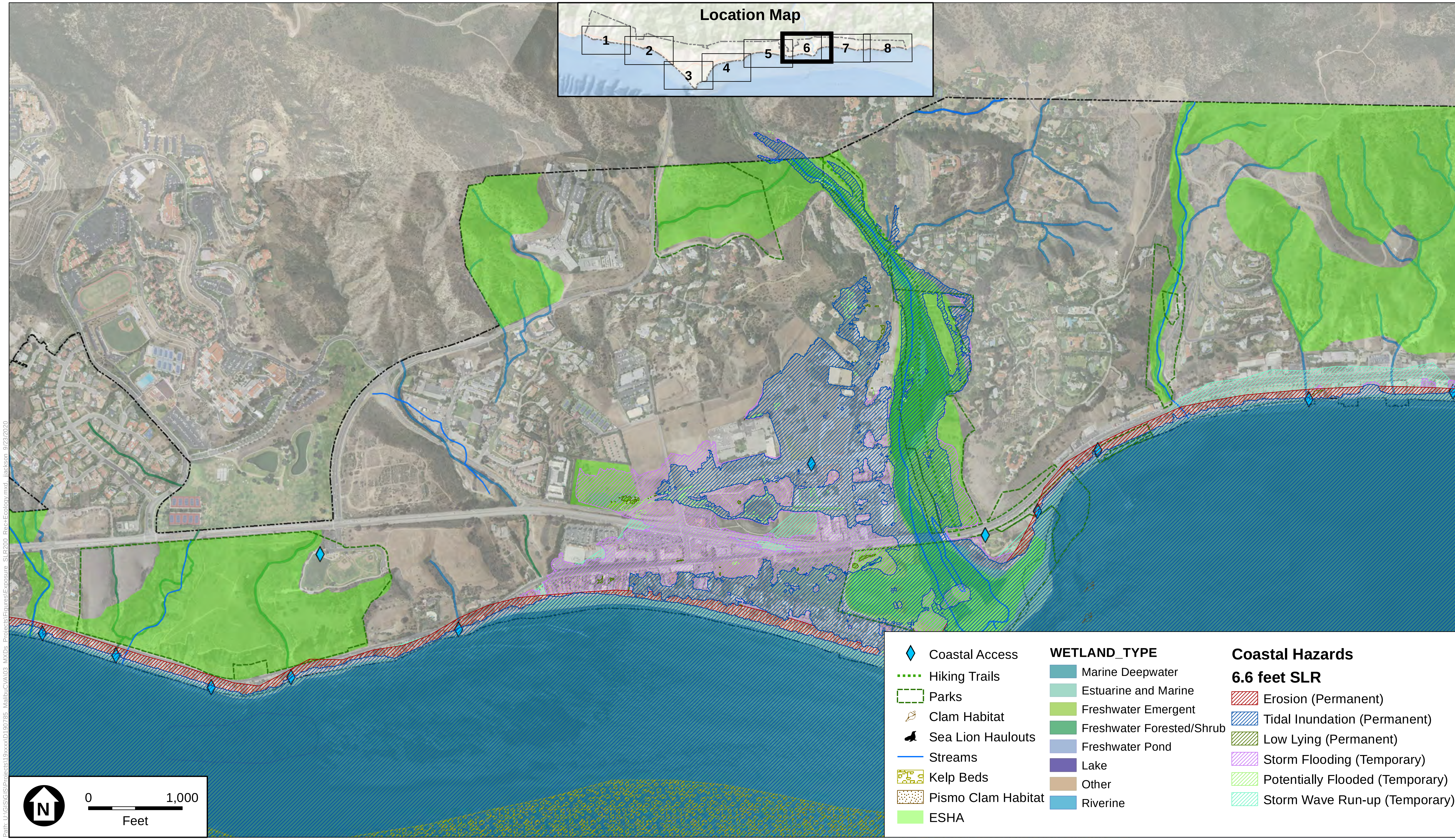
Figure D3-13
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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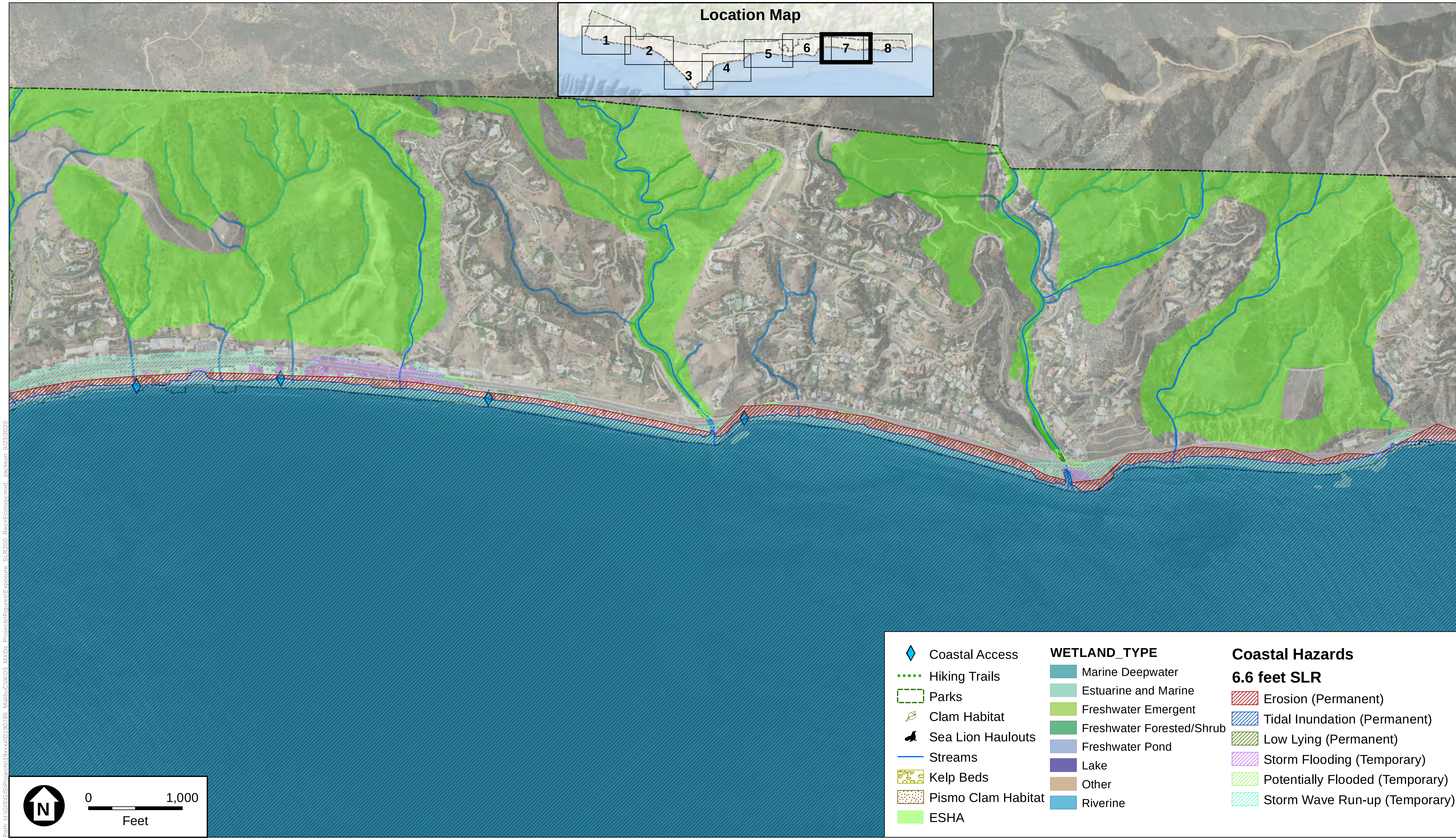
Figure D3-14
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets



SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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Figure D3-15
Malibu Exposure Map - 6.6 Feet Sea-Level Rise
Recreation and Ecology Assets

ESA

SOURCE: City of Malibu, NAIP, LA County, USFWS, CCC, ESA

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Figure D3-16

Malibu Exposure Map - 6.6 Feet Sea-Level Rise

Recreation and Ecology Assets

ESA

Appendix E

Malibu Asset Exposure Summary Table

Table E1. Malibu Asset Hazard Exposure Summary Table

Asset		Hazard Exposure							Potential Consequences					
									Existing Conditions		2.5 feet SLR		6.6 feet SLR	
Category	Class	unit	Low	Med	High	Total Exposed	Average Score	Average Exposure Grade	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary
Communication	Communication Towers	count	3	15	1	19	1.89	Med	0	5	1	9	11	8
Critical Facilities	Fire Stations	count	0	1	0	1	2.00	Med	0	1	0	1	0	1
Critical Facilities	Fire Hydrants	count	42	95	18	155	1.85	Med	1	24	18	34	96	59
Critical Facilities	Legal Facilities	count	0	3	0	3	2.00	Med	0	0	0	0	3	0
Critical Facilities	Lifeguard Towers	count	1	24	6	31	2.16	Med-High	0	17	6	24	24	7
Development	Coastal Armoring Structures	mile	0.00	1.59	5.50	7.08	2.78	High	2.33	4.51	5.96	0.73	7.06	0.02
Development	Commercial Buildings	count	45	59	22	126	1.82	Med	7	30	22	41	75	51
Development	Government Buildings	count	6	22	5	33	1.97	Med	1	17	5	19	14	19
Development	Industrial Buildings	count	1	4	1	6	2.00	Med	0	1	1	0	5	1
Development	Recreational Buildings	count	0	2	2	4	2.50	Med-High	1	2	2	2	3	1
Development	Single Family Homes	count	56	603	613	1272	2.44	Med-High	140	702	613	446	1146	126
Development	Multi-Family Buildings	count	1	29	103	133	2.77	High	41	71	104	18	129	4
Development	Mobile Homes	count	0	3	2	5	2.40	Med-High	0	1	1	1	5	0
Development	Parking Lots	count	12	37	3	52	1.83	Med	0	22	3	31	27	25
Development	Other Buildings	count	0	6	6	12	2.50	Med-High	0	5	6	3	12	0
Development	Malibu Parcels	acre	75.56	366.70	428.52	870.77	2.41	Med-High	177.4	296.4	428.5	246.7	689.1	180.5
Ecology	Wetlands	acre	2.84	90.16	334.76	427.76	2.78	High	243.8	145.3	324.8	76.2	357.8	47.8
Ecology	Beaches	acre	1.01	73.63	152.35	226.98	2.67	Med-High	54.3	153.0	152.3	71.9	191.6	35.4
Ecology	Environmentally Sensitive Habitat Areas	acre	11.33	51.77	144.31	207.41	2.64	Med-High	67.9	47.8	144.3	36.3	169.9	37.0
Energy	Electrical Meters	count	70	50	10	130	1.54	Med-Low	0	0	10	10	60	70
Recreation	Parks and Open Space	acre	13.75	112.91	141.40	268.06	2.48	Med-High	73.2	114.4	141.4	101.0	186.6	81.0
Recreation	Hiking Trails	mile	0.16	0.26	0.61	1.03	2.43	Med-High	0.52	0.19	0.61	0.24	0.74	0.26
Recreation	Coastal Access Points	count	0	15	20	35	2.57	Med-High	0	21	20	9	32	3
Recreation	Paradise Cove and Malibu Piers	count	0	2	0	2	2.00	Med	0	2	0	2	2	2
Transportation	Bridges	count	1	4	1	6	2.00	Med	1	2	1	2	3	3
Transportation	Local Roads	mile	1.17	5.39	1.16	7.71	2.00	Med	0.19	1.58	1.16	2.31	5.52	2.18
Transportation	Pacific Coast Highway	mile	1.62	2.45	0.55	4.63	1.77	Med	0.06	0.19	0.55	0.32	2.71	1.91
Transportation	Fueling Stations	count	2	1	0	3	1.33	Med-Low	0	0	0	0	1	2
Water	Sewer Mains	mile	0	0	0	0	0.00	Low	0	0	0	0	0	0
Water	Sewer Pipes	mile	0.04	0.09	0.00	0.13	1.70	Med-Low	0.00	0.00	0.00	0.00	0.09	0.04
Water	Sewer Treatment	count	0	0	0	0	0.00	Low	0	0	0	0	0	0
Water	Sewer Pump Stations	count	0	0	0	0	0.00	Low	0	0	0	0	0	0
Water	Storm Drain Lines	mile	1.55	5.42	2.45	9.43	2.10	Med	1.09	2.28	2.45	1.46	6.91	1.73
Water	Storm Drain Blocks	count	36	76	9	121	1.78	Med	0	6	9	20	76	45

* separate analysis performed for beach widths